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Effect of Continuum Scattering on Early-type Supergiants Spectra

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Abstract

The effect of radiation scattering in continuum on the frequency distribution of the observed flux in atmospheres of supergiants of the late B and A spectral classes is treated. Thomson scattering on free electrons, which is important for hydrodynamic balance and wind dynamics in extended atmospheres of these stars, is considered as a specific scattering mechanism in the continuum. It is shown how stars of the same bolometric luminosity and with equal radii can belong to different spectral classes. The dependence of the continuum shortwave drift on the density of rarefied plasma has been established. The role of Thomson scattering in different domains of the hydrogen spectrum is revealed.

1. Introduction

An important place among early-type supergiants is belonging to stars of spectral class A and its adjacent subclasses of types B and F. These stars are visually brightest in our own galaxy, as well as in external galaxies. There is evidence for mass outflows and extending envelops in all of these objects, As a part of luminous variable stars they are characterised by comparatively quiescent states interrupted from times to times by outbursts. The shells accelerating by radiation pressure form a kind of more or less opaque winds with moderate terminal velocity (Humphreys & Davidson, 1979, Owocki et al., 2004).

It is well established that scattering of radiation in the continuum plays an important role in forming spectra of these objects. Among other of possible mechanisms of scattering, we will treat the Thomson scattering on free electrons. The high temperature rarefied plasma with highly ionized hydrogen and partly helium evidently makes this mechanism dominant.

The understanding of the importance of taking scattering into account in the continuum goes back to pioneering work of Schuster (1905). The mechanism of Thomson scattering on free electrons in the context of atmospheres of early-type stars was discussed by Ambartsumian (1938) who found that the color temperature of such stars may differ from effective temperature. He concluded that taking the latter instead of the former may lead to the undervalues in estimating the radii of such stars. For temperatures of about $10^5\,K$ he got the upper limit for the gas density below which the electron scattering effect becomes important.

The extreme non-stationarity of luminous and massive stars manifests itself not only in variability of their spectral class but also in specific changes in temperature, emission and absorption, spectrum discontinuities, line profiles. The detailed and comprehensive study of these phenomena will obviously provide a better understanding of the evolution of the stars under study at a later post-core H-burning stages.

In this connection, there is an urgent need in detailed study of electron scattering effect on the main characteristics of the observed spectrum. In this paper we treat the influence of Tomson scattering on the light curve and and its discontinuities in the hydrogen spectrum. The paper can be regarded as a generalization of results we obtained previously in Nikoghossian & Israelian (1996).

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2. The frequency distribution of the flux of radiation emerging from a grey atmosphere.

We start with considering the effect of the scattering process in continuum on the frequency distribution of the observed spectrum. It should be noted that, in order to clarify this question, the scattering mechanism itself is not essential, although it is Thomson scattering on free electrons that is the implication in this paper because of its importance in studying the spectra of early-type supergiants. The equation of radiation transfer for this problem has a form

$$\eta\frac{\mathrm{d}I_\nu}{\mathrm{d}r} = -\left(\alpha_\nu + \sigma\right) I_\nu + \sigma J_\nu + \alpha_\nu B_\nu\left(T\right), \tag{1}$$

where the following notations are used: α_ν is the coefficient of absorption in the continuum and σ is the coefficient of the continuous scattering, each per unit length; $B_\nu(T)$ is the Planck function and

$$J_\nu = \oint I_\nu \frac{d\omega}{4\pi}. \tag{2}$$

The natural boundary condition for the problem at issue is $I(0,\eta) = 0$ for $\eta > 0$.

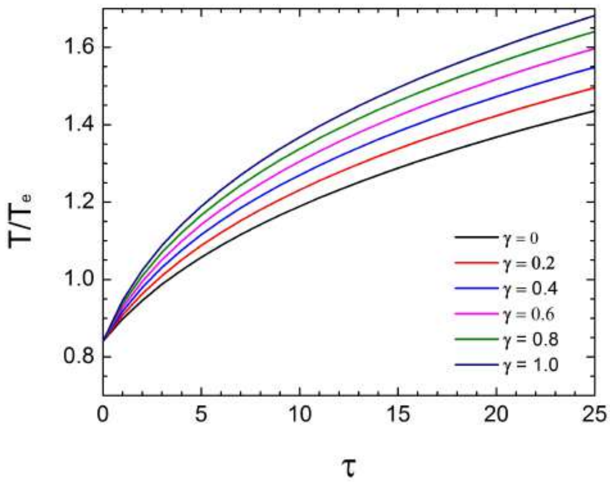

Figure 1. The temperature gradients dependence on the level of electron scattering.

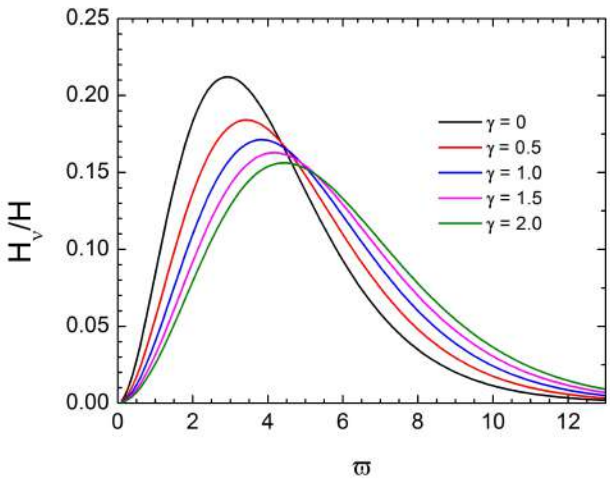

Figure 2. The drift of the continuum due to electron scattering.

It is well known Mihalas (1970) that the scattering processes do not change the form of the condition of radiative equilibrium since the proper emitted and absorbed terms are canceled, so that we have

$$\int_0^\infty \alpha_\nu J_\nu \mathrm{d}\nu = \int_0^\infty \alpha_\nu B_\nu(T)\,\mathrm{d}\nu. \tag{3}$$

Let us now consider a gray hydrogen semi-infinite atmosphere, with no radiation incident on its boundary. As an averaged coefficient of absorption we take Planck's mean given by (see e.g.,Sobolev 1960, Mihalas 1970)

$$\bar{\alpha} = \frac{\int_0^\infty \alpha_\nu B_\nu(T)\,\mathrm{d}\nu}{\int_0^\infty B_\nu(T)\,\mathrm{d}\nu}. \tag{4}$$

Now replacing α_ν with $\bar{\alpha}$ and integrating Eq,(1) over all the spectrum we can write

$$\eta \frac{\mathrm{d}I}{\mathrm{d}\tau} = (1+\gamma)\,I - \gamma J - B(T), \tag{5}$$

where $d\tau = -\bar{\alpha} dr$, $\gamma = \sigma/\bar{\alpha}$ and

$$J = \int_0^\infty J_\nu \mathrm{d}\nu, \qquad B(T) = \int_0^\infty B_\nu(T)\,\mathrm{d}\nu. \tag{6}$$

Now the condition of radiative equilibrium (3) can be rewritten as

$$J = B(T) = \frac{ac}{4\pi} T^4, \tag{7}$$

where a is the Stefan constant.

Having this in mind, Eq.(5) takes a form

$$\eta \frac{\mathrm{d}I}{\mathrm{d}t} = I - B(T). \tag{8}$$

and the problem is reduced to the solution of the classical Milne equation for the function $J(t)$, where $t = (1+\gamma)\tau$

$$J(t) = \frac{1}{2}\int_0^\infty J(t')\mathrm{Ei}\left(\left|t - t'\right|\right)\mathrm{d}t' \tag{9}$$

with well-known solution

$$J(t) = \pi F\,(t + q(t)), \tag{10}$$

where $q(t)$ is Hopf's function. In view of Eq(6) we find for the temperature gradient in the medium

$$T(t) = T_{\mathrm{eff}}\,(t + q(t))^{1/4}, \tag{11}$$

Thus, we arrive at the temperature gradient of the common functional form where, however, the opacity is due to both the pure absorption and the scattering process.

Fig.1 demonstrates the run of temperature with optical depth in the atmosphere in terms of τ. As would be expected, the Thomson coherent scattering process acting on quanta of all wavelengths across the spectrum increases the opacity hindering the escape of quanta from the medium. This obviously leads to steeper rise in temperature within the medium. It is important to note that this occurs under constant values of effective temperature (as well as of surfaces temperature, in the Eddington approximation) and integral flux. This, in its turn, implies that the star with the generated scattering in its outer layers will not change the luminosity. At the same time the observer should obviously detect a change in the star's spectrum towards short waves, as it is shown in Fig.2 that presents the theoretical fluxes versus γ given in the Eddington approximation

$$\frac{H_\nu(0)}{H} = 0.31\varpi^3 \int_0^\infty \frac{\mathrm{E}_2(\tau)\,\mathrm{d}\tau}{\mathrm{e}^{\varpi p(\tau,\gamma)} - 1} \tag{12}$$

where $\varpi = \frac{h\nu}{kT_*}$, $p(\tau,\gamma) = \frac{3}{4}(1+\gamma)\tau + \frac{1}{2}$ This implies that the spectral class of the star moves to the earlier classes without any change in the luminosity. On the HR diagram it looks as a drift to the left of it parallel to the axis of spectral classes.

$$L = 4\pi R_*^2 \sigma T_{\mathrm{eff}}^4 \tag{13}$$

is replaced by the color temperature. This obviously leads to the diminished values for radii of stars. We point now to another possible errors that can arise in using the L versus T_{eff} Hertzsprung-Rassel diagram for this kind of peculiar stars. Indeed, having at our disposal the luminosity and the radius of a star determined by the other independent methods, the spectral class predicted by the H-R diagram may differ from the actual one.

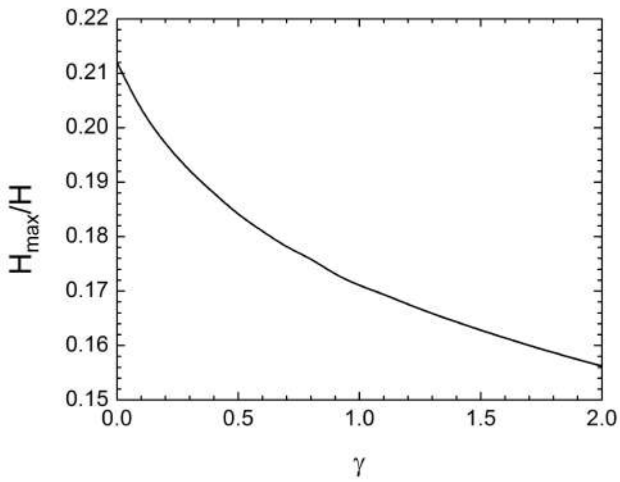

Figure 3. Variation of the maximum value of the flux with an increase of the level of the electron scattering.

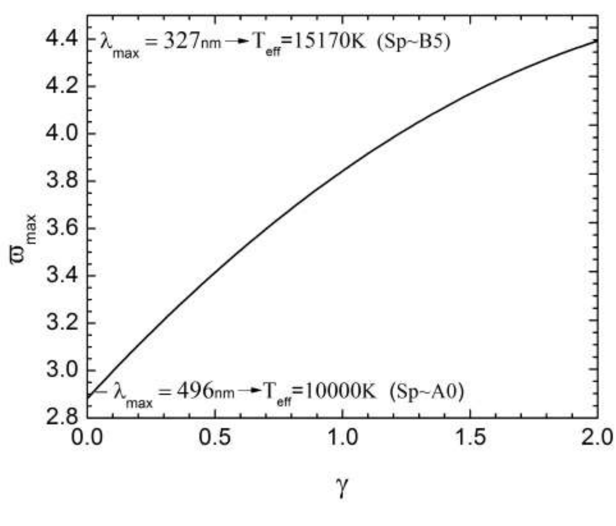

Figure 4. Drift in the location of the maximum flux due to the electron scattering.

Let us now turn to the question of under which conditions the Thomson scattering effect becomes important. Ambartsumian (1938) was the first who considered this point for the helium spectrum in the context of atmospheres of the W-R type stars by taking $T = 10^5K$. Employing the formulas for the mean absorption coefficient given in (Chandrasekhar, 1934) and (Unsöld, 1934) (he obtained for the upper limit for the gas density $\rho \leq 10^{-9}g/cm^3$ which corresponds to the ions or electrons number density of the order $\sim 10^{15}cm^{-3}$. Similar estimate for the hydrogen spectrum with $T = 10^4K$ we obtain is $\rho \leq 10^{-13}g/cm^3$ and correspondingly, $n_{\mathrm{e}} =\sim 10^{11}cm^{-3}$.

However, it is also of great interest the effect of continuum scattering in different domains of the spectrum. To this end, let us consider the hydrogen spectrum where absorption coefficient per unit length is given by the well-known formula (see, e,g,, Sobolev, 1963)

$$\alpha_\nu = C\left(T\right)\frac{n_e n^+}{\nu^3}\left(\frac{2\chi_1}{kT}\sum_{i=i_0}^{\infty}\frac{1}{i^3}\mathrm{e}^{-\frac{\chi_i}{kT}}+1\right)\left(1-e^{-\frac{h\nu}{kT}}\right), \tag{14}$$

where the Gaunt coefficients are taken equal to 1,

$$C\left(T\right) = \frac{2^4\pi^2 e^6 kT}{3\sqrt{3}ch(2\pi mkT)^{3/2}}, \tag{15}$$

and for other values, well-known designations have been adopted: h and k are correspondingly Planck's and Boltsman's constants, e and m are the charge and the mass of electron. The value of i_0 is determined by inequality $h\nu \geq \chi_i$. For $T = 10^4K$ we obtain

$$\alpha_\nu = 36.71\cdot 10^5\frac{n_e n^+}{\nu^3}\left[31.44\left(7.05\cdot 10^6+6.44+0.21+...\right)+1\right]\left(1-e^{-\frac{h\nu}{kT}}\right),. \tag{16}$$

We are interested in the first greatest three terms in parentheses corresponding to the Lyman, Balmer and Pashen series. To this end, we find it expedient to use some averaged approximate values of absorption coefficients for each of these domains in the shortwave vicinity of the series jumps. Representing these estimates in the form $\alpha_\nu = A\cdot n_e n^+ cm^{-1}$, we find $A = 2.3\cdot 10^{-32}, 1.4\cdot 10^{-36}, 5.4\cdot 10^{-37}$ correspondingly for the Lyman, Balmer and Pashen jumps. On the other hand, the Thomson scattering coefficient $\sigma = n_e\sigma_0$, where

$$\sigma_0 = \frac{8\pi}{3}\left(\frac{e^2}{mc^2}\right)^2, \tag{17}$$

is of the order of $10^{-25}cm^2$,, Then assuming that hydrogen is completely ionized, we get $\sigma/\alpha_\nu = 2,9\cdot 10^7 n_e^{-1}$ in the vicinity of the Lyman jump and, respectively, $4,8\cdot 10^{11}n_e^{-1}, 1,2\cdot 10^{12}n_e^{-1}$ for the Balmer and Pashen jumps. Thus, we see that the effect begins to affect the rarified plasma starting from the electron densities of the order of $10^{12}cm^{-3}$ and less which in the case of the fully ionized hydrogen corresponds to the matter density of the order of $10^{-12}g/cm^3$. This result is consistent with that obtained by Ambartsumian for temperatures of the order of 10^5K in connection of the W-R stars. At the same time, we see that the electron scattering effect begins to appear primarily in the long-wave domains of the spectrum. For instance, the effect in the UV domain may become significant only at densities less than $10^{-6}, 10^{-7}g/cm^3$

3. Effect of Thomson scattering on spectrum discontinuities

Our goal in this section is to determine the effect of multiple coherent scattering on free electrons on the Lyman, Balmer and Pashen discontinuities in the hydrogen spectrum. To this end, let us turn to transfer equation Eq.(1) in the Eddington approximation. We have

$$\frac{1}{3}\frac{\mathrm{d}J_\nu}{\mathrm{d}\tau} = \left(k_\nu+\gamma\right)\bar{H}_\tau, \frac{\mathrm{d}\bar{H}_\nu}{\mathrm{d}\tau} = k_\nu\left(J_\nu - B_\tau\left(T\right)\right), \tag{18}$$

where, again, as above, $d\tau = -\bar{\alpha}dr$, $k_\nu = \alpha_\nu/\bar{\alpha}$ and $\bar{H}_\nu = H_\nu/2\pi$. The set of equations Eq.(18) can be reduced to

$$\frac{\mathrm{d}^2 J_\nu}{\mathrm{d}\tau^2} = \bar{\kappa}_\nu^2\left(J_\nu - B_\nu\left(T\right)\right), \tag{19}$$

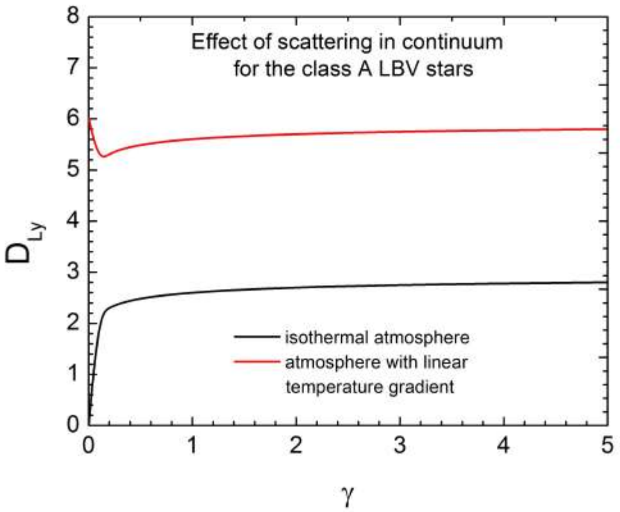

Figure 5. Effect of Thomson scattering on Lyman discontinuities.

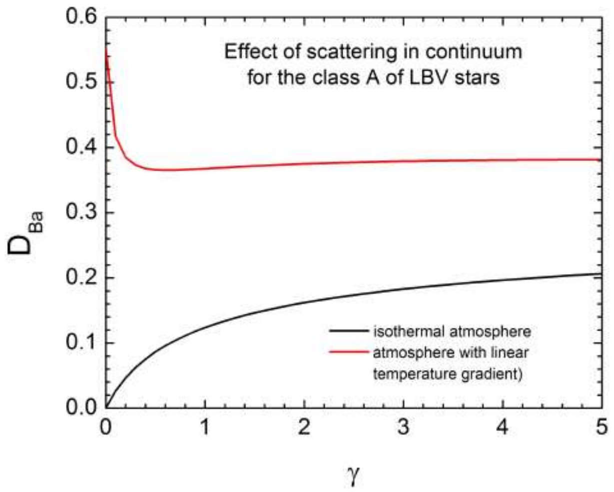

Figure 6. The same as in Fig.5 for Balmer discontinuities.

with $\bar{\kappa}_\nu^2 = 3k_\nu\,(k_\nu + \gamma)$.

In solving Eq.(19) we assume that the depth variation of temperature is linear so that $B_\nu(\tau) = B_\nu(T_0)\cdot(1+\beta_\nu\tau)$, where (see, e.g., Sobolev 1960)

$$\beta_\nu = \frac{3}{8}\frac{h\nu}{kT_0}\left(1-\exp(-\frac{h\nu}{kT_0})\right)^{-1}. \tag{20}$$

Eq.(19) is solved under usual assumptions of absence of external incident radiation and requiring the solution to be bounded at infinitely great depths. We obtain

$$\bar{H}_\nu\,(0) = B_\nu\,(T_0)\left(1+\frac{\beta_\nu}{\bar{\kappa}_\nu}\right)/\left(2+\sqrt{3\left(1+\frac{\sigma}{\alpha_\nu}\right)}\right) \tag{21}$$

This allows to find the requisite values of discontinuities $H_{\nu>\nu_0}/H_{\nu<\nu_0}$, where $H_{\nu<\nu_0}$ and $H_{\nu>\nu_0}$ are emergent fluxes before and after jumps. Knowledge of $\alpha_{\nu<\nu_0}/\bar{\alpha}$ and $\alpha_{\nu>\nu_0}/\bar{\alpha}$ from Eq,(16) leads to the required result.

In the next part of this study we will examine some other manifestations of electron scattering in the context of the spectra of early type supergiants. ....

Figures 5-7 demonstrate dependence of Lyman, Balmer and Pashen discontinuities $D = \log\frac{H_{\nu>\nu_0}}{H_{\nu<\nu_0}}$ on the relative role of Thomson scattering γ. Each of the figures depicts two curves related to the

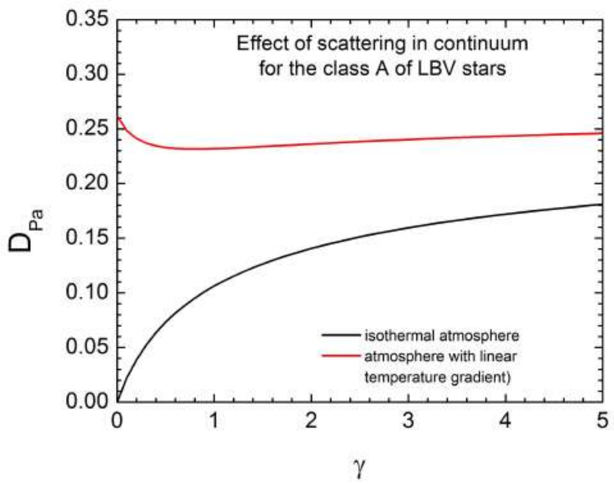

Figure 7. The same as in Figs.5,6 for Pashen discontinuities.

isothermal atmosphere (black) and to the atmosphere with linear temperature gradient (red). The given curves allow making a number of important conclusions. As it should be expected, the jumps formed in the atmosphere with the depth-varying temperature are greater as compared to those in the isothermal atmosphere.Further, the scattering process in the isothermal atmosphere leads to jumps due to the fact that quanta with a frequency before and after jumps come out of different depths and the number of scatterings they undergo before leaving the atmosphere is different. With increasing role of scattering the quanta that leave the outer layers of the atmosphere are, naturally, more affected, so the size of the jumps tends to increase with increasing γ. This effect is similar to the behaviour of the absorption line profiles in the nucleus and wings with an increase in the probability of the quantum's re-radiation at an elementary scattering act. A more complex picture is observed in the case of an atmosphere with a temperature gradient, where jumps are formed in the absence of scattering. Here, the behaviour of the jump size with γ depends on the relative role of true absorption and Thomson scattering processes in different parts of the spectrum.

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On the Thermal Regime and Density in the Star-Forming Regions

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Abstract

We developed an automatic code to determine some physical parameters describing the radiation of a simple one-temperature black body model and implemented it to calculating the temperatures and masses of molecular clouds in several star formation regions, using the observed IR emission fluxes for the chosen sources. Calculations show that the used commonly simplifications need to study in more detail for estimating the accuracy of computing results.

Keywords: *radiative transfer – infrared: ISM - ISM: molecular cloud*

1. Introduction

Modern stellar cosmogony adopted the idea that stars in our Galaxy (and in other galaxies) form in the cold and dense cores of giant molecular clouds. In any case, the physical connection between new formed stars and molecular clouds is obvious from observations. It is also evident that the star formation process has a recurrent behavior, and takes place several times during the galaxy lifetime. Therefore, the statement that star formation is an ongoing process, which continues in our epoch has been accepted (Ambartsumian, 1947).

The majority of adherents of the modern stellar cosmogony do not accept all the concepts put forward in Ambartsumian (1947) classical paper. Moreover, the scientific community does not retain these ideas and one can find some mentions of them, if any, in comprehensive reviews of the field. Usually authors refer these ideas as having only historical significance.

We do not consider here any conceptual issues concerning the origin of molecular clouds. Actually, the traditional cosmogony considers the molecular clouds as the direct inherent of the matter formation process due to the big bung event. Ambartsumian was not a supporter of the Universe formation owing to the single explosion of the physical vacuum. According to his vision, we have no adequate knowledge and research tools to reach the very beginning our baryonic Universe. His concept limits our mental speculations to times to which physical extrapolations are still able of giving more or less confident results. Therefore, his concept of the matter structure states only that all the existing cosmic objects have been formed thanks to the decay of much more dense matter.

In his paper "On the Origin of Nebulae" (Ambartsumian, 1982) the author mentions that the origin and evolution of stars always draws the attention of astrophysicists. However, states the author, the problems of the origin and evolution of researchers considered much less.In the paper the author takes up two different, at first glance, types of links between nebulae and stars. In the case of nebulae linked to individual stars, there is no doubt, that the stars ejected the matter to form the surrounding nebulae. The situation is more complicated when diffuse nebulae are considered. The author mentions his deep impression due to the observational facts arguing in favor of existing several diffuse nebulae within each OB stellar association. He also repeats the conclusion he made based on the given data,

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stating that generation of a group of young stars takes place parallel with the formation of surrounding them diffuse nebulae.

Sometimes researchers use the observational fact that young stars are embedded in the diffuse molecular clouds to argue their origin from nebulae. Considering all the observational data available the author arrives at a conclusion that the large nebulae located within the OB associations are in the process of mass growth, and that their mass is growing owing to the mass ejection from the objects embedded deep in the nebulae.

Although, the issue we are going to discuss here does not depend on the physical mechanism of the nebulae formation, nonetheless this brief introduction into the subject seems to be essential. It gives some information on the alternatives existing on the molecular clouds possible formation, which is usually ignored considering this subject.

In this paper, we are going to describe the computational method we used to calculate the temperature and mass of the cold dust in the star formation regions using the SED in the IR range of radiation. Method is developed and used by other researchers and we applied it for our sample only. However, its application and especially results of calculations led us to some conclusions that we would like to share here.

2. Used method and interpretation

We tried to find some physical characteristics of IR sources using simplest relations between the energy source, which provides the radiation field, and the scattering medium through which the energy transfers. This is a classical radiative transfer problem, which requires the determination of the source function. Usually, the radiation flux emerging from any emitting area is given by the following simple formula:

$$F_\nu = \oint d\omega \int_0^{\tau_0} I_\nu(\tau_\nu) e^{-\tau_\nu} d\tau_\nu, \tag{1}$$

where the first integral (in very simplified model) can be calculated immediately and shows the solid angle corresponding to the source of radiation, $I_\nu(\tau_\nu)$ is the radiation intensity at the optical depth τ_ν. Intensity depends on the temperature through the optical depth. It is obvious, that this dependence can be determined only solving the equation of the radiation transfer.

In the first approximation, one can disregard the dependence on the optical depth and substitute the intensity for the blackbody radiation for some average temperature. Then one can obtain the following relation:

$$F_\nu = \Omega B_\nu(T_d)(1 - e^{-\tau_{0_\nu}}), \tag{2}$$

where Ω is the solid angle corresponding to the given source, $B_\nu(T_d)$ is the Planck function for the dust temperature T_d and τ_{0_ν} is the optical thickness of the dust column in the radial direction. This simple formula, easy for application,has been in usage for rather long time.

Observations provide the real flux F_ν, therefore, one can use the relation 2 for determination the dust temperature and optical thickness. There are two quantities to be determined using any method of fitting, namely, the temperature T_d and optical thickness τ_{0_ν}. Both these quantities define the frequency dependence of the observed flux, but not its absolute magnitude. Therefore, one can normalize the flux values constructing the ratios

$$\eta_\nu = F_\nu / F_{\nu_1}, \tag{3}$$

where for ν_1 one can use the lowest observed frequency.

The observational quantities should fit the same quantities calculated using the model for some value of temperature. We used very simple algorithm when searching the best fitting temperature. The following sum is calculated for different temperatures:

$$\Delta(\eta) = \sum_{\nu_i} (\eta_{obs} - \eta_{mod})^2, \tag{4}$$

to find the temperature which makes the difference minimal. We used an iterative procedure of progressive approximation. In order to fulfil the procedure we started calculations with the given initial temperature T_0. After calculating the value $\Delta(\eta)$ we put $T = T + \delta T$ and find the value $\Delta(\eta)$ again. If the new value is smaller than the previous one we continue the procedure after the next increment of the argument. On the other hand, if in any step of this procedure the value $\Delta(\eta)$ increases, the special program compiled for this procedure makes the following substitution $\delta T = -\delta T/2$ and continues calculations. This procedure continues to satisfy the inequality $|\delta T| \leq \varepsilon$, where ε is the accuracy for computing the temperature.

Second physical parameter to be determined within this framework is the optical thickness of the cold dust cloud, defining its mass on its turn. Therefore, all the procedure described above we fulfilled for various values of the optical thickness. As a result, the computing program provides a set of temperature values satisfying our requirement of fitting conditions.In the final stage of the procedure computer chooses the lowest value from the set and issues the corresponding physical values.

The optical thickness of the absorbing cloud has the following form (Hildebrand, 1983):

$$\tau_{\nu_0} = \mu_{H_2} m_H K_\nu N(H_2), \tag{5}$$

where μ_{H_2} is the mean molecular weight (adopted to be 2.8 here to take into account the relative mass abundance of helium equal to 25%), m_H is the mass of hydrogen atom, K_ν is the opacity coefficient and $N(H_2)$ is the hydrogen column density. Here the frequency dependence of the opacity coefficient has the following form $k_\nu = k_0(\nu/\nu_0)^\beta$, where $k_0 = 0.1\,cm^2\,g^{-1}$ at the frequency $\nu_0 = 1200\,GHz$ ($250\,\mu m$) for a gas-to-dust ratio of 100 (André et al., 2010, Hildebrand, 1983). In Beckwith et al. (1990) is stated that the equity $k_0 = 0.1\,cm^2\,g^{-1}$ is correct at the frequency $\nu_0 = 1000\,GHz$ ($300\,\mu m$). Usually, authors put $\beta = 2$ to reduce the number of free parameters and facilitate the fitting process.

3. Numerical Results

We implemented the computational program verified using model calculations for finding the temperature and mass of molecular cloud for several IR sources. We used FIR data in the range $70 - 500\,\mu m$, obtained through *Photodetector Array Camera and Spectrometer* (PACS, Poglitsch et al., 2010) and the *Spectral* and *Photometric Imaging Receiver* (SPIRE, Griffin et al., 2010) operating at the *Herschel Space Observatory* Pilbratt et al. (2010).

For our analysis, we used photometric data and images of *PACS* 70, 160 μm catalogue and the *Herschel Infrared Galactic Plane Survey* (Hi-GAL, Molinari et al., 2016) in 70, 160, 250, 350 and 500 μm wavebands. Not all the sources have measured data in all wavebands. For the ultimate calculations, we excluded data related to the emission at the wavelength 70 μm. Therefore, all the calculations are implemented for four or less wavelength bands.

In the Table 1 we present results of the numerical calculations as an illustration. In the first column is given the radius of a source in arcseconds, the columns (2)-(5) represent here the measured fluxes in the bands 160, 250, 350 and 500 μm correspondingly. Last four columns show the temperatures and masses of the gas we received from our computations. Both values are computed using slightly different algorithms. As we described above we repeated the calculations for revealing the temperature for various values of the optical thickness for the given source. Owing to this procedure, we find different temperatures which correspond to the given optical thickness and various values of the accuracy $\Delta(\eta)$. Calculations show that the dependence of $\Delta(\eta)$ on optical thickness is not trivial as it could be if all the physical suggestions are correct. One can reveal several minima of the value $\Delta(\eta)$, which makes the selection of the optical thickness and corresponding temperature problematical. In order to smooth the mentioned dependence we used averaging of $\Delta(\eta)$ values. Therefore, we have two sets of temperature, which are shown in columns (6) and (8). The columns (7) and (9) represent masses derived from the dust emission using the relation

$$M = (d^2\Omega/k_{300})\tau_{300}, \tag{6}$$

where $k_{300} = 0.1\,cm^2\,g^{-1}$ is the opacity per unit mass computed at $300\,\mu$m assuming a gas-to dust ratio of 100 (Beckwith et al., 1990), and d = 7.8 kpc.

Table 1. Results of the numerical calculations

R (arcec) (1)	$\mathbf{F}_{160}$ (2)	$\mathbf{F}_{250}$ (3)	$\mathbf{F}_{350}$ (4)	$\mathbf{F}_{500}$ (5)	**T (K)** (6)	**M (sol)** (7)	$\mathbf{T}_{aver}$ **(K)** (8)	$\mathbf{M}_{aver}$ **(sol)** (9)
14.7	937.35	3010.82	1716.84	1629.68	7.7	8.4	10.2	11.2
30.5	1271.52	0.00	3040.54	0.00	10.2	23.2	10.2	23.2
8.4	2371.00	7223.45	3121.39	1510.98	9.3	5.9	9.4	5.9
12.3	4257.00	6153.49	3053.85	1118.18	10.3	9.4	10.2	9.4
9.9	2788.00	3628.48	0.00	3147.02	11.9	8.8	11.9	8.8
12.1	6876.00	11696.93	5084.87	3014.18	10.3	9.2	9.7	8.8
9.6	5572.00	10381.26	7172.18	3606.51	11.4	8.2	11.5	8.3
6.9	1469.00	1180.27	844.96	0.00	15.7	8.1	15.7	8.1
8.7	1351.00	1138.02	501.87	0.00	15.0	9.8	15.0	9.8
14.5	2793.00	12439.93	6148.01	1767.46	14.4	15.6	14.4	15.6
8.4	3140.00	5700.70	3425.12	1783.12	11.3	7.1	11.3	7.1
14.9	5308.00	5009.48	3110.22	1645.09	14.8	16.4	14.8	16.4
14.3	1694.97	7368.99	4367.79	3490.74	7.8	8.3	7.8	8.4
16.7	2125.46	7673.70	4149.23	2557.88	8.5	10.6	8.5	10.7
18.8	1533.75	4725.34	0.00	1003.04	8.9	12.4	8.9	12.5
27.8	934.36	10306.26	10680.46	3829.32	6.9	14.4	6.9	14.4
18.5	579.64	3898.39	2849.43	1163.10	7.5	10.4	7.5	10.4
12.4	3149.00	4762.17	2694.73	1326.15	12.2	11.4	12.3	11.4
13.8	1722.67	8057.09	2346.18	893.03	8.5	8.8	8.5	8.8
15.1	3302.00	5743.38	3968.28	3529.04	11.6	13.1	11.6	13.1
16.9	1645.74	2761.04	3382.35	1156.78	11.0	14.0	11.0	14
8.9	2863.00	5841.19	2304.80	1572.25	10.1	6.7	10.0	6.6
10.0	2703.00	4276.10	2771.28	0.00	11.9	8.9	11.9	8.9
12.0	5140.00	3884.68	1783.74	0.00	16.7	14.9	16.5	14.8
12.3	3218.94	7620.25	3339.08	0.00	9.6	8.8	9.6	8.8
12.0	21103.00	13614.83	5797.80	0.00	18.2	16.3	18.2	16.3
13.1	18514.00	17472.91	6755.87	0.00	12.8	12.5	12.9	12.7
10.8	9397.00	10449.92	5174.50	0.00	12.7	10.3	13.3	10.8
9.4	1734.00	2285.95	2686.00	0.00	11.9	8.4	11.9	8.4
9.9	1812.00	4627.39	6037.34	0.00	9.7	7.2	9.7	7.2
11.5	4086.00	7347.94	0.00	0.00	11.4	9.9	11.5	9.9
10.5	1546.00	3507.15	2058.25	1669.82	11.0	8.6	11.0	8.6
10.6	1145.00	1469.08	2176.42	0.00	11.5	9.1	11.5	9.1
13.1	2469.99	3383.57	1813.73	0.00	11.8	11.6	11.7	11.5
19.0	749.66	2358.91	1447.72	0.00	8.9	12.6	8.9	12.7
16.8	1571.04	3423.60	1650.72	0.00	10.0	12.5	10.0	12.5
11.3	1868.00	2175.02	1049.56	0.00	11.0	9.3	11.4	9.6
15.4	3796.00	4828.40	1675.96	0.00	11.5	13.2	11.7	13.4
13.4	5570.00	9360.75	4957.03	1239.90	10.4	10.5	10.8	10.8

4. Discussion

Calculations show that the physical picture of the process is more complicated than researchers consider for studying it. Actually, all the attempts used for modelling the process going on in the molecular clouds are extremely simplified. There are two main suggestions used by researchers, simplifying the situation. First assumption facilitating the model is one that the intensity does not depend on the optical depth. Undoubtedly, this is not correct, but the general solution of the problem makes its usage very uneasy. The second one, in our opinion, is replacement of the intensity in the relation 1 by a one temperature Planck function. These simplifications led to some uncertainties, which show up during the procedure of the temperature determination.

We have no any theoretical recipe for overcoming this situation. However,we are going to study the problem in more detail to reveal at least which simplification is rougher and how big can be errors using it.

Acknowledgements

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Spectral obervations of flare stars TZ ARI and ROSS 867

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Abstract

The results of spectral observations of flare stars TZ Ari and Ross 867B are presented. Observations have been carried out by the 2.6m telescope of Astrophysical Byurakan Observatory in 1999, 2001 and 2018. The spectral cameras "ByuFOSC" and "SCORPIO" were used during the observations. A strong change of emission lines detected on TZ Ari in 2018, while at the same time the brightness changes of the star in all measured spectral ranges are within the framework of measurement errors. Slight variations of brightness and $EW_{H\alpha}$ are detected in quiescent state of star during the observations in 1999. A strong flare of Ross 867B were observed, with a duration of more than 20min. In this case if $EW_{H\beta}$ shows strong change, when its maximum value corresponds to the photometric maximum of flare, at the same time $EW_{H\alpha}$ shows decrease, similar to that, observed earlier during the flares of stars EV Lac, HU Del, CM Dra and WX UMa.

Keywords: *variable star, T Tau stars, UV Ceti stars, spectroscopy,TZ ARI,Ross 867B*

1. Introduction

The majority of the stars in Galaxy are flare stars. They are on, or very close to the main sequence with spectral types ranging from early G to late M. The phenomenon of stellar flares was discovered accidentally by Hertzsprung (Hertzsprung, 1924). This discovery was long period forgotten until A. H.Joy and M. L. Humason (Joy & Humason, 1949) detect similar phenomena on UV Cet, Yz CMi and WX UMa. More than 100 flare stars are known recently in the solar neighborhood, most of which lie within 20pc of the Sun (Pettersen, 1991), and majority are emission line stars. The term "emission line stars" refers to the presence of hydrogen lines in emission in the optical spectrum, indicators of intense chromospheric heating (Cram & Giampapa, 1987, Cram & Mullan, 1979).

Recently there has been increased interest in flare stars. New flare stars, as well as new regions of star formation that are rich in UV Ceti-type flare stars and young irregular T Tau-type variables, have been discovered. The simultaneous presence of these two types of young stars in young stellar systems confirms their youth and their possible evolutionary relationship (Ambartsumian, 1954, Ambartsumyan, 1970). Studies of flare stars at the Byurakan Observatory began in the 1960's. When possible, spectral studies were also made of UV Ceti type stars in the neighborhood of the sun and of flare stars in young stellar systems (Melikian, 2014, Melikian et al., 2006, 2011, 2012, 2013, Melikyan et al., 1994, 1995, Tamazian et al., 2005). Since 1999, as a part of various observational programs at the 2.6-m telescope of the Byurakan Observatory, about 140 spectra have been obtained for 9 flare stars in the neighborhood of the sun and in the Orion association. Some data on the flares have been published. These data mostly confirm the results of earlier spectral studies of stellar flares. But there are also some interesting new results.

In this paper the results of spectral studies of two known flare stars in the neighborhood of the sun TZ Ari and Ross 867B are presented.

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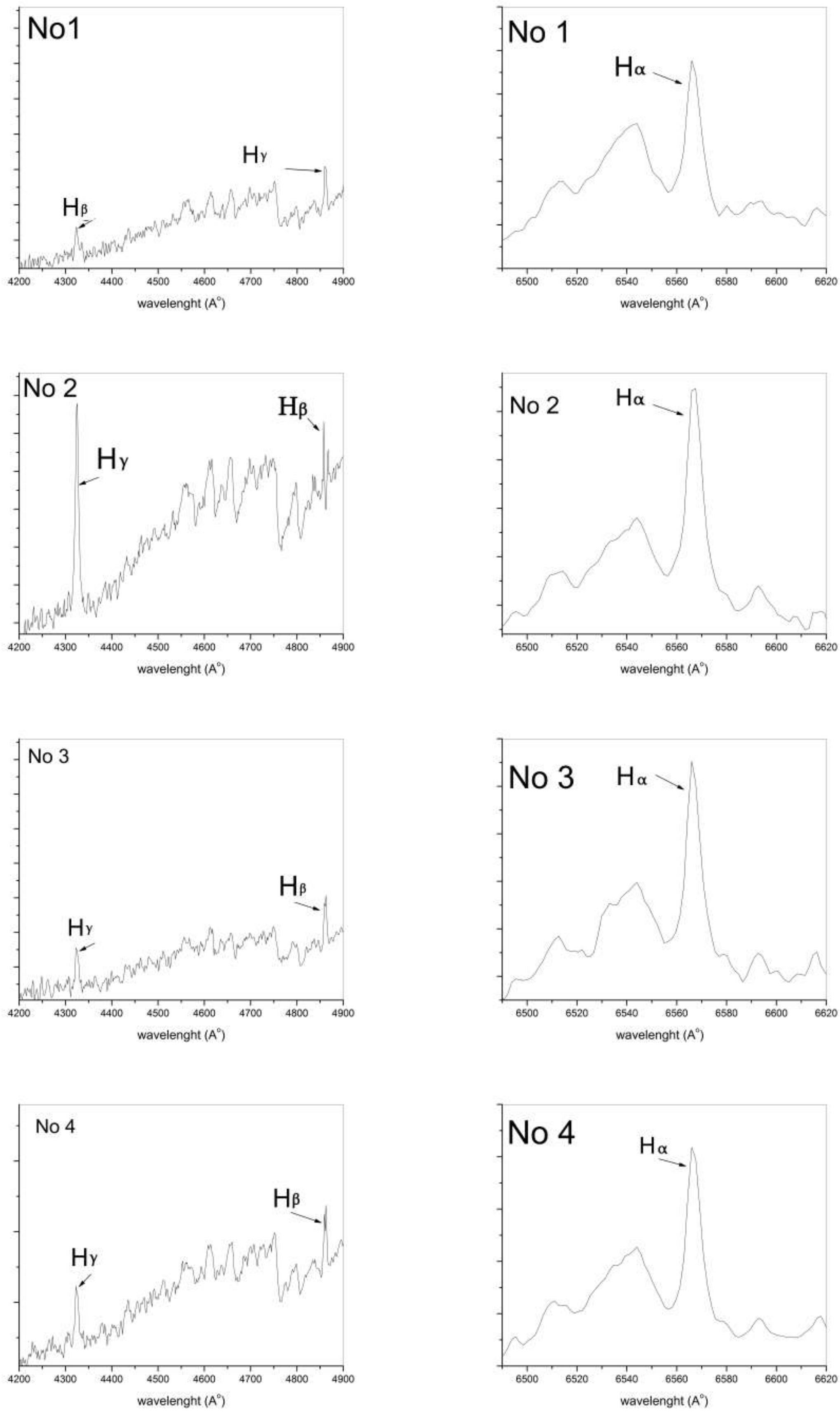

Figure 1. Spectra of TZ Ari in the the spectral ranges 4200-4900$\AA$ and 6490-6620$\AA$

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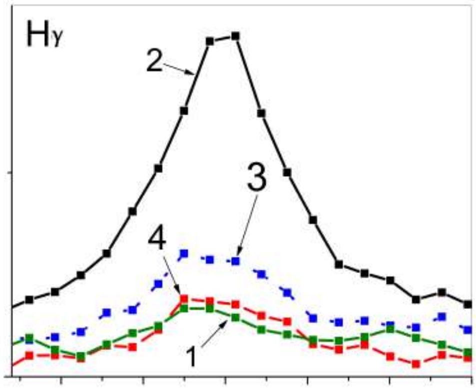

Figure 2. The profiles of emission line Hγ on four spectra. The number of spectra are shown by arrows.

2. Observations

The spectral observations for the stars TZ Ari and Ross 867 was obtained with the 2.6-m telescope in 1999, 2001 and 2018. 27 spectra were obtained for the program stars during 3^h40^m effective time of observations. Observations in 1999 were carried out with the "ByuFOSC" detecting system using the 1060x1028 pixel "Thomson" CCD with grism (spectral range 5450-7550$\mathring{A}$, dispersion 1.7$\mathring{A}$/pixel) (Movsessian et al., 2000). The observations with the SCORPIO spectral camera were carried out in 2001 and 2018. It employs a 2058x2063 pixel CCD and covers a spectral range of 4050-7250$\mathring{A}$. The net field of the telescope is 14x14' with a spatial resolution of 0.42"/pixel. The spectra were obtained using a grism with a 600 lines/mm grating and an ultimate linear dispersion of 1.7$\mathring{A}$/pixel. The operation of the SCORPIO spectral camera has been described in detail by Afanas'ev et al. (Afanasiev et al., 2005). Preliminary processing of the observational data (background subtraction, radiative flux and wavelength calibrations) was carried out with a program package developed specially for data taken by SCORPIO (Afanasiev et al., 2005, Moiseev, 2002). A neon lamp was used for wavelength calibration during the observations. The quality of the images during the observations was 2 angular seconds or less. A spectrum of the standard star was taken with each series of spectra. The variation in brightness was estimated using the integral emissions of the star and of a standard in the chosen spectral range. It was assumed that the minimum values of the ratios of the recorded integral fluxes of the program star and the standard correspond to the minimum brightness's of the stars. The errors in measuring the amplitudes of the light variation in the star's brightness fluctuate within limits of $\sigma(\Delta\mathrm{m})=0^m1-0^m2$, and the error in measuring the equivalent widths of the emission lines are within σ(EW)=0.3-1.0 $\mathring{A}$, depending on the exposure time and the brightness of the star.

In Table 1 log of the program stars observations carried out with the 2.6m telescope of Byurakan observatory presents. In the columns of the table list are the designations of the stars, observation dates, apparatus used, number of spectra obtained, exposure for each spectrum, and observed spectral range.

Table 1. The log of observations.

Star	Obs.Date	Instrument	N	Exp.time (min.)	Spect.range
TZ Ari	04.12.1999	ByuFOSC	10	5m	5400-7600
TZ Ari	05.12.1999	ByuFOSC	10	5m	5400-7600
TZ Ari	26.11.2018	SCORPIO	4	3m	4050-7000
Ross 867B	06.09.2001	SCORPIO	3	10m	4050-7250

3. Observational results

Over approximately 3.7 hours of total effective time of observational period, 27 spectra for the program stars TZ Ari and Ross 867B were obtained. During the observations a strong changes of emission lines was observed on TZ Ari in 2018 and a strong flare of brightness and strong changes of emission lines detected in case of star Ross 867B in 2001. The detail results of the observations for each star are presented separately below.

3.1. TZ Ari

The known flare star TZ Ari (=Gl83.1=L1159-16) is a red dwarf with a large proper-motion (van de Kamp et al., 1966) and with an apparent visual magnitude of 12^m29. This star known as a flare star (Gershberg, 1970, Pettersen, 1991) which lies relatively close to the Sun at a distance of about 4.4pc. To all probability detected emission in Hα has variable character: it changes in large interval - from $EW_{H\alpha} = 0\mathring{A}$ (Davison et al., 2015) up to $EW_{H\alpha} = 6.33\mathring{A}$ (Rauscher & Marcy, 2006). Different estimation of spectral type of TZ Ari - from dM3.5 (Fuhrmeister et al., 2018) up to dM8e (Agrawal et al., 1986) were reported as well. These results indicating that changes of spectral characteristics taking place not only during the flare events but also during the quiescent state of the star.

As one can see in table 1 four spectra of TZ Ari have been obtained in 2018. In fig.1 the spectral ranges 4290-4900$\mathring{A}$ (including the emission lines $H\gamma$ and $H\beta$) and 6490-6620$\mathring{A}$ (around $H\alpha$) from every obtained spectrum are presented. On each spectrum in Fig.1 the number of observed spectrum is presented, as well as hydrogen emission lines in this spectral region are shown by the arrows. On the second spectrum we detect a very strong rise of $H\gamma$ emission line intensity. Unfortunately on the second spectrum, just in the middle of $H\beta$ emission line there is a cosmic defect that we could not rid of during processing the spectrum. As it can be seen not so strong as $H\gamma$, no enough strength increase of $H\alpha$ emission line was detected as well.

In Table 2 the measured values of equivalent widths (EW) of emission lines $H\alpha$, $H\beta$ and $H\gamma$ on four obtained spectra are presented. In the Table 2 the number of obtained spectra and the start time for every exposition in UT, as well as the measured amplitudes of brightness variation of star in three spectral ranges (4000-5000$\mathring{A}$; 5000-6000$\mathring{A}$ and 6000-7000$\mathring{A}$) are given. It must be pointed out that the exposition time for every spectra equal to 180sec. Four spectra were obtained during 18 minutes, typical average duration for flare events of UV Ceti type flare stars. As one can see the brightness changes of the star in all measured spectral ranges are within the limits of measurement errors (0^m1 – 0^m2), while the emission lines show the strongest changes, similar to stellar flares. Specially strong changes were recorded in equivalent width of the emission line of $H\gamma$, which increased during almost 3 minutes more than 4 times. At the same time, $EW_{H\alpha}$ increases less than twice.

Table 2. EW of measured emission lines.

Sp	T (start) UT	Δm 4000-5000$\mathring{A}$	Δm 5000-6000$\mathring{A}$	Δm 6000-7000$\mathring{A}$	$EW_{H\alpha}$	$EW_{H\beta}$	$EW_{H\gamma}$
1	19^h59^m	0^m00	0^m04	0^m15	4.0$\mathring{A}$	3.6$\mathring{A}$	6.7$\mathring{A}$
2	20^h05^m	0^m22	0^m00	0^m003	7.3$\mathring{A}$	>5$\mathring{A}$	28.5$\mathring{A}$
3	20^h09^m	0^m02	0^m04	0^m00	6.4$\mathring{A}$	5$\mathring{A}$	18.8$\mathring{A}$
4	20^h13^m	0^m02	0^m00	0^m07	5.6$\mathring{A}$	4.3$\mathring{A}$	12.5$\mathring{A}$

In Fig.2 the profiles of the Hγ emission line in different observed spectra are presented. In the figure the numbers of the spectra are shown by the arrows. The numbers in the figure correspond to the numbers from Table 2. As can be clearly seen in the figure, during rather short observational time (∼18m), not only strong changes in the Hγ emission line intensity, but the changes of symmetry of its profile, also were detected.

To study the behavior of the Hα emission line in quiescent state of TZ Ari, we have 20 spectra obtained in 1999 during 2 nights. The spectra were registered in spectral range 5400-7600$\mathring{A}$. It giving possibility to follow for the behavior of emission line Hα only. In Table 3 the results of measurements, the amplitudes of the integral light variation in spectral region 5500 – 7500$\mathring{A}$ in stellar magnitudes

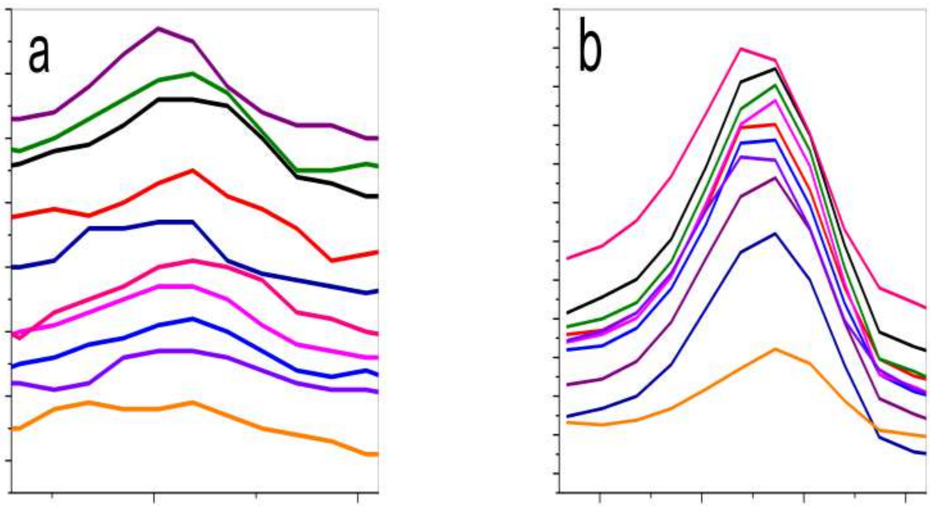

Figure 3. Hα emission line profiles for 2 nights of observations in the same spectral range 6553-6571$\mathring{A}$

(Δm), and values of $EW_{H\alpha}$ on every spectra in angstroms are presented. In the Table3 the date of observations, number of obtained spectra (No) and start time for every exposition T_{start} in UT are given as well. As can be seen from the data of Table 3, the measured amplitudes (Δm) of the star integral brightness and equivalent widths show slight changes not exceeding the measurement errors (3σ). Average value of Ha equivalent width for the first 10 spectra (NoNo 1-10) is 3.04$\mathring{A}$, while for the next 10 spectra average value of $EW_{H\alpha} = 4.75\mathring{A}$.

Table 3. Variation of brightness and $EW_{H\alpha}$ for 20 spectra..

04.12.2005				05.12.1999			
No	T_{start} UT	5500-7500$\mathring{A}$ Δm	$EW_{H\alpha}$ $\mathring{A}$	No	T_{start} UT	5500-7500$\mathring{A}$ Δm	$EW_{H\alpha}$ $\mathring{A}$
1	18^h57^m	0^m19	2.6	11	17^h55^m	0^m00	4.9
2	19^h08^m	0^m00	3.6	12	18^h03^m	0^m26	4.8
3	19^h15^m	0^m07	3.3	13	18^h09^m	0^m14	5.3
4	19^h42^m	0^m05	2.9	14	18^h15^m	0^m01	5.0
5	19^h49^m	0^m16	3.4	15	18^h21^m	0^m17	5.0
6	19^h57^m	0^m06	3.5	16	18^h27^m	0^m17	4.6
7	20^h03^m	0^m00	2.6	17	18^h41^m	0^m28	4.8
8	20^h10^m	0^m02	2.9	18	18^h47^m	0^m15	4.4
9	20^h17^m	0^m19	2.6	19	18^h53^m	0^m24	4.5
10	20^h25^m	0^m06	3.0	20	18^h59^m	0^m14	4.2

In Fig.3a,b the profiles of Hα emission line for first (3a) and second (3b) observational nights separately are presented. It must be noted that every spectrum has been received with 5 minutes exposure time. Variation of asymmetry of Hα profiles as well as its intensity changes one can see on the figure.

3.2. Ross 867B

The results obtained from the spectral observations of Ross 867B are presented. Ross 867B (=V639Her=Gl669B) is a flare star with a spectral class dM4.5e (Gershberg, 1970, Kunkel, 1967). Ross 867B is a member of a wide visual binary system (separation — 22”), with an apparent visual magnitude 12^m97, and lies at a distance of 10.8pc from the Sun (Pettersen, 1991). At the quiescent state of star a variation of 0.15 magnitudes was observed in the V-band with a period l.95 days (Doyle et al., 1986). Despite the fact that Ross 867B has been known as a flare star for a long time, it was not studied so often.

3 spectra of Ross 867B was observed in 2001 with equal exposure times – 10 minute. Accidently, a brightness increase with the amplitude Δm ($\lambda\lambda$4050-7200$\mathring{A}$) $= 1^m7$ is detected during the observations. The continuum and emission lines intensity changes are detected during the flare. In fig.4 the obtained spectra are presented. In figures the number of spectrum is presented, and, hydrogen emission lines are shown by the arrows. The signal/noise ratio do not allowed to measure EW for Hγ. A strong change shows emission line Hβ on the second spectra.

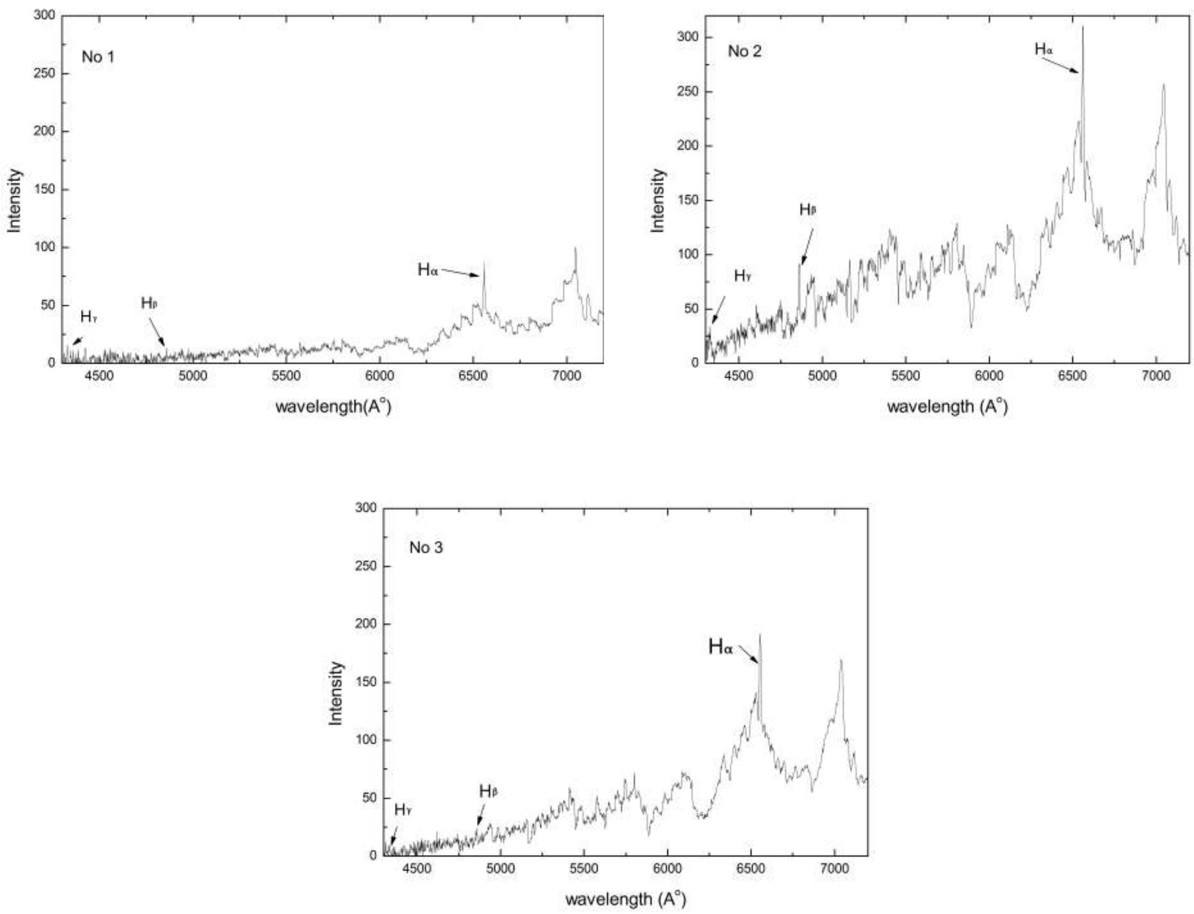

Figure 4. Obtained spectra of Ross 867B

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In Table 4 the measured values of equivalent widths (EW) of emission lines Hα and Hβ, as well as amplitudes of brightness variation of star measured on obtained spectra in the spectral ranges Δm_1 ($\lambda\lambda$4050-5200$\mathring{A}$), Δm_2 ($\lambda\lambda$5200-6200$\mathring{A}$) and Δm_3 ($\lambda\lambda$6200-7200$\mathring{A}$) are presented. The errors in measuring of the star's amplitudes is $\sigma_{\Delta m} = 0^m1 - 0^m2$, and the equivalent widths of emission lines are measured with errors $\sigma_{EW} = 0.5$-$0.8\mathring{A}$.

In the Table 4 the number of obtained spectra (Sp.No) and the start time - T_{st}. for every exposition in UT, as well as the measured amplitudes of brightness variation of star (Δm_1, Δm_2, Δm_3) in three spectral ranges (4050-5200$\mathring{A}$; 5200-6200$\mathring{A}$ and 6200-7200$\mathring{A}$) are given. It must be pointed out that the exposition time for every spectra is equal to 10 minute. Four spectra were obtained during 40 minutes. On the first obtained spectrum the star is in quiescent state. As one can see from these data a strong flare were detected with the duration of more than 20 min. The amplitudes of brightness decreases from short to long wavelengths, which is typical for the usual flare events of UV Cet type flare stars.

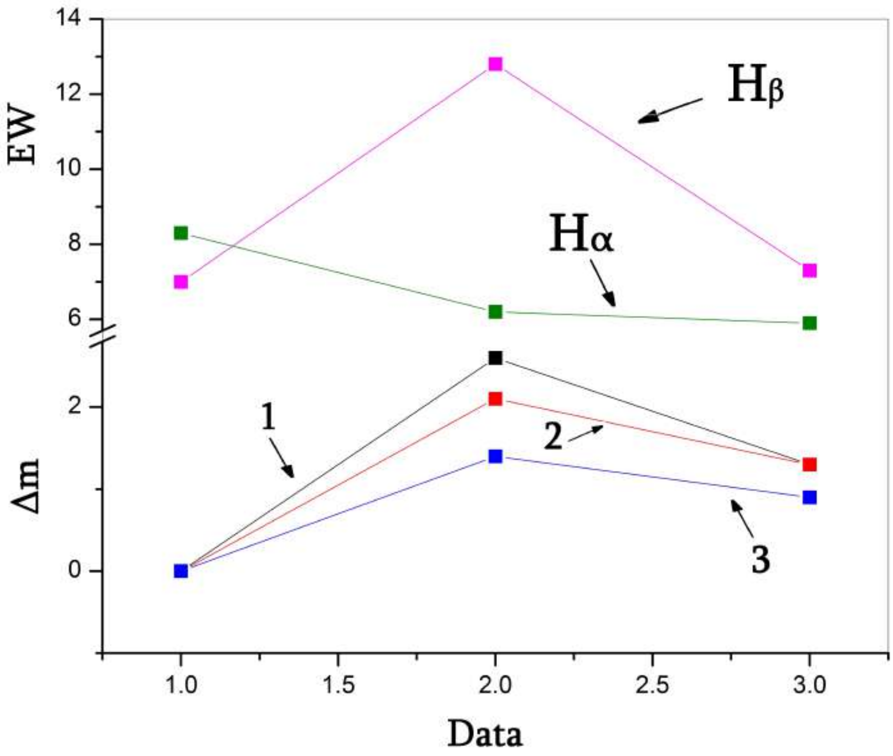

Figure 5. Equivalent widths and brightness variations of Ross 867B during the flare.

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The strong changes of equivalent widths also are detected. But if $EW_{H\beta}$ shows flare like variation with the maximum on second spectrum, $EW_{H\alpha}$ shows decrease similar to that observed earlier (Melikian, 2014, Melikian et al., 2006, 2013, Tamazian et al., 2005).

Table 4. Measured amplitudes and equivalent widths of detected flares.

Sp No	T$_{st}$ UT	Δm_1 4050-5200$\AA$	Δm_2 5200-6200$\AA$	Δm_3 6200-7200$\AA$	$EW_{H\alpha}$ $\AA$	$EW_{H\beta}$ $\AA$
1	20^h28^m	0^m0	0^m0	0^m0	8.3	7.0
2	20^h45^m	2^m6	2^m1	1^m4	6.2	12.8
3	20^h58^m	1^m3	1^m3	0^m9	5.9	7.3

The variations in the brightness and equivalent widths are illustrated on Fig.5. On fig.5 equivalent widths are shown by the arrows. Bellow in the figure the brightness variation in different spectral ranges 1-(4050-5200$\AA$), 2-(5200-6200$\AA$) and 3-(6200-7200$\AA$) are presented. As one can see from the figure maximum value of $EW_{H\beta}$ corresponds to the photometric maximum of flare, while at photometric maximum $EW_{H\alpha}$ decreases.

4. Conclusion

During the spectral observations of flare stars TZ Ari and Ross 867B two flares were detected. In case of TZ Ari flare-like strong changes are detected of hydrogen emission lines during the observations carried out in 2018, while at the same time the brightness changes are within the observational errors. During 3 minutes $EW_{H\gamma}$ increases from 6.7$\AA$ (first spectrum) to 28.5$\AA$ (second spectrum), at the same time $EW_{H\alpha}$ show changes from 4$\AA$ to 7.3$\AA$. The duration of flare like variation of these emission lines is more than 10 min.

A strong flare is detected on Ross 867B. The continuum and emission lines intensity changes are detected during the flare. During the flare the measured amplitudes of variation decreases from short to longer wavelengths. But if maximum of $EW_{H\beta}$ variation corresponds to the photometric maximum of flare, the maximum value of $EW_{H\alpha}$ at photometric maximum decreases, similar to that observed earlier on flare stars EV Lac, HU Del, CM Dra and UX UMa (Melikian, 2014, Melikian et al., 2006, 2013, Tamazian et al., 2005).

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Continuum Scattering and Formation of Emission Lines

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Abstract

The effect of radiation scattering in continuum on the spectral lines formation is treated. Compared to the early works in this direction, the conditions of emission lines appearance in the atmosphere with the temperature gradient with depth is discussed in detail. For simplicity's sake, the coherent scattering in the spectral line frequencies is adopted. By the example of atmospheres of supergiant stars of type A and adjacent classes, it is shown which lines and in what parts of the spectrum can be observed in the emission.

1. Introduction

This article continues our study (Israelian & Nikoghossian, 1996) on the effects of continuum scattering on spectral line formation. Besides the purely theoretical meaning, the problem is important in interpreting spectra of non-stationary stars of different types at some stages of their evolution. The concrete implication of this study concerns supergiants of type A and adjacent classes with extended atmospheres. The high degree of ionization of hydrogen, partly helium, due to high temperature and low gas density, provides a sufficient number of free electrons to make the effect of electron scattering quite measurable (Owocki et al., 2004, Wolff, 1983).

In the first part of this study (Nikoghossian, 2020), we reviewed in detail the effect of this scattering on the brightness curve and the hydrogen spectrum jumps of these objects. The main purpose of this work is to determine the conditions under which the emission line formation Shuster's mechanism operates (Schuster, 1905). The problem was considered by various authors under different initial assumptions (see, e.g. Gebbie & Thomas, 1968, Hummer & Rybicki, 1967). The LTE nd Non-LTE models of the problem were discussed. Of particular importance in the problem is a more accurate account of the temperature gradient in the atmosphere. This problem was solved by Harington but for the grey atmosphere. In this paper we adopt a simpler approach to the problem, which is based on Ambartsumian's principle of invariance (Ambartsumian, 1943, 1960) and on some other results we obtained in this direction.

2. The simplest problem of coherent scattering in both the continuum and spectral line

Before addressing the problem under study, let us first consider the auxiliary problem and introduce the values that control the scattering processes in the atmosphere.

Consider the 1D semi-infinite isothermal atmosphere absorbing and scattering in both the continuum and spectral line, the boundary of which is illuminated by the continuum radiation of unite intensity. Photons falling on the medium can be absorbed and scattered both in the continuum and within the spectral line. By denoting the densities of neutral atoms and electrons respectively through n_1 and n_e, for the probability of the photon scattering in the continuous spectrum, p_1, we can write

$$p_1(\nu) = \frac{n_e \sigma_0}{n_1 (\chi_\nu + \kappa_\nu) + n_e \sigma_0}, \tag{1}$$

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where the following notations are used: χ_ν and κ_ν are the coefficients of absorption in the continuum and spectral line, respectively, per hydrogen atom. We adopt the two - level model, so that the atoms are either ionized or are in the ground state. The electron scattering coefficient σ_0 is expressed through electron's classical radius to yield

$$\sigma_0 = \frac{8\pi}{3}\left(\frac{e^2}{mc^2}\right)^2, \tag{2}$$

where m and e are the mass and the charge of electron, and c is the light speed. Assuming that the number of free electrons is due solely to the ionization of hydrogen atoms, Eq.(1) can be rewritten in a more compact form

$$p_1(x) = \frac{\bar{\gamma}}{\alpha\left(x\right) + \beta + \bar{\gamma}} \tag{3}$$

where the following notations are introduced $\bar{\gamma} = (n^+/n_1)(\sigma_0/\kappa_0)$, n^+ is ions density, and κ_0 is the line absorption coefficient at the central frequency, $\alpha(x)$ is the line absorption profile, x is the dimensionless frequency measured by displacement from the center of the line in Doppler widths and β is the ratio of the continuum absorption coefficient to that in the center of the line.

By an analogous manner, for the probability of a photon to be scattered in the line denoted by p_2, we may write

$$p_2(x) = \frac{\lambda\alpha\left(x\right)}{\alpha\left(x\right) + \beta + \bar{\gamma}} \tag{4}$$

where λ is the coefficient of the quantum re-radiation in the elementary event of scattering in the line. The frequency redistribution function consists of two components, $r_1 = \alpha(x)\delta(x - x')$ and $r_2 = \bar{\gamma}\delta(x - x')$, correspondingly for the spectral line and continuum (here δ is Dirac's delta function). It is easy to see that these two scattering processes can be combined and considered as a single diffusion process with a scattering coefficient $\tilde{\lambda}$, where

$$\tilde{\lambda}\left(x\right) = \frac{\lambda\alpha\left(x\right) + \bar{\gamma}}{\lambda\alpha\left(x\right) + \beta + \bar{\gamma}} \tag{5}$$

The explicit expression obtained with use of invariance principle for the reflection coefficient for monochromatic scattering (see, e.g., Sobolev 1963), has a form

$$\rho\left(x\right) = \frac{1}{\tilde{\lambda}}\left(2 - \tilde{\lambda} - 2\sqrt{1 - \tilde{\lambda}}\right), \tag{6}$$

which in view of Eq.(5) after some simple algebra yields

$$\rho\left(x\right) = \frac{\sqrt{v\left(x\right)} - \sqrt{u\left(x\right)}}{\sqrt{v\left(x\right)} + \sqrt{u\left(x\right)}}, \tag{7}$$

where, for brevity, the following notations are introduced: $v(x) = \alpha(x) + \beta + \bar{\gamma}$, $u(x) = (1 - \lambda)\alpha(x)) + \beta$. The function $\rho(x)$ has probability meaning and gives the profile of radiation reflected from semi-infinite isothermal atmosphere denoted hereafter by $R(x)$. We will not discuss this auxiliary result and proceed directly to the problem under study.

3. The atmosphere with the temperature gradient

It is well known (see, for instance Mihalas, 1978, Sobolev, 1963) that the problem of the spectral lines formation in the Milna-Eddington model with allowance for the absorption in continuum is reduced to the solution of the transfer equation with a source term, describing the distribution of primary energy sources, of the following form

$$\varepsilon\left(\tau, x\right) = u\left(x\right) B_\nu\left[T\left(\tau\right)\right], \tag{8}$$

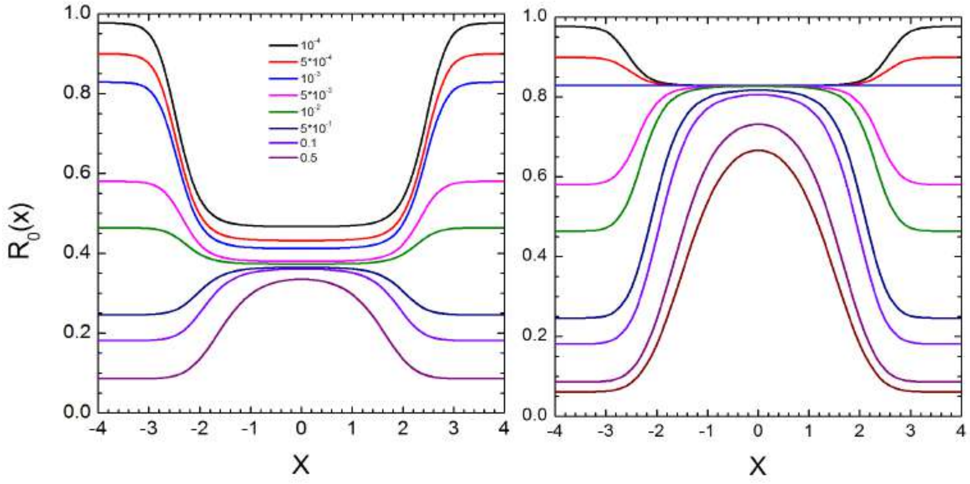

Figure 1. The line profiles formed in an isothermal atmosphere for $\lambda = 0,9$ (left) and $\lambda = 0.5$ (right) for indicated values of $\bar{\gamma}$. In both cases β is 10^-3

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where $B_\nu(T)$ is the Planck function depending through temperature on optical depth in the center of the line. In solving the considered problem it is usual to make use of an expansion of the Planck function in the form of a series in terms of τ, as given by

$$B_\nu \left[T\left(\tau\right)\right] = \sum_{n=0}^{\infty} \frac{B_{\nu n}}{n!} \left(\beta\tau\right)^n. \tag{9}$$

In our papers (Haruthyunian & Nikoghossian 1978, Nikoghossian & Haruthynian 1979) we suggested an easy way of determining spectral line profiles formed in atmospheres with distributed in it energy sources of the form Eq.(9). It has been shown that line profiles for arbitrary internal sources of the form Eq.(8) are expressed in a recursive way in terms of the profile formed in an isothermal atmosphere with $\varepsilon = u(x)$. Note that $u(x)$ also has a probabilistic meaning by giving the probability that the line photon will undergo true absorption and thermalized either in the line frequencies or in the continuum. In the first of the above works we have shown that there is a simple relationship between the line profile formed in the isothermal atmosphere, R_0, and the reflected line profile R_*.

$$R_*\left(x\right) + R_0(x) = 1. \tag{10}$$

This relationship has a plain probabilistic interpretation and follows from the fact that the radiation incident on the medium is either reflected from it or is thermalized in the course of multiple scattering in it. Now with use of Eq.(7), we find

$$R_0\left(x\right) = 2/\left(1 + \frac{1}{\sqrt{u\left(x\right)/v\left(x\right)}}\right). \tag{11}$$

Consider the question under what conditions in this simple case of isothermal atmosphere the spectral line can appear in the emission. Obviously, it requires that $R_0(x) > R_0(\infty)$. Eq.(11) yields

$$\left(1-\lambda\right)\bar{\gamma} > \lambda\beta. \tag{12}$$

In the simplest case of isothermal atmosphere, Eq. (12) is a necessary and sufficient condition for the spectral line to appear in the emission. At least two important conclusions can already be drawn on the base of Fig.1 We see that this condition will be satisfied above all by weak lines, which, on an average, are formed in deeper layers of the atmosphere. This emphasizes the importance of taking into account the temperature gradient in it. In addition, as might be expected, the degree of ionization, on which the density of free electrons depends, plays an important role in the appearance of emission lines.

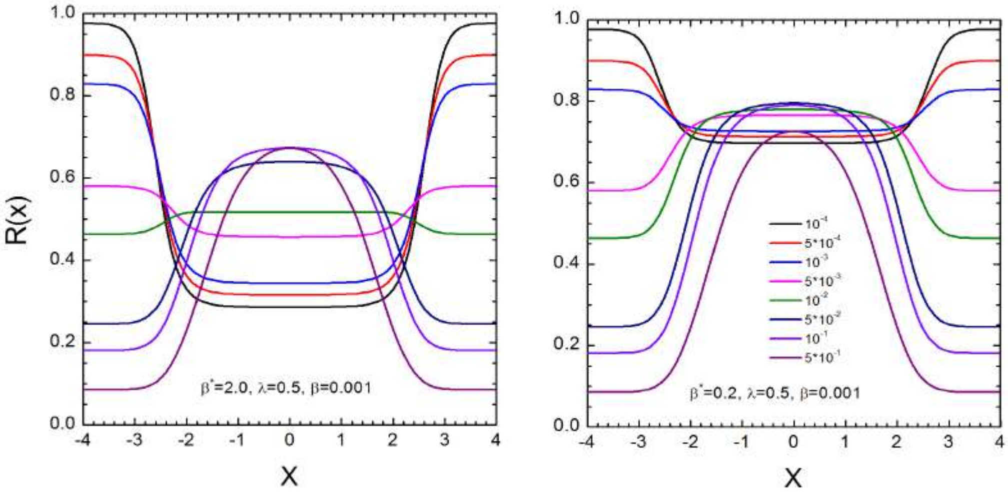

Figure 2. The profiles of spectral lines with $\lambda = 0,5$ formed in the atmosphere with temperature gradient in the presence of electron scattering. The lines of two extreme domains of continuum spectrum are depicted

We give some estimates for the degree of ionization of hydrogen for temperatures about $10^4 - 10^5$K and spectral lines with moderate values of $\lambda \leq 0,8 \div 0,9$in a wide range of wavelengths 300-900nm. We have $\gamma = \sigma_0/\kappa_0$, where $\sigma_0 = 6.65 \cdot 10^-25cm^2$ and κ_0 for the pure Doppler broadening of the line is given by (see,e.g., Mihalas, 1978, Sobolev, 1963)

$$\kappa_0 = \frac{\lambda_0^3}{8\pi^{3/2}v}\frac{g_k}{g_i}A_{ki}, \tag{13}$$

where λ_0 is the wavelength of the line center, A_{ki} are Einstein's coefficients of atomic spontaneous transitions and $v = \sqrt{2kT/M}$ is the mean thermal velocity (for other quantities the usual designations are adopted). To estimate the order of magnitude for the degree of ionization, note that the right side of the inequality (12) at the chosen numerical values of parameters is the value less than 10^{-4}, while the ratio σ_0/κ_0 for the lines with A_{ki} of about $10^5 \div 10^6\,\mathrm{sec}^{-1}$ lays in the interval $10^{-9} \div 10^{-10}\,\mathrm{sec}^{-1}$. This means that the degree of ionization of the order of 10^5 and above is sufficient for the appearance of emission lines resulting from transitions between the upper energy levels. Such a high degree of ionization may well occur in the high-temperature and rarefied shells of the stars under consideration.

Let us turn now to the effect of the temperature gradient. In a linear approximation, we have

$$B_\nu\left(T\right) = B_\nu\left(T_0\right)\left(1 + \beta_\nu^* \bar{\tau}\right), \tag{14}$$

where $\bar{\tau}$ is the optical depth in continuum in terms of Planck's mean coefficient of absorption, and

$$\beta_\nu^* = \frac{3}{8}\frac{h\nu}{kT_0}\left(1 - \mathrm{e}^{-\frac{h\nu}{kT_0}}\right)^{-1}. \tag{15}$$

In accordance with Haruthyunian & Nikoghossian (1978), for the normalized profile of the line, we have

$$R\left(x\right) = \left[P\left(x\right)/P\left(0\right)\right]R_0\left(x\right), \tag{16}$$

where

$$P\left(x\right) = 1 + \frac{\beta_\nu^*\beta}{v\left(x\right)\sqrt{1 - \tilde{\lambda}\left(x\right)}} = 1 + \frac{\beta_\nu^*\beta}{\sqrt{v\left(x\right)u\left(x\right)}}. \tag{17}$$

The transition from the center of the line to its wings in functions $R_0(x)$ and $P(x)$ occurs in mutually opposite directions, and there is not any closed-form formula for conditions of the line appearance in emission.

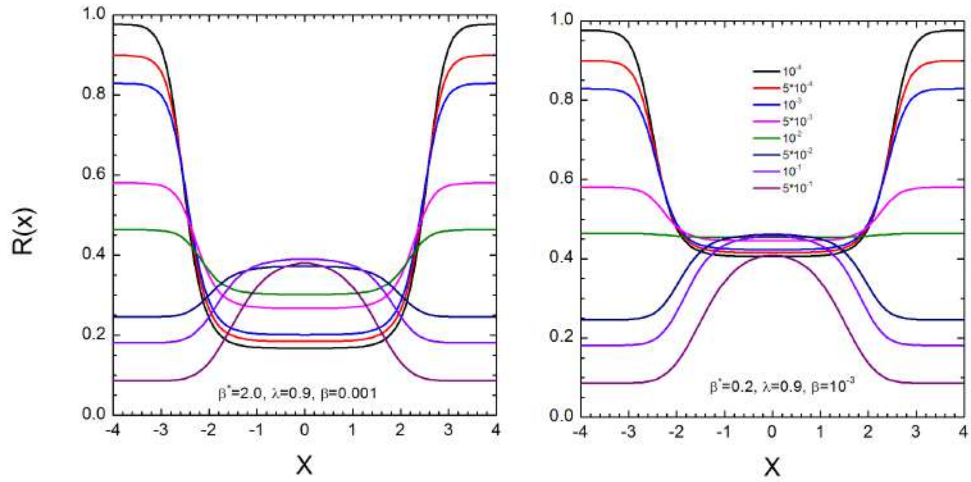

Figure 3. The same as in Fig. 2 for $\lambda = 0,9$

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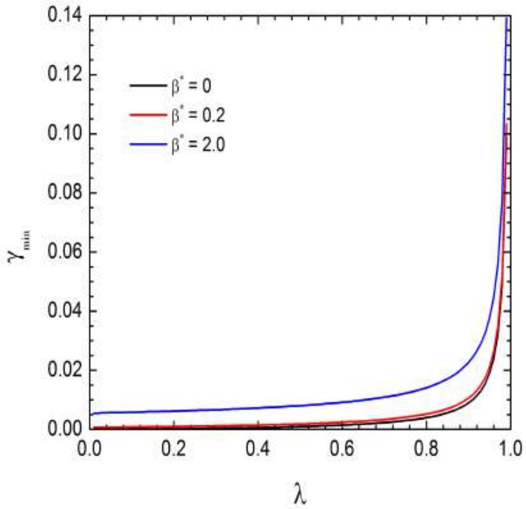

Figure 4. Dependence of threshold values of $\bar{\gamma}$ on the coefficient of scattering within a line.

Figs.2,3 show the line profiles formed in non-isothermal atmospheres with a linearly growing with depth temperature. Two cases corresponding to two values of the coefficient β_ν^* which refer to two different (shortwave and long-wave) spectrum domains are considered. We see that, as in the isothermal atmosphere, the threshold for the influence of electron scattering on the spectral lines here also depends to a large extent on the λ value. This is particularly well illustrated in Fig.4, which shows the dependence of the lower threshold of the scattering action in continuum resulting appearance of the lines observed in emission.

The specified threshold also essentially depends on value β_ν^*, that is, on what area of a continuous spectrum the line is formed. Taken together, these facts allow us to conclude that the most probable is the appearance of emission in relatively weak lines in the long-wave regions of the spectrum. In all, the differences between the line profiles formed in an isothermal atmosphere and in an atmosphere with a temperature gradient are quantitative and mainly repeat each other. Profiles of both absorption and emission lines basically are broadened and bell-shaped, which become narrower with the increasing role of electron scattering. The latter is due to the fact that these lines, on an average, are formed in more superficial and relatively low-temperature layers of their formation.

The results presented in the paper show that despite the comparatively small coefficient of electron scattering, under certain physical conditions spectral lines can be observed in the emission. At the same time, the line profiles have a form characteristic of electron scattering. However, in some cases it may be necessary to address the problem in a more general formulation, taking into account the frequency redistribution within the line. At the same time, it is important to take into account the dynamics of the medium in the line formation, so when interpreting it, problems similar to that we treated should be combined with one or another dynamic models.

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The observation of Angegh–Vulture (Cygnus) constellation in Armenia 32 000 years ago

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Abstract

The “Qarahunge Observatory”or “Zorats Qarer” megalithic monument-complex has been little studied and till today the opinions of different scholars on the age of its construction and significance vary widely. In this article, using astronomical and geometric methods, we have tried to show that this ancient astronomical observational complex could have been built only 32300 years ago by the Angegh–Vulture (Cygnus) constellation model, when the declination of the Sadr star corresponded to the local latitude. It has also been attempted to substantiate the direct link between the constellation and the structure in several respects, in particular, it has been shown that 7800 years ago, some changes were made to the structure, the opening of some stone holes, and the observations of some of the stars of the Angegh–Vulture (Cygnus) constellation. At the same time, however, the original layout-composition of the complex and its contents have been preserved.

Keywords: *Qarahunge Observatory: Zorats Qarer: megalithic monument: Cygnus: Angegh: Swan constellation: Deneb: Sadr: Göbekli Tepe: Vulture*

1. Introduction

Not far from Sisian town of Syunik region of Armenia there is a historical-cultural megalithic monument now known as “Qarahunge Observatory” or “Zorats Qarer”. It is situated at an altitude of 1770 metres above sea level and covers about 7 hectares. The coordinates are North latitude $39°33'$, East longitude $46°01'$ (Figure 1a).

In recent decades, the issue of the name of the monument has become quite controversial due to the conflict of opinions of various authors. In this publication we will use terms “monument”, “megalithic structure”, or “astronomical observational complex”. Ultimately, it is more important to answer the questions connected with age and significance that are constantly discussed. In the 1980s, in their publications, Khnkikian (1984) and Parsamian (1985) re-assigned the ancient menhirs to possible astronomical significance. After that, in the 1990s, Heruni (2006), with his expedition, mapped the monument, measured the azimuthal directions of some stones with holes, and numbered the stones (Figure 1b) and based on the obtained data with 4 independent methods he showed that this structure was an observatory more than 7500 years ago and has operated for about 5500 years.

He also showed stones with holes corresponding to the rising and setting azimuths of some of the brightest stars of that time (such as Deneb’s (α Cygni) about 7600 years ago). One of the most interesting notions concerning this megalithic complex is Vahradyane & Vahradyane (www.anunner.com) hypothesis that the composition of the menhirs is almost identical to the modern constellation of Swan-Cygnus (Angegh-Vulture in old Armenian tradition) in general, except for the south angle which is about 120° (Figures 1a,b,c) in the case of constellation γ Cygni - ε Cygni - ζ Cygni angle[1] is about 160° (Figure 4). This inconsistency was explained by the author with a relatively large value of ε Cygni star proper motion (0.4869 angular sec/yr, positional angle of proper motion 47.4°) and by this

[1]Here and thereafter, the angles drawn by the lines connecting the constellations’ bright stars will be marked wit hthe corresponding letters of the stars, in the center the star corresponding to the top of the corner will be marked as accepted in geometry.

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method he found correspondence of angles of the south arm of the structure and γ Cygni - ε Cygni - ζ Cygni about 14500 years ago.

This idea is nice and at the same time very logical, but it raises some issues that are still unanswered. In particular:

1) The stars of Angegh (current Swan) constellation ε Cygni, γ Cygni and δ Cygni have never been aligned on a single line, such as the straight line of stones from the south to the north of the monument without "arms" is. Therefore, if it was constructed using the constellation model and the angle of the south arm was taken into account, it would be logical to assume that all angles would have to be aligned, or vice versa, no angle would be clearly preserved. This makes the logic base of calculation of the age of the monument vulnerable, no matter how obvious the similarity of the Angegh–Vulture (Cygnus) constellation and the monument layout is.

2) 14500 years ago the constellation Angegh–Vulture (Cygnus) was near the North pole and none of its stars δ (declination) corresponded to the local latitude $39°33'$ (Figure 6).

3) A problem arises when the angle between the northern direction of the northern arm of the structure and its bend to North-West is compared with the γ Cygni - δ Cygni - ι Cygni angle (about 10 - 15°). These angles would also have to coincide, taking into account that the angular velocities of these stars' proper motions are relatively small (γ Cygni - 0.0027; δ Cygni - 0.068; ι Cygni – 0.1462 angular sec/yr) and during last 40000 years angle, the δ Cygni peak is changing substantially, making about 142° when the corresponding angle of the monument is about 150-162° (The angles were measured on three different angular structure maps (Figures 1a,b,c) and on the constellation map data and their arithmetic means are summarized in Table 1).

The purpose of our study is to answer the above questions, to resolve any problems that may arise and to obtain the most likely period of construction of this multi-layered monument.

To illustrate the layout angles, we will next use the Latin uppercase letters matching the center letter to the angle peak, for example, the KID_1 angle peak will be I (Figure 2b).

2. Material and methods

This monument differs from the many other megalithic monuments in the layout of the menhirs, which is the core of these research material. The other basic parametric data is its latitude $39°33'$. If we look at the structure of the monument as layout-composition, it is obvious that the builders placed the greatest importance on the central part (Figure 1,2,3). This oval-shaped cromlech, centered on a circular structure, intersects with a straight line of stones stretching from South to North, bending South-West at a GEZ angle, and North-North-West (GDI), then turning North. (DIK) (Figure 2a). When looking at the North part, one should first look at its slightly wavy course, which can form two angles that are different from one another: GDI, DIK, and GD_1I, D_1IK (Figure 2a).

If we analyze the data in Table 1, it will be clear that in future calculations the GDI and DIK angles can be used as data, since DIK $\approx$ 154° corresponds to the δ Cygni - ι Cygni - κ Cygni angle, which, as mentioned above, does not change significantly over time. In addition, the ratio of lengths $\frac{DI}{IK}$ (R $\approx$ 3) also corresponds to the current ratio of the projection distances $\frac{\delta Cygni - \iota Cygni}{\iota Cygni - \kappa Cygni}$ (r $\approx$ 3) in contrast with $\frac{D_1I}{IK}$ (R $\approx$ 2) (Figure 2a). Of course, such mismatch of relations is not accidental, since the stars ι Cygni, κ Cygni and δ Cygni also have their proper motions (the angular velocity of Cygni's proper motion is 0.1466 angular sec/yr), and if we recalculate time, we will see that r $\approx$ 2 about 30000 years ago. This indicates that this multi-layered ancient place has also undergone some changes during the formidable period to accommodate the stellar sky. However, when discussing older periods, it would also be appropriate to consider GD_1I and D_1IK angles to avoid inaccuracies. As one can see, the averaged numbers in Table 1 are closer to the drone shooting data and should be viewed as being true. The GDI $\approx$ 157° angle is more interesting, which differs from the constellation γ Cygni - δ Cygni - ι Cygni angle (142°) by about 15 and cannot be combined. The GEZ angle of the south arm also differs markedly from the current constellation γ Cygni - ε Cygni - ζ Cygni angle, which is due to

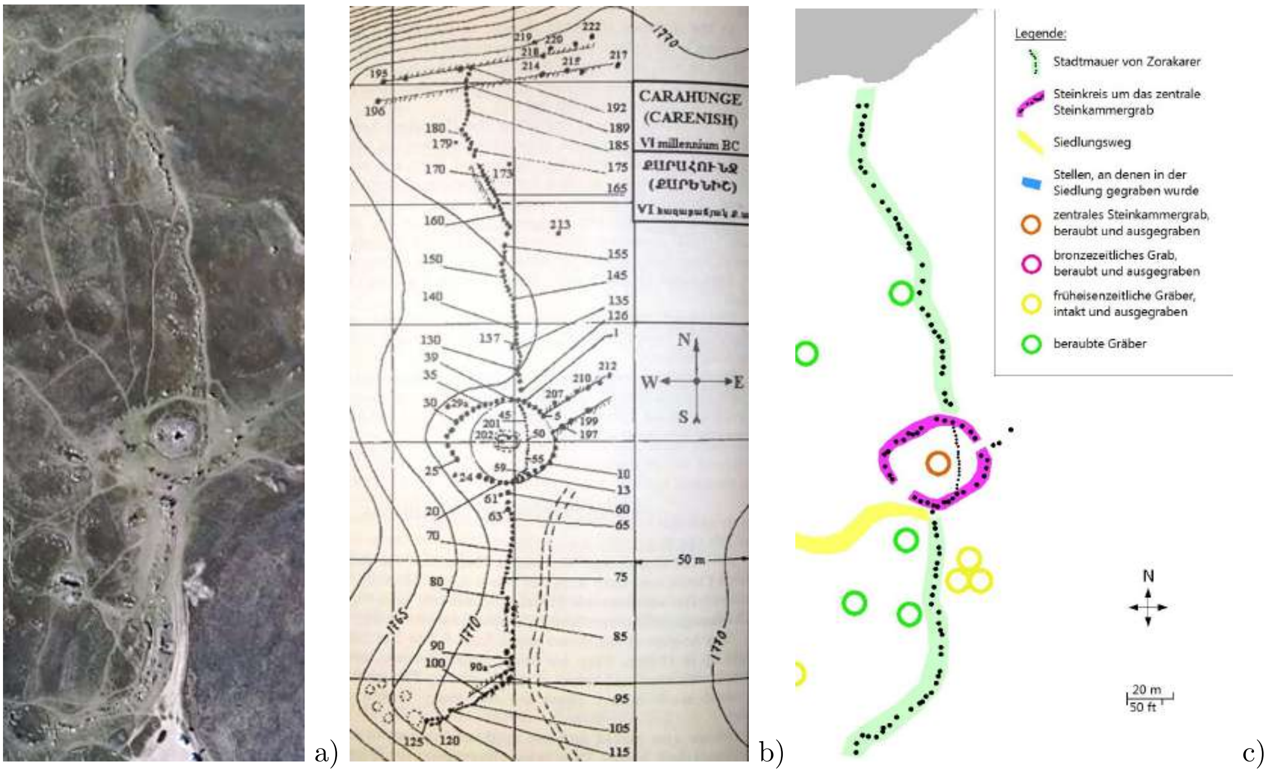


Figure 1. a) The view of the megalithic complex from above. Photo (Drone: DJI, Phantom 4 Advance. 1-inch 20mp, 4K/60fps), b) Map of the monument according to the academician P. Heruni, c) Graphic map (Source: File: Gelände von Zorakarer (Graphik).jpg-Wikimedia Commons). www.wikimedia.org

Angle	GEZ		GDI(GD_1I)	DIK(D_1IK)
According to P. Heruni's mapping (°)	123	<	162(152)	154(149)
Photo of drone (°)	122	<	156(150)	154(152)
Graphic Map (°)	127	<	154(152)	155(147)
Arithmetic mean (°)	124	<	157.33(151.33)	154.33(149.33)
The relationship of angles	$\wedge$		$\vee$	$\approx$
Corresponding corner of the current Cygnus (°)	157	>	142	154

Table 1. Comparison of the layout angles of the monument (obtained by 3 different methods) with the corresponding angles of the Angegh (Cygnus) constellation. Possible error of goniometer is 2°.

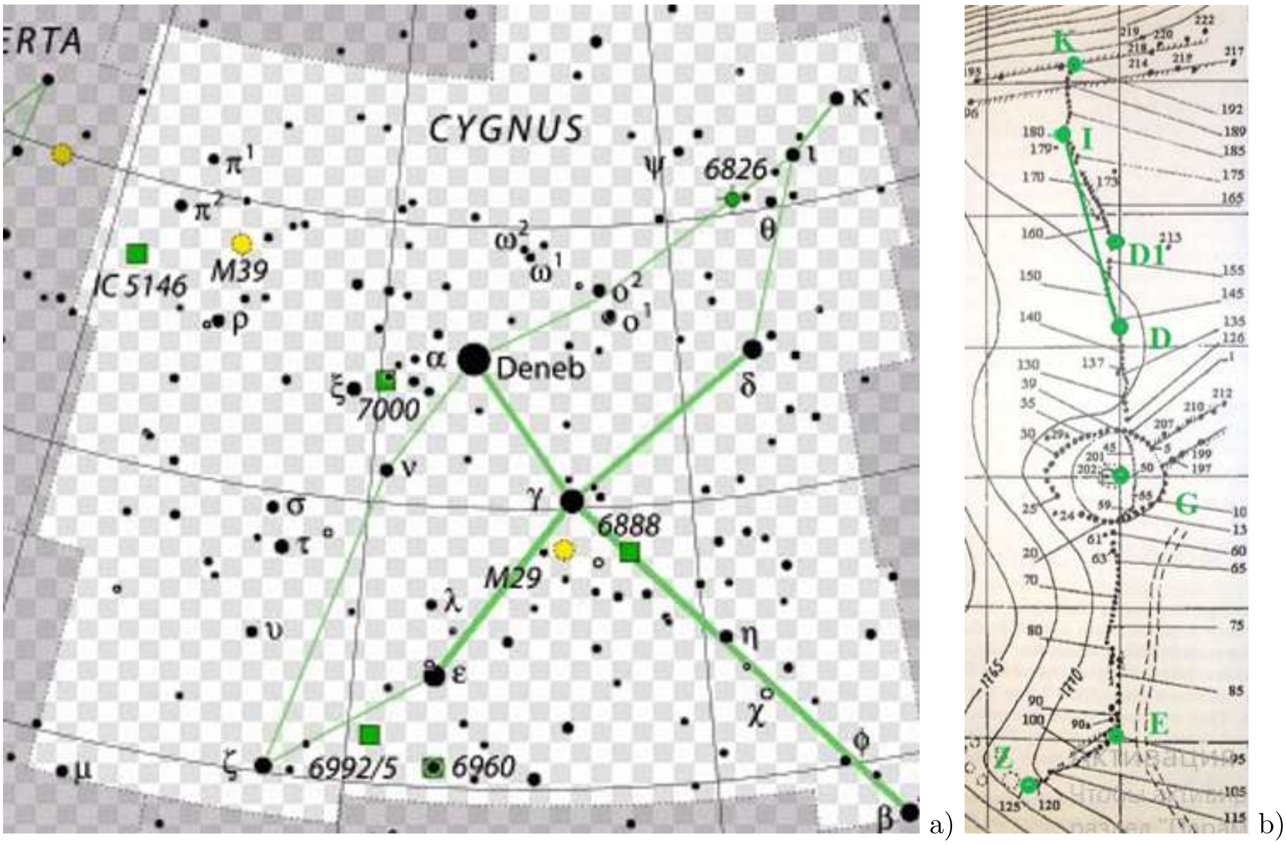


Figure 2. a) Current map of the Angegh–Vulture (Cygnus) constellation, b) The Latin uppercase letters of the points have been matched to the stars: K - κ Cygni, I - ι Cygni, D and D_1 - δ Cygni, G - γ Cygni, E - ε Cygni and Z - ζ Cygni.

the relatively high angular velocity of ε Cygni's proper motion. All this make it possible to compare not only the constellation map with the layout of the monument, but also to observe its position with respect to the celestial meridian and the zenith point. Note that the stars of ε Cygni, γ Cygni and δ Cygni have not been in a single line for the last 40000 years. At the same time, points E and D of the monument layout, which we can compare with those stars, are located on the South-North line (which is the projection of meridian on the ground). This allows us to place the construction of the monument at a time when ε Cygni and δ Cygni stars intersect at the celestial meridian at the same time (when the deviation of the ε Cygni - δ Cygni axis is $0°$ from celestial meridian).

The next most important issue concerns the central structure. Both with its composition, its size and the layout of the structure it should be emphasized. At the same time, the center of the sky is the zenith point for the viewer above the ground. It is therefore logical to assume that the stars corresponding to it would have to pass through the zenith point during the construction of the monument. As such, one can consider the star Sadr (γ Cygni), which joins the parts of Angegh–Vulture (Cygnus) and has a central position in the constellation. It turns out that at the time of construction of the complex Sadr's declination was to correspond to the local latitude of $39°33'$ and that star could have been observed in the zenith. It is noteworthy that 7800 years ago the declinations of Deneb and Sadr were approximately the same (Deneb - $\delta = 39°52'$; Sadr - $\delta = 39°33'$) (*Stellarium 0.19.1* computer program was used). It is also interesting that not even a separate standing stone coincides with Deneb, which allows one to assume that Sadr could have been of greater importance to the observatory builders. At least it is necessary to consider the periods when the declinations of Sadr and/or Daneb corresponded to the local geographic latitude, and the stars of ε Cygni and δ Cygni crossed the celestial meridian at the same time and at that time the obtuse angles with celestial meridian of the constellation ε Cygni - ζ Cygni and δ Cygni - ι Cygni (later we will use α and β names for them, Table 2) also corresponded to the GEZ and GDI angles of the monument layout (Figure 2a,b, Table 2).

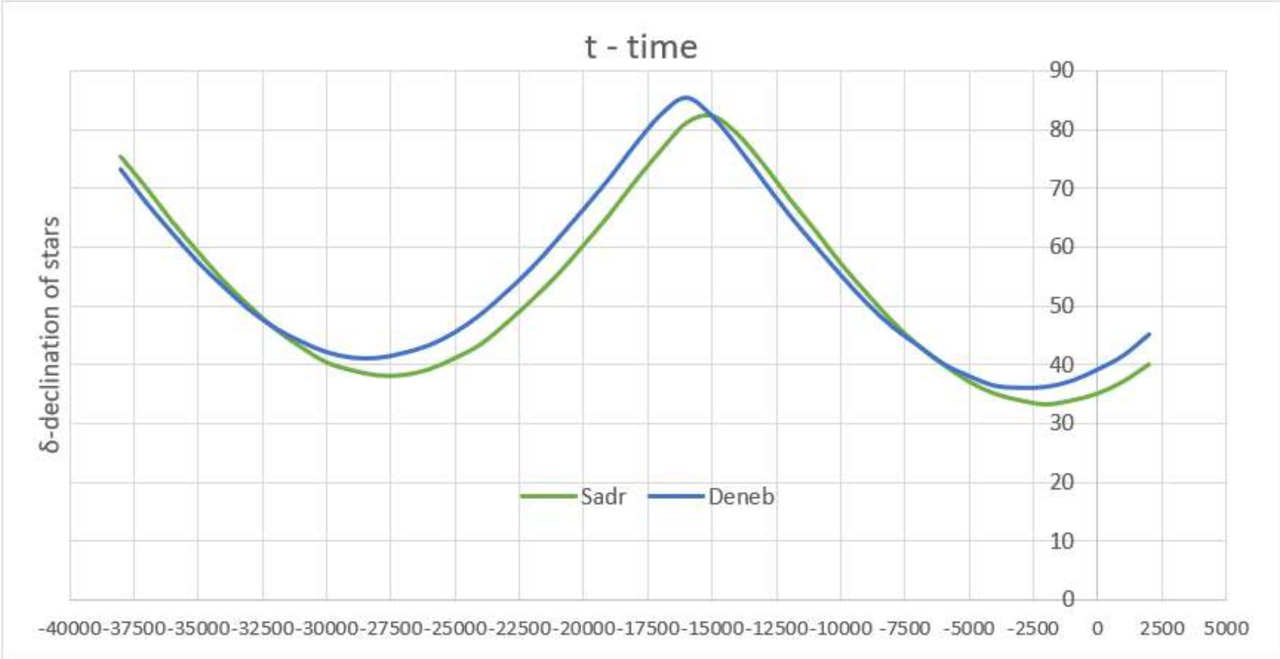


Figure 3. Changes in declination of Sadr and Deneb over 40000 years (Stellarium 0.19.1 computer program was used).

Year before us	250	6650	7800	16500	28000	31300	31400	32300
Declination of Sadr	$39°33'$	$36°30'$	$39°33'$	$81°35'$	$39°33'$	$39°33'$	$39°44'$	$41°13'$
ε Cygni - δ Cygni axis	-40°	0°	+10°	0°	-20°	-2°	0°	+7°
β angle	123°	154°	158°	138°	103°	121°	122°	124°
α angle	199°	152°	143°	157°	190°	165°	163°	157°
Relations of α and β angles	$\alpha < \beta$	$\alpha \approx \beta$	$\alpha < \beta$	$\alpha > \beta$	$\alpha < \beta$	$\alpha > \beta$	$\alpha > \beta$	$\alpha > \beta$
Declination of Deneb	$44°29'$	$37°38'$	$39°52'$	$79°43'$	$43°35'$	$41°35'$	$41°41'$	$42°36'$

Table 2. Comparison of the Angegh–Vulture (Cygnus) constellation parameters and position with the monument layout at different times. Possible angle error is 2°.

If we recalculate, we will first meet the Sadr $39°33'$ declination in the 18th century AD (Figure 3). Of course, this period is not a matter for discussion, especially since at that time deviation of the ε Cygni - δ Cygni axis from the celestial meridian is about 40°. The previous coincidence of Sadr's declination and local latitude was 7800 years ago. In this case, Deneb has a similar declination of $39°52'$, and the deviation of the ε Cygni - δ Cygni axis from the celestial meridian is about 10° (Table 2), but the celestial meridian is intersected almost simultaneously by the stars ζ Cygni, Sadr and δ Cygni. At that moment the γ Cygni - δ Cygni - ι Cygni angle is approximately 142° (Table 1), and the γ Cygni - ζ Cygni - μ Cygni angle is about 140°. As we can see, there are many discrepancies, especially if we consider that the ε Cygni - δ Cygni axis can coincide with the celestial meridian only 1150 years after Sadr's declination is $36°30'$, Daneb's $37°38'$, and in this case angles of γ Cygni - ε Cygni - ζ Cygni and γ Cygni - δ Cygni - ι Cygni are approximately equal (Table 2, in 6650 years ago). Considering such inconsistencies, it is necessary to consider older periods. Figure 3 shows the changes of declination of Sadr and Deneb during the Earth's procession over the last 40000 years.

The graphic in Figure 3 shows that Sadr's declination of $39°33'$ (as opposed to Deneb's) was 28000 and 31300 years ago. 28000 years ago the ε Cygni – δ Cygni axis deviated from the celestial meridian by about 20°, and $\beta \approx 103°$, which is also a large difference (the α angle is the obtuse angle of the δ Cygni - ι Cygni celestial axis and the celestial meridian at the δ Cygni peak and the angle is the obtuse angle of the ε Cygni - ζ Cygni axis and the celestial meridian with a peak at ε Cygni). All the parameters discussed above correspond to the position of 32300 to 31300 years ago ($\alpha > \beta$) (Table 2). The combination of the constellation map and the monument layout (if scaled) seems to be ideal

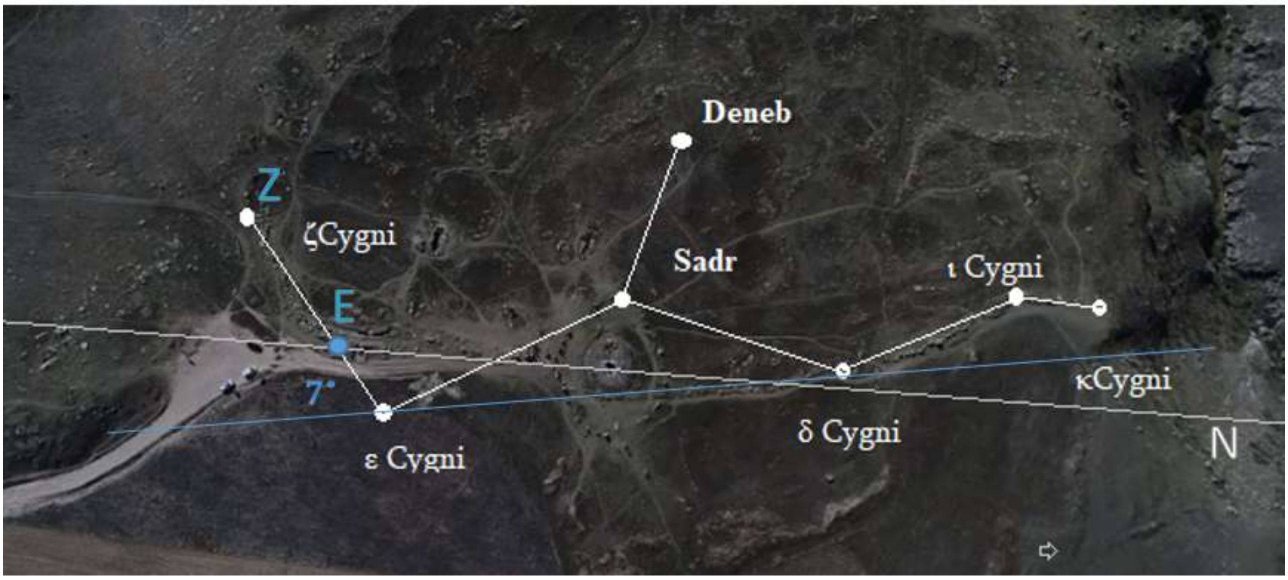


Figure 4. Scale combination. 32300 years ago the 7° deviation of the ε Cygni - δ Cygni axis (blue line) from the celestial meridian is expressed in the layout.

31400 years ago except for one major mismatch. It turns out that the EZ length of the layout is smaller than the ε Cygni - ζ Cygni projection distance (for scaling, Figure 4), and the α angle of the north arm is larger. But these problems are solved 32300 years ago when the axis of constellation ε Cygni - δ Cygni with respect to the celestial meridian is deviated by about 7° (Figure 4, Table 2).

It also explains the 7° angular deviation from the North-South axis (Figure 4) of the menhir range of the line joining the stones № 143 and 56 (Figure 5b), and the projection point of the ε Cygni star on Earth should correspond to the area East to the stones 80-85 where the land was cultivated and very probably the stones were moved from their original places (stone numbering according to P. Heruni). As it can be seen in Figure 4, Sadr overlaps the peak of oval-shaped cromlech. To the South of there is the separate manhir № 24 and circular located stones (Figures 5a,b). The calculation shows that the Sadr's position would correspond to the above mentioned point in the layout 31400 years before us (Figures 5a,b), if we compare δ Cygni with point D rather than point D_1 (in this case, the separate standing stone № 173 is possible to correspond the ι Cygni star) (Figure 5a).

Thus, 32300 years ago not only does the β and α angles directly coincide with the GEZ and GD_1I angles of the monument layout, but also the relations between the projections of the stars and the length of the monument layout, which is excluded during the observation of any other period. This circumstance already proves that the builders of the complex have carried out precise measurements and precise design work, keeping sincerely adhering to the ancient principle of "whatever is in heaven, it is on Earth". If this huge complex was built using the Angegh–Vulture (Cygnus) constellation model, it would be logical to assume that the visible stars of the constellation Deneb, Sadr, ε Cygni and δ Cygni were also observed here. Taking into consideration that the declinations of Deneb and Sadr correspond to the geographic latitude of 7800 years before us (Figure 5), it is possible that more active changes (opening of new holes, movement of some stones, etc.) have been made during this period. Let's consider the azimuths of several standing stone holes facing the stars above 7800 years ago (Table 3, Figure 7b) (stone numbers according to Figure 1b). Of the 37 standing stones with holes, we identified 9 stones through whose holes some stars of the Angegh–Vulture (Cygnus) constellation could be viewed 7800 years ago. Let's consider the positions of some of them.

Let's start by analyzing the North arm. № 181 stone's positioning exactly matches point I (Figure 2b), corresponding to the ι Cygni star (Figure 4), the setting of which can be seen from its hole (Table 4). The positioning of the 143th stone coincides with point D (Figure 2b), corresponding to the δ Cygni star (Figure 4), the rising of which can be seen from its hole (Table 4).

If we compare the angular distance of δ Cygni - ι Cygni with DI length, then the location of the ε Cygni star will be approximately at point E, but 6650 years ago (Table 2). It is more interesting when

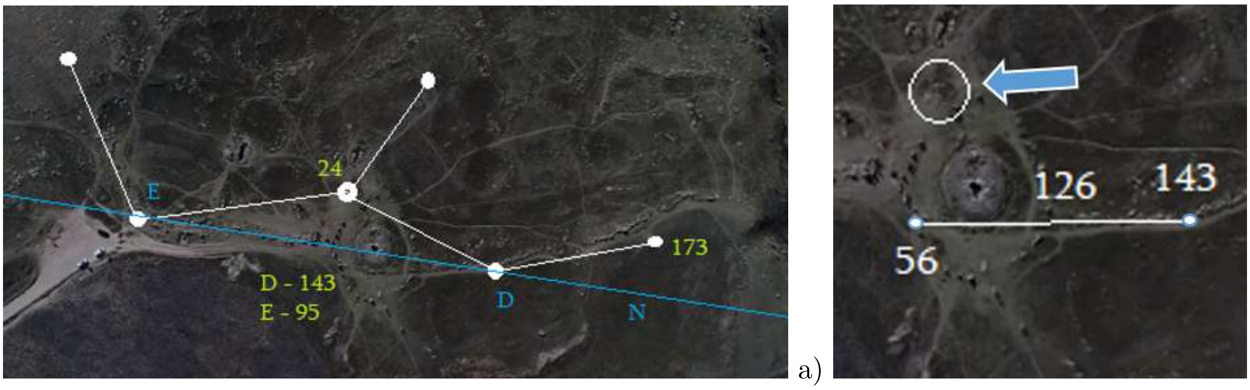


Figure 5. a) Projection curve 31400 years ago; b) the megalithic alignment along the line connecting stones № 143 and 56 is deviated from the North-South line.The arrow shows the positioning of № 24 stone and the circular stones.

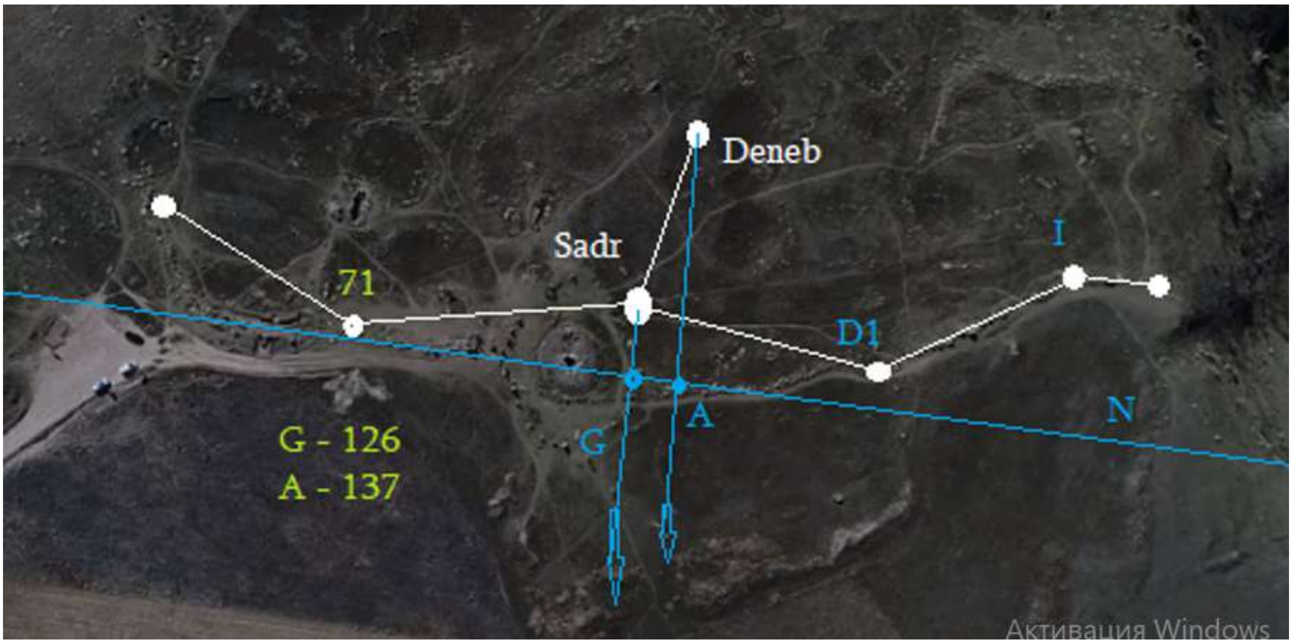


Figure 6. The comparison of the layout and the Angegh–Vulture (Cygnus) constellation 7800 years ago.

we compare δ Cygni and ι Cygni stars 7800 years ago not with DI but D_1I points. (Figure 6). In this case № 71 stone of the South arm would correspond to Cygni with its positioning, from which the Cygni star can be observed (the azimuths in Table 3 are calculated from the South point, as accepted in astronomy[2]). If we project the motion of constellation to the celestial meridian on the layout of the monument, it will be clear from Figure 6 that the star Sadr (γ Cygni) must intersect celestial meridian at point G and Deneb at A. The stone № 126 corresponds to point G, the hole of which the makes it possible to observe rising of Sadr and Deneb 7800 years ago, and the point A corresponds to № 137 stone, which has an angular tubular digging the upward side of which is directed to the zenith point (periscope stone, according to academician P. Heruni), by which Sadr and Deneb could have been viewed 7800 years ago with about 30 minute differency.

Another very important fact was recorded when we considered the azimuthal directions of the holes of chord's stones № 51 and 44. It appears that from these holes, it was possible to see ε Cygni and δ Cygni stars respectively near the horizon at the same time (at the same minute) 7800 years ago. This already means that the azimuths of a large number of holes have not changed significantly over the millennia. In general, it is clearly emphasized that the stones with holes directed at ε Cygni are located

[2]The above mentioned work of P. Heruni gives the geographical azimuths which are calculated from the North point.

The number of the stone (№)	44	51	53	71	84	122	126	137	143	181
The azimuth of the hole axis (°)	142	131	1	107	147	147	223	0	208	158
Elevation (°)	15	2,5	22,5	33	15	16	6	90	8	7
Positioning		Chord			South arm			North	arm	

Table 3. Azimuths of stone holes by academician P. Heruni (corner error 2°)

Stone №	7800 years ago they could have been viewed	Declination of the star	Positioning
44	δ Cygni	47°56′	
51	ε Cygni	31°50′	Chord
53	γ Orionis	-26°50′	
71	ε Cygni	31°50′	South
84	ι Cygni, α Lyrae	53°20′, 54°33′	arm
122	ι Cygni, α Lyrae	53°20′, 54°33′	
126	Sadr (γ Cygni), Deneb (α Cygni)	39°33′, 39°52′	
137	Sadr (γ Cygni), Deneb (α Cygni)	39°33′, 39°52′	North
143	δ Cygni	47°56′	arm
181	ι Cygni	53°20′	

Table 4. Visible stars of the Angegh–Vulture (Cygnus) constellation could be viewed 7800 years ago through the holes of 9 stone.

from center to South, and the stones with holes facing δ Cygni to the North, which further indicates that this astronomical observational complex was constructed by the model of the Angegh–Vulture (Swan) Constellation. Moreover, the positioning of stones № 44 and 51 on the chord[3] in some way confirms the circumference of the ε Cygni - δ Cygni axis being deviated from celestial meridian by approximately 7° during construction (Figure 4).

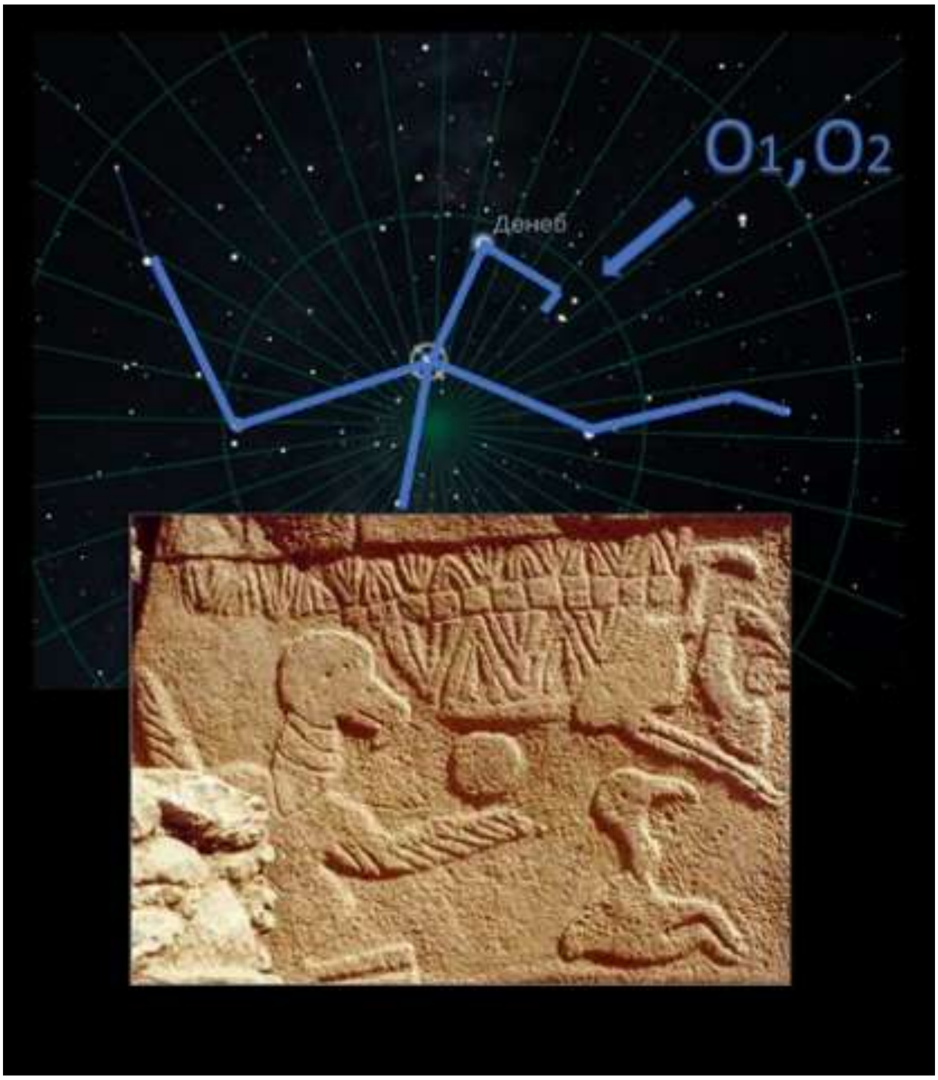
3. Results and discussion

Thus, if we compare the constellation of Angegh–Vulture (Cygnus) to the composition-layout of the megalithic structure in different millennia, the greatest conformity (with all observed parameters) is 32300-31400 years ago (Figures 4,5). This period should coincide with the age of the initial planning and construction of the complex-structure, while the holes on the stones and addition of some new stones may also be attributed to later periods, in particular the last corrections may have been made 7800 years before us (24500 years after the construction, almost 1 full precession period (25776 years). By this logic the separate standing stone № 24 may correspond to the Sadr star 31400 years ago (Figure 5). Taking into account the circumstance that all angles were measured by goniometer (because of which there can be some small errors), except for the comparison of defined angles, we also considered their relationship ($\alpha > \beta$ or $\alpha < \beta$), which allows us to draw more confident conclusions. Even if we assume quite large error of the goniometer, the results will remain unchanged, as the relationship GDI > GEZ (or GD_1I > GEZ) is clearly emphasized in the structure of layout angles of the monument.

In addition to comparison of the layout angles, the relation of the layout distances and the angular distances of the corresponding stars was also compared. This also leads to the same result: More than 32000-7800 years ago the Angegh–Vulture (Cygnus) constellation, the rising and setting of its bright stars, zenith transitions and some other events[4] were observed in Armenia. This is evidenced by the vulture sculpture found in the Portasar (Göbekli Tepe) area dating back more than 11000 years (Göbekli Tepe's Pillar 43, The Vulture Stone Collins (2018) with additional research by Rodney Hale). The shape and position of this bird's beak is a clear proof that the constellation resembled a vulture (angegh in Armneian) and was named Angegh–Vulture by those who observed the visible stars o1 Cygni and o2 Cygni stars (see Figure 7a), and the name Swan appeared much later. Collins (2018)

[3] The central cromlech "intersects" through a series of 20 relatively small stones (from № 40 to 60), which P. Heruni called Chord.

[4] There are other noteworthy observations that we will touch upon in the next article on this monument.



a)

b)

Figure 7. a) The appearance and position of the Angegh–Vulture (Cygnus) constellation on the celestial meridian and zenith 31400 years ago. Göbekli Tepe's Pillar 43., The Vulture Stone: b) A stone with hole.

publication that Deneb and Sadr were viewed in Portasar 11000 years ago in conjunction with ε Cygni and δ Cygni stars also indirectly confirms the validity of our hypothesis. Of course, the observations of azimuths of stone holes and the discussion of the placement of these stones convincingly show that these observations took place 7800 years ago. This leads to the idea that some transformations to the monument must have taken place in those times. The point is that at that time Deneb and Sadr had "returned from the North" (Figure 3) and had been given the opportunity to be included in "observation program". Fortunately, such work, as we have seen, did not bring major changes to the basic layout. Undoubtedly, this astronomical observational complex has many layers, and is also evidenced by the waveform process of the North arm, the position of some of the separate menhirs we have discussed (eg № 173), etc.

If this megalithic structure was built 32300 years ago by the Angegh–Vulture (Cygnus) constellation model and was modified 7800 years ago to observe the Angegh–Vulture (Cygnus) constellation, preserving the logic (composition) of the structure, then it must be concluded that the knowledge was passed down through the generations without interruption and significant changes.

4. Conclusion

1) The Megalithic monument-complex now known as "Qarahunge Observatory" or "Zorats Qarer" was built using the Angegh–Vulture (Cygnus) constellation model for observations 32300-31400 years before us and has been in operation for over 25000 years.

2) During that time, 7800 years ago in particular, some transformations were made to adjust the positions of several stones with holes and the directions of their holes to the position of stars at the given time.

3) During this great period of time the transmission of astronomical and no doubt ritual knowledge has been without serious interruptions.

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The irreplaceable role of ubiquitous cosmic rays in the space chemistry: from the origin of complex species in interstellar molecular clouds to the ozone depletion in the atmospheres of Earth-like planets

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Abstract

A review is given of low-energy cosmic rays (1 MeV-10 GeV), which play an important role in the physics and chemistry of interstellar medium of our Galaxy. According to the generally accepted theory of star formation, cosmic rays penetrate into molecular clouds and ionize the dense gaseous medium of star formation centers besides due to a process of ambipolar diffusion they establish a star formation time scale of about 100-1000 thousand years. The source of cosmic rays in the Galaxy are supernovae remnants where diffusion acceleration at the shock front accelerates particles up to energies of 10^{15} eV. Being the main source of ionization in the inner regions of molecular clouds, cosmic rays play a fundamental role in the global chemistry of clouds, triggering the entire chain of ion-molecular reactions that make it possible to obtain basic molecules. The review also noted the importance of cosmic rays in atmospheric chemistry: playing a significant role in the formation of nitric oxide, especially with an increase in the flux, they cause a decrease in the concentration of ozone in the atmosphere with all climatic consequences.

Keywords: *cosmic rays - sources - molecular cloud chemistry - origin of complex species - nitric oxide in terrestrial atmosphere - ozone content*

1. Introduction

Cosmic rays (CR) were discovered in 1911 by the German physicist V. Hess in 1912 in a series of balloon experiments showing an increase of the background radiation with height. The history of the discovery with interesting details can be found in Ginzburg (1996). Currently, cosmic rays are considered to be one of the most important component of the galactic interstellar medium, along with gas and dust which play an important role in the whole energy balance in the Galaxy, and regulate important processes in molecular clouds associated with star formation, initiation of astrochemical reactions, the origin of complex organic species, etc. CRs are nuclei of atoms in the energy range of MeV-GeV and higher, starting with protons and α particles. The remaining nuclei are observed in accordance with their cosmic abundance, excepted nuclei formed during CR transport in the Galaxy. CRs are observed up to energies of 10^{20} eV, which are clearly extragalactic and do not, by the way, have a generally accepted explanation of the source of origin. In this review, we restrict our discussion about CR with energies up to 10^{15} eV arising in galactic sources through generally accepted acceleration mechanisms, one of which (diffusive) will be considered in sufficient details. We outline the important role of CR in determining the star formation time scale, and finally, analyze the possibility of formation complex compounds in molecular clouds initiated by CR, and some other questions, like ozone behavior in atmospheres of exoplanets (having earth's atmosphere as an example), also influenced by CR. Other questions of CR physics, related, for example, to CR transport in the Galaxy, accompanying nuclear reactions, etc., will remain outside our consideration.

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2. Cosmic rays in general: sources, acceleration and interaction with matter

The main sources of CR in the Galaxy are supernova remnants (SNII) Schlickeiser (2002), Longair (2011), Bykov et al. (2018). As is known, in a supernova explosion, namely, during a nuclear collapse, it is possible to release energy of the order of $\sim GM^2/R$, up to 10^{53} erg during a mass collapse of $M \sim M_\odot$ into a region with the size of $R \sim 10^6$ cm, that is, with the formation of a neutron star. In this case, according to observational data, of the order of $\varepsilon \sim$ 10-30 % of the kinetic energy of the expansion of the remnant (so, $E_{kin} \sim MV^2 \sim 10^{51}$ erg), with an expansion velocity of 10^9 cm/s of the mass of $M_\odot$) goes into the energy of CR particles, up to 10^{15} eV per proton Longair (2011), Bykov et al. (2018). We recall, for completeness, that the excess energy of the explosion is carried away by neutrinos that practically do not interact with the medium.

Returning to CR, it should be emphasized that in order to ensure the observed average CR flux (at proton energies ~1 MeV moving with a velocity V_p) in the Galaxy of the order of $1.\cdot 10^{-4}$ particles $\cdot\, \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1} \cdot \Delta \mathrm{E}^{-1}$ Stone et al. (2005), Scherer et al. (2008), and for which one can write an approximation formula

$$J_p = \varepsilon \cdot \frac{MV^2 \cdot V_p}{4\pi \cdot \tau \cdot V_G \cdot \Delta E}\,, \tag{1}$$

it is necessary to have a supernova explosion frequency (of type II) in the Galaxy, $\tau \sim 1$ for 50 years Diehl et al. (2006), more precisely, $\tau = 1.9 \pm 1.1$ per century), per unit volume. For V_G in the form of a disk with a radius of 15 kpc and a height of 10 pc, we get just the value of J_p for $\Delta E \sim 1$ MeV, $J_p = 4 \cdot 10^{-4}$ particles $\cdot\, \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1} \cdot \Delta \mathrm{E}^{-1}$, which, in order of magnitude, coincides with the above observed value by Voyager 1 in the vicinity of the Sun Stone et al. (2005), if $\varepsilon = 0.1$. Then, for the CR density in the energy range $E \sim 1$ MeV, we have $\varrho(CR) \cdot \Delta E = 4\pi J_p/V_p \approx 1$ eV/cm^3, which coincides with the densities of thermal ($\sim nkT_e$), magnetic ($\sim H^2/8\pi$) and internal (in this case directional: $\sim \rho v^2$) gas flow energies of the interstellar medium (ISM) of the Galaxy (Dopita & Sutherland (2003)). Interestingly, it is also coincides with the ISM UV radiation energy ($\sim \rho_\nu \sim F_\nu/c$, where $F_\nu = 4\pi J_\lambda \lambda = 4 \cdot 10^{-2}\, \mathrm{erg} \cdot \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$) at $\lambda = 5000$Å Mathis et al. (1983), so again $\rho_\nu \sim 10^{-12}$ erg/cm^3=1 eV/cm^3.

3. The role of CR in star formation timescale

According to the generally accepted point of view stars are formed as a result of contraction of interstellar molecular clouds under the Jeans condition, that is, at the excess of gravitational forces over the total forces of internal gas - thermal, magnetic and turbulent pressures. However, the details and degrees of impact of the latter two are not entirely clear in the case of the formation of large mass stars Bodenheimer (2011). On the other hand, it is known that during the formation of small-mass stars, magnetic pressure contributes to the process of controlling the contraction of the cloud. The theory of the process is well known Bodenheimer (2011), in particular, it is known that the mentioned magnetic and turbulent pressure forces may decay much earlier than the cloud compresses with the formation of a protostar. The fact is that the force of magnetic pressure, which counteracts compression, weakens over time due to the phenomenon of ambipolar diffusion, which leads to field reduction: in reality, a key process is a redistribution of magnetic fluxes over the cloud volume but not field reduction Bodenheimer (2011). As is mentioned above there is an ion drift with respect to the neutrals, which leads to such effects.

To estimate the time of free fall of the cloud mass M at a distance R in the absence of pressure forces we take $t_{ff} = R/v_s$ where v_s is the speed of sound in the cloud medium under isothermal compression with a temperature $T_c = 10$ K. Actually, the free fall velocity is $v_{ff} > v_s$, but since we need just the lower limit of the compression time, we use $v_s = \sqrt{kT_c/\mu m_p} \approx 0.3$ km/s. For the protostellar cloud under the Jeans criterion, with $R_c \sim 10^{17} - 10^{18}$ cm, then $t_{ff} \approx 10^5 - 10^6$ years.

Let us now estimate the time of a significant weakening of the magnetic field due to the phenomenon of ambipolar diffusion. As is known, ambipolar diffusion is caused by the displacement of ions relative to neutrals in the inner regions of the clouds, induced by a magnetic field, and the field itself weakens mainly due to the redistribution of the magnetic flux in the cloud (Bartelmann, 2013). To estimate the characteristic time of the phenomenon, it is necessary to have an estimate of the rate of ion displacement relative to neutrals, v_d. The process is determined by collisions of particles (ions with neutrals) in a plasma with a magnetic field strength B: the final result is given by (Bartelmann, 2013)

$$v_d \approx \frac{B^2}{4\pi\gamma\rho_i\rho_n R}\,, \tag{2}$$

where R is the characteristic radius, ρ_i and ρ_n are the densities of ions and neutrals, and γ is the so-called coefficient of friction, which actually determines the process rate. In the approximation of small relative velocities, $\gamma \sim 10^{14}$ cm^{3}g^{-1}s^{-1} Padmanabhan (2000). The diffusion rate can be related to the degree of ionization x, equating the forces of gravity and friction (caused by particle collisions) acting on the unit volume:

$$\frac{GM\rho}{R^2} = n_i\langle\sigma\cdot v\rangle n(H_2)m(H_2)v_d. \tag{3}$$

Then

$$v_d = \frac{4\pi}{3}\frac{G\rho R}{n_i\langle\sigma\cdot v\rangle} \approx R\frac{10^{-8}}{x}\,, \tag{4}$$

and,

$$t_{AD} = \frac{R}{v_d} = 5\cdot 10^5\frac{x}{10^{-8}}\,. \tag{5}$$

The degree of ionization in the inner regions of the clouds is small, $x \sim 10^{-8}$ (see below), so the ambipolar diffusion is able to weaken the magnetic field to a degree that does not prevent further compression of the cloud in general, and the formation of a protostar, in particular. Since the cloud is fragmented during compression Padmanabhan (2000), it is the diffusion of the magnetic field in the cloud (as well as the turbulent pressure decay process not considered here) that determines the temporal and spatial scales of star formation.

4. The degree of ionization in molecular clouds

Cosmic rays play an active role in the regulation of star formation, through the ionization of the inner parts of the cloud. The degree of ionization is usually not very high; it can be estimated as follows. Molecular hydrogen is ionized first, and two channels of interaction are possible:

$$\mathrm{H}_2 + CR \rightarrow \mathrm{H}_2^+ + e \tag{6}$$

$$\rightarrow \mathrm{H}^+ + \mathrm{H} + e, \tag{7}$$

with ionization rates $\zeta = 1.2\cdot 10^{-17}$ s^{-1} and $\zeta = 2.9\cdot 10^{-19}$ s^{-1}, respectively. Then a reaction occur with H_2, which velocity is k (in cm^3/s),

$$\mathrm{H}_2^+ + \mathrm{H}_2 \rightarrow \mathrm{H_3}^+ + \mathrm{H} \tag{8}$$

with $k = 2.1\cdot 10^{-9}$ cm^3/s, and

$$\mathrm{H}_3^+ + e \rightarrow \mathrm{H}_2 + \mathrm{H}, (k' \approx k). \tag{9}$$

Accordingly, since the degree of ionization in molecular clouds is determined by the rate of molecular hydrogen ionization by CR, and CO molecules and O atoms are very abundant, H_3^+ most often reacts with them via

$$\mathrm{H}_3^+ + \mathrm{CO} \rightarrow \mathrm{HCO}^+ + \mathrm{H}_2, \tag{10}$$

$$\mathrm{H}_3^+ + \mathrm{O} \rightarrow \mathrm{OH}^+ + \mathrm{H}_2, \tag{11}$$

moreover, OH^+ immediately hydrogenates (by adding H_2) to form OH_3^+. Further, HCO^+ and OH_3^+ recombine with free electrons to form neutral molecules. Ultimately, for electron concentration we can write

$$\frac{d[e]}{dt} = \zeta[\mathrm{H_2}] - k_r([\mathrm{HCO^+}] + [\mathrm{OH_3^+}])[e], \tag{12}$$

where k_r is the average value of the coefficient of electronic recombination HCO^+ and OH_3^+ with electrons ($k_r = 2.5 \cdot 10^{-6}$ cm^3/s at 10 K), and the square brackets indicate the concentrations. Since these two ions are the dominant carriers of a positive charge, we can define the condition of the charge balance in the form Tielens (2005)

$$[\mathrm{HCO^+}] + [\mathrm{OH_3^+}] = [e]. \tag{13}$$

Then, under stationary conditions, for the degree of ionization we have:

$$\frac{e}{\mathrm{H_2}} = \sqrt{\frac{\zeta}{k_r[\mathrm{H_2}]}} = \frac{2.2 \cdot 10^{-6}}{\sqrt{[\mathrm{H_2}]}}, \tag{14}$$

whence it follows that the degree of ionization in dense, cold clouds is small, for example, $\sim 10^{-8}$ at $[\mathrm{H_2}] = 10^4$ cm^{-3}.

We emphasize here that if the value of the CR flux, $F(E)$ is known from observations, then the value of the ionization rate of molecular hydrogen by CR, ζ can be estimated by the formula Jenniskens (1993)

$$\zeta \sim F(E)\Delta(E)\sigma(E), \tag{15}$$

where $\Delta(E) = 1$ MeV, and $\sigma(E)$ is the ionization cross section in cm^2 (Fig. 1, where now $\Delta(E) =$ 1 eV). Since, say, $\sigma(5\mathrm{MeV}) \sim 1.0 \cdot 10^{-17}$ cm^2, and $F(5\mathrm{MeV}) \sim 1.0$ particles$\cdot$cm$^{-2}\cdot$s$^{-1}\cdot$ sr$^{-1}\cdot$MeV^{-1}, then $\zeta \sim 1.0 \cdot 10^{-17}$ s^{-1}, which by order of magnitude coincides with observed values.

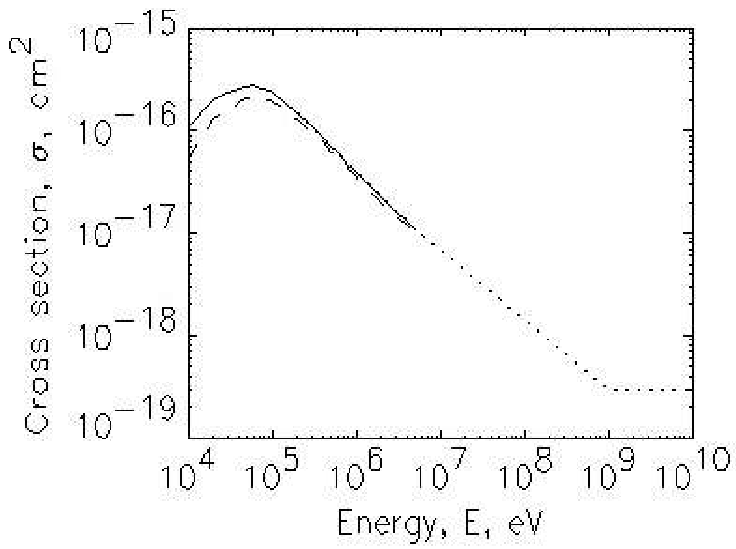

Figure 1. The dependence of the ionization cross section of H_2 by protons on energy.

5. On the diffusive acceleration of particles at the front of a shock wave

Let us now turn to the possibility of particle acceleration under the conditions of interaction of expanding stellar material with the interstellar medium (or with the remnant of the previous outflow matter). It is clear that the definition of expanding stellar material includes not only the remnants of supernovae studied in detail in Longair (2011), but also stellar winds, including solar

Scherer et al. (2008). At present, diffusive acceleration by the Fermi 1 mechanism at the front of a magnetohydrodynamic shock wave is considered as the most effective one for particles acceleration. This assumes the presence of a certain amount of energetic particles from superthermal ions entering the acceleration mode in the region of the internal shock front (such particles are known as injected).

Further, there are a large number of analytical and numerical models describing the intensities of energetic particles accelerated at the front of the shock wave and taking into account many features of the process, such as the formation of an energetic spectrum of particles, the orientation of the magnetic field vector relative to the normal to the front, sources of superthermal particles that are accelerated by the diffusive mechanism and transformed into the anomalous component of cosmic rays (ACR in the case of the heliosphere) Drury (1983), Ellison et al. (2005), Fahr & Versvharen (2008), Fahr & Versvharen (2009), Yeghikyan (2018b), Yeghikyan (2018a). These theories predict reasonable values of particle intensities consistent with direct observations of Voyager probes in the heliosphere. Therefore, the results of one such analytical theory describing the spectrum of particles under conditions of a parallel shock wave in the heliosphere Yeghikyan (2018a), and used for the conditions of WR nebulae Yeghikyan (2018b), will be presented below. Under the heliosphere, we are talking about the case when the protons of the solar wind are reflected from the front of a quasi-parallel magnetohydrodynamic shock wave upstream and are captured in the form of a group of superthermal particles entering into the diffusive acceleration process Fahr & Verscharen (2016), Fahr & Versvharen (2009). Here the question may arise about the similarity of the conditions of shock waves of the heliosphere and the WR nebulae, while nothing is known about the geometry of the magnetic fields of the latter. Here, we restrict ourselves to the references in Fahr & Versvharen (2008), Scherer & Fahr (2009), where it is shown that the manifestations of the quasi-parallel configuration of the shock wave in the heliosphere are very probable and significant, and we will mention the similarity with WR stars below.

Thus, in the case of a planar front, for the conditions of a quasiparallel shock, we have for the differential intensity of accelerated particles (in units of particles$\cdot$cm$^{-2}\cdot$s$^{-1}\cdot$sr$^{-1}\cdot$MeV^{-1}) Fahr & Versvharen (2009):

$$\Phi_0(E) = \frac{1}{4\pi}\frac{\varepsilon_1 n_1 v_{01}}{\Lambda(s)}\frac{1}{2E_0}\left(\frac{E}{E_0}\right)^{\frac{2-q}{2}}, \tag{16}$$

where $v_{01} = \sqrt{2E_0/m} \cong 2U_1$ is the injection velocity at the solar wind velocity U_1=400 km/s. Further, n_1 is the concentration of wind protons in the region of the shock wave of the heliosphere ($n_1 = 0.0005$ cm^{-3}), $\varepsilon_1 \cong 0.03$ is the fraction of protons reflected from the front and injected into the process of diffusive mechanism of acceleration by the shock, with the result of the particles of the ACR. In fact, as already noted, this fraction depends on the angles of inclination of the magnetic field and was determined in Fahr & Versvharen (2008) (see below, on the alternative value of ε_1). The remaining quantities in (16) are the functions $\Lambda(s) = \left(\left[\frac{4s-1}{3s} - 1\right]\frac{s-1}{3}\right)$ and $q = \frac{3s}{s-1}$ with the shock compression ratio of $s = U_1/U_2$ Fahr & Versvharen (2008).

Particle acceleration from the momentum value p_0 to p_{max} occurs in a characteristic time Drury (1983)

$$\Delta\tau_{acc}(p_0, p_{max}) = \frac{3}{U_1 - U_2}\int_{p_0}^{p_{max}}\left(\frac{\kappa_1}{U_1} + \frac{\kappa_2}{U_2}\right)\frac{dp}{p}, \tag{17}$$

which for energies $E \le 1$ GeV can be written as Fahr & Versvharen (2008)

$$\Delta\tau_{acc}(p_0, p_{max}) = \frac{3\kappa_0\frac{v_{01}}{c}}{s-1}\frac{1+s}{U_1 U_2}(x_{max} - 1). \tag{18}$$

Here the diffusion coefficient κ is equal to

$$\kappa = \kappa_0\frac{v_{01}}{c}\left(\frac{p}{p_0}\right)^n, \tag{19}$$

where $n = 1$ for protons with $E \le 1$ GeV and under the heliospheric conditions $\kappa_0 \cong 10^{21} - 10^{22}$ cm^2/s Fahr & Versvharen (2008), and references therein. Also, $x_{max} = p_{max}/p_0$ and $x_0 = 1$ are the upper and lower limits of integration in Eq. (17). The injection efficiency for transition to the acceleration mode, as is known, strongly depends on the number of seed particles reflected from the barrier in

Table 1. The proton acceleration time $\Delta\tau_{acc}$ for the indicated energies, and, for comparison, the characteristic diffusion time $\Delta\tau_{diff}$, for WR nebulae conditions (time in years, see text)

E=1 MeV, $\Delta\tau_{acc}$, yr	$\Delta\tau_{diff}$, yr	E=10 MeV, $\Delta\tau_{acc}$, yr	$\Delta\tau_{diff}$, yr	E=100 MeV, $\Delta\tau_{acc}$, yr	$\Delta\tau_{diff}$, yr
Time						
s=2.31	11	71298	36	22546	113	7130
s=3.00	164	71298	517	22546	1636	7130
s=3.90	860	71298	2719	22546	8600	7130

the shock wave upstream and passing into diffusive acceleration mode. In Chalov & Fahr (1996), the fraction of these particles was calculated (with an energy increase of about 30 times compared with the initial one), and using the distribution function of the mixture of wind protons with superthermal protons loaded upstream it was found that approximately 2% of all protons enter the acceleration mode resulting as ACR.

Here again the question arises of an analogy between shocks in the heliosphere and a WR (or PN) nebula, in particular, can one expect the presence of loaded particles in the region of shocks of WR nebulae, as in the heliosphere? The answer is positive, if we recall that the winds of WR stars, as well as stars at the previous stage, are very heterogeneous, including density condensations Smith (2014), which can serve as a source of seed injection of loaded particles. It should also be recalled that in Dworsky & Fahr (2000) it was shown that, in reality, seed injection of loaded particles is not necessary, since it can be replaced by energy diffusion due to wave-particle interaction (Fermi-2 process), which again leads to the case with seed injection. Further, due to a more intense and faster stellar wind, and as a result, a higher density and possibly more developed turbulence in the WR nebulae as compared with the interstellar medium around the heliosphere, the conditions in these objects differ, which should affect the values of the diffusion coefficient. Indeed, according to the interpretation of gamma sources from supernova remnants interacting with close molecular clouds, the diffusion coefficients of particles in the energy range GeV-TeV and higher are of the order of $10^{26}(E/10\text{GeV})^{\delta}$ cm^2/s, $\delta = 0.5$ Aharonian & Atoyan (1996). Obviously, for particles of lower energies, of the order of MeV, the values of the diffusion coefficient should be less, therefore, taking the above estimate as the upper limit, we obtain an estimate of the upper limit of the acceleration time, according to Eq. (18). The results for different energies, for WR nebulae conditions are shown in Table 1. The corresponding diffusion times are also shown there according to the estimate $\Delta\tau_{diff} = L^2/4\kappa$: the fact is that, for an obvious reason, the acceleration time cannot exceed the diffusion time in the acceleration region with a characteristic size L Reimer et al. (2006) (here $L = r_i = 3 \cdot 10^{18}$ cm). Despite the roughness of the estimates used, it gives an idea of the order of the value of $\Delta\tau_{diff}$. As can be seen, the acceleration time in all cases is shorter than the diffusion time, with the exception of high-energy particles of about 100 MeV at $s =$ 3.9. However, even at $E = 50$ MeV, again the acceleration time is less than the diffusion time for all s. Due to the steepness of the spectrum, this circumstance is not of particular importance in terms of radiation impact, for example, in radiation-chemical calculations a low energy part of the spectrum dominates, at most, in the range of 1–50 MeV. Finally, it should again be emphasized that Table 1 shows the upper limits of the acceleration time associated with the upper limits of the diffusion time used: for lower diffusion coefficients, the acceleration time decreases and the diffusion time increases. More accurate estimates of the diffusion time (as well as the diffusion coefficient) require self-consistent calculations using data on the magnetohydrodynamic turbulence spectrum and relative fluctuations of the magnetic field $\delta B/B$.

According to Fahr & Versvharen (2008), the maximum achievable momentum value is estimated by the formula ($n = 1$):

$$p_{max}/p_0 = \frac{c}{v_{02}}\sqrt{\frac{12}{q-4}\left[\frac{2+4s+3s_2}{3(1-s^2)} + \frac{q-2}{3}\right] + 1}, \qquad (20)$$

or $p_{max} \cong 9p_0$, $119p_0$ and $564p_0$ respectively for $s = 2.31$, 3.0 and 3.9. Then, as expected, $E_{max} \cong$

947, 1877 and 7785 MeV for the same s. Here it is necessary to distinguish $v_{01} \cong 2U_1$ - the value of the initial injection velocity from $v_{02} \cong \sqrt{2E_{02}/m}$ - the values at the start of the acceleration process, and, as already mentioned, $E_{02} = 30E_{01}$. Recall also that U_1 is 400 km/s and 1500 km/s for the solar wind, and for the WR star fast wind, respectively. Then, for the time of proton acceleration to the indicated energies, under the conditions of WR nebulae, the values given in Table 1 are obtained. From these data it follows that for a time shorter than the dynamic time of WR nebulae ($\sim 10^5$ years) part of the spectrum of energetic particles in the energy range $E \leq 100$ MeV it will have time to form (taking into account the above reservation regarding the exact value of the diffusion coefficient). It should be emphasized that with the expansion of the nebula, that is, with an increase in its inner radius, its ability to produce energy particles decreases, which follows from (16), especially if it is rewritten in the form Yeghikyan (2018b):

$$\eta \frac{1}{4\pi} \frac{\dot{M}_f V_f^2}{4\pi r_i^2} = \int_{E_1}^{E_{max}} \Phi_E(E) dE, \tag{21}$$

where $\dot{M}_f$ is the WR star's mass loss rate (g/s), V_f is the wind speed (cm/s), $\Phi_E(E)$ is the differential intensity of accelerated particles (erg $\cdot$ cm^{-2}s^{-1}sr^{-1}MeV^{-1}), and η is the fraction of the kinetic energy of the wind spent on the acceleration of protons by the shock wave (as in (16), i.e. here $\varepsilon \equiv \eta$) in energy range $E_1 \leqslant E \leqslant E_{max}$.

By the way, according to the generally accepted theory of the origin of galactic cosmic rays in the expanding shells of supernovae, usually $\eta = 0.1$–0.3, but according to later numerical calculations supported by observations, larger values also are possible, $\eta = 0.5$ Ellison et al. (2005).

In Fig. 2, the function $\Phi_0(E)$, which depends on different values of s, is shown for two values of ε_1 in the heliosphere, 0.03 and 0.0001. It should be noted that according to heliospheric observations, s_{obs}=2.5 Richardson et al. (2008).

It is interesting to compare the estimate of (16) for the solar wind with the measurements of the Voyager 1 probe Stone et al. (2005) (see their Fig. 2.). Assuming

$$J_E(E) = J_E(E_1)\left(\frac{E_1}{E}\right)^{\gamma}, J_p(E) = \frac{J_E(E)}{E_1}, \tag{22}$$

where E_1 MeV, γ=2-4, for the differential particle intensity at $E = E_1$ =1 MeV (in the mentioned units) we have Yeghikyan (2017b):

$$J_p(E_1) = \frac{J_E(E_1)}{E_1} = \frac{\gamma - 1}{E_1^2} \eta \frac{1}{4\pi} \frac{\dot{M}_f V_f^2}{4\pi r_i^2}. \tag{23}$$

Taking $\dot{M}_f = 2 \cdot 10^{-14} M_{\odot}$/yr, V_f=400 km/s, r_i=100 a.u., η=0.1, for γ=2,3,4 we obtain, respectively, $J_p(E_1)$ $\cong$0.8, 1.6, 2.4 *particles* $\cdot$ cm^{-2}s^{-1}sr^{-1}MeV^{-1}, which accuracies, up to a factor of 2, coincide with the result of Voyager-1 measurements, namely, in the same units, $\approx$1.4 Stone et al. (2005), Scherer et al. (2008). In the same units, Φ_{02}=2.4 for s=2.31 if ε_1=0.0001 is chosen. We emphasize once again that the phenomenological estimate (21) gives the same accuracy (within a factor of less than 2) if η=0.1 is chosen. A comparison of the functions of (16) and the estimate (21) is given in Fig. 2.

6. Intensities of accelerated particles under conditions of WR and PN nebulae

We now turn to the calculation of the differential intensity of energetic protons under the conditions of WR nebulae (see Fig. 3). Let take $\dot{M}_f = 1 \cdot 10^{-5} M_{\odot}$/yr, V_f=1500 km/s, $r_i = 3 \cdot 10^{18}$ cm, $\eta = 0.1$, then (17) give values, shown in Fig. 5, in comparison with (**??**) from Fahr & Versvharen (2009), where the concentration of the fast wind near the shock is determined by the ratio $n_1 = \dot{M}_f/(4\pi r_i^2 V_f m_p)$.

It should be emphasized that the average galactic value of the differential intensity for CR is $J_p(E_1) = 2 \cdot 10^{-4}$ particles$\cdot$cm^{-2}$\cdot$s^{-1}$\cdot$sr^{-1}MeV^{-1}, that is, at the inner boundary of the nebula (1 or

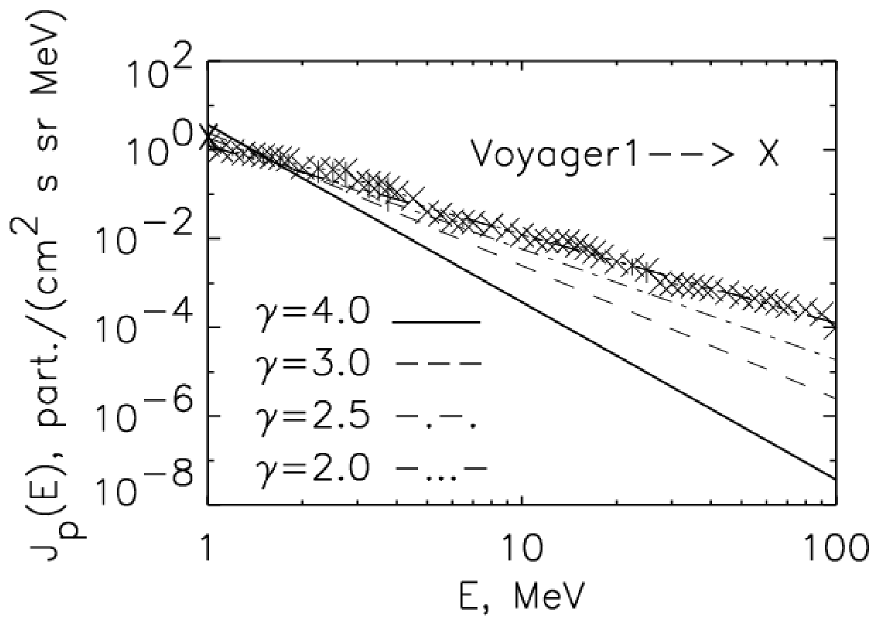

Figure 2. Results for the solar wind and corresponding Voyager 2 probe measurements

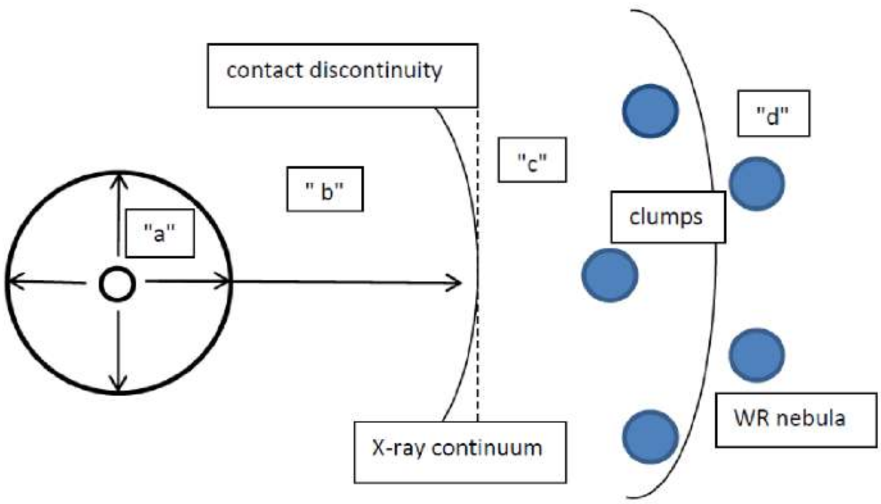

Figure 3. Schematic picture of the interaction of fast stellar wind with the circumstellar environment

10 pc) the intensity of energetic particles (1000 or 10, respectively) by more than several orders of magnitude (7 or 5) exceeds the average galactic one. This is not surprising, since even the heliosphere, formed by a much weaker wind, nevertheless causes the appearance of similar accelerated particles by 4 orders of magnitude larger intensity than the average galactic Scherer et al. (2008).

Thus, WR (or PN) nebulae can be a very powerful local source of energetic particles (with not very high energies) and it would be interesting to study their possible observational manifestations in the nebula itself.

The first thing to be considered is the reason for the relatively low plasma temperature behind the shock emitting in the X-ray range. According to usual estimates, a flow at a speed of the order of 1500 km/s, colliding with a practically static (relative to the flow) matter, should cause a temperature value behind the shock of more than 10^7 K, while X-ray observations of WR nebulae using XMM and Chandra telescopes show a narrow range of values 1-2$\cdot10^6$ K for diffuse sources Toala & et al. (2017) and references therein. In other words, the theoretical post-shock temperature $T_{shock} = (3/16)(\mu/k)V_f^2$ (where $\mu \approx$0.6 and 1.2 for a fully ionized matter with and without hydrogen, respectively) is more than an order of magnitude higher than the observed plasma temperature T_X in the citet work. The authors of observations attribute such a decrease in temperature to the influence of electronic heat conduction.

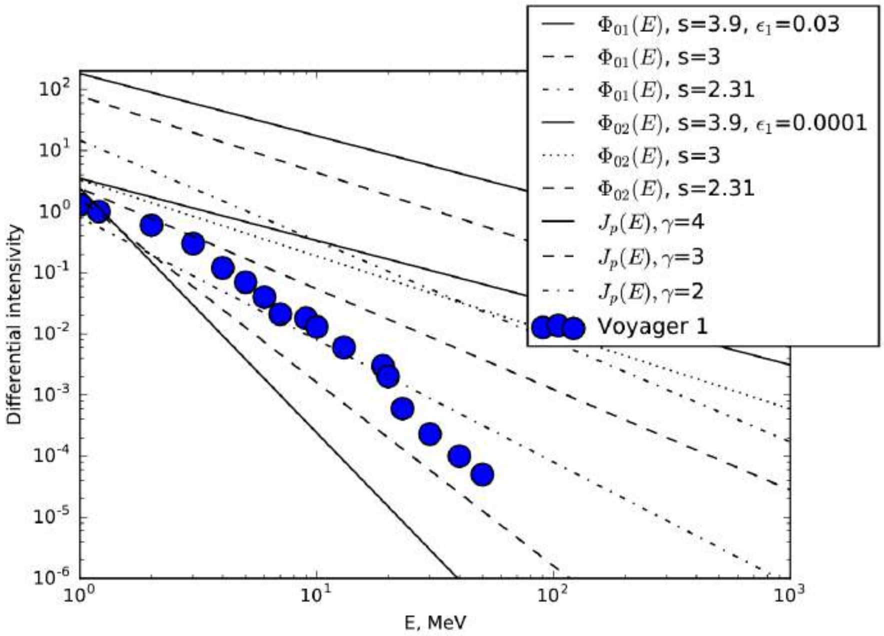

Figure 4. Differential intensities for various parameters of injection efficiency

It is interesting that the same phenomenon also occurs in the case of planetary nebulae Steffen et al. (2008), Toala & Artur (2016) and references therein, where the same mechanism of heat conduction is discussed for explanation. Also, sometimes, the so-called loading ions coming from the condensation of matter and collided with fast wind were involved: before leaving the emitting X-ray radiation region, these ions are thermalized, lowering the temperature. However, there is no simple solution to this "low temperature problem" Soker & et al (2010). It is clear that the solution of such problems should be based on a self-consistent consideration of the energy balance over all input and output channels, which is beyond the scope of this article. Therefore, without rejecting, in principle, mentioned possibilities, we recall that a similar problem in interpreting X-ray observations of supernova remnants is solved within the framework of the so-called theory of "diffusive acceleration by a modified shock wave" Decourchelle (2008) and references there. According to this theory, the thermal plasma behind the shock is heated to a temperature sufficient for radiation in the X-ray range, and at the same time, the shock itself accelerates the charged particles of the medium by a known diffusive mechanism, and changes the thermodynamic state of the medium: the more efficient the acceleration, the lower the temperature in the region of the shock wave Ellison et al. (2005), Decourchelle (2008). With effective acceleration, the above relationship between the speed of the fast flow and the steady-state temperature is no longer applicable, and must be consistent with the conditions of the modified shock wave. There is a lot of observational data of young supernova remnants illustrating this phenomenon and confirming the relationship between the effective acceleration of protons and the observed lower values of T_X Ellison et al. (2005), Decourchelle (2008). Thus a small fraction of the kinetic energy of expansion of the shell spent on particle acceleration, at the same time, directly affects the X-ray radiation of the region around the shock wave. An analogy can be drawn between the expanding supernova shell in the interstellar medium (or in the medium of matter from the previous stellar wind) and the fast WR (or PN) stellar wind colliding with matter from the previous slow wind. Then, the lowered temperatures of the interaction region of the winds radiating in the X-ray range can also be explained by the loss of energy for effective acceleration of protons, and leading to a decrease in temperature in the interaction region. Strictly speaking, the indicated (analytical) theory of diffusive acceleration by a modified shock wave Ellison et al. (2005), Decourchelle (2008) and references there, is developed for strictly relativistic particles, and quantitative criteria for the transition to the modification mode for the energy range 1-100 MeV are poorly known, and a separate consideration of the possibility of modification is required, which is beyond the scope of this work (see, however, below). Therefore, here we should confine ourselves to a qualitative statement of the fact that the lowered temperatures

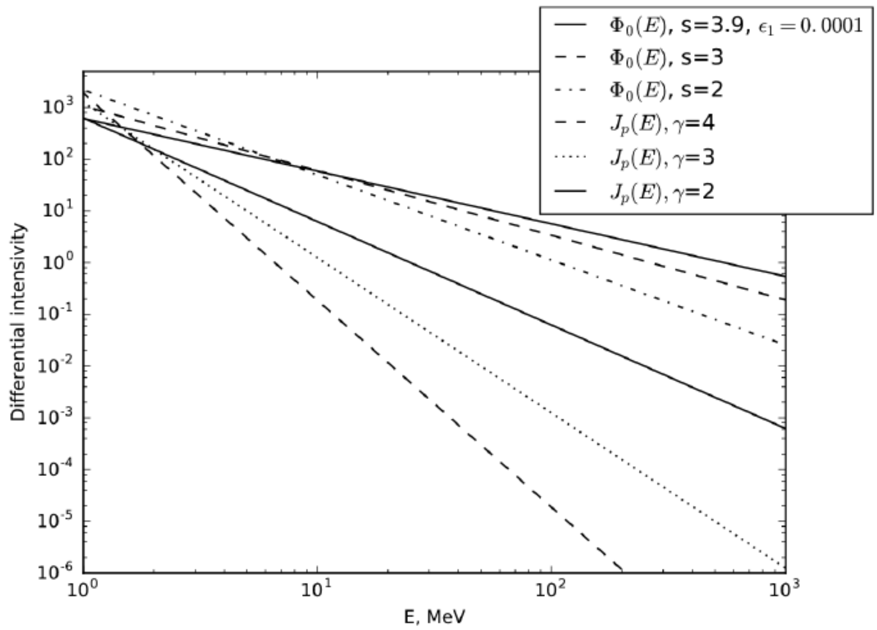

Figure 5. Differential intensities of energetic particles for WR nebulae

of the nebulae under consideration probably indicate effective acceleration by the shock wave, as, for example, in the case of supernova remnants.

Another aspect of the temperature problem behind the shock in the case of WR and PN nebulae is, depending on the situation, the different behavior of electrons and ions in the shock region, possibly also affecting the temperature. In this case, as the average electron energies in the region behind the shock wave in the heliosphere are of the order of 1 keV Fahr et al. (2015), Fahr & Verscharen (2016) that is, under similar shock wave conditions in WR nebulae (in turn, similar to the corresponding shock waves of planetary nebulae) for the temperature of electrons and protons one can write the following estimates Fahr et al. (2015), Fahr & Verscharen (2016):

$$T_p < T_e \lesssim \sqrt{\frac{m_p}{m_e}} T_p \simeq 43 T_p. \tag{24}$$

In conclusion of this section we emphasize once again that the shock modification mode, as described in Berezhko & Ellison (1999), depends on a rather complicated way on the key parameters of the acceleration process, in particular, on such parameters as the momentum of injected particles proportional to λ and the degree of injected particles η. λ is determined by very complex processes ($\lambda > 1$), and for $\eta \geq \eta_*$, where

$$\eta_* = \left(\frac{u_0}{c}\right)\left[\frac{2\sqrt{50}}{3}\lambda\left(\frac{p_{max}}{mc}\right)^{1/4}\right]^{-1}, \tag{25}$$

the shock is highly modified (here $u_0 = V_f$). The critical value of the shock velocity u_0^*, corresponding to the transition to the modification mode is determined through the formula

$$u_0^* = \frac{2\sqrt{50}}{3}\lambda\eta\left(\frac{p_{max}}{mc}\right)^{1/4} c, \tag{26}$$

and is equal (for λ >1 and for p_{max}/mc=1.39, E_{max}=900 MeV) to the velocity $u_0^* = 1500$ km/s, regardless of the value of λ. The degree of particle injection in this case is $\eta_* = 9.78 \cdot 10^{-4}/\lambda$. We emphasize that from the point of view of energy sources for chemical reactions, particles with energies of 1-10 MeV are of the greatest interest, since even with minimal exponents ($\gamma \simeq$2.3), the steepness of the spectrum is still quite noticeable, and in the integrals describing, for example, the fraction of absorbed energy, particles with energies above 10-20 MeV practically do not contribute. Therefore, the formulas describing the energy spectra are merely illustrative, and when using them one should always remember the reservations with which they were obtained, especially in the case of relativistic particles.

Above, we obtained the value of the critical velocity of the shock transition to the modification mode, of the order of 1500 km/s, while for example, the observed values of terminal velocities for more than half of the sample of WR stars are more than 1500 km/s, (of the 50 observed WR stars, only 19 have the outflow velocity less than 1500 km/s, while for 31 are greater, reaching values of more than 2000 km/s) Niedzielski & Skorzynski (2002). That is, for less than half of the WR stars, the shock waves caused by their stellar winds are not modified, and therefore, they cannot efficiently accelerate particles, and the pressure caused by them cannot be the reason for the relatively low temperature behind the front. At the same time, for the (larger) half of the (observed) WR stars, the positions of the above theory are quite applicable. This should be applicable also for PN cases where again similar distribution of outflow velocities exist. We note once again that in this article we are primarily interested in the energy distribution of particles in the immediate vicinity (10–20 MeV) from the lower edge of the spectrum of the order of 1 MeV.

7. Dust irradiation with energetic particles

Due to the high fluxes of energetic particles obtained, it is interesting to estimate the radiation doses of some species in such nebulae. We have expressions (**??**) for the flux of accelerated particles in the energy range 1-100 MeV, which is important in the irradiation of species, as well as in the ionization of molecular hydrogen. Assuming, as is mentioned above, the same parameters for WR and PN, for the differential intensity of energetic protons at 1 MeV, we can write for two values of the internal radius r_i=1-10 pc:

$$J_p(E_1) = 10.0 - 1.0 \cdot 10^3 \tag{27}$$

in units particles·cm^{-2}·s^{-1}·sr^{-1}·MeV^{-1}, which by 5–7 orders of magnitude larger than the average galactic one Scherer et al. (2008). Further, since the flux of energetic protons, the ionization rate ζ, and the ionization cross section of molecular hydrogen by protons σ are related by the simple relation $F(E)dE = \zeta/\sigma$, $F(E) = 4\pi J_p(E)$ Jenniskens (1993), it is clear that the ionization rate under such conditions will also be larger than the average value in the interstellar medium $\zeta(GCR) : \zeta(WR) = 10^5 - 10^7 \zeta(GCR)$. It is clear that such estimates make sense only when the WR nebula itself contains a molecular gas or is close enough to some molecular cloud, such as WR 7 (NGC 2359) Rizzo et al. (2001). In particular, for this nebula, the column density is of the order of 10^{20} cm^{-2} (ibid), which implies that protons with energies of 1 MeV and higher will practically not lose energy along this path Yeghikyan (2017a), Yeghikyan (2017c), and the flow will decrease due to the divergence according to the law r^{-2} Scherer et al. (2008). The influence of the magnetic field (if any) can be twofold: on the one hand protons can be reflected from magnetic inhomogeneities, and, depending on the strength and geometry of the magnetic field (1-10 μG), the flux can decrease by 1-2 orders of magnitude Yeghikyan (2017c) and references therein. On the other hand, nonthermal protons of relatively low energies can possibly be accelerated to values of 1-10 MeV in the presence of magnetohydrodynamic turbulence with a certain spectrum (Fermi-2 process) Cesarsky & Volk (1978), Shchekinov (2005). Thus, in this case, assuming these processes compensate each other, the actual particle flux at the outer boundary of the nebula can decrease, at most, as r^{-2}, that is to the value of 10-1000 in the same units.

As is known dust is observed in many WR nebulae, the origin of which is still being discussed Hendrix (2016); possibly, dust is formed under the conditions of colliding winds of massive pairs Monnier et al. (2007) (in the case of PN dust is siply come with AGB winds).

It is possible to calculate the dose of dust irradiation D_p by energetic protons in the nebula over time t using a simple relation Yeghikyan (2017a) Yeghikyan (2017c) and references therein:

$$n_t \cdot M(n_t) \cdot \frac{D_p}{dt} = \int_{E_1}^{E_2} F(E)S(E)dE, D_p = \frac{D_p}{dt} \cdot t, \tag{28}$$

where $F(E) = 4\pi J_p(E)$ and $S(E) = -dE/dx$ is the energy losses of the particle during the passage of the path dx (in units of keV/μ) in a dust particle with a concentration of n_t and a molecular weight of $M(n_t)$ (accordingly, the amount of the absorbed by the dust particle energy dE will be positive). $S(E)$ in the energy range 1-100 MeV can easily be calculated using the Bethe-Bloch formula, for example, using the SRIM computer program Ziegler et al. (2003), in particular, $S(E = 1$ MeV$)$=52.0 keV/μ for graphite with a density of 2.26 g/cm^3 (1.13 atom/cm^3), and $S(E = 10$ MeV$)$=9.3 keV/μ, while $S(E = 50$ MeV$)$=2.5 keV/μ. For hydrogenated amorphous carbon (a: C-H) with a density of up to 2.4 g/cm^3 (Yeghikyan 2018 and references therein) the energy loss is approximately 1.06 times greater, $S(E = 1$ MeV$)$=55.1 keV/μ. Further, choosing the least steep type of spectrum, $F(E) = F(E_1)(E_1/E)^2$ we obtain D_p=1.5-150 eV/a.m.u. for the values of the inner boundary about r_i=10 and 1 pc, respectively, and for a characteristic time interval of 100000 years. If there is a hydrogen deficiency in the stellar wind, that is, when helium predominates, the resulting value should be multiplied by 10, since the energy loss of particles is an order of magnitude larger, and the doses will be 15-1500 eV/a.m.u.

In some cases, dust characteristic PAH emission bands are also observed Marchenko & Moffat (2017). There is a point of view that further UV irradiation of PAH with subsequent dehydrogenation can even lead to the formation of fullerenes Scott & et al. (1997), Otsuka & et al. (2014), Zhen & et al. (2014), which are observed in different (but WR radiation-like) objects, for example, in planetary nebulae spectra Otsuka & et al. (2014). Therefore, we also estimate the radiation dose for such systems (HAC, fullerenes) under conditions of WR nebulae, since, as a rule, in the radiation-chemical transformations of complex compounds, the electromagnetic and particle radiation are equivalent, and this fact must be taken into account Jenniskens (1993). From the point of view of irradiation of fullerenes, laboratory data on the stability of C_{60} and C_{70} are interesting: the oligomerization of molecular crystals with a dominant content of C_{60} (fullerite, density 1.7 g/cm^3) begins with radiation doses (either γ-rays or α-particles are used) of the order 2.6 MGy=2.6$\cdot 10^{10}$ erg/g=20 eV/a.m.u., while amorphization requires about 100 times a larger dose of 250 MGy (2000 eV/a.m.u.). Cataldo & et al. (2009). Thus, the dose of fullerite irradiation in the WR nebulae (at the inner boundary) is comparable to the dose for graphite (1.5-150 eV/a.m.u. for 100000 years), and for HAC it is somewhat larger. The doses of HAC decomposition and fragmentation of PAH are obviously less than laboratory values of the doses of fullerene amorphization and are comparable with the actual doses obtained in the WR nebulae, at which, as already noted, doses in the range of 1.5-150 eV/a.m.u. can be expected (15-1500 eV/a.m.u. in the case of hydrogen deficiency). Thus, not only dust can be formed in nebulae, but also PAH (which are observed in some cases), and even fullerenes, the manifestations of which should be looked for in the observed spectra.

8. The formation of nitrogen oxides under the influence of CR in the atmospheres of earth's like exoplanets

We now turn to the question of an excess of NO in the atmosphere (stratosphere) of exoplanets, using the Earth's atmosphere as an example. It has long been known that nitric oxide in the atmosphere, in addition to natural (purely terrestrial) sources, also has a formation channel due to CR, the contribution of which is usually small Chamberlain (1978). The mechanism of the process is as follows: CRs in the energy range MeV-GeV and higher, penetrating the stratosphere, form a pair of ions for every 35 eV of energy loss when interacting with air molecules. The process ends, ultimately, with the formation of nitrogen atoms (≈ 1.4 atoms from each pair of ions) that either destroy particles NO_x,

$$\mathrm{N} + \mathrm{NO} \longrightarrow \mathrm{N_2} + \mathrm{O} + 1.39\,\mathrm{eV}\,, \beta_{29} = (8.2 \pm 1.4) \cdot 10^{-11} e^{-(460\pm60)/T} \mathrm{cm^3/s}, \tag{29}$$

or contribute to their formation,

$$\mathrm{N} + \mathrm{O_2} \longrightarrow \mathrm{NO} + \mathrm{O} + 1.39\,\mathrm{eV}, \beta_{30} = 5.5 \cdot 10^{-12} e^{3200/T} \mathrm{cm^3/s}. \tag{30}$$

If excited nitrogen atoms participate in the reaction, then the rate of the process via this channel is much higher:

$$\mathrm{N(^2D)} + \mathrm{O_2} \longrightarrow \mathrm{NO} + \mathrm{O} + 3.76\,\mathrm{eV}, \beta_{31} = 7 \cdot 10^{-12} \mathrm{cm^3/s}, \tag{31}$$

since the activation energy of the reaction is mostly compensated by the excitation energy of the ^{2}D level of nitrogen atom. This is important because, according to estimates Chamberlain (1978), about half of the nitrogen atoms appear in an excited state. We briefly describe the formation of NO by reactions of N_2O of a biospheric origin, with excited oxygen atoms (we indicate only those which are the most effective):

$$O(^1D) + N_2O \longrightarrow 2NO + 3.54\,\text{eV},\ \beta_{32} = 1.1 \cdot 10^{-10}\text{cm}^3/\text{s}. \tag{32}$$

The decay channels of N_2O are collisions with the same exited oxygen in the stratosphere,

$$O(^1D) + N_2O \longrightarrow N_2 + O_2 + 5.4\,\text{eV}, \beta_{33} = 0.7 \cdot 10^{-10}\text{cm}^3/\text{s}, \tag{33}$$

and photodissociation, which is the main destruction mechanism:

$$N_2O + h\nu(\lambda \leqslant 2300\text{AA}) \longrightarrow N_2 + O(^1D). \tag{34}$$

So, the balance of NO_x in an unperturbed atmosphere depends on the formation rate of N_2O at the Earth's surface, and the rate of its transfer to the stratosphere.

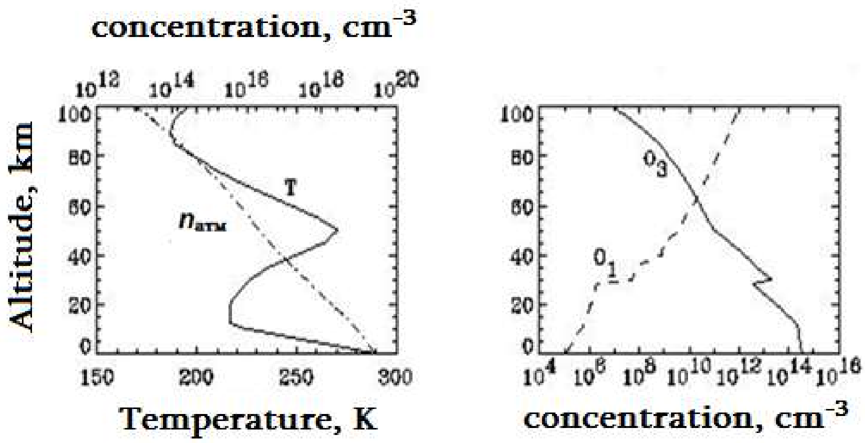

Figure 6. The standart atmospheric model of the atmosphere (left) and distibutions of atomar oxygen and ozone during a Chapman cycle (Chamberlain, 1978).

Result of the calculations can be summarized as follows. The ozone content in the perturbed atmosphere (and, for comparison, in the unperturbed one) was calculated according to the following scheme.

(P1) - Using US Standard Atmosphere data Brasseur & Solomon (2005) on altitude profiles of average atmospheric gas concentrations and temperatures, we first calculate the distribution of atomic oxygen and ozone in the Chapman cycle approximation Chamberlain (1978), that is without HO_x and NO_x (see Fig. 6). Recall that hereinafter we assume the presence of photochemical equilibrium, which in the lower stratosphere, ($z \leqslant$ 25-30 km), is not satisfied, and implies that the distribution of ozone in this region also depends on the dynamic processes of vertical and horizontal mixing of air masses Chamberlain (1978).

Indeed, according to observations, the calculated ozone concentrations at these altitudes are approximately 30–40 % higher than those observed Chamberlain (1978). In part, this difference is explained by the contribution of the impurities HO_x, NO_x, and ClO_x the first two will be taken into account below. The remainder of the ozone deficit is apparently responsible for industrial emissions of fluorocarbons (although there is a problem explaining the transfer to the stratosphere), methane, biospheric methane, and volcanic gases, the exact accounting of which is possible only within the framework of a non-stationary dynamic physicochemical model. As for the phenomenon of the so-called "ozone holes" (ozone deficit of about 30-40 %, relative to the average annual value) observed in the circumpolar regions, they are seasonal in nature, and there is a consensus of researchers that they can be explained by the effect of a full combination of the above factors, within, of course,

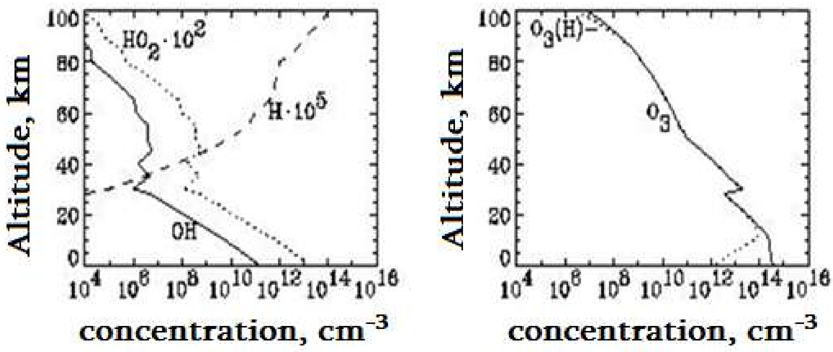

Figure 7. Distributions of HO_x (left), influence on ozone (right)

self-consistent 3-dimensional dynamic models. The effect of the excess of HO_x and NO_x, caused by extraterrestrial factors considered in this paper, causes much larger changes in ozone, which makes it possible to use the above (semi)analytical model.

(P2) - We now take into account the influence of HO_x in an undisturbed atmosphere, for which we use their altitude profiles known from observations Chamberlain (1978). The calculation results are shown in Fig. 7. As one can see, a slight effect is noticeable only in the upper mesosphere (80-100) km, and in the layers adjacent to the troposphere ($z \leqslant 20$ km), and in the latter case, the result cannot be considered correct, due to the lack of equilibrium conditions.

(P3) - The influence of NO_x is taken into account as is mentioned above, the results are presented in Fig. 8. Note that here the NO_x profiles are calculated according to the data from Chamberlain (1978), Crutzen et al. (1975), and, as already noted, it is the inclusion of N_2O that allows one to adjust the calculated profiles with the average observables. It is interesting that the contribution from the current galactic CR (GCR) flux (although insignificant) can both increase the ozone content (in the upper stratosphere) and lower it (between the troposphere and stratosphere). Recall that in the latter case, this (analytical) model may be incorrect, and that accounting for (small) contributions from small impurities is currently implemented by numerical dynamic models, involving all possible mechanisms. Similarly, the solar CR (SCR) spectrum, caused by the powerful solar flare of 1972, reduces the ozone content in the upper stratosphere (also slightly). The energy spectrum of cosmic rays in the heliosphere is given in Yeghikyan (2018a). Recall that the anomalous CR (ACR) component increases when the Sun passes through the ISM clouds (in the range of 1-100 MeV), in particular, at $n(H) \sim 100$ cm^{-3}, the intensity of ACR will increase by about 10^3 times, assuming that in the modern era, in the vicinity of the Sun, $n(H) \sim 100$ cm^{-3}. Assuming that the concentrations of NO_x will increase by the same amount, we use these (extrapolated) values to calculate the ozone content when the Earth passes through a diffuse HI cloud. The calculation results are shown in Fig. 9

As one can see, due to passing through a different HI cloud, with $n(H) \sim 100$ cm^{-3}, the O_3 abundance at heights of 20 km $\leq z \leq 60$ km decreases by 1-3 orders of magnitude (!). Recall that through such clouds the Sun passes about 10 times more often than through MC (every 30 million years), and reduced values of $n(O_3)$ must be maintained in the atmosphere over a period of time of several hundred thousand years. Obviously, such a decrease in the concentration of ozone in the stratosphere should be accompanied by significant changes in climate, and as a result of the increased background of UV radiation, a catastrophic restructuring of environmental relations. The consequences of the so-called superflares on the Sun are also quite large - a 10-fold excess of the 1972 flare intensity Crutzen et al. (1975), can reduce the ozone content in the stratosphere by no less than an order of magnitude (Fig. 11, right).

(P4) - The influence of HO_x increased due to the possible passage of the Sun through the MC with $n(H) \sim 1000$ cm^{-3} and higher, we take into account, according to Yeghikyan & Fahr (2004). The calculation results for $n(H) \sim 10^3 - 10^5$ cm^{-3}, are shown in Fig. 11. As expected, a decrease of $n(O_3)$ is significant in the mesosphere, which qualitatively coincides with the result obtained above (Fig. 10). The quantitative difference reaches a factor of 2-3, and is apparently associated with the more

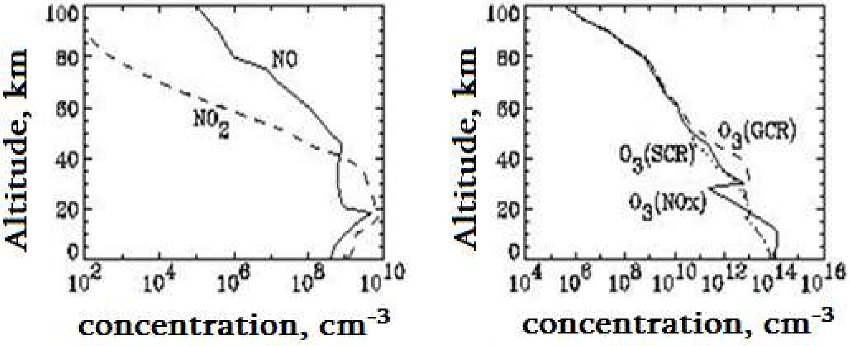

Figure 8. Distributions of NO_x when the influence of N_2O dominates (left), influence on ozone: $O_3(NO_x)$ - contribution of only N_2O, O_3(GCR) - contribution of GCR, O_3(SCR) - contribution of the solar flare caused a tenfold increase of SCR (right).

refined approach used here to take into account the influence of HO_x. In this case, the effect is more pronounced, and therefore, the conclusion made on the formation of a global layer of nocticlucent clouds in the mesosphere, with subsequent serious climatic consequences, remains valid.

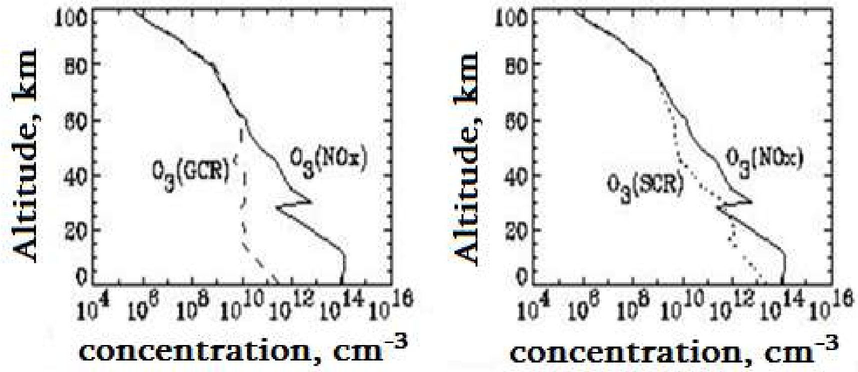

Figure 9. Ozone content with increased CR fluxes. $O_3(NO_x)$ - unperturbed value, O_3(GCR) - values taking into account ACR induced by the cloud with n(H)$\sim$ 100 cm^{-3}, O_3(SCR) - values taking into account a tenfold intensity of solar CR.

(P5) - The total effect of the increased, due to the passage of the Sun through the MC, HO_x and NO_x, was taken into account by a combination of the listed above two items (P3, P4), for the case of passing through the MC with a concentration of $n(H) \sim 1000$ cm^{-3}. The result is shown in Fig. 11.

9. Conclusion

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This article reviewed the role of low-energy cosmic rays (CR) with energies of 1 MeV and higher in astrophysics. Processes of establishing the ionization balance in dence interstellar clouds, the timescale of star formation by collapsing clouds and the role of ambipolar diffusion are considered.

Particulat attention is paid to the description of mechanisms of particle acceleration at the MHD wave front. A semi-analytical particle acceleration formula is proposed depending on the star mass loss rate, outflow velocity and the wind kinetic energy conversion factor to the particle acceleration energy. In the solar wind case this formula coincides remarkably with the Voyager 2 zond observations at the mentioned conversion factor to be of 10 %.

Irradiation by particles in the MeV-GeV energetic range of species like HAC, PAH and fullerens, as well as water ice and other ice mixtures, is also described.

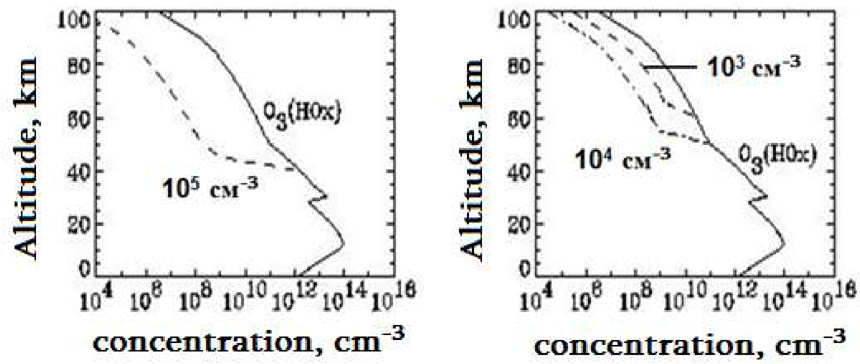

Figure 10. The ozone abundance at the increased fluxes of H and ACR particles caused by the Sun passing through interstellar clouds with concentration of $n(\mathrm{H}) \sim 10^3, 10^4$ and 10^5 cm^{-3}.

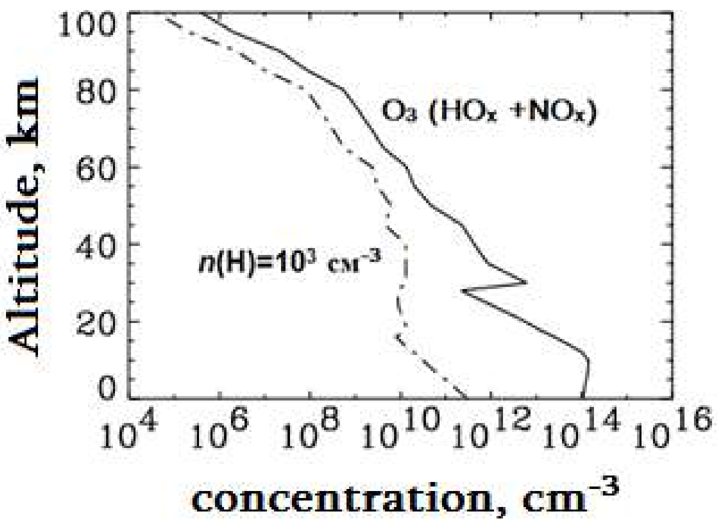

Figure 11. The ozone abundance at the increased fluxes of H and ACR particles caused by the Sun passing through interstellar clouds with concentration of $n(\mathrm{H})$. $\mathrm{O_3(HO_x + NO_x)}$ – is the unperturbed value of $\mathrm{O_3}$.

The question of the formation of nitric oxide under the influence of cosmic rays in the atmosphere of exoplanets is also considered on the example of the terrestrial atmosphere. The ozone content in both the mesosphere and the stratosphere decreases with the passage of the Earth through the MC. The impact on the mesosphere is associated with the penetration of the hydrogen atoms of the cloud into the atmosphere, and the increased at the orbit of the Earth's ACR flux in the range of 1-100 MeV causes an increase in NO_x, which, in turn, affects the ozone content in the stratosphere and causes climate changes.

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Concept of scanning imaging device for optical telescopes

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Abstract

We propose an approach of a focal plane imaging device for a telescope, which is based on spatially-scanned solitary photodetector, and can be used as an alternative to matrix detectors (CMOS or CCD). This approach allows to set efficient sensor size, pixel resolution, sensitivity and recording time on customer demand. Technical feasibility of up to 200 pixel/mm (5000 ppi) spatial resolution for focal field of up to astronomical photographic plate size, with the detection noise-equivalent power of 3×10^{-15} W/$\sqrt{\text{Hz}}$ and the measurement time of ≈ 1 minute per megapixel is justified.

Keywords: *optical astrophotography; telescope focal plane imaging; image sensors*

1 Introduction

Most of modern detection systems used in optical telescopes are based on two-dimensional matrix (array) light sensors: charge-coupled devices (CCD) or complementary metal–oxide–semiconductors (CMOS), which have successfully replaced photographic plates widely used in past. Matrix sensors with different spatial resolution, sensor size, sensitivity and response time have been developed. Electronic control and digital readout of data for matrix cameras allow implementation of various image processing and enhancement techniques, such as interpolation, filtering, motion detection, etc.

The "parallel" image recording approach used in visual observations, and later in classical and digital photography, is basic, but not unique. An image can also be constructed by sequential point-by-point registration of a light signal. In our previous works, this approach was used to visualize objects in a strongly scattering and absorbing medium (Vardanyan et al. (2010), Vardanyan et al. (2011)). A method was developed and tested in which a laser diode and a photodiode mounted on the same holder spatially moved stepwise along a certain path, covering a rectangular area, and a stationary sample under study was installed between them. The operation of the device was completely computer controlled. The system was designed to be used for biomedical imaging, as well as technological and security screening applications.

The present work analyzes the possibility of using the method of pointwise image formation in astronomical photography.

2 Scanning technique and algorithm

The key distinction of the proposed approach from the conventional image recording techniques is the use of a single-pixel spatially-scanned photodetector instead of matrix (array) detector. With this approach, the image is being built as the solitary detector passes step by step across the whole detection area. Schematic drawing of the scanning algorithm is depicted in Fig. 1.

In fact, with this approach the image pixel field is formed by temporal sequence of photodetector positions, and the pixel size is determined by the aperture of the photodetector sensor. This "temporal

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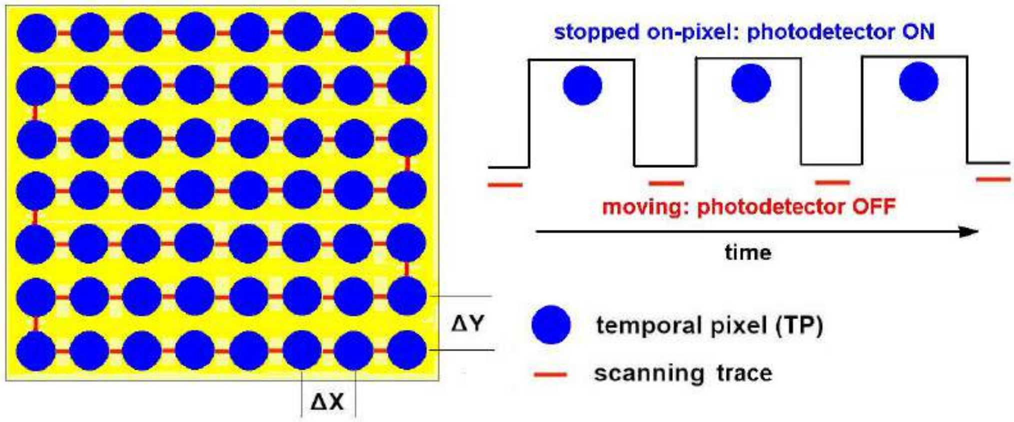

Figure 1: Schematic drawing of the scanning algorithm (*see text*).

pixels" (TP) touch each other, forming a filled view area. The most intuitive trace for scanning is line-by-line movement, with direction reversal on each subsequent line (see red lines in Fig. 1). Scanning is realized by "jump-and-stop" principle: on each pixel, photodetector stops for defined time allowing readout and integration of the signal, then it jumps to the neighboring pixel position, with readout off (integration reset), then the cycle repeats (see a right-side diagram in the figure).

The entire course of the scan can be easily controlled by a computer program: one can set the scan step (spatial resolution) along the X and Y axes, the jump time from pixel to pixel, the stop (readout) time on each pixel; it is also possible to change the scanning trace or select a separate area with the given position and sizes for detailed study.

Despite the apparent complexity, this approach to image construction has several advantages compared to the generally accepted method of recording images with CCD or CMOS cameras. Firstly, it allows to easily set the integration time of the signal from each pixel, and hence the sensitivity. This is especially important for astronomical applications, where the studied objects are relatively stationary. Secondly, since each pixel is formed by the same photodetector, the dispersion of parameters in pixels inherent in matrix detectors is outright eliminated. Thirdly, it gives flexibility to vary scanning parameters to user demand, which can be helpful for real observation (for example, fast preliminary search and identification of the proper view field with low resolution, followed by high-resolution recording). Finally, this method allows extension of the effective imaging sensor size at user demand (up to the size of astronomical photographic plates), preserving spatial resolution (pixel per mm) invariable.

Another advantage of the scanning technique is the data acquisition principle, which facilitates handling and processing of recorded information. As the measurement data is being recorded in series, as a temporal sequence synchronized with the scanning, it is straightforward to implement various data manipulation methods, such as elimination of background illumination, contrast enhancement, highlighting moving objects in an image (by removing still ones), etc. These enhancements can be realized, in particular, by subtraction of data of neighboring pixels in the same frame, and subtraction of data from the same pixels in consecutive frames. Such data processing techniques have been successfully implemented in transmission imaging for revealing objects embedded in highly-scattering and absorbing matrix environment (Vardanyan et al. (2010), Vardanyan et al. (2011)).

Besides the above mentioned advantages, the proposed scanning imaging approach has also some drawbacks, such as mechanical motion in the detection system and slowness of image recording. Nevertheless, the proposed technique can be considered as a real alternative to the existing approach to astronomical photography. In the next section, we will analyze in detail the key parameters and characteristics of the individual units of the proposed device to justify its applicability in astronomical observations.

3 Technical implementation and performance estimates

In this section we will consider the general scheme of the device, the main requirements and operation parameters for its different components, and technical feasibility of the proposed imaging approach.

Direct placement (mounting) of photodetector on the scanning head is not preferable for several reasons. First, for photodetectors, the sensor aperture serving as effective detection pixel is unacceptably large (typically $> 100\ \mu$m). Second, mounting a relatively heavy opto-electronic component with wiring on a movable scanner head may cause mechanical vibration and non-proper operation of the actuators. Third, it is difficult to provide proper thermal stabilization of the photodetector and its immunity against ambient electric noise when it is moving.

As an appropriate solution can be delivery of light to an unmovable photodetector using an optical fiber with a termination mounted on an actuator-driven 2D translation stage (see Fig. 2). The most appropriate for this is pigtailed photodiode with flat cleave termination. In this configuration, the diameter of optical fiber core rather than photodetector sensor size determines the size of effective pixel. We should note that single-mode fibers have much smaller core diameters than multi-mode fibers. Typical single-mode optical fibers (SMF) carrying only a single mode of light, the transverse mode, consist of a core ($\oslash$ 5 μm), a cladding ($\oslash$ 125 μm), a buffer ($\oslash$ 250 μm), and a jacket ($\oslash$ 900 μm). Therefore, the use of a SMF with flat cleave termination makes it possible to attain spatial physical resolution of 200 pixels/mm.

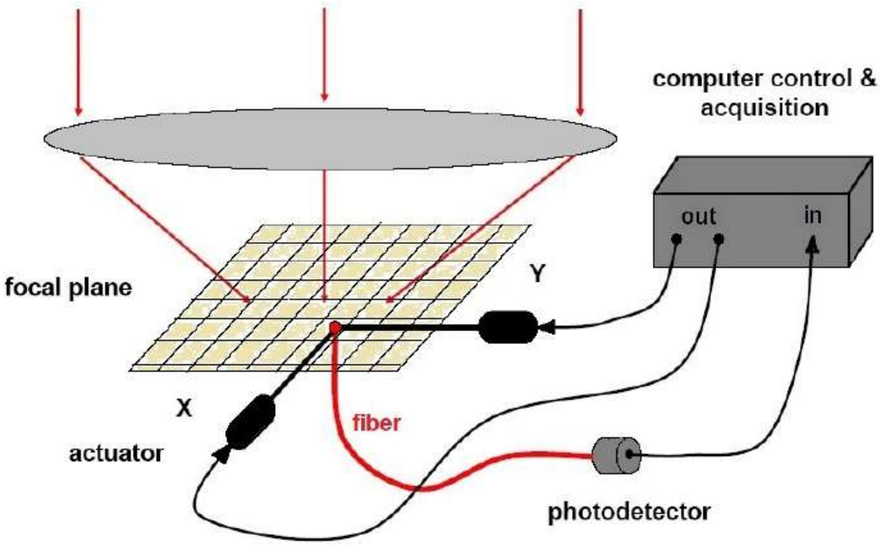

Figure 2: Schematic drawing of the detection system.

Let us now briefly discuss operation characteristics of the single-frequency fibers. Among the most important parameters is the Numerical Aperture (NA) of a fiber, which is defined as the sine of the largest angle the incident ray can have for total internal reflectance in the core. A higher core index, with respect to the cladding, means larger NA. Rays launched outside the angle specified by a fiber's NA will excite radiation modes of the fiber, which will impose losses. NA also indicates how easy it is to couple light into a fiber. Another important parameter is the "normalized frequency parameter of a fiber", also called the V number, mathematically expressed as

$$V = \frac{2\pi a}{\lambda} NA = \frac{2\pi a}{\lambda} \sqrt{n_{core}^2 - n_{clad}^2} \quad , \tag{1}$$

where a is the fiber core radius, λ is light wavelength, n_{core} is the index of refraction of the core, n_{clad} is the index of refraction of the cladding ($n_{core} > n_{clad}$) Hidehiko et al. (2006). Many fiber parameters can be expressed in terms of V, such as: the number of modes at a given wavelength, mode cut off conditions, and propagation constants. For example, the number of guided modes in a step index multimode fiber is given by: $M \approx V^2/2$, and a step index fiber becomes single-mode for a given wavelength when $V < V_c = 2.405$. The value of V_c determines also the cutoff wavelength of the fiber λ_c, the minimum wavelength for which a particular fiber still acts as a single-mode fiber. Above the cutoff wavelength, the fiber supports a single mode, while below it becomes multimode. Knowing V_c, the value of λ_c can be determined using Eq. 1.

Pigtailed photodiodes couped to patch fiber cables with flat cleave termination are commercially available for different wavelengths ranged from visible to near-infared. The single-mode wavelength bandwidth of these fibers in visible reaches up to 150 nm. In order to avoid light input losses, the fiber tip should be antireflection coated in operation wavelength range. In any case, we should note that the proposed approach intrinsically implies monochrome imaging. However, spectral decomposition of the recorded light from each "time pixel" is also possible. When using a single-mode fiber, spectral analysis can be carried out in a relatively narrow range of supported wavelengths (see above). For spectral studies, dispersing elements as well as narrow-band filters can be used.

Two-dimensional spatial scanning of the fiber tip in the focal plane can be performed by backlash-free actuators based on stepper motor-controlled linear translation stages, which allow computer control of the scanning trace and speed. Such devices meeting the set requirements are commercially available. For example, FCL50 from Newport provides 50 mm travel range with 20 mm/s speed, 150 nm incremental motion, ± 1 μm accuracy and bi-directional repeatability, and axial (lateral) load capacity of 40 N sufficient to carry the optical fiber.

Now let us consider the next key element of the scheme, the photodetector. Independently of the type of light sensors (matrix, or array, detectors such as CCD or SMOS, opposed to solitary, or point detectors such as photodiodes), detection of light can be decomposed in three simplified steps: i) conversion of light to free electrical charge-carriers; ii) conversion of current to voltage; and iii) measurement of voltage. Both types of photodetectors are characterized by the following figures of merit – common parameters to quantify their operation: responsivity, quantum efficiency, noise-equivalent power, specific detectivity, and response time (see e.g. Posch (2010)).

1) Responsivity R_λ measured in A/W denotes for given wavelength the input–output relationship, or gain of a detector, and is defined as the ratio of light-induced photocurrent density J_{ph} and the incident optical power per unit area P_0:

$$R_\lambda = \frac{J_{ph}}{P_0} \quad . \tag{2}$$

Responsivity of Si-based detectors can reach maximum value of ~ 0.8 A/W at $\lambda \sim 1000$ nm.

2) Quantum efficiency η, usually given in percent, is defined as the number of photon-generated free charge carriers (J_{ph}/q, where q is the electron charge) per impinging photon (the number of photons is P_0 divided by the energy of one photon $h\nu$):

$$\eta = \frac{J_{ph}/q}{P_0/h\nu} = R_\lambda \frac{h\nu}{q} \quad . \tag{3}$$

Although quantum efficiency of some state-of-the-art detectors may exceed 90 %, the real values are usually smaller. Thus, for Hubble Space Telescope's Wide Field and Planetary Camera 2, $\eta \approx 35 - 40$ % in the spectral range of 600 – 800 nm.

3) The noise-equivalent power (NEP) measured in W/$\sqrt{\text{Hz}}$ is defined as the intensity of incident light required to generate a current equal to the noise current j_n, or yielding a signal-to-noise ratio (SNR) of unity in a 1 Hz frequency bandwidth:

$$NEP = j_n/R_\lambda = \frac{\sqrt{\sum j_{ni}^2}}{R_\lambda} \quad . \tag{4}$$

The lower limit of light detection is determined by the noise characteristics of the device of different origin (j_{ni}). The typical photodetector noise is the sum of thermal noise and shot noise from dark current and photocurrent. For commercial photodiodes, the value of NEP can be as low as 5×10^{-16} W/$\sqrt{\text{Hz}}$. It is important to note that for matrix detectors such as CCD the value of NEP is always higher because of additional noise contribution from the "read noise".

4) Specific detectivity D^* measured in Jones units (cm$\cdot\sqrt{\text{Hz}}$/W) is defined as the ratio of detector area S_{det} and noise frequency bandwidth Δf_n to the NEP:

$$D^* = \frac{\sqrt{S_{det}\Delta f_n}}{NEP} \quad . \tag{5}$$

Specific detectivity of modern silicon PIN photodiodes can be as high as 10^{13} Jones.

5) The response time (or rise/fall time) quantifies the response of photodetector to abrupt change of photon flux. Silicon PIN photodiodes allow fast detection with rise/fall time below 0.1 ns. For CCD cameras, the readout is the slowest step in the image acquisition. A ms-range integration time is typical for most of matrix (array) detectors.

Summarizing, one can see that despite the obvious convenience of using CCD cameras, which allow to directly obtain an image of the object under study, their performance characteristics are generally inferior to solitary (point) photodetectors, in particular silicon PIN photodiodes. The drawbacks of matrix detectors mainly originate from the readout (additional noise contribution and slower operation). Moreover, for real matrix imaging detectors, the performance characteristics somewhat vary from pixel to pixel, which may cause overall image distortion.

Commercially available silicon pigtailed PIN photodiodes coupled with 4-5 μm-diameter and NA = 0.13 single-mode fibers (e.g. FDSP series from Thorlabs) provide noise equivalent power of 3×10^{-15} W$\cdot$Hz$^{-1/2}$ with 700 ps rise/fall time and 0.01 nA dark current, available for 610 – 770 and 780 – 970 nm wavelength ranges.

Finally, let us consider the functionality of the computer control & acquisition device. It comprises three main structural units: i) a computer with installed control/acquisition software and user desktop interface; ii) a multifunctional analog/digital input/output (DAQ) device serving as an interface between the computer on one side, and photodetector and actuator stepper motors on the other side; iii) signal conditioning circuits, which allow to adopt the operation voltages and currents of photodetector and stepper motors to the input/output signal levels of DAQ device.

Control software installed in the computer designs and sends to DAQ device a multichannel sequence of phase-shifted pulses needed to control the operation of actuator stepper motors. Control pulses formed at the 8 output channels of DAQ device (by 4 for each motor) undergo power amplification at the output signal conditioning unit, which feeds X and Y actuator stepper motors. Translation trace, step, speed, and stopping (data acquisition) time at each temporal pixel are software-controlled with user desktop interface.

In turn, the photodiode signal generated during the stopping (on-pixel) periods enters the operation amplifier serving as input signal conditioning circuit to match the DAQ analog input voltage. After analog-to-digital conversion, the digitized signal enters the computer. As scanning control and data acquisition channels are mutually synchronized via a unique system clock, building of image frame after completion of scanning cycle (or even in the course), is rather straightforward.

Hardware solutions for structural elements of the computer control & acquisition device are well elaborated and widely available. There are no special requirements for a computer. It can be a desktop PC, a notebook, or even a low-cost Raspberry Pi single-board computer. It just has to support the control software of a multifunctional analog/digital input/output (DAQ) device (e.g. LabView if National Instruments DAQ device is chosen).

A DAQ device should support at least 8-channel digital outputs (DO) for the control of stepper motors and at least one analog input (AI) channel for recording a photodetector signal (preferably with at least 24 bit resolution and 100 kS/s sample rate). Many companies produce such devices. We should note that if commercial translation stages are used as actuators, such as FCL Series from Newport, they can be connected to computer directly via USB port, without a need of a 8-channel digital outputs, and DAQ board with a single AI channel will be sufficient.

Signal conditioning circuit to drive stepper motors is a simple power amplifier scheme converting low-current logic high/low voltage signal to control pulses needed to operate the chosen motors. As for conditioning the input analog signal from the photodetector, a low-noise linear voltage amplifier should be used, which will allow you to match the voltage range from the photodiode with the working range of the input channel of the DAQ device. Both the output and input signal conditioning circuits are commercially available, but they can be also easily home made.

4 Conclusions

To summarize, we have considered applicability of the method of pointwise image formation for astronomical focal plane photography. A practical scheme of the imaging device is proposed, its achievable characteristics and parameters are estimated based on realistic technical solutions and available structural units.

The use of a flat cleave core termination of the single-mode optical fiber as a "temporal pixel" allows to attain pixel size of $\oslash$ 5 μm. Such fibers coupled with silicon pigtailed fast PIN photodiodes operating in visible and near infrared and having noise equivalent power of 3×10^{-15} W$\cdot$Hz$^{-1/2}$ are commercially available. Also stepper motor driven translation stages supporting 5 μm scanning step with ± 1 μm precision are available. Supposing 50 μs integration time per pixel, which is sufficient for sensitive detection of astronomical objects, recording of image from 1 megapixel area (5×5 mm) will last ≈ 1 minute. Important to note that effective sensor size for this approach is limited by the travel range of actuators (translation stages), and in principle can match the size of standard astronomical photographic plates.

Recording of images is fully computer-controlled and customizable on user remand, realized with the use of available DAQ devices and elaborated software.

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Studies of Seyfert galaxies in Fesenkov Astrophysical Institute

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Abstract

This article provides an overview of the main research results of a large group of Seyfert galaxies, carried out at Fesenkov Astrophysical Institute (FAI) over the past 50 years. Spectral observations have been performed since 1970. At an early stage, a three cascade image-tube (UM-92) was used as a radiation receiver. In the 90s, the equipment was modernized, and at present, the modern CCD cameras are used as radiation detectors at the output of spectrographs.

The results of observations were used to determine the absolute fluxes of the emission lines and to study their profiles. Several additional emission features were detected on the wings of the broad emission lines $H\alpha$ in the spectra of two galaxies NGC 4151 and Ark 120. These features are emitted by compact ionized objects, rotating in the field of Central Body (CB).

Photometric observations of Seyfert galaxies have been carried out at FAI since 2010. Light curves of more than 20 Seyfert galaxies have been obtained. In particular, the light curves of the galaxy NGC 4151, obtained last years, shows that an active stage of its nucleus took place in 2015–2016, when the brightness increased by $0^m.5$ in the V filter, and by almost 2^m in the R filter. Then, in $2018 - 2019$ there was a rather sharp decline of brightness, and B V R magnitudes returned to their minimal values.

Keywords:*AGN, Seyfert galaxies, emission lines, individual objects: NGC 4151, Ark 120, NGC 3227, NGC 1068*

1. Introduction

In 1968 a new diffraction spectrograph of an original design was developed in FAI. The three-cascade image-tube UM-92, probably one of the most effective image amplifiers in the world, was used as a receiver Denissyuk (2003). The spectrograph was mounted to the telescope AZT-8 ($D = 0.7\,m$) and proofs the high efficiency for observations of the faint emission objects. A new spectrograph made it possible to obtain measurable spectra of the objects up to 18^m with the medium spectral resolution.

Regular spectral observations of the objects from the $1-st$ Survey of the Markarian galaxies were carried out with the new spectrograph in $70-80\,s$, sometimes together with the observers from SAO: V. Lipovetskii and V. Afanasiev. As a result of these observations, spectra of more than 300 galaxies from Markarian's lists were described, radial velocities were measured, and the absolute magnitudes of them were estimated Denissyuk (1971b), Denissyuk (1971c), Denissyuk (1971a), Denissyuk (1973), Denissyuk (1974a), Denissyuk (1974b) and Denissyuk (1974c). There were 49 Seyfert galaxies among them Denissyuk & Lipovetskii (1973), Denissyuk & Lipovetskii (1977) and Afanasiev et al. (1979). Currently observations of the galaxies are actively continued.

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2. Observations and reduction

The modern spectral observations are performed with the spectrographs, mounted to the eastern 1 meter telescope of Tyan Shan Observatory (TShAO) and to the telescope $AZT-8$. CCD cameras SBIG STT-3200 (2184×1472, 6.8μ) are the radiation receivers at the output of the spectrographs. The spectral range available for observation is $\sim$ 3500 $\AA$ ($4000-7500$, $\AA$). During observations the spectra of the galaxy and standard star were obtained. The entrance slit of spectrograph about 5" $-$ 10" is used, to ensure pass of the full fluxes as from the nucleus of galaxy and standard star. Obtained spectrograms were reduced in the standard manner: dark subtraction, flat fielding and wavelength calibration using $He-Ne-Ar$ lines. All results were corrected for atmospheric extinction. Comparison of the observed energy distribution in the spectrum of the standard with the data from the Catalog Kharitonov et al. (2011) makes it possible to determine the spectral sensitivity of the equipment. After all reductions, the spectrum of a galaxy in the absolute energy units is obtained.

Photometric observations were carried out with the western 1 meter telescope (TShAO), equipped with the same CCD camera SBIG STT-3200 ($2184\times1472, 6.8\mu$) and with the set of B V R filters. Field stars with the known brightness values were used as photometric standards. The primary image processing consists of standard operations with the Bias, Dark and Flat files. Image measurements are performed using standard IRAF and MaximDl 6 programs. The corresponding equations are used to transform the obtained instrumental brightness estimates to the standard system B V R.

3. Results of spectral observations

Search and analysis of emission details that are observed on the wings of broad hydrogen lines in the spectra of some galaxies is one of the aim of Seyfert galaxies study . The presence of such features was noted by a number of authors Boksenberg et al. (1975), Ulrich et al. (1991) and Shapovalova et al. (2009). So, in the very first spectrogram of the galaxy NGC 4151, published by Seyfert 9Seyfert (1943)), an additional emission was located on the red wing of the $H\beta$ line. Such emission features can be originated in the rather compact ionized bodies, while the center of the galaxy serves as the ionization source. It is possible to measure three parameters of the observable emission detailes: average velocity, total flux and width. Firstly it is necessary to subtract the wing of the broad emission line, on which this detail is superimposed. Only then it is possible to measure correctly the wavelength, flux and radial velocity of the emission detail. The radial velocities, measured relative to the center of the narrow emission line at different time reflect the motion of an object in the gravitational field of a supermassive CB.

Necessary observable data for time interval about 50 years (1967 - 2019) were obtained for the galaxies NGC 4151 and Ark 120. Based on these data, in the framework of classical mechanics, the orbits of motion of the bodies emitting such emissions were calculated, and the central masses of appropriate galaxies were estimated without taking into account the possible effects of general relativity.

3.1. Seyfert galaxy NGC 4151

Fragments of our spectrograms of the galaxy NGC 4151 in the red wavelengths range are presented in Fig. (1) Variations of the width and flux of the line with time are noticeable, and narrow emission features are distinct on the wing of the broad emission component. On the "blue" wing, a similar emission detail was observed only in a few spectrograms in 1997 and it disappeared in 2003. In order to separate emission feature in a pure form, the wing of the broad component was approximated by a high-order orthonormal polynomial, (in this case the 12th order) and was subtracted (see Fig. (2)). The result of subtracting is shown at the bottom of Fig. (2). The total width of this emission feature was about $\pm1000\,km/s$. The results of processing of our spectrograms, obtained in 1997 - 2010, allowed to construct the most probable orbit of the motion of the object, responsible for this additional emission, and, in particular, to estimate the mass of the CB of NGC 4151: $M = 61-65\times10^6\,M_\odot$ Denissyuk et al. (2011). A weakening of the fluxes from this emission feature was noted as the object moved away from the ionization source Denissyuk et al. (2011). Since middle 2010, the shape of all emission lines in the spectrum of NGC 4151 remains unchanged, and additional emission details do not appear.

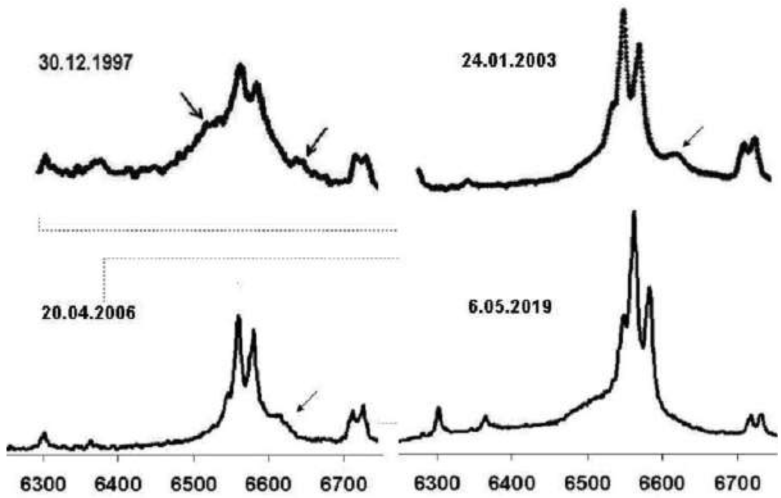

Figure 1. Fragments of spectrograms of the galaxy NGC4151 in the $H\alpha$- line region. Emission features are indicated by arrows.

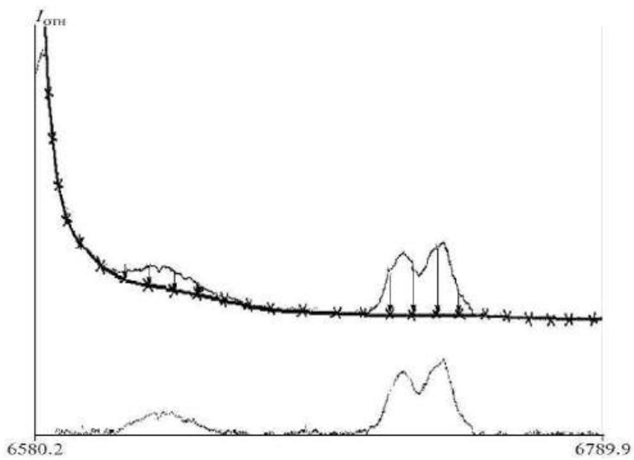

Figure 2. Scheme of subtraction of the broad wing of the $H\alpha$ - line. Bold line − is an orthonormal polynomial of the 12th order, approximating the "red" wing. The result of the subtraction is below.

3.2. Seyfert galaxy Mrk 1095 = Ark 120.

This rather bright galaxy was discovered by Arakelian Arakelian (1975) and was included in Catalog Markarian et al. (1989). It is actively explored in a wide range of wavelengths by both ground and space tools. The first spectrograms of this galaxy at FAI were obtained in November 1976. Subsequent observations of this galaxy revealed three emission details on the wings of the $H\alpha$ line, similar to those in the spectrum of NGC 4151. In this case, two objects emitting these emissions had positive radial velocities relative to the center of the narrow emission component, and the third object had a negative radial velocity. In addition to our data, we also used the results of observations, kindly provided by B. M. Peterson. After processing the observational data, the parameters of Keplerian orbits were obtained for three bodies emitting these emissions. The parameters of these three orbits are published in Denissyuk et al. (2015). A common parameter of these orbits is the central mass of this galaxy. It turned out to be equal $(167.5 \pm 2.8) \times 10^6\, M_\odot$. Fig. (3) shows the radial velocities of these three objects, measured relative to the center as a function of time. As in the case of the galaxy NGC 4151, the removal of such objects from the pericenter leads to a noticeable attenuation of their radiation. Fig. (4) shows two spectrograms of Ark 120, obtained in middle of December 2014 and in 2015 with an exposure of 1.5 hours. Two emission features with the radial velocities of -2160 and $+2510\,km/s$ are marked by arrows on the spectrogram of 2014, and those with the velocities -3030, $+1690$ and $+2270 km/s$ are marked on the spectrogram of 2015 Fig. (3). As the intensities of these emissions are small, some of them may be a noise.

It is clear that spectral observations of this and other Seyfert galaxies should be continued, highly desirable in cooperation with other observatories. The probability is high that the nucleus of Ark 120 is binary Yan-Rong et al. (2019). This result was obtained, in particular, on the basis of observations made at FAI. Spectral observations of this and other Seyfert galaxies continue in order to search for the new emission details.

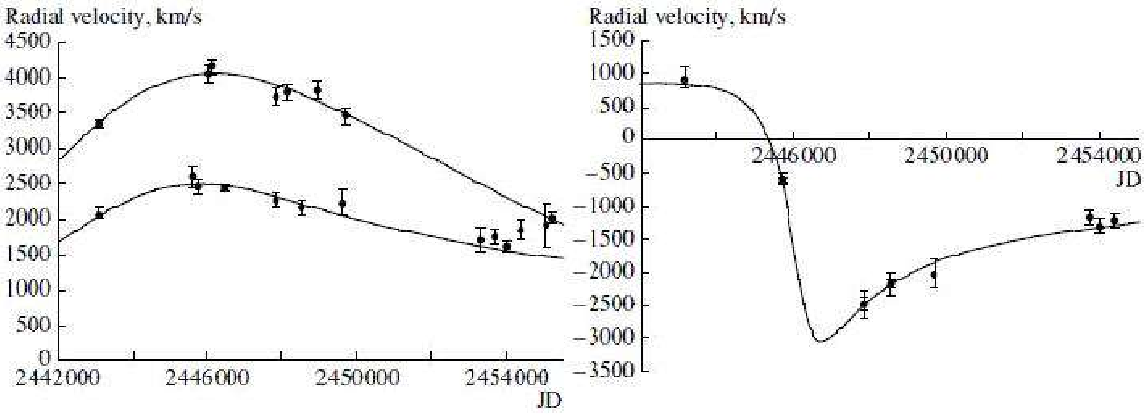

Figure 3. Radial velocities of the three emission features relative to the centre of the galaxy Ark 120 in dependence on the time.

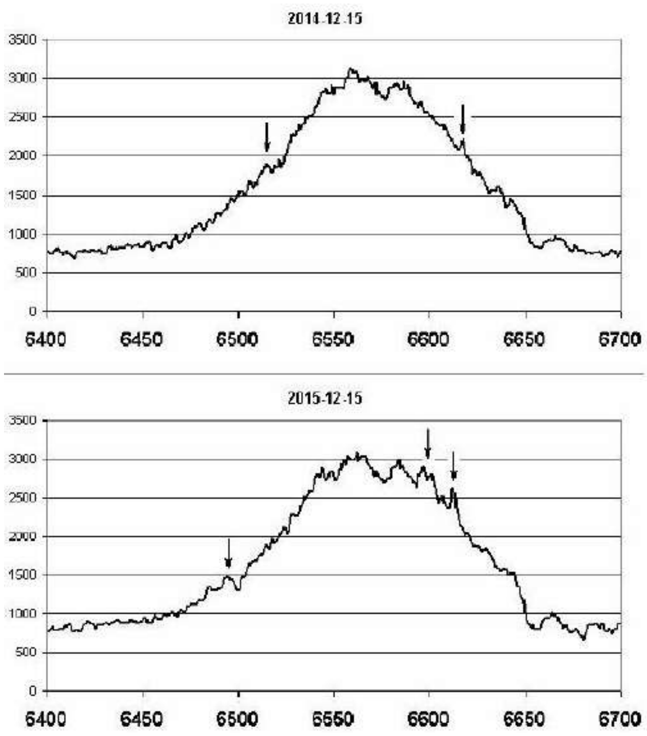

Figure 4. Emission features on the wings of $H\alpha$ in 2014 and 2015 in the spectrum of the galaxy Ark 120.

3.3. Galaxy NGC 1068

Galaxy NGC 1068 belongs to the class Sy2, it is a fairly bright object ($V = 8^m.9$) and one of the closest to the Sun galaxies. In the spectrum of this galaxy, broad components of the hydrogen lines are practically absent. Fig. (5) (upper panel) shows a fragment of the original spectrogram in the region of the $H\alpha$ line, obtained using the AZT-8 telescope with an exposure of 1.5 hours. Profiles of the $H\alpha$, [NII], 6548, 6583$\mathring{A}$ emission lines in the center and on the 10" distance on both sides of the continuum are presented on bottom panel. It can be seen that the position of these lines on the spectrogram varies depending on the distance to continuum. This is the result of rotation of emission objects at different distances from the center of galaxy. The results of measurements of the positions of two emission lines at different distances from the center on both sides of the continuum made it possible to construct rotation curve of the galaxy. Fig. (6) shows the differences in the rotation of the eastern and western (relative to the center) parts of the galaxy. In the region of $\pm 1.5\, kpc$, the rotation is close to solid-state. If we assume that at a distance of 6 kpc the average observed velocity of rotation is about 300 km/s and take into account the inclination of the galactic plane to the line of sight, then the mass inside this radius can be estimated using the formula $M_\odot = V^2 r/G$. Then the mass will be equal to approximately $8 \times 10^{11}\, M_\odot$.

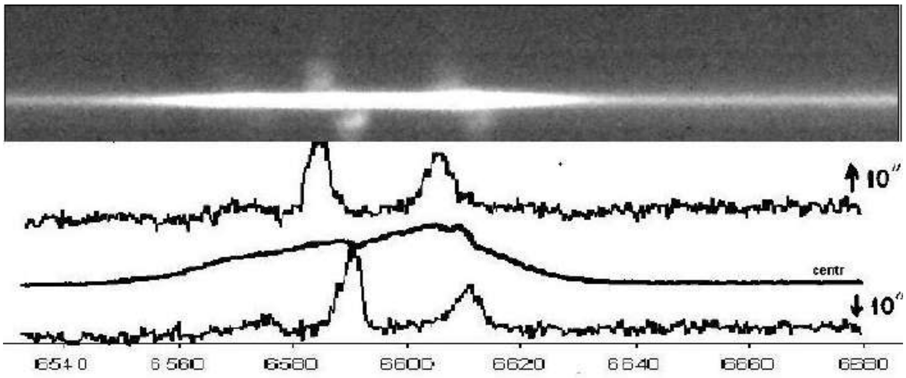

Figure 5. Fragment of the spectrogram of the galaxy NGC 1068 with the $H\alpha$ and [NII] emission lines (upper panel). Bottom panel-emission profiles of $H\alpha$, [NII], 6548, 6583$\mathring{A}$ along continuum and on the 10″ distance on both sides of it. Axis X- wavelengths in angstroms, axis Y–intensities in arbitrary scale.

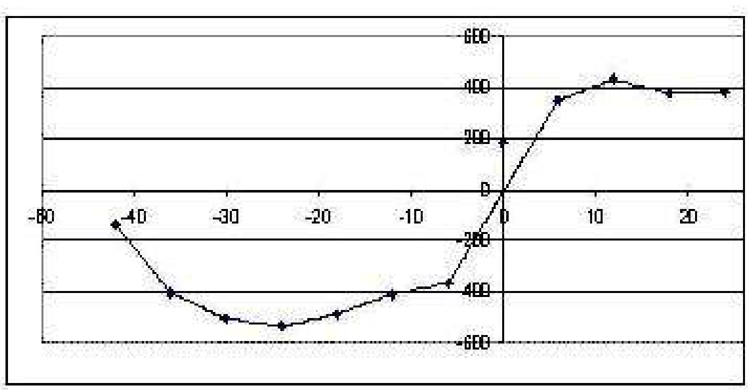

Figure 6. Rotation curve of the galaxy NGC 1068 from Denissyuk & Valiullin (2019). Axis X–distance the centre in arcsec, axis Y-radial velocity in $km = sec$.

3.4. Results of photometric observations

Photometric data for more than 20 Seyfert galaxies were obtained in FAI during the last 10-12 years Shomshekova et al. (2019). The light curves of the galaxy NGC 4151, obtained last years are presented in Fig. (7). An active stage of nucleus of this galaxy was observed in 2015 - 2016, the brightness in the V filter increased by $0^m.5$, and in the R filter by almost 2^m. Then, in 2018 - 2019 there was a rather sharp decline of brightness, and B V R magnitudes returned to their minimal values. The radiation intensity of the emission feature depends on strength of the ionizing source and on the distance to it. The delay in the reaction of the emission feature to a change in the brightness of the CB reflects the absolute distance of this object from the nucleus, and may be a criterion for checking the orbit parameters.

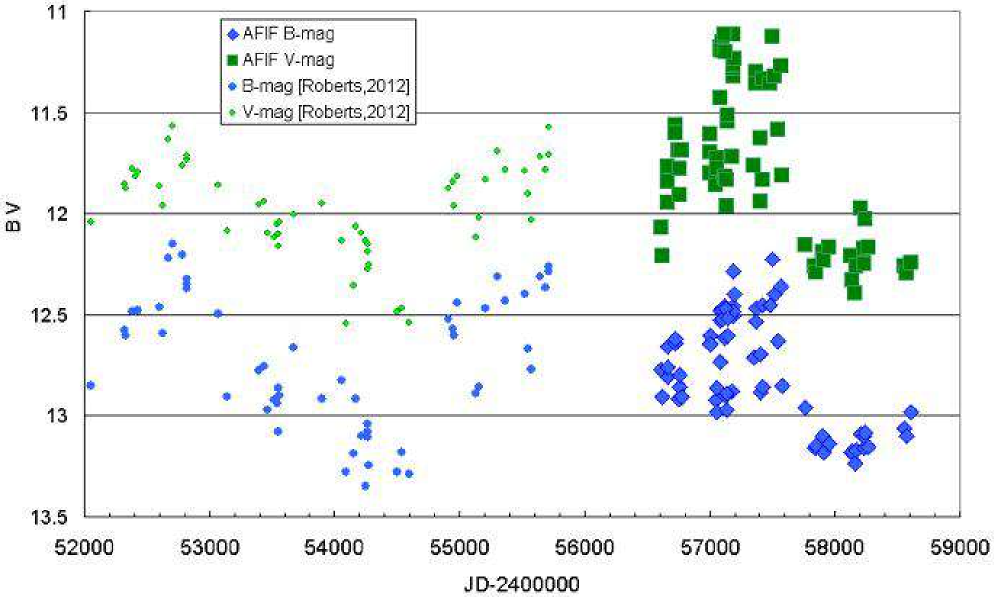

Figure 7. Light curves of the galaxy NGC 4151. Axis X –JulianDates, axis Y – B and V magnitudes.

4. Conclusions

Spectral observations of Seyfert galaxies unambiguously indicate the appearance in the vicinity of the Center of objects emitting sufficiently powerful emission lines in the presence of strong ionizing radiation. Such emission details are also observed on the wings of broad emission lines in the far ultraviolet.

The power of these emissions is a significant part, up to 10 percent, of the power of the broad emission component. There are no reliable estimates for the mass of matter emitting the broad component. However, it is obvious that this mass should be several orders of magnitude larger than the solar mass. Accordingly, the mass of objects, emitting emission features, should be at least ten solar masses, and possibly much more. Emission features have a noticeable width, caused to rotation, most likely. It is highly probable that such objects do not have their own energy sources and are invisible at a large distance from the center of the galaxy.

The rather frequent appearance of such objects near the galactic center may indicate that they are as ordinary members of the galaxy as stars, nebulae, or interstellar medium.

Taking part in the general rotation, some of such objects , can change their orbit due to random interactions with other masses, and appear in the Center where they are ionized and become visible. The spatial orbits of such objects, built on the basis of the dependence of their radial velocities on time, can be checked independently. To do this, it is enough to measure the time delay of their intensity changes from fluctuations in the brightness of the ionizing CB. It is important to have regular data on the dependence of the brightness of galactic CB on time. For a number of galaxies, similar observations are also carried out in FAI.

Acknowledgements

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IAU South-West and Central Asian Regional Office of Astronomy for Development

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Abstract

The International Astronomical Union (IAU) announced its Strategic Plan on Astronomy for Development in 2009, during the International Year of Astronomy (IYA). 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 them, 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 (both for well-known archaeoastronomical heritage and the presence of the famous Byurakan Astrophysical Observatory (BAO) founded by Viktor Ambartsumian in 1946) 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*, TF2 *Children and Schools* and TF3 *Public Outreach*. We present our projects and all other accomplishments and discuss the role of our ROAD in maintaining contacts and development of astronomy in the region, as well as contacts between Europe and the Eastern Partnership countries. Most up-to-date information about the IAU SWCA ROAD is available on its webpage at http://iau-swa-road.aras.am/eng/index.php.

Keywords: *IAU – OAD – ROAD – astronomical research – astronomical education – public outreach – astronomy for development – European Eastern Partnership.*

1. Introduction

The International Astronomical Union (IAU) developed and adopted in 2009 a decadal Strategic Plan (SP) now entitled *"Astronomy for Development"* (IAU, 2009). The SP significantly increases the role of astronomy for other sciences, technology, culture and society, as it is tightly linked to all this (Figure 1). This plan has been resulted from an extensive process of consultation beginning with a meeting of stakeholders in Paris in January 2008 and including feedback from key stakeholders during the various drafts of the SP. It was endorsed by the General Assembly of the IAU in Rio de Janeiro in August 2009, and builds on the momentum of the very successful International Year of Astronomy 2009 (IYA). The objective of this SP is to use Astronomy to stimulate development in all regions of the world. Crucial to the implementation of the SP was the creation of a global "Office of Astronomy for Development" (OAD). The OAD is tasked with establishing and strategically coordinating Regional Offices (ROADs) and Language Expertise Centres (LOADs) across the world as well as three Task Forces, namely (i) *Astronomy for Universities and Research*, (ii) *Astronomy for Children and Schools*, and (iii) *Astronomy for the Public*.

Through a strong partnership with the South African government, the OAD is hosted at the South African Astronomical Observatory (www.astro4dev.org), a facility of the National Research Foundation. Furthermore, 8 regional offices were created, one of them in Armenia.

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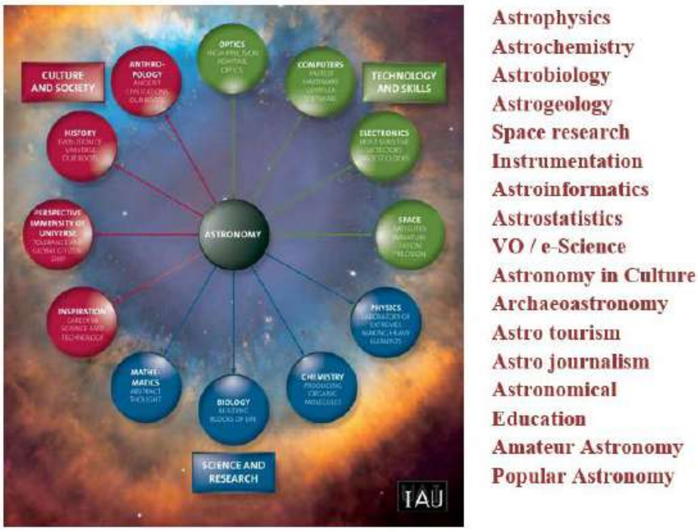

Figure 1. The relation of Astronomy with other sciences, technology, culture and society. A number of inter- and multi- disciplinary sciences and other fields are listed having tight relation to astronomy.

2. The Establishment of the IAU SWA ROAD

Armenia showed interest and activities in the establishment of one of the regional IAU offices since the beginning of the initiative (2009-2011). Armenia's proposal to host a ROAD was rather strong both from the point of view of the available facilities and ongoing activities. The proposal was finally approved on 10 June, 2015 and an agreement was signed between the IAU and the Byurakan Astrophysical Observatory (BAO) on 6 August 2015. The office was formally established on 1 September 2015 and was called **IAU South West Asian (SWA) ROAD**. *Dr.* Areg Mickaelian became its Director. SWA Regional Steering Committee was created in September 2015, as well as SWA webpage was opened also in September 2015 (http://iau-swa-road.aras.am, Figure 2). The staff members joined on 1 October 2015. Finally, the Inauguration Ceremony was held on 13 October 2015. IAU OAD / SWA ROAD Workshop was also attached to this event. Representatives from the IAU (General Secretary Piero Benvenuti, former Vice-President George Miley, OAD Director Kevin Govender) and representatives of regional and some other countries (Georgia, Iran, Turkey, Russia, Israel, Jordan) were present.

Like our long tradition to organize joint Armenian-Georgian (Byurakan-Abastumani) workshops (colloquia) since 1974, we conducted a new series of Armenian-Iranian Astronomical Workshops (AIAW). The first one was organized on 13-16 October, 2015 in Byurakan, so that all Iranian guests were able to participate in the IAU SWA ROAD Inauguration Ceremony.

Georgia and Iran were the first countries along with Armenia to officially join the SWA ROAD. During many years and centuries, these countries have had numerous relations in all areas, including science and Astronomy.

Figure 2. IAU South West and Central Asian ROAD webpage.

Astronomy in Georgia is generally represented in Abastumani Astrophysical Observatory (AbAO) founded in 1932. It is one of the leading scientific institutes in the country. Main fields of research are Solar System bodies (including near-Earth asteroids), various aspects of Solar physics, stellar astronomy (including binary stars and open clusters), extragalactic objects (AGNs), theoretical astrophysics, cosmology, atmospheric and Solar-terrestrial physics. Although research in these fields are carried out in other institutions in Georgia as well: Institute of Theoretical Physics at Ilia State Univ., Javakhishvili Tbilisi State Univ., School of Physics at Free Univ. of Tbilisi. In AbAO, several telescopes are operational today: 70cm Maksutov meniscus telescope, 53cm azimuthal reflector, 22cm reflector ORI, 40cm double astrograph, 53cm large and 11.5cm small solar coronagraphs. Spectroscopic and photometric observations are carried out. In 2007 the Observatory was integrated with Ilia State Univ., merging scientific research and education which facilitated the growth of a new generation of researchers.

Astronomy in Iran routes back to many thousand years ago. When Cyrus the Great, the founder of the Persian Empire, captured Babylon in 539 B.C., Magi who migrated there transformed Babylonian astronomy. In 13th century, Maragheh Observatory with a unique place in the history of Medieval Astronomy, was established. At present, research in Astronomy and Astrophysics has been conducted in a number of universities in Iran. There are two dedicated research institutes in Iran, IPM School of Astronomy in Tehran and Research Institute for Astronomy and Astrophysics in Maragheh (RIAAM). Among the most active universities in Astronomy are IASBS in Zanjan, Ferdowsi Univ. of Mashhad (FUM), Univ. of Tabriz, Shiraz, Birjand, Kerman and Zanjan universities, and Amirkabir Univ. of Technology and Sharif Univ. of Technology, both in Tehran. With nearly 400 members, the Astronomical Society of Iran (ASI) is an NGO that represents the Iranian community of astronomy. It also publishes the *International Journal of Astronomy and Astrophysics* (IJAA). The Iranian National Observatory (INO) is under construction at an altitude of 3600m at Gargash summit 300km southern Tehran. One of the major observing facilities of the observatory is a 3.4m alt-azimuthal Ritchey-Chretien optical telescope which is currently under design.

Since the beginning, IAU SWA ROAD developed activities in all three Task Forces. A number of meetings and schools were organized and a number of other projects were accomplished. Especially, successful were the activities related to Scientific Tourism (and later more specific Astronomical Tourism or Astro Tourism) in Armenia and in the region. We were awarded two grants in 2016: OAD grant for the development of Astro Tourism in the South West Asia and Swiss SDC grant for the development of Scientific Tourism in Armenia.

SWA ROAD representatives, the Director Areg Mickaelian and BAO Director Haik Harutyunian took part in the **IAU Arab World ROAD opening** in December 2015. In February-March 2016, Areg Mickaelian and Sona Farmanyan took part in the **OAD/ROADs meeting in Cape Town, South Africa**. The whole SWA team (Areg Mickaelian, Susanna Hakopian, the new TF1 coordinator, Sona Farmanyan, and Gor Mikayelyan) visited Georgia in March-April 2016 for tightening the collaboration and exchange of scientific knowledge. In August 2016, Areg Mickaelian and Sona Farmanyan were invited to RIAAM, Maragheh, Iran to participate in a workshop and gave talks.

We hold regular telecons both with OAD/ROADs and with the SWA ROAD Steering Committee to give short reports on the accomplished affairs, and to discuss all current and future matters.

3. Expansion to IAU SWCA ROAD

In May 2016, Areg Mickaelian and the Scientific Secretary of BAO Elena Nikoghosyan visited three Central Asian countries, Uzbekistan, Kazakhstan and Tajikistan to recover our former contacts and collaboration. As a result, during June 2016, Kazakhstan and Tajikistan with official letters also joined our ROAD. This significantly strengthens our centre and expands its sphere of activities to Central Asia.

In **Kazakhstan**, Fesenkov Astrophysical Institute (APhI), Almaty (founded in 1941) is the main astronomical centre. At present *Dr.* Chingiz Omarov is the Director, and *Dr.* Assylkhan Bibossinov (also member of the SWCA Steering Committee) is the Deputy Chairman of the National Centre of Space Research and Technology, to which APhI is affiliated. One of the outstanding scientists, *Prof.* Eduard Denissyuk, was one of the first astronomers to spectroscopically observe Markarian galaxies and has long-year collaboration with BAO astronomers. There are three attached observatories to APHI: Kamenskoe Plateau Observatory (altitude 1450m, AZT-8 70cm, Zeiss-600 60cm, Hertz telescope-reflector 50cm, Wide aperture Maksutov meniscus telescope 50cm), Tian-Shan Observatory (TShAO, altitude 2735m, two 1m telescopes) and Assy-Turgen Observatory (altitude 2750m, 1m telescope). The research subjects are: *physics of stars and nebulae; physics of the Moon and planets; cosmology, stellar dynamics & computational astrophysics; nuclear astrophysics; artificial Earth satellites; advanced astrophysical research.* Kazakh National University (KazNU) (with 16,000 students) is the main university preparing professional astronomers/astrophysicists.

In **Tajikistan**, Institute of Astrophysics of Academy of Science of the Republic of Tajikistan, in Dushanbe (founded in 1932) is the main astronomical centre. At present, *Dr.* Gulchehra Kokhirova is the Director. *Profs.* Pulat Babadjanov and Khursand Ibadinov, former directors and most eminent Tajik astronomers, are still active and strongly supported collaboration in frame of IAU ROAD as well. There are three attached observatories: Hissar Observatory (HisAO, altitude 730m, AZT-8, 40cm astrograph), the observatory “Sanglokh” (altitude 2300m) in Dangara area (1m telescope, 60cm Carl Zeiss) and its branch, the observatory “Pamir” (altitude 4350m) in Murghab district of Badakhshan (70cm telescope). Sanglokh Observatory was recently re-operated and the President of Tajikistan was present at the opening ceremony. The Institute’s research subjects include: *comets and asteroids, experimental astrophysics, meteor astronomy, ionospheric, astrometry, variable stars, structure and dynamics of stellar systems.*

Due to the involvement of Kazakhstan and Tajikistan, our regional centre was renamed to **IAU South West and Central Asian (SWCA) ROAD**. Corresponding changes and additions were done at our webpage.

On November 17, 2017, **Turkey** officially joined the South West and Central Asian ROAD office and expressed its desire to carry out its activities for the development of Astronomy by adopting Armenia’s coordinating role. It is important to state that we also made a political big step. Armenia recognized as an astronomical centre by Turkey. Although it was set up by the IAU, however at present Turkey also accepts it and joins. Now our cooperation will be closer, visits and exchange of scientific experience more active. We hope to work on various astronomical topics to develop astronomy, to organize conferences, to carry out all the activities that this cooperation assumes. There is a number of observatories, astronomical institutes, and universities with astronomy/astrophysics departments in Turkey (the first institute of astronomy was established in 1933 in Istanbul University). At present the main observatory is TUBITAK National Observatory (TUG, founded in 1995). Currently TUG is the most modern observatory of Turkey consisting of 1.5m Russian-Turkish Telescope (RTT150), 1.0m telescope and several smaller size robotic telescopes. In 2014 Ataturk University (Erzurum) opened the latest astronomy department. By 2021, it is expected that the two largest telescopes in Turkey will be 4m and 2.5m.

4. Other Collaborations

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 neighbouring ROADs: **East Asian** (based in Beijing, China), **Arab World** (based in Amman, Jordan) and **European** (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 Armenia. Arab World ROAD is in fact in the same big region (Middle East) and is our closest neighbour (an official agreement was signed between SWCA and Arab World ROADs). The more recently established European ROAD (E-ROAD) in fact 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.

In addition, we have discussed with Indian astronomers the possibilities to collaborate, as India is not a member of any ROAD and the closest one is SWCA.

5. Projects and Other Activities

It is a rule that both senior and young scientists from regional countries (especially Georgia and Iran) most often participate in our meetings, schools and other events. We also have many missions to the regional countries, again most often Georgia and Iran.

Armenia is rather active in organizing astronomical meetings, schools and other events. Among the most important meetings and schools held in Armenia, we would like to mention the **IAU Symposia and Colloquia**: IAU S029: *Non-Stable Phenomena in Galaxies* (1966), IAU S129: *Observational Evidence of Activity in Galaxies* (1986), IAU S137: *Flare stars in Star Clusters, Associations and Solar Vicinity* (1989), IAU S194: *Activity in Galaxies and Related Phenomena* (1998), IAU C184: *AGN Surveys* (2001), and IAU S304: *Multiwavelength AGN Surveys and Studies* (2013). Another large event was the all-European annual astronomical meeting in 2007, **JENAM-2007** (Joint European and National Astronomical Meeting), held in Yerevan, Armenia. It was the biggest ever scientific event in Armenia. Out of other meetings, one may mention joint meetings with a given country, namely Byurakan-Abastumani (Armenian-Georgian) Colloquia in 1974–2013, Armenian-French Workshops in 1995 and 2009, and the Armenian-Iranian Astronomical Workshop in 2015, as well as many meetings dedicated to the anniversaries of BAO, Viktor Ambartsumian, Anania Shirakatsi, Beniamin Markarian, Ludwik Mirzoyan, Marat Arakelian and others. Especially many guests from the regional countries were present at BAO-70 anniversary meeting in 2016 and Viktor Ambartsumian 110th anniversary meeting in 2018. Our office has been awarded OAD grants for organization of **Regional Astronomical Workshops** in 2018 and 2019, and many regional guests were present as well.

Among the summer schools, **Byurakan International Summer Schools (BISS)** are already very famous. We have started this initiative in 2006 and so far, have organized 6 such events: 1BISS in 2006, 2BISS in 2008, 3BISS combined with the IAU International School for Young Scientists (ISYA) in 2010, 4BISS in 2012, 5BISS in 2016 and 6BISS in 2018. Next 7BISS will be organized in September 2020. A **Regional Summer School on Space Sciences and Technologies** was organized in 2019 and this was the first step to establish the above-mentioned subjects in Armenia. **Byurakan Summer Schools for YSU students (BSS)** are our local schools. They have been organized in 1995, 2005, 2009, and 2013. For the school students, on the initiative of Sona Farmanyan, we organize **BAO Science Camps (BSC)**; 6 such events were held in 2014-2019. **ArAS School Astronomical Lectures** program was started in 2012 on the initiative of Yervant Terzian and Areg Mickaelian. During 2012-2020, we have organized 7 such programs. In addition, since 2016, we have had "My Universe" contest and the winners visited BAO.

Our ROAD representatives are rather active in participating in many international and regional meetings and have given numerous talks at such events related to our activities: scientific, educational, public, and in general about our SWCA ROAD.

In frame of the collaboration between Armenia and Iran, on 15-18 August 2016, Areg Mickaelian (IAU SWCA ROAD Director) and Sona Farmanyan (IAU SWCA ROAD TF3 Programme Coordinator) were invited to the **Research Institute for Astronomy and Astrophysics of Maragha (RIAAM)**. During these days, the 8th Advanced Astrophysics Workshop of Maragheh was organized. Areg Mickaelian delivered two lectures on "*Astronomical Surveys, Catalogues, Databases, Archives, and Virtual Observatories*" and "*Multi-Wavelength Studies of Active Galaxies*". Sona Farmanyan delivered two talks on "*Archaeoastronomy and Cultural Astronomy in South West and Central Asia*" and "*Ancient Mythology and Cosmology*". Sona also presented the IAU SWCA ROAD activities during 2015-2016. A number of discussions were held with Iranian astronomers, including *Prof.* Hossein Ebadie (RIAAM Director) and *Prof.* Pantea Davoudifar, with whom there was a collaboration in co-supervising of two Iranian MSc students.

The fourth **Middle East and African IAU Regional meeting (MEARIM IV)**, was jointly hosted by Entoto Observatory & Research Center (EORC) and East African Regional Office of Astronomy for Development (ROAD-IAU) and was conducted from 22-25 May 2017 in Addis Ababa, Ethiopia with the theme of *"Exploring our Universe for the benefit of Humankind"*. During the symposium there were activities such as scientific paper presentations, Plenary Guest and Invited speaker sessions, meetings and discussion on the general progress and Assessments of Astronomy and Astrophysics development in the Middle East and Africa Region. From Armenia, Areg Mickaelian (Director of BAO and SWCA ROAD) and Sona Farmanyan (Public Outreach Coordinator of SWCA ROAD) participated to the meeting and presented 5 talks on various subjects, including the one about SWCA ROAD.

A number of visits have been conducted to **Georgia, both Tbilisi and Abastumani**. Areg Mickaelian has been invited to deliver lectures in frame of the European Eastern Partnership (EaP) program in Tbilisi, particularly at EaPEC conferences and in frame of European GEANT project. In July 2019, our team visited Abastumani Astrophysical Observatory (AbAO) and delivered two invited seminars (by Areg Mickaelian and Arus Harutyunyan), as well as discussions were held on the collaboration in frame of the SWCA ROAD and Astro Tourism project.

Visits to Iran have been conducted in 2015, 2016 and 2018. In November 2018, our team visited Tehran (Institute for Fundamental Research, IPM, Iranian National Observatory, INO and Tehran University) and gave two invited seminars (by Areg Mickaelian and Grigor Broutian). Discussions were held on future collaboration both on research and education and outreach.

The International Conference *"Astronomical Heritage of the Middle East"* approved by UNESCO Director General within UNESCO Participation Program for 2016-2017 was devoted to the role of Astronomy in Culture and other fields of human activities was held on 13-17 November, 2017 in Armenia. The conference brought together over 70 participants from 20 countries. A discussion of the problems of astronomy-related interdisciplinary sciences and further possible collaborations was organized. The Proceedings of the Meeting will be published by the Astronomical Society of the Pacific Conference Series (ASP CS), which is a world-wide known publication and the papers will appear in all libraries and electronic databases (including ADS).

We have given many **presentations on our ROAD** and its activities at a number of international meetings: NKAS (Belgrade, Serbia, 2015), IAU GA XXIX (Honolulu, Hawaii, USA, 2015), Arabic ROAD Inauguration Ceremony (Amman, Jordan, 2015), Conferences on *Astronomical Silk Road* (Beijing and Urumqi, China, 2015), OAD/ROADs meeting (Cape Town, South Africa, 2016), EWASS-2016 (Athens, Greece), 8th Advanced Astrophysics Workshop of Maragheh (Iran, 2016), MEARIM-IV (Addis Ababa, Ethiopia, 2017), EWASS-2017 (Prague, Czech Rep.), Armenia-Brandenburg Workshop (Nor Amberd, Armenia, 2017), The 12th Arab Conference on Astronomy and Science Space (Amman, Jordan, 2018), EWASS-2018 (Liverpool, UK), IAU GA XXX (Vienna, Austria, 2018), EWASS-2019 (Lyon, France), and OAD/ROADs meeting (Cape Town, South Africa, 2020).

We maintain a tight relation between the **IAU SWCA ROAD and Eastern Europe**. This includes collaboration with European countries, collaboration (and partial involvement) with the IAU European ROAD, ArAS affiliation to the European Astronomical Society (EAS), ArAS collaboration with the Euro-Asian Astronomical Society (EAAS), Armenia's participation in South-East Regional European Astronomical Committee (SREAC), H2020 program (since 2016 Armenia is an associate member), collaboration between the Armenian Virtual Observatory (ArVO) and EuroVO, VO-France (also VO-Paris), GAVO, and VObs.it. We also have contacts with other European organizations; Euroscience, SEAC, etc.

6. Summary

The status of the regional astronomical centre supports the regional and international contacts and collaboration both for Armenia and the neighboring countries; this way Armenia, by holding such a centre, strongly contributes to collaborations at all levels: professional, educational and popular. Astronomy in fact plays an important political role in establishing and strengthening friendship and cooperation of the regional nations, which is especially important in our complicated area.

Among our future plans, we envisage to enlarge the number of participating countries (involving more Central Asian and maybe some other ones), work harder for fundraising for implementation of various projects (in all three task forces), organize regional meetings, workshops, conferences on Astronomical Heritage and Astro Tourism, schools and camps.

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Astronomy in Armenia: Recent Activities

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Abstract

A report on the activities and achievements of the Armenian Astronomical Society (ArAS) and the Armenian astronomy in general during the last years is given. ArAS membership, ArAS electronic newsletters (ArASNews), ArAS webpage, Annual Meetings, Annual Prize for Young Astronomers (Yervant Terzian Prize) and other awards, international relations, participation in international organizations, Byurakan International Summer Schools (BISS), regional and local schools, Byurakan science camps, astronomical Olympiads and other events, other matters related to astronomical education, astronomical heritage, amateur astronomy, astronomy outreach and ArAS further projects are described and discussed.

Keywords: *Armenian Astronomical Society – electronic newsletter – annual meeting – summer schools – science camps – astronomical school lectures – annual prize – astronomical heritage – astronomical education – outreach.*

1. Introduction

The Armenian Astronomical Society (ArAS) was in fact created on 22 June 1999, when the first database of Armenian astronomers was collected, it was decided to create the society, By-Laws were developed and ArAS founding meeting was held. It is true that the Society was officially registered by the Armenian Ministry of Justice in two years, on 29 August 2001. Anyway, before that, actions were taken to involve astronomers in the membership, identify and organize the future activities of ArAS. After the official registration, the first steps were the affiliation to the European Astronomical Society (EAS) in September 2001, the creation of ArAS website in 2002, preparation and distribution of electronic newsletters ("ArASNews") since 2002 and establishment of the ArAS annual meetings since 2002. Since then, almost all events in Armenian astronomy are to a large extent connected with ArAS, and in the 2000s Armenian astronomy by its activeness has reached and in some ways exceeded the previous successes present during the Soviet Union years. ArAS reports have also been published in some other papers (Mickaelian, 2014, 2016, Mickaelian & Farmanyan, 2018, Mickaelian et al., 2019).

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2. Membership

ArAS is an organization of exclusively professional astronomers (though a few exceptions are allowed), and also aims at establishing close ties with the Armenian foreign astronomers, inviting them to join and cooperate with astronomers in Armenia. ArAS founding members were 16 astronomers of the Byurakan Astrophysical Observatory (BAO). ArAS currently has 95 members (including 13 founding ones) representing 49 institutions from 21 countries (http://www.aras.am/Members/members.html), including: Armenia – 48 (BAO – 29, YSU – 4 and others), USA – 13, Germany – 6, Russia – 5, France – 3, Mexico – 3, Italy and Spain – 2 (each), Bulgaria, Canada, Chile, Greece, Hungary, India, Ireland, Netherlands, Portugal, Romania, Switzerland, Thailand, and UK – 1 (each). Among the famous ArAS members there are Michel Mayor (Switzerland), Brent Tully (USA), Vahe Petrosian (USA), Daniel Weedman (USA), Igor Karachentsev (Russia), Daniel Kunth (France), Massimo Turatto (Italy) and many others. We have created for each member a personal webpage containing basic information on his personal and professional data. ArAS has 2 Co-Presidents: Haik Harutyunian and Areg Mickaelian (Acting President), ArAS Vice-President: Tigran Magakian, ArAS Scientific Secretary: Elena Nikoghosyan, Treasurer: Marietta Gyulzadyan, ArASNews Editor: Sona Farmanyan, and ArAS Webpage Administrator: Gor Mikayelyan.

3. ArAS Electronic Newsletter

Until recently ArAS released periodically electronic newsletters (ArAS Newsletters, ArASNews; http://www.aras.am/ArasNews/arasnews.html) typically 8 times in a year (periodicity of 1.5 month). The Editors have been: Tigran Magakian (2002-2004, issues #1-12), Lusine Sargsyan (2005, issues #13-16), Lilit Hovhannisyan (2006-2007, issues #17-24), Areg Mickaelian (2008-2014, issues #25-76) and Sona Farmanyan is the editor since 2015 (issues #77-112). Since 2015 the Newsletter became monthly, 12 issues in a year (however, in 2018 and 2019 it was mostly not published). In total, including the beginning of 2020, 116 issues have been prepared and released. In all ArASNews, already 961 articles have been published with total 1543 pages. ArAS Newsletters give news, announcements, articles on Armenian astronomy and BAO, ArAS new members, international and local meetings, summer/winter schools and participation of Armenian astronomers in them, astronomical education in Armenia, Armenian archaeoastronomy and astronomy in culture, anniversaries, scientific, scientific-popular, information materials, etc. A Reference List of ArASNews articles (http://www.aras.am/ArasNews/arasnewsreference.html) has been also created allowing easy access to all articles related to any subject.

4. ArAS webpage

ArAS webpage (http://www.aras.am/) was created in February 2002, at first to give the necessary information about ArAS, including ArAS objectives and forms of activities, list of ArAS members, annual meetings and other events, etc. In early 2009, in connection with the International Year of

Astronomy (IYA-2009), ArAS webpage was fundamentally enriched and renewed and became a repository containing full information on Armenian astronomy. There is information about BAO history, achievements, current projects and international collaboration, received grants, all publications since

2000 have been installed, all meetings with individual pages, new sections have been opened for other scientific institutions in Armenia related to astronomy, 21 famous Armenian astronomers, database of 257 Armenian astronomers throughout the world, astronomical education, amateur astronomy, archaeoastronomy, etc. Without any exaggeration, in terms of the amount of information, ArAS webpage is the richest one among all Armenian scientific organizations and one of the best in the world. We also published in ArAS website Calendars of Astronomical Events of 2014-2020.

5. Participation in international organizations

Armenia is one of 82 member-states of the International Astronomical Union (IAU), as well as ArAS is recognized by IAU. Areg Mickaelian is the Secretary and the Acting President of the IAU National Committee for Astronomy (NCA) in Armenia. ArAS is one of EAS 28 affiliated societies, and by its activities it seconds only the most powerful countries in Europe: UK, Germany, France, Italy and some others. ArAS is also the official representative of the Euro-Asian Astronomical Society (EAAS) in Armenia. Areg Mickaelian is one of the EAAS Vice-Chairs and is a member of the EAAS International Bureau, and Tigran Magakian is a member of the EAAS Scientific-Technical Committee. Together with the Ministry of Education, Science, Culture, and Sports, ArAS is also one of the official representatives of International Astronomical Olympiads (IAO) in Armenia. Armenia joined the international Galileo Teachers Training Program (GTTP) with its official representatives Areg Mickaelian (Ambassador in Armenia) and Marietta Gyulzadyan (Armenian Coordinator). Armenia is an associate member of the Sub-Regional European Astronomical Committee (SREAC) acting in Southeast Europe and an associate member of the International Planetary Data Alliance (IPDA). The last EAS Annual Meeting (European Week of Astronomy and Space Science, EWASS) was held in 2019 in Lyon (France); ArAS Acting President Areg Mickaelian and other Armenian astronomers took part from Armenia.

6. ArAS awards

ArAS has 5 kinds of awards given at ArAS webpage (http://www.aras.am/Prize/awards.htm):

- ArAS Annual Prize for Young Astronomers (Yervant Terzian Prize)
- ArAS/BAO Awards (2009)
- ArAS Certificates
- ArAS/OxArm (Oxford Armenian Society) Awards for scientific journalists
- Galileo Teachers Training Program (GTTP) Certificates

Since 2004, ArAS awards Annul Prize for Young Astronomers (since 2009 it was renamed to Yervant Terzian Prize). It is being awarded to the most active young astronomers (younger 35) taking into account all annual activities. The award is sponsored by ArAS Co-President *Prof.* Yervant Terzian and BAO. At present it totals USD 500, and it is being awarded with ArAS Certificate. In 2019, Naira Azatyan was awarded the Prize. In 2019, the GTTP international certificates were awarded to Arus Harutyunyan and Gor Mikayelyan.

7. ArAS meetings and other events

Since 2002, ArAS holds regular annual meetings, however some of them were associated or combined with other conferences and events, where ArAS acted as co-organizer. ArAS XIII annual meeting was unprecedented in its theme. It took place on 7-10 October 2014 in Byurakan and was called *"Relation of Astronomy to Other Sciences, Culture and Society"* (RASCS, http://www.aras.am/Meetings/RASCS/index.html). In addition to astrophysical issues it included Philosophical Problems of Astronomy, Astrobiology, Astroinformatics, Astronautics, Archaeoastronomy, Astronomical

Year	No.	ArAS annual meeting description and other related conferences
2002	I	Scientific Sessions and Annual Report
2003	II	Scientific Sessions combined with Armenian-Georgian Colloquium
2004	III	Scientific Sessions and Annual Report
2005	IV	Scientific Sessions and Annual Report
2006	V	Scientific Sessions combined with BAO 60th Anniversary Meeting
2007	VI	Scientific Sessions combined with 15th EAS Annual Meeting (JENAM-2007)
2008	VII	Scientific Sessions combined with Ambartsumian's 100th Anniversary Meeting
2009	VIII	Scientific Sessions related to IYA-2009 (incl. Astrobiology and Archaeoastronomy)
2010	IX	Scientific Sessions and Annual Report
2011	X	Scientific Sessions and Annual Report
2012	XI	Scientific Sessions combined with Anania Shirakatsi 1400 meeting
2013	XII	Annual Report and Summary of Astronomical Year 2013
2014	XIII	Scientific Sessions combined with RASCS meeting
2015	XIV	Scientific Sessions combined with Armenian-Iranian Astronomical Workshop
2016	XV	Annual Report and Summary of Astronomical Year 2016
2017	XVI	Scientific Sessions combined with the International Conference "Astronomical Heritage of the Middle East"
2018	XVII	IAU South West and Central Asian 2nd Regional Astronomical Workshop
2019	XVIII	IAU South West and Central Asian 3rd Regional Astronomical Workshop

Education, Amateur Astronomy, Scientific Tourism and other topics related to astronomy. It brought together astronomers, philosophers, historians, archeologists, philologists, artists and representatives of other fields. ArAS dedicates small-scale events (one-day conferences or seminars) to the anniversaries of famous astronomers.

8. Summer Schools and Science Camps

Since 2006, ArAS and BAO organize regular Byurakan International Summer Schools (BISS, http://www.aras.am/Meetings/meetingsSummerSchools.html), once every two years. In 2018, during the IAU General Assembly XXX in Vienna, Austria, BISS were announces as one of the top-3 international astronomical schools (along with ISYAs and Vatican Observatory Summer Schools, VOSS). Since 2005, local summer schools for YSU Physics Department students are being organized to cause and increase interest to astronomy. They are the continuation of the initiative started in 1995. ArAS has also organized a Conference for Young Astronomers in 2011. A Regional Summer School on Space Sciences and Technologies was organized in 2019 to establish the Armenia's first steps to this area. Armenian

Year	Summer school name	Short
2005	1st Byurakan Summer School for YSU PhysDep students	1BSS
2006	1st Byurakan International Summer School	1BISS
2008	2nd Byurakan International Summer School	2BISS
2009	2nd Byurakan Summer School for YSU PhysDep students	2BSS
2010	3rd Byurakan International Summer School / IAU International School for Young Astronomers	3BISS/ISYA
2011	FSU countries Young Scientists Conference	FSU-YSC
2012	4th Byurakan International Summer School	4BISS
2013	3rd Byurakan Summer School for YSU PhysDep students / IAU S304 training	3BSS
2016	5th Byurakan International Summer School	5BISS
2018	6th Byurakan International Summer School	6BISS
2019	Regional Summer School on Space Sciences and Technologies	RSS-SS&T
2020	7th Byurakan International Summer School	7BISS

young astronomers regularly attend several international schools and conferences: IAU International Schools for Young Astronomers (ISYA), European NEON/OPTICON schools, Vatican Observatory Summer Schools (VOSS), Virtual Observatory (VO) training schools, and a number of others. ArAS website holds a directory table of the most important regular international schools (http://www.aras.am/SS2010/ss_other_schools.htm) which helps young astronomers and students to follow and find their respective schools based on the level of the students, location, subject, etc.

Since 2014, on the initiative of Sona Farmanyan, ArAS also organizes Byurakan Science Camps (BSC) for school pupils aged 12-15. Fund for Armenian Relief (FAR) partially sponsors these camps. In 2019, the Six Byurakan Science Camp was organized.

9. Astronomical Olympiads

Since 1996, International Astronomical Olympiads (IAO) and since 2007, International Olympiads on Astronomy and Astrophysics (IAOO) are being organized. Armenian pupils have regularly taken part in both of them and have achieved excellent results. In total, they have won 10 Gold, 7 Silver and 24 Bronze medals. Marietta Gyulzadyan has especially big contribution in the achievements of our team; she has been the team leader since 2006. Among the most successful participants are: Zhirayr Avetisyan and Mkrtich Soghomonyan (each have won one I, one II, and one III rank prizes), Tigran Shahverdyan (one II and one III rank prizes), Tigran Nazaryan, Hayk Saribekyan, Hayk Tepanyan, Hayk Hakobyan and Edgar Vardanyan have one I rank prize each. Igor Chilingarian from Russia has won I rank prize as well.

10. ArAS School Lectures

ArAS Co-President Yervant Terzian and some other American sponsors of Armenian origin, co-finance a program of ArAS School Lectures, which runs jointly with the Armenian Ministry of Education and Science (MES). The lecturers are professional astronomers and their visits leave vivid impression for the school children. Schools are also given astronomical materials (books, booklets, sky maps, calendars, etc.), connection is being established with gifted children. In 2012, 2013, 2014, 2016, 2018, 2019 and 2020 such a program was implemented in Armenia and Artsakh schools.

11. Other matters of astronomical education

ArAS tries to contribute to the astronomical education matters in Armenia. Summer Schools, Science Camps and Olympiads are also in this field. Network for Astronomy School Education (NASE) program was implemented in Armenia in 2019. Projects *"Under the Common Skies"* and *"Young Explorers Clubs"* were organized in 2018 and 2019 in collaboration with Poland (Ewelina Gradzka) and support from the USA. Other activities include installation of various information on ArAS webpage, preparation and release of educational CD/DVDs (recently released *"Astronomy for schools"* and *"Astronomy for students"* DVDs, which are collections of astronomical textbooks, books, dictionaries, encyclopedias, articles, reports, photos, videos, software, etc.). In November 2014, on the initiative of Sona Farmanyan ArAS founded Facebook group *"Junior Astronomer's Club"* (JAC). *"Viktor Ambartsumian's Descendants"* Educational Charitable Foundation was founded in August 2014.

12. Archaeoastronomy and Astronomy in Culture

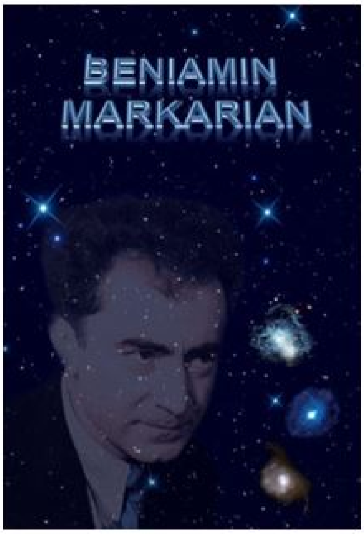
To coordinate issues related to Archaeoastronomy, an appropriate section was opened on ArAS webpage (http://www.aras.am/Archaeoastronomy/astronomyancientarmenia.html). These questions are currently given great importance in the world, in particular, they are in the focus of international organizations such as UNESCO (*"Astronomy and World Heritage"* project), IAU (Working Group *"Astronomy and World Heritage"*), International Council of Monuments and Sites (ICOMOS), European Society for Astronomy in Culture (Société Européenne pour l'Astronomie dans la culture, SEAC), *"Starlight"* initiative and others. In 2014, IAU created a new working group (WG) *"Archaeoastronomy and Astronomy in Culture"* (AAC). Already several related meetings have been organized in Armenia in 2011, 2012, 2014, 2015, 2016 and 2017. ArAS Newsletter now has a permanent section *"Archaeoastronomy and Astronomy in Culture"*. Areg Mickaelian is an Organizing Committee member of the newly founded (in 2018) IAU WG *"Astronomy and World Heritage"*.

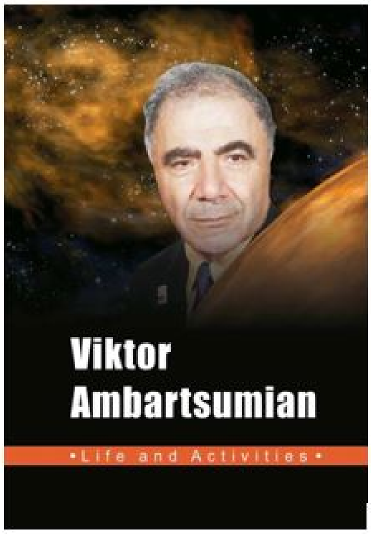
13. Astronomy outreach

Armenia actively participates in the IAU Astronomy for Development (we have established a regional office in Armenia; see the corresponding article) and Astronomy Outreach programs. The IAU Office for Astronomy Outreach (OAO) has been established in Tokyo, Japan. The Armenian National Coordinator of the latter is Sona Farmanyan.

ArAS gives importance to the development of amateur astronomy. There is *"Goodricke John"* amateur astronomers organization created by Ruben Buniatyan, which put efforts and reached the recognition of 18 September (Viktor Ambartsumian's birthday) as Astronomy Day in Armenia. ArAS created on its webpage a section for amateur astronomy (further to establish Armenian Amateur Astronomical Society, ArAAS), as well as a Facebook group, where one can register as an amateur astronomer.

In December 2010, to promote scientific, especially astronomical journalism, the group of Scientific Journalists in Armenia was formed, which includes more than 100 journalists. ArAS periodically prepares and disseminates press releases, organizes press conferences, interviews, and scientific journalism seminars. Press releases contain astronomical news, events organized by ArAS and BAO and held in BAO, occurred and expected celestial phenomena, as well as scientists anniversaries, Armenian and other international scientific news. Astronomers hold public lectures at different organizations. On ArAS webpage, online *"Astghagitak"* ("Astronomy Expert") popular astronomical journal was created, where materials in Armenian are being placed for those interested in astronomy.





ArAS publishes a number of books (Proceedings of its Annual Meetings), popular booklets, calendars, sky maps and other promotional material.

14. Further plans

More serious attention should be paid to *"Astronomy and World Heritage"* program. In particular, it is planned to implement a global program on Archaeoastronomy and History of Astronomy, Astronomy in Culture, as well as global programs on Amateur Astronomy and Astronomy Education. In parallel to the UNESCO World Heritage list, the IAU WG *"Astronomy and World Heritage"* has established a list of Outstanding Astronomical Heritage (OAH), and our aim is to include in it a number of Armenian astronomical items, particularly the Armenian ancient calendar and chronology, Armenian astronomical rock art, Zorats Karer (or Karahunge, the *"Armenian Stonehenge"*), Metzamor Hill astronomical platform, Anania Shirakatsi's astronomical heritage, and the architectural ensemble of the Byurakan Astrophysical Observatory (BAO).

Yet in deficient condition is the amateur astronomy; amateur telescopes, observational programs, amateur astronomers meetings, educational programs, and wider publicizing of astronomy are needed. Global programs are aimed at coordinating the whole area in Armenia. We intend to create new sections on ArAS webpage, namely Armenian duplicates of the *"Portal To The Universe"* (PTTU) and other webpages.

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Under the Armenian sky-for development and interchange of experiences

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1. Introduction

Under the Armenian sky was an educational project run in cooperation between two partners: Polish Association *Under the common sky and Byurakan Astrophysical Observatory (BAO)* in 2018/2019. Although, the project's name suggests it was related strictly to Armenia it was connected to a larger initiative run by the Association *Under the common sky* based on its leading idea, experience, methodology and knowledge. The Association's fundamental aim is "popularization of the cutting-edge knowledge about the Universe as well as teaching skills using modern technology like Stellarium program and telescopes. It is also inspired by the Ancient Greek ideas of arête, paideia and theoria which give a more humanistic component to the project. It is believed that in the excess of contemporary focus on STEM subjects it is important to remember about humans unique capacity to contemplate the reality that surrounds them. This enriches them as reasonable human beings who desire to know just for the sake of it. Surprisingly, such an attitude gives positive results and participants of the project appreciate this" (Gradzka, 2019).

2. History

The two organizations had a first chance to meet on 11th March 2016 when Polish coordinator of projects and its main author Ewelina Gradzka came for a preparatory visit to Armenia in search for partners. Sona Farmanyan and Areg Mickaelian were the hosts and represented BAO. During that event Mrs Gradzka had an opportunity to discover the greatness of BAO, its people and its history. Mrs Farmanyan and Mr. Mickaelin organized a meeting with the staff who was introduced to the main features of the project, its objectives, requirements and plan of work. The project had already been running in Kyrgyzstan with a considerable success and it was recomendable to use that experience in Armenia which possess such a long and spectacular astronomical heritage naming at least the work of Viktor Ambartsumian. Additionally, the perspective of cooperation seemed attractive for the two organizations as both sides could share and gain valuable experience. The Association could share the experience of its direct work with teachers' trainings and engagement with astronomy clubs in schools whereas the Observatory as large academic institution could share its experience with science camps for children, astronomy conferences and international engagement in the Office of Astronomy for Development of the International Astronomical Union. Nevertheless, the project did not received funding. At that moment also Georgia was considered a partner country and was represented by Ilia State University and Abastumani Astrophysical Observatory.

The second phase of the cooperation could be considered invitation of Mrs. Gradzka to the International Conference "Astronomical Heritage of the Middle East" held on 13-17 November 2017 at the Armenian National Academy of Sciences in Yerevan. During that event Mrs. Gradzka shared the experience of running projects in Kyrgyzstan and the importance and effectiveness of developmental help if correctly prepared and engaging directly with the improvement of human capital in her speech: *"Under the Kyrgyz sky- from astronomy to development"*. (Gradzka, 2019) A new meeting during the conference motivated both sides to try again and apply for the project dedicated this time entirely to Armenia.

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Figure 1. Preparatory meeting for the project of Mrs. Ewelina Gradzka and Mrs. Sona Farmanyan, 11th March 2016, BAO.

Finally, the project *Under the Armenian sky* was accepted and granted financial support by the Polish Foundation 'Education for Democracy' from their grant program *RITA-region in transition.*

3. Astronomy and democracy

A difficulty among specialists in political science exist in precisely defining what democracy really is. The concept is vague and wide and in different countries it is practiced with a variety of methods (some would be considered undemocratic in other countries like having a king or a queen, being fined for not participating in the elections, or even usage of ID). However, some key elements can be distinguished and among them we can name:

1) "political system for choosing and replacing the government through free and fair elections;
2) the active participation of the people, as citizens, in politics and civic life;
3) protection of the human rights of all citizens;
4) a rule of law, in which the laws and procedures apply equally to all citizens". (Diamond, 2020)

Interesting for the purpose of the project is point number two which relates democracy directly to the idea of civil society. Often, democracy is reduced to the idea of free election and free press but there is a much deeper aspect of it. It requires ordinary people to engage on all levels from school and local community until governmental. There is even more to that. It is claimed that democratic system is beneficial for the character of people. According to philosophers like John Stuart Mill or Jean-Jacques Rousseau it makes people stand up for themselves. Hence, it encourages autonomy of a person. "When they participate in making decisions, they have to listen to others, they are called upon to justify themselves to others and they are forced to think in part in terms of the interests of others". (Christiano,, 2018) Obviously, democracy has also weaknesses as Plato complained that it undermines expertise that is necessary to govern and favors those who are skillful in rhetoric and persuasion. He also undermined the idea that majority of people are capable of thinking good enough to make proper decisions.

In the project democracy is understood in relation to these ideas. Therefore, it focuses on development of:

- communication and teamwork,
- empowerment of people,
- critical thinking skills,
- access to information and ability to use it,
- organizational skills,
- volunteering and work for local community.

The project aims at preparing children for democracy so to refute in practice Plato's arguments.

4. Experience

The Association *Under the common sky* has been running their projects since 2015 when the first one was launched in Kyrgyzstan[1]. It has been focusing on post- Soviet countries due to the common experience of Poland and ex-member states of Soviet Union. However, it does not limit the idea of the project to that particular region. It simply determines present activity restricted also by the possibility of founding financial support for the projects.

Since 2015 there have been 9 independent projects related to teacher training and establishment of astronomy clubs as well as 7 one-week astrocamps for most active participants of the clubs. In total in the projects have participated 73 astroclubs, 119 teachers have been trained, and approximately 1405 school children have engaged in the clubs and 350 took part in the camps[2]. The project has already been organised in four countries- Kyrgyzstan, Poland, Armenia and Tadjikistan and is going to take place in Uzbekistan.

The Association has worked with various types of partners which gives additional value to the universality and flexibility of the project. The partners have been:

- ngo related to Catholic Church mission- *Svet lubvi*, Kyrgyzstan;
- ecological and cultural heritage ngo- *Institute for Sustainable Development*, Kyrgyzstan;
- engineering ngo- *Foundation for Innovative and Sustainable Technology*, Tajikistan;
- democracy building ngo- *Institute for Youth Development*, Kyrgyzstan;
- academic institutions- *Byurakan Astrophysical Observatory*, Armenia and *University of Central Asia*, Tajikistan;
- public school- *State secondary school named after Mirzo Ulugbek*, Uzbekistan

This shows that astronomy as a tool for improvement of human life can be used in various context. Additionally, the unique experience of those partners enriched the project with different insights and attitudes into local problems and the Association's management skills.

[1]In 2015 the project was officially run by another organization (Dom Spotkań im. Angelusa Silesiusa), but by the same team that since 2016 has organized all the projects in the name of the Association *Under the common sky.*

[2]These numbers are approximate as in many cases the number of engaged in the work of the clubs was changing during the school year and in some cases exceeding the required min. 15, sometimes in one school there were two groups divided by language, eg. Kyrgyz and Uzbek or Kyrgyz and Russian.

Table 1.

N	Title	Year	No. of school (astroclubs)	No. of teachers	Approx. no. of students
1.	Under the Kyrgyz sky ed. I, II, III	2015, 2016/2017, 2017/2018	15	30	300
2.	Under the common sky –Poland	2016	10	20	150
3.	Under the Kyrgyz sky-on the camp (ed. I, II, III, IV)	2016 2017 2018	10	11	350
4.	Under the Kyrgyz sky in the Kashubian region	2017	1	1	50
5.	Astrojailoo- under the Kyrgyz sky-astronomy for development and biocultural diversity	2018	5	10	75
6.	Under the Armenian sky	2018/2019	10	20	150
7.	Astronomy for development of civil competencies of schoolchildren ed. I & II, Kyrgyzstan	2018/2019 2019/2020	12	17	180
8.	Under the Tadjik sky	2019/2020	10	10	150
9.	Under the Uzbek sky[3]	2020/2021	(6)	(12)	(90)
	SUMMARY	**2015-2019**	**73(79)**	**119 (131)**	**1405(1495)**

5. Under the Armenian sky

The core idea of the project run in Armenia (as well as in other countries) had three phases. The first one was related to teachers trainings and provision of equipment. The second one focused on establishment of astronomy clubs by each teacher in their school and in the third phase astroclubs should organize events for local communities. To be able to do so, partner organizations announced an open call for schools with project requirements. Any school that was wishing to participate had to send application form where one of the questions was related to motivation. The next step was to choose together the schools that best fit the project requirements. After that, telescopes were bought for all 10 schools and shipped it from Moscow astronomy shop. Additionally, tools like laser pointers (to run sky observations), football caps with red light (for sky observations), Sky Atlas (with impressive illustrations) were provided. In the first phase, there were two trainings planned. A four-day training took place at BAO on 26-30 July 2018 in the very beginning of the project. The training was divided into two parts: day-time and night-time. During the day (despite scorching heat) there were 9 hours of workshops focused on basic concepts in astronomy starting from solar system, planets, solar activity, stellar evolution, galaxies, constellations. The methodology used was based on hands-on activities with small lectures on particular subjects. Additionally, there was introduction to Stellarium computer program used to simulate night sky (and can be used as simple planetarium) and practice on computers. In the evening, the participants developed their skills in usage of the sky map and telescope which means search for constellations, planets, deep sky objects as well as Moon and Sun observations. Using the opportunity of having a training at professional observatory the teachers paid a visit to the BAO facilities guided by Mrs Anahit Sargsyan. There was also a lecture given by Mr. Areg Mickaelian on his professional research in astronomy. The whole training finished with a final exam to check teachers' readiness to run astronomy clubs on their own. The second three-day

Figure 2. PA four-day teachers' training at BAO on 26-30 July 2018.

training was held on 19-21 April 2019 in the second half of the project[4]. Had the same schedule but different material related to teachers needs stated in evaluation form filled before arrival for the training. Usually, and in this case as well, additional practice of the previously acquired skills is expected and new hands-on activities are presented.

Figure 3. A three-day teachers' training (activity with spectroscopes) at BAO on 19-21 April 2019.

The day time part was run by Mrs. Ewelina Gradzka and night time part by Mr. Tsovak Voskanian. This was the first time a local amateur-astronomer was engaged in the project. Mr. Voskanian proved very professional even though he lacked experience in running trainings for large group of participants (there were 10 telescopes with 20 people to coordinate at the same time). Experience of amateur astronomer like Mr. Voskanian suits better for the training on small telescopes than of professional astronomers. Usually, amateur-astronomer's ability to find deep sky objects and use various types of

[4]The official dates of the project were 01.06.2018 until 31.05.2019.

telescopes far extends that of professionals.

In the second phase of the project astronomy clubs were run by the trained teachers for students of their schools. Each club was asked to meet twice a month and an exemplary program of the meetings was prepared at the end of the teachers' training based only on the activities presented during the training. Therefore, the teachers who are often new to the subject[5] are capable of running the clubs for a year without major problems.

At the end of the project, as third phase, which usually coincides with the end of the school year as in case of *Under the Armenian sky* the clubs were requested to prepare astroevents for local communities.

The major focus of the trainings is to change teachers' attitude to teaching (provide modern, engaging methodology) as well as to their students (develop more partnership relations in the club). These give both, the teacher and the student, a new perspective on learning process where teachers stop to be providers of knowledge and rather accompany students in their development, learning with them and not having to know better all the aspects of the new material (very often students get much better in using Stellarium or telescope then their teachers or surf the Internet for cutting-edge discoveries or technologies that the teacher knows nothing about). This becomes a joint adventure into the wonders of the Universe. On the other hand, it is observed that students appreciate such an attitude and it pays off. It is quite common that in the clubs the most engaged are pupils who before showed no interest for STEM subjects and caused trouble. The students are encouraged to take responsibility for the equipment like the telescope and to collaborate together especially in the preparation of the event for local community. The event is planned to teach students to share their knowledge, skills and enthusiasm and promote volunteer work. The students report that it is a positive challenge for them and it empowers them. This is very motivating when you can stand in front of others and show what you have learnt and what type of interesting, international project you have participated in. Generally, it has to be admitted that astronomy leaves no one indifferent so the task to inspire others is quite easy.

6. Challenges

All the projects run by the Association had to face many different challenges that differ among countries and their peculiarities. Nevertheless, at least a group of three main areas can be distinguished. It is teachers, donors and relations with academia.

First of all, challenges related to teachers refer to their relations in school. It is common that either the teacher is engaged in the project but lacks support from the director or the director is interested in the project but the teacher is not and is forced to participate. Another issue is related to the reality of teachers' work. They are overloaded with paper work and tasks, exposed to a lot of stress, earn very small salaries and they lack support from parents (whose children become more and more spoiled and bad-behaved). Nevertheless, the project had teachers who devoted a lot of free time to run the clubs with a lot of passion and engagement. One of them in Armenia is Mrs. Cristina Mkrtumyan from Syunik Gorayk Secondary School. Mrs. Mkrtumyan frequently reported on her advancement of work with her students, prepared with them videos of their events and even after officially the project has finished she continues her work and contact with the Association publishing her students' achievements and night sky observations on Facebook group of the Association.

Another challenge mentioned are donors. It is often difficult to find a donor whose expectations can be met by the project described. It is common that support is more often granted to projects related to infrastructure (building hospitals, schools) or humanitarian needs (like food supply, medicine, clothing). Nowadays, ecology became an important issue as well as support for protection of cultural heritage. Development of human capital is still underestimated. Additionally, very often donors have their specific organizational expectations like they do not allow hiring foreign trainers or require working with inexperienced partners. There are sound reasons for that, however, in many cases work in

[5]Even though majority of them are physics teachers they lack good knowledge in astronomy and for sure modern methodology; but there are also sometimes mathematicians, informatics, geography and biology teachers or even history or language teachers- who very often turn out to be the most devoted.

Figure 4. Mr. Areg Mickaelian visiting astronomy club run by Mrs. Cristina Mkrtumyan from Syunik Gorayk Secondary School in 2019.

the field verifies this. Length of projects is also problematic as it requires time to influence change in people's behaviors, attitudes, beliefs or motivations. The Association is trying to respond positively to these problems and one of the method is flexibility in adjusting the core idea to particular expectations of the donors. It is also an enriching task as it guided the project into cooperation in the work on ecology issues (tasks like 'There is not planet B' were added or building solar system from recyclable materials to raise awareness), cultural heritage (creation of new constellations related to local traditions or gathering historical information on astronomy in the region), finding ways to co-finance (then foreign trainers salaries are covered by other organizations) or simply strengthening argumentation skills and gaining knowledge (like investigation of reports on humanitarian and developmental aid) to improve effectiveness in convincing donors to support the projects.

The last challenge worth considering is relation between non-governmental organizations (NGO) and academia (like universities or science institutions). First of all, there is an organizational difference as NGO operates faster and is more flexible whereas large institutions have long administrative path and decisions must be taken in hierarchical order. Work in project requires often a dynamic attitude to the plan and decisions must be taken on the spot. In large institutions also responsibility is blurred. It is difficult to decide whose action failed and why (not to accuse anybody, rather to reflect on improvement in the future). Additionally, there is still underestimation of the work done by the Association in the opinion of large institutions' workers. It has been as issue that NGO competences were undermined and lack of expertise was claimed. Professional science institutions also still do not fully see themselves as collaborators with the society. They follow the role of prestigious science institution which role is to do science and not to engage with the public. In this case, in the first place such experience is evaluated to be used effectively in the future and plan better and much in advance (taking into consideration longer administrative path) as well as more time and consideration are devoted to establish personal relations and respond patiently and with understanding to the doubts and reluctance. It is also recommendable to prepare clear task and responsibility division.

7. Future

The future of the project in Armenia depends on schools, teachers and students. They have all the necessary knowledge, skills, equipment and help from the Association as well as BAO to continue their work. It is hoped that further projects based on the idea of Under the Armenian sky will be organized but it requires finding other donors and schools and teachers interested in participation.

The Association will continue promoting its flag-ship project and it has been confirmed that the new edition is going to take place in Uzbekistan between 2020/2021. However, due to global coronavirus (COVID-19) pandemia the dates are under consideration. It is hope that in the future the project will reach the rest of post-Soviet countries like Georgia, Ukraine or Kazakhstan. Nevertheless, it is not restricted to this geographic/historic area and it is open for implementation in other parts of the world.

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“AYAS”: From Aerospace Club to Aerospace Society

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Abstract

The history of educational activity and linking the education with research in the aerospace-related areas in Armenia is presented - all the way from the creation of an extra-curricular study group for school students dubbed the “AYAS” Aerospace Club to the foundation of the “AYAS” Aerospace Society.

Keywords: *education, aerospace, Armenia*

1. The Very Start

In September 1988 we created in Yerevan a new extra-curricular study group for school students who are interested in aerospace-related areas, namely aeronautics, aviation, astronomy, and astronautics. Our goal was to:

- encourage and develop school and university student’s interests towards aerospace-related areas, science and technology, invention and design, provide deep knowledge and understanding of everything related to the Universe and its exploration;
- conduct events contributing to our goals (educational courses, seminars, discussions, excursions, interesting and instructive meetings with professionals from Armenia and abroad);
- develop scientific and educational research projects involving as well related specialists;
- involve also the public in our activity to try to contribute to higher understanding and valuing of science and technology in Armenia.

We called this group “AYAS” Aerospace Club keeping in mind that at some point we will be grown enough for our dream to come true and “AYAS” will stand for “Armenian Youth Aerospace Society” bringing together a lot of young people interested in STEM, space, research and investigation, discovery and innovation.

Later, we realized that we had really created something new, dissimilar to other study groups oriented towards the same areas due to our specific approach that includes three main aspects:

- strong faith in the ability of students to gain in-depth knowledge of STEM, the power of their imagination and ability to innovate;
- complete freedom for the students for creative thinking and opportunities for engaging their abilities;
- education which instead of dogmatic approach (just memorizing pure information, getting limited set of skills and narrow specialization), motivates to get real knowledge by asking questions, digging into underlying basics of any information and understanding deeply all the studied areas and the relationships between them – the basis for creative thinking.

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Initially, we had just a few 10th-grade school students having enough knowledge to develop a preliminary innovative concept for a space mission. The first task was to develop a design of a spacecraft that could drill the Moon deeper than ever and bring the soil samples to Earth. In result of intensive research work and brainstorming, our students decided to use the idea of Russian engineer Mikhail Tsiferov for digging into the Earth’s soil more efficiently by means of the jet stream of a missile device. The tests of such a device weighing 25 kg performed in 1968 showed excellent results – it drilled a well with a depth of tens of meters in a soil obviously harder than the Moon’s soil.

We developed a new version of that missile device modernized for the Moon, the spacecraft carrying that device (the lander and the ascent stage), and the device that could go down the well, take 30 soil samples from the layers of different levels, rise back, and put the filled sample cartridges into the return capsule. All technical solutions, material choices, sizes, masses, and layout were defined and justified by calculations. We also developed a specific technology for drilling enough deep into the wall of the well for taking soil samples chemically unaltered during the missile penetration.

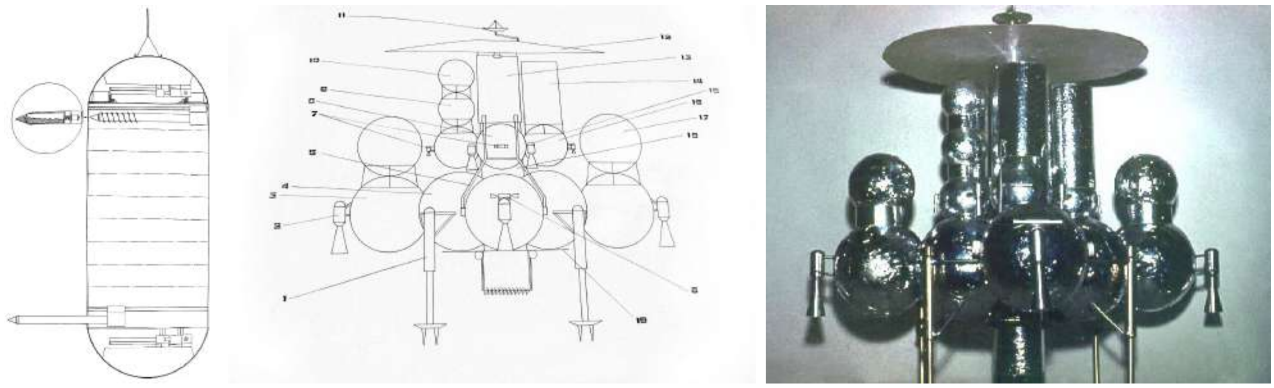

Figure 1. The “Ani” robotic space probe.

The estimated overall characteristics of the spacecraft, that we called “Ani” robotic space probe (Figure 1), proved the feasibility of this project within the scope of space technologies and transportation systems available at that time.

This was an excellent example of a design task that could stimulate interest and would require applying knowledge of mathematics, physics, chemistry, celestial mechanics, rocket science, programming, etc., thus resulting in a significant educational outcome.

We presented this project at the “Space” All-Union Contest of the USSR in 1989 and got “Yuri Gagarin” diploma from the Federation of Cosmonautics of the USSR for the best theoretical justification. The work was presented by the 10th-grade student Hayk Sargsyan. He then graduated the Yerevan State University (YSU) and quickly climbed high in his career: became an outstanding physicist, Doctor of Science, professor, member of the committees of the Republican Olympiads in physics and YSU entrance exams in physics of different years, published numerous articles in highly ranked local and international scientific journals, taught physics at Shirakatsi Seminary, Physic-mathematical school in Yerevan, Physics Department of YSU and Saint Petersburg State University, supervised numerous graduate and post-graduate works leading his students and fellows up to the degree of Doctor of Science. To this day, he is in close contact with “AYAS”, participates in our events and supports us in every way.

Our next project developed in 1990 was the Lunar Observatory “Shirakatsi” (Figure 2). It was designed as a version of the Hubble Space Telescope that could be set on the Moon to operate from there benefiting from the advantageous moon conditions for astronomical observations.

The long night duration (14 days) providing the possibility of much longer exposures, Moon’s slow axial rotation requiring slower rotations of the telescope’s mounting for tracking the object, the firm foundation for the mounting unlike for orbital telescopes, the low night temperature decreasing the noise level and thus increasing the telescope’s sensitivity, and finally the absence of atmosphere make the Moon an ideal platform for such a telescope. The only disadvantage is the big distance from Earth making the service missions very hard and expensive and requiring such a level of safety for the telescope’s systems that can ensure its operation (remotely controlled from Earth) for decades.

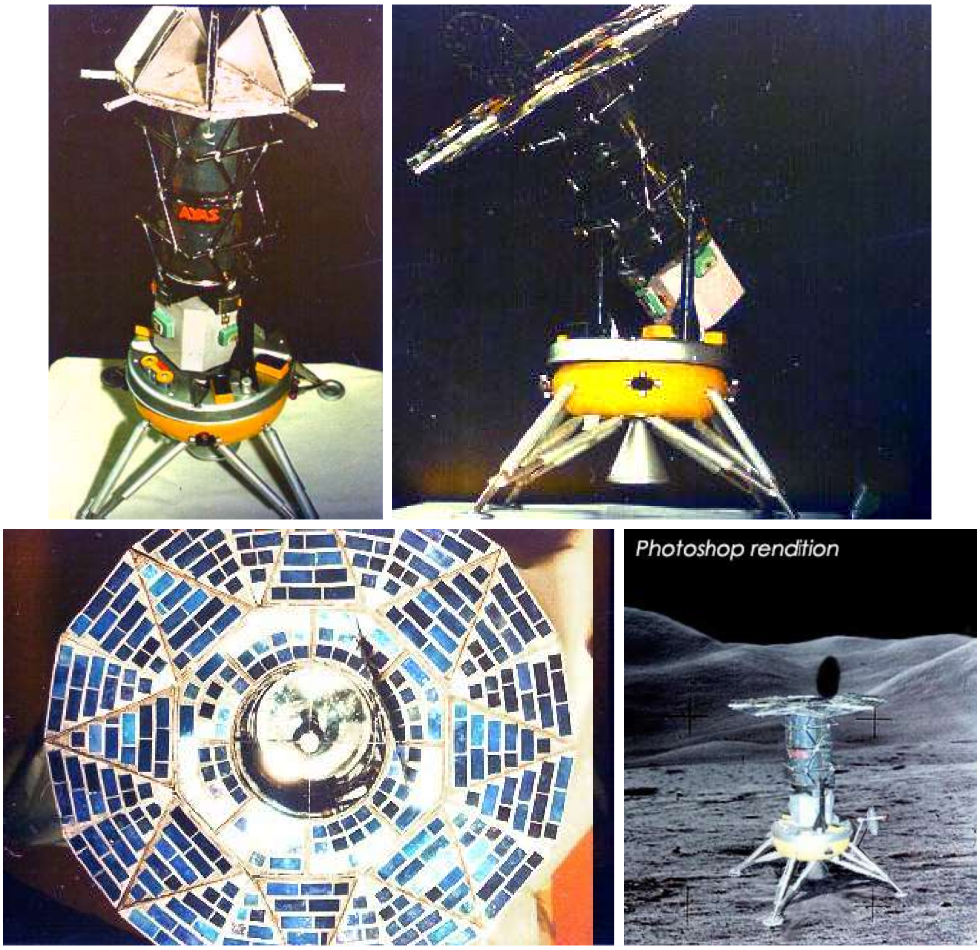

Figure 2. Lunar Observatory "Shirakatsi".

Again our design and calculations proved the feasibility of the project given the payload capabilities of the Energia booster available at that time. Our 10$^{\text{th}}$-grade student Tigran Ghazaryan presented this project at the "Space" All-Union Contest of the USSR and won the first prize. The representative of the Federation of Cosmonautics of the USSR ranked it as the only really feasible project among others and worth for realization.

After this success, we proceeded with a new, more sophisticated project – the "Noah" lander for the first manned Mars mission (Figure 3). However, because of the lack of financial support, we couldn't participate in the International Student Contest "Together to Mars" that was organized by the Planetary Society and held next year in Washington. Unfortunately, a lot of innovative ideas, constructive solutions, calculations, drawings and impressive results of computer simulations of our lander's descent from areocentric orbit to the surface of Mars and ascent of its ascent stage back to the same orbit remained on the shelf.

One can imagine our reaction to the NASA's rendering of a perspective lunar rover released in 2007 (16 years later) showing a novel approach on how to prevent the lunar dust harmful for astronauts' health entering the Moon-based habitats. In our project of 1991, the same approach was proposed not only for resolving the dust challenge but also for preventing mutual biological contamination between the ecosystems of Earth and Mars.

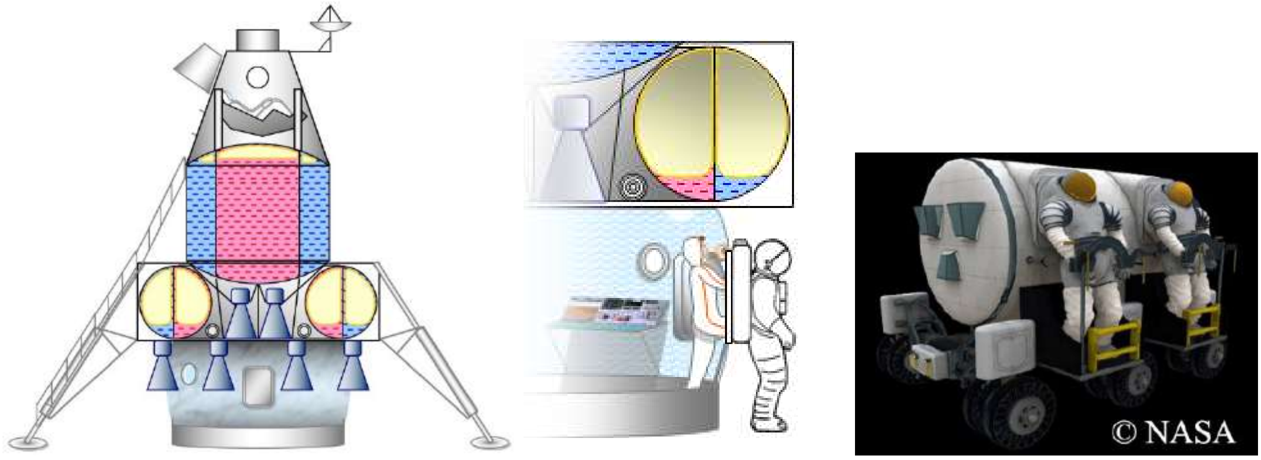

Figure 3. The "Noah" Mars Lander.

2. Hard Times and New Beginnings

After the collapse of the USSR, hard times came for Armenia. We could hardly continue our classes but never stopped. The development and testing of a two-year educational course were in progress. Having no heating in winter we had to assign different research topics for every student so that they could do their work at home under the remote supervision of the mentor and then bring a written report and present the results of their research works to the group in spring. The procedure of reporting was similar to defending a bachelor thesis. All this was useful for them also for getting acquainted with the traditional ways of conducting scientific research work and presenting the results.

Such presentations soon became traditional, and when the University students (mainly "AYAS" graduates) started participating in this work, we reached another major milestone (Figure 4). In October 1995 we held a youth symposium, where both invited specialists from various scientific institutions and "AYAS" members presented the results of their research works.

Figure 4. Participants of the "AYAS" 1st Symposium.

Later, some of those students presented these works at the Physics Department of YSU as their diploma studies. This three-day symposium, organized in accordance with the traditional procedures of international symposiums, was an unprecedented event in the history of Armenia.

In August of the same year "AYAS" actively participated in arranging and holding the Republican Astronomy Olympiad and Astronomical School (Figure 5), organized by the Byurakan Observatory. About 30% of the participants were "AYAS" members. Our school students were awarded 1st and 2nd diplomas and the university students presented their research works.

Figure 5. Republican Astronomy Olympiad and Astronomical School in Byurakan, 1995.

3. Model Rocketry

In the following years we intensified the search for new solutions in rocket modeling (Figure 6). We were developing new automated systems and conducting flight tests at Arzni airport. Model rocketry became a very useful and creative component of our activity.

Figure 6. Model rocketry.

Once again we posed a difficult task for us – to create models of air-to-ground missiles. To achieve this goal, we developed a special ignitor for the rapid and reliable ignition of the rocket engine, rail launchers to be attached under the wings of a remote controlled model aircraft and even small warhead equipped with a shock fuse. Since 1996, this system has shown high reliability and a spectacular flight of the rocket during all tests (Figure 7). This was also an unprecedented success.

Figure 7. Air-to-ground missiles.

4. Visiting Science and Technology Sites

Over time, the visits to various science and technology sites became traditional (Figure 8): Byurakan Astrophysical Observatory, “Granit” Special Design Bureau, Aviation Institute, AREAL (Advanced Research Electron Accelerator Laboratory), CANDLE Synchrotron Research Institute, Herouni Radio-Optical telescope (ROT-54/2.6), Yerevan Aerology Station, airshows in Erebuni and Arzni airports, Museum of Space, planetarium, DigiTech Expo exhibitions, and so on. The students who managed to become a participant of an international contest got the opportunity to visit Zvyozdny Gorodok (the Star City) and Museum of Cosmonautics in Moscow, Special Astrophysical Observatory of the Russian Academy of Science in the Northern Caucasus (the telescopes BTA-6 and RATAN-600), Crimean Astrophysical Observatory, the Air and Space Museum near Paris, etc.

The most beloved site for the students is the Byurakan Astrophysical Observatory. They get acquainted with the observatory, its history and achievements, telescopes and ongoing activity, visit Viktor Ambartsumian’s house-museum, observe the Sun and its spectrum, perform night observations, participate intellectual contests, launch model rockets, helicopters, balloons, gliders, kites, etc.

Figure 8. Visiting Science and Technology Sites.

5. Participation in International Olympiads

In 1996 our two students for the first time participated the International Astronomy Olympiad (IAO), and Vazgen Ghazaryan (“AYAS” graduate and student of Yerevan Physic-mathematical school) was awarded a special diploma for the best result in the observational round. Next several years were missed because of the lack of funding. Only in 2000 the funding was provided and Tigran Shahverdyan (“AYAS” graduate and student of Yerevan Physic-mathematical school) won 2^{nd} degree diploma (silver medal) in IAO. Inspired by this success, in 2001 the Ministry of Science and Education of Armenia funded the participation of 6 people: 2 leaders (Avetik Grigoryan and Armen Oskanyan, who, by the way, took over the whole training work) and 4 students (Tigran Shahverdyan, Vahagn Yeghikyan, Mkrtich Soghomonyan, and Zhirayr Avetisyan). All of them were awarded 2^{nd} and 3^{rd} degree diplomas (bronze and silver medals). In 2002 Tigran Shahverdyan won also a bronze medal in the International Physics Olympiad (Figure 9)

Figure 9. Tigran Shahverdyan

This was just the beginning of successful participation of our students in international Olympiads. Later, many of them (students of Quantum college and Yerevan Physic-mathematical school) won gold, silver and bronze medals in IAO, IOAA, IPhO, IOI, IBO, IZhO, etc.

6. The Educational Course

In 2002 our two-year educational course was already well developed and tested. The problem was that the wide range of topics (aeronautics, aviation, astronomy, and astronautics) and related subjects (physics, mathematics, chemistry, biology, technology) are strongly mutually interconnected with numerous links like in a tangled skein (Figure 10).

When explaining a certain topic, one needs to refer to other related subjects, then to others and so go all over around and find out that it is hard to avoid referring to notions that will be explained later. It was necessary to untangle this extremely tangled skein and sort the topics in the such an order that would allow to go all the time from simple notions to more complicated ones, from the learned material to the new ones and thus build the knowledge like a tower - from bottom to top. This was a rather complicated task given the wide range of topics. However, the solution was successfully found and it became the know-how of the developed course.

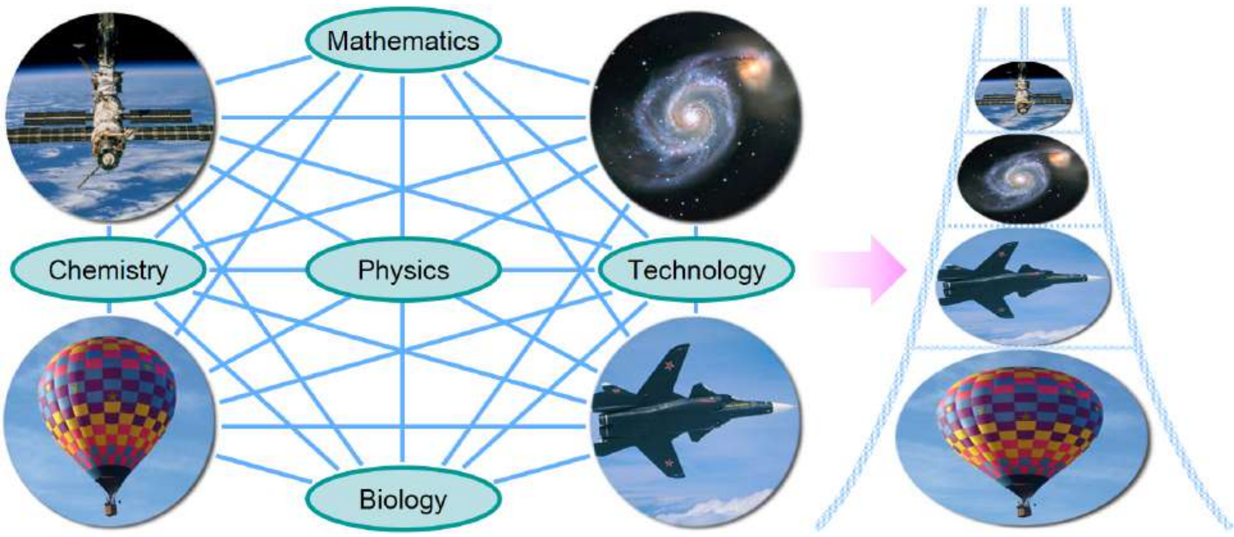

Figure 10. The know-how of the educational course.

7. Popular Science Book

Due to the developed educational course and the gained methodical experience a comprehensive popular science book “From the Deep of Ages to the Universe” was written in Armenian[1] presenting a fascinating story about the path of cognition passed by the mankind in aeronautics, aviation, astronomy, and astronautics starting from the ancient ages to our time and the forthcoming space future (Figure 11). Under the attraction of the extraordinary phenomena and mysteries of outer space, this book leads the reader step by step from simplest and ordinary notions to deep understanding and encyclopedic knowledge in natural sciences and technology, awakes curiosity, develops ability and tendency to creative search and investigation, as well as gives a comprehensive view of the Universe and the history of its study.

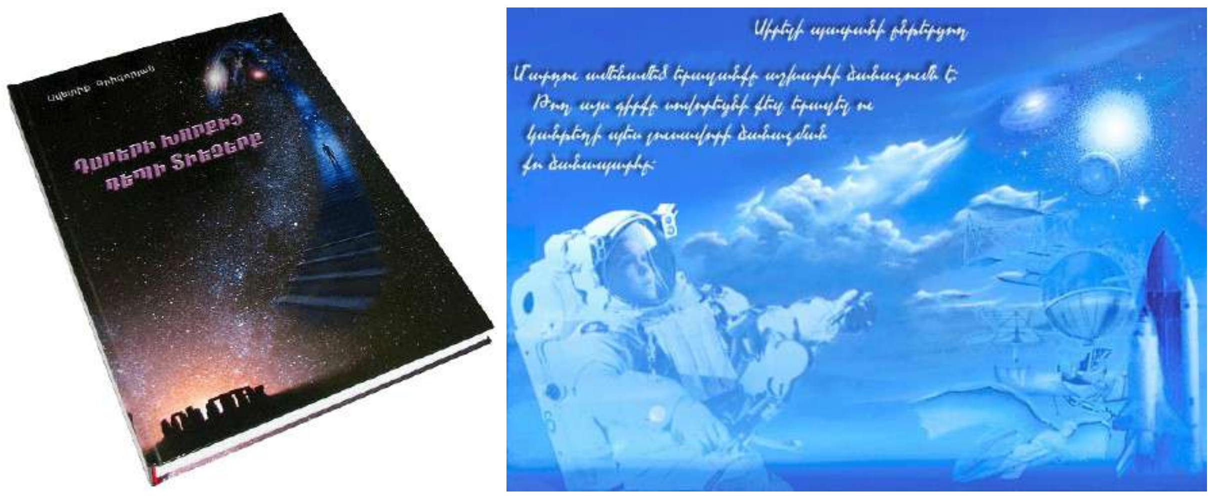

Figure 11. The book “From the Deep of Ages to the Universe”.

This is not an encyclopedia of separate articles collected in one book. Such a style would not allow the reader to reach the required depth and get systematized knowledge and view, understand the relationship between different areas. Instead of that, the book is written in a systematic textbook sequence as a unified story of an adventurous journey through which the reader passes, gradually learning and understanding the world more and more deeply. This makes the reader read the book as a holistic novel, from the beginning up to the end, without jumping and skipping sections. The explanations are simple, intelligible and convincing.

[1] http://books.ayaspace.info/en/about-the-book/

The National Institute of Education of the Ministry of Science and Education of Armenia examined the book and recommended it as an auxiliary school-book for study of natural sciences in the secondary schools of Armenia.

The book was published in 2013, presented in National Academy[2] and delivered to the school libraries of Armenia.

Due to the written content of the book, even before its publication, we easily transferred our educational course to colorful, obvious presentations full of explanatory pictures, photos, diagrams and animations making the course much more clear and efficient.

8. “AYAS” Alumni

Every generation of “AYAS” students loved attending the Club. It became their beloved educational hearth and a blissful place for them where they could satisfy their curiosity and find the answers to their numerous questions; gain serious scientific interests, comprehensive outlook and knowledge, ability to formulate scientific and technological problems; put forward innovative ideas; design, create, invent and discover.

They were happily working together in the Club, supporting each other as they could, making incredible leaps of creative thought and enjoying together their success. Sometimes after classes, it was hard to convince them to go home.

Later, they realize how important was their involvement in “AYAS” activity, how it changed their life, making it much more interesting and successful. So, one of the memorable events in their life is getting the graduation diploma from “AYAS” (Figure 12).

Figure 12. Graduation.

Many of them became close friends and after graduating the training course kept their relationships with the Club and its members, supported the Club’s activity with all their skills and abilities never waiting for others to do that. So today’s sponsors of the Club are first of all its members and alumni.

The “AYAS” members made impressive success in their career. They had significant achievements in studying natural sciences (many diplomas from international Olympiads and competitions) and after graduation became highly qualified specialists: physicists, astronomers, mathematicians, programmers, and engineers. Many of them are working now in Armenia and some in the USA, Europe, and Russia (14 Doctors of Philosophy, and one Doctor of Science, professor). Among the graduates of the training course – 10 medalists of International Olympiads (Olympiads of astronomy, physics, biology, mathematics and informatics), six winners of annual educational award of Armenia’s president, two laureates of Presidential Award and two laureates of State Award in natural sciences. They also contribute to education in Armenia by teaching in different educational centers (Figure 13).

[2] https://www.youtube.com/watch?v=stdvuzJJSZw&feature=youtu.be

Figure 13. International awards and diplomas.

9. Events

Besides visiting science and technology sites, we have arranged a lot of events inviting for participation not only “AYAS” members but also everybody interested in the event: seminars on different topics, meetings with specialists in aerospace-related areas (pilots, cosmonauts, astronauts) (Figure 14), forums and celebrations.

Figure 14. Meeting with Buzz Aldrin.

For the senior members of “AYAS”, one of the ways of supporting the Club’s activity was delivering seminar lectures on the topics of their professional areas. This was extremely useful for the juniors to get acquainted with the front end areas and problems of modern science and technologies (Figure 15). The example of seniors inspires the juniors and shows that they also can work hard and achieve such success.

In order to link the generations of “AYAS” members of different years, we tried to involve them together in our events and even arranged special forums for introducing them to each other, encouraged to exchange contacts and ideas, support each other in their career and even work together (Figure 16).

Figure 15. Seniors teaching juniors.

Figure 16. All-“AYAS” forum.

In 2013 we celebrated the 25th anniversary of “AYAS” (Figure 17), reviewed our history and outlined the future goals and plans[3]. The contribution of each of us, as well as partners, associates and supporters (students, scientists, educators, directors of Schools and Scientific institutions, journalists) was mentioned and appreciated. The “AYAS” members were awarded special certificates of honor on the occasion of the 25th anniversary of “AYAS”.

Figure 17. Celebration of “AYAS” 25th anniversary.

[3] https://www.youtube.com/watch?v=4oMMV1C0yCg

10. Foundation of “AYAS” Aerospace Society

From the very beginning of our activity, it was obvious that we are actually performing as an active non-governmental organization, not just a study group or club. We tried to officially fix this status but realized that it will not make any sense to struggle the bureaucratic obstacles and achieve that goal when we have no sponsors, no chance for financial support, not even sufficient level, experience and resources for initiating serious scientific and engineering research projects and applying for international grants.

However, in 2018 the situation started to radically change. The elder generation of “AYAS” graduates has grown up and could already provide its expertise. The opportunities for getting involved in international projects, participating in different local and international inducement prize competitions, participating governmental initiatives as a legal entity also grew. We even gained experience of founding “AYAS” clubs in other educational centers of Armenia (two schools in Yerevan and the COAF SMART Center in the Lori province) in parallel with the main Club operating in the Quantum college (Figure 18). Thus, our activity started spreading throughout Armenia and involving not only students but everybody interested in aerospace-related areas and rooting for ”AYAS”.

Figure 18. Opening “AYAS” club in the COAF SMART Center.

So, it was high time to officially register our organization with its statute (Figure 19), logo, and certified seal. In May 2018 the “AYAS” Aerospace Club was certified as “AYAS” Aerospace Society[4].

Figure 19. “AYAS” logo.

11. Future Goals and Plans

The official registration as an NGO imposed new tasks and responsibilities requiring us to intensify our activity and work on a higher level. The following goals for “AYAS” are now targeted for the

[4] https://www.facebook.com/ayasspace/

upcoming 5 years:

- Develop new educational project “Science in School” for spreading the experience and culture of conducting research works in school gained by “AYAS” and Quantum college over other schools of Armenia. Discuss this initiative with the Ministry of Education, Science, Culture and Sports of Armenia, promote its conceptual and procedural ideas for including them in the concepts of the upcoming republican competitions of school student’s research works.
- Intensify the research activity of “AYAS” so that it will require a higher scientific-technological level.
- Establish collaboration with the universities of Armenia, first of all with the Yerevan State University, American University of Armenia, State Engineering University of Armenia, and Russian-Armenian University, involve their students in “AYAS” activity, assist and encourage them to create their own research groups.
- Establish collaboration with Space Remote Sensing companies of different countries, obtain corresponding educational and technical resources for this activity and involve the university and school students of Armenia in analyzing the space images of Earth and Mars.
- Establish a new field of “AYAS” activity – high altitude balloons and platforms, develop and accomplish corresponding projects.
- Using all possible means promote Armenia towards establishing its National Space Agency, developing its National Space Program and starting activity in space to become a space-faring country. “AYAS” should have significant contribution in designing and creating the CubeSat that will be launched as the first Armenian satellite.

The State of Astronomy Education in Iran: Challenges and Solutions

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Abstract

Astronomy has a long history in Iran. Our ancestors were pioneered in astronomy and from ancient years was an excelled country in the construction and use of astronomical buildings. Today, there are more than 200 local astronomical societies and centers in the country that the amateur astronomy community has played a significant and influential role in the education and promotion of astronomy to the general public since 2000. A greater part of astronomy education was provided by amateur astronomers through outreaching events, observing nights, and education and outreach projects. Another part of it has been disseminated by science journalists who are amateur astronomers and astronomy teachers in the media and newspapers. Considering the enormous potential that has existed in the growth and development of Iranians in the field of astronomy, in the meantime, challenges such as the specific cultural and social constraints for women's activities, lack of sufficient knowledge of the teachers as well as the training required for them, the lack of a standard curriculum for teaching astronomy and network of astronomy teachers, and also economic barriers, have caused socio-economic development and education through Astronomy to grow less in Iran. This survey suggests challenges for teaching astronomy in general.

Keywords: *Astronomy education, Education and public outreach, Amateur astronomy, Innovation in astronomy communication, Scientific literacy, Iran*

1. Introduction

The first moves in the formation of informal and amateur astronomy in Iran date back to the 1960s and the first step in this direction was taken by the Institute for the Intellectual Development of Children and Young Adults in Tehran. Thus, a planetarium was set up in one of the centers of the public library in the district of Shohada Square which attracted and engaged the youth and general public of the city. After the Islamic Revolution (1979), the Office of Research and Planning of Textbooks affiliated with the Organization for Educational Research and Planning was formed, but there was still no independent textbook for teaching astronomy among dozens of textbook titles, until in 1997 a new and independent book called "An Introduction to Astronomy" was written by Dr. Mohamadreza Heidari, Dr. Mohamadreza Khajepour and Dr. Mohammad Taghi Mirtorabi and entered the education cycle.

Each year, education and outreach in Iran create over 800 astronomy engagement opportunities for the general public and astronomy enthusiasts, but to make all of this possible, educational programs and outreach need the cooperation and support of numerous teachers and outreach professionals volunteers and relevant educational institutions as well.

The needs of tomorrow's society required us to be able to educate our children today and live in the future. Being satisfied with what we have today is to ignore the future. If nothing happened in our lifetime, we needed again to think about tomorrow. While the roles and needs of individuals in the present age are changing. Thinkers emphasize that education is one of the most important

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infrastructural institutions that can fulfill this important goal and prepare people for tomorrow's life. Producing the proper and innovative educational materials is one of the most important tasks of education in achieving this goal.

This article attempts to describe and suggest some challenges facing astronomy, mainly in education, but also relating it to a wider social setting. The paper goes on to suggest a series of underlying reasons for why we should consider these challenges and solutions for our current situation in astronomical society in Iran. This description is tentative and explorative, and is meant to give ideas for a discussion of possible explanations.

2. How astronomy teachers can make the most of their effective participation

2.1. Schools need qualified teachers in astronomy and space

Teachers can change the world. We must have skilled and experienced teachers with sufficient knowledge of teaching that arena to inspire students. In Iran, teaching astronomy classified into three different societies. The first society is academic society which working on professional topics in astronomy and physics in university level. Second, society is amateur astronomy community that teaching amateur astronomy by education and outreach programs and in some institutes and NGOs by some private and public courses on different levels. Third, the community of teachers who teaches elementary concepts of astronomy, which are part of the content of natural science, geography, and physics textbooks in school. Teachers society is the most effective and influential group that has the ability to get teens interested in astronomy (in early, middle and late adolescence) in primary stages of education and learn them the scientific concepts in an accurate and precise way. Furthermore, amateur and professional astronomers are among the most influential people who have been teaching amateur astronomy to the general public through scientific experiments, observing nights in schools and universities and astronomy outreach activities over the past two and three decades in an environment outside the classroom of students and sometimes even inside schools. The basic question is how many teachers are qualified for teaching astronomy in schools or outside of the educational environment? Are the learning resources and materials of students and learners prepared and presented according to their age range? What are the teaching methods and principles for each age group and how do they develop it? Answering these questions is a remarkable issue that should be considered by every teacher, especially those who are teaching in schools, and teachers who have been continuously organizing astronomy courses at private institutions and science-based organizations for many years. Acquiring knowledge of a science and how to acquire the teaching skills of that field to the learner are two different scopes that every teacher should be aware of and pre-study before starting teaching.

2.2. Astronomy curriculum is a key factor to sustain and develop the interest in astronomy and science

Curriculum development is not an easy task to perform or the responsibility cannot be given to anyone out of the blue. Idea implementation and its related policies are somewhat different in each country based on the social, cultural, political and religious factors, of course, if it can be implemented in the best possible form and shape. Implementing the astronomy curriculum known as "The universe, earth and life" during primary and high school education, works as a course that can engage the minds of students at any time instant by considering the learners' perception of the world around them and teach them a different look at life and the complex world around them; in this way, their knowledge of the world around them and the place they live in, as well as their responsibility as an amateur human being on the planet earth, increases after graduating from the school.

Figure 1. Andromeda is a mobile educational team with the aim of promoting science and astronomy and sharing the joy of learning science with all interested parties, especially for children and youth.

3. How to implement and evaluate astronomy education in outreach activities and programs

3.1. Who needs astronomy – and why?

Sharing knowledge with a group of students who don't have any particular interest in science, or politicians who do not pay much attention to topics and challenges of modern science, or even answering the challenging questions of individuals who believe in fortunetelling and astrology more than astronomy, i.e. people who have a guard against the word "scientific", could change their point of view regarding this branch of science. How to engage and involve minds of individuals from different groups is a vital and fundamental issue that some astronomy communicators and teachers are unaware of. First of all, before trying to engage the people of a society with scientific issues or answer their questions, we should ask ourselves questions such as what benefits and advantages would knowing this science bring for them? How does this science help improve our lives? What is the necessity of knowing and promoting astronomy in a situation where more than 736 million people live in extreme poverty? What is the importance of science and technology in education? What is the importance of knowing astronomy and sending probes into space in today's society? Along with pseudoscientific-like defensive answers and questions that always grow in the turbulent path of astronomy teachers and communicators. The answers to these questions make it clear to us that those who want to (or have) become interested in this science in the first point of contact, should not limit astronomy merely to the beautiful images of nebulae, or the discovery of a galaxy at the farthest point in the universe. The nature of this science is inclined to find out who we are and what is our place in the universe. Rather than describing astronomy to anyone, we have to convince ourselves regarding nature, why and how and the uses and applications of this science from all aspects, so that we can make the importance and necessity of knowing it in the face of challenging questions from people and lay audience, more understandable.

3.2. Choosing the target audience and how to engage and educate them

What topics should say to who person? Educational topics that offered for teenagers are different from topics that offered for adults. The percepts of audiences are different by noticing to some relative factors such as education, social situation, culture and literacy for understanding social complexity of different topics. identifying of these factors are change in different situations. For example, if you are in the class with teenage students you can extract personal features about that age group. But if you are in the conference which the audience of that is all group of people who are interested in astronomy, before beginning your offered you faced by some statistical questions and you should ask the audiences to answer the questions by raising their hands. Or people should ask the lecturers that ask some short questions by the form of question and answer to the participants in middling or beginning of their offered. So we can receive effective group information from program audience level by noticing to the items of breaking time, networking, chatting and having reflection and challenge questions. Generally, teachers and communicators of astronomy should notice to this part that for presenting astronomy content to different audiences, introducing surprising facts which tells for the public is not necessary. Sometimes by noticing to the time and the need of that group we can get them some information and distinct story tellings.

Figure 2. An amateur astronomer and graduate student of philosophy of science who plays the role of an astrologer to discusses challenging questions about how much the different groups of people believe in astrology and superstition.

3.3. The need to organize astronomy teacher training program and create a network of astronomy teachers nationwide

The presence of an excellent teacher is important for students' progress, therefore, it is of incredible importance that teachers are not just told what to teach but how to teach. Before they enter the classroom, and throughout their time in the classroom, we must focus on their own learning and development as much as we focus on pupils. As mentioned earlier, teaching astronomy in Iran is pursued in a limited range only in a few schools and mostly in out-of-school in scientific and astronomical institutions, centers and groups. In addition, the community of amateur astronomers has played a vital role in teaching amateur astronomy to the public in scientific and cultural environments. Given the linguistic, cultural, and geographical diversity in Iran, half of the astronomy teachers spectrum, have to consider the geographical and linguistic considerations when teaching astronomy to their corresponding learners, and certainly each of them has had a different experience in their own cities and villages, compared to the teachers living in metropolitan areas. The explanation of astronomy and physics topics and notions, and their perception by the learners are somewhat different based on the language and culture of the area they live in. Therefore, it is necessary to use these experiences, teaching challenges, and up to date educational methods in a conversation hall in order to increase the knowledge of teachers. Holding annual events for training the astronomy teachers, is a way for gathering the educators in this field, so that they can both increase their knowledge in the specialized areas of education, psychology, and methodology, and update themselves on various astronomy topics in the world and their educational and training aspects.

Figure 3. The first SciComm Conference brought together science communicators, amateur astronomers, scientists and science journalists and to give talks that are challengeable and solution-focused.

3.4. Creating a Farsi language hub to provide tools, programs and resources in astronomy education for organizers, teachers and parents and academia

Astronomy teachers require contents and resources to be able to educate their students in different educational stages, both theoretically and practically. The scope and categorization of these resources could be such that make them applicable in out-of-school educational environments and in outreach activities. Currently, the majority of educational resources and tools are provided freely, and mostly in English, to the public by well-known space agencies and observatories and also the largest relevant scientific/astronomical institutions. Some of these open educational resources are designed based on the educational and cultural systems in other countries; although such resources can still be implementable in every country, design and production of such resources that are formulated based on the national considerations of each country and are based on the country's culture and society, could help the teachers, students, and their parents to have access to these resources and educational documents in their native language and via translated instructions. In addition, the scientific, historical, and cultural achievements and legacies of each country are the most important and valuable information that each country should be diligent in preserving and teaching them to the general public. Thus, the method of preserving this heritage in the education curriculum of schools and holding camps to visit historical, natural, and cultural heritage of the country would help in gaining a better understanding and learning of the topics.

4. Astronomy education in media and society - current challenges and possible solutions

4.1. Gender Equality issues in astronomy: a snapshot of real and/or perceived causes for the gender gap

A considerable part of the amateur astronomers in Iran is comprised of women, and they have the greatest participation in teaching astronomy in and out of schools, especially to children and teenagers. A significant number of these women are currently undergraduate or graduate students in the fields of physics and astronomy, however their incomes as a teacher are so low that even the men who have long been interested in teaching astronomy in and out of schools, choose this profession only temporarily, and are not able to accept this profession as their main job due to its low income. On the other hand, girls are forced to be content with this low income, because the lack of a satisfactory job corresponding to their field of study, does not allow them to easily find and work in any job. Over the past two or three decades, girls who were born in religious and traditional families, were not easily able to obtain the permission of their parents in writing in order to attend out-of-time observing programs and tours at night, or even attend and teach in these gatherings as an expert. However, these limitations have been largely solved among some families. The Sepideh's documentary tells the story of some Iranian girls who get into problems with their families regarding their interest in astronomy. Poverty, geographical isolation, minority status, disability, early marriage and pregnancy, gender-based violence, and traditional attitudes about the status and role of women, are among the many obstacles that stand in the way of women and girls fully exercising their right to participate in, complete and benefit from education (UNESCO).

Figure 4. A scene from the Sepideh: Reaching for the Stars documentary and Sepideh's physics teacher, Mr. Kabiri, the man who started the astronomy club in Saadat Shahr city.

4.2. Combining astronomy and entrepreneurship can lead to new practice opportunities in innovative education and outreach projects

The consumer basket of any science, is complemented by products, resources and programs that provide a combination of the science and the product for fans, enthusiasts, and public. This product could be either an educational content presented to the user through an application, or a product in the shape of intellectual games and educational and entertaining goods. A great deal of astronomy enthusiasts from different fields of study and the astronomy experts, have ideas in mind, that not only help the events, classes and different scientific activities as a product, but also could be commercialized in the form of entrepreneurial ideas, and used to gain money both online and face-to-face. These activities in culture, art, media, and tourism, or any other field that can connect astronomy with entrepreneurship, could advertise and even promote astronomy in the form of a consumer product, and gradually lead to socio-economic growth of this science among other fields of economy. Today, some grassroots scientific organizations, centers, and groups, have gained the opportunity to better present their products and digital media advertisements and public relations and communications services in cooperation with these business and grassroots entrepreneur groups.

4.3. Teaching and bring up amateur astronomers and astronomy educators to learn science journalism as an essential skill or alternative profession

Nowadays knowing journalistic knowledge in the online environment is essential for those who are producing multimedia science content in the online world to keep people informed of science and technology news. Science journalism is one of the fields along with science communication which has been promoting science for many years and by asking about the accuracy of scientific topics, especially in basic and natural sciences, from experts and scientists to restates the knowledge of that field in simple and fluent language for the general public and lay audience in print and online media. Learning science journalism as a skill that can cover astronomy and space news in a more accurate and fluent way with the appropriate publication method in print and online media for active amateur astronomers which is the main arm for organizing astronomy education and outreach programs in the online and face-to-face environment in Iran is significantly important. In addition to strengthening and developing the knowledge and skills of narrating, reporting, authenticity and news analysis allows the astronomy community to make the most impact on education and scientific literacy among the general public through a variety of intellectual styles. Moreover, improving and developing the knowledge and skills of narrating, reporting, authenticity, and news analysis allow the astronomy society to make the most impact on education and scientific literacy among the general public through a variety of intellectual styles, besides, when pseudoscience and superstition are spread, and become popular through a viral process of Internet sharing, they will be able to use their journalistic ability and writing power to enhance general public understanding and awareness of fake news on scientific websites and well-known news agencies. Moreover, the implementation of this certainly applies to the production of digital video, visual and audio content, which today are among the most visited and influential places to change people's viewpoints and perspectives on scientific topics and news.

4.4. The need to learn and design innovative ideas for teaching and learning astronomy on different platforms

In recent decade by developing technology and availability of free resources, materials and training tools in online spaces, besides production and implementing ideas for attracting all kinds of people through face to face outreach activities has led to a significant increase in the volume of content and the number of education and outreach programs and projects, especially in the social media atmosphere. In the meantime, the implementation of repetitive and common ideas in these spaces is less effective in engaging astronomy enthusiasts and the general part of people in different age groups. Today, innovative, creative and original ideas should be used in astronomy education and outreach programs in order to influence and dignity of the content on the audience's mind as much as possible, otherwise, astronomical content is duplicated and monotonous for the audience. This is why the general public does not follow remarkably the contents of astronomical groups in the midst of countless content, or only follows some groups that have popular ideas and new projects in the field of teaching and promoting of astronomy. The tastes and styles of the audience are varied in the online environment and the type of interest they have in joining these spaces is also different. Learning and produce videocast, podcast, infographics, application and software, scientific blog in form of web series are among the tools that help to better engage and captivate the audience and the importance of news and astronomical topics for its followers. Besides, astronomy can be brought astronomy to society by giving public lectures to the public in an organized program through various local, national and international events that need to communicate with the audience and engage them face to face with astronomers, scientists and communicators and using different gates to gather the public such as booth performance design, holding a conference, educational workshop and exhibition interest them to the world of astronomy. Among different multimedia project, String Cast podcast, is an example of success and popular digital audio file that attracting a lot of people to science narratives such as astronomy and space topics by using narrative ability and the storytelling structure of its creators with the theme of "strange corners of science". They have nailed their audience into these narratives wherever they can hear it. In the part of projects which are trying to attract and bring astronomy among people, there is a mobile observatory known as Tara Observatory. This particular idea plus abundant competency and perseverance was able to solve the problems of observatories which are usually located in the outside cities and far from living parts to run moving anywhere and make it a unique opportunity for people to easily observe the sky. This is certainly a nonstop adventure. This observatory also can move to the furthest regions of Iran and introduce people to the science of astronomy and the beauties of the night sky under the dark skies of cities and villages far and near.

Figure 5. The Tara observatory is home to one of the largest telescopes in the country which allows the general public to observe the sky by entering the van.

5. Conclusion

However, it seems that astronomy, in terms of its unique features has easily attracted everyone's attention and interest. Therefore, it can be said that its development has been more successful by providing its teaching tools and resources in an amateur way (outside of school and textbooks) in Iran. The same feature of astronomy is observed in other countries.

We should promote the integration of creativity and design into education curricula to drive innovation, as well as incorporating contemporary socio-economic and educational issues into higher education studies and science communication research to foster progress in astronomy education and outreach in Iran. The results of these include the role of astronomy in capturing the public's attention and thereby promoting general science literacy and proficiency, its service as a gateway to science, technology, engineering, and mathematics careers.

IAU100 Activities and Recent Developments in Turkish Astronomy

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Abstract

In this paper, astronomy activities in Turkey in the year of 2019 are summarized. Especially, public outreach activities and teacher training programs in the framework of IAU 100 celebrations are given. Current status of the Eastern Anatolia Observatory and Turkish Space Agency are also summarized. Finally, recently established working group on the legislation for the light pollution is introduced.

Keywords: *astronomy: general, observatories, miscellaneous*

1. IAU 100 Events

2019 marks the 100th year since the International Astronomical Union has been established. In order to create a global public awareness and attraction to science but with focus in astronomy, IAU has organized several projects in different themes. Turkey took part on these events through the coordination of the Turkish Astronomical Society (TAD) and the National Outreach Coordinator (NOC). Information about the global events and their listing were given in the IAU100 website[1] whereas local events in Turkey are presented in the TAD's special website devoted for IAU 100[2].

Figure 1: IAU 100 logo in Turkish.

One of the most participated event amongst other IAU 100 activities was the ***100 Hours of Astronomy***. This event was designed to be held continuously through the globe during 10-13 January, 2019. Almost 30 individual events have been registered for this project with a total participants of 4000. Some event posters are given in Figure 2 and some representative photos taken during 100 Hours of Astronomy events are given in Figure 3.

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[1]https://www.iau-100.org/

[2]http://iau100.tad.org.tr

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Figure 2: Sample of 100 Hours of Astronomy event posters. From left to right; events organized by Ege, Erciyes and Istanbul Universities, respectively.

Figure 3: Some photos taken during the 100 Hours of Astronomy events.

IAU had organized an exoplanet naming campaign in 2015 to name 19 planets. Taking the opportunity to celebrate it's 100th anniversary, IAU launched another version of NameExoWorlds campaign which almost 100 countries have participated. Each country supposed to name an exoplanet and the host star which revolves around it. WASP-52 in the constellation Pegasus assigned to Turkey together with it's planet WASP-52b.

Figure 4: Result of the IAU 100-NameExoWorlds campaign for Turkey. Anadolu and Göktürk were selected as the proper names for WASP-52 and its planet, respectively.

A nationwide campaign carried out by the Turkish Astronomical Society which involves all educational, scientific and related institutions. Each institution supposed to propose a name for star and a name for the planet based on their internal selection. Nearly 300 submissions have been made to the campaign. A national selection committee consisting of seven distinguished researchers and chaired by the IAU Turkey National Outreach Coordinator, has evaluated the submissions. A short list of names, after filtered out already existing names of celestial objects and names that are not complying the rules, voted by the members of the society. The committee decided to propose three couples (one main and two back-ups) of proposition in the end of this process. Following the examination of the IAU NameExoWorlds Executive Committee, ***Anadolu*** and ***Göktürk*** have been approved to be the proper names for the star WASP-52, and for the exoplanet WASP-52b, respectively.

Besides ***100 Hours of Astronomy***, ***Open Astronomy Schools***, ***Women and Girls in Astronomy***, ***Moon Landing 50***, and ***IAU 100 NameExoWorlds*** projects were the activities that many people engaged and followed. For the IAU 100 celebrations, more than 60 individual event have been organized in Turkey.

ISTEK Belde Schools Astronomy Museum[3] hosted an exhibition for the 50th anniversary of the Moon landing. Astronomy Museum in the school is the first and only astronomy museum within a K12 educational institution. Moon Landing exhibition lasted between the dates 16 April 2019-30 December 2019 and visited by 7661 people according to the Astronomy Museum's records.

As the final event for the IAU100 framework, 30th anniversary of the "**Pale Blue Dot**" image was also celebrated. Author of the present paper gave a public talk in Istanbul University for an audience of 200 people.

[3]http://www.astronomimuzesi.com

Figure 5: Exhibition organized by ISTEK Belde Schools Astronomy Museum for the 50th anniversary of the Moon Landing.

2. Teacher Training Programs

Turkish Astronomical Society’s Public Outreach Commission, known as AstroBilgi[4], organizes regular teacher training programs countrywide as well as special programs for childen. In 2019, TAD-AstroBilgi organized 10 different events for teachers. Almost 600 teachers have participated to these training programs. Some of the event posters are given in Figure 7.

The event held in the city of Duzce between 3-5 May 2020 was supported by the *IAU100 Open Astronomy Schools* project.

Istanbul University Department of Astronomy and Space Sciences started a special teacher training program in collaboration with Istanbul Branch of the Ministry of Education (see Figure 8). This program lasts 10 weeks for 40 teachers. Participants for the program selected based on the their field and interest that is shown with an essay. A curriculum for the teachers has been designed by the astronomy department together with counsels from the Ministry of Education. This intense training program aims to improve the knowledge of K12 school teachers who especially teach astronomy or conduct astronomy activities in schools.

[4]http://www.astrobilgi.org

Figure 6: Photos from the Pale Blue Dot event in Istanbul University.

Figure 7: Sample teacher training events that have been organized by AstroBilgi, Turkish Astronomical Society's Public Outreach Commission. Examples here for the events in the cities Düzce, Kars, and Kahramanmaraş, respectively.

Figure 8: Teacher training program organized by Istanbul Branch of Ministry of Education together with Istanbul University, Department of Astronomy and Space Sciences.

3. Turkish Space Agency

Long awaited state organization Turkish Space Agency officially established on 13 December 2018. Agency is dependent to the Ministry of Industry and Technology which all science and technology related state institutions are also part of. Agency was busy with establishing its organizational structure in the first half of 2019. Current President of the Turkish Space Agency is Mr. Serdar Hüseyin Yıldırım. Mr. Yıldırım leads to the agency and the executive board which has seven members, including the Director of the TÜBİTAK National Observatory[5]. Members of the Executive Board can be seen in Figure 9 with the Minister of Industry and Technology, Mr. Mustafa Varank.

Figure 9: The first Executive Board meeting of the Turkish Space Agency took place on the 3rd of September, 2019.

Turkish Space Agency is responsible at first place to develop a national space program. Some of the main duties of the agency are as follows:

- Develop remote sensing applications; for security, for agriculture, and for disasters.
- Develop international collaborations; especially with other space agencies and related organizations
- Coordinate all activities at national level in accordance with international respective bodies.
- Coordinate and develop aerospace technologies.
- Coordinate human resources and related infrastructures for developing aerospace technologies.
- Cooperate with related industries for the sake of aerospace technologies.

4. Updates for the DAG Telescope

Turkey's largest science project is currently on the track. Building of the Eastern Anatolia Observatory continues. In 2019, 80% of the enclosure construction has been completed by the Italian company *EIE*[6] at the site. In parallel to the enclosure, the construction of the building is ongoing. Almost 90% of the main building have also been completed by the Turkish company DAB Construction[7].

Nearly all necessary infrastructures for the observatory are in place such as electricity, fiber internet, dirt road. Asphalt road will be completed during 2020-2021 period before the mirror has been transported.

[5]http://tug.tubitak.gov.tr
[6]http://www.eie.it/en
[7]http://www.dabinsaat.com

Figure 10: Status of the Eastern Anatolia Observatory (DAG) as of November 2019.

DAG telescope has been manufactured completely in the relevant *AMOS*[8] and *EIE* workshops, dissembled and ready for the transportation to the observatory site in 2020. Following the completion of the enclosure in summer 2020, assembling of the telescope will be started. In the meantime, telescope's M2 and M3 mirrors are ready and packed for the transportation, whereas M1 mirror is in the stage of final coating which will be ended in June 2021.

DAG telescope will be very unique such that a 4m Ritchéy-Chretien telescope supported with active and adaptive optics. Adaptive optics facility and the de-rotators of the telescope have been designed and built in FMV Isik University's Optomechatronics Research and Application Center (OPAM[9]) in Turkey and ready to transport to the observatory.

Recently, an article about the current status of the DAG project has been published on the Science[10] magazine.

5. Light Pollution Working Group

In parallel of the efforts building a 4m optical+NIR telescope, Turkey also struggles to decrease the light pollution. These efforts especially important for the cities of Antalya and Erzurum, where the TUBITAK National Observatory and the Eastern Anatolia Observatory is located, respectively.

Turkish Astronomical Society took it very serious and established a working group for the light pollution awareness. Light pollution studies in Turkey was first initiated by Prof. Zeki Aslan who is the founder director of the TUBITAK National Observatory. Prof. Aslan is also contributing the TAD's working group as a honorary member.

Light pollution WG aims to create a public awareness and with this support legislation about the illumination can be modified. France's recent law about preventing and decreasing light pollution is very promising. In order to make similar legislation become reality, WG contacted with the Turkish National Committee on Illumination[11] and both bodies decided to act in cooperation for this purpose.

In a recent astronomical public outreach activity, National Sky Fest (Fisek and Alis, 2020), the Minister of Industry and Technology, Mr. Varank, convinced about the negative effects of light pollution on observatories, especially to TUBITAK National Observatory. Following his affirmative opinion, TAD increase the efforts regarding to prepare a legislation draft for the illumination. President of the Turkish Astronomical Society gave several speeches to the newspapers and TV channels (see Figure 11) in order to attract public interest.

[8] https://www.amos.be

[9] http://opam.isikun.edu.tr/en

[10] https://www.sciencemag.org/news/2020/03/we-put-everything-it-modest-telescope-could-have-big-impact-turkish-science

[11] http://www.atmk.org.tr

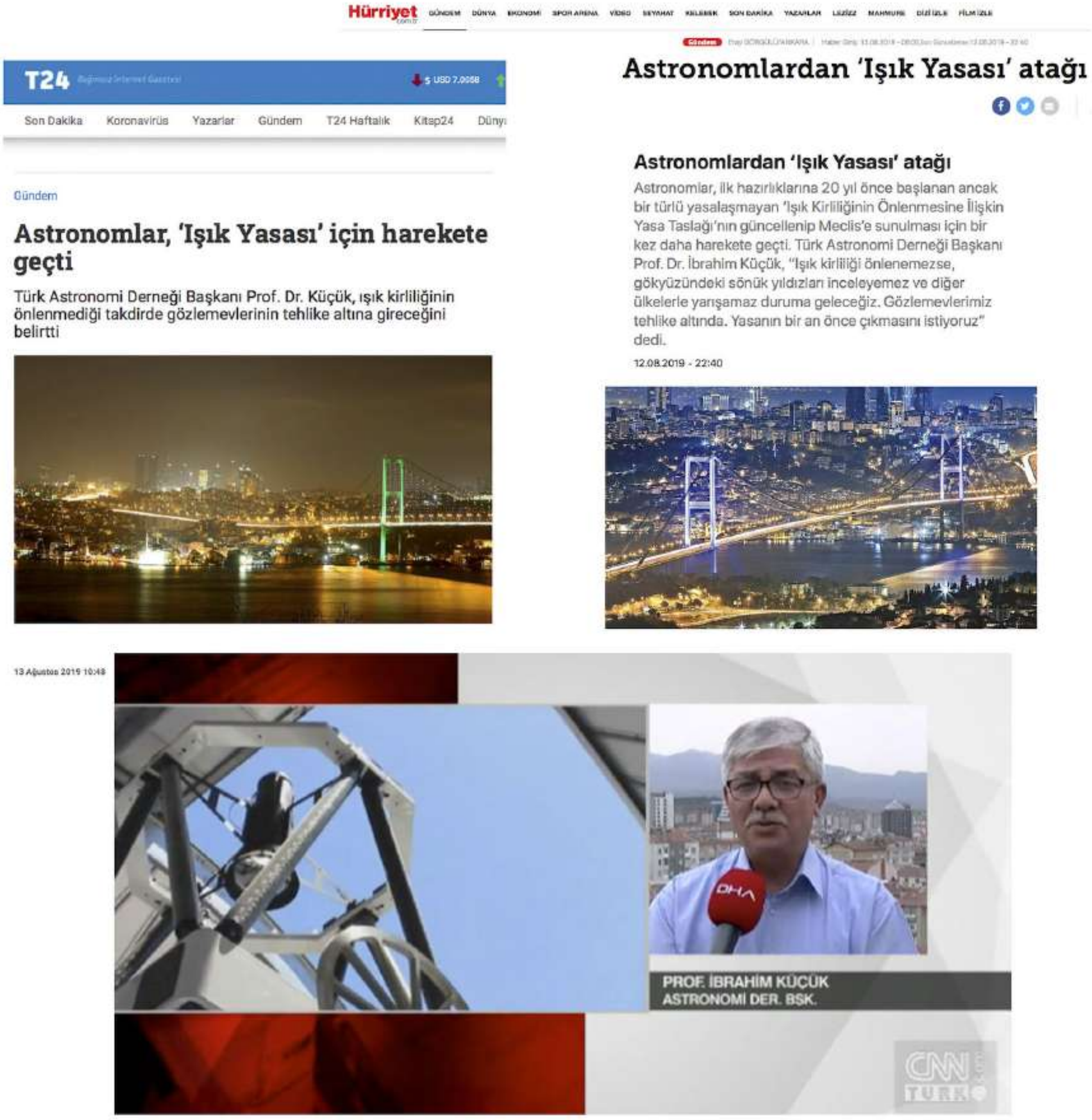

Figure 11: A collage of news about the need and call for a legislation for the light pollution.

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BAO Outreach Activities and Scientific Journalism in Armenia

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Abstract

The paper gives an overview of BAO Outreach Activities and Scientific Journalism in Armenia. We emphasize the role of scientific journalism in raising awareness among public on the topics of astronomy and science in general.

1. Introduction

Science journalism is an occupation that conveys reporting about science to the public. We're living in a century of abundant information. Information itself is a power, thus, valuable information is the greatest power. Journalism is an occupation that disseminates the information, brings people together around various topics. Scientific journalism (science journalism or science writing) is a tool that makes science available to people and brings them close to science. In our humble opinion, humanity moves forward, due to science. So, basically science unleashes human potential, serves to the goals of humanity, whereas, science journalism makes these activities publicly known.

Science journalism covers some of the most complex, exciting, and important issues of our day. And these stories like any other appear in newspapers and magazines, in print and online, on the radio and TV, and in podcasts and videos. Nowadays, blogs, Facebook and twitter pages are among the widely used media tools. Among them, for instance, National Geographic, a television network and flagship channel is widely known, airing non-fiction television programs, featuring documentaries with factual content involving science; or we can note different blogs, such as Cosmos, Science daily, Science, Scientific America, etc., all serving as a bridge between scientists and the community.

2. Scientific journalism in Armenia

The situation is a bit different in Armenia. When we google the term "scientific journalism" in Armenian we find few materials on it. The same refers to the curricula of the universities. Armenian universities have great courses on journalism, even some high schools and colleges have that specialty. However, the courses of scientific journalism have not been established yet, though, we believe, it can be beneficial to have this field developed not only for Armenia but also for the whole world in general. It will create a platform for cooperation making exchange of information possible.

Big efforts have been made for the development of Scientific Journalism in Armenia. With the purpose of that, in 2010 Facebook group of Scientific Journalists of Armenia was formed due to Areg Mickaelian, 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 and Annual Awards have been presented to journalists at 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

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(Armenian Astronomical Society) and the Oxford Armenian Society, and the tradition continued in 2014, 2016 (BAO-70) and special prizes were awarded to ARMACAD scientific network (founder and coordinator – Khachik Gevorgyan) and the Armenian Scientific Cooperation (ARMSCOOP, founder and coordinator – Armen Martirosyan) 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- Grigor Emin-Teryan; the best audio/video news coverage-Yelena Chobanyan; the most active journalists - Ani Karapetyan and Mari Taryan.

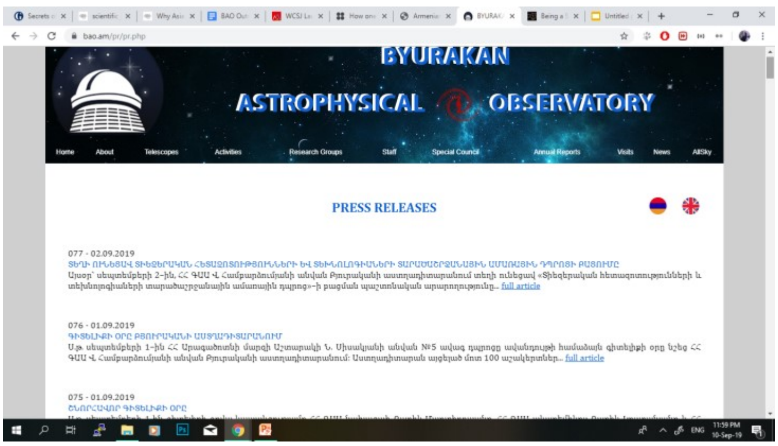
ArAS has a great role in developing scientific journalism in Armenia as well. ArAS webpage contains information, regular press-releases.

"Astghagitak" ("Star Expert") is E-journal that collects information on astronomy and provides the links to the materials for the users of all ages (https://www.aras.am//Astghagitak).

3. BAO outreach activities

Due to its outreach activities, BAO contributes to the development of scientific journalism as well:

- 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. (almost 80 press releases by September, 2019). The press releases are available on BAO official website, Facebook page. 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.



- 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. 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.

- 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 thousands of people (RA and other citizens) visit BAO annually.

- Astro Tourism. BAO is also actively engaged in Astro Tourism (science tourism), being one of the leading institutions of RA. Nowadays, BAO has a project called *"Development of Astro Tourism in South West Asia"*. The leader of the project is Areg Mickaelian, Director of IAU SWA ROAD. The objective of the project is to develop 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 summary, we wish to emphasize that the development of scientific journalism should be a joint effort for both humanity and science can contribute from it.

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Scientific Tourism, Astronomical Tourism and Possible Solutions of Scientific Tourism

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Abstract

The article discusses the ways and prospects of the development of scientific, in particular astronomical, tourism in Armenia.

Keywords: *scientific tourism, types of tourism, astronomical tourism, regional tourism, resources of scientific tourism, scientific tourism in Armenia.*

There is no sphere in the world that can develop without science. Armenia is considered to be a scientific country. Tourism is an industry, the existence of which brings income, permanent and temporary jobs. This is the reason why after a long discussion our government came to the conclusion that scientific tourism department should be established. The head of department became the director of Byurakan Observatory Areg Mikaelyan. The department with the scientists and students of Russian International Academy of Tourism participated in International scientific tours in Armenia and Kars Province in Historical Armenia for 3 years. The aim was to create for the first time a tourist product for the single country. We managed to create a new product for Russian market with the name of "Russian Trace" in the Armenian and Kars territory. It had a big resonance.

Figure 1.

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Scientific tourism is a type of sustainable tourism according to a purpose and it has a direct connection with geographical, ethnic, archaeological, museum, cultural, astronomical, ethnographic types of tourism. People are very much interested in space, stars and other celestial bodies. In this regard astronomical tourism is the youngest but the most required one.

Development of astronomical tourism will promote the organization of regional tours, especially taking into consideration the possibilities of our neighbouring Iran's facilities of observatories.

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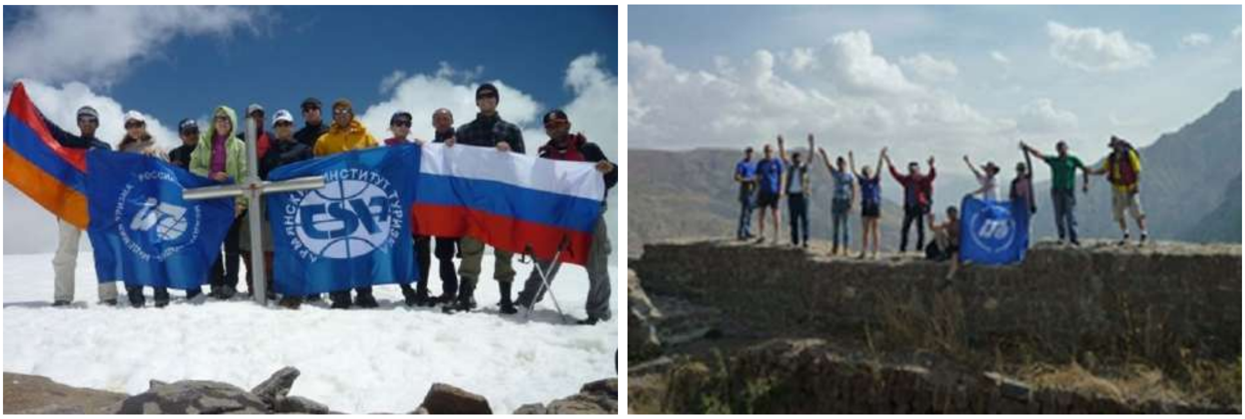

Figure 2.

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In recent times tourism tends to innovate new types. From this perspective the development of science tourism in Armenia can be innovative and profitable. Scientific tourism expands and makes diverse a range of services as well as raises country's rating.

Nowadays specialists divide scientific tourism into 3 groups:

- **Cognitive:** Tourists get acquainted with nature, archaeological excavations, take part in stargazing during the travel.
- **Experimental science tourism:** In this case tourists take part in scientific works, for example in restoration of monuments.
- **Individual scientific tourism:** Tourists are scientists: astronomers, archaeologists, botanists, zoologists, architects, ethnographers, etc.

By definition of UNESCO scientific tourism is the discovery and recognition of scientific achievements, archaeological places and monuments. Scientific tourism is observed as a means of accessibility of scientific values as well as an effective means of preservation and recognition of heredity. Scientific tourism carries out scientific, exploratory activities in those areas which aren't considered to be a permanent residence for a tourist or areas that include at least one overnight stay without material benefit.

Scientific tourism is one of professional types of tourism and has the following features[1] :

- **It's a rare type of non-mass tourism**
- **It's a laborious process for the creation of the final tourism product**
- **It's a type of tourism which can make capital**
- **It has common features with different types of tourism (ecological, cognitive, business)**
- **It deals with individual's secondary demands**
- **With the use of non-traditional means of financing.**

One of the most important factors in scientific tourism development is cultural and historical potential. Countries with non-developed economy but with rich natural and cultural potential are at the top of international tourism market.

The main types of scientific tourism according to visits are:

[1] Холодилина Ю.Е. Ресурсный потенциал региона как основа развития научного туризма. ВЕСТНИК ОГУ N 8 (144)/август 2012, ст. 169.

- **Astronomical: visits to observatories, observation at night, show programs of observatories, etc.**
- **Biological: study of flora and fauna**
- **Geo-climatic: study of unique climatic zones**
- **Ethnic: study of people's culture and lifestyle**
- **Geological: exploration of geological landscape and areas**
- **Archaeological study of ancient cultures and history of civilization**

The purposes of scientific tourism are:

- **Acquaintance with professional researches which are interesting from the scientific point of view**
- **Practical and educational visits of students (geological, historical, archaeological practice)**
- **Acquaintance with cultural and historical heritage and the history of scientific research of rare natural wealth.**

The area where scientific tourism develops can be called the scientific tourism zone. The scientific tourism zone is the area where a unique object of great interest is situated.

The following demands are necessary for the effective activity of scientific tourism zones:

- **Provision of resources (interesting objects for scientific tourists)**
- **Scientific platform (buildings and equipment for acquaintance and participation in scientific activity)**
- **Special equipped conditions for living and food**
- **Engineering building with electricity, heating and drainage system.**

For scientific tourism development the following problems should be solved:

- **Active collaboration for the unique cultural, historical and natural heritage preservation of the given place.**
- **The rise of people's pride and responsibility for their unique heritage.**
- **Tourism development program with the use of the unique local heritage.**

Scientific places of visit, generally included in the travel packages projected by Armenian incoming tour operators, are the following:

- **Erebuni Historical & Archaeological Museum-Reserve**
- **Metsamor Historical-Archaeological Museum-Reserve**
- **Byurakan Astrophysical Observatory after V. Hambardzumyan of NAS of RA (National Academy of Sciences of the Republic of Armenia)**
- **Agarak Historical and cultural reserve**
- **Matenadaran Research of Ancient Manuscripts named after M. Mashtots**
- **Memorial Complex of Sardarapat Battle, National Museum of Armenian Ethnography and History of Liberal Struggle**

- **Aragat Cosmic Ray Research Station**
- **Zorats Karer (Carahunge)**

For the development of scientific tourism it's necessary to have the definite list of the resources of scientific interest which can become zones/centers of scientific tourism. It's important to mention the importance/description of the scientific resource and the development of scientific tourism in that area in the given list.

People are very much interested in space, stars and other celestial bodies. In this regard astronomical tourism is one of the newest and the most demanded types of tourism.

People travel to different parts of the world to see rare celestial phenomena such as solar and lunar eclipses, night sky views, explorations, etc.

Astronomical tourism is an amateur astronomers' group trips to ecologically clean areas accompanied by experienced scientists. Such trips are usually conducted in mountainous areas. This is explained by the fact that mountainous terrain is a suitable place to watch the celestial bodies as there isn't city dust and air pollution.

Astronomical tourism also includes visits to modern observatories where stargazings with telescopes are organized, as well as excursions to observatories remained from ancient times are conducted. Such excursions also have historical and cognitive function.

The interest of people to this type of tourism makes the management of observatories build suitable infrastructures to provide the visitors overnight stay and food. For example, in Chile a rest zone is created where a telescope is placed on the roof of every cottage.

It should be mentioned that the Byurakan observatory's management takes steps to develop astronomical tourism. There are designed tourist routes with interesting names[2], developed lectures with a wide selection of topics, a souvenir trade point, a hotel, a canteen and other conditions to satisfy tourists' demands. But for developing scientific tourism, especially for expanding the possibilities of astronomical tourism, it can be more favorable to implement united regional astronomical tourism. There are many opportunities and wide interests. It's necessary to arrange united regional astro-touristic packages and bring them to the international market. If we regard the neighbouring Islamic Republic of Iran, we'll see that it has many attractive resources from this perspective, for example the Maragheh observatory which was established in 1259 CE and was active for more than 100 years. It must be noted that Alenoush Terian was a famous Iranian-Armenian astronomer and physicist who was one of the founders of the first Iranian solar observatory.

Based on the given situation and problems it's important to solve the problems of the youth's integration and team work.

It's important to unify the activities of Armenian, Iranian and Russian young people who are engaged in the sphere of astronomy. It's necessary to join forces to solve tomorrow's problems. We mustn't wait today. It's urgent to unify ideas and abilities of young astronomers to solve common problems with the help of young astronomical tourism in favor of the participating countries.

It's recommended to make scientific travel packages with scientific opportunities of Georgia, Armenial, Iran, Turkey forming a regional travel package.

Professor Jafar Jafari in his book "Encyclopedia of Tourism" indicated that specialists of many branches such as historians, archaeologists, palaeontologists, philosophers, psychologists, culturologists, ethnographers, anthropologists, environmentalists, marketers, economists are interested in different types of tourism.

Each of these specialists studies tourism in his own way. Scientific tourism unites all these studies and makes tourism complete.

[2] http://www.aras.am/SciTourism/arm/tours.php

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The Possible Potentials of Astrotourism in Caucasus

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Abstract

Astrotourism is not a new topic, but it is certainly a title that has been in the forefront of tourism and astronomy for less than two decades. For nearly half a century, observatories and science centers have been opening their doors to the public on special occasions, such as Astronomy Day. However, for less than a decade, astrotourism has been the constant presence of tourists alongside professional astronomers, especially on weekends. They have made it possible by following all the principles. Until the early 1990s, one of the most important countries in the world to host the world's largest astronomical observatories was the Soviet Union. The Caucasus region in the former Soviet Union hosted very important observatories due to its high altitudes, pure nature, and very low amount of light pollution and, of course, the proper weather in warm seasons. Byurakan in Armenia, Abastumani in Georgia, Shamakhi in Azerbaijan, and BTA-6 in Russia are the four main collections left from that period. Fortunately, nearly two decades after the independence of the countries in the region, the restoration and updating of these observatories have been on the agenda. One of the helping arms to accelerate the revival of these observatories is to take advantage of the potential of astrotourism; especially with the location of these three countries near Iran, which has one of the largest astronomy enthusiast communities in the region.

Keywords: *Astrotourism, Scientific tourism, Caucasus, Astronomy Outreach, Abastumani, Byurakan, Shamakhi, BTA-6*

1. Introduction

The night sky has played a key role in the development of civilization, including orientation and navigation, agriculture, calendars, cultural travel, and celebrations Fayos-Solà et al. (2016). In the last two decades, a new role has been created for the night sky: astrotourism with special attention to places with dark skies. However, the naturally dark sky is a rare phenomenon in developed countries. Therefore, it is necessary to protect it. The dark sky is an essential condition for the establishment of Dark Sky Park, which is the basis for increasing area attractiveness from astrotourism viewpoint Labuda et al. (2016). However, astrotourism is not limited to the night. Astrotourism refers to any tourist activity that is provided by the use of the sky day and night. Astronomy-related tourism can be divided into some main types. The first one is connected to cultural and sightseeing tourism. It involves visiting facilities related to astronomy: planetariums, observatories, museums, and others that relate to the development of this field of science. Another type of astrotourism is visiting the areas with a clear, dark sky Mitura et al. (2017). With pristine parks and established infrastructure, astrotourism would be a natural extension of daytime nature tourism into nighttime stargazing Jiwaji (2016).

There are dark-sky awards in the world that accelerate night sky protection against light pollution. Achieving a dark-sky award is undoubtedly an attractive addition to off-season tourism. It is a relatively fast and inexpensive initiative that can attract significant attention to the region MacMillan (2016). Especially in areas with long-standing observatories. Astrotourism includes only travel program visit the observatory, which includes specific astronomical observations, and not just a demonstration of observations by professional astronomers, but direct observation of every individual tourist.

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Astrotourists is necessarily, and direct observer, in an astronomical sense Belij & Tadic (2015); However, this experience is with small telescopes and not professional telescopes.
Regardless of the effort invested in a reasonably complex organization that includes astronomical institutions and instruments, professional astronomers, or so-called science educators, and attractive sites, astrotourism still attracts a small number of people who are lovers of astronomy and mostly, residents of large cities in developed countries Tadic (2016) Since 2009 (International Year of Astronomy, IYA-2009, declared by UNESCO), these activities are developed in Armenia, one the countries in the Caucasus region, that includes observations of starry skies, visits to modern observatories, space museums and planetarium, as well as popular astronomical lectures Mickaelian & Farmanyan (2016). In order to launch astrotourism, however, more than anything else, it is necessary to provide a platform and facilities and at the same time, enough advertising to implement it. The Caucasus region, known as the Caspian Sea and the Black Sea, with two large Caucasus Mountains and the Lesser Caucasus, is essential for astrotourism in several respects at the confluence of Eastern Europe and West Asia. The less damaged nature of the area, the sky free of light pollution, and, most importantly, the attractive spaces of observatories, given their location in the pristine areas, as well as historical telescopes and domes of these observatories, have given astrotourists a rare opportunity. However, astrotourism has not yet had a long history in the region, providing only a small percentage of an observatory's costs. The reason for this can be found in a series of search factors. What seems to be more important than anything else is the reliance of these observatories on domestic tourists and visitors; this may be due to linguistic differences and difficult access to some of these observatories. However, the author's experience in conducting astrotours with Iranian amateur astronomers showed the high potential of these observatories in astrotourism . This experience was so well-received by Iranian amateur astronomers that each was repeated between two or more times in recent years. In the following, I will review the features, general observing tools, and the type of access to each of these observatories.

2. Observatories in Caucasus

2.1. Abastumani Observatory

The Abastumani Observatory was founded in 1932 on Mount Khanobili, 240 km from Tbilisi and 30 km northwest of Akhaltsikhe, at an altitude of 1,700 meters above sea level. However, early observations on this mountain date back to the 1890s. The ideal observational conditions of this mountain made it possible for Abastumani to host hundreds of astronomers and thousands of eager observers of the sky every year with the establishment of the observatory. One of the main features of this observatory for amateur astronomers and astronomy enthusiasts is the possibility of observation with a 40 cm refracting telescope with a focal length of 680 cm. The telescope has been active since 1937 and can be called the 50th largest refracting telescope in the world. One of the features of this telescope's observatory is the possibility of changing the mechanical height of the observer's location, which is unique in this region. It is possible to visit this observatory for the first hours after sunset and if the sky is cloudless.

2.2. Byurakan Observatory

Byurakan Observatory near Yerevan, Armenia, is the best Caucasus observatory in terms of access to the capital. Launched in 1946, the observatory is located 30 km from Yerevan, the capital of Armenia. Researchers still use the observatory's 2.6-meter and one-meter telescopes, which has an astonishing history and can be visited daily. The observatory is located at an altitude of 1,400 meters above sea level and is more cloudless than its other Caucasian counterparts. In addition to observing the sky by the 32-cm telescope, astrotourists can visit the large telescopes, the Viktor Ambartsumian House-Museum, along with the opportunity to have a public lecture about astronomy. Byurakan observatory became a popular destination by accurate documentation of its history, easy reservation (by email), and services in three languages, Armenian, English, and Russian. Moreover, the reopening of the observatory's residence for astrotourists has made Byurakan a popular destination

Figure 1. Abastumani observatory in Georgia

for astro-photographers, as they can spend the night without disturbing professional astronomers on the observatory's field. Furthermore, the observatory's managers' efforts to register the First Byurakan Survey as UNESCO's Memory of the World have attracted tourists interested in contemporary history and documentation. The official FBS page at UNESCO states: "First Byurakan Survey (FBS or Markarian survey) contains the records of a unique astronomical survey carried out by the Byurakan Astrophysical Observatory (BAO) from 1965-1980. The survey involved the largest-ever astronomical study of the nearby universe and is considered one of the most important achievements of 20th-century astrophysics."

2.3. Shamakhi Observatory of Azerbaijan

Named after Nasreddin Tusi, the Shamakhi Observatory of Azerbaijan was established in 1959, 145 km east of Baku, and 22 km north of Shamakhi. The observatory is located at an altitude of 1,435 to 1,500 meters above sea level and hosts a 2-meter telescope. In total, there are four telescopes to work on the night sky and two solar telescopes in this observatory. The observatory was rebuilt between 2009 and 2013. Housing facilities at the observatory are no doubt better than other counterparts in the Caucasus. However, construction near the observatory's grounds could pose a threat to the region's dark skies.

2.4. The BTA-6 Observatory

The BTA-6 Observatory is home to the largest Eurasia telescope. The telescope is located near Mt. Pastukhova and at an altitude of 2070 above sea level. The first exposure of the telescope, located north of the Caucasus Mountains, took place in 1975. The telescope was the world's largest telescope before the Keck-1 telescope was built in the 1990s. Although this location has a low level of light pollution, it has not been targeted by astrotourists due to the distance from major cities. This observatory is 380 km away from Krasnodar and nearly 500 km from Sochi, making it difficult to visit. However, its history and rich nature can make this observatory a popular destination for astrotourists.

3. Impacts of Astrotourism

Strengthening astrotourism maintains sustainable development in many target areas. Protecting dark skies against light pollution besides protecting the world's natural and cultural heritages are just some of the advantages of astrotourism. At best, astrotourism can change the course, improve, and even rebuild and strengthen the livelihoods of the people of a region. So changing the style of mass tourism to alternative tourism in the region, fund-raising for developing and better maintenance of

Figure 2. Byurakan observatory in Armenia

observatories along with protecting of observatories against changing policies, and providing sustainable livelihood for local people are other advantages of astrotourism. Last but not least, encouraging people to rediscover their place in the universe is one of the best achievements of astrotourism that will lead to more peace.

4. Opportunities

There are several hidden treasures of astronomy in Caucasus. The hidden treasures in the Caucasus region are pure nature, the night sky free from light pollution, and observational tools with a rich history. Traditionally, these destinations were available to the people of this region. However, with the brilliance of tourism in these countries, especially in the last decade, and also with the advent of astrotourism, new opportunities have been presented to these astronomical centers. Note that the other observatories in the area are either not so professional or close to the public. Easy access for Iranian, Russian, and Turkish people by the air and land makes them an attractive destination for astronomy enthusiasts in the Eurasian region. Locating between and around the Caucasus with special climate and history, from Soviet Union to the post-Soviet era, behind these astronomical centers will absorb more non-science related tourists to these points.

Figure 3. Shamakhi observatory in Azerbaijan

5. The gateway to the future

With all the advantages that observatories have in the Caucasus region, there are still disadvantages and problems that make it difficult for tourists to connect with these observatories. There are a few updated information about observatories on websites of the observatories, especially in English. Information on travel guide websites is not reliable enough. Scientists or public relations are planning these programs with limited assistance from travel agencies. There is no online booking system that works, and there are no advanced tour packages, such as mountain climbing and stargazing. However, there are many ways to improve the hospitality of astrotourists in these centers, which I would like to mention here: Planning new routes for astrotourism in collaborations of countries, such as from Karahunj to Abastumani. Associating nightscapes with heritage is a logical step in astrotourism Metodijeski et al. (2017). Another solution is creating an online platform for reservation and contracting with agents in other countries. Astrotourism needs to be better publicized in order to grow. It is a niche with such potential that it could be a good idea for travel agencies to better publicize the destinations that promote such tourism Matos (2017). In the end, there are two other suggestions: Planning two types of programs, one for the public and one for amateur astronomers and making new and special festivals such as Messier marathons in collaboration with amateur astronomers (especially Iranian amateur astronomers). Undoubtedly, there is much potential for improving the level of astrotourism in this region.

6. Conclusions

The undeniable potential of the Caucasus region, from pristine nature to rich history, and the fact that the observatories of this region are open to the public, provide a unique opportunity to improve astrotourism in these centers. By taking advantage of this opportunity, these observatories, in addition to having a favorable cultural impact on society and preserving the night sky, have a direct impact on improving the livelihoods of the people of their region. These observatories can also become successful examples for other observatories in other countries to protect their astronomical history.

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Armenian Astro Tourism Map

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Abstract

Armenia is a country with rich history, as well as high-level science. It is 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 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 museum is astronomy and space science related museum. Despite the fact that Astronomical (Astro) Tourism is a new direction, it has great perspectives, and Armenia has a great potential in this field. It is very important to introduce Armenia from this aspect. In this paper we present major astronomical tourism centers of Armenia and the whole picture as a map.

Keywords: *Scientific tourism – Astronomical Heritage – Astro Tourism – Armenian Calendar – Rock Art – Zorats Karer – sundials – Byurakan Astrophysical Observatory.*

1. Introduction: Scientific Tourism in the world and in Armenia

Scientific Tourism is a new area not only in Armenia but also in the world. Scientific tourism 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 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.

Conditionally, scientific tourism centers can be divided into 5 groups:

- science-related archaeological sites;
- medieval educational institutions (universities, etc.);
- nature sites;
- modern research institutions;
- scientific or science-related museums.

We have created and published the Scientific Tourism map of Armenia, based on our cognitive tours, studies, and also Internet resources.

Among four of the listed types; archaeological sites, medieval universities, modern research institutions and museums, there are sites having relation to astronomy. Here we give brief description of the Armenian astronomical tourism centres, including those, which are not still active but may serve as sites for scientific tourism.

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2. Astronomical Tourism centres in Armenia

There are many petroglyphs (rock art) spread in the territory of Armenia. Armenia is unique from this point of view. Ancient "observatories" or sites, where astronomical observations were made, are also among the astronomical heritage, like Metzamor and Zorats Karer. Armenia is famous with its modern professional observatory, Byurakan Astrophysical Observatory (BAO), and it is unique among dozens of countries to have space museum.

2.1. Astronomical archaeological sites of astronomical nature

Here we list the most important ones:

- Metzamor Hill Astronomical Platform and attached historical-archaeological reserve museum
- Zorats Karer (Karahunge) Ensemble; an ancient astronomical observatory
- Geghama Mountains rock art
- Ukhtasar rock art
- Voskehat rock art
- Sundials on monasteries and churches

Metzamor Hill Astronomical Platform

The ancient settlement of Metzamor is one of the unique monuments of world culture in the territory of which ancient copper and bronze old complexes, sanctuary, supposed observatory, tombs, etc. were excavated. It is located 35 km South-West from Yerevan in Armavir province, not far from Taronik village on the shore of Metzamor River.

Metzamor is one of the possible ancient observatories in Armenia. Metzamor was an ancient town. There was a settlement since V millennium B.C. It was first interpreted as an archaeoastronomical monument in the middle of the 1960s by *Prof.* E.S. Parsamian (1985). There is an observatory out of the fortress. The most probably estimation of the age is 4600 years. As Zorats Karer (Karahunge), Metzamor also needs a better study and proper attitude both from the Armenian government and world archaeoastronomical community.

Zorats Karer (Karahunge) Ensemble

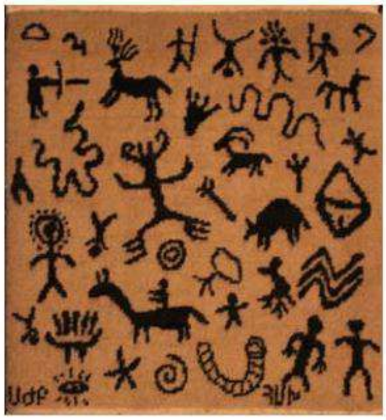
The most fascinating historical astronomical building is Karahunge (the "Armenian Stonehenge", the name derives from kar "stone" and may mean "singing stones"; and the other famous name is Zorats Karer). It is a megalithic assemblage, 200 km from Yerevan, and 3 km from town Sisian; at an altitude of 1,770 m. The northern latitude is 39°34', and eastern longitude is 46°01'. It is an assemblage of many stones put in a circle and a few arms starting from it. As many other such buildings, Karahunge was thought to be a religious assemblage. However, only in the middle of 1980th, Karahunge was first interpreted as an archaeoastronomical monument and was studied by *Prof.* E. S. Parsamian (1999) and *Prof.* P. M. Herouni (1998). Estimations give from 7700 to 4000 years for the age of Karahunge.

There are 222 stones with a total extent exceeding 250 metres, including 84 with holes (with 4-5 cm diameters). Dozens of astronomical stone instruments with accuracy of 30 arcsec may be found. 40 stones form the central ellipse with 45x36 m sizes, having a ruined stone-cluster in the centre. There is a 8m wide 8-stone road to N-E. Some stones were used to find the directions to definite stars.

By some estimations (observations of definite stars), the observatory was used during 7700-2200 B.C., for about 5500 years. According to many authors (ex. Bochkarev & Bochkarev 2005), a comparison of the present state of the monument with its situation a hundred years ago reveals a considerable degradation. Thus, the monument needs an urgent protection. The monument is unique of its kind at least in the Trans-Caucasian region and could be even the oldest known observatory in the world. If the estimated age of Karahunge is confirmed by archaeological methods, it clearly should be included in the UNESCO World Heritage list of the most important cultural memorials of our planet.

Armenian Astronomical Rock art

Studies of the Armenian rock art present in the territory of modern Armenia (historic Armenia was ten times larger, having 300,000 square km area) show that the Armenians were interested in heavenly bodies and phenomena. The Earth, the Sun, the Moon, planets, comets, Milky Way, stars, constellations are reflected in these pictures drawn on rocks in mountains around Lake Sevan and elsewhere in Armenia. These pictures and drawings are being studies by a number of historians, archaeologists, and astronomers. However, there is not enough governmental attitudes to organize large-scale studies or at least try to catalog and preserve these ancient treasures.



2.2. Research Institutions

Among the modern institutions, those are considered as scientific tourism sites, where equipment or laboratories presenting attraction from the point of view of tourism are present. Among the astronomy and space science related ones are:

- NAS RA V. Ambartsumian Byurakan Astrophysical Observatory (BAO)
- Viktor Ambartsumian Astronomical Observatory of the Yerevan State University (YSU)
- Aragatz Cosmic Particles Station (belongs to Alikhanyan National Laboratory, Yerevan Physics Institute, YerPhI)
- Herouni Space Centre (not operational)

NAS RA V. Ambartsumian Byurakan Astrophysical Observatory

BAO is a historic-cultural high value and thus one of the most important places of Armenia and attracts tens of thousands of visitors every year, both from Armenia and from abroad. It is no coincidence that for many years the visit to the Observatory is included as a mandatory program in the list of Armenian schoolchildren tours and an offer to visit the Observatory is almost always on the list of travel agencies.

BAO was founded in 1946 and it is the only professional astronomical observatory in Armenia. It has unique architectural ensemble, rich botanical garden, as well as it is a visiting card to represent

Armenia. It is situated in Aragatzotn Province, on the Southern slope of Mt. Aragatz, near village Byurakan.

Viktor Ambartsumian's house-museum is located on the site of the Observatory, where he lived 46 years, in 1950-1996. It was established in 1998 and introduces visitors to the life and activities of the great scientist.

The visitors can see **the largest 2.6m telescope** and get an understanding on its operation, the **1m Schmidt telescope** is also possible to see during the longer visits, and have observations with a dedicated small 32cm telescope during the evening or night hours. One of the most important values at BAO is the famous and unique in the world **Markarian spectroscopic survey** and its digitized version, which has been included in the UNESCO's *"Memory of the World"* International Register of documentary heritage list. It is worth to mention that it is one of the 11 UNESCO heritage items from Armenia and is rather rare in these lists as a scientific value.

The Observatory has a Conference Hall, where many international and local symposia, conferences, workshops, seminars, summer schools for young astronomers and other events have been taken place. **Viktor Ambartsumian office** is being used for smaller events, which has been preserved in its original state and is being used for Scientific Council sittings, solemn meetings, seminars, lectures, etc. There are many possible subjects for **popular lectures** that BAO offers for its visitors, as well as **Astronomical films** are also performed accompanied by professional astronomers.

There is a hotel (Guest House) just in the territory of the Observatory for some 25-30 guests, built in the Armenian national architectural traditions by the famous architect Samvel Safaryan. The hotel has a kitchen and laundry. The Observatory also has a canteen, where the hotel habitants can take meals, as well as receptions, dinners and other events may be organized for up to 70 persons.

Several types of visits are being organized and Astronomical lectures are being given by professional astronomers. The full information is given at BAO Scientific Tourism webpage: https://www.aras.am//SciTourism/eng.

Herouni Space Centre

The famous telescope (ROT-54/2.6) is located a on Mount Aragats, at a height of 1,711 metres. The radio telescope has a diameter of 54m. It is hemispherical, and fixed to the ground, with a movable secondary mirror with a diameter of 5m. This provides a useful diameter of 32m. It has a surface accuracy around 70/100 μm, giving an operating wavelength of 30-3mm (10-100GHz), and was originally designed to observe down to 1 mm (300 GHz). Construction took place between 1975 and 1985, first operating in 1986. It was not damaged by the 1988 Armenian earthquake, and was used for observations between 1987 and 1990. The optical telescope has a 2.6m mirror, with a 10m focal length. Telescope never operates from the date of its implementation.

2.3. Science-Related Museums

Among museums having relation to astronomy and space sciences are:

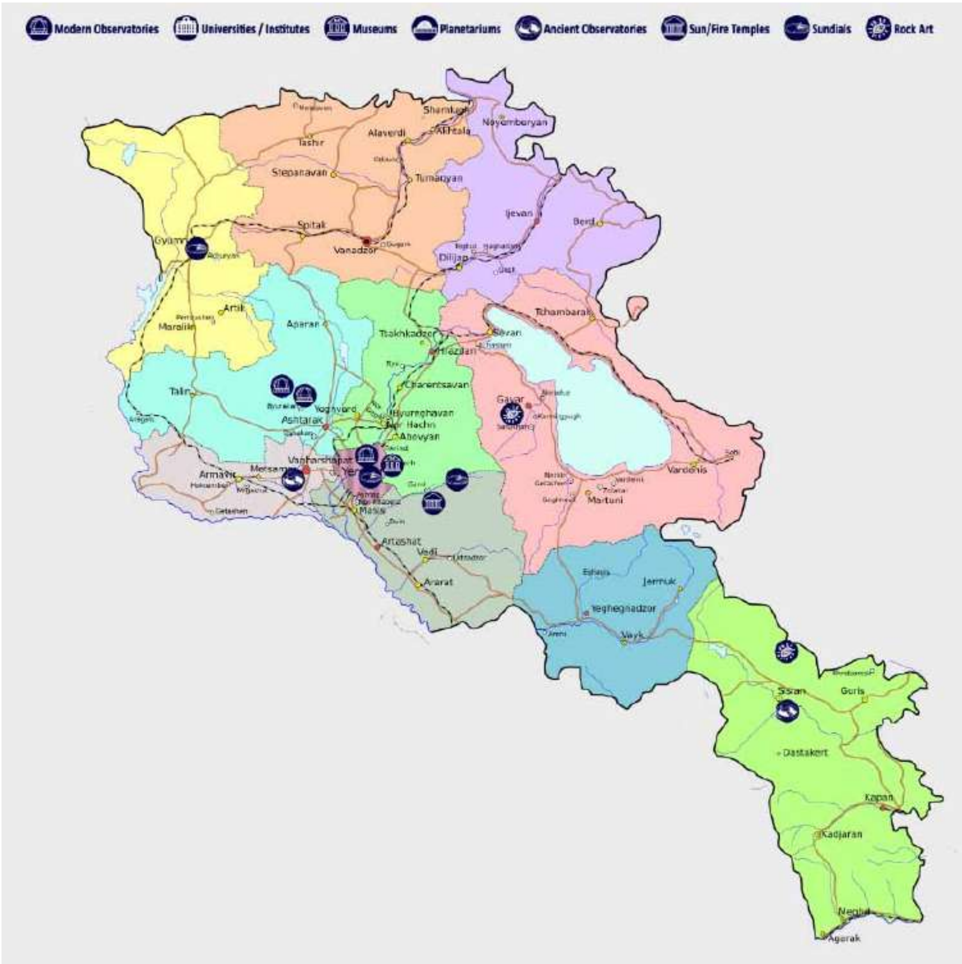
- Space Museum
- Matenadaran museum of ancient manuscripts (where a lot of manuscripts of astronomical nature are present)
- Viktor Ambartsumian house-museum in Byurakan

Space Museum

It was founded by Grigor Gurzadyan in 2001 in Garni, and in 2015 was moved to Yerevan. The museum exhibits early samples of space research, including landing equipment returned from the Cosmos, other spacecraft, a copy of the ORION-2 Observatory, which was exhibited in Hannover EXPO 2000. The museum collection includes documents, manuscripts authored by cosmonauts, Vostok, Soyuz space engineers, scientists, and from NASA. One of the most valuable examples is the manuscript of Nobel Prize laureate Hans Bethe, written jointly with Grigor Gurzadyan.

3. Armenian Astro Tourism Map

Armenia has a very rich Astronomical Tourism map, as mentioned above, many items of different types (ancient astronomical sites: rock art, ancient observatories, sundials; medieval universities, Byurakan Astrophysical Observatory, other modern institutions, the Space Museum, Viktor Ambartsumian house-museum) are present. We have created the Astro Tourism map of Armenia, which may serve as a reference for theoretical (study) and practical (implementation) Astro Tourism.



The Armenian Astro Tourism Map. Mentioned items are (from top to bottom): Sundial on Holy Saviour Church in Gyumri, Herouni Space Centre, Byurakan Astrophysical Observatory (BAO), Rock Art in Geghama Mountains (Gegharkunik Province), Space Museum in Yerevan, Viktor Ambartsumian Observatory of the YSU, Sundial on Saint Gregory the Illuminator's Cathedral in Yerevan, Sundial on St. Stephen's Monastery of Goght (Geghard?), Garni Sun Temple, Metzamor Hill Astronomical Platform, Rock Art in Ughtasar (Syunik Province), and Zorats Karer (Karahunge) Ensemble (Syunik Province).

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Astro Tourism sites in Georgia

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Abstract

The main astro site in Georgia is the Abastumani Astrophysical Observatory. The history of astronomy in Georgia begins no later than IX century. During the Middle Ages, there were at least four observatories in Georgia, including the Arab Observatory in Tbilisi (Narikala - a fortress). This observatory operated between IX-XIV centuries. Two other observatories functioned in monasteries in eastern part and one - in western part of the country. All these places are active touristic sites in Georgia.

Keywords: *Astronomy, History of Astronomy, Astro Tourism*

1. The Abastumani Observatory

The Abastumani Observatory, or E. Kharadze Georgian National Astrophysical Observatory was founded in 1932. This is a "classical" observatory with small telescopes. Observations are carried out in almost all fields of astronomy. We observe variable stars, the Sun, the bodies of the Solar system and extragalactic objects - Blazars and other AGNs. Observations for optical counterparts of GRBs and GW sources added to the above list in recent years.

Usually the observatory hosted only schools for excursions and only on weekends. The observatory is open for everyone every day from 11 am to 1 am starting from 1990es. Tourists have the opportunity to look at interesting celestial objects using the 40-cm refactor, visit the museum of the Georgian astronomy and attend popular lectures. Visitors come from different parts of Georgia, as well as from different countries.

2. Middle Ages

An arabian observatory was established in Tbilisi in the IX century. The observatory was situated close to the Narikala fortress and functioned until XIV century. It seems that the observatory had rather qualified staff. For example, when Nasir Al-Din Al-Tusi began to build Maragheh observatory according to Hulagu Khan's order, he invited Fakhrt Al-Din Al-Ikhlati from the Tbilisi observatory together with Mu'ayyad Al-Din Al Urdi, Fakhr Al-din Al Maghrabi and Najm AL-Din Al-Qazwini. There are some archaeological findings on the site of the observatory that are especially important because "we know practically nothing about the buildings themselves and, by the way, our ignorance is not restricted to this particular observatory (Maragheh observatory – N. K.); we may say that in general we hardly know anything about the organization of Greek and Muslim observatories" Sarton (1929).

Gelati Academy in the western part and Ikalto Academy in the eastern part of Georgia were established in the beginning of the XII century. They have been active for several centuries and Astronomy was one of the mandatory subjects there. It is known that observatories existed in these academies, and Georgian kings and nobles were observing themselves for astrological purposes. David the Builder the king who reigned in 1089-1125, wrote himself in his "The canon of repentance" about observing celestial objects Jokhadze (2005).

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It is highly likely that observatories existed also in other monasteries of Georgia, including the David Gareja complex.

All these places are active tourist destinations nowadays.

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National Sky Fest in Turkey

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Abstract

In this paper, TÜBİTAK[1] National Sky Fest which is held annually in Turkey is presented. In 2019, approximately 1000 people attended to the sky fest. This event has been organized since 1998 with an approximate participants of 400 each year. There are several activities in the festival which span the three days both in daytime and in night programs. TÜBİTAK is planning to organize the event internationally for 2020.

Keywords: *public outreach - sky fest - star party - amateur astronomy*

1. Introduction

In Turkey, there are many astronomy public education and outreach activities organized by astronomy and related departments (Alis, 2018). Among these events, TÜBİTAK National Sky Fest is a special one because it brings people enthusiastic about astronomy together from all over the country.

The first sky fest was organized in 1998 by the TÜBİTAK Science and Technics Magazine[2] and since 1998, every summer the sky fest has been organized by the team there. Since 2009, the event is carried out by TÜBİTAK National Observatory [3].

The aim of the sky fest is to give fundamental knowledge about astronomy and introducing night sky to the participants. Also, the most important part of the sky fest is to provide telescope viewing experience guided by the expert astronomers in such a dark place.

2. Location

The sky fest takes place in a ski center at the outskirts of Mount Bakirli, Antalya where TUG is located (Figure 1). There is almost no light pollution and the location is suitable for camping and related activities. Daytime and nighttime views of the camping area are shown in Figure 2.

3. Participation and Participants

The sky fest is free and open to participation of everyone. The only restriction is that the minors can only participate with their family members. Each year roughly 400 people participate to the festival and this has been the case until 2019. In 2019, more than 6000 people applied to participate the sky fest and approximately 1000 people were allowed to participate. In average, there are always 10 times more application than the capacity of the festival. Therefore, for many years the selection of participants is done under an official overview by a notary and the selection is broadcasted online.

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[1]The Scientific and Technological Research Council of Turkey (tubitak.gov.tr/en)

[2]https://bilimteknik.tubitak.gov.tr

[3]TÜBİTAK National Observatory(tug.tubitak.gov.tr/en)

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Figure 1. **(a)**Antalya's location on the map of Turkey. **(b)** TÜBİTAK National Observatory's location on the map of Antalya. The distance from city center is about 65km and 1 hour driving distance.

Figure 2. **(a)**The ski center and camping area in daytime. **(b)** Camping area in night.

In order to be in the selection process, people who want to participate to the event should apply either individually or as a family from the sky fest website (senlik.tug.tubitak.gov.tr). The website contains all information regarding the event and photos and videos from the previous festivals.

The transportation of participants from Antalya city center to the event area and their food and beverage (water, coffee, tea, etc.) supplies are free of charge during the event. Participants stay in their own tents. In addition, each participant receives an amenity kit (thermal mug, shoulder blanket, sky atlas, cap, etc.) that they can use during the festival. Also, fully equipped ambulance, healthcare professionals and security guards work throughout the event.

Figure 3. **(a)**Group photo in 2015. **(b)** Group photo in 2019.

Figure 4. A collage of photos from daytime activities.

4. Program

The event program is divided into two as daytime and night programs. Some examples from the daytime program are shown in Figure 4 whereas some scenes of the night program are shown in Figure 5.

A group of university students works with the TÜBİTAK staff during the event as an organization team. These people are mostly selected from students studying in astronomy departments and they are acting as the instructors and responsible for almost all activities.

4.1. Daytime

The daytime program of the event includes popular astronomy talks given by university professors, hands-on activities (mostly for children) and solar observation. In addition, amateur astronomy clubs from all around Turkey have their own stands and interact with participants during the daytime program. Additionally, telescope brands are also represented by the corresponding distributors.

4.2. Night

During the night program, participants observe planets, deep-sky objects via telescopes guided by the team of astronomers. During this telescope viewing sessions, team introduce night sky to the participants, explain some phenomena, and answer questions from them. Mostly these sessions

Figure 5. A collage of photos from night activities.

continue until 4 AM in the morning. Depending on the weather the session can be ended earlier, especially due to cloud coverage, humidity or cold.

In order to provide a dark sky to the participants, TÜBİTAK chooses the dates for the sky fest when the Moon rises late, towards early morning. Observing session starts with planets and the objects near the horizon. After a short break for the session, the team introduces the sky for participants and gives information about objects on the sky that can be observed with the naked eye.

A list of objects ordered by their setting times is followed by the astronomer team whose are responsible for the telescopes. Depending on the aperture size, telescope may have slightly different observing plan. Specifically, two of the telescopes follow an observation program like a demonstration of the "Stellar Evolution" which is also mentioned in the daytime program. First, participants observe star formation regions like the Eagle Nebula (M16) and then they observe open clusters like the Ptolemy (M7) for "baby" stars, middle-age stars like Altair and Arcturus, "old" stars like Antares respectively and they finish the sequence by observing planetary nebula (the Ring Nebula, etc.), supernova remnants (the Veil Nebula, etc.) and black holes (GRS 1915-105, Cygnus X-1, etc.).

Moreover, astrophotographers and astrophotograph groups whose are famous nationwide have their own area to take sky/deep-sky photos during the night. They give some information to the participants who is interested in astrophotography such as what is the best equipment for astrophotography, how they can take an image from the sky and processes the image. Two sample photographs that were taken during the sky fest shown in Figure 6.

5. Summary

More than 6000 people applied to the sky fest held in 2019, and 1000 of them were allowed to participate the sky fest[4]. This year, more than 11000 people applied to the sky fest which will held in 2020 and 1000 of them will be allowed. As is often the case, the applicants are mostly students (4684) and teachers (1760) in this year and also, most applicants have Bachelor's degrees. Distributions of the education level of the applicants are as follows: 11.6% of applicants have Master degree, 42.5% of applicants have Bachelor's degree, 14.6% of applicants are high school graduate, 7.4% of applicants

[4] http://senlik.tug.tubitak.gov.tr/?page_id=2413

Figure 6. Veil Nebula was taken at the sky fest in 2019 (left) and Hercules Globular Cluster was taken at the sky fest in 2016 (right). Both photos are courtesy of Murat Sana.

are Secondary School graduate, 8.7% of applicants are Primary School graduate, 4.9% of applicants have Associate degree, 4.3% of applicants have Doctor's degree, 4.1% of applicants are students of the Pre-school education, 1.9% of applicants are students of the kindergarten class. The ratio of men(47.9%) and women (52.1%) is almost equal among the applicants.

Although, Antalya is an appropriate city/region for summer holidays, the conditions at the event location can be quite challenging even in summer. Camping in the nature for 3 days under a thinner atmosphere at 2000 meters above the sea-level scorches when it is sunny. Some cold nights happen when you need to wear protective garments. Despite these conditions, those who are willing to participate to the sky fest play an important role for achieving the purpose of the event. The busy schedule of the sky fest is enjoyable and beneficial instead of being bored especially for enthusiastic participants. Those people, when they gain enough experience in the sky fest can lead for other outreach activities afterwards.

Nowadays, there are many similar events held in Turkey but TÜBİTAK (Inter)National Sky Fest continues to be the most special one. Interest from the public to the similar events is increased every day. There are programs from TÜBİTAK that give support with substantial grants which organizations like universities, municipalities and science centers can apply and with the help of that grant they can organize similar events locally throughout the country.

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