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# Can the Existence of Dark Energy Shed Light on the Dark Sides of the "Byurakan Concept"?

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#### Abstract

The Ambartsumian's idea on the existence of superdense matter and its decay due to evolution is considered using the new observational data. We suggest a new approach to the problem using the number density of baryons for describing the cosmic object instead of mass density. The atomic nuclei and baryons increase their mass due to the gradual decrease of the nuclear binding energy, which, in its turn, takes place as a result of the influence of dark energy. This effect increases the mass of all cosmic objects and the Universe as a whole. Apparently, the smart mechanism of transformation of the mass into energy and vice versa in the atomic nuclei level regulates mass density everywhere. The self-consistent change of the baryonic mass and their number density maintain the balance in the baryonic world.

Keywords: Dark energy, baryon matter, interaction, energy exchange, nuclear binding energy

# 1. Introduction

The roots of modern cosmogony and cosmology go far into Kant's post-Newtonian hypothesis on the creation of the solar system. The belief in the formation of more massive and dense objects from sparse and lower mass ones gradually became the cornerstone of the modern post-Kantian paradigm and serves the conditional science for more than three centuries. When Hubble (1929) discovered the expansion of the Universe, no noticeable change occurred in the basic ideas governing the evolutionary chains of the objects under consideration. We believe that the main reason for such a constant commitment to the conditional paradigm is most likely the firm conservative tradition within scientific schools.

Actually, all branches of science, going ahead, always try to maintain the existing basement built on some principal ideas. The principal idea, in this case, is the apriori concept that the expanding and therefore possessing of positive energy expanding Universe had innumerable inhomogeneity points possessing negative energy. The trick is that no one really knows how so many heterogeneities formed and no self-consistent explanation exists.

A completely different approach suggested Ambartsumian in the middle of the last century. This approach, known as the "Byurakan concept", used the analysis of observational data available at that time. Exactly 75 years ago, Ambartsumian published his epochal paper "Evolution of Stars and Astrophysics" (Ambartsumian, 1947) (see the English version in this issue), in which for the first time he showed that the star formation process is going on in our Galaxy. One can find in the mentioned paper a multifaceted analysis of the observational data, using methods of statistical dynamics. Actually, all of the physical conclusions drawn by the author are met with distrust and skepticism from the very beginning. Nevertheless, the same community eventually accepted everything, with the exception of one. The conclusion on the superdense pre-stellar condition of matter appeared to be very heretical for the established paradigm of star formation.

Roughly, the same thing happened with another completely new idea concerning the activity of galactic nuclei. Like the case of stars, the author again started with the research on the dynamic stability of multiple galaxies. The first report on this subject he represented at the IAU Symposium in Dublin in 1955 (Ambartsumian, 1955). Based on the results of this research the author arrives at the conclusion that clusters of galaxies did not reach the statistical balance. Then, taking into account that the probability of composing multiple systems from single galaxies is negligible compared to the probability of decay of such

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systems, the author arrives at the conclusion that galaxies in multiple systems were born together and have not yet had time to separate from each other.

More comprehensive description of the suggested concept along with the available related data and methods of research the author gave in his Solvay lecture in 1958 (Ambartsumian, 1958). This paper is like the one devoted to the star formation problems, namely, it is much conceptual and with consideration all available relevant data in detail. Again, the main conclusion he arrived at, was one insisting that objects' formation could begin from an unknown matter of very high density or a super-dense matter. Al dynamical processes and statistical estimates did not give room for other scenarios. Like the case with stars, the astronomical community finally adopted the main conclusions made on the base of these studies, except one concerning the formation from the superdense state of matter. It appeared that the laws of modern physics do not allow the existence of superdense matter of required masses.

This is, in fact, an impasse not only for the new concept but also for the stellar and galactic cosmogony as a whole. The fact is that all observational data speak in favor of the mentioned approach, which is quite transparent and does not require the inventive construction of complex scenarios. Nevertheless, apparently, the laws of physics do not support this point of view. Obviously, the physical picture cannot be selfconsistent, satisfy all the requirements of statistical and dynamic analysis, but at the same time contradict the physical laws On the other hand, the scientific community emphasizes that the known physical laws constitute a complete set of natural laws, and therefore all conclusions drawn from them must be correct. Therefore, a very important detail of the concept has remained rejected over the past seven decades.

# 2. Dark energy changes the game rules

One of the consequences of the discovery of the accelerated expansion of the Universe at the end of the 20th century (Perlmutter et al., 1999, Riess et al., 1998) remains in the shadow of the great discovery of dark energy. With this discovery, it suddenly turned out that we do not know all the physical laws of Nature. Moreover, we did not know about the largest store of energy-matter in our Universe. Immediately prior to this momentous discovery, accurately measuring the deceleration rate of the universe was mentioned as one of the key problems in 21st-century astrophysics (Sandage, 1997). The existing gravitational theory predicted that the expansion of the Universe in any case should have a slowing down character. Measuring the rate of deceleration should have given a more detailed scenario of the fate of the universe. But instead, the scientific community was once again convinced that we simply did not know all the laws of Nature. There were and still are laws unknown to us, which will be discovered sometime in the future.

Undoubtedly, the discovery of dark energy had a huge potential to change our ideas about the structure of matter and could become a starting point for revising the laws of self-organization of matter at various hierarchical levels of our baryonic Universe. This should be kept in mind and emphasized periodically when thinking about the consequences of the existence of dark energy. Actually, the accelerating expansion of the baryonic Universe, together with the external "player" in the form of dark energy, does not at all represent some new version of the long-exploited Big Bang hypothesis. The discovery of a new phenomenon has actually completely changed the objective picture of the Universe, and now it is fundamentally different from the baryonic world that was considered born at the Big Bang.

The most important and significant from the point of physical view and for physical consequences property of the dark energy or its unknown carrier interacts with the baryonic matter. Evidently, it was clear from the very beginning. Indeed, if there were no interaction with baryonic matter, there would be no acceleration of galaxies. No acceleration of the expansion of galaxies, no discovery of dark energy could happen. Therefore, no doubt that the acceleration mechanism is the injection of the energy, called later dark energy. All the mentioned aspects together serve as a sufficient condition for proving the interaction between two different substances and the exchange of energies between them.

For further discussion, one should notice that dark energy is exceptionally positive energy, which according to modern conception homogeneously fills all space and performs a physical work gradually accelerating the expansion of the universe. It does mean that the absolute amount of dark energy in any given volume is proportional to the volume. If the density of dark energy is  $\rho_{de}$  then one can represent the energy contained in the volume V as:

$$E_{de} = V \rho_{de},\tag{1}$$

It is obvious that a baryonic object occupying any volume experiences the influence of the dark energy

filling the same volume. For modern astrophysics, the most essential issue is the behavior of the baryonic objects simultaneously occupying the same volume of space with dark energy and therefore interacting with its carrier. The acceleration of the expansion of the Universe is the most obvious and trivial consequence of the baryonic matter interaction with the carrier of dark energy. One should stress that researchers revealed the acceleration effect for cosmological distances, for much larger scales than Hubble discovered the expansion effect at the very beginning. Actually, the acceleration effect is something we should have expected to exist, knowing that the removal speed is proportional to the Hubble constant.

Indeed, let us denote the length of the segment AB by r and rewrite the Hubble law in the form

$$\frac{dr}{dt} = H_0 r. \tag{2}$$

Let us now formally differentiate both sides of the relation 2

$$\frac{d^2r}{dt^2} = \left(H_0^2 + \frac{dH_0}{dt}\right)r.$$
(3)

It is obvious that, if the Hubble constant does not depend on time, namely, if  $H_0 = const$ , the relation 3 will have the following form

$$\frac{d^2r}{dt^2} = H_0^2 r.$$
 (4)

Certainly, the density of dark energy is very tiny. Its influence becomes noticeable, as shown the relation 4, for greater distances. Therefore, the majority of researchers do not even consider this effect for the smaller scales, fairly believing that any immediate effect is very tiny. Nonetheless, tiny does not mean zero. On the other hand, one should keep in mind that energy or work has a cumulative behavior, and the processes under consideration last for billions of years.

Another notion we would like to do is the following. According to modern conceptions, dark energy mainly works against gravity, accelerating the expansion of the universe. However, there is no scientifically backed explanation, as to why it could not act against other attractive energetic fields. From the general physical understanding of the situation, one can arrive at a conclusion that there is no hint that its behavior is purely anti-gravitational. Most probably, this is only the first revealed manifestation of the universal repulsion effect. It is natural that its discovery took place for its anti-gravitational influence since gravitation is the weakest force. The stronger the attractive force, the shorter considered distance, and the harder revealing of the repulsion effect.

# 3. Interaction between the baryonic world and the carrier of dark energy

Physical science took a rather long time for the Universe only its smallest component consisted of baryonic matter. The modern structure of the Universe is completely different because of the discovery of dark energy – the largest storage of the mass-energy. Its interaction with baryonic matter seems to be the most essential physical influence the baryonic world undergoes constantly, perhaps, since the very beginning of its existence.

Obviously, the energy must have its own carrier. Although we do not know what is the carrier of dark energy, for sure, it is, and this unknown substance interacts with baryonic matter. We will assume that the process of interaction of baryonic matter with a carrier of dark energy occurs according to the well-known laws of thermodynamics. The last statement is not provable, but it can be used based on general physical principles. Then one should agree to apply the second law of thermodynamics when calculating the energy balance due to the exchange of energy between interacting substances. This means that due to the exchange of energy, the interacting substance, which has less energy, receives part of the energy, and the other part loses.

Any system consisting of baryonic objects possesses kinetic and potential energy. It is known that all balanced systems have negative total energy

$$E_{tot} = T + U < 0 \tag{5}$$

and the virial theorem is equal to zero

$$W = 2T + U = 0.$$
 (6)

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There are two very essential points one should carefully consider for understanding the energy exchange consequences of the interaction between baryonic matter and the carrier of dark energy. While estimating the physical changes in a system consisting of baryonic objects, consisting in their turn of baryonic objects belonging to the lower hierarchical levels, one should keep in mind that the virial theorem greater than zero always means that such a system should expand. The second point is that all baryonic objects and systems existing in a stable stage satisfy the condition 5. Those exist as a whole only owing to the lack of energy.

Taking into account these points, we inevitably arrive at the conclusion that due to the interaction between the carrier of dark energy and baryonic matter, there is always a transfer of energy from the first source to baryonic substances. From the point of view of modern physics, this conclusion is inevitable. However, some details require further clarification if one is trying to get a comprehensive understanding of such interactions.

The fact is that we usually consider the microcosm as a completely different world, although it is from the objects of this world that all the upper hierarchical levels of the baryonic world consist. The quantum behavior of atomic nuclei and elementary particles separates them from objects of the next levels. All researchers know that quantum objects of the same name are identical and indistinguishable from each other. Moreover, it is accepted as an axiom that the objects of a microcosm do not undergo any evolution process and remain unchangeable for billions of years, while all other objects of the higher levels change over time drastically. Is it correct or not, one can find out only by carrying out a rigorous analysis of the relevant observational and experimental data.

Let us dwell briefly on the structural features of atomic nuclei. According to modern physics, atomic nuclei are composed of neutrons and protons, which, in turn, have quarks in their structure, tightly bound by the strong force. The neutrons and protons themselves exist in nuclei, bound to each other due to the residual strong forces penetrating outward from the hadron's interior. The structure of atomic nuclei, which is the basis of all baryonic structures, on the other hand, is the most accurately "calculated" self-consistent brick of the baryonic world, which exist owing to the mass defect or binding energy.

Regardless of the degree of development of the existing theories, all quantitative estimates describing the atomic nuclei and this physical phenomenon come from empirical research only. There is no doubt that many essential details of our knowledge on the structural features of atomic nuclei are the result of the use of the phenomenological approach. Obviously, the values of the mass defect of various atomic nuclei are among these extremely important data and are of purely empirical origin. Well-known empirical formulas, in turn, are simple fitting expressions derived from these values.

In fact, up to now, in our opinion, there is no clear understanding of the mechanism of change in the mass of nuclei, or we simply do not know it. Nevertheless, using all the known physical characteristics of atomic nuclei, one can argue without a doubt that the mass of hadrons decreases if they are in the nucleus of an atom. Moreover, this change is different for different nuclei, which means that a hadron can have different values of mass. Therefore, we can conclude that the baryon mass changes depending on various physical circumstances, without even specifying the real mechanism of this phenomenon. One can interpret this, like nuclei, as a defect in the mass of the baryons themselves, or find another explanation, but the fact of the existence of a mechanism that regulates the mass of baryons in accordance with physical conditions does not depend on this, and is undeniable. That is a very essential feature of the baryonic world as a whole.

So, what can happen with atomic nuclei due to their interaction with the carrier of dark energy? Taking into account the general viewpoint that dark energy fills homogeneously all spatial scales, one can consider the consequences of its interaction with the atomic nuclei and elementary particles under the governance of the laws of thermodynamics. The most credible conclusion seems to be the one asserting that the portion of dark energy transferred to the atomic nucleus will cover the lack of energy called nuclear binding energy. It does not matter at all how tiny or insignificant an amount of energy transfers to the nucleus per unit of time. It is very significant that this portion is larger than zero and that energy is of a cumulative nature.

Summarizing the above, we arrive at the conclusion that the interaction of the carrier of dark energy with atomic nuclei and baryons simply decreases the binding energy. However, on the other hand, a decrease in the binding energy leads to an increase in mass. Consequently, one can argue that energy exchange during such an interaction inevitably leads to an increase in mass. Then the considered interaction takes on a completely different meaning: the nucleus structure of baryonic matter gradually converts dark energy into mass, most probably keeping constant the number of elementary particles.

If our considerations are correct, then there should not be a doubt that the objects belonging to the microcosm also evolve heavily over time. Moreover, evolution occurs in the direction of the growth of the mass of these objects and, as a consequence, the entire baryonic universe. This conclusion, we believe, is

exceptionally important for the interpretation of some widely known phenomena. We mention here one of that phenomena only. This concerns the paradox of the ongoing expansion of the universe.

Indeed, if all baryonic matter exists already since 370 thousand years after the so-called big bang, then the entire baryonic universe was inside the Schwarzschild radius. According to the laws of modern physics, the substance formed after the big bang should have immediately formed a black hole. However, it is expanding and, as it turned out, is expanding with acceleration. It is suspicious that in some strange way the researchers do not notice this egregious discrepancy.

# 4. The number of baryons and the mass of an object.

Our conclusion that evolving matter grows in mass due to interaction with the carrier of dark energy is unusual from a traditional point of view, but, of course, does not violate the law of conservation of mass/energy. However, one should consider this finding in more detail, as it predicts some structural changes that we believe may have far-reaching implications. These consequences are extremely important, for example, for understanding the chemical abundances of various space objects and the mechanism of the evolution of metallicity in general. In order to clarify the questions of interest, one can use the approach of a mental (or "as if") experiment, having the necessary tools of the corresponding physical laws to study the chain of changes that occur with atomic nuclei. Such changes can last for billions of years. Evidently, we cannot give any quantitative estimates for the duration of the processes or the cross sections of the processes that we are going to describe here. Our research approach is purely phenomenological in nature, and therefore we can only compare the result of our experiment with the corresponding observational data.

The most important thing to pay attention to is the process of decreasing the binding energy of the nucleus. This has at least two major consequences. First, as already noted, the mass of any given nucleus increases. In addition, the nucleus gradually loses its stability margin and finally passes into the class of radioactive nuclei. However, radioactivity is a statistical phenomenon and nuclear decay is a Poisson process. It is easy to understand that, having become radioactive, the nucleus continues its interaction, and the binding energy continues to decrease due to excessive energy accumulation in the nucleus. Therefore, over time, its half-life will constantly decrease, while the kinetic energy of the decay products increases.

The transition into the class of radioactive ones gradually changes the relative amounts of nuclei of various masses. The amount of light nuclei increases due to the decay of more massive atomic nuclei. This means that owing to the exchange of energies, the relative amount of nuclei, consisting of a smaller number of hadrons, and possessing at a given moment of time a relatively smaller mass, gradually increases. Thus, if we accept the concept of the interaction of baryonic matter with a carrier of dark energy discussed here, we arrive at the conclusion that the evolution of atomic nuclei leads to an increase in the number of nuclei consisting of a smaller number of hadrons. This, by the way, agrees with the law of increasing entropy but contradicts modern concepts of the formation of atomic nuclei.

According to the paradigm we are developing here, the masses of baryonic objects, and hence the mass of the baryonic universe, become time-dependent and continuously growing quantities. This is a non-obvious effect, and rigorous studies and a self-consistent approach are needed to detect and confirm it. On the other hand, the number of baryons in our baryonic universe is likely to remain unchanged. This assumption is obviously unprovable. Nevertheless, modern physics insists that the baryon number is a strictly conserved number, and so we and we start from this premise.

If the total amount of atomic nuclei become larger with time, the number of hadrons in each nucleus decreases, and the mass of each hadron increases, then we can draw a conclusion about the atoms of the cosmological past. To do this, one should understand what the reverse processes lead to. It is obvious that the deeper we penetrate into the past of baryonic matter, the more hadrons in atomic nuclei should find on average, and each individual hadron should possess of lesser mass. To what size the nuclei can be extrapolated is not yet known. In any case, we can talk about ancient hadron embryos, combined in very large numbers into proto-nuclei. Moreover, some intermediate versions of such proto-nuclei can exist in the central parts of baryonic objects of large masses.

Our conclusion about the growth of the mass of atomic nuclei opens up the possibility of searching for the spectral manifestation of this evolution. Indeed, the frequency of spectral lines depends on the reduced mass of the electron and the atomic nucleus. For the simplest hydrogen (or hydrogen-like) atoms the wavelength of a photon corresponding to the transition between energetic levels is given by the following formula

$$\frac{1}{\lambda_{mn}} = Ry \frac{1}{hc} \frac{M_p}{m_e + M_p} \left(\frac{1}{m^2} - \frac{1}{n^2}\right),\tag{7}$$

where

$$Ry = \frac{m_e e^4}{8\varepsilon_0^2 h^2} \tag{8}$$

is Rydberg's energetic unit.

One can see that the wavelength is inversely proportional to the reduced mass of the electron and proton (nucleus)

$$\lambda \sim \frac{m_e + M_p}{m_e M_p} = \frac{1}{m_r}.$$
(9)

If our conclusion is correct and, indeed, there is a monotonous increase in the masses of elementary particles and the atomic nucleus, then in the spectrum of distant objects, in addition to the Doppler redshift, there must be some component due to the evolutionary lag of baryonic matter compared to our epoch.

The higher the reduced mass, the shorter the wavelength. This means that in the process of evolution of baryonic matter the spectral lines should shift to the blue side of the spectrum. In other words, less evolved atoms have redshifted spectra if compared with more evolved ones. On the other hand, the further the object is, the deeper in its past we observe it and the shorter the path length of its evolution. Thus, the further the object is, the bigger its non-Doppler redshift should be.

The first things that come to mind after this conclusion are the metallicity of cosmic objects and the redshift of galaxies caused by the expansion of the Universe. The question arises cannot a part of the redshift be due to insufficient evolution of the emitting baryonic matter? After all, a decrease in the reduced mass has the same effect on the spectrum as the removal rate. Actually, it is extremely difficult to separate one effect from another. One needs to find some process, which separates somehow these phenomena in manifestation.

# 5. Dependence of the Evolution Rate on Mass.

An essential issue relevant to the problem under consideration could be the dependence of the evolution rate on the mass of the given object. This is not a trivial issue, since our knowledge concerning the carrier of dark energy is extremely scant or practically zero. We have only some incomplete information on the external manifestation of its interaction with the baryonic objects and that is all. Therefore, one needs using of some circuitous way for finding a more or less realistic solution. We assume that the ratio of gravitational energy of a baryonic object and dark energy in the volume occupied by the object can serve as an indicator of object firmness against the dark energy influence. The larger the ratio the harder the evolution process is forced by dark energy.

Let us test it for the spherical object. The gravitational energy of an object of mass M and radius R is proportional to the second order of the mass:

$$E_{gr} \sim G \frac{M^2}{R}.$$
(10)

where

$$M = \frac{4\pi}{3}R^3\rho = V\rho. \tag{11}$$

Using the relations 1, 10, and 11 one easily finds for the mentioned ratio

$$f = \frac{E_{gr}}{E_{de}} \sim G \frac{M}{R} \frac{\rho}{\rho_{de}}.$$
(12)

It is clear from the relation 12 that for the objects of bigger mass the coefficient f. gets bigger if the density of the objects does not decrease faster than grows the ratio M/R. The early-type galaxies obey a narrow relation traced by their stellar content between the mass and size (Burstein et al., 1997). For high-mass galaxies, the classical relation confirmed by many authors has the following form

$$\log R_{1/2} \sim 0.54 \log M,$$
 (13)

while for the dwarf systems, the relation has a shallower slope

$$\log R_{1/2} \sim 0.3 \log M,$$
 (14)

where  $R_{1/2}$  is the half-light radius and M is the galaxy's stellar total mass.

Taking in to account that  $R \sim R_{1/2}$ , one arrives at the conclusion that the mass of high-mass galaxies depends on their radius approximately as  $R \sim M^{1/2}$  and for the dwarf systems -  $R \sim M^{1/3}$ . It does mean that for the dwarf systems f increases with the mass, while this correlation gradually stops and disappears for the large mass ones. It turns out that in the case of dwarf galaxies, the smaller the mass of the galaxy, the more malleable its substance to evolutionary changes. Apparently, after a certain mass, this effect weakens, and then for very massive galaxies it is always bigger but does not depend on the mass.

This conclusion is very important. If the coefficient f really can serve as a measure of the evolution rate, one can conclude that for dwarf galaxies the fainter the object the bigger the evolution rate. Therefore, if we study, at least, early-type galaxies of various luminosities formed nearly at the same time, we can insist that the ones possessing lower luminosity (mass) have a long evolution path. Based on the conclusion above, we can expect that the fainter galaxies possess lower metallicity and lower redshift compared with their massive congeners.

The mass-metallicity relation is well established (Lequeux et al., 1979). Undoubtedly, the huge observational data provided by the Sloan Digital Sky Survey (York et al., 2000) gave an excellent possibility to improve thoroughly the statistics of both stellar mass and metallicity of galaxies in the local Universe and assess the significance of the mentioned relation. Tremonti et al. (2004) studied imaging and spectroscopy of  $\sim 53,000$  star-forming galaxies at z  $\sim 0.1$  to study the relation between stellar mass and gas-phase metallicity. This relation holds for a broad range of stellar masses (from  $10^7 M_{\odot}$  to ~  $10^{12} M_{\odot}$ ), but its shape changes with varying stellar mass content of galaxies: it is steeper at low masses, then its slope changes in correspondence of a characteristic value of asymptotically flattening towards a saturation metallicity (see for references also Curti et al. (2020)).

Another effect, which we noted in the previous paragraph, predicted that the more massive the galaxy, the greater its redshift, all other things being equal. It is not so easy to verify such a statement, but if we use the galaxies of the same cluster, then we can assume in the first approximation that their distances and ages are approximately the same. Therefore, we used three known clusters of galaxies, namely, the Virgo cluster, the Fornax cluster and the Coma cluster for checking the prediction rightfulness. It appeared that the objects from the two closest clusters show the predicted redshift versus luminosity (mass) dependence, while objects from the Coma list of galaxies do not (Harutyunian et al., 2019).

It is not yet clear why the behavior of this effect is so different for the studied clusters. Most likely, we did not take into account some effects depending on the distance. This is indicated by the fact that the effect is observed with high reliability for nearby clusters, while no such correlation is observed for a distant cluster. It is necessary to study many clusters more comprehensively, including closer and more distant ones, in order to have better statistics. Obviously, the farther away the cluster, the more difficult the spectroscopy of dwarf members. Moreover, the difficulties of spectroscopic measurements necessary for a useful determination of redshifts are disproportionately difficult at large distances. Perhaps this is one of the reasons why the hypothetical effect could not be detected for the Coma cluster. However, the interpretation of mass/metallicity relation and mass/redshift relation, at least for the closest clusters of galaxies, make our considerations firmer and allows using them for the interpretation of other relevant phenomena.

## 6. The Number of Baryons Instead of Mass.

Considering the physical processes that occur owing to the interaction of macro or mega objects, physicists usually neglect their atomic structure and rely mainly on the masses that characterize the objects. When describing, for example, the movements of planets in the solar system, the researcher is not interested in the atomic structure of these planets, since the masses of objects and their speeds are sufficient to solve any kinematic and dynamic problems. This approach is justified if we consider the situation for a short period compared with the cosmological times. Otherwise, one should take into consideration the evolutionary effects, we described above. We believe that the evolution of atomic nuclei and elementary particles is the principal phenomenon, determining all evolutionary effects we observe in cosmic objects and their systems.

However, if the above physical picture of the interaction of baryonic matter with a carrier of dark energy is correct in principle, then we must reconsider some of our views regarding the manifestation of the properties Harutyunian H.A. 7 of baryonic matter. ne should estimate both the quantity and quality of corrections inevitably appearing when an object or a system exists for a longer time, comparable with the cosmological. The first extremely important issue is to take into account the change in the mass of macro and mega objects due to the gradual increase in the masses of atomic nuclei and elementary particles, and the interrelation between the mass and the number of baryons originating the mass. Indeed, if the mass of baryons and their systems grows gradually increasing the mass of cosmic objects, then the amount of baryons gains a much more fundamental role in any physical interactions and becomes a conditioning factor for any further analyses.

From general physical considerations, one can assume in the first approximation that in any massive / multi-baryon object, a gradient of evolutionary changes towards the center should exist. The closer to the center of the object, the lower the "evolutionary age" of the corresponding particles of baryonic matter. This is due to the positive density gradient created by the object's own gravitational field. Indeed, the closer the considered part of the object is to its center, the greater the density of matter. Let's compare two small volumes of spherical shape and the same radius, one of which is closer to the center, and the other is closer to the surface layers. Then, by virtue of relation 12, we come to the conclusion that the ratio of the coefficients f is given by the square of the ratio of the matter density values

$$\frac{f_c}{f_s} = \frac{M_c}{M_s} \frac{\rho_c}{\rho_s} = \left(\frac{\rho_c}{\rho_s}\right)^2,\tag{15}$$

where the indices "c" and "s" stand for "center" and "surface".

On the other hand, within the framework of this paradigm, the shorter the period of evolutionary aging of matter, the closer it is to its original state. Thus, we arrive at an important conclusion that the physical conditions of the early periods of the evolution of the baryonic universe are preserved in the depths of massive/multi-baryon objects. Moreover, the more massive the object, the greater the temporal depth of its interior. We do not yet have any tool for a quantitative assessment of how much the clumps of matter of an object located at different depths lag behind in evolution, and how this lag depends on depth. We can only assume that the more massive the object, the greater the differences in the "evolutionary age" that we can register. One can also predict that over time, due to the injection of dark energy into the baryon structure of ordinary matter, the mass of the latter will increase and its instability will arise, and in order to restore stability, the object must throw out the excessive energy and mass. What this energy and mass are, apparently, should depend on the size of the object and the duration of the energy accumulation period.

Bearing in mind the considerations above, we can somewhat change the wording of Ambartsumian's "Byurakan concept". For the sake of accurate describing the physical state of the interior of any huge object, instead of large masses of superdense protostellar matter, we must speak of clumps of a huge number of baryons, the evolutionary path of which was much shorter than the evolutionary age of already formed stars and interstellar matter. Due to the evolutionarily lagging matter ejection, which inevitably occurs when the instability reaches a critical point, the ejected clump of matter suddenly appears in space, which possesses different physical conditions.

What can happen to this clump in terms of physical transformation? The same thing happens with a piece of ice taken from the refrigerator and placed next to the stove. It very quickly changes its phase state and turns into a liquid, which corresponds to a given temperature. In this process, some molecules overcome the attractive forces and move far away. In other words, takes place liquidation and evaporation from the surface layers of the solid piece of ice. Obviously, the clump of matter we are considering, ejected from the bowels of a massive object, must also accelerate the process of evolution in order to adapt to existing conditions.

This leads to the chain decay of all atomic nuclei that are much larger than the critical size and cannot exist under external conditions. The process is similar to radioactive decay, but far exceeds the scale of the processes we know on Earth. The rapid process of energy release and the formation of ordinary baryonic matter occurs most intensively in the near-surface layers of the ejected clump (or its fragment, if fragmentation has occurred as well). Owing to this process, the outermost layer of the clump evolves first and forms a kind of a hot atmosphere around the main body, which in turn slows down the decay of deeper layers, thus creating a quasi-stable state for this fragment like a star. The further life and evolution path depends on the physical characteristics of the ejected clump and the degree of its evolutionary retardation.

# 7. Conclusions.

Our hypothesis on the evolutionary aging of baryonic matter due to interaction with dark energy seems appears to support Ambartsumian's concept of superdense matter. However, "superdense" does mean in this case a huge number of baryons in the volume unite but not a very big mass. Observational facts that we studied in this connection, speak of the gradual increase of baryonic mass due to energy injection into atomic nuclei and elementary particles. For atomic nuclei, this process decreases the nuclear binding energy and accordingly increases the mass. The same most probably happens with the elementary particles, which exist owing to the binding energy as well. Therefore, one can speak about the "potentially big masses" in the depth of stars and galactic nuclei, which still exist in the form of baryonic embryos.

Although some facts fit excellently our ideas on these subjects, we are going to carry out a more comprehensive analysis of relevant observational data. If this hypothesis is correct then physical consequences should manifest themselves everywhere. Of course, the effect could be very small or even negligible, but it should exist and show up when the observational accuracy is appropriate for it.

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# Fine classification of the emission-line spectra of active galaxies

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#### Abstract

We refine the classification of galaxies by activity types based on a number of samples of objects having homogeneous optical medium resolution spectra from SDSS. SDSS spectra provide many spectral features and details that were not available before. Three diagnostic diagrams and eye examination have been used and the combined activity types have been derived. A fine classification scheme was developed, where QSOs have subtypes like Seyferts, Narrow Line QSOs are introduced, subclasses for Narrow Line Seyfert 1s are used and Composite spectrum objects have their subtypes. This classification scheme much better describes all fine details in the optical spectra and allows further study of active galaxies by the subtypes for better understanding the Unified model and the physical properties of AGN and Starbursts.

Keywords: galaxies – galaxies: active – galaxies: starburst – AGN – techniques: spectroscopic – classification

### 1. Introduction

Many active galaxies, especially active galactic nuclei (AGN), are strong emitters not only in optical, but also in Gamma- X-ray, UV, IR, submm/mm and radio wavelengths. That is why multiwavelength (MW) approach in classifications is the most acceptable. However, most of the classifications have been build up on the optical emission-line spectra. Even these classifications have a lot of disadvantages due to rough approach and not considering fine details. Based on homogeneous SDSS medium resolution classification of many samples we have worked out a general fine classification scheme for active galaxies, mainly for Active Galactic Nuclei (AGN), as well as Starbursts (SB). In this paper we give this classification scheme and describe all possible classes and subclasses based on their emission-line features, both main emission lines (H, NII, OIII, OI, SII) and other minor details. Our scheme is based on our research carried out during the last 10-15 years (HyperLEDA (2007), Mickaelian (2015), Mickaelian et al. (2007, 2011, 2018, 2021), Gavrilović et al. (2007), Abrahamyan (2020), Abrahamyan et al. (2018a,b, 2019a,b, 2020), Paronyan et al. (2019, 2020), Mikayelyan et al. (2019), and many others.) and has a strong observational basis. We give the details of the classification of all types and subtypes and give typical examples for most of the objects. We recommend to use this scheme for further homogeneous and detailed classification of most of the active galaxies that appear in SDSS spectroscopic database, as SDSS gives 90% of all available medium resolution spectra.

# 2. Fine classification of galaxies for activity types and subtypes

In a number of our papers, we have used unified approach to classify thousands of spectra for active galaxies from various samples (Abrahamyan, 2020, Abrahamyan et al., 2018b, 2019a, 2020, Mickaelian et al., 2018, Mikayelyan et al., 2019, Paronyan et al., 2019, 2020). Our approach is based on BPT diagrams (Baldwin et al., 1981, Veilleux & Osterbrock, 1987), however we use most recent options of such diagrams (Kewley et al., 2006, Reines et al., 2013). To guarantee the best accuracy and consider all possible details, we classify the objects in several ways and then consider all obtained types and subtypes:

• By the 1<sup>st</sup> diagnostic diagram (DD1) using line intensity ratios  $[OIII]/H_{\beta}$  vs.  $[OI]/H_{\alpha}$ 

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- By the  $2^{nd}$  diagnostic diagram (DD2) using line intensity ratios  $[OIII]/H_{\beta}$  vs.  $[NII]/H_{\alpha}$
- By the  $3^{rd}$  diagnostic diagram (DD3) using line intensity ratios  $[OIII]/H_{\beta}$  vs.  $[SII]/H_{\alpha}$
- By comparison and using the 1st, 2nd and 3rd diagnostic diagrams simultaneously
- By eye (considering all features and effects). Very often, the diagnostic diagrams do not give full understanding for all objects and only eye can reveal some details.

As it is known, the diagnostic diagrams are for classification of narrow line ratios, i. e. objects having Sy1 features (broad lines), QSOs, etc. cannot be classified by them. In addition, the classification by eye has been done in comparison with the classification by diagnostic diagrams because not all objects appear on them due to lack of line measurements data. The eye examination of spectra allows revealing broad lines (for Seyfert subtypes Sy1.0-Sy1.9), estimate (and later measure) the width of broad lines and reveal FeII lines on both sides of  $H_{\beta}$  to identify Narrow Line Seyfert 1s, etc., as well as classifying absorption line objects. On diagnostic diagrams, for Sy/LINER separation, we have used the criteria:  $[OIII]/H_{\beta} > 4$ , and to distinguish AGN from HII, we have used the criteria:  $[SII]/H_{\alpha} > 2/3$  and  $[OI]/H_{\alpha} > 0.1$  (Mickaelian et al., 2018, Reines et al., 2013). For all classifications, we have used the following lines:

- Absorption lines: NaI 5890/5896 doublet, MgI 5175, Hydrogen Balmer lines (mostly  $H_{\alpha}$  and  $H_{\beta}$ ), etc.
- Emission lines: most prominent are Hydrogen Balmer series lines ( $H_{\alpha}$  6363,  $H_{\beta}$  4861,  $H_{\gamma}$  4340, etc.), Oxygen lines ([OIII] 4959 and 5007, [OII] 3727 and [OI] 6300), Nitrogen lines ([NII] 6548 and 6484), Sulfur doublet ([SII] 6716/6731), Helium lines HeI 5876 and HeII 4686, etc.

## 3. The Classification Scheme

Our classification scheme is mainly based on types given by Osterbrock (1980, 1981), Véron-Cetty & Véron (2000, 2010), Winkler (1992), and HyperLEDA database at http://leda.univ-lyon1.fr/leda/ rawcat/a109.html (Gavrilović et al., 2007, HyperLEDA, 2007). Here we give in Table 1 the detailed description of all types and subtypes we have used in our classification. In addition in Table 2, we also describe the types and subtypes used in many known catalogs, such as VCV-13. Some of the spectra are taken from our similar SDSS based classification papers, as here our goal is to explain the most typical features for each type and subtype (Mickaelian et al. (2021) and references therein).

> Table 1: Detailed description of all types and subtypes of active galaxies based on the SDSS spectroscopy partially used in our classification from other available sources and those introduced by the authors for the first time.

QSO (Quasar, Quasi-Stellar Object, Quasi-Stellar Radio-source) objects having very broad emission lines (FWHM = 5,000-30,000km/s with large redshifts, first discovered by Schmidt (1963). The optical spectra are similar to those of Sy1 nuclei, but the narrow lines are generally weaker. The direct images do not differ from those of the stars on DSS1 and even DSS2 or SDSS, however, objects typically brighter than  $17^m$  and/or with redshifts smaller than 0.3 show weak "fuzz", indicating the host galaxy. They have very high luminosities  $(M_{abs} > -23)$ . Quasar luminosities are often defined as  $M_B < -21.5$  $+ 5 \log h_0$  (Schmidt & Green, 1983). QSO/S1 separation have been conditionally defined by the luminosity limits ( $M_B = -21.5...-24.0$ ), extension (QSOs as star-like and Seyferts as extended objects), and redshift limit (z=0.1; Hewitt & Burbidge, 1993), however at present the first criterion is accepted, though also conditional. There are radio-loud QSOs (quasars or  $\mathbf{RL}$   $\mathbf{QSOs})$  and radio-quiet QSOs (or **RQ QSOs**) with a dividing power at  $P_{5GHz} \approx 10^{24.7}$  W Hz<sup>-1</sup>. RL QSOs are 5-10% of the total of QSOs. There is a big gap in radio power between RL and RQ varieties of QSOs. All radio quasars have FR II morphology.



**Q1.0** – objects that have quasar luminosities and similar to Seyfert 1.0s show only very strong broad permitted emission Balmer HI lines and narrow forbidden lines. Typically, the narrow lines are weak and due to large distances of many QSOs and lower S/N ratio, they are hardly observed over the noise. When the redshift is high and Balmer lines are not observed, we apply the same criteria for fine classification to MgII and other line profiles.



 $\mathbf{Q1.2}$  – objects that have quasar luminosities and similar to Seyfert 1.2s show very strong broad permitted emission Balmer HI lines and narrow forbidden lines, as well as weak narrow permitted Balmer lines. Typically, the narrow forbidden lines are also weak and due to large distances of many QSOs and lower S/N ratio, they are hardly observed over the noise. When the redshift is high and Balmer lines are not observed, we apply the same criteria for fine classification to MgII and other line profiles.







**Q1.8** – objects that have quasar luminosities and similar to Seyfert 1.8s show broad permitted emission Balmer HI lines and narrow forbidden lines, as well as strong narrow permitted Balmer lines. The permitted lines show strong narrow components and weak broad components only for  $H_{\alpha}$  and  $H_{\beta}$ . When the redshift is high and Balmer lines are not observed, we apply the same criteria for fine classification to MgII and other line profiles.



**Q1.9** – objects that have quasar luminosity and similar to Seyfert 1.9s show broad permitted emission Balmer  $H_{\alpha}$  line and narrow forbidden lines, as well as strong narrow permitted Balmer lines. The permitted lines show strong narrow components and weak broad components only for  $H_{\alpha}$ . When the redshift is high and Balmer lines are not observed, we apply the same criteria for fine classification to MgII and other line profiles.

NLQ1 – (Narrow-Line Quasar 1) – QSO with relatively narrow broad lines. Analogous to NLS1 defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow (~2000 km/s) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization. The permitted lines may show or not show narrow component, depending on the subtypes. In case of low S/N and low quality, many objects are being classified as NLQ1 without a subclass.

**NLQ1.0** – (Narrow-Line Quasar 1.0) – QSO with relatively narrow broad lines. Analogous to NLS1 defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow ( $\sim 2000 \text{ km/s}$ ) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are abundantly present, as well as often strong [FeVII] and [FeX] lines with higher ionization. The permitted lines do not show narrow component.







**NLQ1.2** – (Narrow-Line Quasar 1.2) – QSO with relatively narrow broad lines. Analogous to NLS1 defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow ( $\sim 2000 \text{ km/s}$ ) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization. The permitted lines show weak narrow component.



**NLQ1.5** – (Narrow-Line Quasar 1.5) – QSO with relatively narrow broad lines. Analogous to NLS1 defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow ( $\sim 2000 \text{ km/s}$ ) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization. The permitted lines show medium strength narrow component. The intensity ratio of broad and narrow components is approximately equal.



**BL Lac, BLL** – BL Lacertae type object. BL Lac variable "star" is the prototype of this class (Hoffmeister, 1929), first such object to be identified as an extragalactic one (Schmitt, 1968). This class was proposed by Strittmatter et al. (1972) and BL Lac absorption lines were observed and redshift was measured by Oke & Gunn (1974). They are stellar in appearance with variable, intense and highly polarized continuum. Strong featureless continuum; no emission or absorption lines deeper than ~2% are seen in any part of the optical spectrum, or only extremely week absorption and/or emission lines are observed, as a rule at minimum of their very highly variable phase. The weak lines often just appear in the most quiescent stages. So that their redshifts can only be determined from features in spectra of their host galaxies. Show polarization, and are strong radio sources with flat spectrum (Lawrence, 1987, Miller, 1978, Miller et al., 1978). The parent population of BLLs is made of FR I radio galaxies.

**S1.0** (S1, Sy1.0, Seyfert 1.0 or BLS1, Broad-Line Seyfert 1) – Seyfert 1 with broad lines. Broad permitted Balmer HI, HeII and other lines (FWHM = 1,000–10,000 km/s; typical is 2,000–6,000 km/s) that originate in a high-density medium ( $n_e \leq 10^9$  cm<sup>-3</sup>) and narrow forbidden lines ([OIII], [NII], [SII], etc. with FWHM = 300–1,000 km/s) that originate in a low-density medium ( $n_e \approx 10^3$ -10<sup>6</sup> cm<sup>-3</sup>). Narrow hydrogen lines are completely lost in strong broad components. Physically, these are the same objects as QSOs, but have lower luminosities ( $M_{abs} >$ -23). Typically, they are radio quiet. According to Winkler (1992), H<sub>β</sub>/[OIII]5007 > 5.0. NGC 4151 is the prototype. The subtypes S1.0-S1.9 were introduced by Osterbrock (1981).









S1.2 (Sy1.2, Seyfert 1.2) – AGN with spectra that have parameters intermediate between classical Sy1 and Sy2 galaxies; i. e., both broad and narrow components of the resolved lines are present (in our case the  $H_{\alpha}$  and  $H_{\beta}$  line profiles are of this kind) (Osterbrock, 1981), but the broad lines are stronger and the ratio of the narrow components  $2.0 < H_{\beta}/[OIII]5007 < 5.0$  (according to Winkler, 1992). Often erroneously related to NLS1s or S1n.



S1.5 (Sy1.5, Seyfert 1.5) – AGN with spectra that have parameters intermediate between classical Sy1 and Sy2 galaxies in which narrow and broad line components are observed. The Balmer series hydrogen lines have roughly equal intensities (narrow profile overlapped on broad wings) (Osterbrock, 1981), According to Winkler (1992), the ratio of the narrow component of  ${\rm H}_\beta$  to [OIII]5007 is 0.333 < $H_{\beta}/[OIII]5007 < 2.0$ . The intensities of the broad and narrow components are roughly equal.



250

200

200

150

100

50

S1.8 (Sy1.8, Seyfert 1.8) - AGN with spectra that have parameters intermediate between classical Sy1 and Sy2 galaxies. They have relatively weak broad  $H_{\alpha}$  and  $H_{\beta}$  components superposed on stronger narrow lines (Osterbrock, 1981), and according to Winkler (1992), ratio of narrow components  $H_{\beta}/[OIII]5007 < 0.333$ .

**S1.9** (Sy1.9, Seyfert 1.9) – AGN with spectra that have parameters intermediate between classical Sy1 and Sy2 galaxies and have a relatively fainter broad Ha component superposed on a stronger narrow line. Broad  $H_{\beta}$  component is not observed (Osterbrock, 1981), and according to Winkler (1992), narrow component of  $H_{\beta}/[OIII]5007 <$ 0.333.



**S2.0** (Sy2.0, Seyfert 2.0, also may be given as S2, as there are no other subtypes) – AGN with spectra displaying relatively narrow (compared to Sy1) resolved emission Balmer and forbidden lines with almost equal FWHM ( $\geq$ 300km/s), usually in the range of 300-1000 km/s (Khachikian & Weedman, 1974, Weedman & Khachikyan, 1968) that originate in a low-density medium ( $n_e \approx 10^3 - 10^6$  cm<sup>-3</sup>). The broad component is not visible. The condition [OIII]5007/H<sub> $\beta$ </sub>  $\geq$  3, serves as a secondary classification criterion, so they can be distinguished against NLS1s (Lawrence, 1987, Veilleux & Osterbrock, 1987). NGC 1068 is the prototype.

**NLS1** (Narrow-Line Seyfert 1, S1n) – Seyfert 1 with narrow lines. Defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow (~2000 km/s) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization, unlike what is seen in Seyfert 2s. The ratio [OIII]5007/H<sub> $\beta$ </sub> < 3, but exceptions are allowed if there are also strong [FeVII] and [FeX] emission lines present. FWHM(H<sub> $\beta$ </sub>) < 2000km/s (Goodrich, 1989, 1995).

**NLS1.0** (Narrow-Line Seyfert 1.0) – Seyfert 1.0 with narrow lines. Defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow (~2000 km/s) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization, unlike what is seen in Seyfert 2s. The ratio [OIII]5007/H<sub> $\beta$ </sub> < 3, but exceptions are allowed if there are also strong [FeVII] and [FeX] emission lines present. FWHM(H<sub> $\beta$ </sub>) < 2000km/s (Goodrich, 1989).





**NLS1.2** (Narrow-Line Seyfert 1.2) – Seyfert 1.2 with narrow lines. They are defined as soft X-ray sources; the resolved lines are relatively narrow ( $\sim 2000 \text{ km/s}$ ) and they have widths that are only slightly broader than the forbidden lines. FeI, FeII, and FeIII appear and often strong lines with higher ionization [FeVII] and [FeX] often, along with various emission lines (Osterbrock & Pogge, 1985).



**NLS1.5** (Narrow-Line Seyfert 1.5) – Seyfert 1.5 with narrow lines. They are defined as soft X-ray sources and the permitted broad lines are relatively narrow ( $\sim 2000 \text{ km/s}$ ) with widths only slightly exceeding those of the forbidden lines. FeI, FeII, FeIII appear and often strong lines with higher ionization [FeVII] and [FeX] often, along with various emission lines (Osterbrock & Pogge, 1985).



**NLS1.8** (Narrow-line Seyfert 1.8) – these are soft X-ray sources having narrow permitted lines only slightly broader than the forbidden ones; many FeI, FeII, FeIII, and often strong [FeVII] and [FeX] emission lines present. Only  $H_{\alpha}$  and  $H_{\beta}$  permitted broad components are observed, the same criterion as for S1.8 subtype (Osterbrock, 1981).



200 200 5 150 5 50 4 000 5000 6000 7000 8000 9000 10000 Wavelength (Angstroms)



**LINER** (Low-Ionization Nuclear Emission-line Region, also given as S3, Seyfert 3). Galactic nuclei with emission lines formed in low ionization regions. Introduced by Heckman (1980), they are low activity AGN, the weakest form of AGN activity. They have S2-like spectra with relatively strong low-ionization lines ([OI], [OII]). The ratios [OII]3727/[OIII]5007  $\geq 1$ , [OI]6300/[OIII]5007  $\geq 1/3$ . [NII]6584/H<sub> $\alpha$ </sub> > 0.6 according to Kauffmann et al. (2003). According to Ho et al. (1997), there are 2 classes of LINERs: type 1 shows broad Balmer emission analogous to S1s (weak broad H<sub> $\alpha$ </sub> visible), and type 2, without broad H<sub> $\alpha$ </sub> analogous to S2s. May be either radio quiet or radio loud. Most of the nuclei of nearby galaxies are LINERs. However, their emission line spectra are not necessarily caused by active nuclei.



HII (HII regions, H2) - Isolated extragalactic HII regions as defined by Sargent & Searle (1970) or HII galaxies as defined by Terlevich et al. (1991). Have spectra similar to SB, i. e., spectra with strong narrow (FWHM  $\leq$  300 km/s) emission lines but with ratios [OIII]/H<sub> $\beta$ </sub>  $\geq$ 3 and [NII]6583/H<sub> $\alpha$ </sub> < 0.6, combined with a blue continuum (Veilleux & Osterbrock, 1987, Winkler, 1992). Essentially the same as SB, but for classification of SB the value of the star formation rate (SFR) is needed.





HII/LINER - Composite spectrum galaxy, having a mixture of HII and LINER features. Very often one of the emission line ratios may show on HII and the other ratio shows on LINER. Otherwise, a typical HII spectrum may show very strong [OII] 3727 and/or [SII] doublet.

Seyfert features. Very often one of the emission line ratios may show on HII and the other ratio shows on Seyfert.



 $\mathbf{LINER}/\mathbf{Sy}$  – Composite spectrum galaxy, having a mixture of LINER and Seyfert features. Very often one of the emission line ratios may show on LINER and the other ratio shows on Seyfert. Otherwise, a typical Sy spectrum may show very strong [OII] 3727 and/or [SII] doublet. We give an example of LINER/S2.0 composite.



HII/Sy - Composite spectrum galaxy, having a mixture of HII and

15

10

0

4000

5000

(10<sup>-17</sup> erg/s/cm<sup>2</sup>/Ang)

AGN (Active Galactic Nuclei) - AGN without a subclass due to relatively low-quality (both resolution and/or S/N) spectra in which only a few emission lines are observed, mainly  $H_{\alpha}$  with NII lines and a [NII]/H<sub> $\alpha$ </sub> ratio typical for AGN, i. e. Sy or LINER. Of course, the LINER spectra are not necessarily related to the activity of their nuclei, but this may aid in case of rough classification.



Em (Emission-line galaxy, ELG) - Relatively low-quality (both resolution and/or S/N) spectra in which only one or a few emission lines are observed (H<sub> $\alpha$ </sub>, [NII]6584/6548, and [OII]3727) without the possibility of classifying them precisely. These spectra usually have a strong stellar component (continuum and absorption), and the emission lines are hard to see against continuum and absorption lines.

Abs (Absorption-line galaxy) - Spectra with only absorption lines superimposed on the continuum. Mainly the stronger stellar lines, MgII 5175 and NaI 5890-96 lines show up, along with the Balmer lines. No signs for any (nuclear or starburst) activity. Also called normal galaxies, though the latter ones may show some weak emission lines as well. IR, radio, or X-ray sources with spectra of this kind often may contain hidden AGN.



7000

6000

8000

9000

4000 5000 6000 7000 8000 9000 10000 Wavelength (Angstroms)

Table 2: Description of the types and subtypes of active galaxies used in other available sources, mainly VCV-13 and BZCAT.

BAL QSO - Broad absorption line QSO. Besides broad emission lines they show deep blue-shifted very broad (10,000-30,000 km/s) absorption lines with P Cyg type profiles corresponding to resonance lines of CIV, SiIV, NV. All of them are at  $z \ge 1.5$ because the phenomenon is observed in the rest-frame UV. At these redshifts, they are about 10% of the observed population. BAL QSOs tend to be more polarized than non-BAL QSOs.

Peterson, B. (1997)

DLA QSO - Damped Ly-alpha QSO. Show unresolved absorption lines even on very high-resolution spectra (<1A), with typical widths of 10-12A, resulting in a column density of  $>10^{23}$ , indicating the presence of high-density galactic size masses along the line of sight.

# **Table 2 Continued:** Description of the types and subtypes of active galaxiesused in other available sources, mainly VCV-13 and BZCAT.

<b>Blazar</b> – Combination of two most powerful AGN classes; BLL and OVV/HPQ (Optically Violent Variable quasar / High Polarization Quasar), introduced by E. Spiegel in 1978. These are believed to be objects with a strong relativistically beamed jet in the line of sight. When the angle between the relativistic jet axis and the line of sight is small, the jet is Doppler boosted by a large factor and the whole spectrum (from radio to $\gamma$ -ray) is dominated by a compact, highly polarized, highly variable, superluminal, almost featureless continuum, called blazar. As these two types have many common and different physical properties, the question of definition of blazars is still open (Mickaelian, 2015). There are many parameters that may be regarded as criteria for definition of blazars, such as high luminosity, radio flat spectrum, presence of X-ray and $\gamma$ -ray, optical and/or radio variability, polarizations, etc.	Kellermann, K. (1992)
<b>S1i</b> – S1 infrared. S1 with a broad Paschen $Pa_{\beta}$ line, indicating the presence of a highly reddened BLR. Seyfert 1 with an absorbed BLR visible in NIR.	Goodrich et al. (1994), Véron-Cetty & Véron (2010)
S1h – S1 hidden. S2 showing S1 like spectra in polarized light (Antonucci, 1993, Antonucci & Miller, 1985, Barger et al., 2000, Miller & Goodrich, 1990, Tran et al., 1992, Urry & Padovani, 1995). Seyfert 1 with a hidden BLR.	Antonucci (1993), Antonucci & Miller (1985), Barger et al. (2000), Miller & Goodrich (1990), Tran et al. (1992), Urry & Padovani (1995), Véron-Cetty & Véron (2010)
<b>SBN</b> and <b>SBG</b> – Starburst nuclei or Starburst galaxy. M82 was the archetype SB galaxy. The major observable feature that distinguishes SB from Sy is their strong narrow emission lines FWHM $\leq$ 300km/s. According to Balzano (1983), SB is a spiral galaxy with a bright, blue nucleus that emits a strong narrow emission line spectrum similar to low-ionization HII region spectra. They have strong, narrow (FWHM $\leq$ 250km/s) low-ionization ([OIII]/H <sub><math>\beta</math></sub> < 3) emission lines; absolute luminosities -17.5 > M > -22.5; characterized by having conspicuous stellar or semistellar nuclei. SB can occur in disk galaxies; however irregular galaxies often exhibit knots of SB spread throughout the galaxy. SFR is a few M <sub><math>\odot</math></sub> yr <sup>-1</sup> , but may reach up to 10 <sup>3</sup> M <sub><math>\bigcirc</math></sub> yr <sup>-1</sup> (the maximum is 2200-2300 M <sub><math>\bigcirc</math></sub> yr <sup>-1</sup> ). Based on the relative energy output of the SB (L <sub>SB</sub> ) to that of the rest of the galaxy (L <sub>G</sub> ) and the SB age, R. Terlevich classified SB into 3 classes (subtypes): SB galaxies having L <sub>SB</sub> $\gg$ L <sub>G</sub> , Galaxies with SB having L <sub>SB</sub> $\sim$ L <sub>G</sub> , and Normal galaxies having L <sub>SB</sub>	Balzano (1983), Weedman (1977)
<b>BCDG</b> – Blue Compact Dwarf Galaxy as introduced by Thuan & Martin (1981) and described by Gallego et al. (1996). Subtype of SB. Have HII spectra. Most of them have a high rate of star formation. Dwarf, low-mass, low-metallicity, dust-free objects. The BCDG classification involves spectral-morphological parameters; they are blue objects with $M(B) > -17.5$ and linear sizes of less than $D \leq 3$ -4kpc. IZw18 is the most well-known BCDG being the most metal poor one.	Gallego et al. (1996), Thuan & Martin (1981)
<b>WR galaxy</b> – Wolf-Rayet Galaxy. Subtype of SB having a large portion of bright stars as early-type Wolf-Rayet ones. Because these stars are both very luminous and have very distinctive spectral features, it is possible to identify them in the spectra of the entire galaxies. They show prominent broad emission lines of highly-ionized He and N or C. NGC 6764 and Mrk 309 are WRG prototypes.	Osterbrock & Cohen (1982)
<b>S</b> (Sy, Seyfert galaxy) – Seyfert galaxy (no accurate classification if given without a subclass). Emission-line galaxies observed by Seyfert (1943). Relatively low luminosity AGN with MB > $-21.5 + \log h_0$ . Their host galaxies are clearly detectable. Depending on the width of optical emission lines, Seyfert types 1 and 2 (Khachikian & Weedman, 1974, Weedman & Khachikyan, 1968) and subtypes (Osterbrock, 1981) were introduced.	Seyfert (1943)
$\mathbf{S3b}$ – LINERs (S3) with broad Balmer lines, the same as LINER type 1.	Ho et al. (1997), Véron-Cetty & Véron (2010)

Table 2 Continued: Description of the types and subtypes of active galaxies used in other available sources, mainly VCV-13 and BZCAT.

<b>S3h</b> – LINERs (S3) with broad Balmer lines seen only in polarized light.	Véron-Cetty & Véron (2010)
<b>Composite</b> (Composite spectrum galaxy, HII/LINER, HII/Sy or LINER/Sy) – objects with composite spectra in which spectral features of two or more activity types (HII and LINERs, HII and Sy, or LINERs and Sy) are present, and in some cases, all three, as a rule, a combination of Seyfert, LINER and/or HII types. Before, they were regarded as transition objects due to their location in transition regions of diagnostic diagrams. Often, they are classified differently on different diagrams. They may be LINER/S2, HII/S2, HII/LINER or even a combination of S1 subtypes (S1.8, S1.9) and a LINER or HII. HII/S2 and HII/LINER are considered to be a superposition of S2 or LINER nucleus with circumnuclear HII regions.	Véron et al. (1997)

# 4. Summary and conclusions

Homogeneous classifications of active galaxies have always been a tricky task. Most of the classifications have appeared as historical ones based on some definite survey or spectroscopic material, and from the modern point of view, often having very low quality. Classifications based on optical emission-line spectra began as early as in 1943, when Carl Seyfert (Seyfert, 1943) observed emission-lines in the spectra of some spiral galaxies ("extragalactic nebulae"), including presently well-known AGN like: NGC 4151, NGC 4051, NGC 1068 (also known as M77), NGC 1275 (also known as Perseus A radio galaxy), NGC 3516, NGC 5548, and NGC 7469. Especially surprising was the presence of broad emission lines (or broad wings of lines) that were not observed in the spectra of the galactic nebulae. These objects were called Sevfert (Sy or S) galaxies. Using an optical spectrum obtained with the 200-inch Hale Telescope on Mt. Palomar, Maarten Schmidt was the first to interpret the spectrum of the radio source 3C 273 as having very largely redshifted (z=0.158) broad emission Balmer lines corresponding to recession velocity of 47,000 km/s (Schmidt, 1963). This discovery allowed other astronomers to measure redshifts from emission lines of other radio sources thus extending our knowledge to much farther extragalactic universe. These point-like extragalactic radio sources were called quasi-stellar radio sources (quasars) or quasi-stellar objects (QSOs). Later on, based on the presence or absence of broad emission lines, Seyferts were classified into S1 and S2, respectively (Khachikian & Weedman, 1974).

AGN zoo appeared with a big mixture of properties and confusion in definitions and classifications. Optical Emission Line Diagnostics of AGN is based on study of spectra in optical range, which allows to distinguish 11 Seyfert galaxies, LINERs and Starburst (or HII regions). First diagrams were introduced by Baldwin, Phillips and Terlevich in 1981 (BPT diagrams; Baldwin et al. 1981). They used emission line intensities ratios to distinguish Seyferts against LINERs and Starbursts. Veilleux & Osterbrock improved this technique by modifying line ratios to  $[OIII]5007/H_{\beta}$ ,  $[NII]6583/H_{\alpha}$ ,  $[OI]6300/H_{\alpha}$  and  $[SII]6716+6731/H_{\alpha}$ (Veilleux & Osterbrock, 1987), as some BPT ratios need reddening correction while the Veilleux & Osterbrock ratios do not (being close in  $\lambda$ ). There are a number of other diagnostic diagrams as well. Stephanie Juneau has developed a comprehensive AGN diagnostics (Juneau et al., 2014), where both optical and other wavelengths are considered. AGN spectra contain numerous iron (FeI, FeII and FeIII) lines. They appear around  $H_{\beta}$  (from both sides) and elsewhere and interfere accurate line identification and measurements. Fe templates have been built to be fitted and subtracted from a given spectrum. Especially numerous and intense are Fe lines in NarrowLine Seyfert 1 Galaxies (NLS1). On the other hand, Osterbrock (1981) introduced intermediate Seyfert subtypes based on the presence and significance of broad and narrow lines. Many other subtypes were introduced as well, and AGN zoo very often creates problems for overall understanding of these objects.

In this paper, we have developed a fine classification scheme for active galaxies and accordingly carried out classification of the SDSS spectra for active galaxies.

The most important result related to the classification of active galaxies and other results is introducing the fine classification scheme for active galaxies using SDSS spectroscopy. This became possible for the first time, as SDSS quality spectra were not available before. Detailed description of the types and subtypes of active galaxies is given, including many of them **introduced for the first time**. The most important novelties in our classification scheme are the following:

- Introducing QSO subtypes analogous to Seyferts (Osterbrock, 1981): Q1.0, Q1.2, Q1.5, Q1.8 and Q1.9;
- Introducing Narrow Line Seyfert 1 (NLS1; Osterbrock & Pogge 1985) subtypes based on the same criteria used by Osterbrock (1981); NLS1.0, NLS1.2, NLS1.5, NLS1.8, NLS1.9;
- Introducing Narrow Line QSOs and their subtypes analogous to NLS1s (Osterbrock, 1981, Osterbrock & Pogge, 1985); NLQ1.0, NLQ1.2, NLQ1.5, NLQ1.8 and NLQ1.9;
- Fine classification of Composite spectrum objects (Véron et al., 1997); Sy/LINER, Sy/HII, LINER/HII, as well as Sy/LINER/HII (with all variety of subtypes of Seyferts participating in each subtype of Composites).

To summarize our types and subtypes, we give Table 3 for comparative analysis of all properties. Here we give only most important types and subtypes and those, which often appear in our classifications.

Types	Broad lines		Narrow lines						
	$H_{\alpha}$	$H_{\beta}$	Other	HI	[OII]	[OIII]	[OI]	[NII]	[SII]
Q1.0	Strong	Strong	yes	No	Weak	Strong	Not obs	Strong	Not obs
Q1.2	Strong	Strong	yes	Weak	Weak	Strong	Not obs	Strong	Not obs
Q1.5	Strong	Strong	yes	Medium	Weak	Strong	Not obs	Strong	Not obs
NLQ1.0	Strong	Strong	yes	No	Weak	Strong	Not obs	Strong	Not obs
NLQ1.2	Strong	Strong	yes	Weak	Weak	Strong	Not obs	Strong	Not obs
NLQ1.5	Strong	Strong	yes	Medium	Weak	Strong	Not obs	Strong	Not obs
S1.0	Strong	Strong	yes	No	Weak	Strong	Weak	Strong	Weak
S1.2	Strong	Strong	yes	Weak	Weak	Strong	Weak	Strong	Weak
S1.5	Medium	Medium	yes	Medium	Weak	Strong	Weak	Strong	Weak
S1.8	Weak	Weak	No	Strong	Weak	Strong	Weak	Strong	Weak
S1.9	Weak	Not obs	No	Strong	Weak	Strong	Weak	Strong	Weak
NLS1.0	Strong	Strong	yes	No	Weak	Strong	Weak	Strong	Weak
NLS1.2	Strong	Strong	yes	Weak	Weak	Strong	Weak	Strong	Weak
NLS1.5	Medium	Medium	yes	Medium	Weak	Strong	Weak	Strong	Weak
NLS1.8	Weak	Weak	No	Strong	Weak	Strong	Weak	Strong	Weak
NLS1.9	Weak	Not obs	No	Strong	Weak	Strong	Weak	Strong	Weak
S2.0	No	No	No	Strong	Weak	Strong	Weak	Strong	Weak
LINER	No	No	No	Strong	Strong	Strong	Strong	Strong	Strong
HII	No	No	No	Strong	Weak	Weak	Weak	Weak	Weak
Comp	Any	Any	Any	Strong	Any	Any	Any	Any	Any

Table 3. A comparative analysis of all properties for different types and subtypes of AGN and Starbursts.

As seen from Table 3, almost all subtypes (beside S2.0, LINER and HII) have strong, medium or weak broad lines (at least  $H_{\alpha}$ ), which makes impossible their classifications by the diagnostic diagrams. Among the narrow forbidden lines, some ([OIII], [NII], etc.) are almost always observable, however when the broad lines are strong, better resolution spectra are needed to distinguish [NII] from broad  $H_{\alpha}$  and narrow  $H_{\alpha}$ and  $H_{\beta}$  from their broad components. In general, one has to accept that any classification works well for the given spectral range and quality (spectral resolution and S/N ratio). When classifying other than SDSS spectra, new features and details may appear. However, our classification scheme may be useful for many studies, as 4.3 million SDSS spectra at present comprise some 80% of all medium and high resolution spectra available in astronomy (dozens of millions of low-resolution spectra are provided by objective prism surveys, such as DFBS (Mickaelian et al., 2007), HQS (Hagen et al., 1995), HES (Wisotzki et al., 1996) and will be available from Gaia, however very poor and only preliminary classification will be possible based on them).

The fine classification of AGN may strongly support the understanding of the Unified Scheme and all details about the position (angle of observation) of different types and subtypes of AGN in this scheme. 22Mickaelian et al.

To summarize the results of this paper, one can emphasize the development of a detailed homogeneous fine classification scheme for active galaxies considering all available spectral features in SDSS spectroscopy. We have based on the available historical classifications and used the newest BPT-type diagnostic diagrams; however, many new subtypes have been introduced to fit the same approach for QSOs and Seyferts, broad (BLS1) and narrow (NLS1) line Seyfert 1s.

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# The Spectral Line Evolution in a Semi-infinite Atmosphere with Local Time-dependent Energy Sources

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#### Abstract

The time-dependent problem of spectral line formation in a one-dimensional semi-infinite scattering and absorbing atmosphere containing a local energy source radiating equally in both directions is considered. The energy release is assumed to be non-stationary and to be either  $\delta(t)$ -shaped or of the unit jump form given by the Heaviside H(t) function. The main attention is paid to the temporal dependence of the observed line profiles on the depth of energy eruption in the atmosphere. The role of scattering in the continuous spectrum is emphasized.

# 1. Introduction

In our previous works (Nikoghossian, 2021a,b) we used a relatively simple way of finding solutions to the time-dependent problems of the line radiation transfer in 1D atmosphere. The method is based on the construction of Neumann series for the quantities sought and goes back to the works of Ganapol (1979), Matsumoto (1967, 1974). Solutions were constructed for diffuse reflection from a semi-infinite atmosphere as well as for diffuse reflection and transmittance for a medium of finite optical thickness. In both cases the scattering was assumed to be coherent. These mathematically simple model problems in the above approach have a number of advantages. The main one is that, despite the assumptions made, they allow one to clearly trace the evolution of the spectral lines formed depending on the values of various quantities determining the local optical properties of the medium and location of primary sources. In a number of cases, it is not difficult to conclude that some of detected patterns remain valid also for fairly more general problem formulations. The assumption of scattering coherence in the problem simplification is crucial, since in some cases the coefficients in the expansion of the Neumann series are constants and are calculated once and for all. Tables of such coefficients for the coefficient of reflection from a semi-infinite atmosphere are given in Nikoghossian (2021b). The frequency dependence of the reflection function, as well as the dependence on the local optical properties of the medium, appear through a certain parameter  $\lambda$ , of the form

$$\tilde{\lambda}(x) = \frac{\lambda \alpha(x) + \gamma}{\lambda \alpha(x) + \beta + \gamma} \tag{1}$$

where  $\lambda$  is the coefficient of the quantum re-radiation in the elementary event of scattering in the line,  $\alpha(x)$  is the line absorption profile, x is the dimensionless frequency measured by displacement from the center of the line in Doppler widths,  $\beta$  and  $\gamma$  correspondingly are the ratios of the continuum absorption and scattering coefficients to that in the center of the line. It is noteworthy that, with the assumptions we have made, the role of scattering in the continuum, which is also assumed to be coherent, is taken into account quite simply. This is another advantage of the approach used. In astrophysical applications, one of the most common scattering mechanisms in the continuum spectrum is scattering on free electrons (see, for example, Nikoghossian, 2020) and the list of literature there. In this paper, we will continue the study of the temporal variations of spectral lines in various problems frequently encountered in astrophysical applications, in which multiple scattering of radiation in the medium should be taken into account. Here we will assume that the primary energy source is located inside the atmosphere at some predetermined optical depth  $\tau_0$ .

# 2. The line radiation transfer in a semi-infinite atmosphere with the local energy sources.

Before addressing to our problem it is expedient to present some formulas and relations being in use in solving the problems of diffuse reflection (and transmission for finite atmosphere) we have considered in the cited papers (Nikoghossian, 2021a,b). The reflection function from the semi-infinite atmosphere  $\rho(x)$ , as was said, is sought in the form of a Neumann series

$$\rho(x) = \sum_{n=1}^{\infty} \rho_n \tilde{\lambda}^n (x).$$
(2)

The coefficients  $\rho_n$  for n > 2 are found recurrently by

$$\rho_n = \frac{1}{2} \left( \rho_{n-1} + \frac{1}{2} \sum_{k=1}^{n-2} \rho_k \rho_{n-k-1} \right)$$
(3)

taking of  $\rho_1 = 0.25$  and  $\rho_2 = 0.125$ .

Analogously, in the case of a medium of finite optical thickness  $\tau_0$  for the reflection and transmission functions are given by

$$\rho(x,\tau_0) = \sum_{n=1}^{\infty} \rho_n(x,\tau_0) \,\tilde{\lambda}^n(x), \qquad q(x,\tau_0) = \sum_{n=0}^{\infty} q_n(x,\tau_0) \,\tilde{\lambda}^n(x). \tag{4}$$

Note that the coefficients in these series depend on the frequency in the line. The first two coefficients in the series are found immediately to give

$$\rho_1(x,\tau_0) = \frac{1}{4} \left( 1 - e^{-2\nu(x)\tau_0} \right), \qquad \rho_2(x,\tau_0) = \frac{1}{8} \left[ 1 - \left( 1 + 2\nu(x)\tau_0 \right) e^{-2\nu(x)\tau_0} \right], \tag{5}$$

$$q_0(x,\tau_0) = e^{-\nu(x)\tau_0} \qquad q_1(x,\tau_0) = \frac{1}{2}\tau_0 e^{-\nu(x)\tau_0},\tag{6}$$

where  $v(x) = \alpha(x) + \beta$ . The remaining coefficients associated with the twofold reflection processes are calculated sequentially by means of the formulas

$$\rho_n(x,\tau_0) = 2\nu(x) \int_0^{\tau_0} \Phi_n(x,t) e^{-2\nu(x)(\tau-t)} dt,$$
(7)

$$q_n(x,\tau_0) = \nu(x) \int_0^{\tau_0} \Psi_n(x,t) e^{-2\nu(x)(\tau-t)} dt,$$
(8)

where the functions  $\Phi_n(x,t)$  and  $\Psi_n(x,t)$  are determined as

$$\Phi_n(x,\tau_0) = \frac{1}{2} \left[ \rho_{n-1}(x,\tau_0) + \frac{1}{2} \sum_{k=1}^{n-2} \rho_k(x,\tau_0) \rho_{n-k-1}(x,\tau_0) \right],$$
(9)

$$\Psi_n(x,\tau_0) = \frac{1}{2} \left[ q_{n-1}(x,\tau_0) + \frac{1}{2} \sum_{k=1}^{n-1} \rho_k(x,\tau_0) q_{n-k-1}(x,\tau_0) \right].$$
(10)

Having now all the prerequisites we formulate problem under consideration as follows. Suppose that the primary source of energy is located at depth  $\tau_0$  in the 1D atmosphere and radiate equally in both directions (see Fig. 1). If the total intensity is taken as unity, for the probability distribution function of radiation  $P(x, \tau_0)$  outgoing from the atmosphere one obviously can write

$$P(x,\tau_0) = \frac{1}{2} \frac{(1+\rho_{\infty}(x)) q(x,\tau_0)}{1-\rho_{\infty}(x) \rho(x,\tau_0)}.$$
(11)  
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Figure 1. Schematic picture of the radiation transport in the presence of internal energy sources



Figure 2. Profiles of spectral lines formed in the stationary regime.

For further treatment, it is convenient to replace the ratio  $1/(1-\rho_{\infty})\rho$  with corresponding infinite series as follows,

$$\frac{1}{1 - \rho_{\infty}(x) \rho(x, \tau_0)} = \sum_{i=0}^{\infty} \left[ \rho_{\infty}(x) \rho(x, \tau_0) \right]^i,$$
(12)

which, obviously, converges at any values of the physical parameters if only  $\lambda < 1$  when  $\gamma = 0, x = 0$ . The convergence rate is higher at lower values of optical thickness, scattering coefficient, also in the wings of the line, where the scattering effect is weakly expressed.

Typical examples of spectral line profiles formed in the stationary regime are shown in Fig. 2. The results are shown for the case when there is no scattering in the continuum (left panel) and for the case when it is present (right panel). As could be expected with sources located inside the atmosphere, we observe in both cases absorption lines in spite of the difference in the levels of the continuous spectrum. However, in the absence of scattering in the continuum, the lines have a specific shape associated with emission components in their wings. There exists a clear correlation between the depth of the energy source and the equivalent width, as well as the central depth of the spectral line.

Fig. 3 shows the equivalent width of the resulting spectral line as a function of the depth of the internal energy source. Both cases, with and without allowance of scattering in the continuum, are depicted. It is seen that when photons are scattered both in the line and in continuous spectrum, the equivalent width of the line grows more slowly with optical depth. Thus, the shape of the spectral line together with its equivalent width provide a fundamental opportunity to judge the depth in the atmosphere where the energy release occurs. Below we will see that the time characteristics of the line appearance can provide additional information about the energy release in the atmosphere.



Figure 3. The depth variation of equivalent widths of the spectral line.

# 3. The time dependent problem of the spectral line formation in the semi-infinite atmosphere with local non-stationary sources of energy

After solving the stationary problem, it is easy to construct the solution of the corresponding time-dependent problem. To this purpose let us return to Eq.(11) and write it briefly in the operator notation

$$P = \frac{1}{2}(1+R_{\infty})Q\sum_{i=0}^{\infty} (R_{\infty}R)^{i}.$$
(13)

When passing to the time-dependent problem, it is necessary to know the coefficients in the expansions of each of the above operators with respect to the powers of  $\tilde{\lambda}(x)$ .

$$Q = \sum_{n=0}^{\infty} q_n (x, \tau_0) \,\tilde{\lambda}^n (x), \qquad R = \sum_{k=1}^{\infty} \rho_k (x, \tau_0) \tilde{\lambda}^k (x), \qquad R_\infty = \sum_{i=1}^{\infty} \rho_i^\infty \tilde{\lambda}^i (x, ),$$
$$P = \sum_{k=0}^{\infty} p_k (x, \tau_0) \,\tilde{\lambda}^i (x), \qquad R_\infty R = \sum_{i=1}^{\infty} \tilde{\lambda}^i (x) \sum_{j=1}^i \rho_j^\infty \rho_{i-j} (x, \tau_0). \tag{14}$$

Eq.(13) shows that the calculations numerically are reduced to the multiplication of power series according to the well-known Cauchy formula, which does not meet any fundamental difficulties. In the first approximation, which neglects the multiple interactions between finite surface part  $(0, \tau_0)$  of the atmosphere and its the rest infinitely deep part, we will have

$$p_n(x,\tau_0) = \frac{1}{2} \left( q_n(x,\tau_0) + \sum_{l=1}^n \rho_l^\infty q_{n-l}(x,\tau_0) \right),$$
(15)

and, in the second approximation, limiting ourselves to the linear part in the infinite series in Eq.(13),

$$2p_n\left(x,\tau_0\right) = q_n\left(x,\tau_0\right) +$$

$$\sum_{l=1}^{n} \left[ \rho_{l}^{\infty} q_{n-l}(x,\tau_{0}) + q_{l} \sum_{i=1}^{l} \rho_{l}^{\infty} \rho_{l-l}(x,\tau_{0}) + \sum_{i=1}^{l} \rho_{l}^{\infty} q_{l-l}(x,\tau_{0}) \sum_{k=1}^{l} \rho_{k}^{\infty} \rho_{k-l}(x,\tau_{0}) \right].$$
(16)

Obviously, the accuracy of the results obtained depends largely on the number of terms that have to be limited in the corresponding expansions. Difficulties are usually associated with finding the coefficients of the Neumann series for the reflection and transmittance functions of the finite atmosphere, through which the required values of  $p(x, \tau)$  are expressed. However, as can be concluded from Fig. 4 and Fig. 5, in fact it is often sufficient to limit ourselves to a small number of terms in



Figure 4. Coefficients in the Neymann series of reflectance and transmittance of finite media of different thicknesses and indicated values of other parameters. The data are enveloped by B-splines for illustration.



Figure 5. The same as in Fig.4 for the function  $P(x, \tau_0)$ .

the proper expansions in order to achieve the necessary accuracy. For clarity, in the above mentioned figures, the discrete set of coefficients is enveloped using B splines. Figures show that even for relatively large values of the scattering coefficient the required number of terms in the Neumann series is small even in the central frequencies of the spectral line.

Having the coefficients of  $p_n$ , we pass to the time-dependent problem and establish the temporal characteristics of changes in the observed spectral line. As we showed in the cited papers (Nikoghossian, 2021a,b) such transition is carried out by multiplication of coefficients in the Neumann expansion of the quantity under study by the total time taken by the quantum at the corresponding number of scattering events. Referring the reader to the above-mentioned works for the reasoning in deriving the distribution law of the total time spent by the quantum while staying in the medium, the probability distribution function (PDF) of this time is given by

$$F_n(z) = e^{-z} \frac{z^{2n-1}}{(2n-1)!},$$
(17)

where the time variable  $z = t/\bar{t}$  and  $\bar{t} = t_1 t_2/(t_1 + t_2)$ . Here we used the commonly adopted notations:  $t_1$  is the average time of the atom stay in the exited state, and  $t_2$  is the mean time of the quantum travel between two successive events of scattering.

Hence the evolution of the observed spectral line profile for the pulse of  $\delta(t)$  form of the internal



Figure 6. Typical graphs of PDF and CDF for the photons in the center of the line in the absence of continuum scattering when  $\lambda = 0.9$ .



Figure 7. The same as in Fig.6 for  $\lambda = 0.5$ .

energy release can be written as

$$\bar{P}(x,\tau_0,z) = e^{-z} \sum_{n=0}^{\infty} p_n(x,\tau_0) \tilde{\lambda}^n(x) \frac{z^{2n-1}}{(2n-1)!}$$
(18)

Another case of interest is the internal energy source burst of the form os unite jump H(z) known as The Heviside function. Then Eq.(18) yields

$$\bar{P}(x,\tau_0,z_0) = e^{-z_0} \sum_{n=0}^{\infty} p_n(x,\tau_0) \tilde{\lambda}^n(x) \sum_{k=0}^{z_0} \frac{z^{2n+k}}{(2n+k)!}$$
(19)

Figures 6 and 7 demonstrate the PDF (probability density function) and CDF (cumulative distribution function) of the observed spectral line for different values of optical and geometrical parameters. Note that the time reading of  $z, z_0$  in the figures coincides with the moment of the beginning of the quanta' exit from the semi-infinite atmosphere.

The effect of radiation multiple scattering in a spectral line on their temporal characteristics is demonstrated in Figures 6 and 7, where two cases with particular values of  $\lambda = 0.9$  and 0.5 are depicted. The main salient trait is that when the level of the scattering process is high, the different regions of the line are set to plateau at different time intervals, with the core of the line being set later, as a rule. Another characteristic feature of the large role of radiant energy scattering manifests itself in the dependence of the time of spectral line appearance on the depth where the primary energy release occurs. It is most discernible in the case of the  $\delta(t)$ -form energy release by comparing the time



Figure 8. Variations of the maximum values of PDF with optical depth of the primary energy sources.

the observed line reaches its maximum intensity depending on the depth in the atmosphere where the primary source of energy is located. These functions are shown in Fig. 8, from which one can see that the dependence is stronger the stronger the process of radiation scattering in the line developed. At the same time, it is seen that the role of scattering in the continuous spectrum here is insignificant. It is important to note that the effect of scattering in the continuum on the evolution of the spectral line profile is negligible for both strong and weak lines and weakly depends on the value of the scattering coefficient  $\lambda$ .

# 4. Concluding remarks

The Neumann series for the reflection coefficient from a semi-infinite atmosphere, as well as for the reflectance and transmittance of a medium of finite optical thickness, constructed in our previous works, allow to turn to a time-dependent, more general classical problem in which it is assumed that the primary energy sources are located inside the atmosphere. In the problem considered here, these sources themselves also depend on time. Two possible types of non-stationarity of the sources are considered:  $\delta(t)$ -shaped energy emission and the form of a unit jump given by the Heaviside H(t)function. The problem posed was to describe the evolution of the profile of the observed absorbtion lines and to reveal its dependence on the depth of local energy sources and the role of scattering in the continuous spectrum. The calculations showed that the influence of the source depth on the observed characteristics of the observed line is strong enough to make, in principle, an idea of the internal source depth on the base of the indicated characteristics (equivalent width, central residual intensity). The temporal characteristics of line changes provide additional information about the capacity and depth of energy released within the atmosphere. It is also shown that scattering in the continuous spectrum does not play a significant role in the evolution of the spectral line profile.

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# Gasdynamical flows in star forming regions

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#### Abstract

A review of gas-dynamical flows in astrophysics is given with an emphasis on accretion flows and outflows. Analytical estimates of the dependence of the velocity and density on the radius during spherical accretion are considered, as well as the rate of mass inflow and the corresponding luminosity of the accretion disk are also estimated. Some features of gas inflow and outflow near the star are mentioned, like mass-loading flows where source functions of mass and momentum are presented and analyzed. The velocities and radii of the ionization fronts of hot stars are considered. The Sedov-Taylor analytical formula on the dependence of the radius of the fireball on time during a strong explosion is given, where the explosion energy and density of the medium act as parameters. Examples of the use of dimensional theory in astrophysics, in particular, in accretion flows used above are considered. An example of a numerical solution of the interaction of an interstellar cloud with the solar wind is also given, followed by an estimate of the inflow of the cloud's gas environment into the Earth's atmosphere, which affects the terrestrial ozone content.

Keywords: ISM: gas-dynamical flows: dimensional analysis: star formation via mass-loading flows

# 1. Introduction

Ordered motions of a mass of gas, that is, gas-dynamic flows, occur in astrophysics on all scales, which emphasizes their importance when considering many processes, especially those associated with the formation of stars. In particular, many interesting questions are connected with the reverse influence of these flows on the medium of the star formation. The present review is devoted to such flows, which are especially often formed during the collapse of clouds that give rise to stars, especially flows with loaded mass, but which also often also introduce momentum into the medium of the star formation source.

## 2. Star formation via accretion onto a gravitating center

Let us consider the motion of a gas towards a stationary center with mass M. The mass potential at a distance r will be respectively given by Frank et al. (2002).

$$\Phi = -GM/r,\tag{1}$$

and for the converted part of the energy

$$\Delta \Phi = GM/r,\tag{2}$$

provided sufficiently large initial distances. Since we are talking about the conversion of potential energy into kinetic energy, a unit mass will acquire speed

$$v_{ff}^2/2 = GM/r,\tag{3}$$

where  $v_{ff}$  is the speed of free fall. It is interesting that by means of formulas (2,3) one can immediately estimate the order of the largest part of the potential energy that can be converted into the kinetic energy of motion in this process (spherically symmetric accretion onto a fixed center). Assuming that the mass mhas a rest energy  $mc^2$ , we obtain

$$\frac{mGM/r}{mc^2} = (1/2)v_{ff}^2/c^2 = 1/2 \tag{4}$$

provided that the value of  $v_{ff}$  approaches the speed of light. Usually, this happens during accretion onto compact relativistic objects such as black holes and neutron stars. Recall that, for example, in thermonuclear fusion reactions, for example, helium, only  $\Delta E = 0.007 \cdot mc^2$  is released, that is, accretion is indeed the most efficient energy converter in nature.

# 3. On the formation of massive stars

The formation of low-mass stars is widely known, and is described in detail in, for example, Bodenheimer (2011); Stahler & Palla (2005). Massive stars are more interesting in terms of environmental feedback, but there are also many unresolved problems (e.g. Louvet (2018)). Let us clarify that we will call massive stars with a mass of the order of  $8M_{\odot}$  and more. Being powerful sources of  $L_c$  radiation and stellar wind, newly forming stars have a significant impact on the vicinity of the molecular cloud, the source of matter for forming stars, and bring a large amount of mass, momentum and energy into the interstellar medium right after formation. Note that the characteristic glow time of a star with luminosity,  $L_*$ , mass,  $M_*$ , and radius  $R_*$  is determined by the formula  $t_K = (GM_*^2)/(R_* \cdot L_*)$  which can be rewritten as (Dyson (1994))

$$t_K = (GM_*^2)/(R_* \cdot L_*) = 3 \cdot 10^7 \cdot (M_*/M_{\odot})^2 (R_*/R_{\odot})^{-1} (L_*/L_{\odot}))^{-1} years,$$
(5)

and, since  $L_* = M_*^{3.5}$  on the upper part of the main sequence (MS), this time is highly dependent on mass, and is no more than  $10^5$  years even for the stars with minimal for that case masses of  $M_* = 10 M_{\odot}$ . To estimate the time of accumulation of matter by a protostar (accretion time), we set  $\dot{M} = M_*/t$ , where  $t = R_*/v$ , and v is the virial velocity  $v^2 = (GM_*)/R_*$ , that is,  $\dot{M} = v^3/G$ , and so (Shu et al. (1987)),

$$t_{acc} = (GM_*)/v^3,\tag{6}$$

where also v = a is the isothermal speed of sound at the corresponding temperatures - the rate of transmission of gas-dynamic perturbations in this process. Comparing the estimate of  $t_K$  with the time it takes for the protostar to collect matter ( $t_{acc}$  - is the accretion time), Dyson (1994) noted that massive stars should continue to gain mass, that is, accrete, already in the nuclear reactions phase that can serve as energy sources, since this time is clearly longer:

$$t_{acc} = (GM_*)/(a^3) \approx 4 \cdot 10^4 (M_*/M_{\odot}) (a/(1km/s))^{(-3)} yr,$$
(7)

and  $t_{acc} = 5 - 10 \cdot 10^5$  years, again for  $M_* = 10 M_{\odot}$ .

As a result, the protostar (with the reservation about the beginning of nuclear reactions) remains immersed in a gas-dust shell (cocoon), which is very sensitive to the onset of hard radiation and the stellar wind, analyzed in detail in (Kahn (1974)).

The density distribution in this accretion phase is given by the obvious formula

$$\rho(r) = \frac{\dot{M}}{(4\pi r^2 v)} = \frac{\dot{M} r^{-3/2}}{4\pi (2GM_*)^{1/2}},\tag{8}$$

together with (3), this formula determines the behavior of the main gas-dynamic parameters at the early stage of accretion. To describe the temperature, it is necessary to clarify which stage, isothermal or adiabatic accretion, is in question. Recall that with intensive emission, an isothermal process with a constant temperature is established, and

$$P = K\rho^{-1}, K = const., \gamma = 1.$$
(9)

And when energy is conserved, an adiabatic process takes place, in which

$$P = K\rho^{-\gamma}, K = const., \gamma = 5/3.$$
<sup>(10)</sup>

When the protostar reaches the main sequence, but still gaining mass, the star (protostar) begins to ionize the surrounding gas, and the so-called ultra-compact HII region - UCHII is formed. We will analyze the propagation velocity of the boundary of this region below, in Section 9.



Figure 1. Scheme of the formation of a protostar.

# 4. On the formation of a disk rotating around a gravitating center

The rotation of the collapsing cloud, even with a low initial speed, due to the conservation of angular momentum, causes the resulting disk to rotate at a rather high speed. The point, obviously, is that the streamlines, together with the collapsing matter, deviate from the axis of rotation towards the equatorial plane (Cassen & Moosman (2019)). At the same time, since for the accretion of matter with a cessation, for example, on the surface of a star, the released energy (per unit mass) is estimated as (Frank et al. (2002))

$$v_{ff}^2/2 = GM/r,\tag{11}$$

and in the case of the formation of a disk with Keplerian orbital motion

$$E_{orb} = GM/2r,\tag{12}$$

and the rest can be converted into the internal energy of the gas, and/or, by means of radiation, leave the medium. Let us discuss some features of the resulting disk. Since the specific angular momentum of a homogeneous cloud rotating with a uniform angular velocity  $\Omega$ 

$$j = vr \tag{13}$$

is conserved under compression, and the ratio of the rotational to the absolute value of the gravitational energy is

$$\beta = E_{rot} / |E_{grav}| = r^2 \Omega^2 / 2 / (GM_*/r) = (r^3 \Omega^2) / (2GM_*).$$
(14)

According to observations,  $\beta=0.1$ -0.01 (Bodenheimer (2011)). One can introduce the concept of the critical centrifugal radius,  $R_{ct}$  on which the centrifugal force is balanced by the gravitational one. According to the definitions

$$R_{ct} = (\Omega^2 r^4)/GM,\tag{15}$$

where it is necessary to put  $r = R_*$  at the moment of equilibrium of these forces. From this radius value, all the infalling matter goes to the disk, since the conservation laws rule out another place of accretion, such as the surface of a star.

So, part of the released energy of the accreted matter goes to increase the internal energy of the disk medium. In an adiabatic process, the internal energy is determined by the expression

$$e = P/(\gamma - 1)\rho, \tag{16}$$

where  $\gamma = 5/3$  and pressure is related to temperature by the usual equation of state,

$$P = R_{qas}\rho T/\mu,\tag{17}$$

 $R_{gas} = 8.31 \cdot 10^7 \text{ erg/(mole K)}$  is the gas constant, and  $\mu$  is the average molecular weight.

The disk temperature T is given by the energy balance of the disk, taking into account many processes, however, for orders of magnitude estimates, we can write, as shown above,  $1/2(GM_*)/r = P/(\gamma - 1)\rho = R_{gas}T/(\gamma - 1)\mu$ , and

$$T = 1/2(\gamma - 1)\frac{GM_*}{r}\frac{\mu}{R_{qas}}.$$
(18)

For a protostar with a solar mass, the disk temperature can be about  $10^4$  K during accretion to form a disk at a distance of 1 AU. Further, this energy can, for example, be radiated, respectively, the luminosity (of a black body) will be

$$L_* = \dot{M}GM_*/r = 4\pi r^2 \sigma T^4.$$
(19)

# 5. On the gas-dynamic description of the accretion process

Let us now discuss the description of accretion in the absence of a magnetic field, more precisely, when the magnetic forces are insignificant compared to the gravitational ones. In the absence of sources (mass and momentum), the conservation laws dictate the following system of gas-dynamic equations (Frank et al. (2002))

$$\partial \rho / \partial t + \nabla \cdot (\rho \vec{v}) = -\nabla P + \vec{f}, \qquad (20)$$

$$\rho \partial \vec{v} / \partial t + \rho \vec{v} \cdot \nabla \vec{v} = -\nabla P + \vec{f},\tag{21}$$

$$\partial/\partial t(1/2\rho v^2 + \rho e) + \nabla \cdot \left[ (1/2\rho v^2 + \rho e + P)\vec{v} \right] = \vec{f} \cdot \vec{v}.$$
<sup>(22)</sup>

Here

$$P = \rho kT / (\mu m_H), \tag{23}$$

and

$$\vec{f} = \rho \vec{g}, g = (GM_*)/r^2.$$
 (24)



Figure 2. Distribution of velocity and density along the radius, according to free-fall dependencies for spherically symmetric accretion,  $M_* = 10 M_{\odot}, \dot{M} \approx 10^{22} g/s \approx 10^{-3} M_{\odot}/yr$
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First of all, we will discuss stationary spherically symmetric accretion. From the most general considerations, we have in this case:

$$\dot{M} = 4\pi r^2 \rho v = const.,\tag{25}$$

and also  $M_* \approx const.$  From conservation of mass in (20) it follows

$$\nabla \cdot (\rho \vec{v}) = 0, \tag{26}$$

or

$$d/dr(\rho v r^2) = 0. \tag{27}$$

Thus, in free fall mode, when  $v = v_{ff} = \sqrt{2GM_*/r}$ , then

$$2/r + 1/\rho d\rho/dr + 1/v dv/dr = 0,$$
(28)

so  $1/\rho d\rho/dr = -3/2r$ , and  $\rho(r) = const. \cdot r^{(-3/2)}$ , in full agreement with (8), with spherically symmetric accretion onto a fixed gravitating center.

As noted above, for the accretion rate in this case we can write  $\dot{M} \approx M_*/t_{ff}$ , where, as is easy to see  $t_{ff} \approx 1/\sqrt{G\rho}$ . The exact value of the numerical coefficient is also easy to obtain (Dyson & Williams (1997), for the neutral HI cloud):

$$t_{ff} = \sqrt{(3\pi/32G\rho)} = (4.3 \cdot 10^7/\sqrt{n_H} \quad years.$$
 (29)

It is from the condition that the gravitational energy of the cloud exceeds the thermal one (in the absence of a magnetic field and turbulent vortices) that the Jeans condition of gravitational instability follows, when the cloud contracts into a protostar, and the critical value of the radius is easy to determine:  $C \cdot GM_*^2/R_J \geq 3/2 \cdot R_{gas}T_*M_*/\mu$ , and

$$R_J = 0.4GM_*/R_{gas}T.$$
 (30)

It is easy to verify that the critical value of the Jeans radius is approximately equal to the time of free fall multiplied by the isothermal speed of sound a (the perturbation transfer rate):

$$R_J = \sqrt{(R_{gas}T/\mu) \cdot 1/\sqrt{(G\rho)}} \approx a \cdot t_{ff}.$$
(31)

Here  $a = \sqrt{(R_{gas}T/\mu)}$ , and, as noted above, also

$$\dot{M} \approx a^3/G,$$
(32)

with  $L_* = G\dot{M} \cdot M_*/R_*$ .

Let us give numerical estimates. For example, for a cold clump with T = 10K,  $M_* \approx 0.14M_{\odot}$ ,  $R_* \approx 10^{16}$  cm, the accretion rate is  $\dot{M} \approx 10^{20}$  g/s, and the protostar luminosity is  $L_* \approx 10^{34}$  erg/s (at a = 0.187 km/s), while for massive stars  $M_* \approx 10M_{\odot}$ ,  $R_* \approx 10^{18}$  cm, the accretion rate is  $\dot{M} \approx 10^{22}$  g/s, while the luminosity of the protostar is  $L_* \approx 10^{37}$  erg/s (at the same values of temperature and sound speed).

# 6. Bernoulli equation: inflow and outflow of flows in the vicinity of the center

Under the condition of stationarity, the Euler equation (21) can be written as (Frank et al. (2002)):

$$v\frac{dv}{dr} + \frac{1}{\rho} \cdot \frac{dP}{dr} + \frac{GM_*}{r^2} = 0 \tag{33}$$

direct integration of which will give,

$$\frac{v^2}{2} + \int \frac{dP}{\rho} - \frac{GM_*}{r} = const. \tag{34}$$

Taking into account (10)  $dP = K\gamma \rho^{\gamma-1} d\rho$ , so

$$\frac{v^2}{2} + \frac{K\gamma}{\gamma - 1}\rho^{\gamma - 1} - \frac{GM_*}{r} = const.,$$
(35)

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where  $\gamma \neq 1$ . But  $K\gamma\rho^{\gamma-1} = \gamma P/\rho = a^2$ , where *a* is the isothermal sound speed, and we obtain the Bernoulli integral about conservation of (36) along the streamlines:

$$\frac{v^2}{2} + \frac{a^2}{\gamma - 1} - \frac{GM_*}{r} = const.$$
 (36)

From it, as expected, at large distances from the protostar, the speed tends to the speed of sound, slightly exceeding it (and both together - to zero), and at small distances - to the speed of free fall.

Now we transform (33):

$$v\frac{dv}{dr} = \frac{\frac{2a^2}{r} - \frac{GM_*}{r^2}}{v^2 - a^2},\tag{37}$$

and because  $1/\rho \cdot dP/dr = a^2/\rho \cdot d\rho/dr$ , so, from (27)  $1/\rho \cdot d\rho/dr = -1/(vr^2) \cdot d/dr(vr^2)$ . Then from (37) it follows that the flow velocity becomes equal to the speed of sound *a* at the coordinate of the "sound point" according to

$$r_s = (GM_*)/(2a^2),$$
 (38)

moreover, from the definition of the "second cosmic velocity" at this point,

$$v_{esc} = \sqrt{2GM_*/r_s},\tag{39}$$

it follows

$$v_{esc} = 2a. \tag{40}$$

Using de l'Hopital's rule at the sound point,

$$\frac{dv}{dr(r=r_s)} = \frac{\pm 2a^3}{GM_*} = \frac{\pm 2\dot{M}}{M_*},\tag{41}$$

we obtain that both inflows and outflows of matter are possible during gas-dynamic spherically symmetric accretion, and we recall that the accretion (outflow) rate  $\dot{M}$  is determined by the formula (32)  $\dot{M} \approx a^3/G$ .

#### 7. On the expansion of supernova remnants after the explosion

Let us briefly discuss the process of interaction of expanding supernova remnants with the surrounding interstellar medium. As is known, during a supernova (type II) explosion, namely, during the collapse of the nucleus, it is possible to release energy of the order of  $E_* \approx (GM^2)/R$ , or up to  $10^{53}$  erg during the collapse of the mass  $M \approx M_{\odot}$  in a region with a size of  $R \approx 10^6$  cm, that is, during the formation of a neutron star. The rest of the mass of the pre-supernova star is thrown out, the formed shell expands at a high speed of about 5000-10000 km/s (see Figures 3 and 4). At the same time, according to observational data (Dyson & Williams (1997)), about  $\epsilon \approx 1\%$  is the kinetic energy of the remnant expansion ( $\approx MV^2 \approx 10^{51}$  erg, at an expansion velocity of  $\approx 10^4$  km/s with a mass of about  $1M_{\odot}$ ). Let us mention, for completeness, that the excess energy of the explosion is carried away by neutrinos that practically do not interact with matter.

At the adiabatic stage, radiative energy losses are insignificant, and the total energy of the shell behind the shock wave front, thermal and kinetic ( $e_T$  and  $e_K$ , per unit mass), should be equal to the explosion energy,  $E_*$ . It can be shown (Dyson & Williams (1997)) that for a monatomic gas both types are equal,

$$e_T = e_K = 9/32 \cdot \dot{R}^2, \tag{42}$$

where R is the radius of the shell, and  $\hat{R}$  is its velocity. Then the total energy of the shell,  $E_T$ , with a gas of density  $\rho_0$  (and concentration  $n_0$ ), is:

$$E_T = 4/3 \cdot \pi R^3 \cdot \rho_0 \cdot (e_T + e_K) = 3/4\pi n_0 m_H R^3 \dot{R}^2.$$
(43)

Because  $E_T = E_*$  then

$$R^3 \cdot \dot{R}^2 = 4/3\pi E_*/\rho_0. \tag{44}$$

Since at  $t \to 0, R \to 0$ , then the solution to (44) is (the Sedov-Taylor formula - Dyson & Williams (1997))

$$R = (25/3\pi)^{1/5} \cdot (E_*/\rho_0)^{1/5} \cdot t^{2/5}, \tag{45}$$

and

$$\dot{R} = 2/5 \cdot (25/3\pi)^{1/5} \cdot (E_*/\rho_0)^{1/5} \cdot t^{-3/5}.$$
(46)



Figure 3. The Crab Nebula, SN 1054. (NASA, ESA, J.Hester and A.Loll). The Crab Nebula is the... remnant, of a massive star in our Milky Way that died 6,500 light-years away. Astronomers and careful observers saw the supernova in the year 1054. Image credit: NASA, ESA, J. Hester and A. Loll (Arizona State University)

# 8. On the use of dimension theory in the study of astrophysical flows associated with star formation processes

We will solve several problems concerning flows of interstellar matter (with one exception) using the methods of the theory of dimensions, including the problems discussed above. In some cases, the theory of dimensions of physical quantities is successfully used during the initial assessments of astrophysical processes (Dibay & Kaplan (1976)). Here the concepts of the defining parameters of a physical system in a quasi-stationary state are used. We will solve several problems on the application of the theory of dimension in astrophysics, from which the details of the use will become clear.

**Problem 1.** For example, for a planet rotating around the Sun, the determining parameters are the mass of the Sun (M), the period of rotation (P), the radius of the orbit (r), and, the gravitational interaction constant (G), which determines the process itself. Here, the number of defining parameters is one more than the number of basic dimensions, in this case, "cm, g, sec". Dimensions of defining parameters are given in a matrix of dimensions, compiled from a table of basic dimensions and defining dimensions. Let's make a matrix of dimensions.

Table 1.									
defining parameters	$\mathbf{M}$	Ρ	$\mathbf{R}$	G					
basic dimensions	g	s	cm	$cm^3 \cdot g^{-1} \cdot s^{-2}$					
g	1	0	0	-1					
cm	0	0	1	3					
S	0	1	0	-2					

Multiplying the rows of the matrix with a vector row of exponents  $\alpha, \beta, \gamma, \delta$ , in accordance with the procedure for constructing a dimensionless complex *const*. =  $M^{\alpha} \cdot P^{\beta} \cdot R^{\gamma} \cdot G^{\delta}$ , we obtain the following system of linear algebraic equations (according to the theory, exponents can only be rational numbers, and arguments to functions other than rational fractions must be dimensionless):

$$1 \cdot \alpha + 0 \cdot \beta + 0 \cdot \gamma - 1 \cdot \delta = 0, \tag{47}$$

$$0 \cdot \alpha + 0 \cdot \beta + 1 \cdot \gamma + 3 \cdot \delta = 0, \tag{48}$$

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Figure 4. Supernova remnants inflowing into the ISM with density  $\rho_0$ .

$$0 \cdot \alpha + 1 \cdot \beta + 0 \cdot \gamma - 2 \cdot \delta = 0. \tag{49}$$

The number of variables is greater than the number of equations, therefore, without loss of generality (as is usually done when solving overdetermined systems), we can set  $\alpha = 1$ , then  $\beta = 2, \gamma = -3, \delta = 1$ , that is  $MP^2R^{-3}G = const.$ , or

$$\frac{P^2}{R^3} = const. \cdot \frac{1}{GM}.$$
(50)

Thus, from the most general considerations, Kepler's 3rd law was obtained. The numerical value of the constant is not determined, which is obvious, by the methods of the theory of dimensions, and can be obtained from a rigorous theory. But, since this constant is the same for all planets, we have for any two planets  $P_1^2/R_1^3 = P_2^2/R_2^3$ .

**Problem 2.** In the problem of a strong explosion, when describing the behavior of supernova remnants in the interstellar medium (cf. p.7), the defining parameters are E – explosion energy (erg),  $\rho$  – density of the interstellar medium (g/cm<sup>3</sup>), R – radius (cm), and t is time (s). We make a matrix of dimensions.

Table 2.										
defining parameters	E	ρ	$\mathbf{R}$	t						
basic dimensions	$Erg \text{ or } g \cdot cm^2 \cdot s^{-2}$	$g \cdot cm^{-3}$	cm	s						
g	2	-3	1	0						
cm	1	1	0	0						
s	-2	0	0	1						

The dimensionless complex  $const. = E^{\alpha} \rho^{\beta} R^{\gamma} t^{\delta}$  reduces to the system

$$2 \cdot -3 \cdot \beta + 1 \cdot \gamma + 0 \cdot \delta = 0 \tag{51}$$

$$1 \cdot \alpha + 1 \cdot \beta + 0 \cdot \gamma + 0 \cdot \delta = 0 \tag{52}$$

$$-2 \cdot \alpha + 0 \cdot \beta + 0 \cdot \gamma + 1 \cdot \delta = 0. \tag{53}$$

We choose  $\gamma = 1$ , and we get  $\alpha = -1/5$ ,  $\beta = 1/5$ ,  $\delta = -2/5$ . Eventually,  $R = const. \cdot (E/\rho^{1/5}t^{2/5})$ , and,  $\dot{R} = const. \cdot 2/5(E/\rho)^{1/5}t^{-3/5}$ . And this is the Sedov-Taylor formula in the problem of a strong explosion, which was successfully used to describe the explosion of a supernova and the expansion of its remnant (eq. 45-46). And again, the value of the numerical constant is not known, but it appears in the exact formula (45).

Table 3.									
Defining parameters	$\mathbf{R}$	V	Μ	G					
Basic dimensions	cm	$\rm cm/s$	kg	$cm^3 \cdot s^{-2} \cdot g^{-1}$					
g	1	1	0	3					
cm	0	0	1	-1					
S	0	-1	0	-2					

**Problem 3.** Consider the problem of determining the velocity of a gas freely falling towards the center of gravitation. Expressions for the first (and second) cosmic velocities are defined similarly. The defining parameters here are R, V, M and G. We compose a matrix of dimensions,

The dimensionless complex const. =  $R^{\alpha}V^{\beta}M^{\gamma}G^{\delta}$  is reduced to the system

$$1 \cdot \alpha + 1 \cdot \beta + 0 \cdot \gamma + 3 \cdot \delta = 0 \tag{54}$$

$$0 \cdot \alpha + 0 \cdot \beta + 1 \cdot \gamma - 1 \cdot \delta = 0 \tag{55}$$

$$0 \cdot \alpha - 1 \cdot \beta + 0 \cdot \gamma - 2 \cdot \delta = 0. \tag{56}$$

We get the solution:  $\alpha = 1, \beta = 2, \gamma = -1, \delta = -1$ , and write down the formula:

$$R = const.GM/V^2,\tag{57}$$

which coincides with formula (3) with an accuracy of a factor of 2.

**Problem 4.** Let's solve the problem of the spherically symmetric accretion rate of onto a fixed center. The defining parameters here are M, V, M and G. We compose a matrix of dimensions,

Table 4.									
Defining parameters	М. М	V	$\mathbf{M}$	G					
Basic dimensions	g/s	cm/s	g	$cm^3 \cdot s^{-2} \cdot g^{-1}$					
g	1	1	0	3					
cm	0	0	1	-1					
S	0	-1	0	-2					

The dimensionless complex const. =  $\dot{M}^{\alpha}V^{\beta}M^{\gamma}G^{\delta}$  reduces to the system

$$1 \cdot \alpha + 1 \cdot \beta + 0 \cdot \gamma + 3 \cdot \delta = 0 \tag{58}$$

$$0 \cdot \alpha + 0 \cdot \beta + 1 \cdot \gamma - 1 \cdot \delta = 0 \tag{59}$$

$$0 \cdot \alpha - 1 \cdot \beta + 0 \cdot \gamma - 2 \cdot \delta = 0. \tag{60}$$

We get the solution:  $\alpha = 1, \beta = 2, \gamma = -1, \delta = 1$ , and write down the formula:

$$\dot{M} = const. \cdot (MV^3)/G, \tag{61}$$

which coincides with formula (32) with an accuracy of a numerical factor of order 1.

#### 9. On mass-loaded flows during formation of massive stars

When a molecular cloud is contracted, followed by the formation of a star, flows with continuously added gas along the motion are possible. The source of this gas can be clumps - condensations, which are 3-4orders of magnitude denser than the current density, and one should distinguish between the period of the onset of hard radiation, but without stellar wind, when UCHII is already formed. It is also possible that the influence of the stellar wind is insignificant, which is typical for not very massive stars. We should be interested in the period with an intense wind, on the order of  $\approx 10^{-6} M_{\odot}/yr$ , when UCHII is formed under the influence of both hard radiation and a sufficiently powerful wind. In this case, the wind flow itself can be considered isothermal, since the loaded mass is excited and immediately radiate, and the emission measure is proportional to the square of the density. As a result, a uniform temperature of the order of  $\approx 10^4$  K Yeghikyan A. G.

is established in the region of intense HII emission. The ionization is responsible for the radiation of the protostar, where thermonuclear reactions are already taking place, the radiation energy from these reactions propagates to the outer layers and is radiated through the photosphere into the environment, in the first approximation, as an absolutely black body with an effective temperature inherent in massive O, B stars.

In the case of mass-loaded flows, taking into account stationarity and isothermality, equations (20-21) should be written as (Hartquist et al. (1986), Yeghikyan (1999)):

$$\frac{d}{dr} \cdot \rho v r^2 = S r^2, \tag{62}$$

$$\frac{1}{r^2}\frac{d}{dr}\rho v^2 r^2 = -Su_c - \frac{dP}{dr} - \frac{GM_*}{r^2},$$
(63)

and also

$$P = \rho \cdot c^2, \tag{64}$$

where the first term on the right in (63) takes into account the momentum of gas portions flowing from moving clumps, and the minus sign is the direction towards the wind. Our goal is to show that a reasonable combination of the observed parameters of fast winds leads to the establishment of protostar parameters that do not contradict the observations. We emphasize that here we take into account one type of source, due to cloud clumps, with one type of elementary processes responsible for adding mass, namely, photoionization.

After some algebraic transformations, we bring the system to the form:

$$\frac{du}{dr}(u^2 - c^2) = -\frac{S}{\rho}(u^2 + c^2 + uu_c) + \frac{2uc^2}{r} - \frac{GM_*u}{r^2},\tag{65}$$

$$\frac{d\rho}{dr} = -\frac{\rho}{u}\frac{du}{dr} - \frac{2\rho}{r} + \frac{S}{u}.$$
(66)

Let us first neglect the term on the right in (65), which takes into account gravity, and exclude  $\rho$  by means of (25), which in this case is written as

$$4\pi r^2 \cdot \rho u = \dot{M}_s + 4\pi \cdot \int_{r_0}^r Sr'^2 dr',$$
(67)

where  $M_s$  is the mass loss rate of the central star,

$$\dot{M}_s = 4\pi r_0^2 \rho_0 v_\infty.$$
 (68)

The values with the index "0" refer to the inner boundary of the cloud from the side of the star, and  $v_{\infty}$  is the limiting speed of the fast wind, and

$$4\pi \int_{r_0}^r Sr'^2 dr' \equiv I(r).$$
 (69)

After subsequent integration, we finally get:

$$u = -\frac{v_s I(r) + v_\infty \dot{M}_s}{\dot{M}_s + I(r)},$$
(70)

and

$$\rho = \frac{[\dot{M}_s + I(r)]^2}{(4\pi r^2 [v_s I(r) + v_\infty \dot{M}_s])}.$$
(71)

Gravity is not taken into account here, but the momentum introduced during the loaded mass from condensations (clumps) is taken into account. For the first time in analytical theories of the formation of massive stars in this form, they were used in (Lizano et al. (1996)), and in models of planetary nebulae, in (Yeghikyan (1999)). Mention should also be made of (Johnson & Axford (1986)), where the same equations are used to describe the galactic wind. The distribution (70,71) for one set of parameters is shown in Fig. 5.

With a uniform distribution of mass loading centers,  $S(r) = S_0 = const$ , and  $v_s = 20$  km/s=const, we have  $I(r = r_m) = (4/3)S_0\pi r_m^3$ , where  $r_m^3 = 10^{18}$  cm – is the maximum value of the radius from which accretion starts. With a power dependence of the form  $S(r) = S_0(r_0/r)^{\alpha}$ ,  $I(r) = 4\pi S_0(r^{3-\alpha} - r_0^{3-\alpha})/(3-\alpha)$ . Yeghikyan A. G. 41 Gasdynamical flows in star forming regions



Figure 5. Velocity and density distribution along the radius, (70,71) for spherically symmetric stationary accretion with loaded mass,  $M_* \approx 10 M_{\odot}$ ,  $\dot{M} \approx 10^{19}$  g/s  $(10^{-6} M_{\odot})$ ,  $v_{\infty} = 2000$  km/s,  $v_s = 20$  km/s,  $\alpha = 0.5$ 

Finally, in the general case, one should separate the possibility of mass loading directly from cloud clumps (we denote it as  $(S_c$ -primary) and by means of the stellar wind  $(S_W$ -secondary), then the equations will be written in the form

$$\frac{d\rho}{dr} = -\frac{\rho}{u}\frac{du}{dr} - \frac{2\rho}{r} + \frac{(S_w + S_c)}{u},\tag{72}$$

$$\frac{du}{dr} = \frac{u}{(\rho(u^2 - c^2))} \left[ S_c(u_c - u) - S_w(u + u_c) \right] - \frac{(GM_*u)}{((u^2 - c^2)r^2)} - \frac{(c^2(S_w + S_c))}{\rho(u^2 - c^2)} + \frac{(2uc^2)}{(r(u^2 - c^2))} \right].$$
(73)

The solution of the system of differential equations (72,73) for one set of parameters is shown in Fig. 6.

The possibility of mass loading via two channels (photoionization and charge exchange reactions) is described in more detail in Yeghikyan et al. (2022), and a comparison with observations is also made there.

## 10. Propagation velocity of ionization of the HII region - the velocity of the photoionization front

As soon as a massive star reaches the MS and becomes a source of strong radiation that ionizes hydrogen, an HII region is formed in the molecular cloud, the boundary of which separates it from the HI region (Fig. 7), which, in turn, passes into the completely molecular  $H_2$  region. The rate of progress of the boundary between the ionized and non-ionized parts of hydrogen, dr/dt, can be determined, under the condition of stationarity of the processes, by means of relations

$$J \cdot dt = n_0 \cdot dr,\tag{74}$$

where J is the flux of hydrogen-ionizing photons arriving at the interface at time t, and  $n_0$  is the hydrogen concentration. Hence,  $dr/dt = J/n_0$ , and, since according to the definition of the Strömgren sphere at stationarity, the total number of  $L_c$  quanta emitted by the star must be equal to the total number of photons absorbed by hydrogen and photorecombination photons

$$S_*(L_c) = 4\pi r^2 J + 4/3\pi r^3 n_0^2 \beta_2, \tag{75}$$

where  $\beta_2$  - is the total number of photorecombinations per level 2 of the hydrogen atom (Dyson & Williams (1997)). From (74,75) we find

$$\frac{dr}{dt} = \frac{S_*}{(4\pi r^2 n_0)} - 1/3r n_0 \beta_2,\tag{76}$$



Figure 6. The distribution of velocity and density (concentration) along the radius, given by (72,73) for spherically symmetric accretion with loaded mass rate, primary  $(10^{-3}M_{\odot}/\text{yr})$ , and secondary  $10^{-6}M_{\odot}/\text{yr})$ ,  $M_* \approx 10M_{\odot}, v_{\infty} = 2000 \text{ km/s}, v_s = 20 \text{ km/s}$ . Initial conditions:  $v = 100 \text{ km/s}, n = 10^9 \text{ cm}^{-3}$  at  $r_0 = 10^{15}$ cm.

where

$$R_s = \left(\frac{3S_*}{4\pi n_0^2 \beta_2}\right)^{1/3} \tag{77}$$

is the radius of the Strömgren sphere. As a result, introducing the notation for dimensionless quantities,  $\lambda = r/R_s, \tau = t/t_r, V_r = R_s/t_r, \lambda = dr/dt/V_r$ , and also  $t_r \approx (n_0\beta_2)^{(-1)}$  - characteristic photorecombination time, we get equation (78)

$$\dot{\lambda} = 1/3((1-\lambda^3))/\lambda^2,\tag{78}$$

whose solution is

$$\lambda = (1 - e^{-\tau})^{1/3},\tag{79}$$

with the initial condition,  $\tau \to 0, \lambda \to 0$ .

Table 5. The numerical example for  $S_*(L_c) = 10^{49} \text{ s}^{-1}$  and  $n_0 = 100 \text{ cm}^{-3}, \beta_2 = 2 \cdot 10^{-13} \text{ cm}^3 \text{ s}^{-1}$ , (Dyson & Williams (1997), Table 7.1).

$\tau$	$\dot{\lambda}$	$\lambda$	dr/dt
0.1	1.42	0.46	2630
0.7	0.25	0.80	460
0.9	0.19	0.84	352
1.0	0.16	0.86	300
2.0	0.05	0.95	93
4.0	0.006	0.99	11

## 11. One example of a numerical solution of a system of gas-dynamic equations describing the gas flow of a molecular cloud around the Sun, passing through such a cloud

Every few hundred million years, the Sun, along with the Earth, passes through molecular clouds, while the heliosphere is compressed somewhere about to the Earth's orbit and the cloud material enters directly into the Earth's atmosphere (Yeghikyan & Fahr (2004a), Yeghikyan & Fahr (2004b), Yeghikyan & Fahr 43Yeghikyan A. G.



Figure 7. Velocity of the photoionization front separating the HII and HI regions around a massive star with a photon flux J (according to Dyson & Williams (1997)).

(2006)). The description of the flow of cloud matter around the heliosphere is reduced here to solving a system of gas-dynamic equations in the form

$$\frac{\partial \rho_j}{\partial t} + \nabla(\rho_j \mathbf{V_j}) = S_{\rho}, j, \tag{80}$$

$$\frac{\partial(\rho_j \mathbf{V_j})}{\partial t} + \nabla \mathbf{\Pi_j} = \rho_j (1 - \mu_j) \nabla(GM/R) + S_V, j, \tag{81}$$

$$\frac{\partial E_j}{\partial t} + \nabla [\mathbf{V}_{\mathbf{j}}(E_j + P_j)] = \rho_j (1 - \mu_j) \mathbf{V}_{\mathbf{j}} \nabla (GM/R) + S_E, j,$$
(82)

where  $\rho_j, V_j$  and  $P_j$  – are the density, velocity and (scalar) pressure of atoms (j=n) and protons (j=p) of the flow, respectively,  $\Pi_{ik,j} = \rho_j V_i V_k + P_j \delta_i k$  – is the hydrodynamic stress tensor, and  $E_j = 1/2\rho_j V_j^2 + P_j/(\gamma - 1)$ – is the energy density. The right-hand sides contain source terms due to gravity and photoionization, and mutual recharging of atoms and protons:

$$S(\rho, n) = -\beta_{phi}\rho_n + (\rho_p^2 \alpha)/m_p, \qquad (83)$$

$$S(\rho, p) = \beta_{phi}\rho_n - (\rho_p^2 \alpha)/m_p, \qquad (84)$$

$$S_{(V,n)} = -\beta_{phi}\rho_n \mathbf{V_n} - v_{ce} - \rho_n (\mathbf{V_n} - \mathbf{V_p}) + (\rho_p^2 \alpha)/m_p,$$
(85)

$$S_{(V,p)} = \beta_{phi}\rho_n \mathbf{V_n} + v_{cen}\rho_n (\mathbf{V_n} - \mathbf{V_p}) - (\rho_p^2 \alpha)/m_p,$$
(86)

$$S(E,n) = -\beta_{phi}E_n + v_{ce} - (E_p - E_n),$$
(87)

$$S_{(E,p)} = \beta_{phi}E_n - v_{ce} + (E_p - E_n).$$
(88)

See (Yeghikyan & Fahr (2004a)) for more details. We choose the initial and boundary conditions as follows: the flow of initially neutral hydrogen around the undisturbed heliosphere from left to right, and, due to the symmetry of the flow with respect to the axis, the lower boundary is "reflecting", and the outflow of matter occurs through the upper and right boundaries. So, the system with right-hand sides (83-88), written in the standard form of a hyperbolic system of partial differential equations for hydrogen atoms and ions, was solved by the computer program CLAWPACK (Yeghikyan & Fahr (2003), Yeghikyan & Fahr (2004a), Yeghikyan & Fahr (2004b), Yeghikyan & Fahr (2006)), separately for atoms and protons, by the method of successive approximations: usually, several iterations were sufficient for the relative error of the residual vector of the desired functions not to exceed 0.001. The calculation results are shown in Fig. 8. (Yeghikyan & Fahr (2004a)). Lines of equal concentration and axial components of hydrogen velocities are shown as functions of z and r.



Figure 8. Lines of equal concentration and axial velocities of atoms (top) and protons (bottom) of the flow, on the plane (z, r). Contours of concentration values are marked with numbers in cm<sup>-3</sup>, on the left, and velocities in km/s, on the right. Parameter values:  $n_i = 1000 \text{ cm}^{-3}$ ,  $V_i = 26 \text{ km/s}$ ,  $T_i = 100 \text{ K}$ ,  $\beta_0 = \beta_{phi}$ ,  $\mu = 0.1$ .

### 12. Conclusion

A review of some problems of gas-dynamic astrophysical flows related to the formation of stars is given. The behavior of gas accreting onto a gravitating center is considered, some regularities in the formation of massive stars and the main characteristics of forming disks revolving around protostars, such as temperatures, are noted. When describing the accretion process in the spherically symmetric case, formulas for the dependence of velocity and density on the radius are given, as well as the Jeans criterion for the possibility of cloud collapse, which makes it possible to estimate the radius of the cloud from which a star is born, and the mass of the star itself. An analysis of the Bernoulli equation shows that the transition from supersonic to subsonic flow occurs at a point with a radius that depends only on the mass of the protostar and on the value of the speed of sound, which is equal to half the "second space velocity" in the system. It is also shown that both inflows and outflows of gas are possible, however, without taking into account the state of the disk. The Sedov-Taylor formula is obtained as applied to the expansion of the supernova remnant, on the power-law dependence of the radius and velocity on time. Examples of the use of dimension theory in the study of astrophysical objects associated with star formation processes are given. The gas dynamic equations of gas flow with the loaded mass are analyzed, taking into account the momentum introduced by the loaded mass. For the first time, analytical formulas for velocity and density (albeit in the absence of gravity) are given for known ratios for mass loading. Ordinary differential equations are also derived for the first time, which describe the velocity and density functions in the general case, when the mass loading is associated both with cloud condensations and can be caused by the stellar wind of O, B stars. Numerical solutions of these equations can be verified by observations. For completeness of description, an expression is given for the rate of propagation of the ionization of the HII region, that is, for the rate of the photoionization front around the emerging massive protostar. At the end, one example of a numerical solution of the complete system of gas-dynamic equations describing the gas flow of a molecular cloud matter around the Sun, passing through this cloud, with direct penetration of the neutral component into the Earth's atmosphere, is also given.

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## Growth of accreting intermediate mass black hole seeds

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#### Abstract

This communication aims to review the mass assembly history of seed black holes to the present time of accreting intermediate mass black hole (IMBH)-candidates. Given the masses and redshifts at present time of 137 IMBH-candidates collected from the literature, we have undertaken a large series of numerical simulations to achieve this goal. The crux is that, we utilize the *microscopic theory of black hole* (MTBH), which explores the most important novel aspects expected from considerable change of properties of spacetime continuum at spontaneous breaking of gravitation gauge symmetry far above nuclear density. As a corollary, this theory has smeared out the central singularities of BHs, and makes room for their growth and merging behavior. We compute among the others the masses, the growth-time scales,  $T_{BH}$ , and the redshifts of seed BHs. In particular, for the present masses  $\log(M/[M_{\odot}]) = 2.20$  to 5.99 of IMBH-candidates, the computed seed masses are ranging from  $\log(M^{seed}/[M_{\odot}]) = -0.50$  to 3.29, with corresponding growth-time scales  $T_{BH}$  ranging from  $\log(T_{BH}/[yr]) = 8.82$  to 10.09. We derived scaling mass-luminosity relation, by means of which we compute the luminosities of IMBH-candidates ranging from  $\log(L/[erg s^{-1}]) = 39.13$  to 41.653.

**Keywords:** black hole physics-intermediate mass black holes-galaxies: dwarf-globular clusters-ULXs and HLXs

### 1. Introduction

One of the achievements of present observational astrophysics is the development of a quite detailed study of the physical properties of growth and merging phenomena of astrophysical black holes, even at its earliest stages. Although proving the existence of seed BHs in the early Universe is not yet feasible with the current instrumentation, remained below the observational capabilities, the detection and study of those seed BHs that did not grow into supermassive BHs (SMBHs), can be found as IMBHs in the nearby Universe. In past decades, the debate about population of IMBHs was less fettered by observational evidence, but it gathers support from a breakthrough made in recent observational efforts (e.g. Baldassare & Reines, 2015, Baldassare & et al., 2016, Barth et al., 2004, Baumgardt, 2017, Chen & Shen, 2018, Feldmeier et al., 2009, Ferrarese & Merritt, 2000, Fragione et al., 2018, Gallerani et al., 2017, Gebhardt & et al., 2000, Gerssen et al., 2002, Graham & Scott, 2013, Harrison, 2018, Ho & Kim, 2016, Inayoshi & Visbal, 2019, Johnson & Haardt, 2016, Kaaret & Feng, 2017, Katz et al., 2015, Kiziltan et al., 2017, Koliopanos, 2017, Latif & Ferrara, 2016, Latif & Schleicher, 2018, Lützgendorf et al., 2012, 2013, Nguyen et al., 2017, Noyola & Gebhardt, 2010, Perera & Stappers, 2018, Perera et al., 2017, Reines et al., 2013, Sakurai et al., 2017, Soria et al., 2017, Takekawa et al., 2019, Wang et al., 2015, Webb, 2017, Woods et al., 2019, Xiao et al., 2011), and at present it would require a good deal more ingenuity, which is of immense significance for their formation and growth. The multiwavelength methods, used to trace the growth of seed BHs, suggest that a population of IMBHs, very likely, exists. For an up-to-date review of all the observational evidence found so far and the different evolutionary pathways for creation of IMBHs, see (e.g. Inayoshi & Visbal, 2019, Koliopanos, 2018, Mezcua, 2017)). This has strong implications for understanding of key questions how the seeds of massive BHs may have first assembled, and how did they grow into IMBHs. The study of accretion physics of IMBHs is of vital interest for evaluating the role of the BH in the formation of the first galaxies.

However, even thanks to the fruitful interplay between theoretical and computational analysis, and astronomical observations, the scientific situation remains, in fact, more inconsistent to day. A systematic analysis of these properties happens to be surprisingly difficult by conventional theoretical methods. A

principle feature that makes general relativity (GR) distinctively different from other field theories is the occurrence of curvature singularities in spacetime. The singularities lead to regions of the Universe that cannot be observed. This causes an observer's inability to access the degrees of freedom that are hidden beyond the horizon which, in turn, leads to thermodynamical behavior of BHs. Notwithstanding, much remarkably efforts have been made in understanding of BH physics, many important issues still remain unresolved and, thus, a situation is unclear, than described so far. The astrophysical significance of the issue, and the importance of considering the gravitational collapse of a matter cloud within the framework of the GR theory, with reasonable physical properties for the matter included, stems from the fact that GR predicts that a star more massive than about five to eight times the mass of the Sun, cannot stabilize to a neutron star final state at the end of its life cycle. Thereby the estimates on the mass limit for a star in order to collapse are indefinitely vary depending on different models for the star's interior and equation of state for matter at very high densities. It must collapse continually under the force of its own gravity on exhausting its internal nuclear fuel, and there are no known forces of nature that would halt such a collapse. General relativity predicts that such a star must then terminate into a spacetime singularity where densities and spacetime curvatures blow up and the physical conditions are extreme. One of the most important open issues in the theory and astrophysical applications of modern day BH and gravitation physics is that of the Roger Penrose's Cosmic Censorship Conjecture (CCC) (Laporte et al., 1969). The CCC assumption that any physically realistic gravitational processes must not lead to the formation of a singularity which is not covered by an horizon, thus hiding it from external observers in the Universe. This of course includes the complete gravitational collapse of a massive star which, if the CCC is true, must terminate generically into a BH final state only. Such a singularity is then crucial and is at the basis of much of the modern theory and astrophysical applications of BHs today. Despite the past four decades of serious efforts, we do not have as vet available any proof or even any mathematically precise formulation of the cosmic censorship hypothesis.

The consideration of dynamical evolution of collapse is a crucial element of the CCC. Many solutions of Einstein field equations are known which present naked singularities (such as, for example, the superspinning Kerr solutions), nevertheless almost none of these solutions can be obtained as the dynamically evolved final state of some initially regular matter configuration. For this reason, over the last decades a great deal of work has been done to test the CCC in the few dynamically evolving spacetimes we know. These are typically the scenarios that describe gravitational collapse in spherical symmetry, and some non-spherical collapse models have also been considered, for examples of critical collapse with angular momentum. The incredibility of such an inference of CCC has been greatly enhanced by the fuct that in recent years, a wide variety of gravitational collapse models have been discovered where exact analytical calculations (e.g. Giambo et al., 2004, Goswami & Joshi, 2002, Joshi & Malafarina, 2011, 2013, Villas da Rocha & Wang, 2000) and references therein) have meanwhile shown that mass concentrations collapsing under their own weight will no longer form BHs as collapse endstate, rather naked singularities, except for configurations of highest symmetry which are, however, of measure zero among all initial data. By this, even the theoretical existence of BHs is no longer justified. The first examples were restricted to some classes of inhomogeneous dust collapse, and they were extended to the case of collapse in the presence of only tangential pressures, and perfect fluids. The existence of classes of pressure perturbations is shown explicitly, which has the property such that an injection of a small positive (or negative) pressure in the Oppenheimer, Snyder and Datt (OSD) model (Datt, 1938, Oppenheimer & Snyder, 1939), or in a Tolman-Bondi-Lemaitre (TBL) inhomogeneous dust collapse to a BH, leads the collapse to form a naked singularity, rather than a BH (Joshi & Malafarina, 2011, 2013). The classic OSD scenario is the basic paradigm for BH physics today, and the TBL models describe the most general family of dust, i.e. pressureless, collapse solutions. This result is therefore intriguing, because it shows that arbitrarily close to the dust BH model, we have collapse evolutions with non-zero pressures that go to a naked singularity final state, thus proving a certain 'instability' of the OSD BH formation picture against the introduction of small pressure perturbations. In such a case, the super-ultra-dense regions, or the spacetime singularity, that forms at the end of collapse would be visible to faraway observers in the Universe, rather than being hidden in a BH. Thus, rigorous calculations have shown that the expectations of the 1970s have been hasty, that CCC assumption has been premature, because while the CCC states that the OSD collapse final fate is necessarily replicated for any realistic stellar collapse in nature, the result here shows that an arbitrarily small pressure perturbation of the OSD model can change the final outcome of collapse to a naked singularity and therefore the OSD BH may be considered 'unstable' in this sense. Moreover, there is no provision for growth and merging behavior of seed BHs in the framework of phenomenological BH model (PBHM), as peculiar repercussion of GR, because of the nasty inherent appearance of BH singularities, and that if the infinite collapse to the singularity inside the BH is accepted

as a legitimate feature of Nature. Although it is extremely hard to envisage a consistent theory having such a logical impossibility, this problem stood open for nearly a century as a startling preoccupation of wide community of theoreticians (see Ter-Kazarian (e.g. 2014, 2015b, 2016a,b), Ter-Kazarian & Shidhani (e.g. 2017, 2019) and references therein).

Refining our conviction that a complete, self - consistent gravitation theory will smear out singularities at huge energies, and give the solution known deep within the BH, in what follows we advocate with alternative proposal by employing the MTBH, which has explored the most important novel aspects expected from considerable change of properties of space-time continuum at spontaneous breaking of gravitation gauge symmetry far above nuclear density. Explaining in more detail the physical arguments behind the microscopic model of IMBH, therefore, the present article is widely based on the premises of the study of internal structure of IMBHs (Ter-Kazarian & Shidhani, 2019), where we tackled the problems in the theoretical framework of MTBH. In this, we have undertaken a large series of numerical simulations to obtain the integral characteristics of 137 IMBH-candidates. Continuing along this line, in present article we discuss the implications of microscopic model for tracing a mass assembly history of these candidates. These peculiarities deserve careful study. First, because they can be expected to lead to particularly sensitive tests of the theory if they can be subjected to experimental scrutiny. Second, because they furnish valuable theoretical clues about the interpretation and significance of the theory of growth and merging behavior of BHs. Needless to say that we will refrain from providing lengthy details of MTBH. We will not be concerned with the actual details of the MTBH here, but only use it as a backdrop to validate the MTBH with some observational tests. Wherever new results follow from earlier work, we restricted ourself only by a simple reference to earlier papers.

With this perspective in sight, we will proceed according to the following structure. The key objectives of MTBH are briefly outlined in Section 2. In Section 3, we provide a brief discussion of a growth of seed BH driven by an accretion and calculate its mass. In Section 4, we derive an analytical expression for the BH's 'neutrino pre-radiation time' (PRT). We also provide a scaling mass-luminosity relation of IMTB. In Section 5, we calculate the redshift of seed BH. In Section 6, we outline the microscopic model building, research design and methods. The Section 7 deals with the state equation in use, step-by-step away from the domain of lower density up to the domain of higher density. The results of simulation are presented in Section 8. The concluding remarks are given in Section 9. A few more technical details in use are deferred to appendices. In Appendix A, we briefly outline the key points of underlying gravitation theory, discuss a spontaneous breaking of gravitation gauge symmetry and, as a corollary, so-called *inner distortion* (ID) of spacetime continuum. Appendix B deals with the field equations of non-spinning SPC in ID regime, and provide the state equation of baryonic proto-matter. In Appendix C, we explain some technical details of spinning SPC.

#### 2. The MTBH, revisited

For a benefit of the reader, as a guiding principle to make the rest of paper understandable, in this section we necessarily recount some of the highlights behind of MTBH, which are in use throughout the paper. We extend preceding developments of the model of a non-rotating SPC (Ter-Kazarian, 2010, 2014, 2015b, 2016a,b, Ter-Kazarian & Shidhani, 2017, and references therein), without going into the subtleties, as applied to the study of BH-growth. There are several important topics not touched upon here, which will eventually benefit from the proposed theory. Although some key theoretical ideas were introduced with a satisfactory substantiation, we have also attempted to maintain a balance between being overly detailed and overly schematic.

The MTBH was extension of PBHM and rather completes it by exploring the most important processes of spontaneous breaking of gravitation gauge symmetry at huge energies. The latter yields a significant change of properties of spacetime continuum: the ID-regime. To clarify the distinction between the PBHM and the MTBH, it should help a few noteworthy points of Fig. 1 which schematically plotted the BH in phenomenological and microscopic frameworks.

A crucial point of the MTBH is that a central singularity cannot occur, which is now replaced by finite though unbelievably extreme conditions held in the equilibrium, so-called, superdense proto-matter core (SPC) inside the EH, subject to certain rules, where the static observers are existed. Consisting of the proto-matter core and the outer layers of ordinary matter, the SPC-configuration is the spherical-symmetric distribution of matter in many-phase stratified states. A layering is a consequence of the onset of different



Figure 1. Left panel: Phenomenological model of non-spinning BH. The meaningless singularity occurs at the center inside the BH. Right panel: Microscopic model of non-spinning BH, with the central stable SPC inside the EH. An infalling matter with the time forms PD around the SPC. In final stage of growth, a PD has reached out the edge of the event horizon. Whereas a metric singularity inevitably disappears and UHE neutrinos may escape from event horizon to outside world through vista - a thin belt area  $S = 2\pi R_g d$  - with opening angle  $\theta_{\nu}$ . Accepted notations: EH=Event Horizon, AD=Accretion Disk, SPC=Superdense Proto-matter Core, PD=Proto-matter Disk.



Figure 2. The radial profiles of the pressure, the density, the dimensionless gravitational  $(x_0)$ - and ID (x)-potentials of the SPC-configuration of mass  $\sim 6.31 \times 10^3 M_{\odot}$ .

regimes in equation of state. The simulations confirm in brief the following scenario. The energy density and internal pressure have sharply increased in proto-matter core, with respect to corresponding central values of neutron star, proportional to gravitational forces of compression. This counteracts the collapse and equilibrium holds even for the masses up to  $\sim 10^{10} M_{\odot}$ . Encapsulated in a complete set of equations of SPC-configuration, the SPC is a robust structure that has stood the tests of the most rigorous theoretical scrutinies of its stability (Ter-Kazarian et al., 2007). Minimizing the total energy gives the equilibrium configurations. The second derivative of total energy gives stability information. Although a relativity tends to destabilize configurations, however, a numerical integrations of the stability equations of SPC clearly proves the stability of resulting cores. Due to it, the stable equilibrium holds in outward layers too and, thus, an accumulation of matter is allowed now around the SPC. The seed BH might grow up driven by the accretion of outside matter when it was getting most of its mass.

Without loss of generality, the typical features of SPC-configurations are summing up in the Fig. 2 and Fig.3, to guide the eye. The radial profiles of the pressure, the density, the dimensionless gravitational  $(x_0)$ - and *inner distortion* (ID) (x)- potentials (see App. A) are plotted in Fig.2, for example, for the given SPC-configuration of the mass ~  $6.31 \times 10^3 M_{\odot}$  (that of the Sun,  $M_{\odot}$ ), and the state equation is presented in Fig.3. The special units in use denote  $P_{OV} = 6.469 \times 10^{36} \,\mathrm{erg} \,\mathrm{cm}^{-3}$ ,  $\rho_{OV} = 7.195 \times 10^{15} \,\mathrm{g} \,\mathrm{cm}^{-3}$  and  $r_{OV} = 13.68 \,\mathrm{km}$ . As it is seen, the MTBH is in good agreement with general relativity up to the limit of neutron stars. Moreover, above nuclear density, the SPC always resides inside the event horizon, therefore it could be observed only in presence of accreting matter. The external physics of accretion onto the SPC in first half of its lifetime is identical to the processes in phenomenological BH models. In other words, there is no observable difference between the gravitational field of SPC and Schwarzschild BH, so that the observable signature of BHs available in literature is of direct relevance for the SPC-configurations too. But MTBH manifests its virtue when one looks for the internal physics, accounting for growth and merging behavior of



Figure 3. The state equation of the SPC-configuration of mass  $\sim 6.31 \times 10^3 M_{\odot}$ .



Figure 4. A schematic cross section of the growth of a BH driven by a formation of the proto-matter (PD) disk at accretion, when the PD has finally reached the event horizon of a grown BH.

BHs.

The SPC-configuration accommodates the highest energy scale up to hundreds ZeV in central protomatter core. For preceding developments of MTBH, and its implications for ultra-high energy (UHE) astrophysics, the interested reader is invited to consult the original papers (Ter-Kazarian, 2014, 2015b, 2016a,b, Ter-Kazarian & Shidhani, 2017). Amongst the subsequent developments, particularly, the UHEneutrino fluxes from plausible accreting SMBHs closely linking to the 377 AGNs have been computed by (Ter-Kazarian, 2014, 2015b). We concluded that the AGNs are favored as promising pure sources of the high-energy astrophysical neutrinos, up to the UHE, because the computed neutrino fluxes are highly beamed along the plane of accretion disk, and peaked at high energies and collimated in smaller opening angle. The neutrinos are able to stream freely out of SPC, and the bulk of liberated binding energy of proto-matter must be converted into other forms of internal energy rather than being released immediately in the form of escaping neutrinos. That is, while hard to detect, neutrinos have the advantage of representing unique fingerprints of hadron interactions and, therefore, UHE neutrinos may initiate the cascades of UHE cosmic rays via very complex chains of Z-burst interactions. Some part of UHE neutrinos may produce, in accretion disk and in a torus of hot gas surrounding the AGN core, the secondary electrons with huge energies, which, in turn, may give rise a secondary flux of the GeV-TeV gamma-rays. Above said was sharpened by the recent surprising announcement of the first high-energy neutrino event by the IceCube Neutrino Observatory (Collaboration-170922Aalert, 2018). With the very large volume neutrino telescope optimized for the TeV energy range, they have traced a neutrino with the energy approximately 300 TeV that hit their Antarctica-based detector in September 2017 back to its point of origin in a blazar, TXS 0506+056, the 3.7 billion light-years away. This constitutes the first use of a neutrino detector to locate an object in space. In this regard, it will be of vital interest to compute in the framework of MTBH the high-energy astrophysical neutrino fluxes from aforementioned IMBH-candidates too. However, this will subsequently be an interesting topic for the comprehensive study elsewhere.

## **3.** Growth of BH driven by an accretion

One of the key objectives of MTBH is the increase of mass  $M^{seed}$  and gravitational radius  $R_g^{seed}$  of the seed BH at accretion of outside matter. The matter pulled toward the seed BH (proto-matter core) loses angular momentum through viscous or turbulent processes in an intrinsic accretion disk. Within such a disc, friction would cause angular momentum to be transported outward, allowing matter to fall further inward, thus releasing potential energy and increasing the temperature of the proto-matter. Simultaneously with an increase of seed mass, an infalling matter formes intrinsic proto-matter disk around grown up proto-matter core tapering off faster at reaching out the thin edge of EH. Whereas, the practical measure of a growth of BH is an increase of gravitational radius and mass of the BH:

$$\Delta R_g = R_g - (R_g^{seed})(0) = \Delta R_g^{seed} + \frac{2G}{c^2} M_d, \tag{1}$$

or

$$\Delta R_g = R_g - R_g^{seed} = \frac{2G}{c^2} M_d, \tag{2}$$

where  $M_d = M - M^{seed} = \rho_d V_d$ , and  $R_g^{seed} = (R_g^{seed})_0 + \Delta R_g^{seed}$ . The  $M_d$ ,  $\rho_d$  and  $V_d$  denote respectively total mass, density and volume of the proto-matter disk. At the value of gravitational radius,  $\hat{R}_g$ , when the proto-matter disk has finally reached the EH of grown BH, the volume,  $\hat{V}_d$ , can be calculated in polar coordinates  $(\rho, z, \varphi)$  from the Fig. 4:

$$\hat{V}_d = \hat{V}_d^{\ 1} - \hat{V}_d^{\ 2},\tag{3}$$

provided,

$$\hat{V}_{d}^{1} = \int_{\rho_{0}}^{\hat{R}_{g}} d\rho \int_{0}^{2\pi} \rho \, d\varphi \int_{-z_{1}(\rho)}^{z_{1}(\rho)} dz, \quad \hat{V}_{d}^{2} = \int_{\rho_{0}}^{R_{d}} d\rho \int_{0}^{2\pi} \rho \, d\varphi \int_{-z_{0}(\rho)}^{z_{0}(\rho)} dz, \tag{4}$$

where  $(z_0 - z_1(\rho))/z_0 = (\rho - \rho_0)/(\hat{R}_g - \rho_0)$ , and  $z_0(\rho) = \sqrt{R_d^2 - \rho^2}$ . The integration of (4) gives

$$\hat{V}_d = 4\pi \frac{z_0}{\hat{R}_g - \rho_0} \left[ \frac{(\hat{R}_g)^3}{6} - \frac{\hat{R}_g \rho_0^2}{2} - \frac{\rho_0^3}{3} \right] - \frac{4\pi}{3} (R_d^2 - \rho_0^2)^{3/2},\tag{5}$$

where  $R_d$  is the radius of proto-matter core. In approximation at  $R_d \ll \hat{R}_g$ , we may set  $z_0 \simeq \rho_0 \simeq R_d/\sqrt{2}$ , such that

$$\hat{V}_d \Big|_{(R_d \ll \hat{R}_g)} \simeq \frac{\sqrt{2\pi}}{3} R_d(\hat{R}_g)^2.$$
 (6)

Then the mass of proto-matter disk in solar masses can be written

$$\frac{M_d}{M_{\odot}} \simeq 6.48 \times 10^{-23} \left(\frac{\rho_d}{[\text{g cm}^{-3}]}\right) \times \left(\frac{R_d}{[\text{cm}]}\right) \left(\frac{M}{M_{\odot}}\right)^2.$$
(7)

While, the mass of seed BH over that of the Sun reads

$$\frac{M_{BH}^{Seed}}{M_{\odot}} = \frac{4\pi}{3} \frac{\rho_d R_d^3}{M_{\odot}} = 2.106 \times 10^{-33} \left(\frac{\rho_d}{[\text{g cm}^{-3}]}\right) \left(\frac{R_d}{[\text{cm}]}\right)^3.$$
(8)

Thus,

$$m_s = 2.106 \times 10^{-33} \rho r^3 = m(1 - 6.48 \times 10^{-23} \rho rm), \tag{9}$$

where  $m_s \equiv M_{BH}^{Seed}/M_{\odot}$ ,  $\rho \equiv \rho_d/[\text{g cm}^{-3}]$ ,  $r \equiv R_d/[\text{cm}]$ , and  $m \equiv M/M_{\odot}$ . Thence the cubic equation for unknown variable r is written

$$r^{3} + 3.077 \times 10^{10} m^{2} r - \left(\frac{m}{2.106 \times 10^{-33} \rho}\right) = 0.$$
<sup>(10)</sup>

As far as  $p \equiv 3.077 \times 10^{10} m^2 > 0$ , there is only one real root, which can be represented in terms of hyperbolic functions, as

$$r = -2\sqrt{\frac{p}{3}}\sinh\left[\frac{1}{3}ar\sinh\left(\frac{3q}{2p}\sqrt{\frac{3}{p}}\right)\right],\tag{11}$$



Figure 5. The parameter  $\zeta$  vs m, at  $\rho \simeq 2.6 \times 10^{16}$ .

where  $q \equiv -m/2.106 \times 10^{-33} \rho$ . That is,

$$r = 2.026 \times 10^5 m \sinh\left(\frac{1}{3}ar \sinh\zeta\right),\tag{12}$$

where  $\zeta \equiv 2.29 \times 10^{17} / \rho m^2$ . Hence the mass of seed BH reads

$$m_s = 1.75 \times 10^{-17} \rho \left[ m \sinh\left(\frac{1}{3}ar \sinh\zeta\right) \right]^3.$$
(13)

Since the inequality  $\zeta \ll 1$  holds for considered IMBH-candidates (see Fig. 6), then by virtue of  $r\rho m \simeq 1.54 \times 10^{22}$ , as a first order approximation in  $\zeta$ , the mass of seed BH becomes

$$m_s \simeq 2 \times 10^{-3} m. \tag{14}$$

Therefore,

$$r \simeq 0.983 \times 10^{10} \left(\frac{m}{\rho}\right)^{1/3}$$
 (15)

At the best fit  $\rho_d \simeq 2.6 \times 10^{16} [\text{gcm}^{-3}]$  (Ter-Kazarian, 2014, 2015b), we have

$$R_d \simeq (0.332 [\text{km}]) m^{1/3}.$$
 (16)

#### 4. The neutrino pre-radiation time

To give more credit to this view, next we would like to infer an analytical expression for the BH's ' neutrino pre-radiation time' (PRT), which is referred to as a lapse of time,  $T_{BH}$ , from the birth of BH till neutrino radiation - the earlier part of the lifetime. A typical growth rate for a BH is then given by the time required to reach the final mass, M, and gravitational radius,  $\hat{R}_g$ , when proto-matter disk has finally reached the EH. It is instructive to recast the PRT-scale in the form

$$T_{BH} = \frac{M_d}{\dot{M}},\tag{17}$$

where  $\dot{M}$  is the accretion rate. The order of magnitudes of the accretion rates can be derived if we assume that there is no shortage of the fuel around the BH. Actually, the BHs are fed by the accretion of gas in a process in which a small fraction of the energy of the accreted gas is released in the form of radiation of intensity L. The stars are sufficient to fuel some low luminosity dwarf nuclei: at high densities stellar collisions replenish the central density, and the nuclei can reach higher luminosities. If these conditions are fulfilled, the growth of massive BH can then be accretion-dominated. The mass accretion rate is written (Ter-Kazarian, 2014, 2015b)

$$\dot{M} \equiv \frac{dM}{dt} = \frac{L}{\epsilon c^2},\tag{18}$$

where  $\epsilon$  is the accretion efficiency to transform the gravitational energy into radiation. According to the canonical Bondi accretion rate, the luminosity has increased as  $L \propto \dot{M} \propto M^2$ . At some point, the BH growth slows down when approaching to quasar phase, for which the gas maximum rate accretion occurs nearly at

the Eddington limit, and radiate at Eddington luminosity,  $L_{Edd} = \frac{4\pi GMc}{k} = 1.3 \times 10^{38} \left(\frac{M}{M_{\odot}}\right) [\mathrm{erg\,s}^{-1}]$ (above which the radiation pressure prevents the material to fall in), where  $k = \sigma_T/m_p$  is the opacity. The  $\dot{M}$  is limited by Eddington  $\epsilon c^2 \dot{M} < L_{Edd}$ . In the same time, it should be emphasized that the possibility of super-Eddington accretion has been also explored theoretically by many authors. A basic reason why this may be feasible is the photon trapping effect on small scales near the BH. That is, in a spherically symmetric accretion flow at a rate much greater than Eddington accretion, the emergent radiation flux is reduced by photon trapping in the optically-thick accreting matter. Such an effect operates when the radial gas in flow speed is faster than the outward photon diffusion speed. The photon trapping effect becomes physically relevant when, so-called, the "trapping radius"  $R_{tr} = (k/4\pi c)M$  is outside  $R_g$ . Note that the Bondi radius is generally much larger than the trapping radius. This idea dates back to the works by (Begelman, 1978, 1979), who constructed a global spherical accretion solution for ionized gas at super-Eddington value. In summary, high accretion rates exceeding the Eddington value are possible but produce intense radiation flux toward the polar directions. These results, however, are valid only as long as a sufficient amount of gas at rates of  $M \gg M_{Edd}$  is supplied from larger scales without being impeded by the strong radiation feedback (see e.g. Inayoshi & Visbal (2019)).

In what follows, for simplicity reasons, the mass supply rate from large scales  $\sim \dot{M}_{Edd}$  (precisely tracked as a BH grows by orders of magnitude in mass) is of particular interest to us. Then the Salpeter characteristic time-scale becomes as long as

$$T_s = \epsilon t_{Edd} = \epsilon \frac{kc}{4\pi G} = \frac{M}{\dot{M}_{Edd}} = \left(\frac{dt}{d\log(M)}\right)_{Edd} = \frac{M\epsilon c^2}{L_{Edd}} = \left(\frac{\epsilon}{0.1}\right) 4.5 \times 10^7 \,[\text{yr}]. \tag{19}$$

Thence

$$M\left(\frac{t}{[\mathrm{yr}]}\right) < M(0) \exp\left(\frac{t}{T_s}\right) = M(0) \times 10^{\frac{t \log e}{T_s}} = M(0) \times 10^{\frac{0.434 t}{T_s}}.$$
(20)

Thus, the characteristic minimum time,  $t_{min}$ , which takes at least BH of mass M(0) to grow to mass, M, at the Eddington rate should be

$$t > t_{min} \equiv \frac{T_s}{0.434} \log\left(\frac{M}{M(0)}\right) [\text{yr}] = 1.037 \times 10^8 \log\left(\frac{M}{M(0)}\right) [\text{yr}],$$
 (21)

where the value of efficiency is taken  $\epsilon \simeq 0.1$ , like as for high redshift quasars. For a seed mass, say,  $M(0) \simeq 10^5 M_{\odot}$ , the accretion of mass at the Eddington rate causes a BH mass to increase in time

$$t_{min} = 1.037 \times 10^8 \times 4 \,[\text{yr}] = 4.148 \times 10^8 \,[\text{yr}],\tag{22}$$

to  $\simeq 10^9 M_{\odot}$ . This brings one back in time to an epoch when the Universe was very young and galaxies in their infancy. For example, the observation of luminous quasars well in excess of  $\simeq 10^{47} \, [{\rm erg \, s^{-1}}]$ , at  $z \simeq 6$  (Fan & et al., 2001), implies that the first SMBHs with masses  $\sim 10^9 M_{\odot}$  must have formed already in place when the Universe is only 1 [Gyr] old.

Assuming a typical mass-energy conversion efficiency of about  $\epsilon \sim 10\%$ , in approximation  $R_d \ll R_g$  the PRT reads (Ter-Kazarian, 2014, 2015b, Ter-Kazarian et al., 2007)

$$T_{BH} \simeq 0.32 \frac{R_d}{r_{OV}} \left(\frac{M_{BH}}{M_{\odot}}\right)^2 \frac{10^{39} W}{L_{bol}} \,[\text{yr}].$$
 (23)

According to (21), PRT-time,  $T_{BH}$ , is constrained from the low-limit by

$$T_{BH} > 1.037 \times 10^8 \log\left(\frac{M}{M^{seed}}\right) \text{ [yr]}.$$
(24)

However, unfortunately, the relation (23) cannot be much useful for computing the PRT-scales for IMBHs, because the available observed data of bolometric luminosities of IMBHs at present are scanty. Even though if we use, instead, a proxy of accretion flow and X-ray luminosities of these sources, nevertheless, we certainly Ter-Kazarian G.

have to touch again upon some rough errors due to data of insufficient accuracy. To overcome this problem, the best way is left perhaps to do stepwise as follows: 1) We at first have to calculate the ratio of PRTscales of the two SPCs, invoking the relation of the canonical Bondi accretion rate  $\dot{M} \propto M^2$  for the central SPC of the given mass M (Ter-Kazarian et al., 2007); 2) Afterwards, we have to calibrate this relation by choosing some SMBH as one of them, which links with a host galaxy with the well observational estimates of bolometric luminosity and mass. Then, the resulting relation should perhaps be of a sufficient accuracy for simulations of the PRT-scales of seeds of alluded IMBH-candidates.

Certainly, let M(t) denotes the sum of masses of grown up seed SPC,  $M^{seed}(t)$ , and protto-matter disk,  $M_d(t)$ , at the moment t ( $0 \le t \le T_{BH}$ ). Then according to (17), the PRT-scale  $T_{BH}(t)$ , at moment t, should be

$$T_{BH}(t) = \frac{M_d(t)}{\dot{M}(t)} \propto \frac{M_d(t)}{(M(t))^2} \propto R_d \left(\frac{M(t)}{M(t)}\right)^2 = R_d.$$
(25)

For two BHs of given present masses  $M_1$  and  $M_2$ , the relation (25), in the limit, yields

$$\frac{T_{BH\,1}}{T_{BH\,2}} = \frac{R_{d\,1}}{R_{d\,2}}.\tag{26}$$

To calibrate (26), let choose the estimates of central SMBH mass,  $M_2$ , and PRT-scale,  $T_{BH\,2}$ , based on properties of the host galaxy, say, Mrk 841 SY1 bulge. The time-scale to drive a large mass  $M_2 = 1.26 \times 10^8 M_{\odot}$  to central SMBH, which is a significant fraction of the gas content of a typical galaxy, following (Ter-Kazarian, 2014), is of the order of  $T_{BH\,2} \simeq 7.94 \times 10^8$  [yr]. Thereby the simulations give  $R_{d\,2} \simeq 2.136 \times 10^5$  [cm] and  $M_2^{seed} \simeq 2.88 \times 10^3$ . From the relation (26), it is then readily deduced that

$$\tau \equiv \frac{T_{BH}}{[\mathrm{yr}]} \simeq 3.717 \times 10^3 \, r. \tag{27}$$

The (23) can be rewritten

$$\tau \simeq 5.656 \times \left(\frac{10^{45}}{l}\right) m,\tag{28}$$

where  $l \equiv L_{bol}/[\text{erg s}^{-1}]$ . Comparing (27) with (28), we derive the scaling M - L relation for the mass and bolometric luminosity of IMBHs:

$$l \simeq 1.52 \times 10^{42} \frac{m}{r}.$$
 (29)

### 5. The redshift of seed BH

To follow the history of the BH to the present time in the expanding Universe of a general recession of distant galaxies away from us in all directions, the radiation density at the present epoch can be neglected in comparison with the matter density in the Universe. So, the expansion rate of the Universe depends on the matter density,  $\rho$ , the cosmological constant,  $\Lambda$ , and the curvature, k, of the space. The expansion rate (Hubble's parameter) of the Universe at any epoch at redshift less than about 1000 can be related to the one at the present epoch by (e.g. Bergström & Goobar (2006)):

$$H(z) = H_0 E(z),\tag{30}$$

where

$$E(z) \equiv \sqrt{\left[\Omega_M (1+z)^3 + \Omega_K (1+z)^2 + \Omega_\Lambda\right]},\tag{31}$$

and  $\Omega_{\Lambda} = \frac{\Lambda}{3H_0^2}$ ,  $\Omega_K = \frac{-k}{a_0^2 H_0^2}$ ,  $\Omega_M = \frac{\rho}{\rho_{crit}}$ , and the critical density is  $\rho_{crit} = \frac{3H^2}{8\pi G}$ . There are only two independent contributions to the energy density

$$\Omega_M + \Omega_\Lambda + \Omega_K = 1. \tag{32}$$

Let the proper time, t, be the temporal measure. This is a convenient time measure because it is the proper time of comoving observers. The lookback time is the time difference between the present epoch,  $t_0$ , and the time of an event that happened at the redshift, z. From the definitions of Hubble's parameter and redshift it follows that

$$H = \frac{d}{dt} \log\left(\frac{R(t)}{R_0}\right) = \frac{d}{dt} \ln\left(\frac{1}{1+z}\right) = \frac{-1}{1+z}\frac{dz}{dt},$$
(33)

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where R is called the scale factor of the Universe, and increases as the Universe expands in a manner that depends upon the cosmological model selected. Hence, the lookback time from the present, as a function of the time of flight, reads

$$t_0 - t_1(z_1) = H_0^{-1} \int_0^{z_1} \frac{dz'}{(1+z')\sqrt{\Omega_M(1+z')^3 + \Omega_K(1+z')^2 + \Omega_\Lambda}}.$$
(34)

Whereas by choosing  $t_1 = 0$  (that is  $z_1 \to \infty$ ) in this equation, we obtain the present age of the Universe,  $\tau$ . For the Einstein-de Sitter Universe ( $\Omega_M = 1$ ,  $\Omega_{\Lambda} = 0$ ), with from the present epoch z = 0 to the beginning of time at  $z = \infty$ , by integration of (34) one may infer the age of the Universe  $\tau = \frac{2}{3H_0}$ .

Relating the PRT-scale,  $T_{BH}$ , to the redshifts of BH, z, and its seed,  $z^{seed}$ , let we place ourselves at the origin of coordinates, r = 0, (according to the Cosmological Principle, this is mere convention). Consider a light traveling to us along the -r direction, with angular variables fixed. If the light has left a seed BH, located at  $r_s, \theta_s, \varphi_s$ , at time  $t_s$ , that happened at the redshift  $z^{seed}$ , and it has to reach us at present epoch  $t_0$ , at the redshift z = 0, then from the definition of the lookback time (34), it follows that

$$H_0(t_0 - t_s(z^{seed})) = \int_0^{z^{seed}} \frac{dz'}{(1+z')\sqrt{\Omega_M(1+z')^3 + \Omega_K(1+z')^2 + \Omega_\Lambda}}.$$
(35)

Similar expression can be written for the current BH, located at  $r_1, \theta_1, \varphi_1$ , at time  $t_1$ , with redshift z:

$$H_0(t_0 - t_1(z)) = \int_0^z \frac{dz'}{(1 + z')\sqrt{\Omega_M (1 + z')^3 + \Omega_K (1 + z')^2 + \Omega_\Lambda}}.$$
(36)

Subtracting (36) from (35), and taking into account that  $t_1 = t_s + T_{BH}$ , as seed BH is an object at early times, we obtain

$$H_0(t_0 - t_s(z^{seed})) - H_0(t_0 - t_1(z)) = H_0 T_{BH} = \int_0^{z^{seed}} (\cdots) - \int_0^z (\cdots) = \int_z^{z^{seed}} (\cdots).$$
(37)

Thus, we arrived to the general relation between the PRT-scale and the redshifts of BH and its seed:

$$H_0 T_{BH} = \int_{z}^{z^{seed}} \frac{dz'}{(1+z')\sqrt{\Omega_M (1+z')^3 + \Omega_K (1+z')^2 + \Omega_\Lambda}}.$$
(38)

As a supplement to the relation (38), we may derive  $z_s$  as a function of the quantities z and  $T_{BH}$ . Consider a light that travels from a galaxy to a distant observer, both of whom are at rest in comoving coordinates. From radial null-geodesics equation ( $ds = 0, d\theta = d\phi = 0$ ) one derives that if light is emitted from a galaxy at time t and received by us at  $t_0$ , it is redshifted z due to the expansion of space, and the overall redshift is therefore given by the Lemaître's important relationship:

$$z = \frac{R(t_0)}{R(t)} - 1.$$
(39)

Then, according to the definitions of Hubble's parameter (33), we may write down

$$z + 1 = e^{H(z)(t_0 - t_1)}, \text{ for the BH,}$$

$$z_s + 1 = e^{H(z_s)(t_0 - t_s)}, \text{ for the seed BH.}$$
(40)

Setting  $H(z) \simeq H(z_s)$ , and taking into account that  $t_1 = t_s + T_{BH}$ , we obtain

$$\frac{z+1}{z_s+1} = e^{-H(z)(t_1-t_s)} = e^{-H(z)T_{BH}}.$$
(41)

Hence, the function  $z_s(z, T_{BH})$  reads

$$z_s = (z+1)e^{H(z)T_{BH}} - 1. (42)$$

#### 5.1. High redshifts

At large redshifts  $z \gg \Omega_M, \Omega_\Lambda$ , only third power of z in the square root in (38) becomes important, and thus we find

$$T_{BH} \simeq \int_{z}^{z^{seed}} \frac{dz}{H_0 \sqrt{\Omega_M} (1+z)^{5/2}} \simeq \frac{2}{3H_0 \sqrt{\Omega_M}} \left[ \frac{1}{(1+z)^{3/2}} - \frac{1}{(1+z^{seed})^{3/2}} \right].$$
(43)

Therefore, in time to an epoch when the Universe was very young and galaxies in their infancy, the redshift of seed BH reads

$$z^{seed} \simeq \left[\frac{1}{(1+z)^{3/2}} - \frac{3\sqrt{\Omega_M}H_0T_{BH}}{2}\right]^{-2/3} - 1.$$
(44)

Using the inverse distance ladder method based on the baryon acoustic oscillations, the DES collaboration (Macaulay & et al., 2018) present a recently improved supernova measurements of the Hubble's constant. They find the value  $H_0 = (67.77 \pm 1.30)$ [km]/[s]/[Mpc], with the statistical and systematic uncertainties, 68% confidence. This value, incorporating (44) and (28), yield

$$z^{seed} \simeq \left[\frac{1}{(1+z)^{3/2}} - \frac{3\sqrt{\Omega_M}}{2} \left(39.2 \pm 0.75\right) \times \frac{M}{M_{\odot}} \frac{10^{27} W}{L}\right]^{-2/3} - 1.$$
(45)

By virtue of (27), we may as well obtain

$$z^{seed} \simeq \left[\frac{1}{(1+z)^{3/2}} - \frac{3\sqrt{\Omega_M}}{2} \times (25.76 \pm 0.494) \times 10^{-8} \frac{R_d}{[\text{cm}]}\right]^{-2/3} - 1.$$
(46)

#### 5.2. Low redshifts

In time to an epoch when the Universe is old, for low redshifts  $z \ll 1$ , in the first-order approximation by the z, from (38), we derive

$$H_0 T_{BH} = \int_z^{z^{seed}} \frac{dz}{\sqrt{\Omega_M + \Omega_K + \Omega_\Lambda}} \simeq z^{seed} - z.$$
(47)

Hence

$$z^{seed} \simeq z + (25.76 \pm 0.494) \times 10^{-8} \frac{R_d}{[\text{cm}]}.$$
 (48)

## 6. A microscopic model building: Research design and methods

The key physical properties of SPC depend very little on the details of concrete SPC-model, because they are a direct consequence of the fundamental features of underlying gravitation theory. We therefore expect that the key properties of non-rotating SPC, even though without being carefully treated, retain for a rotating SPC (App.C) too. Therefore, we have proceeded below in relatively simple way of considering non-rotating black holes, which is quick to estimate the most important conceptual aspects of associated physics, without loss of generality. In going into practical details, we thus adopt the research design and methods of theoretical and numerical preparations discussed recently in (Ter-Kazarian & Shidhani, 2019) and references therein. We attempt to amplify and substantiate the key assertions made in MTBH, and further expose vie working model of the most generic equilibrium configurations of the two classes, with spherical-symmetric distribution of matter in many-phase stratified states. A layering of configuration is a consequence of the onset of different regimes in equation of state. Below we describe stepwise the SPC configurations away from the domain of lower density up to the domain of higher density.

#### 6.1. The I-class SPC configurations

#### The I-class SPC configurations include:

Domain  $\rho < \rho_{drip} = 4.3 \times 10^{11} \,\mathrm{g \, cm^{-3}}$  - the shell made of cold catalized matter, which is formed after nuclear burning in the density range below neutron drip  $(\rho_{drip})$ . Below  $10^7 \,\mathrm{g \, cm^{-3}}$ , the <sup>56</sup><sub>26</sub>Fe nuclei are dominating. In the inner crust, a Coulomb lattice of heavy nuclei co-exist in  $\beta$ - equilibrium with relativistic electrons.

 $\frac{1}{Domain \ \rho_{drip} \leq \rho < 4.5 \times 10^{12} \,\mathrm{g \, cm^{-3}}}$  inner crust-the electrons, nuclei and free neutrons co-exist in the medium.

Above the density  $\rho > 4.5 \times 10^{12} \,\mathrm{g \, cm^{-3}}$  the I-class configurations are thought to be composed of two phases of ideal cold n-p-e gas, which is mixture of neutrons, protons and electrons in complete  $\beta$ - equilibrium. The first phase state covers the intermediate density -

Domain  $4.5 \times 10^{12} \,\mathrm{g\,cm^{-3}} \le \rho < \rho_d = 2.6 \times 10^{16} \,\mathrm{g\,cm^{-3}}$  which is the regular n-p-e gas in absence of ID. For the intermediate density domain of regular n-p-e gas in absence of ID, according to (?), the proton-neutron ratio initially decreases, as the density increases, and reaches a maximum value of 0.0026 at  $\rho_0 \simeq 7.8 \times 10^{11} g cm^{-3}$ , and afterwards rises monotonically to 1/8 for high densities. Second phase state is-

Domain  $\rho > \rho_d$  - the n-p-e proto-matter at short nucleon-nucleon distances  $r_{NN} \leq 0.4$  fm, in presence of ID.

#### 6.2. The II-class SPC configurations

For the II-class SPC configurations, up to the density range  $\rho \leq \rho_{fl} = 4.1 \times 10^{14} \,\mathrm{g \, cm^{-3}}$ , to which the  $r_{NN} \leq 1.6 \,\mathrm{fm}$  nucloun-nucleon distances correspond, one has the same domains of I-class configurations. Above the density  $\rho_{fl}$ , we consider an onset of melting down of hadrons when nuclear matter consequently turns to quark matter. In the domain of  $\rho_{fl} \leq \rho < \rho_{as} = m_n (0.25 \,\mathrm{fm})^3 \simeq 1.1 \times 10^{17} \,\mathrm{g \, cm^{-3}}$ , where  $m_n$  is the neutron mass at rest, 0.25 fm is the string thickness, we consider two phase states of string flip-flop regimes (Ter-Kazarian & Shidhani, 2019):

Domain  $\rho_{fl} \leq \rho < \rho_d$ , to which the distances  $0.4 \,\mathrm{fm} < r_{NN} \leq 1.6 \,\mathrm{fm}$  correspond- the regular string flip-flop, when ID is absent. This is a kind of tunneling effect when the strings joining the quarks stretch themselves violating energy conservation and after touching each other they switch on to the other configuration. We are interested in the individual particle approximation (Hartree approximation), where the Hartree potential is almost linearly proportional to the string length. The Y shape string is the most convenient for calculations, because the center of it almost equals to the center of gravity. At very first, we shall study the classical strings. In analogy to the case of ordinary quark matter, one may readily show that in order to have bound state the rising potential should be a scalar. Similar to ordinary case a red quark searches for the nearest center and joins with it by a string and so on. One simplifies the calculations by assuming that the centers are uniformly distributed with a particle concentration. We assume that quarks have small ordinary mass  $m_i \simeq m_u = 5 MeV$ . Next, we explore a tunneling effect of quantum fluctuations of string, and the negative potential energy caused by such a quantum jump. The basic technique adopted for calculation of transition matrix element  $\widetilde{K}$  is the instanton technique (semi-classical treatment). Due to quantum string flip-flop, an attractive interaction between quarks is presented, when during the quantum transition from a state  $\psi_1$  of energy  $E_1$  to another one  $\psi_2$  of energy  $E_2$ , the lowering of energy of system occurs. The quark matter acquires  $\Delta E$  correction to the classical string energy, such that the flip-flop energy lowers the energy of quark matter, consequently by lowering the critical density or critical Fermi momentum. The quark matter acquires  $\Delta E$  correction to the classical string energy, such that the flip-flop energy lowers the energy of quark matter, consequently by lowering the critical density or critical Fermi momentum. If one, for example, looks for the string flip-flop transition amplitude of simple system of  $q\bar{q}q\bar{q}$  described by the Hamiltonian  $\widetilde{H}$  and invariant action  $\widetilde{S}$ , then one has

$$< \quad \downarrow \quad \downarrow \quad | e^{-\widetilde{H}T} | \quad \stackrel{\bullet \bullet}{\longrightarrow} \quad > \quad = \quad < \int [d\,\widetilde{\sigma}] \ e^{-\widetilde{S}} >, \tag{49}$$

where T is a (imaginary) time interval,  $[d\tilde{\sigma}]$  is the integration over all the possible string motion. The action  $\tilde{S}$  is proportional to the area  $\tilde{A}$  of the surface swept by the strings in the finite region of ID-region of

 $V_4$ . The strings are initially in the  $\Box$  configuration and finally in the  $\downarrow$  configuration. Note that the maximal contribution to the path integral (49) comes from the surface  $\sigma_0$  of the minimum surface area ('instanton'). A computation of the transition amplitude is strightforward by summing over all the small vibrations around  $\sigma_0$ . Note that string has a finite thickness d, and the width of the area  $\Delta \tilde{A}$  cannot be less than d. This cutoff introduces a factor  $\exp(-a_0 d r_{NN})$ , (where  $r_{NN}$  is the distance between two separated centers) in the amplitude  $\tilde{K}$  resulting in the finite-ranged potential. The interaction energy between two centers has a range of order  $2\tilde{\tilde{r}}$  due to overlap of wave functions. A string thickness d can be estimated to be 0.25 fm.

Domain  $\rho_d \leq \rho < \rho_{as}$ - the string flip-flop regime in presence of ID at distances  $0.25 fm < r_{NN} \leq 0.4 \text{ fm}$ a system is made of quark proto-matter in complete  $\beta$ -equilibrium with rearrangement of string connections joining them.

Domain  $\rho > \rho_{as}$ - the system is made of quarks in one beg in complete  $\beta$ -equilibrium at presence of ID, under the weak interactions and gluons, including the effects of QCD-perturbative interactions. The QCD vacuum has a complicated structure due to the glueon-glueon interactions. The confinement of quarks is a natural feature of the exercising a pressure B on the surface of the local region of the perturbative vacuum to which quarks are confined. This is just the main idea of phenomenological MIT quark bag model, where quarks are assumed to be confined in a bag. Due to the screening of strong forces, the quarks are considered to be free inside the bag and to interact only in the surface region. The surface energy is estimated to be proportional to quark density. The stability of the hadron is ensured by the vacuum pressure B and surface tension. The surface energy is estimated to be proportional to quark density. In most applications, sufficient accuracy is obtained by assuming that all the quarks are almost massless inside a bag. Now, our purpose is to convert this picture to the medium of quark proto-matter. The quark proto-matter is in overall color singlet ground state, which is a non-interacting relativistic Fermi gas found in the ID-region of the spacetime continuum, at  $r_{NN} \leq 0.25 fm$ . We consider the quark proto-matter of u, d and s flavors, in complete  $\beta$ -equilibrium.

Now, let discuss the QCD interaction effects in approximation at hand, with extension to quark protomatter. The first effect is the shift of the vacuum energy per unit volume. The bag constant  $B \simeq 55 MeV/fm^3$  of the MIT bag model must be added to the kinetic energy density. Including the gluon exchange perturbative interactions the energy density of quark proto-matter is then given by the noninteracting Fermi contribution plus bag constant. The first correction to the free ground state is the ordinary exchange energy corresponding to the second order closed loop diagrams. Next correction is coming up from the sum of different ring diagrams, while the quarks will be taken fully relativistic  $m_i \to 0$ .

### 7. The state equation

In our setting we retain the rather concrete proposal of preceding developments of the model of a nonrotating SPC (Ter-Kazarian & Shidhani, 2019) and references therein), without going into the subtleties, as applied to the study of IMBHs. The equations describing the equilibrium SPC include the gravitational and ID field equations, the hydrostatic equilibrium equation, and the state equation of the spherical-symmetric distribution of baryonic-quark matter in many-phase stratified states specified for each domain. We use the Oppenheimer and Volkoff (OV)-units, where a length unit =  $1.368 \times 10^6 cm$ , a time unit =  $4.564 \times 10^{-5}s$ , a mass unit =  $1.843 \times 10^{34}g$ , and energy unit =  $1.656 \times 10^{55} erg$ . We also introduce a new variable  $\nu$  as

$$n_{OV} = 7.96178 \times 10^{55} e^{\nu},\tag{50}$$

and rewrite the hydrostatic equilibrium equation in the form

$$\nu' = -(s_1 + s_2) \frac{1}{2} \left( \ln g_{00} \right)', \tag{51}$$

where (') means  $\partial/\partial r$ ,  $s_1 = \widetilde{P}_{OV}(\nu'/P'_{OV})$  and  $s_2 = \widetilde{\rho}_{OV}(\nu'/\rho'_{OV})$ .

The resulting state equations are specified below for each domain step-by-step away from the domain of lower density up to the domain of higher density.

*I-Class Conffigurations.* The simple semiempirical formula of state equation is given by Harrison and Wheeler (see e.g. Shapiro & Teukolsky (1983)). Domain:  $-27.2 \le \nu < -15.5$ ,

$$P_{OV} = 4.68 \times 10^{-25} \left( 1.93 \times 10^5 \rho_{OV}^{1/3} - 1.44 \right)^5 - 2.32 \times 10^{-26},$$
  

$$s_1 = 1.54 \times 10^{-7} \rho_{OV}^{-1/3} \times \frac{\left[ \left( 1.93 \times 10^5 \rho_{OV}^{1/3} - 1.44 \right)^5 - 1 \right]}{\left( 1.93 \times 10^5 \rho_{OV}^{1/3} - 1.44 \right)^4},$$
  

$$s_2 = 6.64 \times 10^{18} \rho_{OV}^{2/3} \left( 1.93 \times 10^5 \rho_{OV}^{1/3} - 1.44 \right)^{-4}.$$
(52)

Domain:  $-15.5 \le \nu < -2.8$ ,

$$P_{OV} = 0.03\rho_{OV}^{5/4} \left(1 + 2.82 \times 10^{-5}\rho_{OV}^{-1/2}\right)^{-5/6},$$
  

$$s_1 = \frac{0.08 \left(1 + 2.82 \times 10^{-5}\rho_{OV}^{-1/2}\right)}{\left(1 + 3.99 \times 10^{-5}\rho_{OV}^{-1/2}\right)}, \quad s_2 = 3.17\rho_{OV}^{-1/4} \left(1 + 2.82 \times 10^{-5}\rho_{OV}^{-1/2}\right).$$
(53)

Domain:  $-2.8 \le \nu < -0.1$ ,

$$P_{OV} = 1.79 \times 10^{-5} \rho_{OV}^{2/3} \left( 1 + 1.39 \rho_{OV}^{1/6} \right)^6 \right),$$
  

$$s_1 = \frac{1.50 \left( 1 + 1.40 \rho_{OV}^{1/6} \right)}{\left( 1 + 3.50 \rho_{OV}^{1/6} \right)}, \quad s_2 = 8.36 \times 10^4 \rho_{OV}^{1/3} \left( 1 + 1.40 \rho_{OV}^{1/6} \right)^{-5} \times \left( 1 + 3.50 \rho_{OV}^{1/6} \right)^{-1}.$$
(54)

Domain:  $-0.1 \le \nu < 8.5$ ,

-the regular n-p-e gas (ID is absent).

Domain:  $8.5 \leq \nu$ ,

-the state equation of the n-p-e proto-matter reads (Ter-Kazarian & Shidhani, 2019)

$$\widetilde{\rho} = \widetilde{m}_e c^2 \chi(\widetilde{y}_e) / \widetilde{\lambda}_e^3 + \widetilde{m}_p c \chi(\widetilde{y}_p) / \widetilde{\lambda}_p^3 + \widetilde{m}_n c^2 \chi(\widetilde{y}_n) / \widetilde{\lambda}_n^3 \widetilde{P} = \widetilde{m}_e c^2 \varphi(\widetilde{y}_e) / \widetilde{\lambda}_e^3 + \widetilde{m}_p c^2 \varphi(\widetilde{y}_p) / \widetilde{\lambda}_e^3 + \widetilde{m}_n c^2 \varphi(\widetilde{y}_n) / \widetilde{\lambda}_e^3.$$
(55)

For more details and explanation of notational conventions see App.B4.

II-Class Configurations.

For the II-class configurations, up to the density range  $\nu = 8.5$ , one has the same domains of I-class configurations. At distances  $0.25 fm < r_{NN} \le 0.4 fm$ , in the Domain:  $8.5 \le \nu < 9.9$ ,

the string flip-flop phase state occurs in ID regime (Ter-Kazarian & Shidhani, 2019):

$$\widetilde{\rho} = 3\widetilde{m}c^2 \frac{\chi(\widetilde{y})}{\widetilde{\lambda}^3} - 56.29 MeV \widetilde{n}_b, \quad \widetilde{P} = 3\widetilde{m}c^2 \frac{\varphi(\widetilde{y})}{\widetilde{\lambda}^3}.$$
(56)

Domain:  $\nu \ge 9.9$ ,

-the  $\Lambda$ -like system is made of u, d and s quark protomatter in one bag in complete  $\beta$ -equilibrium under the weak interactions and gluons, including the effects of QCD-perturbative interactions:

$$\widetilde{\rho} = \sum_{i} \widetilde{m} c_{i}^{2} \frac{\chi(\widetilde{y}_{i})\widetilde{b}_{I}}{\widetilde{\lambda}_{i}^{3}} + B, \quad \widetilde{P} = \sum_{i} \widetilde{m}_{i} c^{2} \frac{\varphi(\widetilde{y}_{i})\widetilde{b}_{I}}{\widetilde{\lambda}_{i}^{3}}, \tag{57}$$

where the quarks will be taken fully relativistic  $m_i \to 0$ , B is the pressure on the surface of the local region of the perturbative vacuum, to which quarks are confined.

### 8. Simulations

In this section, we are led to the numerical integration of equations of equilibrium SPC-configurations in presence of ID-mechanism, leading from the center of configuration up to the surface. This is rather technical topic, and it requires care to do correctly. In what follows we only give a brief sketch. We claim that a significant change of properties of spacetime continuum in ID regime is essentially dominated over all the other interaction processes, irrespective to the details of the models in use. Computing the mass of seed BH, the PRT-scale, and the redshift of seed BH, a main idea comes to solving an inverse problem. That is, by the numerous reiterating integrations we determine those required central values of particle concentration  $\tilde{n}(0)$ , gravitational  $(x_0(0))$  and ID (x(0)) fields, for which the integrated total mass of configuration has to be equated to the IMBH mass M given from observations (Ter-Kazarian & Shidhani, 2019). Then, together with all integral characteristics, the radius of proto-matter core,  $R_d$ , can also be computed, which is in use in expressions (13), (28), (29), (46) and (48). As it is seen, the BH mass is an important parameter in this study. Of course, there are still large uncertainties in mass estimates collected from the literature of all the observational evidence for 137 IMBH-candidates. As an example, below we present a few comments on the observational mass uncertainties for some of these objects, and their validity or the confidence.



Figure 6. The masses of seed BHs and PRT-scales vs masses of 137 IMBHs.

Kiziltan et al. (2017) show the evidence for a central IMBH with a mass of  $2.2^{+1.5}_{-0.8} M_{\odot}$  in 47 Tucanae, which hosts 25 known millisecond pulsars. This IMBH-candidate might be a member of an electromagnetically invisible population of IMBHs that grow into SMBHs in galaxies.

Baldassare & Reines (2015) present optical and X-ray observations of the dwarf galaxy RGG 118 taken with the Magellan Echellette Spectrograph on the 6.5 m Clay Telescope and Chandra X-ray Observatory. Based on Sloan Digital Sky Survey (SDSS) spectroscopy, RGG 118 was identified as possessing narrow emission line ratios indicative of photoionization partly due to AGN. Higher resolution spectroscopy clearly reveals broad  $H_{\alpha}$  emission in the spectrum of RGG 118. They estimate a IMBH mass of ~ 50,000  $M_{\odot}$ .

The use of integral field spectroscopy, with the Hubble Space Telescope (HST), to obtain the central velocity-dispersion profile and of photometric data have allowed estimating the BH mass in a dozen more globular clusters by comparing the data to spherical dynamical models. This is the case of another strong IMBH candidate in a globular cluster,  $\omega$  Centauri, for which claimed the presence of an IMBH of best-fitted mass  $(4.7 \pm 1.0) \times 10^4 M_{\odot}$  (Noyola & Gebhardt, 2010, Noyola et al., 2008), while it is reported an upper limit of  $(1.2 \pm 1.0) \times 10^4 M_{\odot}$  (Van der Marel & Anderson, 2010). Baumgardt (2017) is also found that the velocity dispersion profile of  $\omega$  Centauri is best fitted by an IMBH of  $10^4 M_{\odot}$ .

Using integral-filed spectroscopy and HST photometry, Lützgendorf et al. (2013, 2015) reported upper limits on the mass of a putative BH in the globular clusters NGC 1851, NGC 2808, NGC 5694, NGC 5824, and NGC 6093 and predicted the presence of an IMBH of  $(3\pm1.0)\times10^3 M_{\odot}$  in NGC 1904, of  $(2\pm1.0)\times10^3 M_{\odot}$ in NGC 6266, and of  $(2.8\pm0.4)\times10^4 M_{\odot}$  in NGC 6388.

Feldmeier et al. (2009) suspected an IMBH of  $(1.5 \pm 1.0) \times 10^3 M_{\odot}$  is also in the globular cluster NGC 5286, and Ibata et al. (2013) reported the possible presence of an IMBH of ~ 9400  $M_{\odot}$  in NGC 6715 (M54), a globular cluster located at the center of the Sagittarius dwarf galaxy.

The natural extension of the well-known  $M - \sigma$  relation for galaxies suggests that the typical central velocity dispersions in globular clusters might be associated to the presence of IMBHs with masses of  $\sim 10^{3-4} M_{\odot}$  (e.g. Ferrarese & Merritt (2000), Gebhardt & et al. (2000)).

The ULXs have attracted a great deal of observational and theoretical attention, in part because their luminosities suggest that they may harbor IMBHs with an ubiquitous feature of the mass fits of more than  $10^2 - 10^4 M_{\odot}$  (H. & Soria, 2011). For overall details regarding this issue, we invite the interested reader to consult further the papers cited in Table 1.

However, for brevity reasons to save space, we put apart the complications of mass uncertainties and retain rather a concrete proposal to proceed in relatively simple way. That is, we select the calculated values of the mass of candidates in the IMBH in order to compare them with the average values of the observational estimates of the mass of the corresponding objects. The masses of seed BHs and PRT-scales vs masses of 137 IMBHs are plotted in Fig.4. The scaling M-L relation for the mass and bolometric luminosity for 137 IMBH-candidates is plotted on the Fig. 5 for 137 IMBH-candidates. The results of the numerical integration of the equations of SPC-configurations of 137 IMBHs, namely the mass of seed BH, the PRT-scale, and the redshift of seed BH, are presented in Table 1. We conclude that for the present masses  $\log(M/[M_{\odot}]) = 2.20$  to 5.99 of IMBH-candidates, the computed seed masses are ranging from  $\log(M^{seed}/[M_{\odot}]) = -0.50$  to 3.29, with



Figure 7. The scaling mass-luminosity relation for 137 IMBH-candidates.

corresponding growth-time scales  $T_{BH}$  ranging from  $\log(T_{BH}/[yr]) = 8.82$  to 10.09.

In Table 2, we present the results of computation for the luminosities of 137 IMBHs with the corresponding Eddington luminosities. The luminosities of IMBH-candidates are ranging from  $\log(L/[\text{erg s}^{-1}]) = 39.13$  to 41.653.

Finally we note that the growth behavior of IMBH-candidates widely based on the premises of runaway core collapse scenario. The latter has always been a matter of uncertainties because we do not have a thorough understanding of details of accretion physics, say, of the physical properties of invoked relativistic plasma flows outside a horizon, with compact coruscating bright spots due to beaming, or magnetohydrodynamic shocks and reconnection in the inner jet. Distinguishing these possibilities requires spatially resolved images much finer than the horizon size, which could be feasible in the near future. Then it is interesting to compare the accretion method with other methods such as radio timing or even the current research of BH imaging using Event Horizon Telescope. Timing observations provide a useful means to study the properties of space-time around extreme gravity systems, such as BHs. That is, if external tracers lead to an estimated horizon radius,  $R_q$ , under a very generic assumption that the object is a BH, then it is possible that finer observations will reveal internal substructures smaller than  $R_g$  or flaring events quicker than the time-scale  $R_q/c$ . Pulsar timing, therefore, has been identified as a space-time probe because of the high precision achievable in the timing measurements. It is also because of the unique nature of pulsars – highly compact and thus uneasily disrupted, narrow mass range, and for millisecond pulsars, high stability in the rotation rate (a stable, reliable clock). Saxton & et al. (2016) proposed that pulsar timing observations will be able to distinguish between systems with a centrally dense dark matter sphere and conventional galactic nuclei that harbour a SMBH. The lack of a perfect horizon means that the effective strong-lensing silhouette of the central structure may differ significantly from SMBH predictions. Besides, there are some theoretical expectations for swarming of pulsars (and other compact stars) to concentrate in galaxy nuclei (Freitag et al., 2006, Miralda-Escudé & Gould, 2000, Pfahl & Loeb, 2004). So far, one magnetar is known near Sgr A<sup>\*</sup>, and there is debate about how many pulsars might also be discoverable (e.g. Macquart & Kanekar (2015)). Although a thorough comparison is beyond the scope of the present communication, it will be an interesting topic for discussion elsewhere.

#### 9. Concluding Remarks

Deep conceptual and technical problems involved in this contribution provide scope for the arguments discussed, aiming to review the physics of growth behavior of seed BHs at accretion of outside matter. The key mechanism of growth is that the infalling matter formes intrinsic proto-matter disk around grown up proto-matter core tapering off faster at reaching out the thin edge of EH. Below we briefly reflect upon the obtained results. For a broad range of parameters, the numerous reiterating integrations of the state equations of SPC-configurations allow to trace an evolution of the mass assembly history of the BHs to the present time of 137 notable accreting IMBH-candidates. Given the masses and redshifts of IMBH-candidates at present time, collected from the literature, we compute among the others corresponding masses of seed

BHs, the PRT-scales, and their redshifts. In particular, for the present masses  $\log(M/[M_{\odot}]) = 2.20$  to 5.99 of IMBH-candidates, the computed seed masses are ranging from  $\log(M^{seed}/[M_{\odot}]) = -0.50$  to 3.29, with corresponding growth-time scales  $T_{BH}$  ranging from  $\log(T_{BH}/[yr]) = 8.82$  to 10.09. We derived scaling mass-luminosity relation, by means of which we compute the luminosities of IMBH-candidates ranging from  $\log(L/[erg s^{-1}]) = 39.13$  to 41.653.

Table 1. Growth of 137 IMBH-candidates. Column (1) Name of source, (2) log of the IMBH mass at present time
over that of the Sun, (3) log of the redshift at present time, (4) log of the radius of proto-matter disk, (5) log of the
mass of seed BH over that of the Sun, (6) log of the PRT-scale, (7) log of the redshift of seed BH, (8) log of the time,
$t_{min}$ , which takes at least seed BH to grow to mass, $M$ , at the Eddington rate (see (21)). The data of the columns
(2) and (3) are taken from the references presented at the end of Table, which marked by superscript in column (1).

	$\frac{1}{M}$	-			$\frac{(T_{\rm DW})}{(T_{\rm DW})}$	$\frac{1}{1}$	
Name	$\log\left(\frac{M}{[M_{\odot}]}\right)$	$\log z$	$\log\left(\frac{n_d}{[\text{cm}]}\right)$	$\log\left(\frac{M^{1-1-1}}{[M_{\odot}]}\right)$	$\log\left(\frac{IBH}{[yr]}\right)$	$\log\left(\frac{\iota_{min}}{[yr]}\right)$	$\log z^{seea}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NGC $4136^{(1)}$	2.20	-2.69	5.25	-0.50	8.82	8.36	-1.77
NGC $3756^{(1)}$	2.60	-2.36	5.39	-0.10	8.96	8.43	-1.67
$M82-X1^{(2)}$	2.63	-3.14	5.40	-0.07	8.97	8.44	-1.75
NGC $3666^{(1)}$	2.80	-2.45	5.45	0.10	9.02	8.46	-1.66
NGC $6093^{(3)}$	2.90	-4.62	5.49	0.20	9.06	8.48	-1.73
NGC $4062^{(1)}$	3.00	-2.60	5.52	0.30	9.09	8.49	-1.66
$NGC 5286^{(4)}$	3.18	-3.75	5.58	0.48	9.15	8.52	-1.68
NGC $1851^{(3)}$	3.30	-2.97	5.62	0.60	9.19	8.53	-1.65
NGC $6266^{(3)}$	3.30	-3.63	5.62	0.60	9.19	8.53	-1.66
47 Tucanae (NGC $104$ ) <sup>(5)</sup>	3.36	-4.21	5.64	0.66	9.21	8.54	-1.66
NGC $1904^{(3)}$	3.48	-3.16	5.68	0.78	9.25	8.56	-1.63
NGC $7078^{(6)}$	3.59	-3.45	5.72	0.89	9.29	8.57	-1.62
NGC $3344^{(1)}$	3.70	-2.71	5.75	1.00	9.32	8.58	-1.58
NGC $5824^{(2)}$	3.78	-3.89	5.78	1.08	9.35	8.59	-1.60
IC $467^{(1)}$	3.80	-2.16	5.79	1.10	9.36	8.60	-1.49
NGC $2715^{(1)}$	3.80	-2.36	5.79	1.10	9.36	8.60	-1.53
NGC $2770^{(1)}$	3.80	-2.19	5.79	1.10	9.36	8.60	-1.50
NGC $5694^{(2)}$	3.90	-3.16	5.82	1.20	9.39	8.61	-1.57
NGC $6715^{(7)}$	3.97	-3.33	5.85	1.27	9.42	8.61	-1.57
NGC $2808^{(8)}$	4.00	-3.46	5.85	1.30	9.42	8.62	-1.56
NGC $3600^{(1)}$	4.00	-2.62	5.85	1.30	9.42	8.62	-1.53
NGC $4096^{(1)}$	4.10	-2.73	5.89	1.40	9.46	8.63	-1.53
$G1^{(9)}$	4.26	-0.44	5.94	1.56	9.51	8.64	-0.40
NGC $514^{(1)}$	4.30	-2.08	5.95	1.60	9.53	8.65	-1.42
NGC $864^{(1)}$	4.30	-2.28	5.95	1.60	9.53	8.65	-1.46
NGC $3486^{(1)}$	4.30	-2.64	5.95	1.60	9.53	8.65	-1.49
NGC $3003^{(1)}$	4.40	-2.31	5.99	1.70	9.56	8.66	-1.45
NGC $3162^{(1)}$	4.40	-2.36	5.99	1.70	9.56	8.66	-1.46
NGC $3041^{(1)}$	4.40	-2.33	5.99	1.70	9.56	8.66	-1.45
NGC $3198^{(1)}$	4.40	-2.64	5.99	1.70	9.56	8.66	-1.48
NGC $6388^{(10)}$	4.45	-3.57	6.00	1.75	9.57	8.66	-1.50
$RGG119^{(11)}$	4.46	-1.26	6.01	1.76	9.58	8.67	-1.06
NGC $3729^{(1)}$	4.60	-2.45	6.05	1.90	9.62	8.68	-1.44
NGC $3430^{(1)}$	4.60	-2.28	6.05	1.90	9.62	8.68	-1.42
NGC $3726^{(1)}$	4.60	-2.54	6.05	1.90	9.62	8.68	-1.45
NGC $4212^{(1)}$	4.60	-3.28	6.05	1.90	9.62	8.68	-1.48
NGC $5139^{(12)}$	4.67	-3.10	6.08	1.97	9.65	8.69	-1.46
NGC $2276-3c^{(2)}$	4.70	-2.09	6.09	2.00	9.66	8.69	-1.38
$RGG118^{(13)}$	4.70	-1.61	6.09	2.00	9.66	8.69	-1.24
NGC $3780^{(1)}$	4.70	-2.10	6.09	2.00	9.66	8.69	-1.38
SDSS J153425.59+040806.7	(14) 4.79	-1.40	6.12	2.09	9.69	8.70	-1.13
NGC $2967^{(1)}$	4.80	-2.20	6.12	2.10	9.69	8.70	-1.38

## ${\bf Table \ 1-} {\it cont}.$

Name l	$\log\left(\frac{M}{[M_{\odot}]}\right)$	$\log z$	$\log\left(\frac{R_d}{[\text{cm}]}\right)$	$\log\left(\frac{M^{seed}}{[M_{\odot}]}\right)$	$\log\left(\frac{T_{BH}}{[vr]}\right)$	$\log\left(\frac{t_{min}}{[vr]}\right)$	$\log z^{seed}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SDSS J095418.15+471725.1	(15) 4.90	-1.49	6.15	2.20	9.72	8.71	-1.16
NGC $4470^{(1)}$	4.90	-2.11	6.15	2.20	9.72	8.71	-1.36
NGC $628^{(1)}$	4.90	-2.66	6.15	2.20	9.72	8.71	-1.42
NGC $3433^{(1)}$	4.90	-2.04	6.15	2.20	9.72	8.71	-1.34
2XMM J123103.2+110648 <sup>(16)</sup>	$^{6)}$ 5.00	-1.35	6.19	2.30	9.76	8.71	-0.81
2XMM J130543.9+181355 <sup>(15)</sup>	5) 5.00	-0.82	6.19	2.30	9.76	8.71	-0.73
SDSS J122548.86+333248.7 <sup>(</sup>	(15) 5.00	-2.96	6.19	2.30	9.76	8.71	-1.41
NGC $3938^{(1)}$	5.00	-2.54	6.19	2.30	9.76	8.71	-1.39
SDSS J153425.58+040806.6	(15) 5.10	-1.40	6.22	2.40	9.79	8.72	-1.11
NGC $3684^{(1)}$	5.10	-2.41	6.22	2.40	9.79	8.72	-1.37
NGC $3686^{(1)}$	5.10	-2.41	6.22	2.40	9.79	8.72	-1.37
SDSS J091032.80+040832.4 <sup>(</sup>	(14) 5.14	-1.14	6.23	2.44	9.80	8.73	-0.95
$HLX-1^{(2)}$	5.17	-1.65	6.25	2.47	9.82	8.73	-1.21
NGC $404^{(17)}$	5.18	-3.97	6.25	2.48	9.82	8.73	-1.40
SDSS J160531.84+174826.1	(15) 5.20	-1.50	6.25	2.50	9.82	8.73	-1.14
SDSS J144012.70+024743.5	(15) 5.20	-1.52	6.25	2.50	9.82	8.73	-1.16
SDSS J101440.21+192448.9 <sup>(</sup>	(15) 5.20	-1.54	6.25	2.50	9.82	8.73	-1.16
SDSS J105100.64+655940.7 <sup>(</sup>	(15) 5.20	-1.49	6.25	2.50	9.82	8.73	-1.14
SDSS J120325.66+330846.1	(15) 5.20	-1.46	6.25	2.50	9.82	8.73	-1.13
POX $52^{(20)}$	5.20	-1.68	6.25	2.50	9.82	8.73	-1.21
2XMM J032459.9-025612 <sup>(16)</sup>	5.29	-1.69	6.28	2.59	9.85	8.74	-1.21
SDSS J112315.75+240205.1	(15) 5.30	-1.60	6.29	2.60	9.86	8.74	-1.18
NGC $3185^{(1)}$	5.30	-2.39	6.29	2.60	9.86	8.74	-1.34
NGC $4245^{(1)}$	5.30	-2.57	6.29	2.60	9.86	8.74	-1.36
NGC $4152^{(1)}$	5.30	-2.14	6.29	2.60	9.86	8.74	-1.31
SDSS J024912.86-081525.6 <sup>(1)</sup>	$^{(4)}$ 5.32	-1.53	6.29	2.62	9.86	8.74	-1.15
SDSS J082443.28+295923.5 <sup>(</sup>	(14) 5.33	-1.59	6.30	2.63	9.87	8.74	-1.17
SDSS J163159.59 $+243740.2^{(}$	$(^{14)}\ 5.33$	-1.36	6.30	2.63	9.87	8.74	-1.07
SDSS J102348.44 $+040553.7^{(}$	(14) 5.34	-1.01	6.30	2.64	9.87	8.74	-0.85
$2 \text{XMM J} 213152.8-425130^{(16)}$	5.35	-0.96	6.30	2.65	9.87	8.74	-0.82
SDSS J022849.51-090153.7 <sup>(1)</sup>	$^{(7)}$ 5.38	-1.14	6.31	2.68	9.88	8.75	-0.94
SDSS $J084025.54 + 181858.9^{\circ}$	(15) 5.40	-1.82	6.32	2.70	9.89	8.75	-1.24
SDSS J085125.81+393541.7	(15) 5.40	-1.39	6.32	2.70	9.89	8.75	-1.08
SDSS J131603.91+292254.0 <sup>(</sup>	(15) 5.40	-1.42	6.32	2.70	9.89	8.75	-1.09
NGC $3593^{(1)}$	5.40	-2.39	6.32	2.70	9.89	8.75	-1.33
NGC $4369^{(1)}$	5.40	-2.46	6.32	2.70	9.89	8.75	-1.34
NGC $3507^{(1)}$	5.40	-2.49	6.32	2.70	9.89	8.75	-1.34
NGC $2276_a^{(1)}$	5.40	-2.09	0.37	2.70	8.79	8.57	-1.29
NGC 2776 $_{h}^{(1)}$	5.40	-2.06	6.32	2.70	9.89	8.75	-1.29
NGC $3359^{(1)}$	5.40	-2.47	6.32	2.70	9.89	8.75	-1.34
SDSS J083346.04+062026.6 <sup>(</sup>	(14) 5.42	-0.96	6.33	2.72	9.90	8.75	-0.82
SDSS J114439.34+025506.5 <sup>(</sup>	(14) 5.43	-0.99	6.33	2.73	9.90	8.75	-0.84
2XMM J120143.6-184857 <sup>(16)</sup>	5.44	-0.80	6.33	2.74	9.90	8.75	-0.70
SDSS J134332.09+253157.7 <sup>(</sup>	(15) 5.50	-1.54	6.35	2.80	9.92	8.76	-1.14
NGC $4314^{(1)}$	5.50	-2.49	6.35	2.80	9.92	8.76	-1.32

## Table 1-cont.

Name	$\log\left(\frac{M}{[M_{\odot}]}\right)$	$\log z$	$\log\left(\frac{R_d}{[\text{cm}]}\right)$	$\log\left(\frac{M^{seed}}{[M_{\odot}]}\right)$	$\log\left(\frac{T_{BH}}{[yr]}\right)$	$\log\left(\frac{t_{min}}{[yr]}\right)$	$\log z^{seed}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NGC 3596 <sup>(1)</sup>	5.50	-2.40	6.35	2.80	9.92	8.76	-1.32
SDSS J162636.40+350242	$2.0^{(14)} 5.54$	-1.47	6.37	2.84	9.94	8.76	-1.10
SDSS J081550.23+250640	$0.9^{(14)} 5.55$	-1.14	6.37	2.85	9.94	8.76	-0.93
NGC $4395^{(18)}$	5.56	-2.97	6.37	2.86	9.94	8.76	-1.34
SDSS J101627.32-000714.	$5^{(14)}$ 5.57	-1.02	6.38	2.87	9.95	8.76	-0.85
SDSS J095151.82+060143	$8.7^{(14)} 5.58$	-1.03	6.38	2.88	9.95	8.76	-0.86
NGC $3043^{(1)}$	5.60	-2.00	6.39	2.90	9.96	8.76	-1.26
2XMM J134736.4+173404	$4^{(16)}$ 5.61	-1.35	6.39	2.90	9.96	8.76	-1.04
SDSS J143450.62+033842	$2.5^{(14)} 5.65$	-1.55	6.40	2.95	9.97	8.77	-1.13
SDSS J131659.37+035319	$0.8^{(14)} 5.66$	-1.34	6.41	2.96	9.98	8.77	-1.04
SDSS J105755.66+482502	$2.0^{(14)} 5.68$	-1.14	6.41	2.98	9.98	8.77	-0.92
SDSS J161751.98-001957.	$4^{(14)}$ 5.68	-1.24	6.41	2.98	9.98	8.77	-0.98
SDSS J172759.15+542147	$7.0^{(14)} 5.68$	-1.00	6.41	2.98	9.98	8.77	-0.83
SDSS J002228.36-005830.	$6^{(14)}$ 5.69	-0.98	6.42	2.99	9.99	8.77	-0.82
SDSS J082325.91+065106	$5.4^{(14)}$ 5.70	-1.14	6.42	3.00	9.99	8.77	-0.9
SDSS J024656.39-003304.	$8^{(15)}$ 5.70	-1.34	6.42	3.00	9.99	8.77	-1.03
SDSS J152637.36+065941	$6^{(15)} 5.70$	-1.42	6.42	3.00	9.99	8.77	-1.07
SDSS J092547.32+050231	$6^{(14)} 5.71$	-0.90	6.42	3.01	9.99	8.77	-0.76
SDSS J032707.32-075639.	$3^{(14)}$ 5.74	-0.81	6.42	3.01	9.99	8.77	-0.70
SDSS J134144.51-005832.	$9^{(14)}$ 5.75	-0.83	6.44	3.05	10.01	8.78	-0.71
SDSS J024009.10+010334	$1.5^{(15)} 5.75$	-0.71	6.44	3.05	10.01	8.78	-0.61
SDSS J082912.67+500652	$2.3^{(14)} 5.76$	-1.36	6.44	3.06	10.01	8.78	-1.04
SDSS J094310.12+604559	$0.1^{(14)} 5.76$	-1.13	6.44	3.06	10.01	8.78	-0.91
SDSS 11749.17+044315.5	$^{(14)}$ 5.77	-0.97	6.44	3.07	10.01	8.78	-0.81
SDSS J083928.45+082102	$2.3^{(14)} 5.78$	-0.89	6.45	3.08	10.02	8.78	-0.75
SDSS J011749.81 -100114	$.5^{(14)}$ 5.79	-0.85	6.45	3.09	10.02	8.78	-0.72
SDSS J093829.38+034826	$5.6^{(14)}$ $5.84$	-0.92	6.47	3.14	10.04	8.78	-0.77
UGC $06728^{(19)}$	5.85	-2.19	6.47	3.15	10.04	8.78	-1.25
SDSS J131926.52+105610	$0.9^{(14)} 5.86$	-1.19	6.47	3.16	10.04	8.78	-0.94
SDSS J103518.74+073406	$5.2^{(14)}$ $5.87$	-1.17	6.48	3.17	10.05	8.78	-0.93
SDSS J144052.60-023506.	$2^{(14)}$ 5.89	-1.35	6.48	3.19	10.05	8.79	-1.02
SDSS J015804.75-005221.	$9^{(14)}$ 5.90	-1.09	6.49	3.20	10.06	8.79	44.00
SDSS J090320.97+045738	$8.0^{(14)} 5.90$	-1.25	6.49	3.20	10.06	8.79	-0.97
SDSS J004042.10-110957.	$7^{(15)}$ 5.90	-1.56	6.49	3.20	10.06	8.79	-1.11
SDSS J082422.21+072550	$0.4^{(14)} 5.92$	-1.09	6.49	3.22	10.06	8.79	-0.88
SDSS J233837.10-002810.	$3^{(14)}$ 5.92	-1.45	6.49	3.22	10.06	8.79	-1.06
SDSS J124035.81-002919.	$4^{(14)}$ 5.93	-1.09	6.50	3.23	10.07	8.79	-0.88
SDSS J080907.58+441641	$.4^{(14)} 5.94$	-1.27	6.50	3.24	10.07	8.79	-0.98
SDSS J090431.21+075330	$0.8^{(14)} 5.94$	-1.08	6.50	3.24	10.07	8.79	-0.87
SDSS J080629.80+241955	$5.6^{(14)}$ $5.95$	-1.38	6.50	3.25	10.07	8.79	-1.03

#### ${\bf Table \ 1-} {\it cont}.$

Name	$\log\left(\frac{M}{[M_{\odot}]}\right)$	$\log z$	$\log\left(\frac{R_d}{[\text{cm}]}\right)$	$\log\left(\frac{M^{seed}}{[M_{\odot}]}\right)$	$\log\left(\frac{T_{BH}}{[yr]}\right)$	$\log\left(\frac{t_{min}}{[yr]}\right)$	$\log z^{seed}$
SDSS J094057.19+03240	$1.2^{(14)}$ 5.95	-1.22	6.50	3.25	10.07	8.79	-0.95
SDSS J131651.29+05564	$6.9^{(14)} \ 5.95$	-1.26	6.50	3.25	10.07	8.79	-0.97
2XMM J011356.4-144239	$0^{(16)}$ 5.95	-1.28	6.50	3.25	10.07	8.79	-0.99
SDSS J091449.05+08532	$1.1^{(14)} 5.96$	-0.85	6.51	3.26	10.08	8.79	-0.72
SDSS J112526.51 $+02203$	$9.0^{(14)} \ 5.96$	-1.31	6.51	3.26	10.08	8.79	-1.00
SDSS J114343.76+55001	$9.3^{(14)}\ 5.97$	-1.57	6.51	3.27	10.08	8.79	-1.10
SDSS J114633.98+10024	$4.9^{(14)} \ 5.97$	-0.91	6.51	3.26	10.08	8.79	-0.75
SDSS J032515.59 $+00340$	$8.4^{(14)}\ 5.98$	-0.99	6.51	3.28	10.08	8.79	-0.81
SDSS J121518.23+01475	$1.1^{(14)} 5.99$	-1.15	6.52	3.29	10.09	8.79	-0.91
SDSS J023310.79-074813	$.3^{(15)}$ 5.99	-1.51	6.52	3.29	10.09	8.79	-1.08

(1)- (Graham & Scott, 2013), (2)-(Wang et al., 2015), (3)-(Lützgendorf et al., 2013), (4)- (Feldmeier et al., 2009), (5)- (Kiziltan et al., 2017), (6)- (Gerssen et al., 2002), (7)- (Ibata et al., 2013), (8)-(Lützgendorf et al., 2012), (9)-(Gebhardt et al., 2005), (10)-(Lützgendorf et al., 2015), (11)-(Baldassare & et al., 2016), (12)-(Noyola & Gebhardt, 2010), (13)-(Baldassare & Reines, 2015), (14)-(Xiao et al., 2011), (15)-(Reines et al., 2013), (16)-(Ho & Kim, 2016), (17)-(Nguyen et al., 2017), (18)-(Peterson et al., 2005), (19)-(Bentz et al., 2016), (20)-(Barth et al., 2004)

Name	$\log\left(\frac{L}{[\operatorname{erg} s^{-1}]}\right)$	$\log\left(\frac{L_{Edd}}{[erg s^{-1}]}\right)$	Name	$\log\left(\frac{L}{[\operatorname{erg} s^{-1}]}\right)$	$\log\left(\frac{L_{Edd}}{[erg s^{-1}]}\right)$
(1)	(2)	(3)	(1)	(2)	(3)
NGC 4136	39.13	40.29	SDSS J153425.59+040806.	7  40.85	42.88
NGC 3756	39.39	40.69	NGC 2967	40.86	42.89
M82-X1	39.42	40.72	SDSS J095418.15+471725.	1 40.93	42.99
NGC 3666	39.53	40.89	NGC 4470	40.93	42.99
NGC 6093	39.60	40.99	NGC 628	40.93	42.99
NGC 4062	39.66	41.09	NGC 3433	40.93	42.99
NGC 5286	39.78	41.27	2XMM J123103.2+110648	40.99	43.09
NGC 1851	39.86	41.39	2XMM J130543.9+181355	40.99	43.09
NGC 6266	39.86	41.39	SDSS J122548.86+333248.	7 40.99	43.09
47 Tucanae (NGC 104)	) 39.90	41.45	NGC 3938	40.99	43.09
NGC 1904	39.98	39.98	SDSS J153425.58+040806.	6 41.06	43.19
NGC 7078	40.05	40.05	NGC 3684	41.06	43.19
NGC 3344	440.13	41.79	NGC 3686	41.06	43.19
NGC 5824	40.18	41.87	SDSS J091032.80+040832.	4 41.09	43.23
IC 467	40.19	41.89	HLX-1	41.11	43.26
NGC 2715	40.19	41.89	NGC 404	41.11	43.27
NGC 2770	40.19	41.89	SDSS J160531.84+174826.	1 41.13	43.29
NGC 5694	40.26	41.99	SDSS J144012.70+024743.	5 41.13	43.29
NGC 6715	40.31	42.06	SDSS J101440.21+192448.	9  41.13	43.29
NGC 2808	40.33	42.09	SDSS J105100.64+655940.	7 41.13	43.29
NGC 3600	40.33	42.09	SDSS J120325.66+330846.	1 41.13	43.29
NGC 4096	40.39	42.19	POX 52	41.13	43.29
G1	40.50	42.34	2XMM J032459.9-025612	41.19	43.38
NGC 514	40.53	42.39	SDSS J112315.75+240205.	1 41.19	43.39
NGC 864	40.53	42.39	NGC 3185	41.19	43.39
NGC 3486	40.53	42.39	NGC 4245	41.19	43.39
NGC 3003	40.59	42.49	NGC 4152	41.19	43.39
NGC 3162	40.59	42.49	SDSS J024912.86-081525.6	41.21	43.41
NGC 3041	40.59	42.49	SDSS J082443.28+295923.	5 41.21	43.42
NGC 3198	40.59	42.49	SDSS J163159.59+243740.	2 41.21	43.42
NGC 6388	40.63	42.54	SDSS J102348.44+040553.	7 41.22	43.43
RGG119	40.64	42.55	2XMM J213152.8-425130	41.23	43.44
NGC 3729	40.73	42.69	SDSS J022849.51-090153.7	41.25	43.47
NGC 3430	40.73	42.69	SDSS J084025.54+181858.	9  41.26	43.49
NGC 3726	40.73	42.69	SDSS J085125.81+393541.	7 41.26	43.49
NGC 4212	40.73	42.69	SDSS J131603.91+292254.	0  41.26	43.49
NGC 5139	40.78	42.76	NGC 3593	41.26	43.49
NGC 2276-3c	40.79	42.79	NGC 4369	41.26	43.49
RGG118	40.79	42.79	NGC 3507	41.26	43.49
NGC 3780	40.79	42.79	NGC 2276	41.26	43.49

Table	2. ]	fhe lu	iminos	sitie	s of	137	IMB	H-candie	dates.	. Colu	mn	(1)
Name	of so	urce,	(2) log	g of	${\rm the}$	pred	icted	luminosi	ties,	$(3) \log$	of	the
Edding	gton l	umino	osities.									

## Table 2-cont.

Name	$\log\left(\frac{L}{\left[\operatorname{ergs}^{-1}\right]}\right)$	$\log\left(\frac{L_{Edd}}{[erg  s^{-1}]}\right)$	Name	$\log\left(\frac{L}{\left[\exp s^{-1}\right]}\right)$	$\log\left(\frac{L_{Edd}}{\left[\operatorname{erg s}^{-1}\right]}\right)$
(1)	(2)	(3)	(1)	(2)	(3)
NGC 2776	41.26	43.49	SDSS J131926.52+105610.	9  41.57	43.95
NGC 3359	41.26	43.49	SDSS J103518.74+073406.	2  41.57	43.96
SDSS J083346.04+062026.	6 41.27	43.51	SDSS J144052.60-023506.2	41.59	43.98
SDSS J114439.34+025506.	5 41.28	43.52	SDSS J015804.75-005221.9	41.59	43.99
2XMM J120143.6-184857	41.29	43.53	SDSS J090320.97+045738.	0  41.59	43.99
SDSS J134332.09+253157.	7 41.33	43.59	SDSS J004042.10-110957.7	41.59	43.99
NGC 4314	41.33	43.59	SDSS J082422.21+072550.	4 41.61	44.01
NGC 3596	41.33	43.59	SDSS J233837.10-002810.3	41.61	44.01
SDSS J162636.40+350242.	0  41.35	43.63	SDSS J124035.81-002919.4	41.61	44.02
SDSS J081550.23+250640.	9  41.36	43.64	SDSS J080907.58+441641.	4 41.62	44.03
NGC 4395	41.36	43.65	SDSS J090431.21+075330.	8 41.62	44.03
SDSS J101627.32-000714.5	41.37	43.66	SDSS J080629.80+241955.	6 41.63	44.04
SDSS J095151.82+060143.	7 41.38	43.67	SDSS J094057.19+032401.	2 41.63	44.04
NGC 3043	41.39	43.69	SDSS J131651.29+055646.	9  41.63	44.04
$2 {\rm XMM} ~ {\rm J}134736.4{+}173404$	41.39	43.7	2XMM J011356.4-144239	41.63	44.04
SDSS J143450.62+033842.	5 41.40	43.74	SDSS J091449.05+085321.	1  41.63	44.05
SDSS J131659.37+035319.	8 41.43	43.75	SDSS J112526.51+022039.	0  41.63	44.05
SDSS J105755.66+482502.	0  41.45	43.77	SDSS J114343.76+550019.	3 41.64	44.06
SDSS J161751.98-001957.4	41.45	43.77	SDSS J114633.98+100244.	9  41.64	44.06
SDSS J172759.15+542147.	0  41.45	43.77	SDSS $J032515.59 + 003408$ .	4 41.65	44.07
SDSS J002228.36-005830.6	41.45	43.78	SDSS J121518.23+014751.	1  41.65	44.08
SDSS J082325.91+065106.	4  41.46	43.79	SDSS J023310.79-074813.3	41.65	44.08
SDSS J024656.39-003304.8	41.46	43.79			
SDSS J152637.36+065941.	6 41.46	43.79			
SDSS J092547.32+050231.	6 41.47	43.8			
SDSS J032707.32-075639.3	41.49	43.83			
SDSS J134144.51-005832.9	41.49	43.84			
SDSS J024009.10+010334.	5 41.49	43.84			
SDSS J082912.67+500652.	3 41.50	43.85			
SDSS J094310.12+604559.	1  41.50	43.85			
SDSS 11749.17+044315.5	41.51	43.86			
SDSS J083928.45+082102.	3  41.51	43.87			
SDSS J011749.81 -100114.	5  41.52	43.88			
SDSS J093829.38+034826.	6  41.55	43.93			
UGC 06728	41.56	43.94			

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# Appendices

#### Outline of key points of underlying gravitation theory Appendix A

In this section we recount some of the highlights behind of underlying gravitation theory, which is the crux of the theoretical framework of MTBH. Much use has been made of the language of fundamental geometric structure - distortion gauge induced fiber-bundle, provided with the spacetime deformation/distortion- framework (Ter-Kazarian, 2011, 2014, 2015b). In the framework of spacetime deformation theory (Ter-Kazarian, 2011, 2015b) and references therein, we consider a smooth deformation map  $\Omega: M_4 \to \widetilde{\mathcal{M}}_4$ , written in terms of the world-deformation tensor  $(\Omega)$ , the general  $(\mathcal{M}_4)$  and flat  $(M_4)$  smooth differential 4D-manifolds. A following notational conventions will be used throughout the appendices. All magnitudes related to the space,  $\widetilde{\mathcal{M}}_4$ , will be denoted with an over  $\prime \sim \prime$ . We use the Greek alphabet  $(\mu, \nu, \rho, ... = 0, 1, 2, 3)$  to denote the holonomic world indices related to  $\mathcal{M}_4$ , and the second half of Latin alphabet (l, m, k, ... = 0, 1, 2, 3) to denote the world indices related to  $M_4$ . The tensor,  $\Omega$ , can be written in the form  $\Omega = D \psi \ (\Omega^m_l = D^m_\mu \psi^\mu_l)$ , where the DC-members are the invertible distortion matrix  $\widetilde{D}(\widetilde{D}^m_{\mu})$  and the tensor  $\widetilde{\psi}(\widetilde{\psi}^{\mu}_l \equiv \partial_l \widetilde{x}^{\mu})$  and  $\partial_l = \partial/\partial x^l$ ). The principle foundation of the *world-deformation* tensor ( $\Omega$ ) comprises the following two steps: 1) the basis vectors  $e_m$  at given point  $(p \in M_4)$  undergo the distortion transformations by means of  $\widetilde{D}$ ; and 2) the diffeomorphism  $\widetilde{x}^{\mu}(x): M_4 \to M_4$  is constructed by seeking a new holonomic coordinates  $\tilde{x}^{\mu}(x)$  as the solutions of the first-order partial differential equations. Namely,

$$\widetilde{e}_{\mu} = \widetilde{D}^{l}_{\mu} e_{l}, \quad \widetilde{e}_{\mu} \, \widetilde{\psi}^{\mu}_{l} = \Omega^{m}_{\ l} e_{m}, \tag{58}$$

where the conditions of integrability,  $\partial_k \psi_l^{\mu} = \partial_l \psi_k^{\mu}$ , and non-degeneracy,  $\|\psi\| \neq 0$ , necessarily hold (Dubrovin & et al., 1986, Pontryagin, 1984). For reasons that will become clear in the sequel, next we write the norm  $d\tilde{s} \equiv i\tilde{d}$  (see App.B) of the infinitesimal displacement  $d\tilde{x}^{\mu}$  on the  $\mathcal{M}_4$  in terms of the spacetime structures of  $M_4$ :

$$i\widetilde{d} = \widetilde{e}\,\widetilde{\vartheta} = \widetilde{e}_{\mu}\otimes\widetilde{\vartheta}^{\mu} = \Omega^{m}_{\ l}\,e_{m}\otimes\vartheta^{l}\,\in\,\widetilde{\mathcal{M}}_{4}.$$
(59)

A deformation  $\Omega: M_4 \to \widetilde{\mathcal{M}}_4$  comprises the following two 4D deformations  $\overset{\circ}{\Omega}: M_4 \to V_4$  and  $\breve{\Omega}: V_4 \to \widetilde{M}_4$ , where  $V_4$  is the semi-Riemannian space,  $\tilde{\Omega}$  and  $\tilde{\Omega}$  are the corresponding world deformation tensors.

In what follows, we restrict ourself to consider only the simplest spacetime deformation map,  $\Omega: M_4 \to M_4$  $V_4$ , where  $V_4$  is the 4D semi-Riemannian space. The quantities denoted by wiggles here refer to  $V_4$  space, but the quantities referring to flat  $M_4$  space are left without wiggles as previously. Given the principal fiber bundle  $\widetilde{P}(V_4, G_V; \widetilde{s})$  with the structure group  $G_V$ , the local coordinates  $\widetilde{p} \in \widetilde{P}$  are  $\widetilde{p} = (\widetilde{x}, U_V)$ , where  $\tilde{x} \in V_4$  and  $U_V \in G_V$ , the total bundle space P is a smooth manifold, the surjection  $\tilde{s}$  is a smooth map  $\tilde{s}: \tilde{P} \to V_4$ . The collection of matter fields of arbitrary spins  $\Phi(\tilde{x})$  take values in standard fiber over  $\widetilde{x}$ :  $\widetilde{s}^{-1}(\widetilde{\mathcal{U}}_i) = \widetilde{\mathcal{U}}_i \times \widetilde{F}_{\widetilde{x}}$ . The action of the structure group  $G_V$  on  $\widetilde{P}$  defines an isomorphism of the Lie algebra  $\widetilde{\mathfrak{g}}$  of  $G_V$  onto the Lie algebra of vertical vector fields on  $\widetilde{P}$  tangent to the fiber at each  $\widetilde{p} \in \widetilde{P}$  called fundamental.

We generalize the standard gauge scheme by exploring a new special type of *distortion* gauge field. Then we also consider the principle fiber bundle,  $P(M_4, U^{loc}; s)$ , with the base space  $M_4$ , the structure group  $U^{loc}$ and the surjection s. The matter fields  $\Phi(x)$  take values in the standard fiber which is the Hilbert vector space where a linear representation U(x) of group  $U^{loc}$  is given. This space can be regarded as the Lie algebra of the group  $U^{loc}$  upon which the Lie algebra acts according to the law of the adjoint representation:  $a \leftrightarrow ad a \Phi \rightarrow [a, \Phi]$ . We assume that a distortion massless gauge field  $a(x) \equiv a_n(x)$  has to act on the external spacetime groups. This field takes values in the Lie algebra of the abelian group  $U^{loc}$ . We build up the world-deformation tensor,  $\Omega(F) = D(a) \psi(a)$ . We connect the structure group  $G_V$ , further, to the nonlinear realization of the Lie group  $G_D$  of the distortion of extended space  $M_6(\rightarrow M_6)$ , underlying the  $M_4$ .

The nonlinear realization technique or the method of phenomenological Lagrangians provides a way to determine the transformation properties of fields defined on the quotient space. We treat the distortion group  $G_D$  and its stationary subgroup H = SO(3), respectively, as the dynamical group and its algebraic subgroup. The fundamental field is distortion gauge field (a) and, thus, all the fundamental gravitational structures in fact - the metric as much as the coframes and connections - acquire a distortion-gauge induced Ter-Kazarian G.

theoretical interpretation. We study the geometrical structure of the space of parameters in terms of Cartan's calculus of exterior forms and derive the Maurer-Cartan structure equations, where the distortion fields (a) are treated as the Goldstone fields.

Addressing the rearrangement of vacuum state, in realization of the group  $G_V$  we implement the abelian local group,  $U^{loc} = U(1)_Y \times \overline{U}(1) \equiv U(1)_Y \times diag[SU(2)]$ , on the space  $M_6$  (spanned by the coordinates  $\eta$ ), with the group elements of  $exp\left[i\frac{Y}{2}\theta_Y(\eta)\right]$  of  $U(1)_Y$  and  $exp\left[iT^3\theta_3(\eta)\right]$  of  $\overline{U}(1)$ . This has two generators, the third component  $T^3$  of isospin  $\vec{T}$  related to the Pauli spin matrix  $\frac{\vec{\tau}}{2}$ , and hypercharge Y implying  $Q^d = T^3 + \frac{Y}{2}$ , where  $Q^d$  is the distortion charge operator assigning the number -1 to particles, but +1 to anti-particles. The group  $U^{loc}$  entails two neutral gauge bosons of  $\overline{U}(1)$ , or that coupled to  $T^3$ , and of  $U(1)_Y$ , or that coupled to the hypercharge Y. Spontaneous symmetry breaking can be achieved by introducing the neutral complex scalar Higgs field. Minimization of the vacuum energy fixes the non-vanishing vacuum expectation value (VEV), which spontaneously breaks the theory, leaving the  $U(1)_d$  subgroup intact, i.e. leaving one Goldstone boson. Consequently, the left Goldstone boson is gauged away from the scalar sector, but it essentially reappears in the gauge sector providing the longitudinally polarized spin state of one of gauge bosons that acquires mass through its coupling to Higgs scalar. Thus, the two neutral gauge bosons were mixed to form two physical orthogonal states of the massless component of *distortion* field, (a)  $(M_a = 0)$ , which is responsible for gravitational interactions, and its massive component,  $(\bar{a})$  $(M_{\bar{a}} \neq 0)$ , which is responsible for the ID-regime. Hence, a substantial change of the properties of the spacetime continuum besides the curvature may arise at huge energies. Hence, a substantial change of the properties of the spacetime continuum besides the curvature may arise at huge energies. The theory is renormalizable, because gauge invariance gives conservation of charge, also ensures the cancelation of quantum corrections that would otherwise result in infinitely large amplitudes. Without careful thought we expect that in this framework the renormalizability of the theory will not be spoiled in curved space-time too, because, the infinities arise from ultra-violet properties of Feynman integrals in momentum space which, in coordinate space, are short distance properties, and locally (over short distances) all curved space-time look like maximally symmetric (flat) space.

## Appendix B Field equations of non-spinning SPC in ID regime

The field equations of non-spinning SPC follow at once from the total gauge invariant Lagrangian in terms of Euler-Lagrange variations, respectively on both the 4D semi-Riemannian space  $V_4 = \tilde{R}^3 \oplus \tilde{R}^0$ , and the 4D flat space  $M_4 = R^3 \oplus R^0$  (Ter-Kazarian & Shidhani, 2019). We are interested in the case of a 1D spherical-symmetric gravitational field  $(a_0(r)), (r \in R^3)$ ), in presence of 1D space-like ID-field  $(\bar{a}(r))$ . In the case at hand, one has the group of motions SO(3) with 2D space-like orbits  $S^2$  where the standard coordinates are  $\tilde{\theta}$  and  $\tilde{\varphi}$ . The stationary subgroup of SO(3) acts isotropically upon the tangent space at the point of sphere  $S^2$  of radius  $\tilde{r}$ . So, the bundle  $p: V_4 \to \tilde{R}^2$  has the fiber  $S^2 = p^{-1}(\tilde{x}), \quad \tilde{x} \in V_4$  with a trivial connection on it, where  $\tilde{R}^2$  is the quotient-space  $V_4/SO(3)$ .

Considering the equilibrium configurations of degenerate baryonic-quark matter, we assume an absence of transversal stresses and the transference of masses in the space  $V_4$ :

$$T_1^1 = T_2^2 = T_3^3 = -\widetilde{P}(\widetilde{r}), \quad T_0^0 = -\widetilde{\rho}(\widetilde{r}),$$
 (60)

where  $T^{\mu}_{\nu}$  is taken to denote the components of energy stress tensor.

The equations of gravitation,  $x_0 := aa_0$ , and ID,  $x := a\bar{a}$ , fields can be written in Feynman gauge as follows (Ter-Kazarian, 2014, 2015b):

$$\Delta x_{0} = -\mathfrak{B}^{2} \left\{ \frac{1-x_{0}}{(1-x_{0})^{2}+x^{2}} \widetilde{\rho}(\widetilde{r}) + \frac{1+x_{0}}{(1-x_{0})^{2}+x^{2}} \widetilde{P}(\widetilde{r}) \right\}, \left(\Delta - \lambda_{a}^{-2}\right) x = \mathfrak{B}^{2} x \left\{ \frac{\widetilde{\rho}(\widetilde{r})}{(1-x_{0})^{2}+x^{2}} - \frac{\widetilde{P}(\widetilde{r})}{(1-x_{0})^{2}+x^{2}} \right\} \times \theta \left(\lambda_{a} - n^{-1/3}\right).$$
(61)

Reviewing notations  $\mathfrak{X}$  is the coupling constant relating to the Newton gravitational constant (G) as  $\mathfrak{X} = 8\pi G/c^4$ ,  $\tilde{P}(\tilde{r})$  and  $\tilde{\rho}(\tilde{r})$   $(\tilde{r} \in \tilde{R}^3)$  are taken to denote the internal pressure and macroscopic density of energy defined in proper frame of reference that is being used,  $\tilde{n}$  is the distorted concentration of particles, r is the radius-vector defined on flat space  $R^3$ ,  $\Delta \equiv \partial^2/\partial r^2$ ,  $\theta(t)$  is the step function  $\theta(t) = \begin{cases} 1 & t \ge 0 \\ 0 & t < 0 \end{cases}$ , and  $\lambda_a$  is the Compton length of the ID-field:  $\lambda_a = \hbar/m_a c \simeq 0.4 \,\mathrm{fm}$ . A diffeomorphism  $\tilde{r}(r) : M_4 \to V_4$  is

defined as  $r = \tilde{r} - R_g/4$ , where  $R_g$  is the gravitational radius of distribution of matter,  $R_g = 2GM/c^2 = 2.95 \times 10^5 M/M_{\odot}$  cm.

In the framework of MTBH, more profound geometrical structures enable an insight to explore a novel aspects expected from a significant change of properties of spacetime continuum in ID-regime. This manifests its virtues below the ID-threshold length, yielding the transformations of Poincaré generators of translations (Ter-Kazarian & Shidhani, 2019), which, in turn, lead to the phase transition of each particle located in the ID-region:

$$\widetilde{E} = E, \quad \widetilde{P}_{1,2} = P_{1,2} \cos \widetilde{\theta}_3, \quad \widetilde{P}_3 = P_3 - \tan \widetilde{\theta}_3 mc, \\ \widetilde{m} = \left| \left( m - \tan \widetilde{\theta}_3 \frac{P_3}{c} \right)^2 + \sin^2 \widetilde{\theta}_3 \frac{P_1^2 + P_2^2}{c^2} - \tan^2 \widetilde{\theta}_3 \frac{E^2}{c^4} \right|^{\frac{1}{2}},$$
(62)

where  $E, \vec{P}, m$  and  $\tilde{E}, \tilde{\vec{P}}, \tilde{m}$  are, respectively, ordinary and distorted energy, momentum and mass at rest, and  $\tan \tilde{\theta}_3 = -x$ ,  $\tilde{\theta}_1 = \tilde{\theta}_2 = 0$ . Consequently, a whole matter found in the ID-region of spacetime continuum is undergone phase transition of II-type.

The explicit form of the line element from the outside of configuration  $\tilde{r} > \tilde{r}_b$ , where  $\tilde{r}_b$  is the boundary of distribution of matter, reads

$$ds^{2} = (1 - x_{0})^{2} d\tilde{t}^{2} - (1 + x_{0})^{2} d\tilde{r}^{2} - \tilde{r}^{2} (\sin^{2}\theta d\varphi^{2} + d\theta^{2}).$$
(63)

Given the state equation, the hydrostatic equilibrium equation can be integrated. While an integration constant is determined from the condition of matching of internal and external metrics. Hence

$$g_{00}(r_f) = (1 - \frac{R_g}{2r_b})^2 \exp\left[\int_0^{\widetilde{P}} \frac{2\widetilde{P}}{\widetilde{P} + \widetilde{\rho}}\right].$$
(64)

To make the reader fully understood, it is worthwhile before proceeding further to discuss in more detail one principle issue in use. Recall that according to the fundamental idea, conceived in the framework of GR, the EH is impenetrable barrier for crossing from inside the BH, because of a singularity arisen at Schwarzschild radius. But this barrier disappears in the framework of MTBH, when a matter, located in ID-region of the spacetime continuum, has undergone phase transition of II-type and, thus, it becomes a proto-matter. To obtain some feeling about this phenomena, note that (according to the field equations (61)), a singularity at intersection of proto-matter disk with the event horizon disappears where a massive component of ID-field is not zero, and hence the crossing event horizon from inside of BH at such conditions is allowed.

### B.1 The n-p-e baryonic proto-matter

The state equation of baryonic proto-matter can be derived usually from the minimization of energy density incorporated with the conservation laws of baryonic and electric charges. The state equation of one-component degenerate Fermi proto-matter can be written (Ter-Kazarian, 2014, 2015b) and references therein:

$$\widetilde{\rho} = \widetilde{m}c^2 \frac{\chi(\widetilde{y})}{\widetilde{\lambda}^3} + \widetilde{n}_b \widetilde{U}(\widetilde{n}_b), \quad \widetilde{P} = \widetilde{m}c^2 \frac{\varphi(\widetilde{y})}{\widetilde{\lambda}^3} + \widetilde{n}_b^2 \frac{\partial \widetilde{U}(\widetilde{n}_b)}{\partial \widetilde{n}_b}, \tag{65}$$

where  $\widetilde{U}(\widetilde{n}_b)$  is the potential energy per baryon. The following notational conventions are used throughout:

$$\begin{split} \chi(\widetilde{y}) &= \frac{1}{8\pi^2} \left\{ \widetilde{y}(1+\widetilde{y}^2)^{1/2}(1+2\widetilde{y}^2) - \left[ \widetilde{y} + (1+(1+\widetilde{y}^2)^{1/2}] \right\}, \\ \varphi(\widetilde{y}) &= \frac{1}{8\pi^2} \left\{ \widetilde{y}(1+\widetilde{y}^2)^{1/2}(\frac{2}{3}\widetilde{y}^2-1) + \ln\left[ \widetilde{y} + (1+(1+\widetilde{y}^2)^{1/2}] \right\}, \quad \widetilde{m} = (\mid \eta \mid)^{1/2}, \\ \eta &= 1 - x^2 - xy/\sqrt{3} - y^2 x^4 \left/ 6(1+x^2) \right\}, \\ y &= P_F/mc = (3\pi^2)^{1/3} \lambda n^{1/3}, \quad \widetilde{P_F} = P_F \zeta^{1/2}, \\ \widetilde{y} &= \widetilde{P}_F/\widetilde{m}c = (3\pi^2)^{1/3} \widetilde{\lambda} \widetilde{n}^{1/3}, \quad \widetilde{P_F} = P_F \zeta^{1/2}, \\ \zeta &= y^2 \left[ 1 - 2x^2/3(1+x^2) \right] + 2xy/\sqrt{3} + x^2, \end{split}$$
(66)

provided,  $\widetilde{P}_F$  and  $P_F$  are distorted and ordinary Fermi momenta,  $\widetilde{n}$  is the distorted concentration of particles,  $\lambda = \hbar/mc$ ,  $\widetilde{\lambda} = \hbar/\widetilde{m}c$ . To simplify the problem in (66), we approximately set  $P_1 = P_2 = P_3 = P/\sqrt{3} = |P|/\sqrt{3}$ ,  $P/mc \simeq x/2$ .

Suppose that the free neutrons, protons and electrons of n - p - e proto-matter, at high densities  $\rho \ge \rho_d$ , are in complete  $\beta$ -equilibrium. That is,  $\tilde{\mu}_e + \tilde{\mu}_p = \tilde{\mu}_n$  and  $\tilde{\mu}_\nu = \mu_\nu = 0$ . Then,

$$\widetilde{m}_e (1+y_e)^{1/2} + \widetilde{m}_p (1+y_p)^{1/2} = \widetilde{m}_n (1+y_n)^{1/2},$$
(67)
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where  $m_e, m_p$  and  $m_n$  are the ordinary masses at rest of electron, proton and neutron. The electrical charge neutrality implies  $\tilde{n}_e = \tilde{n}_p$ , i.e.  $\tilde{m}_e \tilde{y}_e = \tilde{m}_p \tilde{y}_p$ . By virtue of (65) and (66), the energy density and internal pressure read

$$\widetilde{\rho} = \widetilde{m}_e c^2 \chi(\widetilde{y}_e) / \lambda_e^3 + \widetilde{m}_p c \chi(\widetilde{y}_p) / \lambda_p^3 + \widetilde{m}_n c^2 \chi(\widetilde{y}_n) / \lambda_n^3, 
\widetilde{P} = \widetilde{m}_e c^2 \varphi(\widetilde{y}_e) / \widetilde{\lambda}_e^3 + \widetilde{m}_p c^2 \varphi(\widetilde{y}_p) / \widetilde{\lambda}_e^3 + \widetilde{m}_n c^2 \varphi(\widetilde{y}_n) / \widetilde{\lambda}_e^3.$$
(68)

Further simplification gives

$$\widetilde{y}_p = \left(\frac{\widetilde{a}_1 + \widetilde{a}_2 \widetilde{y}_n^2 + \widetilde{a}_3 \widetilde{y}_n^4}{1 + \widetilde{y}_n^2}\right)^{1/2},\tag{69}$$

where

$$\widetilde{a}_{1} = (1/4) \left[ \left( \widetilde{Q} / \widetilde{m}_{p} \right)^{2} - \left( \widetilde{m}_{e} / \widetilde{m}_{p} \right)^{2} \right] \times \left[ (1 + \widetilde{m}_{p} / \widetilde{m}_{n})^{2} - \left( \widetilde{m}_{e} / \widetilde{m}_{n} \right)^{2} \right],$$

$$\widetilde{a}_{2} = (1/2) \left[ \left( \widetilde{m}_{n} / \widetilde{m}_{p} \right)^{2} - 1 - \left( \widetilde{m}_{e} / \widetilde{m}_{p} \right)^{2} \right],$$

$$\widetilde{a}_{3} = \left( \widetilde{m}_{n} / 2\widetilde{m}_{p} \right)^{2}, \quad \widetilde{Q} = \widetilde{m}_{n} - \widetilde{m}_{p}.$$
(70)

The ratio of proton-neutron distorted concentrations takes the form

$$\frac{\widetilde{n}_p}{\widetilde{n}_n} = \left(\frac{\widetilde{m}_p}{\widetilde{m}_p \widetilde{y}_n}\right)^3 \left[ \left(\widetilde{a}_1 + \widetilde{a}_2 \widetilde{y}_n^2 + \widetilde{a}_3 \widetilde{y}_n^4\right) \left(1 + \widetilde{y}_n^2\right) \right]^{3/2}.$$
(71)

## Appendix C Rotating SPC

The non-spinning SPC is static and spherically symmetric. So, one needs to be clear about more general geometry which can describe rotating axisymmetric SPC. It will suffice at first to stress that the principle foundation of the spinning configurations comprises the following additional distinctive features with respect to non-spinning ones: 1) Rapid rotation causes the shape of the SPC to be flattened by centrifugal forces-flattened at poles and buldged at equator (oblate spheroid, which is second order effect in the rotation rate). 2) A rotating massive SPC drags space and time around with it. The local inertial frames are dragged by the rotation of the gravitational field, i.e. a gyroscope orbiting near the SPC will be dragged along with the rapidly rotating SPC. This is probably the most remarkable feature that could serve as a link with the general description of spacetime (also see Ter-Kazarian (2012)). Beside the geodetic procession, a spin of the body produces in addition the Lense-Thirring procession.

The axisymmetric spacetime geometry is analytically treated by Ter-Kazarian (2016a), which describes the rigorous theoretical solutions of stationary and axisymmetric rotating SPC in the framework of axisymmetric space  $V_4$  in 3 + 1 formalism. In the 3 + 1 formalism, as usual, 3+1 foliations of spacetime  $V_4$  by space-like 3-slices  $\{\Sigma_t\}$  play an important role. The study of a dragging effect is assisted by incorporating with the soldering tools in order to relate local Lorentz symmetry to curved spacetime. These are the linear frames and forms in tangent fiber-bundles to the external general smooth differential manifold, whose components are so-called tetrad (vierbein) fields. Given a height-function  $\tilde{t}$ , the time-like unit normal to  $\Sigma_t$  will be denoted by  $n^{\mu}$  and the 3+1 decomposition of the evolution vector field by  $\tilde{t}^{\mu} = Nn^{\mu} + \beta^{\mu}$ , where N is the lapse function and  $\beta^{\mu}$  is the shift vector. The induced metric on the space-like 3-slice  $\Sigma_t$  is expressed as  $\gamma_{\mu\nu} = g_{\mu\nu} + n_{\mu}n_{\nu}$ , with  $D_{\mu}$  the associated Levi-Civita connection and volume element  ${}^3\epsilon = \sqrt{\gamma}d\tilde{x}^1 \wedge d\tilde{x}^2 \wedge d\tilde{x}^3$ , so that  ${}^3\epsilon_{\mu\nu\rho} = n^{\sigma 4}\epsilon_{\sigma\mu\nu\rho}$ . The extrinsic curvature of  $(\Sigma_t, \gamma_{\mu\nu})$  in  $V_4$  reads  $K_{\mu\nu} := -(1/2)\mathcal{L}_n\gamma_{\mu\nu} = -\gamma_{\mu}{}^{\rho}\nabla_{\rho}n_{\nu}$ , where  $\mathcal{L}$  denotes Lie derivative. In accord, all the geometrical objects are split into corresponding components with respect to this time-slice of spacetime.

In particular, the splitting of manifold  $V_4$  into a foliation of three-surfaces will induce a corresponding splitting of the affine connection, curvature and, thus, of the energy-momentum tensor. The 3+1 decomposition of the (matter) stress-energy tensor, measured by an adapted Eulerian observer of four-velocity  $n^{\mu}$ in rest with respect to the foliation  $\{\Sigma_t\}$ , is  $\tilde{T}_{\mu\nu} = \tilde{E} n_{\mu}n_{\nu} + \tilde{p}_{(\mu}n_{\nu)} + \tilde{S}_{\mu\nu}$ , where the matter energy and momentum densities are given by  $\tilde{E} := \tilde{T}_{\mu\nu}n^{\mu}n^{\nu}$  and  $\tilde{p}_{\mu} := -\tilde{T}_{\nu\rho}n^{\nu}\gamma^{\rho}{}_{\mu}$ , respectively, whereas the matter stress tensor is  $\tilde{S}_{\mu\nu} := \tilde{T}_{\rho\sigma}\gamma^{\rho}{}_{\mu}\gamma^{\sigma}{}_{\nu}$ . Latin indices running in  $\{1, 2, 3\}$  will be employed in expressions only involving objects intrinsic to space-like  $\Sigma_t$  slices. That is,  $\tilde{T}^{\alpha\beta} = \tilde{E}n^{\alpha}n^{\beta} + n^{\alpha}\tilde{J}^{\beta} + \tilde{J}^{\alpha}n^{\beta} + \tilde{S}^{\alpha\beta}$ . Here  $n^{\alpha}$  is the unit orthogonal vector to the hypersurface  $\Sigma_t$ , whereas the spacetime metric g induces a first fundamental form with the spatial metric  $\gamma_{\alpha\beta}$  on each  $\Sigma_t$  as  $\gamma_{\alpha\beta} = g_{\alpha\beta} + n_{\alpha}n_{\beta}$ .

The metric of the stationary and axisymmetric space  $V_4$  in the most commonly used 3 + 1 formalism includes one gauge freedom for the coordinate choice. For the spherical type coordinates  $\tilde{x}^2 = \tilde{\theta}$  and  $\tilde{x}^3 = \tilde{r}$ , Ter-Kazarian G. doi: https://doi.org/10.52526/25792776-2022.69.1-47 for example, so-called quasi-isotropic gauge corresponds to  $\gamma_{r\theta} = 0$  and  $\gamma_{\theta\theta} = \tilde{r}^2 \gamma_{rr}$ . Then, one may define the second fundamental form which associates with each vector tangent to  $\Sigma_t$ , and the extrinsic curvature of the hypersurface  $\Sigma_t$  as minus the second fundamental form. Aftermath, one can define the usual Lorentz factor  $W = -n_{\mu}\tilde{u}^{\nu} = \alpha \tilde{u}^t$  for a fluid which is the source of the gravitational field, with conventional stress-energy tensor

$$\widetilde{T}^{\mu\nu} = (\widetilde{\rho} + \widetilde{P})\widetilde{u}^{\mu}\widetilde{u}^{\nu} + \widetilde{P}g^{\mu\nu}, \tag{72}$$

where  $\tilde{\rho}$  is the total energy density and  $\tilde{P}$  is the pressure. Hence  $\tilde{E} = W^2(\tilde{\rho} + \tilde{P}) - \tilde{P}$  and  $\tilde{J}^i = (\tilde{E} + \tilde{P})\tilde{v}^i$ , where the fluid three-velocity  $\tilde{v}^i(i = 1, 2, 3)$  implies  $\tilde{u}^i = W(\tilde{v}^i - \beta^i/\alpha)$ . Thereby the resulting stress tensor can be written  $\tilde{S}_{ij} = (\tilde{E} + \tilde{P})\tilde{v}_i\tilde{v}_j + \tilde{P}\gamma_{ij}$ . The four-velocity for rotating fluid reads  $\tilde{u} = \tilde{u}^i(\partial/\partial \tilde{t}) + \Omega\partial/\partial \tilde{\phi}$ , where  $\Omega = \tilde{u}^{\phi}/\tilde{u}^t$  is the fluid angular velocity as seen by an inertial observer at rest at infinity.

Consequently, the components of the energy - momentum tensor of matter with total density  $\rho$  and pressure P are given in the non-rotating anholonomic orthonormal frame as  $\tilde{T}^{(ab)} = e^a_{\mu} e^b_{\nu} \tilde{T}^{\mu\nu}$ ,  $\tilde{T}^{(00)} = W^2(\tilde{\rho} + \tilde{P}V^2)$ ,  $\tilde{T}^{(11)} = W^2(\tilde{\rho} + \tilde{P}V^2)$ ,  $\tilde{T}^{(01)} = W^2(\tilde{\rho} + \tilde{P})V$  and  $\tilde{T}^{(22)} = \tilde{T}^{(33)} = \tilde{P}$ , with its trace  $\tilde{T} = -\tilde{\rho} + 3\tilde{P}$ , where V is the velocity (in units of c) with respect to the Bardeen observer  $V = \rho B(\Omega - \omega)/\alpha^2$ , so  $W = 1/\sqrt{1-V^2}$ .

The Petrov type D vacuum solutions associate with the gravitational field of isolated massive stationary and axisymmetric rotating SPC. They completely characterized by its mass  $M_{SPC}$  and angular momentum  $J_{SPC}$ . The two double principal null directions define "radially" ingoing and outgoing null congruences near the SPC which is the source of the field. The horizon is a 2D surface of spherical topology, where the redshift factor vanishes. The Petrov type D vacuum solutions for stationary axisymmetric rotating SPC, therefore, satisfy the Robinson's theorem for Kerr solutions in vacuum (Robinson, 1975): the solutions, (i)-are asymptotically flat, (ii)-contain a smooth convex horizon, (iii)- are nonsingular outside the horizon, and are uniquely specified by two parameters: the mass  $M_{SPC}$  and angular momentum  $J_{SPC}$ . The angular velocity of a SPC is the sum of two terms: the classical one given by the intrinsic angular velocity  $\Omega$  and the frame dragging  $\omega$  from the rotation of absolute space.

Near the horizon of SPC, for example, where the redshift tends to zero  $(\alpha \rightarrow 0)$ , the angular velocity of matter  $\Omega$  is completely dominated by the frame-dragging effect. Whatever the intrinsic angular momentum of the incoming matter is, this matter is forced to rotate with the local angular velocity  $\omega$ , which is the maximal angular velocity at event horizon. When matter falls, say into a nonrotating black hole, it is forced to zero rotation near the horizon despite its angular momentum.

The derived global vacuum spacetime solutions describe the oblate and prolate Cauchy horizons. Whereas, an assessment of a distinction from Kerr model is given. It is shown that in the first half of its lifetime, the external physics outside of outer oblate event horizon of accretion onto the SPC with in MTBH is very closely analogous to the processes in Kerr's model. But a crucial difference between Kerr and microscopic models is the interior solutions. The interior solution of MTBH is physically meaningful, because it has smeared out a central ring singularity of the Kerr BH replacing it by the stationary axisymmetric rotating SPC inside event horizon, where the static observers exist. For brevity reasons, we have refrained from providing rigorous theoretical evolutionary paths of the equations describing the rotating black holes. The complete microscopic models of stationary and axisymmetric rotating SPCs based on the above rigorous solution will be an important topic for separate investigation elsewhere.

## Gaia EDR3 Data For Three Young Stellar Objects

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### Abstract

We present Gaia Early Data Release 3 (Gaia EDR3) high accurate astrometric and photometric data and also Catalina Sky Survey (CSS) phase-dependent light curves for three Young Stellar Objects (YSO). **They are LRL 245, 2MASS J04300424+3533238, and CVSO 592. These tree YSOs are presented as periodic variables in the Catalina Surveys Data Release-1 (CSDR1) data base.** CSS phase-dependent curve of LRL 245 shows periodicity with period P=234.66 days and amplitude  $\Delta m \approx 4.0$  mag. For this object high-resolution spectra in H-band (from 1.51 to 1.69  $\mu$ m) was obtained by the APOGEE instrument. LAMOST telescope moderate-resolution CCD spectra is available for object 2MASS J04300424+3522238 only. The spectra shows clear features of M dwarfs.

Keywords: Young Stellar Objects-Variability-Gaia EDR3 data-Individual Objects: LRL 245, 2MASS J04300424+3533238, and CVSO 592

### 1. Introduction

The study of variable stars is one of the most popular and dynamic areas of modern astronomical research. Variability is the property of the most stars, and as such, it has a great deal to contribute to our understanding of them. It provides researches with many additional and important parameters (periods, amplitudes, etc.) which are not available for non-variable stars. These important physical parameters can be used to deduce characteristics of the stars. The study of variability also allows us to directly observe changes in the stars: both the rapid and sometimes violent changes associated especially with stellar birth and death, and also the slow changes associated with normal stellar evolution. An overview of variable stars, including an introduction to variable stars in general, the techniques for discovering and many-sided studying variable stars, and description of the main types of variable stars are presented in more detail in the book by Percy (2007).

Variability has been defining characteristic of young pre-main-sequence (PMS) stars. These fluctuations occur not only over a wide range of timescales but over a wide range of wavelengths and have been used to deduce various properties of these systems. Daily to weekly optical fluctuations up to  $1.0 \div 2.0$  mag are common (Herbst et al., 1994).

PMS variables are often called nebular variables, because, being young, they are usually found near the nebulae from which the stars are born. A PMS star could also be an eclipsing or rotating variable if it had a close companion or a spotted surface. It could even be a pulsating variable if it was located in an instability strip.

In our paper, we present new data for three well-studied Young Stellar Objects (YSO), namely for LRL 245, 2MASS J04300424+3522238, and CVSO 592 from the early installment of the third Gaia data release (Gaia EDR3, see Chapter 2.2). These objects are presented as periodic variables in Catalina Surveys Data Release - 1 (CSDR1, Drake et al., 2014) database. These three periodic variables (out of 1184) presented by Gigoyan et al. (2021) were associated in the SIMBAD database with the YSO (e.g., Gutermuth et al., 2009, Hernández et al., 2007).

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Figure 1. CSS phase-dependence light-curves of three YSOs (accessed via http://nesssi.cacr.caltech.edu/DataRelease/)

## 2. Data Used

### 2.1. The Catalina Sky Survey Data

The Catalina Sky Survey (CSS) data are provided by three telescopes. All the Catalina data are analyzed for transient sources by the Catalina Real-Time Transient Survey (CRTS, Drake et al., 2009). Drake et al. (2014) presented a catalogue of periodic variables selected from CSDR1. The catalogue contains data for 47055 variable objects ("Catalina Survey Periodic Variable Stars", SIMBAD VizieR Catalogue J/ApJS/213/9).

Spectral classes and physical parameters are presented for optically faint periodic variables taken from the CSDR1 (Drake et al., 2014) and LINEAR (Palaversa et al., 2013) data sets. A catalogue containing multi-parameter data on 1184 periodic variables from modern astronomical low and moderate-resolution, spectroscopic and photometric database was generated (Gigoyan et al., 2021, SIMBAD CDS VizieR Catalogue J/other/Ap/64.27). The periods are in range  $10 \le P \le 1504$  days and

Catalina magnitudes are in range  $11.5 \le V \le 20.0$  mag. This catalogue contains also alternative names of objects from the SIMBAD database, references, and spectral classes if possible or elsewhere.

### 2.2. Gaia EDR3 Data

The Gaia satellite executes an ambitious project of the European Space Agency (ESA) to record astrometric, photometric and spectroscopic data of more than one billion objects in the Galaxy and the Local Group up to G = 21 (Gaia Collaboration et al., 2018). We used Gaia Early Data Release 3 (Gaia EDR3) high accurate astrometric and photometric data.

## 3. Results and Discussion

Table 1 presents data for the three CSS periodic variables. The columns are as follows: (1) CSS Number, (2) CSS average V-band magnitude and amplitude of variability, (3) Period (in days), (4) the YSOs Name in SIMBAD database.

CSS Number	<V $>$ mag	Period (in days)	YSO Name
J034345.1+320358 J043004.2+352224 J052309.6+013432	$\begin{array}{c} 18.49 \ (4.00) \\ 16.10 \ (0.35) \\ 15.48 \ (0.10) \end{array}$	$234.660 \\ 10.606 \\ 11.871$	LRL 245 2MASS J04300424+3522238 CVSO 592

Table 1. CRTS data for three YSOs

Figure 1 presents CSS phase-dependent light curves for three YSOs. We note that in the ASAS-SN variability database (Kochanek et al., 2017, Shappee et al., 2014, online access via https://asas-sn.osu. edu/variables/) there are also monitored data for objects 2MASS J04300424+3522238 and CVSO 592 (ASASSN -V J043004.20+352224.1 and ASASSN-V J052309.62+013432.4). In the ASAS-SN variability database, both objects are classified as rotating variables.

Table 2 contains some important Gaia EDR3 (Gaia Collaboration et al., 2021, SIMBAD CDS VizieR Catalog I/350/gaiaedr3) data for three YSOs. We present also the distance information derived from Gaia EDR3 by Bailer-Jones et al. (2021, CDS VizieR Catalog I/352/gedr3dis) for these three YSOs.

The columns are as follows: (1) YSO name in SIMBAD data base; (2) Gaia EDR3 name; (3-5) Gaia EDR3 wide-band G magnitude; BP mag; BP-RP color; (6-7) consequently median of the geometric and photogeometric distances (Bailer-Jones et al., 2021).

Gaia EDR3 ID	G	BP	BP-RP	R(pc)

Table 2. Gaia EDR3 data for three YSOs

YSO Name	Gaia EDR3 ID	G	BP	BP-RP	R(pc)	R (pc)
		mag	mag	mag	geom.	photogeom.
LRL 245	216679729989231744	20.318	21.386	2.621	$164(\pm 50)$	$977(\pm 175)$
2MASS J04300424+3522238	173380030079919488	16.541	18.110	2.823	$533(\pm 25)$	$525(\pm 25)$
CVSO 592	3222177481567112064	15.518	16.778	2.837	$355(\pm 6)$	$357(\pm 9)$

YSO Name	E(B-V) mag	$A_V mag$	$\mathbf{A}_{K_s} \text{ mag}$	$M(K_s)$ mag
LRL 245 2MASS J04300424+3522238 CVSO 592	$\begin{array}{c} 3.041 (\pm 0.479) \\ 11.104 (\pm 7.509) \\ 0.113 (\pm 0.004) \end{array}$	$10.031 \\ 37.081 \\ 0.352$	$1.06 \\ 3.88 \\ 0.039$	$3.92 \\ -0.59 \\ 4.16$

Gaia EDR3 data for three young stellar objects



APOGEE high-resolution spectra for object LRL 245. Figure 2. The APOGEE identification is 2M03434517+3203585 (SIMBAD CDS Catalogue III/284/allstars, Jönsson et al., 2020).

The LRL 245 is the faintest object among the three YSOs (Table 1 and 2) and deserve a special attention for variety of reasons. This object show very high infrared excess which are typical for dusty evolved Asymptotic Giant Branch (AGB) stars. Azimlu et al. (2015) presented 2MASS K<sub>s</sub> mag plotted versus WISE 22  $\mu$ m for 353 point sources (Figure 8 for known YSOs and candidates). In their diagram sources are divided into two main populations. Sources with the same W4 magnitude are divided into two brightness branches in K<sub>s</sub> mag, the "lower group" and "upper group". The "lower group" usually consists of bright stars. Known YSOs and YSO candidates lie in the "upper group", with larger  $K_s$  magnitudes. Extreme brightness in  $K_s$  mag of the lower population suggests that they can be dusty evolved stars. To characterize this "lower population", these authors compared them with the known AGB stars. In Figure 8 these authors matched also all known evolved stars in the Galaxy (including AGB stars, carbon stars, and Mira variables) from SIMBAD with the WISE catalog. Having the apparent 2MASS  $K_s = 11.009$  mag and WISE (22) = 2.265 mag, the object LRL 245 lies in the "upper group" in Figure 8 by Azimlu et al. (2015), where some amount AGB stars also exist.

Adopting the Gaia EDR3 distances (Bailer-Jones et al., 2021) the 2MASS  $K_s$  magnitude is estimated for YSOs of Table 1. We estimate 2MASS absolute  $K_s$ -band magnitude via the usual equation:

$$M(Ks) = K_s - 5Log_{10}R + 5 - A(K_s),$$
(1)

The interstellar E(B-V) color excess is used to take into account Galactic extinction. The color excess is provided by NASA/IPAC Galactic Dust Reddening Extinction service at https://irda.ipac.caltech. edu/application/DUST.

Table 3 present extinction data for three YSOs. In above noted data base we used according to Schlaffy & Finkbeiner (2011) extinction map only, assuming a visual extinction to reddening ratio  $A_V/E(B-V) =$ 3.1. We adopt also  $A_{K_s} = 0.35 \times E(B-V)$ .

The  $M(K_s)$  can be estimated as 3.92 mag, and 4.16 mag, adopting the geometric distances 164 pc and 355 pc, consequently for LRL 245 and CVSO 592. Such values is typical for mainsequence K-type stars (Cifuentes et al., 2020). Below we present some notes to individual objects.

(a) LRL 245 is in a well-studied star-forming cluster IC348 in Perseus. Cieza & Baliber (2006) presented the Spitzer Infrared Array Camera (IRAC; 3.6, 4.5, 5.8, and  $8.0 \,\mu\text{m}$ ) observations for this object which is a part of the c2d legacy project of the IC348 members. Azimlu et al. (2015) estimated M  $= 2.05 \pm 0.25 M_{Sun}$  for LRL 245. As a model grid, they used the method to analyse the spectral energy distributions models (SED) of YSOs developed by Robitaille et al. (2006). The star formation rate in the Perseus Complex is estimated by Mercimek et al. (2017). High-resolution near-infrared spectra for object LRL 245 have been obtained by APOGEE (Apache Point Observatory Galactic Evolution Experiment) spectrograph, which is mounted on the 2.5 m Sloan Digitak Sky Survey (SDSS) telescope (Blanton et al., 2017, Gunn et al., 2006). The APOGEE instrument covers the range from 1.51 to 1.7  $\mu$ m with a typical resolution  $R\sim 22500$ . The SDSS DR16 contains APOGEE spectra for about 430000 stars covering both the northern and southern sky, from which radial velocities (RV), stellar parameters, and chemical abundances of up 80 Gigoyan et al.

to 26 species are determined by Jönsson et al. (2020). The object LRL 245 show periodic variability with amplitude  $\Delta m \sim 4.0 \text{ mag}$  (Figure 1). For this object there are no spectra class information in the SIMBAD database.

(b) 2MASS J04300424+3522238: Near-infrared, mid-infrared data also Echelle high-resolution spectroscopy (on the 3.5 m Canada-France-Hawaii Telescope, CFHT) in the range 3500 to 10500 Å at a resolution 68000, was obtained for this object and is presented by Cieza et al. (2012). This object is classified as an M0 – subtype star but spectra are not included in the paper by Cieza et al. (2012). SED for this object is presented also as a giant planet-forming disk candidate.

Figure 3 presents LAMOST (Large Sky Area Multi-Object Fiber Spectroscopic Telescope) moderateresolution CCD spectra (LAMOST DR5, Luo A-L et al. 2019, spectra available on-line at http://dr5. lamost.org/search/) for YSO 2MASS J04300424+3522238. The lines  $H_{\alpha}$  ( $\lambda$ 6563Å), NaD( $\lambda$ 5893Å) and MgH band at  $\lambda$ 5198Å are well expressed, which are good indicators for M dwarfs (Gray & Corbally, 2009, Johnson et al., 1986).



Figure 3. LAMOST moderate-resolution CCD spectra for YSO 2MASS J04300424+3522238 in the range  $\lambda$ 4000-9100 Å. The lines H<sub> $\alpha$ </sub> and NaD also MgH band are well expressed.

(c) CVSO 592 (Centro de Investigaciones de Astronomia Variability Survey of Orion -CVSO, Briceño et al., 2001, 2005). Bricento et al. have carried out a large-scale survey encompassing  $\sim$ 180 square degree across the Orion OB1 association, with the goal of identifying and characterizing the PMS stars in this extended star-forming complex. This object is a low mass PMS Weak-line T Tau-type star in Orion OB1 association, subclass- M3e (Briceño et al., 2019).

## 4. Summary And Conclusion

We present for the first time some important the Gaia EDR3 photometric data, Catalina Sky Survey phase dependent light curves and 2MASS absolute K-band magnitudes for three well studied YSOs, presented in the CSDR1 data base as periodic variables. The objects 2MASS J04300424+3522238 and CVSO 592 are classified in ASAS-SN database as rotating variables and are classified as M0 and M3e dwarfs consequently. The object LRL 245 show very large infrared color indices and CSS phase -dependent light curve with period P=234.66 days and amplitude  $\Delta m \approx 4.0$  mag and deserve a special interest. Such colors are typical for dusty evolved AGB. From this point of view highly desirable is to have a spectral type of this object.

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# Properties of interstellar matter and stellar population in two star-forming regions

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### Abstract

This study aims to compare the properties of interstellar medium in two star-forming regions with different stellar content, with and without high-mass YSOs. The first region is an extended molecular cloud surrounding five IRAS sources: 05168+3634, 05184+3635, 05177+3636, 05162+3639, and IRAS 05156+3643. The second one is a physically connected pair of ultra compact HII regions, G45.07+0.13 & G45.12+0.13, associated with IRAS 19110+1045 and IRAS 19111+1048 sources, respectively. Using these two star formation regions as an example, one can see the relationship between the initial parameters of the parent molecular cloud (hydrogen column density, dust temperature), the process of star formation itself (external triggering shock or independent condensations), and the parameters of the stellar content. High-mass YSOs were obtained only in the G45.07+0.13 & G45.12+0.13 regions, in which, apparently, the initial density of the parent molecular cloud was higher and the star formation process was initiated by an external triggering shock. In addition, in the IRAS 05168+3634 region, there is a relationship between the density of the interstellar medium and the activity of the star formation process. In those subregions, where the mass and density of the initial, parent molecular cloud is greater, the process of star formation is likely to be more active and have a longer duration. In addition, in these sub-groups, on average, the mass of stars is larger.

Keywords: infrared: stars – stars: pre-main-sequence, fundamental parameter – ISM: dust, HII regions – ISM: individual objects: IRAS 05168+3634, G45.07+0.13& G45.12+0.13

### 1. Introduction

The development of observational astronomy, in particular in the infrared, has largely intensified the study of star-forming regions embedded in gas-dust interstellar matter (ISM), and, consequently, young stellar objects (YSOs) at an early stage of evolution. Nevertheless, despite significant progress, there are significantly much more "white spots" in the theory of star formation than there are answers to questions. However, it is safe to say that stars are formed in dense and cold giant molecular clouds located in the galactic disks (Ambartsumian, 1947, Lada & Lada, 2003). Star formation regions, as a rule, have a complex, multicomponent structure, including genetically interconnected ISM and YSOs (e.g. González-Samaniego & Vazquez-Semadeni, 2020, Pagel & Edmunds, 1981). This necessitates an integrated approach to study of star-forming regions. The integrated approach implies a detailed study and determination of the main properties of already formed young stellar clusters (density, mass function, distribution of evolutionary age, etc.) and the environment (chemical composition, maser emission, density, temperature, etc.).

Often, young stellar clusters or associations have a hierarchical structure both in space and time, i.e. groups of young stars at different stages of evolution may be simultaneously located in one star formation region. In general, the star formation process is a multi-stage, which, moreover, depends on a large extent of the initial conditions in the parent molecular cloud. Previous studies have shown that embedded stellar clusters can tell us a lot about initial star formation scenarios. For example, if the star formation is triggered by external shock, the age spread of new generation stars should be small, while in self-initiated condensations the age spread of young stellar clusters is large (e.g. Preibisch, 2012, Zinnecker & Yorke, 2007). Indeed, many careful studies of star-forming regions find no clear evidence or at most very moderate age spreads of just a few Myr, which is smaller than the crossing time. Such results are in good agreement with and support the scenario of triggered, fast star formation (e.g. Elmegreen et al., 2000).

A special, key place in the theory of star formation is given to high-mass stellar objects. They provide external pressure in the form of expanding HII regions, stellar winds, supernova explosions, and powerful outflows in the surrounding gas, and these factors can initiate a new wave of star formation. Through runaway OB stars, massive star formation can trigger further massive star formation over large (kpc) distances. They are capable of sustaining sequential and self-propagating star formation (Zinnecker & Yorke, 2007) and many previous studies have shown that very often there are dense young stellar clusters in the vicinity of high-mass YSOs (e.g. Azatyan et al., 2016). But at the same time, there are young stellar clusters in which there are no high-mass YSOs. In Ambartsumian (1958) it was suggested that "... those O-associations contain, as a rule, stars of the T Tauri type, on the other hand, there are T-associations that do not contain hot giants. But, apparently, the mechanisms of star formation in O- and T-associations should be similar. This means that any theory of stellar origin for a given type of association must allow for variations that would provide an explanation for the origin of stars in associations of another type."

One of the directions of research aimed at understanding the formation of stars of different masses is the study of the ISM properties in the star-forming regions with different stellar composition, with high-mass stellar objects and without. The aim of this work is to compare the properties of the ISM in two star-forming regions with different stellar content, with and without high-mass YSOs.

### 2. Description of star-forming regions

For a comparative analysis of properties of both the ISM and young stellar content we have chosen two active star-forming regions. The first region is an extended molecular cloud surrounding five IRAS sources: 05168+3634, 05184+3635, 05177+3636, 05162+3639, and IRAS 05156+3643. The second one is a physically connected pair of ultra compact H II (UCHII) regions, G45.07+0.13 and G45.12+0.13, associated with IRAS 19110+1045 and IRAS 19111+1048 sources, respectively. For both regions, detailed studies of both the ISM and the stars were carried out in Azatyan (2019), Azatyan et al. (2022), Nikoghosyan et al. (2021).

The search, identification, and classification of the young stellar population (using the near-, middle, and far-infrared (NIR, MIR, and FIR) photometric data were based on one of the main properties of young stars, namely the infrared excess due to the presence of circumstellar disks and envelopes (Lada & Lada, 2003). Furthermore, the measure of the IR excess in the NIR and/or MIR ranges can be used to characterise the evolutionary stage of a YSO (Class I and Class II). Therefore, YSO candidates can be identified based on their position in colour–colour (c-c) diagrams. The SED fitting tool (Robitaille et al., 2007) was used to determine the main parameters of the stellar objects.

To determine the hydrogen column density  $N(H_2)$  and the dust temperature  $T_d$  of the ISM, we applied the Modified blackbody fitting on *Herschel* images obtained in four bands: 160, 250, 350, and 500  $\mu$ m (Hildebrand, 1983). Following the discussion in previous studies (e.g. Battersby et al., 2011) this wavelength range is well applicable to those cases, where the dust temperature is in the range of 5-50 K, while there are no clear restrictions for the column density.

**IRAS 05168+3634 region.** There are different manifestations of star formation activity in this region: H<sub>2</sub>O, NH<sub>3</sub>, 44 GHz CH<sub>3</sub>OH, and OH maser emission, CS continuum and SiO (J = 2<sup>-</sup>-1) line emission (Varricatt et al., 2010, and ref. therein). Zhang et al. (2005) have discovered a molecular outflow in this region, and Wolf-Chase et al. (2017) - collimated outflows of NIR molecular Hydrogen emission-line Objects (MHOs). According to Sakai et al. (2012) the trigonometric parallax of IRAS 05168+3634 is  $0.532 \pm 0.053$  mas, which corresponds to a distance of  $1.88^{+0.21}_{-0.17}$  kpc. Based on the *Gaia* EDR3 database, in Nikoghosyan et al. (2021) it was shown that all IRAS sub-regions belong to the same molecular cloud, which is located at a distance of ~ 1.9 kpc.

Based on the FIR *Herschel* database it was shown that the ISM has an inhomogeneous structure, forming relativity dense clumps around the IRAS sources, which are interconnected by a filament structure (Nikoghosyan et al., 2021). In general, in the sub-regions  $T_d$  varies from 11 to 24 K, and N(H<sub>2</sub>) - from 1.0 to  $4.0 \times 10^{23}$  cm<sup>-2</sup>. The masses of the ISM vary from  $1.7 \times 10^4$  to  $2.1 \times 10^5$  M<sub> $\odot$ </sub>. Based on the c-c diagrams, Azatyan (2019) a rich population of embedded YSOs (240 objects) with different evolutionary stages (Class 0/I and Class II) was identified in the sub-regions. The distribution of the stellar members is presented in Fig. 1. The star formation efficiently in the sub-regions is less than 0.1%.

G45.07+0.13 & G45.12+0.13 region. The star-forming regions associated with IRAS 19110+1045



Figure 1. Distribution of YSOs on the Herschel  $500 \,\mu\text{m}$  images (left panel: the IRAS 05168+3634 region and right panel: the G45.07+0.13 & G45.12+0.13 region). Class I and Class II objects are indicated by filling red and blue circles, respectively.

and IRAS 19111+1048 sources are designated as G45.07+0.13 and G45.12+0.13 UCHIIs, respectively (Wood & Churchwell, 1989). The regions are part of the Galactic Ring Survey Molecular Cloud (GRSMC) 45.46+0.05. The cloud is a large star formation complex (Simon et al., 2001) that hosts several other UCHII regions. Thus, this complex is an ideal laboratory for studying the early stages of massive star formation and their impact on the natal environment. Multi-wavelength studies suggest that both UCHIIs are sites of active massive star formation. In Hunter et al. (1997) CO(J = 6-5) map is presented, which shows bipolar outflows with an origin well centred on the radio position of both UCHIIs. Both regions contain the probe of massive star-forming clumps, SO 30GHz emission, type-I OH masers, but only G45.07+0.13 produces H<sub>2</sub>O and methanol maser emissions (Varricatt et al., 2010, and ref. theirin). The distance of the region obtained by the trigonometric parallax method is 7.75 ± 0.45 kpc (Wu et al., 2019).

Using the Modified blackbody fitting on the Herschel images it was found that N(H<sub>2</sub>) varies from  $3.0 \times 10^{23}$  to  $5.5 \times 10^{23}$  cm<sup>-2</sup> within the G45.07+0.13 and G45.12+0.13 regions (Azatyan et al., 2022). The maximum T<sub>d</sub> values are 35 K in G45.12+0.13 and 42 K in G45.07+0.13. The gas plus dust mass value in G45.12+0.13 is  $3.4 \times 10^5 \dot{M}_{\odot}$  and  $1.7 \times 10^5 \dot{M}_{\odot}$  in G45.07+0.13. The UCHII regions are connected through a cold (T<sub>d</sub> = 19 K) bridge. The radial surface density distribution of the identified YSOs exhibits dense, embedded in these two physically connected UCHII regions, clusters in the vicinity of both IRAS sources (see Fig. 1 right panel). In total, 37 objects were identified in G45.07+0.13, 87 and in G45.12+0.13.

### 3. Comparative analysis of two star-forming region

Thus, based on the data obtained in previous works, these two active star-forming regions differ significantly in their stellar content. The properties of stellar objects in the regions are shown in the Fig. 2, which presents colour-magnitude (c-m) diagrams, K luminosity functions (KLFs), as well as the histograms of the distribution of stellar objects by colour index  $(J-K)_0$ , which, in fact, reflects the evolutionary stage of YSOs. The tables 1 and 2 present generalized data of both the stellar members and the surrounding ISM in the clusters (sub-region's radius, YSOs number, surface stellar density, percent of younger YSOs with Class I evolutionary stage,  $\alpha$  slope of KLF, ranges of stellar masses, hydrogen column density. and dust temperature, as well as ISM mass).

**IRAS 5168+3634 star-forming region.** The c-m diagram of this region suggests an existence of a very young stellar population (see Fig. 2 left panel). But at the same time, we can see that the stellar members have a wide spread relative to the isochrones. Among the objects there are both ZAMS stars and YSOs younger than 0.1 Myr. On the  $(J-K)_0$  histogram, the objects are distributed fairly evenly. The  $\alpha$  slopes of the KLF of the sub-regions are in the range from 0.12 to 0.21. According to the values of the  $\alpha$  slopes, the evolutionary age of the sub-regions can be estimated at 0.1–3 Myr. Therefore, we can conclude that the evolutionary age spread of the stellar objects is large. Moreover, this is true both for the cluster as



Figure 2.  $K_{abs}$  vs.  $(J-K)_0$  colour-magnitude diagrams for identified YSOs in the considered regions (*left panel*: the IRAS 05168+3634 region and *right panel*: the G45.07+0.13 & G45.12+0.13 region). The PMS isochrones for the 0.1 and 1 Myr and ZAMS are drawn as solid thin and thick lines, respectively (Siess et al., 2000). The positions of a few spectral types are labelled. The solid arrows indicate the average slope of NIR excesses caused by circumstellar discs (López-Chico & Salas, 2007). The dashed arrows indicate the photometric limit of the UKIRT Infrared Deep Sky Survey in K-band. Top and right panels present the histograms of  $(J-K)_0$  and  $K_{abs}$  values, respectively.

a whole and for sub-groups separately. At the same time, according to the previous studies, no high-mass YSOs were found in this region, but only low- and intermediate-mass. This fact is also reflected by the KLF. Using the SED fitting tool in Azatyan et al. (2022) the spectral energy distributions (SEDs) are constructed for  $\sim 50\%$  of the revealed YSOs. Their parameters are correlated well with the conclusions drawn from the c-m diagram and the KLF.

G45.07+0.13 & G45.12+0.13 region. In contrast to the previous region, about 75% of stellar objects in the IRAS 19110+1045 and IRAS 19111+1048 clusters are located to the left of the 0.1 Myr isochrone and concentrated around the ZAMS (See Fig. 2 right panel). That also reflects the distribution of the objects on the (J-K)<sub>0</sub> histogram. In Azatyan et al. (2022) it was shown that about 75% of the YSOs belonging to the IRAS clusters have an evolutionary age greater than 10<sup>6</sup> yr. Therefore, in general, the evolutionary age spread of the vast majority of stellar objects in the both clusters is small. The distribution of their evolutionary ages is only several Myr years. At the same time, on average the spectral types of stellar members are earlier and, accordingly, their masses are higher (see Table 2). The clusters include several high-mass stellar objects. The  $\alpha$  slope of the KLF agrees well with a Salpeter-type initial mass function (IMF) ( $\gamma = 1.35$ ) for a high mass range (O-F stars,  $\beta \sim 2$ ) at 1 Myr.

Table 1. Parameters	Table 1. Parameters of the stellar content and ISM in the IRAS 05168+3634 region								
Parameter/IRAS	05156 + 3643	05168 + 3634	$05177 {+} 3636$	5184 + 3635					
Radius (arcmin)	2.8	3.0	3.5	2.5					
YSOs' number	47	57	79	52					
$n_{star} (arcmin^{-2})$	1.9	2.0	2.1	2.6					
Class I $(\%)$	20	43	28	21					
$\alpha$ slope of KLF	0.15	0.21	0.20	0.12					
Stellar masses $(M_{\odot})$	0.2 - 1.6	0.5 – 2.5	0.2 – 2.2	0.3 – 1.5					
$N(H_2) (x 10^{23}  cm^{-2})$	1.1 - 1.6	1.1 - 3.8	1.1 – 2.3	1.1 – 1.5					
$T_d$ (K)	11 - 12	11 - 24	12 - 13	12 - 15					
ISM Mass $(M_{\odot})$	$1.7\mathrm{x}10^4$	$2.1\mathrm{x}10^5$	$9.2\mathrm{x}10^4$	$4.0 \ge 10^4$					

Parameter/IRAS	$19110 {+} 1045$	$19111 {+} 1048$
Radius (arcmin)	0.8	1.2
YSOs' number	37	87
$n_{star} (arcmin^{-2})$	18.4	19.2
Class I $(\%)$	22	16
$\alpha$ slope of KLF	0.21	0.24
Stellar masses $(M_{\odot})$	3.2 – 7.9	3.1 – 12.6
$N(H_2) (x 10^{23}  cm^{-2})$	3.0 – 5.0	3.0 – 5.5
$T_d$ (K)	13 - 42	13 - 35
ISM Mass $(M_{\odot})$	$1.7\mathrm{x}10^5$	$3.4\mathrm{x}10^5$

Table 2. Parameters of the stellar content and ISM in the G45.07+0.13 & G45.12+0.13 region

Properties of the ISM. According to the data presented in the Tables 1 and 2 it is clear that the clusters differ not only in the properties of the stellar content, but also in the properties of the environment, namely, the values of  $N(H_2)$  and  $T_d$ . In the UCHIIs the values of both parameters are noticeably larger. The higher temperature appears to be directly related to the mass, and hence the temperature, of the stellar members. The presence of high-mass stars causes a higher temperature of the environment in the G45.07+0.13 & G45.12+0.13 region. The higher column density appears to be due to the initial conditions of the parent molecular cloud. It can be assumed that the initial high density was one of the necessary conditions for the formation of high-mass stars.

We would like to draw your attention to one more fact. As we noted above the infrared excess of YSOs, is usually caused by the presence of circumstellar disks. López-Chico & Salas (2007) shown that by incorporating theoretical models of accreting disks, the excess effect on the c-m diagram can be accurately represented by approximately constant slope vectors for disks around Class II T Tauri stars. The coordinates of the vector are (1.01, -1.105) and (1.676, 1.1613) in magnitude units. More massive YSOs are usually much more embedded than T Tauri stars, thus, this correction is unlikely to apply to such objects. However, the presence of a spherical envelope around the disc should cause a greater decrease in J-K for the same variation in the K than in the case of a "naked" disc (Cesaroni et al., 2015). Accordingly, the correction in López-Chico & Salas (2007) can be used to obtain the photometric limit, and therefore lower limit of stellar mass in the region. Using the excess vector we determined the photometric limit of the UKIRT Infrared Deep Sky Survey (UKIDSS) data represented by the dashed arrow in the diagram. It should be noted that for c-m diagram the NIR data from UKIDSS database were used. The arrow is parallel to the excess vector and passes through the ZAMS point with coordinates (0.34, 2.05). The Y-coordinate corresponds to the photometric limit of UKIDSS in the K band (18.02 mag) corrected for distance (7.8 kpc) and interstellar extinction ( $A_v = 13 \text{ mag}$ , (Azatyan et al., 2022)). In turn, photometric limit K = 2.05 mag corresponds to the ZAMS stars with  $\sim 1.4 \,\mathrm{M}_{\odot}$  (Siess et al., 2000).

The c-m diagram shows that the cluster members are well above the photometric limit. Indeed, no objects with a mass equal to or less than  $1.4 \,\mathrm{M_{\odot}}$  were found in Azatyan et al. (2022). For comparison, it should be noted that no such phenomenon is observed in the IRAS 5168+3634 region. There are a significant number of stellar objects here, which are not only concentrated around the vector of the photometric limit (in this region, it is equal to 6.1 mag in K band or ~  $0.4 \,\mathrm{M_{\odot}}$ ), but also below it.

There are several explanations for this so-called "low-mass deficit". First, the significant distance of the region (8 kpc), which undoubtedly imposes a lower limit on the mass of identified stellar objects. Undoubtedly, the remoteness of the region affected the final result. But at the same time, the question arises why, in contrast to another region, on the c-m diagram there are practically no objects localize directly around the vector of the photometric limit. In addition, according to preliminary results in the neighboring GRSMC 045.49+00.04 region located at the same distance, we were able to identify objects with a much lower mass. Of course, errors in determining the mass also affected the final result. A comparison of model predictions for pre-main sequence stars with robust dynamical mass measurements shows that mass errors at the 30–50% level are typical (Hillenbrand & White, 2004). In Bastian et al. (2010) and Hopkins (2018), a number of other reasons (apart from measurement and modeling errors) due to which there is a shortage of low-mass stellar objects in various clusters. Among them is the unusually high frequency of binary. In addition, the most massive stars in large young clusters are often located in the innermost regions of the

cluster. This phenomenon is known as "mass segregation". Mass segregation is primordial when massive stars form predominantly at the center of the cluster potential. As a result, regions of high density within a star-forming cloud produce a larger proportion of massive stars than regions of lower density. One more reason was be pointed out, namely, the evaporation of low-mass stars. However, this mostly applies to relatively old clusters. In all cases, this issue requires a more detailed study based on a larger sample.

### 4. Summarizing

As already mentioned above, the stellar populations in young clusters, namely the distribution of their evolutionary age, carry information about how the process of star formation in their parent molecular cloud was initiated. If the star formation was initiated by an external impact, the age spread of new generation stars should be small, while in self-initiated condensations the age spread of young stellar clusters is large. The formation of the two young star clusters we have considered occurred exactly according to different scenarios. The generation of star clusters in the G45.07+0.13& G45.12+0.13 regions were apparently initiated by an external trigger impact, and star formation proceeded very rapidly. On the contrary, independent condensations occurred in the IRAS 5168+3634 region. Moreover, star formation took place sequentially, so the distribution of the evolutionary age of stars is wide. On the other hand, high-mass YSOs were obtained only in the G45.07+0.13& G45.12+0.13 UCHII regions, in which, apparently, the initial density of the parent molecular cloud was higher. Thus, based of the foregoing, we can conclude that the formation of high-mass stars can be initiated in regions with a higher initial density, and at the same time proceed relatively quickly. The latter is more probable when the star formation process is initiated by an external impact. This conclusion is in good agreement with the generally accepted view (Motte et al., 2018).

A certain relationship between the parameters of the stellar population and the properties of the interstellar medium is also seen in the IRAS 5168+3634 region, where the star formation process, probably, have self-initiated, sequential condensation nature. The sub-regions with the highest  $N(H_2)$  and interstellar medium mass have the largest percentage of young stellar objects with Class I evolutionary stage. In those sub-regions where the mass and density of the initial, parent molecular cloud is greater, the star formation process is likely to be more active and has a longer duration. In addition, in these groups, on average, the mass of stars is also greater.

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## Some studies on First Byurakan Survey late-type stars

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### Abstract

Markarian survey (or the First Byurakan Survey, FBS), was the first systematic survey of the extragalactic sky. This objective-prism survey was carried out in 1965-1980 by B. E. Markarian and his colleagues using the 1 m Schmidt telescope of the Byurakan Astrophysical Observatory and resulted in discovery of 1517 UV-excess (Markarian) galaxies. FBS low-resolution spectral plates have been used long period to search and study faint late-type stars (LTSs, M-type and C(carbon) stars) at high galactic latitudes. I will review in this paper the results obtained for late-LTSs using FBS spectral plates. At present the survey is digitized and DFBS database is available. This paper reports also recent new discovered C and M-type stars, and a huge amount of the LTSs candidates selected in the DFBS data base. This paper informed also detecting some amount of the new dwarf carbon (dC) star candidates.

Keywords: Carbon stars: M stars: surveys: catalogues: data bases

### 1. Introduction

Markarian survey (or First Byurakan Survey, FBS) carried out by B. E. Markarian, V. A. Lipovetski, and J. A. Stepanian in 1965-1980 with Byurakan Astrophysical Observatory (BAO) 1 m Schmidt telescope, is an objective-prism (1.5° prism, giving a reciprocal dispersion of 1800 A/mm near  $H_{\gamma}$  throughout a useful field of  $4^{\circ} \times 4^{\circ}$ ) low-resolution (lr) survey which covers about 17.000 sq. deg. of the Northern sky and part of the Southern Sky at high Galactic latitudes defined by  $\delta > -15^{\circ}$  and IbI>15° and segmented in 28 parallel zones. During the observations, various Kodak emulsions were used (IIF, IIAF, IIAF, and 103aF), providing a  $\lambda$ 3400-6900 Å spectral range with a 70 Å-wide sensitivity gap at 5300 Å and a spectral resolution of R=96 near H<sub> $\gamma$ </sub>. The limiting photographic magnitude is 17.5 – 18.0 mag. There are a total ~40,000,000 spectra for  $\sim 20,000,000$  objects in the entire survey. The original aim was the search for galaxies with ultraviolet excess (UVX, Markarian et al., 1989). The second part of the FBS (which started in the 1990s) was devoted to the discovery and study of blue stellar objects (BSOs) (Abrahamian & Mickaelian, 1996, and reference therein). Since 1990s, the lr spectroscopic plates of the FBS was used to select faint (fainter than 12 mag in V- band) late-type stars (LTSs, M and carbon (C) stars) at high latitudes. The large spectral range of the FBS is well suited to identify various types of objects, and especially cool M - type or C - type stars. Visual inspection with a magnification of  $\times 15$  (using the magnifying glass. before 2007) was used for selecting slitless spectra showing pronounced absorption bands. C stars can be identified through the presence of the Swan bands of the  $C_2$  molecule at 4737, 5165 and 5636 Å (N-type C stars). Several objects also showing the  $C_2$  bandhead at 4382 Å are probably carbon stars of R- or CH -type. M – type stars can easily be distinguished because of the titanium oxide (TiO) molecule absorption bands at 4584, 4762, 4954, 5167, 5500, 6200 and 6700 Å. There have been 15 lists of FBS LTSs published between 1990-2010. As a result, the first version of the FBS LTSs catalogue was generated (Gigoyan & Mickaelian, 2012).

### 2. The Digitized First Byurakan Survey Data

All FBS Ir spectral plates have been digitized, resulting in the creation of the Digitized First Byurakan Survey (DFBS) data base (Mickaelian et al., 2007). Its Ir spectral images are available on the DFBS web portal in Trieste (Italy, accessed via https://www.ia2-byurakan.oats.inaf.it.

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All DFBS spectral plates are analysed with the help of standard analysis softwares (FITSView and SAOImage ds9). This visualization allows us to detect very red and faint candidate C and M stars close to the detection limit in each DFBS plate (particularly, the range ~6500-6900 Å for the very late subclasses of the N-type and M-type stars, Gigoyan et al., 2008, 2009, 2010, 2011, 2012a, 2019a, Kostandyan et al., 2017) and to perform a better selection of red objects using the possibilities of the analysis softwares compared to the eye-piece search used before (Gigoyan et al., 2001). The second and also very significant advantage is using the image analysis softwares for comparatively bright ( $m_v \sim 12.0-13.0$  mag) early-type carbon stars for which in the blue part of the low-resolution spectra the C<sub>2</sub> absorption bands are not easy to detect due to saturation. Such visualization allowed to detect additional 426 new faint objects, 27 C stars of early and late-subtypes, and also 399 stars of late-subclasses M.

The second version of the "Revised And Updated Catalogue of the First Byurakan Survey of Late-Type Stars", containing data for 1471 M and C stars (130 C-type Stars, 1100 M-type giants, and 241 M dwarfs) was generated (Gigoyan et al., 2019b, CDS /SIMBAD VizieR catalogue J/MNRAS/489/2030/catv2).

Figure 1 presents the DFBS lr 2D spectral shapes for early and late-subclasses of the C and M stars, showing TiO and  $C_2$  molecule absorption bands.





M8-M9 Type Star

Figure 1. DFBS lr 2D spectral shapes for two FBS M and C stars.

The user interface (the DFBS portal at https://www.ia2-byurakan.oats.inaf.it in Trieste) presently allows two operations: "Get Image" and "Get Spectra". Objects may be selected by USNO-A2 catalogue B and R photometry. The 2D images can also be downloaded by selecting a check box.

Figure 2 illustrate the operation "Get Spectra" showing the list of objects in radius 10 arcmin and an extraction of a given spectrum (on the right) for CH – type carbon star FBS 0259+444. Spectra for this object in the range  $\lambda$ 7550-8000 Å were obtained with the Haute Provence 1.93-m telescope (OHP, France), equipped with the CARELEC spectrograph and 512 × 512 (27 $\mu$ m×27 $\mu$ m) pixels Tektronix CCD camera as detector. A 1200 line/mm grating was used, providing a resolution of about of 0.89 Å/pixel (Gigoyan et al., 2001).





Figure 2. The operation "Get Spectra" showing the list of DFBS objects and an bSpec extraction of a spectra of FBS 0259+444 (2D image on the right, where  $C_2$  molecule absorption bands are very well expressed, identification is DFBS J030227.08+443829.1, USNO A2 catalogue data are: R = 13.11 mag., B = 14.78 mag., B - R = 1.67 mag., DFBS plate No 1067).

## 3. Spectroscopic Observations

Moderate-resolution CCD spectra were obtained for a large fraction of the FBS LTSs at different epochs and with various telescopes. Optical spectra were obtained with the Byurakan Astrophysical Observatory 2.6-m telescope (BAO, Armenia, spectrographs UAGS, ByuFOSC2 and SCORPIO), the Observatory de Haute Provence (OHP, France) 1.93-m telescope (CARELEC spectrograph), the Cima-Ekar 1.83-m telescope of the Padova Astronomical Observatory (Italy), and the 1.52-m Cassini telescope of the Bologna Astrophysical Observatory (Italy) as describes in Gigoyan et al. (2019b). These spectra allowed to confirm the carbon-rich(C-rich) or oxygen-rich (O-rich) nature of our selected stars.

Figure 3-5 presents consequently the 2.6-m BAO telescope medium-resolution ByuFOSC2 (Figure 3) and SCORPIO (Figure 4) spectra, and OHP 1.93-m CARELEC spectra (Figure 5) for FBS LTSs as illustrative examples.

Moderate-resolution CCD spectra for more than 400 FBS LTSs were secured by LAMOST (Large Sky Area Multi-Object Fiber Spectroscopic Telescope) observations (LAMOST DR5, spectra available on-line at http://dr5.lamost.org/search/). This data set allows an independent verification of our classification, and the O-rich nature could be confirmed for more than 90 percent of the FBS M-giants.

Figure 6 presents the LAMOST moderate-resolution spectra for four FBS M giants.

## 4. Variability Study Of The FBS M Giants.

To determine the variability types of the FBS M-giants, we exploit data from two primary sources, namely the Catalina Sky Survey (CSS, second public data release CSDR2, accessed via http://nesssi.cacr.caltech.edu/DataRelease/) and the All-Sky Automated Survey for Supernovae (ASAS-SN, accessed via https://asas-sn.osu.edu/variables/, Jayasinghe et al. (2018), Kochanek et al. (2017), Shappee et al. (2014)). The CSS comprises two main parts surveying the Northern (Drake et al., 2014) and Southern (Drake et al., 2017) sky, respectively. Both surveys were analyzed by the Catalina Real-Time Transient



Figure 3. 2.6-m BAO telescope ByuFOSC2 moderate-resolution CCD spectra for carbon star FBS 1339-070 in the range  $\lambda$ 4300-6900 Å, obtained on April 6, 1999.



Figure 4. 2.6-m BAO telescope SCORPIO medium-resolution CCD (EEV 42-40) spectra for two M giants FBS 0135+191 and FBS 1911+487, obtained on November 12, 2018.



Figure 5. OHP 1.93-m telescope CARELEC medium-resolution spectrograph CCD (EEV 42-20,  $13.5\mu$ m×13.5 $\mu$ m pixels) spectra in the range  $\lambda$ 4000-7200 Å for four FBS carbon stars, obtained on 26-29 June, 1998.

Survey (CRTS) in search for optical transient (V < 21.5 mag) phenomena. The ASAS-SN project as an all-sky optical monitoring to photometric depth V $\leq$ 17.0 mag providing variability types, periods, and



Figure 6. LAMOST moderate-resolution CCD spectra for a sample of FBS M giants.

amplitudes to the FBS M-giants.

Our final sample consists of 690 SR (Semi-Regular)-type, 300 L-type (irregular) and 110 Mira-type variables (Gigoyan & Kostandyan, 2021). A separate paper is devoted to variability study of the FBS N-type Asymptotic Giant Branch (AGB) carbon stars (Gigoyan et al., 2014).

## 5. Parameters Derived From Gaia Data. 2MASS And Gaia EDR3 Photometry

Gaia EDR3 (Gaia Collaboration et al., 2021) contains astrometry, three-band photometry, radial velocities, effective temperatures, and information on astrophysical parameter and variability for approximately 1.8 billion sources brighter than G = 21.0 magnitude. All FBS M giants (Gigoyan et al., 2019b) were crossmatched with Gaia EDR3 catalogue (CDS VizieR catalogue I/350/gaiaedr3) sources. Combining 2MASS (Skrutskie et al., 2006) Near-Infrared (NIR) and Gaia photometric information, Lebzelter et al. (2018) constructed a new diagram as an analysis tool for red giants. For this, they combined Wesenheit functions in the NIR and in the Gaia range. The 2MASS H and Ks NIR Wesenheit function is defined following (Soszyński et al., 2005) as:

$$W_{Ks,J-Ks} = Ks - 0.686(J - Ks) \tag{1}$$

where as the Wesenheit function for Gaia BP and RP magnitudes (Lebzelter et al., 2018) is defined as:

$$W_{RP,BP-RP} = G_{RP} - 1.3(G_{BP} - G_{RP})$$
(2)

In Figure 7 we show the application of this diagram to spectroscopically confirmed FBS M and C giants with Gaia EDR3 distances (Bailer-Jones et al., 2021, CDS VizieR Catalogue I/352/gedr3dis).

Six distinct groups of red giants with their boundaries had been identified therein by Lebzelter et al. (2018). Lebzelter et al. (2018) showed that these groups correspond to low-mass, untermediate-mass, and massive O-rich AGB stars as well as RSG, C-stars and extreme C-rich AGB stars (Gigoyan et al., 2021).

The majority of the FBS giants occupies the region of low mass, oxygen-rich AGB stars in this diagram. It thus seems likely that the FBS sample primarily consists of stars with  $M < 2M_{Sun}$ . The lack of the RSG and massive AGB stars among the sample of the FBS M giants is evident.

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Figure 7.  $W_{BP,BP-RP} - W_{Ks,J-Ks}$  versus M(K) diagram for FBS M and C giants. Approximate boundaries of regions (a)(low-mass O-rich AGB stars), (b)(C-rich stars and "Extreme" C-rich stars), (c)(intermediate-mass O-rich AGB stars), and (d)(O-rich massive AGB stars and Red Supergiants-RSG) identified for LMC stars in Figure 1 and 3 by Lebzelter et al. (2018) have been reconstructed.

Infra-Red (IR) astronomical databases, namely, IRAS, 2MASS, WISE, and Spitzer, are used to analyze photometric data of 126 FBS carbon stars (Gigoyan et al., 2017).

### 6. FBS M Dwarfs

A total of 235 M-type stars (16 per cent of all FBS M stars detected) are classified as dwarfs. They show detectable **proper motions (PM)** and NIR colours typical for M dwarfs. Figure 8 presents 2MASS J-H versus H-Ks colour-colour plots for all 1471 FBS M-and C-type stars, indicating their luminosity classes. M dwarfs are denoted by red squares.

A special interest present the extremely high proper motion star FBS 0250+167 (Gigoyan et al., 2003). This object was detected on FBS plate No117 (Kodak -IIAF, obtained on 1-m Schmidt telescope 13 November, 1969). In our XIV-th list of the LTSs, we present this object as M7-M8 subtype star (Gigoyan et al., 2003).

Figure 9 presents the DSS1 R and DSS2 R finder charts, and lr 2D spectral shape of the FBS 0250+167 on the plate No117.

Figure 10 present the direction of the motion of the high proper motion star FBS 0250+167, which was constructed, using DSS1, DSS2, DFBS Plate No117data, also Gaia EDR3 high accurate astrometric data.

The study of all new discovered FBS M dwarfs from the Gaia EDR3 point of view is now being carried out and the results will be appear soon (Gigoyan et al., in prep.).

## 7. New Carbon And M Stars Candidates

As it was mentioned above (Chapter 2), the data visualization (zooming the digitized images, changing the scale parameters of the DFBS plates, et al.) with help of the analysis softwares FITSView and SAOImage ds9 allows to detect very red and faint M and C stars and candidates close to the detection limit in each DFBS plate. Using the both softwares, we detected 1471 M and C stars. We selected also a huge amount of new faint candidates, which need to confirm by moderate-resolution spectroscopy. They are:

1. Candidate faint N – type AGB and M – type giants, for which on the DFBS plates only very short spectra (wedge-like) in the range  $\sim 6600-6900$  Å is visible, no C<sub>2</sub> and TiO **molecule absorption** bands are detectable. Some part of the such faint candidates can be dwarf M stars also (for example,



Figure 8. The 2MASS J-H versus H-Ks colour-colour diagram for all 1471 FBS LTSs. Blue circles represents giants, and red squares represent dwarfs (dwarfs are M stars only).



Figure 9. DSS1 R and DSS2 R, finder charts, also DFBS lr 2D spectral shape on the plate No117 for high proper motion star FBS 0250+167.

DFBS J072820.67+310019.7 = LSPM J0728+3100E, which is **high** proper motion object, Lépine & Shara (2005), CDS SIMBAD VizieR catalog I/298. "LSPM-North Catalog", which is M6-M7-sybtype dwarf star, B=16.20, R=14.33, B-R = 1.87). We confirm the C-rich nature for some amount of such candidates by moderate-resolution CCD spectroscopy (Gigoyan et al., 2012b).

2. The second group of the new faint candidates are early-type carbon stars (usually they are CH or R-type carbon stars, also dwarf carbon star (dC) candidates), for which  $C_2$  molecule absorption bands at 5636, 5165, 4737, and 4382 Å are very hardly detectable (or practically no detectable) on the DFBS spectra with help of the FITSView and SAOImage ds9 visualization softwares, because of their faintness (usually they are 1.0 mag. brighter or are close to the detection limit of each DFBS plates).

As illustrative examples, in Figure 11 we present bSpec extraction (one-dimensional and 2D spectrum) for the new CH star candidate DFBS J024615.25+484150.9 and for candidate dC star DFBS J161647.00+633404.3 only. Because of the faintness,  $C_2$  absorption bands are hardly visible on the DFBS plates.

Table 1 presents some important Gaia EDR3 data for two new C star candidates.

Adopting apparent visual magnitudes V=15.29 and V=15.77 for DFBS J024615.25+484150.9 and for DFBS J161647.00+633404.3 (UCAC4, CDS VizieR catalogue I/322A), the absolute V-band magnitude can be estimated M(V) = +1.17 and M(V) = +9.5, respectively. These values are typical for CH (M(V)=+1.17) and for dC (M(V) = +9.5) carbon stars.



Figure 10. Direction of the motion of the high proper motion (PM = 5.122 "/yr) star FBS 0250+167, which was found due to DFBS plate No117. The Gaia EDR3 parallax value of 260.988 mas (pmRA = 3429.083 mas/yr, pmDec = -3805.541 mas/yr, G = 12.263 mag) placed this star at a distance r = 3.83 pc.

Table 1. Gaia EDR3 Data For Two New DFBS Early-Type C Star Candidates

DFBS Number	Gaia EDR3 Name	Gmag	BP mag	BP-RP mag	R (kpc)
J024615.25+484150.9 J161647.00+633404.3	$\begin{array}{c} 438564097055438720\\ 1629378311406218240\end{array}$	$14.28 \\ 15.08$	$15.41 \\ 16.05$	$2.17 \\ 1.94$	$6.641{\pm}1.0$ $0.185{\pm}0.0072$

### 8. Conclusion And Future Programmes

All DFBS low-resolution spectral plates have been analysed for comparatively faint late M -type and Ctype stars. The "Revised And Updated FBS LTSs Catalogue. Version 2" lists a large number of completely new objects (1471 stars), which extended very significantly the census of M giants, faint N-type Asymptotic Giant Branch carbon stars, CH-type carbon giants at high Galactic latitudes, and M dwarfs in the Solar vicinity up to 16.0-17.0 mag. in the visual. We have performed cross-correlations with DFBS, USNO-B1.0, 2MASS, ALLWISE, IRAS PSC/FSC AKARI, ROSAT, SDSS catalogue data (Gigoyan et al., 2019b). Gaia EDR3 broadband G magnitudes are in the range 9.4<G<18.2 for C stars. Large fraction of the new N-type FBS C stars discovered belong to the Galactic Halo population and are considered as Faint High Latitude Carbon stars (FHLCs, R > 13.0 mag., IbI > 13.0 mag., see definition of Margon et al., 2002, Totten & Irwin, 1998). Consequently, their kinematical characteristics provide information on the properties and mass of the Galactic Halo. They are not further than 25.0 kpc from the Sun. Two objects among the FBS C stars deserve maximum attention. They are FBS 1502+359 and FBS 2213+421. Both its medium-resolution spectrum and its very large color index suggests that these objects are surrounded by a dusty envelopes. The FBS 1502+359 is a Semi-Regular (SR) variable C star (Gigoyan et al., 2001, 2014). The second object FBS 2213+421 is a R CrB-type variable with initial mass  $\sim 2M_{Sun}$  (Rossi et al., 2016). Most of our FBS sample of M giants are found at typical distances of 1 kpc above or below the Galactic plane. Spectroscopically confirmed FBS O-rich and C-rich giants show the same separation in the Gaia -2MASS -diagram, as long-period variables (LPVs) in the Large Magellanic Cloud (Lebzelter et al., 2018). The discrimination between O-rich and Crich objects becomes even more visible when using the  $W_{RP,BP-RP} - W_{Ks,J-Ks}$  versus Gaia BP-RP color or 2MASS J-Ks versus BP-RP. This offer the opportunity to use the difference of Wesenheit indices  $W_{RP,BP-RP} - W_{Ks,J-Ks}$  also for chemistry classification in sample with unknown distances while losing the ability of the Gaia -2MASS diagram to separate the stars according to mass (Gigoyan et al., 2021).

Near 16 percent of all FBS M stars detected are classified as dwarfs. They show detectable proper motions and NIR colors typical for M dwarfs. Their distances are in the range 3.8 pc < r < 1000 pc. Based on DFBS Ir spectral plates, the spectral types as M dwarfs we presented for many known proper motion



Figure 11. bSpec extraction of the DFBS low-resolution spectra for new CH star candidate DFBS J024615.25+484150.9 and for candidate dC star DFBS J161647.00+633404.3, which show high proper motion (PM = 124.128 mas/yr).

objects for the first time (Gigoyan et al., 2019b).

Visual inspection of the objects with help of these softwares, resulted to discovery of a huge amount of new M and C star candidates also in the DFBS Ir spectral plates. Some fraction of the new detected faint candidates show double peaked spectral energy distribution (SED), indicating the existence of the dusty envelopes around these objects. Moreover, similar SED show also part of the detected faint objects, which are M dwarf candidates, i. e. they show high PM and NIR J-H and H-K colors, typical for M dwarfs (Bessell & Brett, 1988). Most probably such new candidates are M dwarfs with debris discs around and IR excess emission (Sgro & Song, 2021). All they need in future by moderate-resolution spectroscopic confirmations.

Meanwhile, some amount of the new and faint LTSs candidates can be missed, because of variety of reasons. Therefore, we plan in near future to use machine learning algorithm, to select faint LTSs candidates using a definite spectroscopic criterii.

In 2011, Markarian survey and its digitized version, DFBS, entered UNESCOs Documentary Heritage "Memory of the World" International Register (Mickaelian et al., 2021).

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# On "Observational Instruments" composed of Stones No. 12, 13 and 14 of "Zorats Qarer" Monument

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With inexpressible longing, I dedicate this to my father Andranik Malkhasyan's blessed memory

#### Abstract

The work is dedicated to the discussion of some of the stones of the "Zorats Qarer" megalithic monument (No. 12, 13 and 14) in terms of Astronomy. The methods of their use for observational purposes are revealed. Particularly, it has been shown that the stone No. 14 most likely served as a "seating platform" for the observer looking towards the observation angle of the stone No. 13. The other application method has been the formation of the exact direction by the principle of combining the angles of the stones No. 12 and 13. As a result of the usage of the aforementioned methods, three definite directions emerge. The examination of these directions has been performed for the possible date (9000 BC) which is crucial in terms of the origin of the ancient Armenian calendar (Protohaykian), as well as the results of the study of the monument gained so far. The results of the comprehensive examination have been combined with archeological material, Armenian ethnography and folklore. Comparisons have been drawn between days of observing the celestial bodies and important structural units of Protohaykian calendar. At the same time, the observation conditions and the mythological images of the observed stars have been discussed in the context of the most important stages of the cereal cultivation (sowing, harvesting, etc.). Parallels have been drawn with the Armenian religious beliefs (also of other nations), as well as with the results, already known from the study of this monument.

The study of the mentioned stones has revealed that the stars (up to  $2^m.50$  apparent magnitude), observable in 9000 BC, their mythological perceptions, observation conditions and days, are in complete harmony with the structure and content of the Protohaykian calendar (as well as of the ornament-calendar of the early Bronze Age vessel from Keti), and they are closely related to the worship of the Mother Goddess. Links between the observation positions and the definite stages of the cereal cultivation culture (autumn and spring sowing) reappear. There is no contradiction between previously and currently obtained results of the study of the monument. Moreover, the results obtained so far are complementary.

**Keywords:** Zorats Qarer: Archaeoastronomy: Ancient Observatories: Megalithic Monuments: Armenian Calendar History: Protohaykian Calendar: Cultural Astronomy: Armenian Folklore:

## 1. Introduction

In the present work an attempt is made to discover other "observational instruments" aside from the observational platforms, described in recent studies of "Zorats Qarer" Monument. First, let us remember some principles of using observational platforms. Thus: Platform 1 with the stones No. 60, 62, 64 and 66, were intended for observing the celestial bodies, rising on the eastern horizon (Broutian & Malkhasyan, 2021), and Platform 2 (with the stones No. 158 and 160) was intended to serve for observing the transitions of circumpolar stars (closer to the North Pole) over the horizon (Malkhasyan, 2021b). The important common trait of the platforms is that, as a matter of fact,

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they are "observational instruments", composed of several stones. There has been an opinion about the existence of such a complex in the past. There is also a hypothesis (Herouni (2006), pp. 64-67) that the stones No. 60, 62 and 63 could be used as a complex. Particularly, from the holes of the stones No. 60 and 62, towards the highest point at the top of the stone No.  $63^1$  and the directions, stretching to South, could serve as instruments for observing the transitions (upper culminations) of southern celestial bodies along the southern high points. Another peculiar type of "observational instruments" are "angular stones". In some cases, they (stones No. 197 and 198) have been used as separate stone instruments, indicating quite high directions from the horizon, in other cases, a stone (No. 158) has been used as a guiding stone for the platform (Platform 2). It should also be mentioned that a stone has been used as an instrument, indicating several directions, as with the stone No. 158 (Malkhasyan, 2021b). Aside from the existence of two observational angles, the top of the same stone, with Platform 2, also comprises the third direction. Thus, the stones of the monument have been adjusted in the most various ways, for the purposes of observation, for example, "complex observational instruments", composed of several stones, have been used. Such a usage emerges as a result of the joint examination of the stones No. 12, 13 and 14 as well. Let's find out what function the trio of these stones has and how it has been used for the purposes of observation. Let's start with their description.

## 2. The description of stones No. 12, 13 and 14

First, let's notice that the above-mentioned stones are located in the middle of the monument and are part of the central circle of the stones in a rhombus arrangement, more precisely, are located on the southeastern side of the rhombus. They follow each other in the row of stones, and are shown in Figure 1, from North-East to South-West, respectively in numbers 12, 13 and 14 (Figure 1). Stones No. 12 and 13 stand vertically with rather wide bases.



Figure 1. The location of the stones No. 12, 13 and 14 in the central rhombus arrangement of stones. Photographed from a height of 150 m.

The stone No. 14, although is a part of the row, stands out by both its shape and position. It has a shape of an irregular parallelepiped, and its upper horizontal side reminds a somewhat flat surface. No cut, angles or holes have been found while examining the visible part of the stone. The case is, however, different with the shapes of stones No. 12 and 13. At the top of them there are clearly cut angles, which make them different from other stones of the monument. Stones No. 12 and 13 differ from each other as well. The difference is that the stone No. 12 has two angular cuts at the top of it, and the stone No. 13 has only one (Figure 2). Moreover, the angle of No. 13 is directed to a quite high point in the sky, while the directions of the angles of the stone No. 12 are not clear. To put it simply, if the angles of the stones No. 158, 197, 198 and 13 can be compared to a firearm's iron sights (Malkhasyan, 2021b), then the angles of the stone No. 12 can be compared to the structure of the slingshot. This means that the angles of the stone No. 12 can be subjected to a study only if an

<sup>&</sup>lt;sup>1</sup>Since the stone No. 63 has a certain deviation from its initial position, the problem of addressing it separately remains up to date. This stone, standing out due to the peculiarities of its shape, differs from all the other stones, composing this monument. According to one of the locals, for some reason this stone has moved about its vertical axis approximately 50 years ago, but its position hasn't changed. As a result of a detailed examination, we also got the impression of an additional reinforcement at the base of the stone. However, a late  $19^{th}$  century photograph clearly shows it standing solidly in its current position.

additional guiding circumstance emerges. And this additional guiding circumstance, as it has been revealed as a result of a detailed examination of the monument, is the angle of the stone No. 13. Due to its examination, it has been revealed that the cut of its upper distant point is two-sided, i.e., the vertex of the upper angle by two sides of the stone is hewn. This makes sense only if the angle has been used as an observational instrument from both sides. However, observing from the other side, the direction is not clear as well, as with the angles of the stone No. 12. Thus, this angle also needs an additional guiding circumstance.



Figure 2. The digital point clouds of stones No. 12 and 13 (view from the East). The arrows show the angles of the stones.

It turns out that the angles of stones No. 12 and 13 are guiding circumstances<sup>2</sup> for each other. The two angles of the stone No. 12 will be further referred to as "northern" and "southern", depending on their positions about each other and geographical orientations. It should also be mentioned that the tops of these two angles are located approximately<sup>3</sup> on the meridian. The northern angle of the stone No. 12, in contrast to the southern one, doesn't coincide with the angle of the stone No. 13 from any point<sup>4</sup>. So, if we can determine from what point the observations have been made, combining the vertex of the southern angle of the stone No. 12 and the vertex of the angle of the stone No. 13, then the same observation point will become an additional guiding circumstance for the northern angle of the stone No. 12. Thus, it turns out that an observer from a certain point, combining the southern angle of the stone No. 12 with the angle of the stone No. 13, can simultaneously observe the celestial bodies visible from the northern angle of the stone No. 12. Therefore, there is a certain possibility

that 2 different stars could have been observed from the two angles of the stone No. 12 at the same moment. Such a phenomenon has already been discovered by the examination of the stone No. 158 (Malkhasyan, 2021b). Different stars have simultaneously been observed from the two angles of this stone. Thus, it may be possible, we have to deal with the same observational principle in case of the two angles of the stone No. 12.

Let's view the description of the stone No. 14 in more detail. As it has been mentioned this stone doesn't have any special cuts. It's only noticeable that its upper surface is flat. Let's also mention that the stone No. 14 is located quite near the stone No. 13. More precisely, it's located in a way, that when I made an attempt to look at the direction of the stone No. 13, I found myself sitting on the stone No. 14. So, by continuing the direction of the angle of the stone No. 13 in the opposite direction, it pretty accurately coincides with the eye of the observer<sup>5</sup>, sitting on the edge of the stone No. 14 (Figure 3). It's worth mentioning that it's difficult to attribute another function to the stone No. 14, as long as, a) it doesn't have any special cuts, b) is located quite near the stone No. 13 and c) it is quite uncomfortable for the observer in the direction of the stone No. 13 to do it, without sitting on the above-mentioned stone, e.g., from a standing position.

 $<sup>^{2}</sup>$ In fact, if the angle of the stone No. 13 is observed from the opening of the southern angle of the stone No. 12, i.e., by changing the position of the eye, the tops of the two angles coincide, then we get a single-valued direction, which can already become a subject for an examination.

 $<sup>^{3}</sup>$ The deviation is less than 1 arc degree, which, in this case, taking into account the small distance between the tops, can be neglected.

 $<sup>^{4}</sup>$ Even due to a detailed examination, we didn't succeed in discovering a mutual connection between this angle and another stone. In this case, we have nothing to do but answer the following question: how is this angle connected to the southern angle of the same stone No. 12 and the angle at the top of the stone No. 13 ?

<sup>&</sup>lt;sup>5</sup>We'll discuss the calculation details of this direction and the observation point in the further text.



Figure 3. The mutual positions of the observer, sitting on the stone No. 14 and the angle of the stone No. 13. The photograph depicts the author of this article. The date of the photograph is July 4, 2021.

So, three directions have been distinguished in the monument, which are formed with the help of the stones No. 12, 13 and 14. In order to make the further text clear, let's give these directions the number of the corresponding stone and, taking into account the nearest point to the direction, let's distinguish them by Latin letters (*P-platform, S*southern, N-northern). We get the following directions.

- 1) The direction of the stone No. 13 for the observer on the "seating platform" of the stone No. 14  $(13_P)$ .
- 2) The direction passing through the tops of the southern angle of the stone No. 12 and the angle of the stone No. 13  $(12_S)$ .
- 3) The direction of the northern angle of the stone No. 12 from the observation point, which is also an observation point for the direction, mentioned in Point 2  $(12_N)$ .

The first two  $(13_P \text{ and } 12_S)$  of the mentioned three directions, in fact, are single-valued and are obtained due to measurement, and the third one  $(12_N)$ can change, depending the distance and the height of the observer's eye. Thus, let us see what these directions are, and determine the observation point, which is considered to be a guiding point for the direction  $12_N$ .

## 3. The directions of the angles of the stones No. 12 and 13

As it has been mentioned, the directions  $13_P$  and  $12_S$  are precise (Table 2). The stone No. 14 has probably served as a "seating platform" for the observer in the direction  $13_P$ . In order to see what function the direction  $12_N$  has had, let's learn from what position it is possible to observe in the direction of  $12_S$ . Otherwise, the northern angle of the stone No. 12 would make no sense. In order to find the observation point (i.e., the point that serves as an additional guide for the direction  $12_N$ ), let's first introduce a simplified drawing (Figure 4) and denote some points in it with Latin letters (Table 1).

Figure 4 clearly shows that it is possible to look at the direction  $12_S$  (SK) from the point S of the stone No. 12 to the mark of the ground from any point of the line, stretching in that direction. However, we'll discuss the possible conditions of observation from only two points (D<sub>1</sub> and D<sub>2</sub>), taking into account the sound assumption that the observer was likely to make observations from kneeling or standing positions. The already known fact that in case of Platforms 1 and 2 of the monument the observations have been made from a standing position (Broutian & Malkhasyan, 2021, Malkhasyan, 2021b), breed ground for such an assumption. On the other hand, we also see the stone No. 14, the role of which is so far explained as just having been used as a "seating platform". Since there is no such seating platform<sup>6</sup> in the direction  $12_S$  we have to assume that observations could be made from a kneeling (squatting) position (it's rather uncomfortable, while sitting on the ground) (Figure 4). At the same time, making observations from a bowing or some other inconvenient position, can be considered way too uncomfortable and unlikely, as long as they are rather unstable positions, compared to that of the kneeling one.



Figure 4. The simplified drawing of the possible observation points and stones with Latin letter denotations (Table 1). The drawing is made according to the author of this article. Metrical data are given.

Let's first mention some starting points that are of crucial importance in further calculations.

- 160 cm is considered the altitude of an average height man's eye in a standing position in our calculations. The same value has also been taken into account in the past, while examining observational platforms.
- 1 m will be taken as the height of the observer's eyes in a kneeling position<sup>7</sup>.
- Segments SN and CN pretty precisely coincide with the plane, passing through the points of North, South and the Zenith (the plain of meridian). That is to say, these lines are oriented from North to South<sup>8</sup>. This means that the perpendicular D<sub>2</sub>O must coincide with the parallel plain, namely be directed from East to West.
- The absolute altitudes of all points above sea level (Z) are given in Figure 4.

<sup>&</sup>lt;sup>6</sup>For an observer in a kneeling position the distance from the stone No. 12 is approximately 3 m to North-East. Here the nearest stone is No. 11, which is lying or is horizontally stuck in the ground. This circumstance makes it impossible to find any connection between the primary function of the stone No. 11 with the observation point of the kneeling observer, as well as to exclude such a connection.

 $<sup>^{7}</sup>$ This measure has been taken after determining the height of several kneeling men's (of average height) eyes from the ground mark and averaging it.

 $<sup>^{8}</sup>$ The deviation is less than 1°. In case of such problems, taking into account the roughness of angle cuts, such a deviation can be neglected.

• The distances are measured with an accuracy of 1 mm (Malkhasyan, 2021a): SN=0,25m; SK=3,891m.

The letter	The description
S	Vertex of the southern angle of the stone No. 12
N	Vertex of the northern angle of the stone No. 12
K	Vertex of the upper cut of the angle of the stone No. 14
C	Intersection point of the perpendicular, lowered from point S,
	on the horizontal plane, passing through point N
0	Intersection point of a the perpendicular,
	lowered on the line CN from the assumed observation point $D_2$
D <sub>1</sub>	A standing observer's observation point on the line CK
$D_2$	A kneeling observer's observation point on the line CK
D <sub>3</sub>	The observation point of the observer on the "seating platform" No. 14
D <sub>3</sub> B	The projection distance of points $D_3$ and K in a horizontal plane
	and is equal to 1 m
A	Azimuth
h	The elevation from the mathematical horizon
Z	The absolute altitude above sea level

Thus, let us see what picture we get from the examination of the two mentioned positions.

Table 1.	The table	presents tl	he Latin	letters,	shown	in	Figure 4,	their	meanings,	as well	as	some	data.
		1		/			() /		() /				

### 3.1. In case of a standing observer

Since the task is to understand from what point the northern angle of the stone No. 12 has been observed, first, we must determine the distance of a standing observer's observation point  $(D_1)$  from the point S  $(D_1S)$ , based on which we can calculate the components of the vector  $D_1N$ .

$$D_1 S = K D_1 - S K$$
$$K D_1 = \frac{Z_K - Z_{D_1}}{\sin h_S}$$

Where  $h_S$  is the elevation from the mathematical horizon of the direction  $12_S$  for standing observer and is known from the measurement ( $h_S=12^{\circ}48'$ ).

Thus:

$$KD_1 = \frac{1769,327 - 1768,44}{0,2215485} \approx 4,004m$$
$$D_1S \approx 4,004 - 3,891 \approx 0,113m$$

It turns out that a standing man of average height can combine points S and K by the eye, being at only 11 cm from the point S. An attempt has been made in the monument to watch this direction from such a distance. It has been found that simultaneously seeing the northern angle as well is impossible. Besides, in case of such a small distance we obtain quite a large value of visual parallax<sup>9</sup> for the point S.

$$D_1 S_{(parallaxis)} = 2 \arctan \frac{0,03}{D_1 S} \approx 30^\circ$$

Aside from this, if we consider the absolute altitudes of points  $D_1$  and N above sea level, it becomes clear that the direction from the point  $D_1$  to the point N is directed lower than the mathematical horizon.

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 $<sup>^9\</sup>mathrm{The}$  pupillary distance is taken as 6 cm.

$$Z_N - Z_{D_1} = 1768,395 - 1768,44 = -0,045m$$

As we see, the observations could not have been implemented in a standing position. So, let us see what picture we get in case of observing from a kneeling position.

### 3.2. In case of a kneeling observer

As in the previous case, here as well, we firstly need to determine the distance between the points  $D_2$  and S.

$$D_2 S = K D_2 - S K$$
$$K D_2 = \frac{Z_K - Z_{D_2}}{\sin h_S}$$
$$K D_2 = \frac{1769,327 - 1767,806}{0,2215485} \approx 6,865m$$
$$D_2 S \approx 6,865 - 3,891 \approx 2,974m$$

The next step is to determine the length of CN, in order to remove the vertical component of the direction SN and as a result get the precise azimuth<sup>10</sup> of the direction  $D_2N$ .

$$CN = \sqrt{SN^2 - (Z_S - Z_N)^2}$$
$$CN = \sqrt{0,0625 - 0,009025} = 0,231m$$

To make it simple, let's plot the right triangle  $D_2CO$  (Figure 5), from where we can determine:



Figure 5. Position of the right triangle  $D_2CO$  with respect to geographical directions and the calculated angles in horizontal plain.

$$D_2 O = \sqrt{D_2 C^2 - CO^2}$$

If we assume that  $D_2C \approx D_2S$  (there is a difference of just a few millimeters), and as a result of measurements we have obtained  $A_S = 67.5^{\circ}$ , calculated from the South point, then the angle  $\alpha$  (with the vertex  $D_2$ ) of the triangle  $CD_2O$  will be:

$$\alpha = 90^{\circ} - A_S = 22, 5^{\circ}$$

Since, as mentioned above, the horizontal component of the direction  $D_2O$  is directed to the West then:

$$\sin \alpha = \frac{CO}{D_2C}$$
$$CO = D_2C \times \sin \alpha$$

<sup>&</sup>lt;sup>10</sup>All the azimuths, presented in the article, are calculated from the South point, as it is accepted in astronomy.

$$CO \approx D_2 S \times \sin \alpha$$
  
 $CO \approx 2,974 \times \sin 22, 5^{\circ} \approx 1,138m$ 

Thus, we can determine:

$$NO = CO - SN \approx 1,138 - 0,231 = 0,907m$$

As long as the main purpose of our calculation is to determine  $A_N$ , then it is equal to:

$$A_N = 90^\circ - \beta$$
$$\tan \beta = \frac{NO}{D_2O} = \frac{0,907}{\sqrt{2,974^2 - 1,138^2}} = 0,3301$$
$$\beta = \arctan 0,3301 = 18,27^\circ$$
$$A_N = 90^\circ - 18,27^\circ = 71,73^\circ = 71^\circ 44'$$

The vertical component  $h_N$  of the direction  $D_2N(12_N)$  remains to be calculated:

$$\sin h_N = \frac{Z_N - Z_{D_2}}{D_2 N}$$
$$D_2 N = \frac{NO}{\sin \beta} = \frac{0,907}{0,313495} = 2,893m$$
$$\sin h_N = \frac{1768,395 - 1767,806}{2,893} = 0,203595$$
$$h_N = \arcsin\left(0,203595\right) = 11,75^\circ = 11^\circ 45'$$

Here we also need to calculate the visual parallax of the direction  $12_N$  for a kneeling observer:

$$12_{N(parallaxis)} = 2 \arctan \frac{0,03}{D_2 N} \approx 1^{\circ} 11'$$

So, let's present the data<sup>11</sup>, obtained for three directions in Table 2:

Direction	Azimuth	Elevation	Deviation
$13_{P}$	232°51′	$44^{\circ}22'$	30'
$12_S$	67°30′	$12^{\circ}48'$	30'
$12_N$	71°44′	$11^{\circ}45'$	$1^{\circ}11'$

Table 2. The horizontal and vertical components of the three directions under study are presented. The last column contains acceptable angular deviations for the celestial bodies, observed in the corresponding directions.

### 3.3. On the "seating platform" No. 14

Although it's obvious that for the observer, sitting on the stone No. 14, the direction  $13_P$  quite precisely coincides with the position of his eye (Figure 3 and 4), it's necessary to make sure in it by numerical values (the distance  $D_3B$  is given in Table 1).

$$\tan h_K = \frac{Z_K - Z_{D_3}}{D_3 B}$$

$$Z_{D_2} = Z_K - D_3 B \times \tan h_K = 1769,327 - 1 \times 0,97813 = 1768,349m$$

<sup>&</sup>lt;sup>11</sup>The mentioned error of 30 arc minutes doesn't refer to the measurement data but is taken as a permissible deviation for the celestial bodies, visible from those directions. Since the visual parallax for the direction  $12_N$  is  $1^{\circ}11'$ , then this very value is taken as a permissible azimuth deviation for the stars, observable in that direction.
Thus, that the altitude of the sitting observer's eyes from the surface of the stone No. 14 must be equal to 1768,349 - 1767,668 = 0,681 m (Figure 4), which mostly corresponds to the average height man's eyes from the level of the sitting point. So, we can surely claim that the stone No. 14 has, in fact, served as a "seating platform" for an observer in the direction  $13_P$ .

As a result of such considerations, we can consider that there is a substantial possibility that observations could have been made in sitting and kneeling positions, using these three stones. It could be a manifestation of ritual worship as well. However, this circumstance will be clear when the celestial bodies, observed in the mentioned directions, and their mythological significance become known. Thus, let's see what celestial bodies could be observed in these directions in epochs, important for Ancient Armenian calendars.

#### 4. The observable celestial bodies

As in the previous articles on the monument "Zorats Qarer" (Broutian & Malkhasyan, 2021, Malkhasyan, 2021b), here as well we'll consider tree important dates for Ancient Armenian calendars. Main Armenian Date (Haykian Calendar, 2341 BC) (Broutian, 1985a,b, 1997), 5800 BC, when, as a result of the latest research, some considerable changes have been made in the monument "Zorats Qarer" (Broutian & Malkhasyan, 2021, Malkhasyan, 2020, 2021a) and the beginning of the Protohaykian calendar (9000 BC) (Broutian, 2016, 2017). First, it should be mentioned that only star transitions can be observed in the direction  $13_P$ . The Sun, the Moon and visible planets never pass through this point of the sky. It can also be expected that the two angles of the stone No. 12 have also been intended for observing stars. This assumption is based on several provisions:

- They are directed to quite high points from the real horizon, as the already known angles of the stones<sup>12</sup> No. 197, 198 and 158 (Broutian & Malkhasyan, 2021, Malkhasyan, 2021b).
- The observations of the Sun and the Moon at the points<sup>13</sup>, significantly above the horizon, are not calendar-critical.
- The Sun will appear in the direction of the southern and northern angles of the stone No. 12 respectively 25 and 15 days before vernal equinox (VE) and 25 and 15 days after the autumn equinox (AE). The essential events, connected to these days in the calendars, we are familiar with, are still unknown. So, it's more possible that the observations refer to bright stars and especially their transitions right before sunrise (apparent disappearance) and right after sunset (apparent appearance) (Malkhasyan, 2021b).

So, let's see which stars of apparent magnitude<sup>14</sup> up to  $2.^{m}50$  (Tables 3, 4 and 5)<sup>15</sup> have been observable in the three directions, mentioned in Table 2.

Since it's obvious that there is a mutual connection between the stones No. 12, 13 and 14, it's necessary to study these three directions simultaneously. Let us innumerate several principals which will guide us in the dating of the observable stars.

- 1) The observations of stars in all three directions are more probable if they refer to the same date. We witness such a coincidence for two dates: 5800 BC and 9000 BC.
- 2) The observations of stars are more plausible if they refer to the period when other angular stones have been studied (stones No. 158 and 198 refer to 9000 BC).

<sup>&</sup>lt;sup>12</sup>The research has shown that the angles of these stones have been intended for observing stars.

 $<sup>^{13}\</sup>mathrm{More}$  than  $10^\circ$  above the mathematical horizon.

<sup>&</sup>lt;sup>14</sup>During the previous research of the monument "Zorats Qarer"  $2^m.50$  has been taken as the minimum apparent magnitude. This article also exclusively discusses stars of such brightness.

<sup>&</sup>lt;sup>15</sup>The data and coordinates of all the stars, presented in this article, are taken from the computer package Stellarium v0.20.4 (http://www.stellarium.org).

Date	2341 BC	5800 BC	5800 BC	9000 BC
The star	-	$\alpha$ Ursae Minoris	$\beta$ Ursae Majoris	$\alpha$ Cygni
Apparent magnitude $(m)$	-	$1^{m}.95$	$2^{m}.30$	$1^{m}.25$
Declination ( $\delta$ )	-	$50^{\circ}38'$	52°00′	50°51′
<b>Right ascension</b> ( $\alpha$ )	-	$20^{h}36^{m}$	$0^{h}20^{m}$	$14^{h}41^{m}$
Azimuth (A)	-	$233^{\circ}21'$	$231^{\circ}31'$	233°07′
Elevation (h)	-	$43^{\circ}47'$	$44^{\circ}16'$	44°08′
Apparent disappearance	-	VE - 36 days	SS - 34  days	WS - $35 \text{ days}$
Apparent appearance	-	SS + 36 days	AE + 37 days	SS - 44  days

Table 3. The stars of apparent magnitude up to  $2^m.50$ , which have been observable in the direction  $13_P$  for the observer on the seating platform No. 14.

Date	2341 BC	2341 BC	5800 BC	9000 BC
The star	$\gamma$ Orionis	$\alpha$ Scorpii	$\theta$ Scorpii	$\beta$ Geminorum
Apparent magnitude $(m)$	$1^{m}.60$	$1^{m}.05$	$1^{m}.85$	$1^{m}.15$
Declination $(\delta)$	- 7°45′	- 7°36′	- 8°32′	- 8°10′
<b>Right ascension</b> ( $\alpha$ )	$4^{h}25^{m}$	$12^{h}29^{m}$	$10^{h}12^{m}$	$21^{h}38^{m}$
Azimuth (A)	$68^{\circ}07'$	$68^{\circ}07'$	$67^{\circ}30'$	$67^{\circ}30'$
Elevation (h)	$13^{\circ}09'$	$13^{\circ}21'$	$12^{\circ}38'$	$13^{\circ}10'$
Apparent disappearance	AE + 5 days	VE - $23$ days	WS + 23 days	SS + 48 days
Apparent appearance	VE - 4 days	AE - 38 days	SS + 8 days	WS + 42 days

Table 4. The stars of apparent magnitude up to  $2^{m}.50$ , which have been observable in the direction  $12_{s}$ .

3) There is a substantial possibility that different stars have been observed from the two angles of the stone No. 12 on the same day or at the same moment <sup>16</sup> (we witness something similar in case of the two angles of the stone No. 158). It's evident that in 9000 BC some stars were observable on the same day and at the same moment. Moreover, there are two such coincidences:

a) The apparent disappearance of the main stars of the constellation Gemini have been observable simultaneously in the directions of the two angles of the stone No. 12, 47-48 days after summer solstice (SS).

b) The apparent appearance of the stars  $\alpha$  Lupi and  $\alpha$  Cygni have been observable in directions  $12_N$  and  $13_P$  respectively 44 and 47 days before summer solstice and 35 days before winter solstice (WS). At the same time, as it is known (Malkhasyan, 2021b), 48 days before summer solstice the apparent appearance of the star  $\eta$  Ursae Majoris has been observable from Platform 2 at the top of the stone No. 160. It's obvious that the described observations can be attributed to the same moment or the same day. Here emerges a new connection among the guiding stone No. 160 of Platform 2 and the stones No. 12, 13 and 14, described here.

4) Observations are possible if the observing conditions of the stars (the days before sunrise and after sunset) are in harmony with the structure and content of the well-known ancient calendars. If the function of the stones in question is somehow connected to Platform 2 and the day, 47-48 days before summer solstice (see the previous subpoint), then it is connected to one of the important days of the Protohaykian calendar, when before the holiday

<sup>&</sup>lt;sup>16</sup>By saying "at the same time", we mean that the stars have been observable simultaneously with a difference of no more than 5 minutes or 1 day. Such an error is a result of a permissible deviation of up to 30 arc minutes, taken beforehand for the observations of stars. Such a deviation is also explained by the difference in the brightness of stars, since the visibility of stars of various apparent magnitudes under the same lighting conditions, is different. It may also be explained by the current angular distances of the stars of different brightness from the Sun. For instance, before sunrise the visibility of stars on the eastern horizon is much weaker than that of the stars of the same brightness on the western horizon.

Date	5800 BC	5800 BC	9000 BC	9000 BC
The star	$\alpha$ Hydrae	$\beta$ Tauri	$\alpha$ Lupi	$\alpha$ Geminorum
Apparent magnitude $(m)$	$1^{m}.95$	$1^{m}.65$	$2^{m}.30$	$1^{m}.90$
<b>Declination</b> $(\delta)$	- 6°38′	- 5°20′	- 5°04′	- 6°31′
<b>Right ascension</b> ( $\alpha$ )	$3^{h}01^{m}$	$4^{h}40^{m}$	$5^{h}37^{m}$	$21^{h}18^{m}$
Azimuth (A)	71°23′	72°27′	$72^{\circ}44'$	$71^{\circ}35'$
Elevation (h)	11°23′	$12^{\circ}10'$	$12^{\circ}15'$	$11^{\circ}24'$
Apparent disappearance	AE + 25 days	AE - 30 days	WS - $35 \text{ days}$	SS + 47 days
Apparent appearance	VE + 15 days	VE - 42 days	SS - 47  days	WS + 33 days

Table 5. The stars of apparent magnitude up to  $2^{m}.50$ , which have been observable for a kneeling observer in the direction  $12_{N}$ . 1 arc degree is taken as a possible deviation for this direction. No bright stars have been observable in this direction in 2341 BC.

of Navasard the 40-day period of fasting-bans begins, which we have analyzed in the previous article (Malkhasyan, 2021b).

- 5) The stars observed, using the stones No. 12 and 13, must have some connection to each other. A connection like this is beyond doubt in case of observing the main stars of the constellation Gemini.
- 6) The placement of the stones in the structure of the monument should also be taken into account. The positions of the stones in question and similarities in content clearly correspond to the features of the structure of the Protohaykian calendar.

Let's now see in what points we have a discrepancy for 5800 BC. It's evident that the content of Points 2, 3 and 6 and the mentioned observations are incompatible, and the compliance with Point 5 can be accepted with some reservation. It turns out that at least 3 out 6 provisions do not correspond to the mentioned observations<sup>17</sup>. The discrepancy for 2341 BC is more obvious in all 6 points. So here we'll discuss only 9000 BC, which as we witnessed, corresponds to all 6 provisions, listed above.

# 5. The discussion of 9000 BC (The beginning of the Protohaykian calendar)

As we have witnessed the most possible date for observations is 9000 BC, i.e., the beginning of the Protohaykian calendar. Thus, the stars and their observing conditions must be considered in the already known content of this calendar. So, for 9000 BC we obtain probable observations of 4 bright stars (Tables 3, 4 and 5). They are the stars  $\alpha$  Geminorum and  $\beta$  Geminorum as well as the star  $\alpha$  Cygni (constellation Angegh-Vulture-Swan) and the star  $\alpha$  Lupi. Since the connection of the monument with the star  $\alpha$  Cygni is known (Malkhasyan, 2020), let's start with the discussion of the observing conditions of this star.

# 5.1. The observing conditions of the brightest star of the constellation Cygnus (Angegh-Vulture-Swan)

If we take into account the similarity of the main structure of the monument with the configuration of this constellation (Malkhasyan, 2020), then it is clear that the ones who have built and used the monument, have had a special attitude towards the primary brightest star ( $\alpha$  Cygni) of the constellation. This is traditionally considered to be the tail of the celestial Swan and its name Deneb means "tail" (Allen (1963), p. 195). However, on another occasion (Malkhasyan, 2020), while discussing the monument, it has been specially mentioned that it is more correct to consider this star the head of the celestial Angegh (Vulture) and not the tail. The basis for such

<sup>&</sup>lt;sup>17</sup>A comprehensive analysis is required to discuss 5800 BC. That's why we'll analyze it in detail in future publications.

an assumption is a low-relief of a vulture on the pillar 43, excavated in archeological site Portasar (Göbekli Tepe), which clearly shows the coincidence of the vulture's head and Deneb (Vahradyan & Vahradyan, 2010), moreover, it also clearly shows that the vulture's beak identifies with the stars  $o_1$  and  $o_2$  Cygni (Malkhasyan, 2020). On the other hand, Deneb is the brightest star of the constellation, the primary one, and it's logical that it has been thought to be the "head". In a word, it's more convenient and correct to regard the star  $\alpha$  Cygni as the head of the celestial Angegh (Vulture) in further considerations. It should also be mentioned that the stone No. 13 is a part of the central cromlech and is bigger and higher than all the other stones. On the other hand, the angle of the stone No. 13 is hewn right at the top of the stone, i.e., at the "head".

Let's now discuss the day of observing this star. There is a difference of 4 days from the day of heliacal setting of the star Spica ( $\alpha$  Virginis) of the constellation Virgo. As it has been shown (Malkhasyan, 2021b), the heliacal setting of Spica, 48 days before the summer solstice is related to the Median day of Great Lent, which Armenians call "Mijink". If we pay attention to the observation details of the apparent appearance of the star  $\alpha$  Cygni (Table 3) in the direction  $13_P$ , when observed from the point D<sub>3</sub> (Figures 4 and 6a), we'll see that at the same time it has been at  $45^{\circ}$  ( $44^{\circ}08'$ ) height from the mathematical horizon. This circumstance corresponds to the sacrament of the day, i.e., splitting into two equal parts. On the other hand, the observing day is the median day of the astronomical spring, which also expresses the idea of splitting into two equal parts. What comes to the difference of 4 days, it has a separate explanation, which, however, will not be discussed here<sup>18</sup>.

The peculiar shape of the top of the stone No. 13 should also be mentioned, as long as it's known that special significance has been given to the shapes of the tops of the stones in the monument (Broutian & Malkhasyan, 2021, Malkhasyan, 2021b). The shape of the top of the stone No. 13 (Figures 2, 3, 4 and 6a) reminds of an ideogram from the Armenian "Nshanagirk Imastnots" ("The Sings on Meanings") (these and all other ideograms presented in this article are shown in Table 6), which means "temple" (Martirosyan (1978) pp. 85-89), "tower" (Abrahamyan (1973), p. 234) or [hasarak] (equal, half, midpoint) (Abrahamyan (1973), p. 240). It's interesting that the meaning of the word [hasarak] (equal, half, midpoint) is splitting into two equal parts (Malkhasiants (1944), p. 57), which coincides with the observing conditions of the star. The Mother Goddess (Martirosyan (1978), pp. 59-78) is depicted in a similar way, which corresponds to the idea of temple (church). So, the importance of the cut of this stone is emphasized and beyond doubt. At the same time the constellation Cygnus is perceived as a cross (Northern Cross) (Broutian, 2020a) and the observation of this cross at the top of the stone, "symbolizing a church" (Figure 6a) is a solid argument that such an observation is a fact. We should remember another ideogram here. It's the ideogram "summer" (Abrahamyan (1973), p. 236), which reminds of a "rising cross". The bottom part of this ideogram symbolizes a bird ("two birds" is the ideogram of "spring" (Abrahamyan (1973), pp. 231-239). Thus, it's obvious that we have to deal with the spring-summer period of the year, as well as with the ideology of a bird, which is clearly reflected in the functional-structural content of the stone, discussed here.

Ideogram	Meaning	Ideogram	Meaning	Ideogram	Meaning
ሰ	Temple, tower	ћ	[hasarak] equal	ß	Mother Goddess
7	Summer	$\gtrsim$	Spring	$\sim$	Bird

Table 6. The Ideograms and their meanings. Petroglyph (the first in last column) of Geghama mountains (Armenia) symbolizing the Mother Goddess (Martirosyan (1978), tab. VI, VII, pp. 85-89).

<sup>&</sup>lt;sup>18</sup>In order to explain the difference of 4 days in the calendar content, we need to analyze in detail some structural aspects of the Protohaykian calendar, which is a pretty extensive topic and is subject to a separate discussion.

# 5.2. The observing conditions of the brightest star of the constellations Lupus (Wolf)

The apparent appearance of the star  $\alpha$  Lupi has been observable 48 days before summer solution. As it has already mentioned (Subtitle 5.1), the heliacal setting of the star Spica of the constellation Virgo is on this day (Malkhasyan, 2021b). Similarities with the Werewolf (Wolf-girl) are also presented in the same article. There the parallels of the constellations Cassiopeia and Virgo, as well as wolf-headed dragons have been discussed. Here we already witness the possible observation of the brightest star of the constellation Lupus and the heliacal setting of the brightest star of the constellation Virgo, at the same time. It's interesting that the main stars of the constellation Cassiopeia have been visible on the north-eastern horizon at that moment (their acronical rising (rising right after sunset)). Thus, here as well we can surely discuss the myth of "werewolf transformation". It's noteworthy that in the wellknown content of the Protohaykian calendar the small part of 24 days of the out of the year period, dedicated to the Mother Goddess ends on this day (Broutian, 2022). Parallelly, we have the heliacal setting of the brightest star of the constellation Virgo, the observation of the apparent appearance of the brightest star of the constellation Lupus and the acronical rising<sup>19</sup> of the main stars of the constellation Cassiopeia, all at the same time. Here we should remember that in 9000 BC the facts of observing the constellations Cassiopeia (in the direction of the large angle of the stone No. 158, possibly also in the direction of the angle of the stone No. 197 (Malkhasyan, 2021b)) and Virgo (in the direction of the angle of the stone No. 198 (Broutian & Malkhasyan, 2021, Malkhasyan, 2021a)) have been discovered. Thus, it's quite logical to perceive the observation of the star  $\alpha$  Lupi as a probable reality as well.

#### 5.3. The observing conditions of the main stars of the constellation Gemini (Twins)

As a matter of fact, the apparent disappearance<sup>20</sup> of the star  $\beta$  Geminorum (Pollux) has been observable in the direction  $12_S$  and that of the star  $\alpha$  Geminorum (Castor) has been observable from the same observing point  $(D_2)$  in the direction  $12_N$  (Figure 6b). It's 47 days after summer solstice. Why is this day important? First of all, this is the midpoint of the astronomical summer<sup>21</sup>, furthermore, this day rather precisely corresponds to the time of the spring grain harvest. And we are discussing the date of the beginning of the Protohaykian calendar, and this calendar, as it has been already shown, is closely connected to the culture of breadmaking (sowing, harvesting, breadmaking etc.). This turns out to be the second harvest of the year and it somehow has an idea of doubling, just like Twins. However, if we deal with the harvest day, then we should remember that for the harvest day of the autumn grains, in the same monument the observation of the apparent appearance of the star  $\alpha$  Boötis (constellation Boötes (the Herdsman) ("Tsorenkagh Mshak" (in Armenian) - "The Wheat Harvester") has been observable at the top of the stone No. 158 from Platform 2 (nearly at its lower culmination)) (Malkhasyan, 2021b) has been described. Thus, for the mentioned day we also need to find out in what position the star  $\alpha$  Boötis has appeared 47 days after summer solstice right at the moment when the stars of the constellation Gemini have been observable in the discussed directions. We see that the star  $\alpha$  Boötis has nearly appeared at its highest point (upper culmination) at the same moment. This means that such observations undoubtedly have a connection with spring grain harvest.

In order to clearly understand what importance the constellation Gemini has had in the Armenian highlands in the mentioned millennium, let's remember some of its manifestations. The depicting of the constellation Gemini in the low-reliefs of Armenian "Vishapakars" (Figure 7a) (Petrosyan & Bobokhyan (2015), p. 85) and some petroglyphs (Figure 7b) (Sardaryan (2010), pp. 235-238) is more interesting. The constellation Gemini is depicted as a pair of birds, storks, on "Vishapakars" (Broutian, 2020a). We witness the same in case of the petroglyphs as well. The identification of two brothers with storks is especially emphasized in one of the Armenian Folk Tales ("AFT" (1968), pp. 143-145), where the life of twin storks is directly compared to the trouble, the twin brothers (the

<sup>&</sup>lt;sup>19</sup>The acronical rising of a star is its rising on the horizon right after sunset.

<sup>&</sup>lt;sup>20</sup>The last moment of being seen in that direction, immediately before sunrise.

 $<sup>^{21}\</sup>mathrm{The}$  period between summer solstice and autumn equinox.



Figure 6. a) The position of the constellation Cygnus with respect to the angle of the stone No. 13 for the observer on the "seating platform" No. 14. b) The brightest stars of the constellation Gemini being seen simultaneously in the directions of the angles of the stone No. 12 from the observing point  $D_2$ . Reconstructed in Stellarium v0.20.4 (http://www.stellarium.org)

king's sons) were in. So, we can assume that they have also been considered king's sons. The analysis of the Protohaykian calendar, in accordance with the ornaments on the early Bronze Age vessel (an example of the Black Polished Ware) excavated in the archeological site Keti (Broutian, 2022) also emphasizes the relation of the king's sons with the image of a bird and the position of its days is placed in the period after summer solstice. This also thoroughly corresponds to the dating of the discussed observations. First, the day of possible observations is the midpoint of the astronomical summer, the observable stars have been perceived as birds and king's sons at the same time, and the months dedicated to king's sons are summer months. Aside from this, the shape of the top of the stone No. 12 (Figures 2 and 6b) reminds of the ideogram "bird" (Abrahamyan (1973), p. 239). Here let us remember that we have discussed the observation of the brightest star of the constellation Cygnus in the direction  $13_P$ , and that constellation is also a bird<sup>22</sup> and one of the most important deities of the Armenian mythology (Davtyan (2004), pp. 207-222), the primary deity of Hayasa, U.GUR=Nergal (Ghapantsian (1956), pp. 88-89). This constellation is to some extent directly related to cross worship, and the twin brothers in the Armenian Epic were worshipers of the cross and bore the "heavenly cross" on their right hand (Broutian, 2020b, 2021). In Armenian fairy tales there are many episodes where a bird is set free while choosing a new king, and the bird always chooses the king's younger son, sitting on his head ("AFT" (1959), pp. 277-283)<sup>23</sup>. Here let's again go back to the angle of the stone No. 13 and its position in the cut of the stone. While observing in the direction of the angle of this stone, the cut is seen on the right of the stone (we can also say on its right shoulder, if we accept that the stone "faces" the observer (Figure 6a)). At the same time in Armenian thinking, especially in the Epic "Sasnay Tsrer" ("Daredevils of Sassoun") the twin brothers Sanasar and Baghdasar are born when Mother Tsovinar gets pregnant from "one and a half handful of water" ("Sasountsi Davit" (1961), pp. 10-11). In other words, there is a size difference between them. The same ideas are evident in "Zorats Qarer". The stone No. 13 (Pollux has been observable) is bigger in size<sup>24</sup> than the stone No. 12 (Castor has been observable). Let us mention another significant fact: Pollux is a brighter star (the apparent magnitudes of the stars are presented in Tables 4 and 5). In accordance with this logic, the brightest star of the constellation Cygnus has been observed on "Sanasar's head"<sup>25</sup> (Broutian, 2020a). It should be mentioned<sup>26</sup> that the star  $\beta$  Ursae Majoris has been observable in this same direction in 5800 BC (Table 3). This star is associated with "Khachastgh" (cross star) (Broutian (1997), p. 489) in Armenian sources. On the other hand, the twin brothers to a certain extent complete each other in the episodes of the Epic. In the "Land of Kajants" 40 pahlevans out of 60 are defeated by

 $<sup>^{22} \</sup>mathrm{See}$  Subtitle 5.1.

<sup>&</sup>lt;sup>23</sup>Two storks are emphasized in this tale as well.

 $<sup>^{24}\</sup>mathrm{This}$  stone differs from the other stones of the monument by its size.

 $<sup>^{25}\</sup>mathrm{Although}$ Sanasar is described as bigger in size, he is the younger brother.

 $<sup>^{26}\</sup>mathrm{See}$  Subtitle 4.

Sanasar and the other 20 are defeated only with the help of Baghdasar ("Sasountsi Davit" (1961), pp. 75-79). In the monument we also see (see the discussion of the angles, Subtitle 3) that the stones No. 12 and 13 act together, and considering them separately gives way to problems. In other words, observations could be implemented here only by using the two stones simultaneously. The number of the defeated pahlevans is also worth paying attention to. If we consider them to be 60 days then these two brothers together get two months of 30 days, just as each of the Father God's (Hayk) sons. The division of these two months into 40 and 20-day parts emphasizes the difference of the brothers' powers (sizes). To complete the abovesaid, let's take the example of the two storks (Figure 8a), depicted on the T-shaped pillar 33 of "Portasar" (Göbekli Tepe) (Peters & Schmidt (2004), fig. 9, p. 191), which nearly repeat the Armenian petroglyphs (Sardaryan (2010), pp. 235-238) (Figure 8b). The presence of storks in "Portasar" is also important, since it dates back to the time of the beginning of the Protohaykian calendar, i.e., the time of the observations, discussed here. Although the authors (Peters & Schmidt, 2004) associate them with cranes, the two birds are quite similar by their appearance and lifestyle. What's more, unlike storks, the tails of cranes are more expressive. On the stone we see that the tails of the birds are short and not emphasized. So, it's quite acceptable to consider them storks and not cranes<sup>27</sup>. We can continue this line of these parallels by discussing some additional information<sup>28</sup>, however, this is enough for making sure that the observations of the brightest stars of the constellation Gemini have been important at the mentioned period (9000 BC).





As we have seen, the possible observations refer to the day, 47 days before summer solstice till the day, 48 days after summer solstice. There are 95 days between them, and these two days quite accurately coincide with the midpoints of astronomical spring and summer, respectively. Here we should also remember that three parts of 95 days are separated in a year by the analysis of the ornament-calendar (Protohaykian calendar) of the early Bronze Age vessel from Keti. It's rather tempting to attribute this 95-day period to one of the 95-day parts of the year depicted on vessel (probably to the image of bird) (Figure 12). Let's just mention that there is an inconsistency in the identification of the 95-day parts of a year, found out here and by the analysis of the calendar on the vessel, thus this question is a subject to a separate study. Here there are other similarities as well in the structure of the monument "Zorats Qarer" and the ornaments of the vessel from Keti<sup>29</sup>, which can be discussed in line with the study of the positions of the mentioned stones.

<sup>&</sup>lt;sup>27</sup>In Armenian folklore, especially in fairy tales, cranes and storks frequently appear in similar episodes and have the same function. So, here there are no contradictions at all.

<sup>&</sup>lt;sup>28</sup>There are other circumstances, found in the monument, which confirm the obtained results. Their study is, however, quite a separate problem, which we'll discuss in future publications.

<sup>&</sup>lt;sup>29</sup>See more on the similarities between the calendar of vessel from Keti and the monument in Subtitle 6.



Figure 8. a) Portasar (Göbekli Tepe), encloser D, pillar 33 (10-9<sup>th</sup> millennia BC). The photo taken by I. Wagner, b) Petroglyph of a pair of birds (Armenia).

## 6. The positions of the stones in the structure of the monument

As it has been mentioned in the description of the stones (Subtitle 2), they are located on the south-eastern side of the central rhombus cromlech. That is to say, they are part of that cromlech. There are 40 stones in the central rhombus cromlech, evidently it is connected to the period of the 40-day fasting and bans on female origin (Malkhasyan, 2021b). These 40 days begin 48 days before summer solstice, i.e., 40 days before the holiday of Navasard. These are the 40 days, during which in 9000 BC the star Spica of the constellation Virgo was not visible in the geographic latitude of the monument and was below the horizon at night (from heliacal setting to heliacal rising period).



Figure 9. A part, from the ornament on Side A (Figure 11b) of the vessel from Keti. Small rhombus. End of  $4^{th}$  millennium BC.

In general, when speaking of the connection of the Protohaykian calendar to the monument, we should remember that the star of prime importance of this calendar is Spica (Broutian, 2016), that is, the analysis of the "small rhombus" in the ornament-calendar of the vessel of IV millennium BC closely connects it to the constellation Virgo (Broutian, 2007). The "small rhombus" (Figure 9) contains 10 dots, which are in a separate 4+3+3 arrangement (Broutian, 2022). The author reasonably gives 4 out of 10 numbers to the Virgin. We see the numbers 10 and 4, attributed to the Virgin, the product of which is the number of the 40 stones in the "cromlech". At the same time, each of the 4 sides of the rhombus of the monument contains 10 stones. if accepted, that in the initial structure there has been a symmetrical distribution of stones on the sides of the rhombus. Aside from this, the rhombus in the monument has somewhat curved (swollen outside) sides (Figure 1). Let us also mention that Grigor Broutian explains this by the analogy to the [vilhan] (analogy to the reel, on which the thread is wound), which is a part of the spinning wheel and has the shape of convex square, and spinning wheel symbolizes female

features as well (Broutian, 2022), especially in many of the Armenian Folk Tales ("AFT" (1979), pp. 442-443). The 3+3 dots of the "small rhombus" of the vessel, which symbolize twin brothers, are also worth paying attention to. The fact that these signs are inside the "small rhombus" of the vessel is important as well. It is explained by the circumstance that the Virgin (Virgo) is pregnant, that is, she carries twin sons (number 3 is odd, and the odd number indicates male). Returning to the 3 stones of the monument, under discussion, we see that they are also part of the rhombus. And the most important and peculiar coincidence is that the angles of the stones were directed to the brightest stars of the constellation Gemini in 9000 BC, i.e., the date of beginning of the Protohaykian calendar (also the calendar of the vessel). Let's also discuss the shape of the top of the stone No. 12. As it has been mentioned above<sup>30</sup>, the shape of the stone No. 13 refers to Mother Goddess. It turns out that the shape of the top of the stone No. 12 is also a symbol of Mother Goddess. This shape reminds of the female stone figures, excavated in "Karmir Blur" (Martirosyan (1978), pp. 71-72) (Figure 10). The same ideas are known from "Harich", "Shengavit" and "Moxrablur", which already refer to the early Bronze Age (Figure 11) (Yesayan (1992), pp. 144-145). There is also another similarity between the structure of the stone No. 12 and the mentioned figures. The point is that on some of them there is a special emphasis on mother's breast (a pair of breasts is either bulging or concave, sometimes perforated) (Yesavan (1992), fig. 31(2;3;4:5;10), p. 144). This can also go in line with the two angles of the stone No. 12. These figures (Figure 10 and 11) symbolize Mother Goddess, which has an emphasized belly, showing pregnancy, and the hands, held up, often stand out by the ornaments of plants, which is closely related to agriculture (Martirosyan (1978), pp. 59-78). Here we should also discuss the stone No. 158, which refers to Mother Goddess and cereal cultivation. In the direction of the large angle of this stone in the same date, 9000 BC the apparent disappearance of the brightest stars of the constellation Cassiopeia have been observable nearly at summer solstice. As it has been shown (Malkhasyan, 2021b), these observations refer to the autumn grains harvest. If we compare the shapes of the stones No. 12, 13, 158 and 198, we'll see obvious similarities. Especially, stones No. 12 and 158 both have two angles and refer to the grains harvest (12-spring grains, 158-autumn grains). On the other hand, in case of the stone No. 12 we have Mother Goddess and Twins (Gemini), and in case of the stone No. 158 there are the king's younger son and his stepmother (Cassiopeia). There are also obvious similarities in the shapes of the stones No. 13 and 198 (158 as well) (Figure 11).



Figure 10. The stone figures from Karmir Blur (Teyshebain) (Martirosyan 1978, p. 72). The photograph is taken in the museum of Karmir Blur.

Summarizing the discussed content parallels, we can claim that the stones No. 12 and 13 (also the 40 stones, arranged in a rhombus, in the centre) by their shape and position refer to Mother Goddess, who carries the "twin birds" in her belly, and the stars corresponding to them have been observable in the direction of the angles of the same stones.

Taking into account the above-mentioned similarities of the ornament of the vessel from Keti and the monument "Zorats Qarer", there is a necessity to make comparisons between the general structure of the monument and the structure of the mentioned ornament. The general structure of arrangement of the stones in the monument and the positions of the discussed stones are presented in Figure 12a, and the ornament-calendar on Side A of the vessel from Keti can be found in Figure 12b.

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 $<sup>^{30}\</sup>mathrm{See}$  Subtitle 5.3.



Figure 11. The shapes of the stones No. 158 and 198 (digital point clouds). A statue of a female idol from the early Bronze Age (IV-III millennia BC) (Yesayan (1992), fig. 31.5, p. 144).

Let's present some similarities:

- 1) The rhombus arrangement of stones has a central position in the monument. The same may be witnessed on the ornament in case of the "small rhombus". At the same time the direction of the line of the stones No. 12, 13 and 14 coincides with the arrangement of the dots in rhombuses.
- 2) The "small rhombus", as it has been mentioned, expresses the Virgin Goddess, such a position has the stone No. 198 in the monument (Figure 12a), the star Spica (constellation Virgo) has been observable in the direction of its angle (Malkhasyan, 2021a).
- 3) The "big rhombus", which symbolizes Mother Goddess (Broutian, 2007, 2022), is directed to-wards the first fracture of "Vishap" (dragon), "on the right" (Figure 12b). The stone No. 158 is located in the corresponding place in the monument (Figure 12a), and in the direction of its large angle the stars of the constellation Cassiopeia (this is directly connected to Mother Goddess (Malkhasyan, 2021b)) have been observable.
- 4) As we'll see next, the 24 points of the "large rhombus" in the monument correspond to the "Chord"<sup>31</sup> (Herouni (2006), pp. 20-23), which is included in the stone arrangement of the rhombus.

The similarity mentioned in Point 5, must be discussed in more detail. The thing is that the "seating platform" No. 14, together with the stone No. 13, is located in one of the "**junction points**". The stone arrangement of the rhombus and the row of stones of the "Chord" intersect in this part of the monument. If we again remember the calendar of the vessel from Keti, we'll see that the number of the dots in the big rhombus, dedicated to Mother Goddess, is 24, and these 24 days end the very day, when the 40-day fasting begins. That is to say, the day when the apparent appearance of the brightest star of the constellation Cygnus has been observable from the "seating platform" No. 14. This circumstance perfectly corresponds to the structure of the Protohaykian calendar. Firstly, the 19 stones of the "Chord" (No. 41 - 59) are close in number to that of the dots of the "big rhombus"<sup>32</sup> (Broutian (2022), Capt. 2(4; 5), 3(5)), and besides, these days correspond to the first small part of the out of the year period, after which the larger part of it begins (40 days). On the other hand, the 19 stones of the Chord are evidently also part of the central cromlech, cross the rhombus cromlech at its two (northern and southern) vertices and have a somewhat arc-shaped arrangement, like the sides of the rhombus. By this logic, if we add up the mentioned number of stones of the monument, we'll obtain 40 (cromlech) + 19 (the Chord) = 59 stones (days), which is two lunar months (29,5 + 29,5):

 $<sup>^{31}</sup>$ The central rhombus cromlech "is crossed" by a row of 20 (the stones from No. 40 to No. 59), relatively small stones, which has been called Chord by P. Herouni.

 $<sup>^{32}5</sup>$  out of these 24 numbers must also be considered as addition to the small rhombus. Therefore, 24-5=19 already clearly corresponds to the quantitative arrangement of the stones of the monument.

And this number corresponds to the 60 days, dedicated to the Twins, about which we have already spoken above. If we also add from 3 to 9 stones<sup>33</sup> of Alley<sup>34</sup> (Herouni (2006), pp. 20-23), we'll get 62-68, which in the Protohaykian calendar mostly correspond to the number of the days of the out of the year period (65-70 days) (Broutian (1997), pp. 416-430).



Figure 12. a) The main architectural structure of "Zorats Qarer" in accordance with the measurement, performed by our expedition group in July 2020 (accuracy 1 mm). b) the ornament-calendar on Side A of the vessel from Keti (Khachatryan, 1998). End of  $4^{th}$  millennium BC. The drawing by Hamazasp Khachatryan.

It's obvious that the structure of the monument, the arrangement of its stones, their number and the described observing function are undoubtedly connected to the ornament-calendar of the vessel from Keti. At the same time, only the future course of studies of the monument and vessel<sup>35</sup> and more complete results will help to perform a thorough comparative analysis.

<sup>&</sup>lt;sup>33</sup>In north-eastern Alley only 3 stones (No. 197, 198 and 199) are standing. The rest of them are lying, deviated from their positions or broken. Therefore, a precise calculation is problematic here.

<sup>&</sup>lt;sup>34</sup>The arrangement of stones, stretching from the central cromlech to north-east, has earlier been called Alley.

 $<sup>^{35}</sup>$ Only Side A of the ornament on the vessel from Keti is analyzed. A thorough study of such an ornament on Side B has not been performed yet.

## 7. The significance of the observer's positions

As it has been mentioned above<sup>36</sup>, observations in sitting and kneeling positions could probably have had a religious-ritualistic significance. Therefore, let's now see what the reason for the observations in such positions is. Since observations from the so far known observational platforms have been performed in a standing position, the observations in sitting and kneeling positions must at least have a logical explanation. So, due to the study of the angles of the stones under discussion, as well as the analysis of the positions of the stones and the features of the cuts, it has been revealed that in case of the stones No. 12 and 13, we deal with the worship of Mother Goddess. Moreover, here we come across two different manifestations of Mother Goddess, which has also been revealed by the results, obtained in the past (Malkhasyan, 2021b). Thus, we are dealing with two stones, which symbolize various manifestations of Mother Goddess. Aside from this, these stones are located in a row of 40 stones, arranged in a rhombus, which refers to the 40-day fasting and the days, when the brightest star of the constellation Virgo is not visible<sup>37</sup> (Malkhasyan, 2021b). The observation of the brightest star of the constellation Cygnus in the direction  $13_P$  for the observer on the seating platform No. 14<sup>38</sup>, refers to the same period. It turns out that we can draw parallels<sup>39</sup> with the "Chair" of Mother Anahit (Malkhasyan, 2021b). So, the seating platform No. 14 also corresponds to the discussed observations, to their calendar and mythological content, as an important component ("Chair") of the character of Mother Goddess (also with the constellation Cassiopeia). At the same time, in case of another stone (No. 12), we deal with another manifestation of Mother Goddess. Thus, this stone can be considered the symbol of the Virgin (daughter-in-law, stepdaughter, a virgin, giving birth to twins). It has been mentioned on another occasion, that on "Forty Children's day" ("Yekeghetsakan Oracuyc" (2022), p. 59) in Mush province (Western Armenia) single girls (virgins) used to kneel<sup>40</sup> for 40 times and pray (Bense (1972), pp. 44-45). It's obvious that this traditional prayer, that is connected to the Virgin and children, is performed by kneeling. In case of the monument, we have an arrangement of stones in a rhombus, the stone No. 12, symbolizing the Virgin and her children and the condition of being in a kneeling position for the purpose of observation. In fact, it's thoroughly explainable what the reason for observing in such positions is.

#### Summary

The detailed analysis of stones No. 12, 13 and 14 of the monument "Zorats Qarer", reveals the following circumstances:

1. Except for the standing position, observations have been performed for religious purposes in the monument in sitting and/or kneeling positions as well. It's also confirmed by the stone No. 14, which we have called a "seating platform".

2. "Angular stones" have been applied not only as separate observing tools, but also by the principle of **combining the angles of two different stones**. Such a principle has been revealed in case of the angles of the stones No. 12 and 13.

3. Except for aligning with the outline of the horizon (Broutian & Malkhasyan, 2021), the shapes of the tops of the stones have an ideological content as well.

4. There are connections between the structural-functional content of the monument "Zorats Qarer" and the ornament-calendar of the early Bronze Age vessel from Keti.

Due to the thorough study of the celestial bodies, observable in the directions of the angles of the mentioned stones observing conditions (by the combination of the obtained data, with the results of

<sup>&</sup>lt;sup>36</sup>See Subtitle 3.3.

 $<sup>^{37}</sup>$ On this in detail see Subtitle 5.1.

<sup>&</sup>lt;sup>38</sup>See Subtitle 5.1.

<sup>&</sup>lt;sup>39</sup>This day corresponds to the day when the Virgin "goes to the underworld". Here we should remember the Greek Demeter, who grieves the abduction of her daughter, sitting on the "sorrow stone" (Kun (1989), pp. 82-90).

 $<sup>^{40}</sup>$ It's rather interesting that the name of one of the stars of the constellation Cassiopeia ( $\delta$  Cassiopeiae - Al Rukbah) means a knee (Allen (1963), p. 148).

the previous studies of the monument, Armenian ethnography, folklore and archaeological material) we have got the following results:

A. The stones No. 12, 13 and 14, which are part of the central rhombus arrangement, were installed in 9000 BC, the date of the beginning of the Protohaykian calendar.

B. The observable stars ( $\alpha$  Geminorum,  $\beta$  Geminorum,  $\alpha$  Cygni and  $\alpha$  Lupi) in 9000 BC, their mythological perceptions, observing conditions and days perfectly correspond to the structure and content of the Protohaykian calendar, as well as to the key motifs of Armenian folklore.

C. There is a single-valued connection between the described observations and their positions in the year circle to the stages of cereal cultivation (spring grains, autumn grains).

D. The obtained results are in line with the data, obtained previously due to the studies of the monument, and complete them.

At the same time, we notice the possible observations of some important celestial bodies in 5800 BC. If the same directions were used in later millennia for observing other celestial bodies, and we have already witnessed such a phenomenon from the examination of the stone No. 197<sup>41</sup> of the same monument (Broutian & Malkhasyan, 2021, Malkhasyan, 2021b), then it is necessary to study this date separately.

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<sup>&</sup>lt;sup>41</sup>Here we see the application of the stone No. 197 (it refers to 9000 BC) also in 2341 BC, however, with some change in its vertical axis, which is clearly visible by the examination of the position of the stone.

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## Astronomical Public Activities in Armenia

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#### Abstract

The Byurakan Astrophysical Observatory (BAO) founded by the outstanding scientist Viktor Ambartsumian in 1946 is one of the famous astronomical centers in the world, and particularly in the Eurasian area. Along with large scientific, scientific-organizational, and educational activities, public outreach is also very active. The paper gives an overview of BAO public activities in Armenia and in the region. We emphasize the significance of public activities in raising awareness among public on the topics of astronomy and science in general. BAO serves as a regional center for the IAU initiative Astronomy for Development and hosts the IAU South West and Central Asian (SWCA) ROAD, which has a number of activities, including many public ones.

#### Introduction

Armenia actively participates in the programmes of the IAU Office of Astronomy for Development (OAD, we have established a regional office in Armenia, ROAD, Director Areg Mickaelian; see the corresponding section), Astronomy Outreach (the IAU Office for Astronomy Outreach (OAO) has its Armenian National Coordinator (NOC) Sona Farmanyan and Co-NOC Lilit Darbinyan) and Astronomy Education (the IAU Office for Astronomy Education (OAE) has its Armenian contact points, Marietta Gyulzadyan, Sona Farmanyan and Armine Patatanyan).

BAO and Armenian Astronomical Society (ArAS) also give importance to the development of amateur astronomy. There is "Goodricke John" amateur astronomers' organization created by Ruben Buniatyan, which puts efforts in the field development and in 2009 reached the recognition of 18 September (Viktor Ambartsumian's birthday) as Astronomy Day in Armenia. ArAS created a section for amateur astronomy on its webpage (further to establish Armenian Amateur Astronomical Society, ArAAS), as well as a Facebook group, where one can register as an amateur astronomer.

Along with its scientific, organizational and educational activities, BAO conducts a number of public activities as well: scientific journalism, scientific/astro tourism, popular publications, public events, and other activities. We give an overview on BAO activities related to IAU SWCA ROAD, Scientific Journalism, Scientific/Astro Tourism, Publications, and other public activities.

It is worth mentioning that BAO is the only scientific/research institution in Armenia having Public Relations Department and positions of the head of the department, press-secretary, visits coordinator and event and project manager.

### IAU SWCA ROAD

The International Astronomical Union (IAU) announced its Strategic Plan on Astronomy for Development in 2009, during the International Year of Astronomy (IYA-2009). One of its main components was the creation of the Office of Astronomy for Development (OAD) and corresponding Regional Offices (ROADs) for implementation and coordination of its aims. The OAD was created in Cape Town, South Africa and later on ROADs were created in 11 regions.

Since 2015, Armenia hosts one of these ROADs, IAU South West Asian (SWA), later renamed to South West and Central Asian (SWCA) ROAD. At present, already 6 countries have officially joined (Armenia, Georgia, Iran, Kazakhstan, Tajikistan, and Turkey), but the Office serves for a rather broad region, from Eastern Europe to Central Asia. Armenia's geographical location and its historical role in astronomy

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(both for well-known archaeoastronomical heritage and the presence of the famous Byurakan Astrophysical Observatory (BAO) serve as a link between Europe and Eastern Partnership countries, Middle East and Asia in general.

We run activities in 3 directions, Task Forces (TF):

- TF1 Universities and Research (Professional Astronomy),
- TF2 Children and Schools (Astronomical Education),
- TF3 Public Outreach (Astronomy for the whole community).

Each TF has its people in charge, and this way we also coordinate the activities in the Regional countries. Besides, we are active in the IAU Flagship Programmes, namely Scientific/Astro Tourism is being widely promoted and developed.

Beside activities for the regional countries, IAU SWCA ROAD also encourages and strengthens collaboration with other regions and countries. Especially, promising are contacts with three neighboring ROADs: East Asian (based in Beijing, China), Arab World (based in Amman, Jordan) and European (E-ROAD; Leiden, Netherlands). The first one is coordinating a huge region (China, Mongolia, North Korea) and is especially interested in the development of Silk Road projects that also relate to Armenia. Arab World ROAD is in fact in the same big region (Middle East) and is our closest neighbor (an official agreement was signed between SWCA and Arab World ROADs). The more recently established E-ROAD involves also Armenia and Turkey, as the astronomical societies of these countries are among EAS Affiliated Societies unified by E-ROAD. We have discussed possibilities to tighter collaborate in all areas (TFs) and establish new programs.

### Scientific journalism

Scientific journalism (science journalism or science writing) is one of the many public activities conducted by BAO. Big efforts have been made for the development of Scientific Journalism in Armenia during recent years, namely starting from 2009, the International Year of Astronomy (IYA-2009).

Considering its importance as a tool that makes science available to people and brings them close to science, BAO became the initiator of the field development and made big efforts for that in Armenia. For that purpose, Facebook group of Scientific Journalists of Armenia was formed by Areg Mickaelian in 2010, aiming at gathering journalists around this particular field and enhancing its development. At present, among group members there are around 200 journalists and 500 scientists. Already since 2009 several seminars have been organized. Later on, Sona Farmanyan and Meline Asryan took the responsibility for the development of BAO scientific journalism.

In frame of these activities, Annual Awards have been granted to journalists by BAO. The first Scientific Journalism prizes in Armenia were awarded in 2009 on the occasion of the International Year of Astronomy: having nominations for the most active scientific journalist 2009 and the best scientific paper. Later, prizes were awarded in 2011, which was jointly established by ArAS and the Oxford Armenian Society (OxArm), and the tradition continued in 2014, 2016 (BAO-70) and special prizes were awarded to ARMACAD scientific network and the Armenian Scientific Cooperation (ARMSCOOP) for popularization of science. In summer of 2019 we again attempted to bring journalists together by hosting a seminar on scientific journalism. The journalists, who had significant contribution in disseminating information about science on their own initiative by the end of the year, were nominated for the prizes, hoping to encourage the others to dedicate themselves to this work as well. The Scientific Journalism Prizes 2019 were awarded in 3 nominations: the best printed/online article, the best audio/video news coverage, and the most active journalist. The tradition continued in 2020 and 2021.

Scientific journalism publication activities are given in the Section "Publications".

## Scientific/Astro tourism

Armenia and the whole South West and Central Asia, as the Middle East, are areas with rich history, as well as high-level science. They are rich in scientific, particularly in astronomical sites, among which

archaeological sites related to science, medieval universities, modern scientific institutions and science related museums can be mentioned. Examples of archaeological sites are ancient observatories, petroglyphs (rock art) of astronomical nature, as well as intangible heritage, such as Armenian and other calendars and chronology tightly related to the astronomical knowledge. Modern observatories and astronomical institutions having tools or laboratories which can be presented in terms of tourism, are considered as astronomical tourism sites as well. Space museums are astronomy and space science related museums. Despite the fact that Astronomical (Astro) Tourism is a new direction, it has great perspectives, and Armenia and the neighboring countries have a great potential in this field.

**Scientific Tourism** is a new area not only in Armenia but also in the world. It involves visiting science-related centers. In order to be well organized, it is necessary that the scientific center has proper infrastructure to be able to present the center to the public and in an interesting way. Despite the fact that scientific tourism is a new direction, it has great prospects, and Armenia has great potential in this field. It is very important to present Armenia from this perspective, both science-related archaeological sites and modern institutions and museums. We have created and published the Scientific Tourism map of Armenia, based on our cognitive tours, studies, and also Internet resources.

Astro Tourism. BAO is also actively engaged in Astronomical Tourism, being one of the leading institutions of Armenia. BAO has run projects called "Development of Astro Tourism in South West and Central Asia" and "Scientific Tourism in Armenia" (also involving Astro tourism). The objectives of the projects are to develop Scientific and Astro tourism in South West and Central Asia. Astro Tourism may significantly contribute to education by involving school pupils and students in cognitive tours to research organizations offering society a tight connection with science. In BAO, there are several forms of visits, including both day and night tours, Viktor Ambartsumian house-museum, etc.

More information is given at BAO and ArAS Scientific and Astro Tourism webpages and the Facebook group:

- Facebook group "Scientific Tourism in Armenia": https://www.facebook.com/groups/617695955026936
- BAO as Scientific Tourism centre: https://www.aras.am//BAO/SciTourism/eng/index.php
- IAU OAD project 2016 "Astro Tourism in South West Asia": http://iau-swa-road.aras.am/eng/ AstroTourism/studyvisits.php
- IAU SWCA regional Astro tourism official webpage at: http://astrotourism.aras.am/index.php
- BAO visits page: https://www.bao.am/visits/visits.php

## Publications

The scope of BAO publications is quite wide, both printed and online.

- BAO Press Releases. In March 2019, we started the list of BAO press releases, touching upon various topics connected to BAO and Astronomy in general, including scientific and sky events, BAO scientific and educational activities, etc. (more than 100 press releases yearly in Armenian, but many are also in English). The press releases are available on BAO official website and BAO Facebook and Instagram pages. Moreover, they are occasionally distributed to mass media representatives interested in Scientific Journalism. We should note that BAO closely cooperates with mass media keeping the mailing list constantly updated. This collaboration brings forth to dozens of publications, interviews, press-conferences and articles in Armenian and other languages communicating science to a broad audience. Moreover, BAO has recently been in the center of attention of international mass media companies as well, which once again highlights the legacy it has in science today. Namely, mass media from USA, France, Germany, Switzerland, Poland, Romania, Russia, Latvia, Australia, Kazakhstan, Iran, Lebanon have covered BAO during the last years.
- BAO Interviews. Since 2019, we have initiated BAO interviews to cover various topics of great importance that present interest for the general public and have not received enough coverage by mass media or otherwise. The interviewers are BAO well-known scientists. A number of popular articles (ex. in the NAS RA journal "In the World of Science"), press-conferences, radio/TV programs and films are being produced every year as well.

- ArAS Electronic newsletters ("ArASNews"). Since 2002, via this newsletter, members of the Armenian Astronomical Society (ArAS) community get notified of important events connected to the activities of the society itself and those of BAO. It should be noted, that ArAS has a great role in developing scientific journalism in Armenia: ArAS webpage contains information, regular press-releases, etc.
- Astghagitak ("Star Expert") e-journal. "Astghagitak" contains information on astronomy and provides the links to the materials for the users of all ages. It is different from other classical journals and collects articles available online or includes new scanned articles on various topics. The main topics include: History of Astronomy, Telescopes and Observatories, Astronomy in Armenia, Armenian astronomers, Solar System, Extrasolar planets and Astrobiology, Stars and Nebulae, Galaxies, Cosmology and Cosmogony, Multiwavelength astronomy, Extraterrestrial civilizations, Space flights, Space catastrophes, Astrology, Amateur astronomy, and Astronomical Education.
- Calendar of astronomical events. Since 2012, at the beginning of every year, we release a bilingual online calendar of notorious celestial events occurring during the given year all over the world. It has three main sections: *Sky (celestial) events, International astronomy events, and Armenian astronomy events.* In addition, we have compiled the lists of all *Solar and Lunar eclipses, Triple conjunctions* and *Periodic comets* for 2001-2050, to keep active the recent events and to follow the forthcoming ones at least for the present generations.
- Brochures, calendars and other promotional materials are also published by BAO. Together with the Armenian Ministry of Communications and Transport (and later: Ministry of High-Tech Industry), we have organized the publication of astronomy related postmarks "Viktor Ambartsumian" (2008), "Beniamin Markarian" (2013), "IAU SWCA ROAD" (2016), "BAO-75" postmark (2021) together with a themed postcard and Grigor Gurzadyan (2022).

# Other public activities

- Public Events. BAO organizes various events on Astronomy and related fields, namely public events, like open door events, movie screenings, exhibitions, seminars, conferences, etc. It is important to note that some 24,000 people (Armenian and other citizens) visit BAO annually.
- Films. We have produced a number of short documentary films on BAO and astronomy. In addition, many TV companies are interested in BAO and its activities, and they have produced 9 films during the last 3-4 years. Among them are: "Our Archive" by the Armenian Public TV, 2021, "Byurakan Astrophysical Observatory", by Iranian TV, 2019; "On the Armenian roads: Byurakan", by the Armenian Public TV, 2019; "The Cornerstone: Byurakan", by the Armenian Public TV, 2019; "Viktor Ambartsumian", by Artak Avetyan, 2019; "Viktor Ambartsumian: Episode of Life", by Shoghakat TV, 2018; "The giant star", by Cultural TV of Armenia, 2018; "BAO", by Yerkir Media TV, 2018; "A Universe in the Universe: Viktor Ambartsumian", by the Armenian Public TV, 2017; "BAO", by Geographic TV, 2017.
- Public Lectures. Since 2012, BAO astronomers visit various organizations (schools, universities, army, private companies, etc.) to give popular lectures on various topics of astronomy, such as: Our understanding of the Universe from ancient times to nowadays; Byurakan Astrophysical Observatory and its achievements; Viktor Ambartsumian's life and activity; Beniamin Markarian and Byurakan surveys; Armenian astronomers in the world; Astronomy and Mythology; Solar System; Extrasolar planets; Stars and Nebulae; The World of Galaxies; Large-scale structure of the Universe and Cosmology; Cosmic catastrophes and "End of the World"; Extraterrestrial Civilizations; Astronomy and Astrology; Astronomer's tools; Space Astronomy; Astronomy and Culture, and others.
- **Production of astronomical souvenirs**. For promotional activities, BAO produces a number of varieties of astronomical promotional materials and souvenirs. These are leaflets, fliers, postcards, posters, calendars, cups, pens, coasters, magnets, etc. They are being distributed to amateurs, students, pupils, and the public.

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# The Evolution of Stars and Astrophysics

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#### Abstract

Ambartsumian published this article in Russian 75 years ago. In this work, he showed for the first time that star formation was not interrupted in the past, but continues in our cosmological time. His conclusion was that at the same time as the old stars, such as the Sun, there are also much younger ones, which are only a few tens of millions of years old. Another important conclusion was that stars are born in groups. The author called the groups of young stars stellar associations. Actually, by publishing this article, Ambartsumian established a new, so-called "Byurakan concept" of the formation of space objects.

#### Keywords: Stellar associations, young stars, star formation

Explanation of the origin and evolution of celestial bodies, including such as the Earth and the Sun, is one of the main tasks not only of astronomy but also of all natural science. The field of astronomy that deals with this question is called cosmogony. In the 19th century and at the beginning of the 20th century, cosmogonic information was reduced mainly to the construction of so-called cosmogonic hypotheses. Usually, each cosmogonic hypothesis sought to explain the origin of the present state of that part of the Universe that was known at the time the hypothesis appeared. Thus, after the current state of the solar system was clarified, Laplace raised the question of how it happened. In the recent past, Jeans has already raised the question of the origin of not only the solar system but also the stellar system (Galaxy), where the Sun is one of the members. The same can be said about numerous other cosmogonic hypotheses. However, the authors of the hypotheses were faced with the following difficulty: the planetary system has so far been known only in one example. No other planetary systems have been studied that, being in other stages of development, could give an idea of the possible past or future stages of evolution of our planetary system. Jeans, however, when raising the question of our star system, knew about other star systems, but he was completely possessed by the strange idea that elliptical nebulae and spiral cores do not consist of stars, but their dust and gas. As you know, it turned out that these formations consist of stars. He had a correct idea about the structure of only our star system, and even then in a limited volume around the Sun.

Having no significant observational data on the possible past states of the considered systems of celestial bodies, the authors of the cosmogonic hypotheses were guided by some preconceived notions about the initial state of the system.

Most often, it was assumed that the initial state was a rarefied nebula.

Naturally, this path of research led to speculative constructions, often very fruitless. Only a few of the cosmogonic hypotheses (I mean just the hypotheses of Laplace and Jeans) have played a known positive role in the history of astronomy.

However, over the past thirty years, there has been a radical change in the state of affairs in this area of science. The development of modern astrophysics has led to the accumulation of colossal factual material about stars and stellar systems of the most varied types and at different stages of development. The physical properties of stars in these states have been studied. It is shown that the totality of various states of stars in nature is amazingly diverse. Some are characterized by a high rate of running, i.e., abrupt stages in the evolution of stars, such as the outbursts of novae and supernovae, are observed by us directly and are subjected to careful study. The application of modern statistical-mechanical methods to stellar systems consisting of a large number of members has led to very significant conclusions about the nature of secular changes in these systems.

As a result, the formulation of the cosmogonic problem must be completely changed and has really changed. It should not concern only the current state of an individual system out of a hypothetical initial state. It should already be about the derivation of the general laws of the evolution of celestial bodies and their systems. In particular, the origin of the Sun and the solar system must be understood within the framework of the general theory of stellar evolution.

This does not mean that the task of cosmogony now seems easier than it used to be. On the contrary, the richness of observational data on stars has led to the posing in the cosmogony of a whole series of new and, moreover, very deep questions about which we had no idea before. However, at the same time, it became possible to start solving the problem, starting with a consideration of a simpler problem about which of the observed states of the stars and how are genetically related to each other. By going this way, carefully studying the factual material and introducing at the necessary moments the corresponding physical hypotheses and theories (one cannot deny the usefulness of hypotheses where they are really needed), it will be possible to solve the entire cosmogonic problem.

However, even to this day, some authors continue to follow the path of speculative constructions, such as old cosmogonic hypotheses, which have already become unusable, leaving aside the entire arsenal of modern knowledge about the physical states of stars, neglecting the conclusions of the statistical mechanics of stellar systems and theoretical physics in general, and thereby piling up errors on errors. In this report, I did not consider it possible to dwell on these fruitless constructions.

Those facts and astrophysical data of cosmogonic significance, which I cite below, were obtained largely thanks to the works of Soviet astrophysicists, who, despite some weakness of our observational base, correctly direct their works toward solving the fundamental, fundamental problems of stellar physics associated with the problem development of stars, and achieve success in this field. Therefore, it is appropriate to cite them here, when summing up the results of Soviet science over 30 years.

We will first give data on individual stars and then move on to stellar systems.

Individual stars. The state of each star is characterized by the values of three basic quantities: its mass, radius, and luminosity, i.e., the power of the emitted radiation. However, not all conceivable combinations of values of mass, radius, and luminosity are found in nature. In order to make this clear, let us focus on two quantities: let's say the radius and the luminosity. In the diagram showing the dependence of luminosity on the radius, each star will be represented by one point. It turns out that the points representing the totality of stars that make up our Galaxy are concentrated around some specific lines in this diagram. According to the data we know, the overwhelming majority of stars (tens of billions in our Galaxy) are concentrated around one such line on the radius-luminosity diagram. These stars are called main sequence stars. The so-called white dwarfs, located in another area of this diagram, are the second most abundant. This is the second sequence in the diagram. The absolute number of white dwarfs should be in the hundreds of millions. By the way, this abundance of white dwarfs was first established by Soviet astronomers (Ambartsumian & Shain, 1936). In third place in terms of number is a group or sequence of giant stars. Their number in the Galaxy is, at best, several million. Indications of the existence of another, new sequence - the sequence of subdwarfs, were obtained by prof. Parenago (Parenago, 1944). We do not yet have data on the number of this sequence, and it is difficult to make a judgment about its evolutionary significance.

When the state of the star changes, the values of mass, luminosity, and radius should change. Therefore, in its evolution, the star must move along our diagram. The question is what are the possible routes of this movement.

The very examination of the various sequences we observe in the radius-luminosity diagram allows us to draw interesting conclusions. Namely, it turns out that of all the conceivable paths of evolution, only a few do not contradict this diagram. The rest contradict it and therefore must be discarded.

Obviously, the vast majority of stars are on the main sequence almost all the time. Therefore, almost all the time, their changes should be expressed in moving along the main sequence. However, stars located at different points in the main sequence have different masses. Therefore, any significant movement of a star along the main sequence must be accompanied by a significant change in mass.

This leads to the following conclusion:

Either the star of the main sequence, while remaining in it, hardly changes its state or the mass of the star changes.

It must be mentioned that so far, no possible method for increasing the mass of stars has been observed and has not been proposed theoretically. The increase due to interstellar matter is negligible. As for the decrease in mass, a similar mechanism was proposed by Eddington and Jeans and consists of the loss of mass due to radiation. The data arising from the statistical mechanics of stellar systems leads, as I have shown elsewhere, in a completely unambiguous way to such intervals of the existence of stellar systems in which the mass spent on radiation is negligible in comparison with the total mass of the star.

However, the investigations carried out in recent years (Ambartsumian, 1939b) on the direct emission of 128Ambartsumian V.A.

matter from stars have made it possible to find out that the loss of stellar mass that occurs in this way is many times greater than the loss due to radiation and may have an important evolutionary significance.

Below we will touch on several important examples of such direct mass emission, in which the mass of a star will be significantly reduced. It should be noted here, however, that most of the observed cases of intense ejection of matter refer to hot stars.

As for the giant branch, masses of the same order correspond to different states of this branch. Therefore, possible movements along this branch can occur without a significant change in the mass of the star. In the case of white dwarfs, for most of the known objects of this kind, we do not know the mass value. In this regard, it is still very difficult to talk about what changes in mass are possible for the advancement of white dwarfs along their branches. Finally, we must take into account the possibility of jumping transition from one branch to another.

At the same time, if we take jump-like transitions with a change in mass, then those can be of the most diverse nature and directions (branch of giants - branch of giants, but at a different point, branch of giants - main sequence, white dwarf - main sequence, white dwarf - giant, etc.). The jumps without a significant change in mass do not contradict the radius-luminosity diagram as well, for example, from the main sequence to white dwarfs and back, presumably from white dwarfs to giants or vice versa.

We see that just a simple consideration of this diagram shows, which paths of evolution on this diagram contradict it and which do not contradict it.

It may be asked whether a gradual evolutionary movement between these branches is also possible. We answer: it is possible, but the observed low frequency of stars between the branches indicates either that this happens with only a small percentage of stars, or that the residence time between the branches is very short, i.e., the transition is nevertheless made in leaps and bounds.

In order to choose from the paths of development and evolution allowed by the diagram under consideration, those that are true, i.e. to make a further selection among all conceivable changes in the state of stars, we must turn to a number of facts related to the study, so to speak, of small stellar systems, i.e. double stars and star clusters.

Binary stars converge and diverge from other stars in our Galaxy during their lifetime. At such approaches, the systems are perturbed and the elements of their orbits change. In the course of time, a certain equilibrium distribution of the orbital elements should be established. Analyzing the data on the eccentricities of binary stars, Jeans (1935) came to the conclusion that such a uniform distribution has already occurred. However, on the basis of the data relating to a more significant characteristic for the question under consideration, to the semi-major axes of the orbits, we (Ambartsumian, 1937) found that this conclusion was incorrect. It turned out that the distribution of the elements of the orbits of stellar pairs is completely different from the equilibrium one. This led to the conclusion that the time required for the establishment of an equilibrium distribution (relaxation time) had not yet expired. Thus, it was possible to calculate that the age of the overwhelming majority of stellar pairs does not exceed several billion years.

This is the first, extremely important cosmogonic conclusion from modern astrophysics. However, the approach of a pair with a third star can lead, in other cases, to the breakup of the pair. Theoretically and opposite processes of pairing are conceivable in the case of a random approach of three stars.

In statistical equilibrium, both processes occur equally often, dissociative equilibrium takes place. However, the observed ratio of the number of pairs to the number of single stars is millions of times greater than it should have been at dissociative equilibrium (Ambartsumian, 1937) Since the probabilities of the formation and decay of pairs do not significantly depend on the presence or absence of this equilibrium, it follows that now in the stellar system decay processes occur millions of times more often than the processes of pair formation (see Appendix 1). In addition, we come to the conclusion that the totality of star pairs existing in the Galaxy cannot be the product of random encounters. The components of each pair have a common origin.

This is the second extremely important cosmogonic conclusion from the data of modern astrophysics.

Open star clusters. Open clusters usually consist of several tens or hundreds of stars. In some cases, the number of members of the cluster is measured in thousands. They are systems in which all members are connected to each other by gravitational forces. Typical open clusters are the Pleiades and Hyades. Each star cluster moves as a whole around the center of the Galaxy. However, in addition to this, each star entering the cluster makes some movement within the cluster, under the combined action of the rest of its stars. In stellar dynamics, it is proved that as a result of the random mutual close encounters of individual stars, a certain fraction of the stars will receive kinetic energy sufficient to leave the cluster. So, over time, a complete disintegration of the cluster may occur (Ambartsumian, 1938). The calculation shows that the

time required for such decay is measured in several billion years, and in the case of clusters of poor stars several hundred million years. In this case, dwarfs, i.e. low-mass stars leave the cluster faster, and already at the first stages of its existence, the cluster becomes relatively poor dwarf stars.

Some open clusters, such as and of Perseus, Messier 11, are comparatively rich in dwarfs. One might think that such systems are younger than other ones.

Among the features of these and similar clusters is their richness in B- and O-type stars, i.e., hot stars of high luminosity. Among other things, they also contain hot stars with bright lines and P Cyg stars. Both are distinguished by the fact that from them there is a continuous outflow of matter, which in any case cannot continue in each star for more than several hundred thousand years, otherwise, all the matter of the star will be exhausted. Therefore, such a state, when in the cluster there is continuously one or several P Cyg or Be stars, cannot last more than several tens of millions of years. This confirms the youth of this kind of star clusters. In turn, the presence in such clusters of a large number of hot stars of high luminosity proves that these stars are young.

Star associations. Even stronger evidence in favor of this is the presence of scattered groups of hot stars around some clusters, for example, the double cluster  $\chi$  and h Persei, the NGC 6231 cluster, and others. These scattered groups, which are associations of loosely connected members, are unstable and, for dynamic reasons, must disintegrate over several tens of millions of years. I would suggest calling them star associations. In such a stellar association around NGC6231, there are, among only twenty high luminosity stars, for example, two Wolf-Rayet stars and two P Cyg stars. According to Kozyrev's theory of extended photospheres (Kozyrev, 1934), stars of these types emit one hundred thousandths of the mass of the Sun every year. Therefore, such an outflow cannot continue for one star without change for more than a million or two million years. Therefore, it is not difficult to see that such a state of these stellar associations, which undoubtedly have a common origin, can last generally at most on the order of tens of millions of years.

Especially remarkable is the stellar association around the double cluster  $\chi$  and h Persei. In a circle with a radius of 2.5 degrees centered in this cluster, there are several dozen type B and M supergiants. It is possible that this association also contains many stars of other physical types. Taking a distance of two thousand parsecs for this system, we find that its diameter is about two hundred parsecs. The double cluster forms the core of this association. This core itself may have the same degree of stability as other open clusters, but the entire association as a whole is certainly unstable and should disintegrate under the disturbing influence of the galactic center unless the mass of this system is estimated at millions of solar masses. However, there is no evidence in favor of such a large mass.

Groups of T Tauri variable stars are another striking example of young stellar associations.

The facts show that almost all the variable stars of this type known to us, characterized by extremely irregular changes in brightness and certain other physical characteristics, are concentrated in two or three specific parts of the sky. Such an extremely pronounced tendency towards crowding cannot in any way be connected with the accident in their discovery. There is no doubt that we are dealing here with members of certain physical groups of stars. However, the linear dimensions of each of these groups are so large that there can be no question of their proximity in space to be supported by the forces of mutual attraction. The tidal action emanating from the center of the Galaxy should destroy them very quickly. Most likely, one should assume that these stars are already slowly diverging. So, one of these groups of 7 T Tauri stars, according to Joy (1945), has a center at a point in the sky with a galactic longitude of  $140^{\circ}$  and a latitude of  $-14^{\circ}$ . Joy's data (Joy, 1945) suggest that the linear dimensions of this system reach 10–20 parsecs. Even if we assume that the number of members of this system is more than a thousand, this stellar association, cannot be held for a long time under the influence of internal forces of attraction. The conclusion is that if we now observe these stars together, it is because they have recently formed and have not yet had time to disperse. This stellar association cannot be older than one hundred million years. This period is short compared to the age of the Galaxy, which we estimate at several billion years. Consequently, even now, in our era, the formation of stars in the Galaxy continues. This is also an extremely important conclusion from the data of modern astrophysics.

In the case of T Tau stars, we are already dealing with dwarfs. By the way, they are closely related to small comet-like nebulae, showing bright lines in the spectrum, and, undoubtedly, will bring new important data for cosmogony in the future. Sanford's just-published study on the structure of the T Tauri spectrum confirms that there is a continuous outflow of matter from this star. By the way, almost half of the T Tau stars turned out to be visually binary. In those cases when it was possible to obtain the spectrum of the companion, it turned out to be the spectrum of an M-type dwarf with bright lines. Since there is no doubt about the common origin of the companion and the main star (see above on binary stars), we conclude that

at least these bright-line M-type dwarfs are as young as T Tauri stars.

If we add here that about 40 late-type dwarf stars with bright lines, mainly M-type dwarfs, were discovered in the region of the considered stellar association in Taurus, it becomes clear that they can be attributed to a common origin with the T Tau type variables, and therefore they are also very young stars.

Since most of the stars in the Galaxy are type M dwarfs, further study of this issue will be of great importance for cosmogony.

It is also necessary to pay attention to the fact that due to the low absolute brightness of stars of the T Tauri type, the associations of stars, consisting of them, can still be detected by us only at small distances from the Sun. This is also facilitated by the low density in these associations. This can explain that until now we know only two associations of these variables and, moreover, both at distances of the order of one hundred parsecs. Therefore, there is no doubt that the number of such associations in the Galaxy is measured in at least thousands. If their age is on average about one hundred million years, then one can expect that among them there are also younger ones with an age of the order of, say, ten million years. After all, there is no reason to believe that over the past two hundred million years there was such a special moment in the life of the Galaxy, when such associations immediately, at a time, were formed, after which they ceased to arise.

So, we can say that, although the age of the Galaxy according to all stellar dynamics data is of the order of several billion years, the formation of all star clusters did not occur simultaneously and continues to this day. In any case, in the Galaxy and the Magellanic Clouds, we have very young star clusters and associations that could not exist in their present form for more than several tens of millions of years. The process of formation of open clusters and associations in the Galaxy is now continuing.

On the other hand, the formation of stellar associations and star clusters could not occur by combining into one group of previously independent stars. The proofs of the impossibility of such a mechanical emergence of a cluster (or association) of single stars are of the same nature as the argument about double stars that we gave above. The only difference is that in this case all the arguments become even stronger since the ratio of the probability of destruction of a cluster to the probability of formation of a cluster as a result of star encounters under conditions existing in the Galaxy is expressed by a number containing hundreds of significant digits.

Thus, we come to the result: stellar associations (and some clusters) as systems of stars are young, and somehow arise in our Galaxy, but they do not arise by combining previously independent stars. The stars belonging to associations and clusters, therefore, did not exist before the corresponding associations and clusters emerged. On the other hand, these systems themselves, by definition, are composed of stars.

We come to the inevitable conclusion that stars in open clusters (associations) are formed during the formation of this cluster (associations).

Comparing this with the fact that in the Galaxy we have very young stellar associations with an age of about ten million years, we conclude that the stars contained in these associations have the same age.

If so, then by studying stars in these stellar systems, we should get an idea of the states of stars in the period immediately after their formation.

We see here a rather large variety of states: Wolf-Rayet stars, P Cygnus stars, O and B stars with and without bright lines, variable T Tauri dwarfs, and yellow and red dwarfs with bright lines.

On the radius-luminosity diagram, all these states are depicted by points of the main sequence. In this case, the pure occurrence of bright lines of the P Cygnus type in the spectra of these young stars is evidence that a continuous outflow of matter occurs from them, i.e., they are not yet in stationary states. It is possible that in the future they turn into ordinary stars of the main sequence.

Thus, it should be assumed that newly formed stars enter the radius-luminosity diagram not only from one end of the main sequence but along the entire front of this sequence.

Origin of open star clusters. The question is, from what and how does the formation of stellar associations and open star clusters come about? How do appear the stars that make up these systems, namely, the Wolf-Rayet stars, P Cyg, and T Tau type stars, from which there is a continuous ejection of matter and which, perhaps, subsequently turn into ordinary stars of the main sequence. We do not know of luminous stars of such a large mass, from which, through some fission processes, open star clusters could arise. Obviously, star clusters and associations must arise from some kind of dark or faintly luminous objects of enormous mass.

In this case, there are two possibilities:

a) The original body occupied the same large volume as the stellar system that originated from it (cluster, association). Then it is possible to identify this original body with a dark nebula. At present, the presence

in the Galaxy of a large number of dark diffuse nebulae consisting of cosmic dust can be considered proven. In this case, we must attribute to these nebulae masses of up to several hundred solar masses, which is much higher than the previously estimated masses of dark nebulae.

b) The formation of stellar systems of the type under consideration occurred by the division and mutual removal of the formed parts of a certain body of small dimensions in comparison with the diameters of these systems. For example, it could be a body with a diameter on the order of the diameters of ordinary stars. However, in order to overcome the force of mutual attraction and disperse over large distances, these parts should have received significant kinetic energies at the time of fission. Then the question is why these kinetic energies turned out to be almost exactly equal to the one needed to overcome the attraction field, and there are no cases at all when, after overcoming this field, the star retains a significant fraction of the kinetic energy, and thus the initial velocity.

Such stars, however, would leave the cluster but would remain in the Galaxy in the form of fast-flying stars. But we do not observe fast-flying P Cyg or even B stars in the Galaxy.

At present, no way is seen to overcome this difficulty associated with the hypothesis of an initial body of small linear dimensions.

Therefore, leaving open the question of other properties of the bodies from which the clusters and associations were formed, we must consider the low luminosity of these objects to be reliable.

This idea that star clusters and associations before their formation were some kinds of very weakly luminous objects, perhaps of a very small radius, must be connected with data on the integral emissivity in stellar systems. By the integral emissivity in a stellar system, I mean the amount of energy emitted per unit time by a unit of mass of the stellar system. It is a "macroscopic" quantity that characterizes every point in the system. It turns out that this emissivity (according to Oort) for some elliptical nebulae is, in round numbers, a hundred times less than for the vicinity of the Sun in the Galaxy (Oort 1940). When deriving the value of this coefficient, Oort used data on the rotation rates of these systems. Oort suggested that such a low emissivity value indicates a large amount of diffuse matter (cosmic dust) in them. Now that we know something about the population of elliptical systems (Baade), it is clear that these systems are much poorer in the diffuse matter than the Galaxy, they are almost devoid of it (see Appendix 2). It remains to assume the presence of a large number of clouds of low luminosity and relatively large mass.

And now it is difficult to give a clear answer to this question. However, it is worth paying attention to the close relationship of hot stars with cool supergiants and variable stars of late types. A large number of objects are already known that show in the spectrum, on the one hand, characteristics of O or B type star, on the other, characteristics of cool M star. Suffice it to name the famous star P Aqu, in which not only a set of lines, but even a continuous spectrum seems to be the superposition of continuous spectra of two stars - hot and cold.

Now, after the works of the Leningrad astrophysicist Sobolev, it is clear that in fact, we are not dealing here with the addition of the spectrum of two stars, but we are talking about the addition of the spectrum of the hot core and the outer relatively cold shell.

Even a small increase in the optical thickness of the envelope leads to a complete attenuation of the direct radiation of the hot nucleus, and the energy distribution becomes entirely corresponding to type M. The presence of a nucleus is detected only due to the emission lines. With an even thicker shell, the emission lines should also disappear. We will have an ordinary cold supergiant.

It is also known that the masses of type M supergiants are equal to the masses of stars B and O. Also, the luminosities of both categories of stars are equal.

If the internal structure of yellow and red supergiants and giants would differ significantly from the internal structure of main sequence stars with the same mass, then it would be natural to expect a different performance of energy sources in them. Meanwhile, they obey the same ratio between mass and luminosity, which is established for the stars of the main sequence. This also makes one think that there is no significant difference in the internal structure of the stars of the giant branch and the main sequence. Only the structure of the outer layers is different.

Thus, it turns out that stars of type B and O, i.e. hot stars of high luminosity, surrounding themselves with rarefied shells of a sufficiently large radius, can appear as such cold supergiants.

From the point of view of the spatial distribution, which, as we will see below, is a well-known criterion for the genetic relationship of objects of two types, the situation is good here. The spatial distributions of type B stars and late-type supergiant stars are very similar.

From this point of view, the facts about the rotation of stars, established over the past two decades by Academician Shain and American astrophysicist Struve, are of great importance. They indicate that a very significant part of the stars of types B and A have fast rotation. If the evolution of these stars proceeded along the main sequence towards dwarfs, then among the latter we would have to observe, by virtue of the law of conservation of rotational moment, even higher rotation rates. Meanwhile, observations indicate the opposite. True, part of the torque could be carried away by the ejected substance. But we would have to assume that the overwhelming part of the rotational moment leaves with the ejected matter. Such a mechanism has not yet been proposed. Meanwhile, during the formation of late-type supergiants from a type B star, the linear rotation velocity, due to the same law of conservation of momentum, should decrease, which is actually observed.

However, I must make a reservation here that the requirement to fulfill the law of conservation of the rotational moment regardless of the above question leads to difficulties in a number of other questions of cosmogony. Here I mean not only the problem of the origin of the solar system but also the whole complex of questions related to the origin of multiple stars.

By the way, it is precisely these difficulties associated with the rotational moment that have recently forced many authors, who are following the path of drawing up abstract cosmogonic hypotheses, to again turn to the hypothesis of capture (ready-made satellites or initial matter - it's all the same). Meanwhile, all the factual data convincingly indicate that the formation and evolution of systems of celestial bodies occur due to internal reasons, according to the laws of internal development, and serious difficulties associated with rotational moments indicate only the existence of some, we have not yet clarified, effects, the introduction of which will eliminate these difficulties.

The presence of these difficulties shows that, in theoretical terms, cosmogonic phenomena turn out to be much deeper than we thought until now. Here, in this old problem, apparently, we must still encounter a whole series of qualitatively new, original phenomena that represent a fundamental novelty for science.

However, the formulation of these questions is still moving forward very slowly due to the absence of a correct theory of the internal structure of stars.

The data of modern astrophysics on some extremely proceeding stages in the development of stars are of great importance for cosmogony. While the lifespan of most stars is measured in billions of years, i.e., for most stages of evolution, such periods are required, in comparison with which human life and even the duration of the entire history of human astrophysical observations seem to be an instant, we, along with this, are witnesses to the fact when changes in the structure of a star are directly observed within a few days, and sometimes hours. The outbursts of new stars can serve as an example of such processes.

*Novae*. The outbursts of Novae are cosmic phenomena that are absolutely amazing in scale and speed. Within a few tens of hours, the star increases its brightness by several tens of thousands of times. It throws out into the surrounding space a shell of gas (at a speed of about a thousand kilometers per second), which previously constituted part of its mass. Apparently, we are dealing here with a giant explosion associated with the almost instantaneous release of large amounts of intra-atomic energy. Milne suggested that the outburst of a Nova is a process of rapid transition from the state of an "ordinary" star to the state of a white dwarf.

However, statistical data on the frequency of Novae outbreaks in stellar systems convince us that, at least with part of the stars included in stellar systems, a flare occurs not once, but many times in life.

In this regard, mention should be made of the excellent study of the Moscow astronomers (Kukarkin & Parenago, 1937) concerning Nova-like variables.

The point is that, along with Nova stars, the so-called Nova-like variables have long been known, i.e., those stars that experience flares at regular, albeit inconsistent, intervals. These outbreaks are usually on a smaller scale than the flares of the Novae. Despite the difference in the time interval between two successive flares, i.e., volatility of the cycle, for each Nova variable we have some average cycle length between two successive flares.

It turned out that there is a simple functional relationship between the average cycle length and the average brightness change amplitude. The greater the amplitude, the longer the average cycle. If this dependence is extrapolated to the amplitudes of ordinary Novae, then it turns out that the outbursts of each Nova should repeat once every several thousand years. In other words, the idea arose that Novae differ from Nova-like variables only in the length of the cycle.

The assumptions of Parenago and Kukarkin were brilliantly confirmed when last year the second outburst of the star T Coronae Borealis took place before our very eyes, the first outburst of which took place in 1866. Since until 1946 only one outburst of this star was observed, it was considered an ordinary Nova. The time interval between two flashes was in full agreement with the indicated relationship between the amplitude and the cycle length. Thus, there is no doubt now that all ordinary Novae are recurrent.

As a result of calculations carried out by my colleagues, many methods have been used to determine the masses of the shells ejected during the outbursts of Novae (Ambartsumian, 1939a). It turned out that with each flare, a mass of the order of 10-5 solar masses is ejected. It is natural from this to conclude that with each separate outburst, the structure of the Nova changes little (since the mass also changes little), but a number of successive outbursts lead to a radical change in the structure of the star.

The question arises: the transition between which two states corresponds to this sequence of outbreaks of the Nova, accompanied by a significant change in mass?

The same question can be asked with respect to Nova-like variables.

Finally, Supernovae are of great importance: during such explosions of stars, the stars for several days become a hundred million times brighter than the Sun. The calculation shows that in the case of supernova explosions, a mass is immediately ejected, which in any case constitutes a noticeable fraction of the mass of the star. Therefore, one outburst of such a supernova already means a change in the entire structure of the star, which occurs abruptly.

Again, the question arises, what were the supernovae before the outburst and what do they turn into after the outburst?

Similar examples, when an intermediate state or transient is given, but the initial and final states are unknown, could be multiplied.

Modern astrophysics, along with Nova stars, Supernovae, and Nova-like variables, knows a whole string of types of stars that can be summed up under one general category of nonstationary stars (type Be stars, type Z Andromeda, planetary nebulae, etc.). All these non-stationary states are transient states and have a limited duration. They relate in each case two different stages of a star's life, and the question of which preceding and subsequent states correspond to these unsteady states is extremely important.

I will give one more example here in order to point out later on a possible way of solving such problems.

Short-period Cepheids. Short-period Cepheids form a sharply delineated group of stars that stand out in a number of their features. Changes in their brightness are accompanied by changes in the radius, i.e., pulsations. What state were they in before the onset of pulsations, into what state do they pass after the end of the pulsations, and how long is the stage of variability?

Let us denote the state before entering the stage of a short-period Cepheid by X, and after exiting it by Y. The question is, what are X and Y?

The following method can provide an indication of which physical types of stars to look for X and Y stars.

The point is that the distribution of stellar velocities cannot change sensitively over a period that is small compared to the duration of a star's entire life. Therefore, the distribution of the velocities of shortperiod Cepheids in the case under consideration should be similar to the distribution of the velocities of both X-stars and Y-stars.

Since the velocity distribution determines the spatial distribution of stars, the same can be said for the corresponding spatial distributions. But the spatial distribution of short-period Cepheids has the very important feature that these stars meet at very large distances from the Galactic plane. Therefore, X- and Y-stars should also occur in the corresponding parts of space. The shorter the duration of the variability stage in comparison with the X - Y stages, the greater the number of X - Y stars should be compared to short-period Cepheids. From this point of view, the paper published this year by Humason and Zwicky (1947) on the presence of a known number of blue stars at high galactic latitudes is interesting, showing that in the considered regions of space, along with short-period Cepheids and globular clusters, there are also noticeable numbers of other stars. Data on their numbers are very scarce, but they force us to conclude that the duration of the stage of the short-period Cepheid cannot be very short in comparison with the entire duration of the star's life. It is measured for at least tens of millions of years, if not more. However, for conclusions, it is still necessary to obtain data on the number of dwarfs in these regions of space.

What we said about short-period Cepheids is also applicable to other transitional stages (Novae, Supernovae, planetary nebulae, etc.). We must look for other stages in the development of these objects among stars with similar spatial distributions. Unfortunately, we still do not know very well the galactic spatial distributions for individual physical types, since the transition from the visible distribution over the sky to the spatial one is extremely difficult. But, for example, we can already say that there is a similarity between the distribution of planetary nebulae and the distribution of ordinary dwarfs. A whole series of other interesting examples from this area could be cited, but it would be more expedient to wait until more complete data on the spatial distribution and the distribution laws of the velocities of stars of different physical nature are accumulated.

Planetary nebulae. Until recently it seemed that we were close to solving the problem of the origin of planetary nebulae. The fact is that the gaseous envelopes ejected during the outbursts of Nova stars have a certain similarity with planetary nebulae. However, it was found that the masses of planetary nebulae are measured at least hundredths (if not tenths) of the solar mass and therefore are thousands of times larger than the masses of the shells ejected by the novae. On the other hand, it was found that the brightness of the Nova at the maximum is the higher, the more mass is ejected. Consequently, if only planetary nebulae were formed as a result of explosions similar to the outbreak of Nova, then the scale of such explosions should have been much larger and the brightness of the flared star at its maximum was thousands of times higher than that of Nova. It was natural to assume that such explosions leading to the formation of planetary nebulae are supernova explosions.

Note that the assumption that planetary nebulae are formed as a result of the ejection of an envelope by central stars, in itself, can hardly raise any doubts. Observations indicate that the planetary nebulae we observe are in the process of expanding. On the other hand, it has been theoretically proven that a planetary nebula cannot be in a state of statistical equilibrium. The observed expansion rates of planetary nebulae make it possible to calculate that their age cannot exceed ten thousand years in order of magnitude. During this period they must scatter in space and become invisible. On the other hand, according to the calculations made by (Parenago, 1947), the number of all planetary nebulae in our Galaxy should be about 15000. Under these conditions, to maintain the number of planetary nebulae at this level, it is necessary that on average more than one planetary nebula arise annually. Meanwhile, according to the available data, in one Galaxy, on average, one Supernova flares out in five hundred years. Therefore, supernova explosions cannot be identified with the processes of the formation of planetary nebulae. Consequently, the question of the origin of planetary nebulae requires further study. As for the Supernovae, one should pay attention to the recent suggestion by Rusakov (1947) that diffuse nebulae arise as a result of supernova explosions.

Evolutionary connection between stars and interstellar matter. This connection is one of the most exciting problems in astrophysics. The authors of the so-called cosmogonic hypotheses very often sought to prove that stars and other celestial bodies arose from nebulae. Interstellar matter is a collection of nebulae. We have already seen that modern astrophysics knows many cases when the rarefied matter in a gaseous state is ejected from stars. There are also very strong reasons to believe that particles of interstellar dust can concentrate from interstellar gas.

The presence of reverse processes - the transformation of diffuse matter into stars, has not yet been proven. Their theoretical possibility is not properly substantiated and needs to be studied. However, it should be noted that diffuse nebulae are found in the same galaxies and in the same regions of galaxies where open clusters, type O and B stars, and other young formations are often found. Diffuse nebulae, according to Baade's terminology, belong to the first type of population in the Galaxy. Therefore, their evolutionary role deserves careful study.

Two types of populations of stellar systems. The establishment of two types of populations of stellar systems is a fundamental fact that cannot be ignored when studying the problems of stellar evolution. Since the spatial distribution of the stars that make up the population of these two types differs sharply from each other, it must be assumed that constant transitions from states belonging to one of these types to states belonging to the other type do not occur. Therefore, short-period Cepheids and another type II objects are not directly related evolutionarily to type B, O, Wolf-Rayet stars, and others. However, a deeper evolutionary connection, rooted in the formation of our Galaxy, is by no means excluded. The facts established regarding various types of galactic populations have already forced many to abandon previous misconceptions (for example, the idea that elliptical nebulae are the initial stage in the development of galaxies).

Here we want to draw attention only to the following circumstance. In galaxies such as the Magellanic Clouds, we have a large abundance of supergiants, P Cyg stars, and open clusters. All these are undoubtedly young formations. In particular, in the Large Magellanic Cloud, attention is drawn to a large number of open clusters, which include a significant number of supergiants and which have unusually large linear dimensions. Thus, the NGC 1910 cluster, which includes the brightest of the known supergiants, has a diameter of about 70 parsecs.

On the other hand, it is known that open clusters observed in the Galaxy have diameters on the order of two or three parsecs. It seems that the Large Magellanic Cloud is much richer in open clusters of large diameter. In fact, the difference is apparent. It is easy to see that the above stellar associations in the Galaxy, containing a large number of supergiants, when observed from outer galaxies, should stand out entirely against the galactic stellar background since supergiants are very rare among background stars. For an observer located inside our Galaxy, these supergiants have the same apparent brightness as stars of low absolute brightness, which are close to the observer, and are lost among the latter. Such an observer is struck by only the nuclei of associations, which are ordinary galactic clusters.

So, when observed from the Magellanic Clouds, the association of stars around and Perseus should stand out as a giant star cluster with a diameter of two hundred parsecs with a double core. Obviously, there is no such size association in the Large Magellanic Cloud.

The full significance of the facts relating to different types of population of galaxies will become clear in the coming years. They can quickly generalize the factual material that relates to our Galaxy.

We have given here only a few examples showing the fundamental cosmogonic significance of many facts established by modern astrophysics. These examples provide fair answers to many questions, but it is still impossible to merge them into a unified theory of stellar evolution. In particular, as you can see, we have not yet made any conclusions about the process of star formation.

But it becomes obvious that in the future cosmogony will increasingly rely on a solid and broad base, consisting of the facts established by modern astrophysics, and increasingly lose the character of a speculative discipline, which was inherent in it even in the recent past.

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# Appendices

## Appendix A On the question of the absence of dissociative equilibrium in a stellar system

In a stellar system, from a mechanical point of view, both processes of destruction of stellar pairs and processes leading to the creation of a pair of two single stars are possible. The destruction of a pair can occur when a third disturbing star passes by the pair. The reverse process, when three stars meet and when, under the influence of one of the stars, the other two form a pair, giving the energy of relative motion to the first star, leads to the formation of a double star. In the course of time, a dissociative equilibrium should be established in the stellar system, in which these opposite processes compensate for each other.

Let us set ourselves the task of finding out whether there is a dissociative equilibrium in the Galaxy at the present time.

In this case, for definiteness, we consider pairs made up of two types of stars: stars of the type  $\alpha$  with masses  $m_{\alpha}$  and stars of the type  $\beta$  with masses  $m_{\beta}$ . Let's assume that  $m_{\alpha} > m_{\beta}$ .

The number of single stars  $\alpha$  and  $\beta$  per unit volume is denoted by  $n_{\alpha}$  and  $n_{\beta}$  respectively. Let us now select from the volume unit all pairs  $\alpha\beta$  for which the distance between the components lies between  $r_1$  and  $r_2$ . Let the number of such pairs be  $n_{\alpha\beta}(r_1, r_2)$ . For the number of such pairs, the dissociation formula gives

$$\frac{n_{\alpha\beta}\left(r_{1},r_{2}\right)}{n_{\beta}} = \frac{\Gamma\left(r_{1},r_{2}\right)}{\left(2\pi m_{\beta}\Theta\right)^{3/2}}n_{\alpha},\tag{1}$$

where  $\Gamma(r_1, r_2)$  is the sum over the states corresponding to all possible states of the satellite  $\beta$  around one star  $\alpha$  for which the distance is between  $r_1$  and  $r_2$ .

Here  $\frac{3}{2}\Theta$  is the average kinetic energy of single stars. We have

$$\Gamma\left(r_{1}, r_{2}\right) = \int e^{-\frac{\varepsilon}{\Theta}} d\Gamma_{\beta},$$

where the integration is extended to the region of phase space in which the distance to the main star lies within the considered limits.

Let us now take these limits such that  $\varepsilon \ll \Theta$  is everywhere in this part of the phase space. This requirement, for example, will be satisfied if we take  $r_1 = 100AU$ ,  $r_2 = 1000AU$ 

Then  $e^{-\frac{\varepsilon}{\Theta}}$  under the integral sign can be replaced by unity and

$$\Gamma\left(r_{1},r_{2}\right) = \int d\Gamma = \iiint \iiint dx dy dz dp_{x} dp_{y} dp_{z} = 16\pi^{2} \int_{r_{1}}^{r_{2}} dr \int_{0}^{P_{0}} r^{2} p^{2} dp,$$

where p is the value of the momentum vector. At a given distance r from the central star, in an elliptical motion, p cannot exceed the limit  $P_0$ , given by the formula

$$\frac{P_0^2}{2m_\beta} = \frac{Gm_\alpha m_\beta}{r}$$

otherwise the satellite will be hyperbolic. That's why

$$\int_{0}^{P_{0}} p^{2} dp = \frac{P_{0}^{3}}{3} = frac 13m_{\beta}^{3} \left(\frac{2Gm_{\alpha}}{r}\right)^{3/2},$$

whence it follows that

$$\Gamma(r_1, r_2) = \frac{16}{3} \pi^2 m_\beta^3 (2Gm_\alpha)^{3/2} \int_{r_1}^{r_2} r^{1/2} dr = \frac{32}{9} \pi^2 m_\beta^3 (2Gm_\alpha)^{3/2} \left( r_2^{3/2} - r_1^{3/2} \right)$$

or as in this example,  $r_2^3 \gg r_1^3$ 

$$\Gamma(r_1, r_2) = \frac{32}{9} \pi^2 m_\beta^3 (2Gm_\alpha r_2)^{3/2}$$

Substituting this result into (1), we find

$$\frac{n_{\alpha\beta}(r_1, r_2)}{n_{\beta}} = \frac{32}{9} \pi^{1/2} \left(\frac{Gm_{\beta}m_{\alpha}}{r_2\Theta}\right)^{3/2} n_{\alpha} r_2^3.$$

The two dimensionless factors included in the right-hand side

$$n_{\alpha}r_2^3 and \left(\frac{Gm_{\beta}m_{\alpha}}{r_2\Theta}\right)^{3/2}$$

have a very simple physical meaning. The first one means the number of  $\alpha$  stars per sphere with radius  $r_2 = 1000 AU$ . The number of all stars in such a volume is less than  $10^{-7}$ . The smaller this number is for each separate type of stars  $\alpha$ . The second factor is two thirds of the ratio of the potential energy of a pair with a distance of 1000 AU to the average kinetic energy of a single star raised to the power of 3/2. Its numerical value is in any case less than  $10^{-4}$ , unless  $m_{\alpha}$  is many tens of times greater than the mass of the Sun.

Therefore, we get

$$\frac{n_{\alpha\beta} \left( r_1, r_2 \right)}{n_{\beta}} < 10^{-10}$$

Meanwhile, observations show that pairs with component distances from 100AU to 1000AU make up a significant fraction of all pairs. A significant proportion of visual doubles have just such distances. If we take the main stars of all types  $\alpha$ , then in any case

$$\frac{n_{\alpha\beta}\left(r_{1},r_{2}\right)}{n_{\beta}} > 10^{-2}$$

Thus, the observed percentage of binaries with the considered distances with respect to single ones is  $10^8$  times greater than the number of cases of pair formation as a result of triple encounters. In conclusion, we note that above we limited ourselves to pairs with certain distances in order to give more definiteness to the dissociative formula. If we talk about all pairs in general, then it would be necessary to introduce an upper and lower limit for distances (the upper limit is due to the fact that the distance in a pair cannot be greater than the average interstellar distances, the lower limit is due to the presence of the physical radius of the star). Their determination would require additional calculations, in addition, the lower bound would turn out to depend on the type of stars. This would, however, lead to similar conclusions.

#### On the amount of absorbing matter in elliptical galaxies Appendix B

From a macroscopic point of view, we can characterize each stellar system by specifying in it the volume emissivity  $\eta$  and the absorption coefficient  $\alpha$  as functions of a point. Then the intensity of the light leaving the system will be determined by the formula:

$$I = \int_{0}^{\infty} e^{-\tau} \eta ds, \tag{1}$$

where ds is an element of the ray path, and the optical depth  $\tau$  is a function of the point with abscissa s on the ray.

 $\tau = \int_{0}^{s} \alpha ds.$ 

Sin

ce 
$$d\tau = \alpha ds$$
, equation (1) can be rewritten as:

$$I = \int_{0}^{\tau_1} e^{-\tau} B d\tau$$

where

and  $\tau_1$  is the total optical depth of the entire system in the considered direction.

Taking the average value of B out of the inte ve get:

$$I = \overline{B} \left( 1 - e^{-\tau_1} \right), \tag{2}$$

where

Observing the brightness of the Milky Way in any direction in the galactic equator, we can consider the optical thickness in this direction to be very large. Therefore, for the intensity in the Milky Way, according to (2), we will have:

 $\overline{B} > I.$ 

$$I_M = \overline{B}_{Gal}.$$
(4)

On the other hand, when observing the central regions of elliptical nebulae, we encounter intensities almost a hundred times greater than the brightness of the Milky Way:

$$I_{El} = 100I_M = 100B_{Gal}$$

Comparing with (3), we obtain

$$B_{El} > 100 B_{Gal}$$

Or

in other words, the ratio of the emissivity to the absorption coefficient, i.e., the amount of light matter to the amount of dark matter in elliptical nebulae, is more than a hundred times greater than this ratio in the part of the Galaxy surrounding the Sun. Thus, the mere fact of the high surface brightness of elliptical nebulae leads to the conclusion that there is practically no absorbing matter in them, at least in a continuously distributed form. Observations also do not establish the presence of separate dark clouds in them.

(3)

$$\left(\frac{\eta}{\alpha}\right)_{El} > 100 \left(\frac{\eta}{\alpha}\right)_{Gal}$$

 $B = \frac{\eta}{\alpha},$