The Morphology of the Spiral Galaxies: Encoded Information on the Origin and Evolution Mechanisms

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Abstract

Consequences of the interaction between baryonic matter and dark energy carrier is considered for spinning objects. Some morphological features of spiral galaxies are used as fingerprints of formation processes to show that spiral arms of galaxies could be formed through mass ejection from the core of these objects. The Elmegreens' arm classification allows one to find some opportune features for this end. For the same purpose the ratio of vertical and radial sizes of some edge-on spiral galaxies found in deep fields and SDSS surveys are used.

Keywords: *dark energy – baryonic objects – interaction; spiral galaxies – edge-on spirals; spiral arms – formation; mass ejection – rotating objects*

1. Introduction

Often the formation and evolution features leave somehow their fingerprints on the cosmic objects. Not always are these fingerprints explicit, but one can find some of them having even very foggy ideas. For this purpose, one should use all the available information dealing with the objects' morphology and kinematical/dynamical properties also keeping in mind the laws and axioms of the modern physics.

Actually, researchers employ this approach all the time from the times immemorial. Indeed, all the scientific conclusions made by researchers, take into account the facts concerning the objects morphology. The more the classified morphological features, the richer the informational basis. Availability of various features excludes or decreases possibility of the wrong interpretations but at the same time undoubtedly increases the complexity.

On the other hand, any researcher usually has, at least, some general ideas concerning the cosmic objects formation processes and tries to fit the observational date to the adopted conception. The modern cosmogony from the very beginning adopted the Kant-Laplace hypothesis as the basic paradigm, which describes the formation of cosmic objects as a gravitational contraction of the rarified matter. The later modification of the initial hypothesis added the physical process responsible for the appearance of the rarified matter as if produced owing to the big bang.

There are some other paradigms, attempting to avoid the difficulties arising in the frame of the main paradigm. The adherents of the alternative conceptions are not as many as the ones working in the mainstream. In 50s of the last century, Viktor Ambartsumian put forward a new concept suggesting an opposite physical picture for the formation processes, namely, proposing origination of objects due to the decay of the protostellar superdense matter (Ambartsumian, 1947, 1958). Although this new approach allowed to prove the cosmogonic significance of stellar associations and to show the physical phenomenon of the galactic nuclei activity, finally the astronomical community rejected the principal idea. The rejection is based on the conclusion arrived at using the modern physics laws that the stable existence of large masses of nuclear density is not allowed.

Our recent studies showed clearly the possibility of evolutionary scenarios for the baryonic matter interacting with the dark energy or with its carrier. The reasonable conclusion arrived at owing to

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studies states that such an interaction might change the mass of baryons, which inevitably leads to the conclusion that the cosmic objects and the Universe as a whole could be less massive, but having the same quantity of baryons. This hypothesis, based on the laws and axioms of the modern physics, allows one in solving some widely known paradoxes (Harutyunian, 2017, Harutyunian & Grigoryan, 2018).

Therefore, taking into account new opened perspectives in this issue, we believe that the scientific community rejected Ambartsumian's conception undeservedly and will try to show some observational facts which speak in favor of the mentioned approach.

2. Evolution of objects according to the Ambartsumian's conception

In the framework of Ambartsumian's conception, all the cosmic objects originate and evolve from a superdense bunch, which could maintain before they start evolving in special physical conditions, such as galactic nuclei or stellar deep interiors towards to the center. The evolution process suggests its decay and formation of smaller fragments of the initial bunch. The more massive the object, the bigger the difference of evolution status between the center and outermost layers. Undoubtedly, the course of this process depends highly also on to physical characteristics of the given bunch, namely, on the mass and angular momentum. Values of these to essential parameters as well as the angular momentum per a unit mass ultimately determine the evolutionary path and the morphological features of the object at any stage of its life.

Considering the merits and demerits of the general idea suggested by Ambartsumian,one might enumerate several. An essential merit is the naturalness of the involved process, which, on the other hand, agrees with the thermodynamics second law. Radioactive decay of the heavy atomic nuclei is the natural analogue of this physical process in the micro world and the expansion of the Universe is the same in the mega world. However, the weak issue concerning the instability of superdense large masses interrupted the further development of this paradigm.

After the discovery of dark energy, the physical picture of the baryonic world changed drastically. Nevertheless, we believe that the astronomical community managed to consider carefully not all consequences of this discovery. In particular, what we mention here, concerns the issues of interaction of baryonic matter with a carrier of dark energy. Although one of the widely accepted forms of dark energy is the constant energy density filling space homogeneously, researchers usually avoid using it on small scales, and especially when looking at microscopic processes.

The fact of the interaction between the ordinary baryonic matter and dark energy is beyond doubt. Otherwise, the galaxy recession would not accelerate and researchers would not discover dark energy in this way. That seems obvious. Then such interaction takes place constantly on all scales including the microcosm. Any interaction between different systems of objects involves exchange of energies of these systems according to the laws of thermodynamics, even if the density of dark energy is extremely low.

All the baryonic objects as well as the stationary systems consisted of these objects, starting with elementary particles and atomic nuclei and up to galaxies and clusters of galaxies have negative total energy, according to modern concepts. Dark energy, which expands the baryonic Universe and accelerates its expansion, is highly positive by definition. Therefore, due to the interaction between these two substances the baryonic side of interaction obtains some portion of energy. This follows from the second law of thermodynamics.

The virial theorem states that all objects and their systems are in a stationary state if the following equality is ensured:

$$2T + U = 0, \tag{1}$$

where and are the kinetic and potential energies. So, interacting with the carrier of dark energy, any baryonic object or system of object gains energy. For a spherical object of the mass and radius the potential energy is

$$U = -\frac{3}{5}G\frac{M^2}{R}. \tag{2}$$

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If the process of interaction between dark energy and the given object increases the potential energy of later, one should observe decrease of the ratio. It can happen if decreases the mass of the object or grows its radius. In general, it is easy to see, that energy can grow if the mass of an object increases more slowly than the square root of its radius. Decrease of the mass can take place when in expense of accumulated additional energy an ejection of some portions of the initial mass or its decay into several parts occurs. Taking into account the uniformity of dark energy distribution and the stochastic behavior of mass ejection, one can arrive at a conclusion, that mass ejection process should happen by chance and in an isotropic way.

An object can possess of excessive energy at any stage of its evolution. It can happen, for instance, owing to energy accumulation during long time interactions or because of change its physical conditions, when the object loses energetic equilibrium with its environments. General physical laws state that in such situation a physical object triggers the necessary mechanisms to throw away the excessive energy to establish an equilibrium and bring the object to the lowest energetic level depending on the environmental conditions.

Dark energy on large scale simplements the process of radius growth for any spherical volume, which we perceive as an expansion of the Universe. The same should happen on any scale since dark energy is uniform across the space. Although on smaller scales, the forces generated by dark energy are very tiny but they act protractedly charging the baryonic objects and their systems. When the energy, accumulated by these objects and systems of systems (though any object is also a system composed of baryonic objects belonging to the lower hierarchical levels of the baryonic universe), become unstable and should release the additional energy.

The atomic nuclei and elementary particles belong to the lowest hierarchical level of objects reachable for studies by modern toolkits of research. Although this level differs from the ordinary macroworld, the knowledge available on their structure and physical features allows one to make some conclusions concerning their interaction with the dark energy carrier, if such interaction occurs in reality. One arrives at several conclusions, which may have far-reaching consequences, if one will finally prove their validity. In any case, one may use the technics of thought experiment and compare the results of it with observable data.

First, dark energy injected into atomic nuclei, if any, undoubtedly decreases the nuclear binding energy. Accordingly, simultaneously should increase the mass of atomic nuclei and baryons, making them more vulnerable against decay. Second, it does mean that in the past the nuclear binding energy could be incomparably large and masses of baryons in nuclei – very tiny. Third, in the far past of our baryonic universe could exist atomic nuclei consisted of huge number of baryons. Forth, in the deep bowels of very massive objects, baryonic matter can be in a state of the distant past – consisting of a huge number of baryons with negligible masses. As an observable manifestation of possible interaction of atomic nuclei with dark energy could serve the percentage of light element, since in this scenario the longer the evolutionary path, the lesser the heavy elements. In other words, evolution according this scenario decreases the metallicity of matter.

3. Energy release and the process of morphology formation.

Energy release is a common mechanism for all the baryonic objects belonging to all hierarchical levels of the Universe. Nuclear physicists call this process radioactivity. Planetary scientists call it seismology and volcanism. All stars and galactic nuclei emit electromagnetic radiation and eject mass with different rates. According to Ambartsumian's concept, galactic nuclei eject also huge clumps of baryonic matter, which form younger (and less massive) new galaxies eventually. All these processes combine their essential role in the much more comprehensive development course of object formation and evolution.

Any baryonic object survives thanks to the various forces of attractive behavior. In the microcosm, those are strong forces for baryons, their residuals for atomic nuclei, then molecular (electric) forces, and gravitational forces. The source of any force is the corresponding energetic field. Dark energy creates a force that tends to remove two baryonic points from each other. In this sense, this force acts against other forces and their balance governs all the dynamical and kinematical kinematic processes

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in the baryonic world. How it happens and develops depends on each particular case.

The quantity of dark energy participating in the process of interaction with a baryonic object, most probably, should be proportional to the volume occupied by the object. This statement follows from the space uniformity of dark energy. Within the sphere of radius the amount of dark energy should be proportional to its volume

$$E_{de} = \frac{4\pi}{3}R^3\rho_{de}, \tag{3}$$

where ρ_{de} is the dark energy spatial density. Denoting the matter density by ρ and comparing 3 with the expression 2, one finds that the ratio of gravitational and dark energies has the following form

$$k_E = \frac{E_{gr}}{E_{de}} = \frac{5}{3}G\frac{M}{R}\frac{\rho}{\rho_{de}} \sim \frac{\rho^2 R^2}{\rho_{de}}, \tag{4}$$

which can serve as a "measure of flexibility" of the object. It is obvious, that the bigger the ratio, the lesser the flexibility. In other words, object is more easily amendable to changes forced from the dark energy when the ratio is smaller.

Thus, this ratio depends on and changes with the object radius and mean density. It is not difficult to check the dependence of this factor on the mentioned values within the same hierarchical class of objects, for example, stars and planets or galaxies. If the density is constant, the "inflexibility" of an object increases proportionally toits radius square. It means that at the same density, large objects are more difficult to change when interacting with dark energy. In other cases, one should take into account also the change of the mean density.

The continuous accumulation of energy in a given baryonic object will eventually lead to the need to get rid of excess energy by ejecting portions of the matter. If the object is not rotating or slow rotating the ejection process will be isotropic. Otherwise, an additional centrifugal acceleration occurs in the equatorial region of the object, which essentially facilitates the ejection of matter from this region of the object. Moreover, since the equator is the most vulnerable part of a rotating object, if a piece of matter ejects, the ejection process has all chance to continue if the excessive energy is still huge for the object and hence the tension is not discharged completely yet. On the other hand, ejection from one side generates favorable conditions for another ejection in the diametrically opposite point, provided, that internal tension is sufficient.

One can implement this picture when interprets the morphological variety of galaxies. Indeed, if the object is non-rotational, ejected clumps of matter will have more or less isotropic distribution around the maternal object. This is the case of elliptical galaxies, which do not possess of disk substructure. Process of their formation resembles the physical picture of evaporation, when the clumps of matter take away the excessive energy in a moderate rate. Rotating objects of the same mass, as mentioned above, possesses of more ejection energy depending on the spinning rate. The higher the rotation rate for the given mass, the shorter the tension discharging time.

Let us consider now the spiral galaxies morphological classification scheme suggested by Elmegreen & Elmegreen (1982, 1987), based on the orderliness of spiral arms. Although this classification includes 12 (10 after revision) arm classes, authors divide all spiral galaxies into two larger groups, called floculent and grand design spiral arms. The grand design galaxies possess a morphology of classical two-arm symmetry with longer and prominent arms. The floculent galaxies, on the contrary, composed only of small pieces. Intermediate arm classes show characteristics of both the floculent and grand design types.One of the most essential correlations that found the authors is one that grand design galaxies are physically larger than floculent galaxies by a factor of -1.5. It does mean that symmetrical morphology requires more matter in average.

If one adhere to this scenario of galaxy formation, one inevitably arrives at a conclusion that the closer the location within the spiral arm to the center of galaxy, the younger the matter at the location in the sense of time passed after ejection the matter. On the other hand, the clumps of baryonic matter ejected from a massive object very recently evidently did not have a sufficient time for evolutionary change under the influence of dark energy.

The self-consistent consideration of the interaction mechanism between atomic nuclei and the dark energy carrier leads to very important evolutionary paths (Harutyunian & Grigoryan, 2018). First,

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one can conclude that the interchange of energy resulted due to the interaction decreases the nuclear binding energy and destabilize the atomic nuclei. In its turn, it leads to the formation of lighter chemical elements. Therefore, the more massive galaxies possess a higher metallicity.So one arrives at the conclusion that the closer the part of spiral arm is located to the galaxy nucleus, the higher its metallicity. This regularity is well established and studied in detail by many researchers (see, for example, Ho et al., 2015, and ref. therein). The same conclusion applies to the case of elliptical galaxies, for which is also correct the statement the farther a star is from the galactic nucleus, the longer, on average, has elapsed since its ejection as a pre-stellar object.

4. Disk/plane ratio depending on the redshift.

It is obvious that Ambartsumian's concept on the galaxy formation suggests that in the course of evolution the size of the plane disk should grow. It follows from the main hypothesis that spiral arms originate due to the mass ejection from the central nucleus of the galaxy. The longer the mass ejection time, the farther the first ejected stars in the equatorial plane. Since the linear size of radius depends on various parameters characterizing the given galaxy, the ratio of the bulge height and disk radius can serve as a measure of disk growing, if it grows really. That is easy to do using a sample of edge-on spiral galaxies possessing different redshifts.

In the recent paper by Reshetnikov & Usachev (2021) the authors considered this issue using edge-on galaxies for rather wide interval of redshifts (up to z ∼ 1.2). The authors compare the ratio h_r/h_z (where h_r and h_z are the radial and vertical sizes of a galaxy) for the closer and farther galaxies. It is interesting that for galaxies from deep fields they find $h_r/h_z \leq 10$. For the galaxies chosen from the survey SDSS, this ratio is much wider. It does mean that evolution of galaxies leads to the diminution of the mentioned ratio. Authors mention that the result was expectable according to the CDM models of galaxy formation. It is evident that the same result is predicted also using the Ambartsumian's cosmogonic concept on the galaxy formation. The physical interpretation of the observed correlation is clear and transparent in the second case, since spiral arms represent a kind of matter jet, according to Ambartsumian's concept, which constantly grow their radial size.

Thus, according the observational data used by authors in the past the ratio h_r/h_z was lesser comparing with nowadays value. Of course, the height of bulge h_z could also change in the course of the galaxies evolution, but in our view, there is little chance that the observed grow of the considered ratio is a result of the h_z decrease. The bulge should also increase in size owing to the interaction with the dark energy carrier and accumulation of excessive energy amounts. Therefore, one can conclude that the thickness of the bulge grows slower than the radius of the disk. It seems to be natural, since the growing of bulge is a process resembling the vaporation mechanism, while in the process of spiral arms ejection the centrifugal force holds the main role.

5. Conclusion.

The role of dark energy may be decisive in the process of formation and evolution of baryonic cosmic objects, if the baryonic matter physically interacts with the carrier of dark energy at all scales. This approach allows one to revive Ambartsumian's cosmogonic ideas for the objects formation through the decay of the denser matter. However, for avoiding the objections against the initial concept, there is one significant difference in this version of interpretation. The point is that in the Ambartsumian's scheme the ejected baryonic matter assumed to have the same mass as it has in the core of a galaxy before ejection. The large masses needed for generation of spiral arms or new galaxies could not exist in the core even in the superdense state. The physical laws do not allow stationary or quasi-stationary existence of such clumps. In our scenario, we propose conservation of only the quantity of baryons, but not mass. Mass grows in expense of dark matter, when the matter is already out of the galactic core, where the physical conditions differ drastically from ones in the core.

The mass change occurs because of secular decrease of nuclear binding energy in atomic nuclei, which can accelerate abruptly when the clump of core-born matter ejected into open space. The process of matter adaptation to new conditions can occur very violently with release of huge quantities

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of energy. We observe these processes in spiral arms, but not in bulge or halo. The reason, we believe, is the calm development of mass ejection processes in bulge and halo, where the aging of evaporated matter takes place gradually. Most probably, the slow evaporation process makes favorable conditions for long-lasting gradual aging of matter and makes the population of the halo metal-poor.

We are going to continue our research on the consequences of the interaction between baryonic matter and dark energy carrier to reveal more observational data fitting the results of though experiments.

References

Ambartsumian V. A., 1947, The evolution of stars and astrophysics

Ambartsumian V. A., 1958, in La structure et l'évolution de l'universe. pp 241–249

Elmegreen D. M., Elmegreen B. G., 1982, Mon. Not. R. Astron. Soc. , 201, 1021

Elmegreen D. M., Elmegreen B. G., 1987, Astrophys. J. , 314, 3

Harutyunian H. A., 2017, Astrophysics, 60, 572

Harutyunian H. A., Grigoryan A. M., 2018, Communications of the Byurakan Astrophysical Observatory, 65, 268

Ho I. T., Kudritzki R.-P., Kewley L. J., Zahid H. J., Dopita M. A., Bresolin F., Rupke D. S. N., 2015, Mon. Not. R. Astron. Soc. , 448, 2030

Reshetnikov V. P., Usachev P. A., 2021, Astrophysics, 64, 1

doi: https://doi.org/10.52526/25792776-2021.68.1-50