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Contents

MOLECULAR LINES OF HYDROGEN IN THE VISIBLE AREA OF THE SPECTRUM OF JUPITER AND SATURN

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Based on the observational material on Jupiter and Saturn obtained on the echelle spectrometer equipped with CCD receiver at the Cassegrain focus of the 2nd telescope of the ShAO, weak quadrupole lines of molecular hydrogen of the band H_2(4-0) in the visible region of the spectrum with the spectral resolutions R = 14000 and R = 56000. The upper limit of the Intensity of the S (2) line in the spectra of Jupiter and Saturn is determined. On the lines of the bands H_2 (4-0), S (0) and S (1), certain parameters were determined in various details of the atmospheres of Jupiter and Saturn, which play an important role in understanding their energy balance.

Keywords: Jupiter – Saturn – Quadrupole lines – Ortho- and para-hydrogen.

1. INTRODUCTION

The study of the chemical composition of the atmospheres of giant planets plays an important role in better understanding of their evolution. For the spacecraft "Juno", which in 2014 approached Jupiter, the task was to define the chemistry of the atmosphere of the planet along with other tasks.

In 1938 Gerhard Gerzberg [1] predicted that quadrupole H_2 bands should be detected in the spectra of the giant planets. He also showed [2] that the weak, unidentified absorption line found by Kuiper [3] on the low-dispersion spectrum of Uranus and Neptune is undoubtedly the S(0) (3-0) line, the second overtone-induced H_2 band. It took another 10 years, when Kiess C.C., Corliss C.H. and

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Kiess H.K. [4], detected three lines of the rotational-vibrational overtone (3-0) at about 8,200 Å, and Spinrad H., Trafton L.M. [5] discovered two lines of H_2 (4-0) overtone, about 6400 Å in the spectrum of Jupiter. Later, the lines of both bands of molted hydrogen were found in the spectra of all giant planets: the overtone H_2 (4-0) turned out to be the most useful for quantitative studies of planetary atmospheres. Its utility lies in the fact that the extremely low value of their intensity makes it possible to assert that the lines H_2 (4-0) are not saturated, even in the spectra of H_2 from deep atmospheres.

There exist two kinds of hydrogen: para-(p-H_2) (proton spins are antiparallel) and orthohydrogen (o-H_2) (proton spins are parallel) and at low temperatures H_2 is similar to the mixture of gases that are not in heat equilibrium. A spontaneous transformation of one modification into another is slow; these modifications can be considered as the substances that are differentiated by termic and other physical properties. Noticeable differences in the properties of these gases are observed at low temperatures ($T < 200$ K) and relatively low pressures ($T <10$ MPa).

In the liquid phase of ort-steam, the H_2 conversion can occur at a noticeable rate, especially in the presence of a catalyst, and is accompanied by heat outflow. Thus, it could be expected that as a result of self-projecting equilibrium at low temperatures, certain thermal properties of H_2 will change over time, and certainly this is an important factor in understanding the essence of the mechanism of release of internal energy in giant planets. This feature is sensitive to the abundance of hydrogen, the ratio of ortho-/para-hydrogen vertical structure, and also dependence of the profile of temperatures, pressures in the atmospheres of the planets. Investigations of quadrupole hydrogen lines in the atmospheres of the giant planets will help to reveal the essence of many phenomena that occur in their atmospheres and are reflected in the dynamics of clouds observed on the planet's disk.

Therefore, the conduct of spectrophotometric studies of the absorption lines of molecular hydrogen, which constitutes the main mass of giant planets, is an important problem.

The induced absorption band of S (4-0) molecular hydrogen H_2 has a central wavelength of about λ6420Å and two lines are observed in it- λ 6367.76Å and λ 6435.03Å. The second absorption line of molecular hydrogen in the Jupiter spectrum λ 6435.03Å blends with the NH_3 ammonia line and it is therefore difficult to observe them separately at low resolving power. These studies also include studies of the molecular lines S(0), S(1) (in accordance with 4-0) absorption in the reflected spectrum of giant planets.

2. OBSERVATIONS OF JUPITER AND SATURN

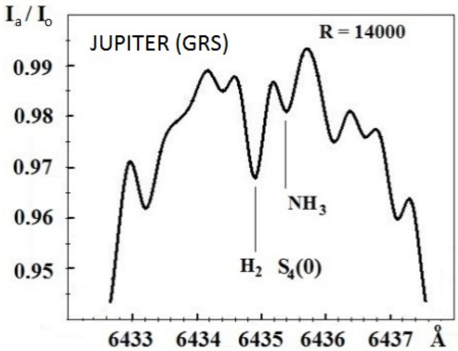
In 2014-2016 the spectrums of Jupiter and Saturn were obtained on the 2-meter telescope of the ShAO with different spectral resolutions R = 14000 and R = 56000. The spectrums with the resolution R = 14000 were obtained with the aid of an echelle spectrometer with a CCD camera (580×530 pixels, cell size 24×18 μm) installed in Cassegrain's Foc. Spectrums with the resolution of R = 56000 were obtained using a fiber-optic echelle spectrograph (ShaFES). The light detector was a US-made CCD camera with a $4K \times 4K$ matrix of elements with a cell size of 15×15 μm. This and other spectrometers installed on a 2-m telescope are described in detail in the works of H.M. Mikailov et al. [6, 7].

From the two lines of the molecular hydrogen H_2 that are in the visible region of the Jupiter spectrum λ 6367.76Å and λ 6435.03Å in the H_2 (4-0) band, one (the second) blend with ammonia line NH_3 6435.30Å (Fig. 1).

In the spectrum of Jupiter, the line of molecular ammonia NH_3 NH_3 λ 6435.30Å (Fig.1a, R = 14000) is not excreted and is seen as ordinary depression. And Fig. 1b shows the absorption line in the same spectral region of Jupiter, obtained with the spectral resolution R = 56000 in the central part of the planet's disk: at high spectral resolution, the bifurcation of the lines at λ 6435.30Å and λ 6435.03Å of particular importance is the spectrum of Jupiter and Saturn (Fig. 1c), semi-spectral with a spectral resolution (R = 56000), along which it is possible to determine the intensities of these two lines of molecular hydrogen and ammonia. The figure shows a clear absorption in the line NH_3 λ6435.30 Å and in the extended line λ 6435.03Å H_2: the intensity of the ammonia line on Saturn is much weaker than on Jupiter.

Observation made for Jupiter on the 2-m telescope with a spectral resolution of R = 56000 allowed us to reveal another term associated with the weak quadrupole transition of molecular hydrogen H_2 (4-0) S(2). The report on the detection of the absorption line at 6313.4 Å was first published in [8], and later in [9]. It should be noted that in Encrenesis et al. [8] previously, the upper limit of absorption in the H_2 (4-0) S (2) line was estimated. The H_2 (4-0) S (2) line in the spectrum of Saturn was revealed during our observations. According to Smith's estimates [9], the intensity of the H_2 (4-0) S (2) line in the Jupiter spectrum is $\sim$ 1.8 mÅ, which agrees with our measurements. During the processing of the observational material of the profile of the H_2 (4-0) S(2) line in the Saturn spectrum, we determined its intensity, which according to our measurements turned out to be $\sim$5 mÅ (Fig.2a and b).

In the spectral region where the absorption line S(1) λ 6367.76Å is located, there is also a weak telluric line 6368.46Å. When we define the equivalent width and correction of Doppler shifts, as a comparison, we took into account the cor-



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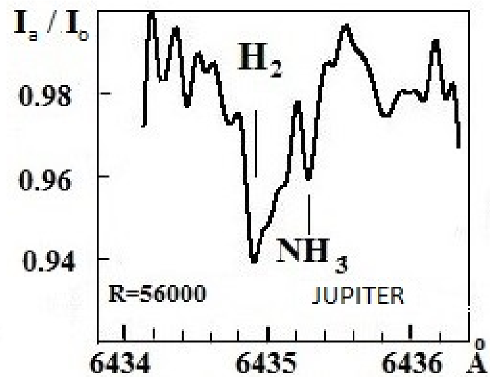

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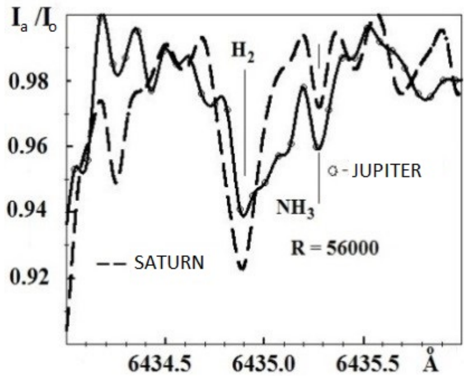
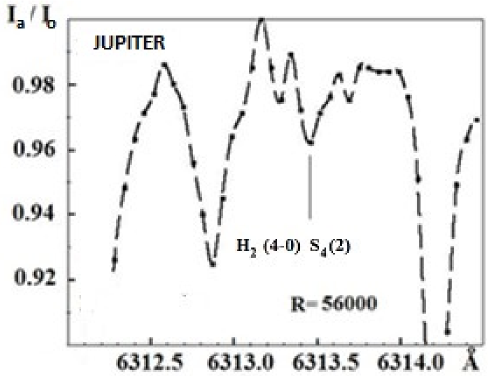


(c)

Fig. 1: The absorption lines of molecular hydrogen H_2 in the band (4-0) λ 6435.03Å and ammonia NH_3 λ 6435.30Å in the spectrum of Jupiter and Saturn: a) R = 14000, b) R = 56000 (Jupiter), c) both lines in the spectra of Jupiter and Saturn.

responding lines of the solar spectrum. In 2014, the spectrum was recorded along the meridian in the direction of the north in two regions of the disk of Saturn - in the center and in the polar region.

The intensities S(0) 6435.03Å and S(1) 6367.76Å of the quadrupole line of the molecules of a bright hydrogen H_2 on Jupiter were determined along the meridian, i.e. in different parts of the planet. After that, according to the intensity ratios S (0) 6435.03Å and S (1) 6367.76Å, the rotational temperature was calculated for the observed details of Jupiter along the meridian (Fig. 3). The results of our calculations in the central part of the disk of Jupiter are in good agreement with the results of the calculated temperature values (105-110 K) corresponding to a level of 150 mbar on Jupiter according to the IR observations of Voyager-1-2



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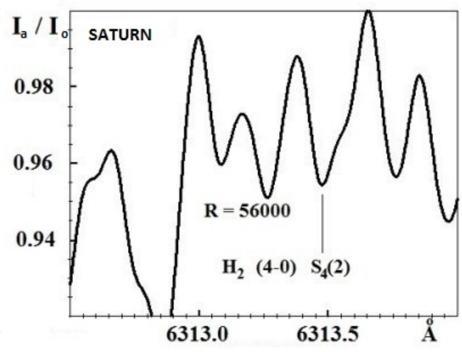

(b)

Fig. 2: The profile of the H_2 (4-0) S (2) line in the spectra of Jupiter (left) and Saturn (right) obtained with the spectral resolution of R = 56,000.

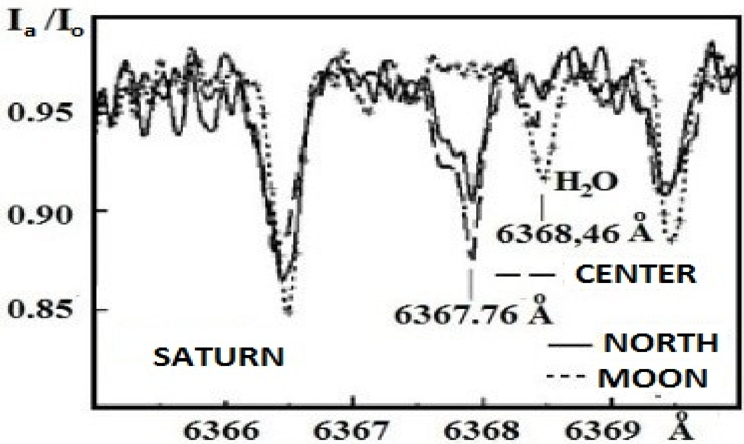

Fig. 3: The spectrum of Saturn in the region of the molecular hydrogen line S(1) λ6367.76Å. (The solid line is the northern line, the dotted line is the central part of Saturn's disk, and the points are the spectrum of the Moon).

along the planetographic longitude L [10].

On the disk of Jupiter in different details along the half-widths of the linesλ 6367.76Å and λ 6435.03Å in the band (4-0) of molecular hydrogen, taking into account the instrumental situation (Table 1). Clearly, in different details on the disk of Jupiter, as well as Saturn, the pressure values should be different. This is clearly seen from Tables 1 and 2. The discrepancies in the pressure values for the Jupiter atmosphere are associated with inadequate determination of the half-width of the weak line S(0) 6435,03Å, which is not devoid of overlapping of the

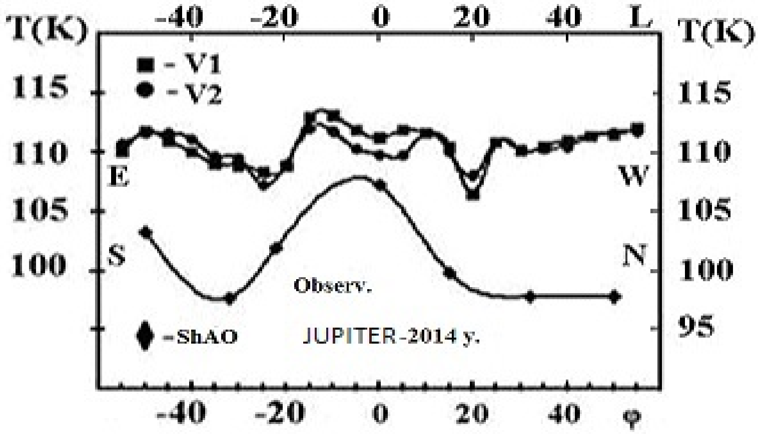

Fig. 4: The calculated temperature values corresponding to the level of 150 mbar on the Jupiter based on the Voyager-1-2 IR observations along the planetographic potential L (EW) (black squares – V_1-March 1979, mugs –V_2 - July-1979). According to the results of our observations, rotational temperatures are calculated in different disk drives along the latitude ϕ of Jupiter (SN).

ammonia line 6435.30Å with a long-wavelength wing of molecular hydrogen.

Table 1: Half-widths of the line of molecular hydrogen H_2 (4-0) S (0), S (1) and calculated pressures on the levels of their formation in the atmosphere of Jupiter.

Jupiter	S(1) 6367,76Å	S(0) 6435,03Å	S(1)	S(0)
Details	$\Delta\lambda$ (Å)	$\Delta\lambda$(Å)	P_1 (atm.)	P_0 (atm.)
EZ	0,15	0,09	0,322	0,189
NEB	0,21	0,131	0,450	0,275
NTRZ	0,16	0,12	0,343	0,252
NP	0,16	0,26	0,343	0,546
STRZ	0,21	0,17	0,450	0,357
SPZ	0,17	0,125	0,365	0,262
GRS	0,12	0,235	0,257	0,493

As is known, the observed course of molecular absorption along the Jupiter disk is not badly interpreted within the framework of a two-layer model for the formation of a line (or strip) of absorption, taking into account the role of multiple scattering and absorption inside an opaque dense cloud layer. To determine the

Table 2: Half-widths of the line of molecular hydrogen H_2 (4-0) S (0), S (1) and calculated values of pressures at the levels of their formation in the atmosphere of Saturn.

R=56000		Center	North Polar Region	
P_{H_2}	$\Delta\lambda$(Å)	P_1 (atm.)	$\Delta\lambda$(Å)	P_2 (atm.)
S(0) 6435,03Å	0.266	0.457	0.146	0.25
S(1) 6367,76Å	0.311	0.547	0.146	0.25

hydrogen content within the framework of the two-layered model of the atmosphere, the growth curve constructed by V.G. Teyfel [11] was used; the necessary parameters were chosen from the results of studies of the absorption bands of the methane ($g_s = 0.5; r_c = 0.75; b^* = 2.0$, where gs is the asymmetry parameter of the indie scattering matrix, r_c is the diffuse reflection coefficient in the invariant , $b^* = \sigma_{a0} H_0$; (H_0 is the altitude scale), σ_{a0} is the volumetric coefficient of aerosol scattering). With the help of this curve, according to the measured intensity values of the lithium S(1) λ 6367.76 Å the concentration of molecular hydrogen in the over-atmosphere atmosphere U (H_2) was determined, the quantity of the gas flowing to the average mean free path of photons between two scattering events in the cloud layer A_L and the specific gas content per unit mean free path ws for the atmospheres of Jupiter and Saturn (Tables 3 and 4).

Table 3: Content of H_2 U (km.amaga), A_L (km.amaga) and $w_s \cdot 10^6$ (km.amaga) cm^{-1} in different details on the Jupiter disk.

Details	W	A	U	w $\cdot 10^6$
NPR	10	3.02	15.10	7.55
NTrZ	9.6	2.87	14.33	7.16
NEB	11.8	3.76	18.82	9.41
EZ	15	5.27	26.34	1.32
GRS	10	3.02	15.10	7.55
STB	11	3.42	17.12	8.56

It was interesting to compare the results of our observations with the results of computations carried out within the framework of a zonally symmetric linear radiation-dynamic model developed in [12]. Figure 5 shows the IRIS (Infrared Interferometer Spectrometer and Radiometer) versus model calculations for Jupiter

Table 4: The contents of H_2 U (km.amaga), A_L (km.amaga) and $w_s \cdot 10^6$ (km.amaga) cm^{-1}) in different details on the Saturn disk.

Saturn	A	U	w·10^6	A	U	w·10^6
Center	4.3	21.5	8.6	9.6	19.11	19.1
Pol. reg.	4.2	20.8	8.3	9.2	18.45	18.5
Center [11]	6.4±2.	25±9	8.5±2.8	15.6±6	22±9	7.5±2.6

and Saturn. Attention is drawn to the good agreement of the seasonal effect of Saturn and the effects of the zonal jets of Jupiter. Poor agreement near the equator, especially for Saturn, is due to the failure of the linear model and the results of our observations in 1971/74 also confirm the identification of a seasonal effect.

The averaged values of the rotational temperature, determined by the lines of the molecular hydrogen, which are formed in the depth of the Jupiter atmosphere, where the pressure correspond to $0,2 \div 0$ atm., correspond to a maximum of 110° K in the center of the planet's disk and less than 100° K in nearby poles. The determination of the tempo-tour was carried out for the Northern polar and central parts of the Saturn disc according to the observations of 2013-2015, which are in good agreement with the measurements of 1971/74.

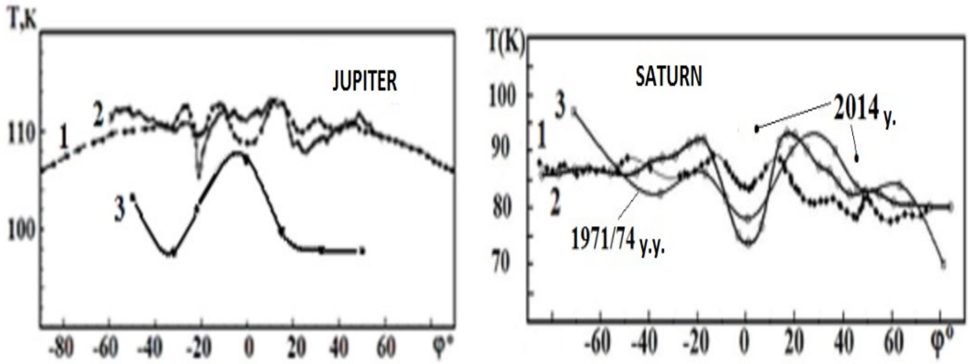

Fig. 5: Comparison of IRIS data with model predictions for Jupiter and Saturn. These temperatures correspond to the level of 150 mbar. 1 - model calculations [12], 2 - IRIS data, 3 - our calculations.

Under the conditions of the atmosphere of the giant planets, the course of the curve of the rotational heat capacity of molecular hydrogen acquires a special form. Under such conditions, as a result of self-equilibrium equilibrium, certain heat properties of H_2 change with time. Further research in this direction would help to obtain new results in physical chemistry and would expand the possibilities of their application.

Knowledge of the physical features of molecular hydrogen under the conditions of the giant planets can improve understanding of the structure of their atmospheres. Under normal conditions, molecular hydrogen is a mixture of two isomers: ortho- and para-hydrogen. In (o-H_2) the magnetic moments of the nuclei (spins) have the same orientation, and in (p- H_2) - the opposite. The usual hydrogen contains $\sim 75\%$ o- H_2 and $\sim 25\%$ p- H_2. The conversion of o-H_2 into p-H_2 is accompanied by the release of heat (~ 1400 J / mole), but does not occur without the participation of catalysts. Therefore, accurate data on quadrupole absorption of H_2 can significantly improve our understanding of the processes taking place in the atmospheres of these planets. In particular, studies of absorption bands of molecular hydrogen in the visible and near-IR spectral regions can shed new light on the energy balance of the planetary giant atmospheres.

3. CONCLUSIONS

On the basis of the observational data on the study of quadrupole lines H_2 (4-0) along different parts of the Jupiter disk along its meridian, it was established that the pressure, temperature and quantity of molecular hydrogen do not obey any monotony. Such a behavior of the pressure and temperature values at the depth of the formation of molecular hydrogen lines may be due to various features of the thermal radiation of the planet. The release of surplus and various energy in various details of the Jupiter disk can be caused by the spontaneous conversion of orthohydrogen to parahydrogen, occurred in the deep layers of Jupiter, in the region above liquid molecular hydrogen; even in the absence of a catalyst (the catalyst accelerates this process). The process of conversion, occurring in different belts, zones and in different depths, has different speeds and spatial scales and depends on the temperature, the amount of orthohydrogen.

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YUPİTER VƏ SATURNUN SPEKTRİNİN GÖRÜNƏN OBLASTINDA MOLEKULYAR HİDROGEN XƏTLƏRİ

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CCD-qəbuledicisi ilə təmin olunmuş ŞAR-ın 2-m teleskopunun Kasseqren fokusundakı spektral ayırdetmə qabiliyyəti R=14000 və R=56000 olan eşelle spektrometrlərinin köməyi ilə Yupiter və Saturnun görünən oblastda H_2(4-0) zolağındakı zəif kvadrupol xətləri tədqiq edilmişdir. Yupiter və Saturnun S(2) xəttinin intesivliyinin maksimal qiyməti təyin edilmişdir. Yupiter və Saturnun energetik balansının aydınlaşdırılmasında mühüm rol oynayan bir neçə parametrin təyini atmosferlərinin müxtəlif detallarında onların spektrlərindəki H_2(4-0) S(0) və S(1) xətləri əsasında hesablanmışdır.

Açar sözlər: Yupiter – Saturn – Kvadrupol xətləri – Orto- və para-hidrogen

ON THE NATURE OF WOLF-RAYET PHENOMENON

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The main physical properties of the Wolf-Rayet stars revealed from the spectral, photometric and other type observations have been presented. The historically proposed and modern methods of spectral classification of these stars were discussed. The determined physical parameters (temperature, mass, radii, etc.) of these stars are given. Unsolved some theoretical and observational problems related to this stars have been discussed.

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Keywords: WR stars – Close binary stars – Spectral classification – Massive stars – Evolution of stars

1. INTRODUCTION

The Wolf-Rayet (WR) stars have always been at the focus of the contemporary astrophysical studies. In 1867 C. Wolf and G. Rayet, with the aid of 40 cm telescope of Paris Observatory, discovered three stars (HD191765, HD192103, and HD192641) in Cygnus, with the unusual broad emission lines [1]. That is where the name WR comes from. The observed strongest lines belonged to nitrogen, carbon, oxygen and helium. In the spectrum of WR stars, on the other hand, the hydrogen lines are usually weak or completely missing. The emergence of this unusual spectrum was not understood until the mid of the twentieth century.

Here we consider only the massive Population of I WR stars of our Galaxy, which are concentrated in Galactic plane. It should be further noted that, low-mass hot Population II stars of our Galaxy, the nuclei of planetary nebulae, also encode the properties of WR stars [2, 3]. In order to distinguish the Population I WR from the nuclei of planetary nebulae, - the latter are referred to as [WR]. It should be also noted that Population I WR stars are significantly massive and brighter than [WR] stars. Moreover, Population I WR stars are young (with the

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average age of about 10^6 years) compared to the [WR] stars. Furthermore, the evolutionary path of [WR] is also very different from the Population I WR stars. It's obvious that, for the emergence of the WR phenomenon, it is necessary to lose initial hydrogen abundant outer shell. According to the modern view, in the case of [WR], the hydrogen abundant outer shell is getting lost when the star passes the red giant phase, as a result of which the hot core becomes exposed.

The stars undergoing the strong mass loss (even temporarily) also show similar properties as WR: novae after some time of explosion, P Cyg type stars, symbiotic stars, Of stars, etc.

It should be noted that, the spectral, photometric, etc. properties of WR stars are very different from the ordinary stars. First, WR stars exhibit very intense and broad emission lines of helium, nitrogen, carbon, oxygen, etc. and weak continuous spectrum. These stars differ from the solar type stars also by their chemical composition. Second, the WR stars are mainly composed of helium and very little hydrogen. In ordinary solar type stars, on the other hand, the opposite contamination is observed, namely less helium and more hydrogen. The hydrogen constitutes roughly 75 % of the mass of the ordinary stars.

Currently, seven catalogs of these stars have been published (Table 1). According to the VII catalog of Galactic Population I WR stars [4], currently 227 stars of this type have been found in our Galaxy. However, in recent years, the number of detected WR stars in our Galaxy has increased significantly and reached to about five hundred. This was triggered by the photometric and spectroscopic searches performed in the near-IR region of the spectrum. Theoretically, - the expected number of Population I WR stars in our Galaxy is about 10^3. These stars are located mainly in the spiral arms of our Galaxy.

The presence of the strong spectral lines in the spectra of WR stars facilitates their detection in nearby galaxies. Currently, 134 and 11WR stars are found in the Large Magellan Cloud (LMC) [5–7], and in the Small Magellan Cloud (SMC) [8] respectively. The presence of WR stars was also revealed in the galaxies of the Local Group. About 10 stars of this type were found in the Andromeda [9], 206 in M33 and some in M31 [10, 11]. There are also special types of galaxies, which consist mainly of young WR stars [12].

The significance of the study of WR stars is related to the following global problems in modern astrophysics:

- the formation of exotic astrophysical objects, such as neutron stars and black holes associated with the evolution of WR stars;

- studies of WR stars is important for the understanding of massive star evolution properties;

- due to the strong mass loss and their explosion as supernovae at the end of the evolution process, the WR stars play an important role in the enrichment of galaxies with the heavy elements, which in turn plays an important role in the formation the new generations of stars;

- taking into according the main structural elements of the universe to be galaxies we could conclude that WR stars play an important role in the evolution of the whole Universe.

According to the modern view, the WR stars are evolved hot massive stars, close to the end of their nuclear burning phase, after that they explode as supernovae.

The insightful detailson WR stars are widely discussed in reviews [13–21], and several symposia of IAU [22–26].

Development of observational technology, using of new high sensitive light detectors (CCD) in spectral, photometric, polarimetric, etc. observations allows one improve the accuracy of the obtained observational data. The application of modern processing methods and the analysis of the observational data by applying modern mathematical statistics methods led to more accurate simulations of nonstationary physical processes occurring in these stars.

Table 1. Currently published catalogues of Galactic Population I WR stars.

Catalogue	**Author(s), year**	**Number of WR**
I	Campbell, 1884 [27]	55
II	Fleming, 1912 [28]	108
III	Payne, 1930 [29]	92
IV	Roberts, 1962 [30]	123
V	Smith, 1968 [31]	127
VI	Van der Hucht et al., 1981 [32]	157
VII	Van der Hucht, 2001 [4]	227

2. MAIN OBSERVATIONAL PROPERTIES OF WR STARS

The main observational properties of Galactic Population I WR stars,revealed from spectral, photometric, polarimetric, etc. observations are as follows:

1. The spectra of these stars consists of very strong and wide emission lines of nitrogen, carbon, oxygen and helium and, hydrogen with different ionization level (N II-NV, C II-CIV, OIV-OVI, HeI, HeII, HI), superimposed on a weak continuum;

2. Unlike the ordinary stars, in the spectra of this stars, the widths of the emission lines reach up to 50-100 Å, and the intensities in the center of the emission lines are 10 to 20 times larger compared to the underlying continuum;

3. According to the modern view, the features of the spectra of WR stars could be explained by the presence of a hot "core" and expanding envelope at speeds of $\sim 1000-3000$ km/s. Emission lines corresponding to the different ions, as well as the low-temperature weak continuous spectrum of the star, are formed in an expanding envelope;

4. The most interesting fact is the simultaneous presence in the spectra of these stars of the low-temperature continuous spectrum and lines of atoms and ions corresponding to the very high (up to 130 eV) ionization potentials;

5. The simultaneous existence of the lines with very different excitation potentials (10-130 eV) in the spectra of these stars could be explained by the presence of strong temperature stratification in the envelopes of these stars;

6. According to the intensity ratios of the selected lines of nitrogen, carbon and oxygen ions at different stages of ionization, WR stars were classified into three types: nitrogen (WN), carbon (WC) and oxygen (WO) ones. In some cases, the intensities of the HeII and HeI lines were additionally used for a more correctly definition of these types. The spectra of WN and WC stars mainly contain nitrogen and carbon lines correspondingly. The spectrum of the WO stars consists of lines of oxygen and carbon;

7. In the spectra of WR stars of all types (WN, WC, WO), helium and hydrogen lines are present, however, hydrogen lines are weak; the number, of hydrogen atoms in the envelopes of these stars are several times smaller than that of the helium atoms, and in some subtypes of WR stars there is no hydrogen at all. For the comparison, we note that in the spectrum of the Sun the hydrogen is about 10 times more abundant than helium;

8. About half of the WR stars are components of the close binary systems (CBS);

9. Exploiting binary stars, the masses of WR stars were found to range from10 $M_{\odot}$ to 83 $M_{\odot}$;

10. The spectral features of these stars (for example, observed absorption components of emission lines on the violet side) indicate strong radial outflow of matter from WR stars. The widths of the emission lines correspond to velocities of $\sim 1000-3000$ km/s, which, within average characteristics of these stars, exceed the parabolic velocity. Therefore, WR stars undergo intensive mass losses. The average rate of mass loss from these stars is $M = 0.3 \cdot 10^{-5} - 1.0 \cdot 10^{-4} M_{\odot} yr^{-1}$, which is approximately 3-4 times larger than for the ordinary hot OB stars;

11. From the studies of the binary WR stars, the physical parameters (masses, radii, temperatures and bolometric luminosities, etc.) of these stars have been determined. Currently, six WR+O eclipsing binary (V444 Cyg, CX Cep, CV Ser, CQ Cep, GP Cep, WR 22) systems are known, which allow us for a more precise determination of the physical parameters of these stars;

12. In the Hertzsprung-Russell (HR) diagram, the WR stars with the most confidently determined physical parameters (temperature and luminosity) lie in the region between the main sequence (MS) and the sequence of homogeneous helium stars. This indicates that these stars have already passed the stage of the MS and are in the late stages of their evolution;

13. The WR stars are mainly located in the galactic plane. The average height z of these stars from the galactic plane is about ± 85 pc. These stars are often found in young clusters and OB associations. Therefore, they are absolutely young objects; with the average age amounting to about 10^6 years;

14. Population I WR stars are very high luminosity $(\sim 10^5 \div 10^6)L_\odot$ hot stars. The absolute magnitudes of these stars are in the range from -4^m to -7^m;

15. According to the modern view, the Population I WR stars of our Galaxy are "bare" hot helium nuclei of the initially massive O stars, which lost their powerful hydrogen envelopes;

16. There are single and binary WR stars with the components of the spectral class O. About half of the WR stars are in WR+O close binary systems. The mechanism of formation and evolution of WR stars in binary and single systems is significantly different. At a certain stage of the evolution of massive CBS, by losing a hydrogen rich envelopedue to the outflow of matter through the internal Lagrange point, the massive O component transforms into a star WR and a system WR + O is forming. A massive single star (with a mass of more than $\sim 60M_\odot$) also, as a result of intensive mass loss in the form of a stellar wind, turns into WR star;

17. The WR stars are, at the final stage of evolution after MS, at the stage of exhaustion of nuclear energy, after which the collapse of the star must follow with the formation of a neutron star or black hole, depending on the initial mass;

18. At the final stage of evolution, WR stars explode as supernovae of type I b/c. In their spectra, only helium (I b) and carbon (I c) lines are present, while the hydrogen line is basically missing. As a result of supernovae explosion, neutron stars or black holes are formed, depending on the initial mass. Thus, WR stars are potential progenitors of neutron stars and black holes. The generation of cosmic gamma bursts is also, in some cases, associated with WR stars.

Currently, in order to explain the observational properties of the WR stars listed above, several models have been proposed. Among these models, the most reliable one is the Beals model [33]. According to Beals model, the WR stars consist of a hot core surrounded by the radially expanding envelope. Beals proposed this model on the basis of the similarity of WR spectra to the spectra of novae

[33]. The Beals model was later developed in other works [34–36]. It should be noted that the studies carried out at the Shamakhy Astrophysical Observatory (ShAO), by A. Huseynzade [37–39] was also significant for the understanding of the physical nature of WR stars. Prior to studies of A. Huseynzade, there was a consensus that radial outflow from WR stars is completely stationary. However, for the first time, based on the high precision observational data, the nonstationarity of the outflow from these stars was found by A. Huseynzade. The latter,was of extraordinary importance for understanding of the WR phenomenon.

3. THE SPECTRAL CLASSIFICATION OF WOLF RAYET STARS

According to the spectral classification of "normal" stars, they are arranged into certain groups called the spectral types. It is known that for "normal" stars the spectral classification depends on the effective temperature and brightness. In the classification scheme of the absorption spectra of "normal" stars, the effective temperature and brightness are interrelated. This is because the absorption lines and the continuous spectrum are formed approximately in the same region of the star. However, a strong emission line spectrum of WR stars is formed in a radial expanding envelope of a star, which is far from the region of formation of the continuous spectrum. That is why, the spectral types of WR stars are not related to the effective temperature and luminosity. The spectral types of WR stars actually reflect the ionization state of their envelopes.

For the first time, the spectral classification of WR stars was carried out by Canon [40] in 1916 for the Henry Draper catalogue. Canon [40] subdivided the WR stars into three spectral types: Oa, Ob, and Oc. The criteria used by Canon for the spectral classification of WR stars are given in Table 2.

More reasonable and close to the modern spectral classification for WR stars was proposed by Beals and Plaskett in 1935 [41] and Beals in 1938 [42]. According to these classification schemes WR stars are divided into two types: WN and WC. Depending on the level of excitation, WN and WC stars also are further subdivided into the subtypes WN5, WN6, WN7, WN8 (WN5-8) and WC6, WC7, WC8 (WC6-8) correspondingly.

In WN5-8 and WC6-8 subtypes, the degree of excitation of the spectrum decreases with the transition to a later subtype, i.e. to a subtype with a larger number. The spectra of WN5-8 and WC6-8 stars mainly consists of emission lines of NIII, NIV, NV and CII, CIII, CIV, OII, OIII, OIV, OV ions correspondingly. In both of these types (WN and WC), the lines of ions HeI and HeII are present. Beals [42] also established a relationship between line widths and the spectral subtype for WC stars. Further studies have shown that the Beals classification [42] is more successful for WC stars than for WN stars.

Table 2. The spectral classification of WR stars according to Canon [40].

Spectral type	The classification criteria	The typical star	The modern spectral type
Oa	wide strong λ 4686 Å line slightly weaker line at λ 4684 Å, lines H_γ and H_δ are strong	HD 97152 HD 192103	WC7+O WC8
Ob	wide strong λ 4686 line, H_β, H_γ and H_δ are strong	HD 191765 HD 50896	WN5 WN6
Oc	narrow strong λ 4686 Å line and λ 4638 Å line, the line λ 4686 Å is twice as intense as the line λ 4638 Å, all hydrogen lines are strong	HD 151932	WN7

In Tables 3 and 4 the spectral subtypes and classification criteria proposed by Beals [42] for WN and WC stars, are given, correspondingly. The spectral classification proposed by Beals [42] was modified by Hiltner and Shild in 1966 [43]. In this classification scheme, the WN stars are divided into WN-A and WN-B subtypes. In the spectra of WN-A stars, the emission lines are narrower, the continuous spectrum is strong and the absorption lines characteristic O-B stars are often visible in the spectra of these stars. WN-A stars are usually found in binary systems. However, WN-B stars are characterized by broad emission lines and these stars are rarely found in binary systems.

Hiltner and Shield [43] noted that it is very difficult for WN stars to exhibit an emission line ratio that varies monotonically along the WN subtypes. NV lines are weak, or blended with the lines NIII, lines HeII are also blended with the lines NIII. It should be noted that the line HeI 5875 used for the spectral classification is an absorption line in the spectra of WN4-A and WN5-A stars, while in the spectra of all WN-B stars it belongs to an emission line.

It was found that the ratio of CIII5696 / CIV5812, which was used for the spectral classification of WC stars by Beals [42], changes monotonically along the WC subtypes, and therefore this ratio is used as the main criterion. Subtypes WN4 and WC5 have been added to the Beals subtypes [42] by Hiltner and Shild [43].In Tables 5 and 6 the classification criteria for the determination of the spectral subtypes WN4-8 and WC5-8, proposed by Hiltner and Shild [43] are shown.

The subsequent modification of the classification scheme of WR stars was carried out by Smith in 1968 [31]. Smith [31] revealed that the spectral subtypes are not uniquely determined with respect to the ratio HeI5875/HeII5412. Table 7 shows the classification criteria for the WR stars of the nitrogen type (WN) proposed by Smith [31]. Note that in the spectral classification of WN stars the following lines of ions NIII, NIV, NV were used:

$$\mathrm{NIII}\lambda 4634 - \lambda 4641, \lambda 5314;$$
$$\mathrm{NIV}\lambda 3479 - \lambda 3484, \lambda 4058;$$
$$\mathrm{NV}\lambda 4933 - \lambda 4944, \lambda 4603, \lambda 4619.$$

The usage of these lines is connected with the fact that they are strong and are not blended with the helium lines. An additional criterion for the classification of WN stars was the presence of helium lines.

For the spectral classification of WC stars the lines of CIII, CIV, and OV ions were used. It should be noted that unlike WN stars, in the case of WC stars, Beals classification criteria [42] are undergoing only small changes. For WC stars, the additional criterion was the width of the line CIII, CIVλ4650.

Table 3. The spectral classification of WN stars according to Beals [42]

WN sybtypes	The classification criteria	The typical star
WN5	$\frac{NV4605-4622}{HeII4686} = 0.2$	HD187282
	$\frac{HeI5875}{HeII5411} = 0.1$	HD211564
	NV4945 line present	
WN6	$\frac{HeI5875}{HeII5411} = 0.5$	HD192163
	the strong emission band at $\lambda\lambda$ 4600-4660 present, NIV4938 line present	HD191765
WN7	$\frac{NIII4640}{HeII4686} = 0.5$	HD151932
	$\frac{HeI5875}{HeII5411} = 1.5$	HD92740
WN8	$\frac{NIII4640}{HeII4686} = 1.5$	HD177230
	$\frac{HeI5875}{HeII5411} = 5.0$	HD96548

In table 8 the classification criteria for the WC stars proposed by Smith [31] are given. It should be noted that there were smaller uncertainties in the spectral

Table 4. The spectral classification of WC stars according to Beals [42].

WC types	The classification criteria	The typical star
WC6	$\frac{CIII5696}{CIV5812} = 0.3$; $\frac{CIII5696}{OV5592} = 1.2$; $\frac{CII4267}{CIV4786} = 0.0$; CIII4650 and HeII 4686 are not separated CIV5812 and HeI5875 are not separated the widths of emission bands ~70 Å	HD 16523 HD165763 HD 16523
WC7	$\frac{CIII5696}{CIV5812} = 0.7$; $\frac{CIII5696}{OV5592} = 8.0$; $\frac{HeI5875}{HeI4411} = 1.5$; $\frac{CIII4650}{HeII4686} = 4.0$; $\frac{CII4267}{CIV4786} = 1.0$; CIII4650 and HeII4686 separated the widths of emission bands ~35 Å	HD 192103 HD119078
WC8	$\frac{CIII5696}{CIV5812} = 3.0$; $\frac{HeI5875}{HeI4411} = 5.0$; $\frac{CIII4650}{HeII4686} = 9.0$; $\frac{CII4267}{CIV4786} = 2.0$; the widths of emission bands ~10 Å	HD184738 HD164270

classification of WC stars than WN stars. The spectral subtypes WN3, WN 4.5 and WC9 are added by Smith [31].

In 1981, in the VI catalog of Galactic Population I WR stars [32], the classification scheme proposed by Smith [31] was mainly used. By using the classification criteria proposed by Smith [31] the subtypes WN3, WN4 and WN5 are clearly separated. However, there were some uncertainties for the definition of subtypes of WN6, WN7 and WN8. Some WN6 stars by the ratio of nitrogen lines are similar to WN7 stars, and some WN7 stars are similar to WN8 stars and vice versa.

In 1995 the authors of [44] added the new subtypes WN10 and WN11. Table 9 and 10 lists currently classification criteria for WN and WC stars correspondingly.

It is known that the Bils-Smith classification [31,41,42] is one-dimensional, i.e., in this classification, the spectral subtypes are determined only by the ionization state of atoms. In the classification scheme of Hiltner and Shild [43], the second criterion, the width of the lines, was added. Hiltner and Shield [43] separeted the WR stars into two groups: with narrow-weak lines (A) and wide-strong lines (B).

Table 5. The spectral classification of WN stars according to Hiltner W.A. and Schild R.E. [43].

WN types	The classification criteria			
WN4	$\frac{NIV4058}{NV4605-22}$		$\frac{NIV5806}{NV4945}$	$\frac{NV4605-22}{HII4542}$
WN5	$\frac{NIV4058}{NV4605-22}$		$\frac{NIV5806}{NV4945}$	$\frac{NV4605-22}{HII4542}$
WN6	$\frac{NIV4058}{NV4605}$	$\frac{NIV4058}{NIII4100}$	$\frac{HeI5875}{HeII5411}$	$\frac{NIII4640}{HeII4686}$
WN7		$\frac{NIV4058}{NIII4100}$	$\frac{HeI5875}{HeII5411}$	$\frac{NIII4640}{HeII4686}$
WN8		$\frac{NIV4058}{NIII4100}$	$\frac{HeI5875}{HeII5411}$	$\frac{NIII4640}{HeII4686}$

Table 6. The spectral classification of WC stars according to Hiltner W.A. and Schild R.E [43].

WN types	The classification criteria			
WC5	$\frac{CIII5696}{CIV5812}$			
WC6	$\frac{CIII5696}{CIV5812}$	$\frac{CII4267}{CIV4441}$	$\frac{CII4297}{CIV4786}$	
WC7	$\frac{CIII5696}{CIV5812}$	$\frac{CII4267}{CIV4441}$	$\frac{CII4297}{CIV4786}$	$\frac{HeI+(CIII)5875}{HeII5411}$
WC8	$\frac{CIII5696}{CIV5812}$	$\frac{CII4267}{CIV4441}$	$\frac{CII4297}{CIV4786}$	$\frac{HeI+(CIII)5875}{HeII5411}$

In 1996, the authors of [45] proposed a three-dimensional classification scheme for the WR stars of the nitrogen subtype (WN). The third criterion was the abundance of hydrogen. The three criteria for which WN stars are classified according to [45] are as follows:

1. HeII5411 / HeI5875 - the main ionization indicator;

2. The half-width (FWHI) of the HeII 4686 emission line and the equivalent width of HeII 5411 - as indicators of width and intensity;

Table 7. The spectral classification of WN stars according to Smith [31].

WN types	**Criteria by nitrogen lines**	**The additional criteria**
WN 8	NIII $\gg$ NIV	the lines of HeI strong and have violet absorption component NIIIλ4640 $\sim$ $HeII\lambda$4686, NIIIλ5314 present
WN 7	NIII $\gg$ NIV	HeI weak ,NIIIλ4640 < $HeII\lambda$4686
WN 6	NIII$\sim$ NIV;	NIII$\lambda\lambda$4634-41 present, weak NV present
WN 5	NIII$\sim$NIV$\sim$NV	NIII$\lambda\lambda$4634-41present
WN 4.5	NIV > NV;	NIII very weak or absent
WN 4	NIV $\sim$ NV;	NIII very weak or absent
WN 3	NIV $\ll$ NV	NIII absent

Table 8. The spectral classification of WC stars according to Smith [31].

WC subtypes	$\frac{CIII\lambda5696}{OV\lambda5592}$	$\frac{CIII\lambda5696}{CIV\lambda5805}$	**The widths of line CIII ,CIVλ4650**	**The spectral subtype according to Beals [31]**
WC 5	< 1.0	0.3	85 A	WC6
WC 6	> 1.0	0.3	45 A	WC6
WC 7	8.0	0.7	35	A
WC 8		1.0		
WC 9		3.0	10 A	

3. The oscillations of the Pickering decrement are an indicator of the presence of hydrogen.

A fairly successful quantitative spectral classification of the WC stars was proposed in [46]. With the help of this classification scheme, WC subtypes are defined more precisely.

In 1971 the Population I WR stars, with enhanced emission doublet OVI 3811, 3834 [47] were discovered. In this context, in 1982, Barlow and Hammer introduced a new type WO [48] along with types WN and WC. According to [48], WO stars are classified by the emission lines of ions OIV, OV, OVI. The authors of [48] proposed WO1, WO2, WO3 and WO4 subtypes (the degree of excitation of the spectrum decreases with the transition to a later subtype, i.e., to a subtype with a larger number). In Table 11 the classification criteria for WO1-4 subtypes proposed in [48] are given. The WO5 subtype was first proposed by us, and the

Table 9. The currently spectral classification of WN stars.

WN subtypes	The criteria according to nitrogen lines	The additional criteria
WN 11	NII strong, NIII absent, NIV present	line of the Balmer series and HeI have PCyg profile
WN 10	NII ≈ NIII, NIV absent	line of the Balmer series and HeI have PCyg profile
WN 9	NIII strong; NIV absent, NII weak or absent	low members of Balmer series lines have P Cyg profile lines of HeI present
WN 8	NIII » NIV, NIII ≈HeII 4686	lines of HeI have strong P Cygp rofile NIIIλ4640 ≈HeIIλ4686
WN 7	NIII > NIV, NIII <HeII 4686 the HeI lines has weak	P Cyg profile, NIII 4640 <HeIIλ4686
WN 6	NIII = NIV; NV present but weak	
WN 5	NIII ≈ NIV ≈ NV	
WN 4.5	NIV > NV; NIII weak or absent	
WN 4	NIV = NV; NIII weak or absent	
WN 3	NIV « NV,NIII weak or absent	
WN 2	NV weak or absent	HeII strong

Table 10. The currently spectral classification of WC stars.

WC subtypes	$\frac{CIII\lambda5696}{CIV\lambda5805}$	$\frac{CIII\lambda5696}{OV\lambda5592}$	The additional criteria
WC 9	CIII > CIV	OV weak or absent	CII present
WC 8.5	CIII > CIV	OV weak or absent	CII absent
WC 8	CIII = CIV	OV weak or absent	
WC 7	CIII < CIV	CIII » OV	
WC 6	CIII «CIV	CIII > OV	
WC 5	CIII «CIV	CIII < OV	
WC 4	CIV strong, CIII weak or absent	OV weak	

criteria for determining of this subtype is given in [49].

Table 11. Criteria for the classification of WO stars acording to [48, 49].

WO subtypes	**Criteria of classification**
WO5	the lines CIVλ5810, OIVλ3400, OVI$\lambda\lambda$3811, 3834 are strong CIIIλ5696/OVλ5590 $<$1 or $\sim$ 1, OVIλ3811, 3834$<$OIVλ3400 (OVI$<$OIV)
WO4	CIV strong, CIII absent, OIVλ3400 and OVI$\lambda\lambda$3811, 3834 are strong; OVI$\lambda\lambda$3811, 3834 $\sim$ OIV3400 (OVI $\sim$OIV)
WO3	OVI$\lambda\lambda$3811, 3834$>$OIV3400 (OVI$>$OIV)
WO2	OIV absent; OVλ5590$<$CIVλ5810 (OV$<$CIV)
WO1	OVλ5590$>$CIVλ5810 (OV $>$CIV)

Table 12. The masses of WR stars of different subtypes according to [62]. * - from [63].

The spectral subtype	**Mass($M_\odot$)**
WN3	$>$ 1.8
WN4	7, 12, 15, 16
WN5	8, 10
WN6	14, 43, $>$ 50
WN7	42, $>$ 48, $>$ 72*
WC5	10
WC6	$>$ 1.5
WC7	11, 18, 20
WC8	12, 19, 34

According to [48], the oxygen lines in the spectrum of WO stars are stronger with respect to the carbon lines, compared to the same value in the WC stars. Such abundance of oxygen in the WO stars is interpreted with the capture of α particle by the carbon nuclei at the end of the helium burning stage in the nucleus of the original massive star. An oxygen-enriched substance is observed on the surface of the star due to the strong stellar wind. In this scenario, the WO stars correspond to the evolutionary stage after the WC phase, the end of helium burning in the core, or the beginning of the burning of carbon in the core.

Table 13. The absolute magnitudes of WR stars of different subtype according to [74].

The spectral subtype	M_ν	The spectral subtype	M_ν
WN2	-2.4	WC4	
WN3	-2.2	WC5	-3.6
WN4	-3.3	WC6	-3.7
WN4.5	-4.1	WC7	-4.1
WN5	-3.7	WC8	-4.4
WN6	-4.8	WC9	-4.6
WN7	-6.5		
WN8	-6.7	WO2	-2.7
WN9			

Table 14. The physical parameters of WR stars of a different subtype, according to [75].

Star(HD №)	Spectra	T_{eff}	d(kpc)	$R/R_\odot$	$Lg/Lg_\odot$	M_{bol}	BC
9974	WN3	50 000	4.29	4.80	5.11	-8.03	-4.45
187282	WN4	45 000	4.90	3.72	4.71	-7.02	-3.44
50896	WN5	50 000	1.94	6.13	5.33	-8.57	-3.86
192163	WN6	45 000	1.70	9.12	5.49	-8.97	-3.76
191765	WN6	45 000	2.05	5.80	5.09	-7.99	-3.29
151932	WN7	30 000	2.09	23.1	5.59	-9.23	-2.69
93131	WN7	30 000	2.63	18.1	5.38	-8.70	-2.54
96548	WN8	35 000	2.48	16.0	5.54	-9.09	-3.46
86161	WN8	35 000	2.48	14.3	5.44	-8.85	-3.31
165763	WC5	50 000	2.62	7.75	5.53	-9.07	-4.34
16523	WC5	45 000	4.41	5.13	4.99	-7.72	-3.21
156385	WC7	50 000	1.70	8.16	5.57	-9.18	-4.28
192103	WC8	40 000	2.00	6.22	4.95	-7.63	-3.32
164270	WC9	20 000	2.84	18.5	4.69	-6.98	-2.11

Table 15. The relative content of hydrogen (in terms of the number of atoms) in the expanding envelopes of the WR stars, according to [92].

Star	The spectral subtype	N(He)/N(H)
HD 9974	WN3	≥ 10
HD 187282	WN4	4.6 (3-10)
HD 50896	WN5	4.0 (3-10)
HD 192163	WN6	2.2 (1.5-5)
HD 191765	WN6	6.1 (3-10)
HD 151932	WN7	3.2 (2-6)
HD 96548	WN8	1.5 (1-3)
MR 119	WN8	0.8 (0.5-1)
HD 165763	WC5	> 10
HD 115473	WC5	> 10
HD 16523	WC5	> 10
HD 119078	WC7	> 10
HD 192103	WC8	> 10
HD 164270	WC9	≥ 10

Table 16. The number of WN and WC stars and the value of the ratio WC/WN + WC as a function from the center of our Galaxy (according to [125]).

r (kpc)	WN	WC	WC/(WN+WC)
7-9	17	24	0.6
9-11	22	15	0.4
11-13	10	5	0.3

The small number of WO stars compared with WN and WC stars is in favor of this assumption. On the other hand, according to [50], WN and WC stars are early and late stages of the evolution of massive stars. The conclusion that the WC stars are older than the WN stars made also by authors of [51], evidences that, contrary to the WN stars, the WC stars are located systematically at large distances from the center of young clusters and associations. This observational fact can be explained either by the fact that WN stars turn into WC stars in the process of evolution, or WC stars are formed from stars of smaller mass and hence evolve more slowly. The chemical composition of the surface of WR stars is in favor of the first hypothesis. In conclusion, we can write the following evolutionary connection between WR types:

$$WN \to WC \to WO$$

Of and transitional Of/WN stars. In 1971, the difference in the spectral features of the star HD 93129A ($O3f^*$) and stars such as WR, HD 93131 (WN7 + abs) was analyzed [52]. It was shown that the spectrum of star HD 93129A ($O3f^*$) is mainly an absorption spectrum and only the lines HeII4686 and NIV4058 are emission lines. The intensity of these emission lines in the spectrum of star HD 93129A ($O3f^*$) is weaker in comparison with HD 93131 (WN7 + abs). The difference in the spectral features of these stars was supposed to be explained by the fact that a star of the type WR, HD 93131 (WN7 + abs) has a more powerful envelope than a star of the type Of. Further similar studies have shown that the stars Of by spectral properties occupy an intermediate position between the O stars and late-type nitrogen WR (WNL) stars.

According to modern view, the Of stars were formed as a result of the evolution of more massive O stars according to the following scenario: $O \to Of \to WNL$

In the initial stage, the massive O star, by losing its mass, transforms into the Of star, and later the Of star turns into WNL.

In contrast to the usual O type stars, the following strong emission lines are observed in the spectra of Of stars: NIII4634, 4640, 4642, CIII4647-4651, CIII5696 and HeII4686.

The spectral type Of/feWN9 was first introduced in [52]. In [53], HDE 269227, which is located in the LMC, is classified as OIafpe. Stars related to this type are called extreme Of stars. In the spectra of these stars, the emission dominates absorption. The stars of this spectral class are very similar to WN stars. In the spectra of Of/feWN9 stars there are absorption lines characteristic for Of stars and emission lines characteristic for WN9 stars. In [54], a list of 10 Of /feWN9 stars,located in the LMC, is given. Only handful of stars of this type has been found in our galaxy (for example: HD 152408).

It should be noted that the brightness, age, H/He ratio, the ionization structure of the envelopes ofWN7/8 stars are different from other WN stars. It is believed that the Of stars turn into WN7/8. The difference between Of and transition WN7/8 stars are as follows:

1. In WN7/8 stars the emission lines (for example, HeII4686)are stronger than in Of stars;

2. In WN7/8 stars, the rate of the mass loss is greater than in Of stars;

3. The density of envelopes in WN7/8 stars is larger than the density of the envelopes Of stars;

4. In WN7/8 stars the nitrogen is abundant, but such abundance in the spectra of Of stars is not observed or is hardly seen.

The WR stars of the mixed subtype, WN + WC stars. It should be noted that in the spectrum of WN stars are present a carbon line CIV5801, 5812 in the visible region and CIV1550 in the UV. It is known that lines CIII4650 and CIII5696 are not usually observed in the spectra of WN stars. If there are lines of CIII4650 and CIII5696 in the spectrum of the WN star, then this star is classified as WN + WC. In the VII catalog of the Galactic Population I WR Stars [4], 11 stars were attributed to this type. WN + WC stars could be binary systems.

According to the modern evolutionary scenarios, the binary WR + WR systems could be formed from the systems WR + O.

WR stars with the absorption lines, WR + abs stars. In the spectrum of some WR stars the absorption lines were observed. Some of these stars are binary WR + O systems and the absorption lines are formed in the O component. It should be noted that in WR + O stars, for which the period of variability of the emission lines is revealed, change in antiphase (or almost in antiphase) with the absorption lines that are formed in the O component. Nevertheless there are some WR+abs stars with the non shifted absorption lines. These stars are called WR + abs stars. A catalog of sixteen WR+absstars lines is given in [55]. According to [55], these stars are divided into five groups:

1. WNL (WN6-9) stars, similar Of, in the spectra of which the hydrogen is present and these lines can be the absorption lines of the Balmer series;
2. WR stars that are not WNL stars and without hydrogen in their atmospheres. The binary nature of some of these stars is revealed;
3. Stars WR, the binary nature of which is suspected, but not confirmed yet;
4. WR stars with the close visual components;
5. Stars WR, the binary nature of which is not investigated yet;

Some WR + abs stars can be long-period variables. If the binary nature of these stars will be revealed, the frequency of binary WR stars will increase by about 10%.

4. THE PHYSICAL PARAMETERS OF WOLF-RAYET STARS

About 50% Galactic Population I WR stars are found in binary systems, which gives us the opportunity to determine the physical parameters (effective temperatures, masses, radius, etc.) of these stars. It should be noted that the determination of the effective temperatures (T_{eff}) and luminosity (L) of WR stars is very important, since the position of these stars on the Hertzsprung-Russel (HR) diagram is determined by these parameters. Knowledge of these parameters also important for the understanding the evolution state of WR stars. There are some difficulties in determining the physical parameters of these stars, which could be primarily related to:

1. The significant deviations of the radiation of these stars from the blackbody radiation;
2. Absence of a correctly developed theory of formation of WR spectra;
3. Inapplicability of simple methods developed for normal stars or nebulae to WR stars.

In six cases, the WR stars are a member of eclipsing binary systems: V 444 Cyg, CX Cep, CV Ser, CQ Cep, GP Cep and WR122. Investigation of these binary systems, allows us for high precision determination of the physical parameters of WR stars. The light curves of eclipsing binaries provide the missing information, namely the inclination of the orbit to our line of sight. Therefore, eclipsing binaries are the only stars whose masses are derived with some confidence. Analyses of eclipsing binary WR stars lead to the conclusion that the radius of the "core" of WR stars at a mass of $10M_{\odot}$ is about $2-3R_{\odot}$, and its temperature exceeds 50,000 K. These parameters are typical for massive helium stars, i.e. we could conclude that the WR stars are helium remnants of initially massive stars.

Currently, the modern methods of stellar atmospheres models are used to determine various physical parameters (luminosity, temperature, mass, abundance of chemical elements, wind parameters, etc.) of WR stars.

The masses of WR stars. The mass of a star is a very important physical parameter, because the rate of evolution and hence stellar lifetime significantly depends on their mass. The morethe mass, the more its lifetime. On the other hand, other physical parameters of the stars (luminosity, radius, density, etc.) also depend on their mass. For example, the more the mass, the more the luminosity of the star. However, this dependence is nonlinear: for instance, when the mass of the star double its luminosity increases by more than 10 times. It should be noted that the masses of stars, from the biggest to the smallest, differ only a few hundred times.

Therefore the determination of the masses of WR stars is very important. The determination of the masses of WR stars by using gravity acceleration is impossible, since we do not have an opportunity to use photosphere lines, because of the presence of a dense envelope. In the case of a single star, the mass is determined by the method of atmospheric models or by comparing to the corresponding synthetic spectrum. If the WR star was a member of an eclipsing binary system, its mass could be determined more precisely. For the first time in 1939, the eclipsing-binary nature of the WR star V 444 Cyg (WN5 + O6) was revealed and the mass of the WN5 star in this system was found to be $10M_{\odot}$ [56]. Based on this, the average mass of the WR stars is taken to be approximately $10M_{\odot}$.

About 50% of the WR stars are members of binary systems containing hot massive stars of the spectral classes O as components. Orbital periods of these binary WR + O stars lie within single day to a few years. Analysis of the spectral, photometric and polarimetric observations of these stars allows to determine-masses of the WR stars. The masses of WR stars inbinary WR + O systems are ranging from 5 to $80 M_{\odot}$. However, in most cases, the masses of WR stars are in the range of 10-25 $M_{\odot}$. The WR stars of the same subtype often have different masses. A clear correlation between the spectral type and mass was not found. However, it is shown that, WN stars are more massive than WC stars. The masses of WN and WC stars are in the range $10-83 M_{\odot}$ and 9-16 $M_{\odot}$, respectively. For most known WR + O systems, the mass of WR stars is smaller than that of the O star and the mass ratio of the components ($q = M_{WR}/M_{O}$) lies within 0.3-1. It should be noted that the WNL stars, with the abundant hydrogen are more massive WR stars. For the hydrogen abundant both WN6ha components in the binary system WR20a, a mass of $\sim 83 M_{\odot}$ was found [57]. According to the modern view, WR stars in binary systems should lose about 40% of their initial mass before becoming a WR star [58]. In connection with the revealing of super massive WR type stars, it becomes clear that they had an initial mass of about 120-150 $M_{\odot}$. This triggers a question on the initial largest possible mass. According to the results of modern theoretical studies, the formation of stars with a mass greater than 150 $M_{\odot}$ is problematic [59], i.e. this mass is the upper limit for star formation. Another double star WR, a star WR21a with lower mass values of the components $64.4 \pm 4.8 M_{\odot}$ and $36.3 \pm 1.7 M_{\odot}$, has been observed. Taking the orbit inclination values for this binary system $i = 58^{\circ}.8 \pm 2$, the values 103.6 ± 10.2 $M_{\odot}$ and 58.3 ± 3.7 $M_{\odot}$ obtained for the masses of the components [60]. However, an even more striking fact is the detection of the WR star, R136a1 with a mass of 265 $M_{\odot}$, which is located in the LMC [61]. The mass of this star differs significantly from the theoretically estimated upper limit. Consequently, the fact of existence of this star makes doubtful the results of theoretical studies of star formation. Astronomers are also considering yet another possibility: supermassive stars can be formed by the fusion of two stars. On the other hand, it is believed that the meridional circulation can play an important role in the formation of anomalous chemical composition (in the separation of WR stars into WN, WC, and WO types) in very massive stars. In Table 12 have shown the masses of WR stars of different subtypes according to [62]. Here the mass of the star WR22a was taken from [63].

The luminosity of WR stars. WR stars are often found in open clusters and associations, which allows us to determine the approximate absolute magnitudes of these stars. The absolute magnitudes of WR stars located in LMO [64, 65] and SMO are more precisely determined, but not all subtypes are found there. The individual determinations of absolute magnitudes for the Galactic Population I WR stars and of WR stars located in M 33 have been carried out in [66–68]. These studies indicate that there are little differences between absolute magnitudes of WR stars located in our Galaxy, LMO and M 33. The absolute magnitudes of the WN stars correlate with the spectral subtypes, increasing in the interval WN3-WN8 from $-4^m.0 \pm 0^m.5$ to the $-6^m.5 \pm 1^m.0$. The absolute magnitudes of the WC are also in the same interval, however in this case the correlation with the spectral subtype is significantly weak.

Recently, by using of the standard model [69, 70] more precise values of T_{eff} and L obtained. By using the standard model, the values of $T_{eff} \sim 35000K$, $logL/L_{\odot} = 5.5 - 6$ were obtained for WNL stars [71]. For WNE stars $logL/L_{\odot} = 5.0 - 5.5$ and a wide temperature range of $T_{eff} \sim 350000 - 90000$ K were deduced [71]

T_{eff} and L from the standard model with the so-called "tailored" analysis of UV and IR observations are considered to be more precise. In [72] for WNL (WN7-8) stars, the values of $T_{eff} \sim 25000 - 30000$ K were obtained and these stars are separated by luminosities. For WNL (WN7-8) stars the values $logL/L_{\odot} = 5.5$ and $logL/L_{\odot} = 5.9$ obtained. These values correspond to, the stars with low hydrogen content ($XH \leq 15\%$) and high hydrogen content (XH = 50%) respectively.

The analogous studies for WC stars were carried out in [73] and $T_{eff} \sim 50000K$ were obtained for WC stars with weak emission lines (WC-weak). For the WC stars with strong emission lines (WC-strong), the values of $T_{eff} \sim 60000 - 100000$ K, and a large luminosity interval $logL/L_{\odot} = 4.7 - 5.5$ have been found.

In Table 14 the absolute magnitudes of WR stars of different subtypes are shown [74]. In Table 14 the effective temperatures, radii, luminosities, bolometric stellar magnitudes, and bolometric corrections of some WR type stars of a different subtype are presented. The values are taken from [75].

The temperatures and radii of WR stars. The temperatures and radii of WR stars are determined by modeling and form the study of eclipsing close binary stars, with one component is representing the WR star. The temperatures of WR stars were also determined by usingthe lines of adjacent ionization stages of helium (HeI and HeII) or nitrogen for WN stars [76,77], or carbon for WC stars [78]. In physical modeling of WR stars, it is assumed that their continuous spectrum is formed in the “photosphere” of this star, where the Rosseland optical depth is $\tau_{Ross} \sim 2/3$. The radius corresponding to this depth is called $R_{2/3}$. The authors of [79], for the star HD 50896 (WN4b), found the values of: $R_{2/3} = 7.7R_{\odot}$and $T_{2/3} = 52kK$. The values of the effective temperatures of WR stars determined by different authors varies from 25 0000 K to 50 0000 K, depending on the subtypes. The temperatures obtained for the same WR star by different authors are sometimes quite different.

It should be noted that actually continuous spectrum of WR star is a superposition of quasi-blackbody radiation of a “nucleus” with a temperature T_{eff} and non-equilibrium radiation of the envelope. In the visible region of the spectrum ($\lambda \sim 5500$) the main contribution is coming from the envelope, while in the UV region ($\lambda < 3000$), the radiation of the hot “nucleus” dominates. Therefore, without involving a particular model to separate the spectra of the “nucleus” from the WR envelope, it is impossible to determine any meaningful value for T_{eff}. Even observations over a wide range of wavelengths do not help in this case. The temperature obtained by simply combining UV observations with optical data cannot be considered as T_{eff}. A combined analysis of the IR and optical observation of an eclipsing binary star of the V444 Cyg for the WN5 component yields $T_{eff} = 900000$ K and $logL/L_{\odot} = 5.69$ [80].

To estimate the effective temperatures of WR stars, the Zanstra method was also used before. This method was first applied to stars of the WR type in [81–84]. By using the HeII 4686 emission line, a value of 70 000 K was obtained for the temperature of WR stars. The Zanstra temperatures of the "nucleus" of WR stars are determined from the lines of various elements [85, 86] and the values of $T \sim 30000 - 1100000K$ were obtained. The inadequacy of this method is that the temperature of the same star often depends on the ionization potential of an atom or ion, used in the temperature determination procedure.

More precise results, both with respect to effective temperatures and luminosities, and other physical parameters, are obtained from studies of eclipsing binary systems containing WR components.

Position of WR stars on the Hertzsprung-Russell diagram. The WR stars with the most precisely determined physical parameters in the HR diagram lie in the region between the MS and the sequence of homogeneous helium stars. This indicates that the WR stars are at late stages of their stellar evolution and have already passed the stage of Main Sequence (hydrogen already “burned out”). The fact that the less massive components of WR + O binary systems are found at late stages of evolution can be explained by the hypothesis of the “effect of changing roles” of components as a result of mass exchange during the evolution of CBS. Initially more massive component of the binary system evolves faster than another component and after the exhaustion of hydrogen; the massive component expands and fills its Roche lobe. At this point a rapid (during $\sim 10^4$ years) outflow of a significant part of the mass (up to 70%) to the component takes place. After loosing of a hydrogen-rich envelope, the initially massive star becomes the WR star. The lifetime of WR star is small ($\sim 10^5 - 10^6$ years), after the exhaustion of nuclear fuel it explodes as a supernova, forming a relativistic object, a neutron star or a black hole.

Figures 1 and 2 show HR diagrams in coordinates $\lg L/L_{\odot}$ and $\lg T_{eff}$. As seen from Fig. 1, the component WN5 of eclipsing system V 444 Cyg falls into the region between the MS and the sequence of homogeneous helium stars. Hence, the WN5 star is at late stage of its evolution after the MS. The position of the WN5 star corresponds to the position of the helium remnant of the initially massive $(30 - 40 M_{\odot})$ component, which lost most of its mass as a result of the exchange. We note that for the WR stars, the helium model was first proposed in [87].

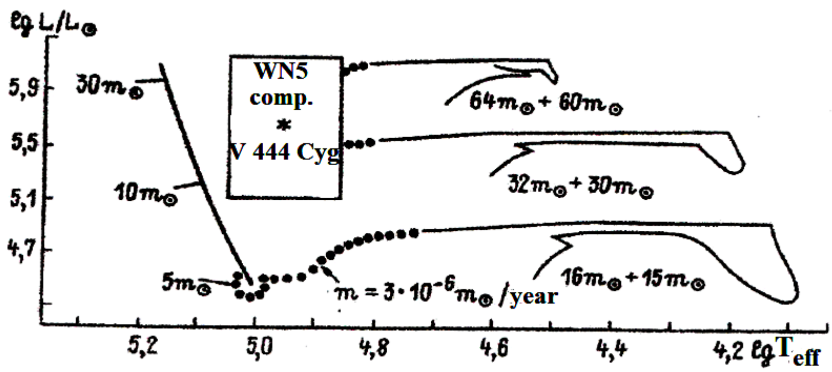

Fig. 1. Position of component WN5 of the eclipse system V 444 Cyg on the HR diagram according to [80]. In the left side the sequence of homogeneous helium stars is presented, while the right side demonstrates evolutionary tracks of the mass lost components of the CBS [88, 89].

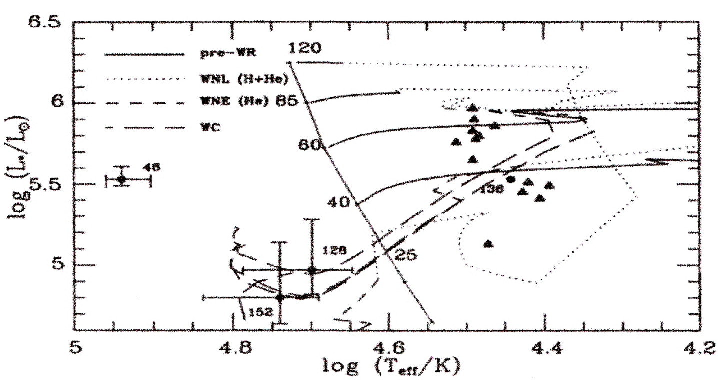

Fig. 2. Position of component WN5 of the eclipse system V 444 Cyg on the HR diagram according to [80]. In the left side the sequence of homogeneous helium stars is presented, while the right side demonstrates evolutionary tracks of the mass lost components of the CBS [88, 89].

5. THE CHEMICAL COMPOSITION OF WOLF RAYET STARS

As noted above, WR stars are subdivided into three types: WN, WC, and WO. According to the modern view, the classification of WR stars into WC, WN and WO types is based on the difference in chemical composition. In the spectra of WR stars of all types, helium and hydrogen lines are present, but the hydrogen lines are weak and chemical composition determination shows that the amount of hydrogen in the atmospheres of WR stars are several times smaller than that of helium. For comparison, wenote that on the Sun the amount of hydrogen is about 10 times more than helium. In Table 15 shows the relative content of hydrogen in the envelopes of WR stars of different subtype according to [92].

The chemical composition of WN stars. The ratio of H/He for WN stars was determined in Refs [93, 94] and it was concluded that the hydrogen is small with respect to helium. In [95], 9 galactic WN7-8 stars were investigated and stars with strong HeI lines were found to show low hydrogen content ($\sim 8\%$ *by mass*).

The C/N ratio for WN stars was first determined in [96] and a value of ~ 0.01 was obtained. For comparison, we note that for the Sun, $C/N \sim 3$. According to [97] for WNE and WNL stars, for the ratio C/N the values of $(2-6)\cdot 10^{-2}$, and $(0.6-4)\cdot 10^{-2}$ have been found correspondingly. For the star HD 50896 (WN5), the value of C/N $= 0.07$, $N/He \sim (0.4-4)\cdot 10^{-3}$ were obtained in [98]. For galactic WNL stars, C/N $= 0.01$, $N/He \sim 0.003-0.008$ were found in [99]. For WNE stars with weak lines, C/N $= 0.05$, $N/He \leq 0.004$ were established in [100].

The chemical composition of WN+WC stars. WR stars of mixed (WN + WC) types were first reported in [101]. It should be noted that ifin the spectrum of WN star there are lines CIII4650 and CIII5696, this star is classified as WN + WC and in the VII catalog of Galactic Population I WR stars [4] 11 stars belonged to this type. For a star of this type, HD 62910 (WN6-C4), it was found that $C/N \sim 0.3$ and $N/He \sim 0.01$ (by number) [102]. Authors of [102] concluded that the star HD 62910 is a single star and according to the abundance of chemical elements occupy an intermediate position between the WN and WC stars. By using the modern methods of investigation for the star HD 62910 the following parameters were obtained: $T_{eff} = 32000K$, $logL/L_{\odot} = 5.1$, $C/N \sim 3$, $C/He \sim 0.02$, $H/He \sim 0$, $C/O \sim 4$ (by number). In [48], in addition to the star HD 62910, two more WN + WC stars (WR 145 and HDE 269485 located in our galaxy and in LMC correspondingly) are investigated. Authors of [103] conclude that WN + WC stars, according to their physical parameters are in the transition evolutionary phase between WN and WC stars.

The chemical composition of WC stars. Numerous attempts to identify hydrogen lines in the UV and IR spectra of WC stars did not yield positive results and it is accepted that the ratio H/He is basically vanishing for these stars [104].

According to [104–108], for the WC stars, C/He = 0.1-0.7, C/He = 0.1, and C/He = 0.1-0.8, values are obtained, respectively.

By using the standard model in [109] for the star HD 165763 (WC5), it turned out that $4C/He \sim 0.5$, $O/C \sim 0.2$. All in all, the results obtained are in very good agreement with the predictions of theoretical studies.

The chemical composition of WO stars. The chemical composition of five WO stars (3 galactic, 1 located in the LMC, and 1 located in the SMC) were determined in [110]. For the Galactic and LMO stars, we found:$C/He \sim 0.51$, $C/O \sim 4.6 - 5.2$, (C + O)/He = 0.62. The corresponding values for the LMC stars are: C/He = 0.81, C/O = 2.7 and (C + O)/He = 1.10. The authors of [110] also concluded that these results are in agreement with the predictions of the relevant theoretical studies.

6. THE MASS LOSS BY THE WOLF RAYET STARS

Spectroscopic data indicate a powerful mass outflow from the WR stars. The widths of the emission lines correspond to velocities of 1000-3000 km/s, which, with the average characteristics of these stars, exceeds the parabolic velocity, i.e., these stars undergo a mass loss. Some emission lines have absorption components on the short-wave side (as in a novae), which supports the model of radial outflow. The average rate of mass loss for WR stars, estimated from the analysis of spectroscopic data, is $0.3 \cdot 10^{-5} - 1.0 \cdot 10^{-4} M_{\odot} yr^{-1}$, which is 3-4 times larger than for hot OB stars. The mass lost by the WR stars enriches Galaxies with heavy elements, which plays an important role in the formation of the next generation of stars.

For the radial symmetric mass outflow, the rate of mass loss from a star can be calculated with the formula:

$$\dot{M} = 4\,\pi\,R_0^2\,\rho_0\,\upsilon_0,$$

where, ρ_0 and υ_0 are the density and the velocity of the envelope at a distance R_0 from the center of the star, correspondingly. This formula, however, is associated with some difficulties. This is because the, determination the values ρ_0 and υ_0 at different distances R_0, from the observations is very complicated. The determination of mass loss rate of WR stars strongly depends on the assumed wind model (accelerated, slowed down, etc.), of the envelope dimensions, etc.

Currently, the determination of the mass loss rate, on the basis of an orbital period change can be considered as a more precise approach. The mass loss rate by WR stars can be precisely determined from the analysis of the orbital period change of the binary WR + O stars. Such a study for the V 444 Cyg

(WN5 + O6) star was carried out in [111] and, a value of $0^s.22$ was obtained for the orbital period change for one year,which corresponds the mass loss rate $(1.1 \pm 0.2) \cdot 10^{-5} M_\odot\, yr^{-1}$ for the WN5 component in this system. In [112], based on theoretical calculations, it was demonstrated, that in the case of the outflow of mass with the rate of $10^{-5} M_\odot\, yr^{-1}$, the period of V 444 Cyg should indeed increase, which is in full agreement with the results of [111]. The change of the period of this system was confirmed also in [113]. Thus, the outflow of mass from the WR stars can be considered proven.

Another more precise method to determine the mass loss rate of WR stars relies on the radio flux measurement. By using the flux in the radio band, the rate of mass loss can be determined by the formula:

$$S_v = 23.2(\frac{\dot{M} z}{V_\infty \mu})^{\frac{4}{3}} (\frac{\gamma g v}{d^3})^{\frac{2}{3}},$$

where,$\dot{M}$- is the mass loss rate (in units of $M_\odot$ per year), V_∞ - terminal speed (in units of km / s), z - average ion charge, μ - average ion mass, γ - number of electrons per ion, v- frequency in hertz, g - free-free gunt factor, S_v- flux.

In [114], the values of $\sim\ 4 \cdot 10^{-5} M_\odot\, yr^{-1}, \sim\ 3 \cdot 10^{-5} M_\odot\, yr^{-1}$ and $\sim 4 \cdot 10^{-5} M_\odot\, yr^{-1}$ for the mass loss rate of WNE, WNL and WC stars were obtained correspondingly. The correlation between the mass loss rate and the spectral subtype was not found [114]. The polarimetric observations of 10 WR + O stars, yielded the values of $(1-10) \cdot 10^{-5} M_\odot\, yr^{-1}$ for the mass loss rate of WR stars [115].

The ring nebulae around WR stars. The authors of [116] reported about the discovery of ring nebulae around WR stars for the first time. A new type of nebula, ehe ring nebulae was revealed. Currently, more than 20 such ring nebulae have been identified. The classification of ring nebulae was carried out in [117,118]. According to this classification, these ring nebulae are divided into four types:

1. W type - (stellar windblown bubble) - mainly observed around WNE stars;
2. E type - (stellar ejected) - mainly observed around WN8 stars;
3. $R_s$type - (shell structured HII region) - mainly observed around WC stars.
4. R_a type - (amorphous HII region) - mainly observed around WNL stars.

Diameters and masses of ring nebulae occupy a wide range, 2-20 pc and 1-40 $M_\odot$ correspondingly. The expansion rates are in the range from 15 to 110 km/s. Higher values of velocities were found for E types. These differences can be due to various mechanisms of formation of these nebulae. The content of the ring nebula can be a product of mass loss by wind and the “swept up” interstellar gas. Hence, by investigating ring nebulae we could know the prehistory of the star and the environment. According to the modern view, in the formation of ring nebulae, the stellar wind, and (or) ejection from the star, as well as swept out interstellar matter, play a role. Studies of the chemical composition of ring nebulae have shown that helium and nitrogen are abundant in ring nebulae around WN stars [119]. Ring nebulae of type E are very similar to the symmetrical HII regions observed around some LBV (Luminosity BlueVariables - blue variables of high luminosity). It was believed that the ring nebulae of type E are formed before the WR, in the RSG or LBV phases.

Ring nebulae were associated with the effect of "swept out" interstellar gas by the strong stellar wind even in the pioneering work of Johnson and Hogg [116]. The theory of the interaction of the wind with the interstellar medium developed in parallel with the observations of these nebulae. And all researchers - observers and theoreticians, without any doubt have agreed with this interpretation. However, in further studies, the ring nebulae were associated with the ejection of the envelope during the evolution of a massive CBS. After that interest to these ring nebulae was increased, it became evident that the formation of ring nebulae around certain WR stars can be the result of an intensive ejection of matter from the system after the X-ray binary stage [120].

At first, it was thought that the ring nebulae exist only around the "single" WR stars of the nitrogen type (WN). However, in subsequent observations, these type nebulas were also found around WR stars of carbon type (WC). According to the VII catalog of Galactic Population I WR stars [4], the numbers of Galactic WN and WC stars with ring nebulae do not differ significantly.

7. THE GALACTIC DISTRIBUTION OF THE WOLF RAYET STARS

The study of the Galactic distribution of WR stars is important for the understanding of evolutionary relationships between different subtypes of WR stars. Studies in this direction were carried out in [121, 122], and it become clear that these stars are very young Population I members of our Galaxy. The subsystem of WR stars is very flat ($z \sim \pm 85 pc$) and occupies an intermediate place between the of OB associations ($z \sim \pm 65$ pc) and open clusters ($z \sim \pm 110 pc$). WR stars often show a genetic connection with the open clusters, with HII regions and associations. According to [123], about 10-30% of the WR stars are members of open clusters and more than 50% are members of the OB associations. From these considerations, the average age of WR stars is estimated to be$\sim 10^6$ years.

It was revealed that in the distribution along the galactic longitude, there is a wide ($\Delta l \sim 80°$) avoid zone in the direction of the anticenter ($l = 140°$–$220°$), without single WR star. This result was confirmed by the following studies. According to the modern view, the presence of an avoid zone is due to the fact that in this direction in the Galaxy the conditions for the formation of massive stars are unsuitable, because of the low heavy elements abundance [124]. It is interesting that, in this area of our Galaxy there are very young stars such as T Tauri and a group of stars with ages of $\sim 10^5$ years.

According to [125], there are significant differences in the distribution of different subtypes in our Galaxy. It was found that the ratio of WN/WC is 0.95 and 0.68 in the inner and outer parts of our Galaxy, correspondingly [125]. It is believed that this is due to the metallicity, since metallicity decreases with the transition from the center to the outer parts of the Galaxy.

The distribution of WR stars as a function of the distance (height) from the galactic plane (z distribution) was studied in [126]. It was found that some WR starsare located at high distances z from the Galactic plane. For example, for the stars HD 9974 (WN3 + abs), HD 95435 (WC5) and HD 197406, the heights from the galactic plane are z = -619.9 pc z = 305.0 pc and z = 585.7 pc, correspondingly [127]. According to the modern theories of the evolution of massive CBS, some of these stars can be WR stars with the relativistic components. The presence of these stars at large distances from the galactic plane may be due to a repulsion induced by the binary system during a supernova explosion [120]. However, according to [128] location of some WR stars at large distances from the Galactic plane, can be explained by the ejection of these stars from massive star clusters due to the effects of collective interactions.

8. INVESTIGATION OF THE WOLF RAYET STARS IN DIFFERENT REGIONS OF ELECTROMAGNETIC RADIATION

X-ray radiation of WR stars. The idea that a collision of winds in binary WR + O systems can lead to X-ray radiation was, for the first time, proposed in [129,130]. In the early X-ray experiments, it was not possible to detect X-ray radiation from WR stars. But more sensitive X-ray systems ("EINSTEIN", "ROSAT") recorded X-ray fluxes from a dozen of WR stars in the interval $L_x \sim 10^{30} - 10^{33}$ erg/s in the range of 0.5-4 keV [131].

The X-ray emission from a WR star HD 50896 (WN5) was observed by "ROSAT" [132]. The X-ray luminosity of $L_x \sim 10^{33}$ erg/s in the range of 0.1-2.5 KeV was found. According to [133], HD 50896 is a WR star with a probable relativistic component. It should be noted that these Lx values are too small for accreting neutron stars.

Significant X-ray radiation ($Lx \sim 3 \cdot 10^{33}$ erg/s) was detected from HD 193793 (WC7 + abs) [134]. The X-ray emission was also detected from WR + O systems. Examples are γ^2 Velorum (WC8 + 09I) and θ Mus (WC8 + 09.5I) [135].
Radiation of WR stars in UV. First ultraviolet observations of WR type

stars were reported in [136–139]. The equivalent widths of UV lines in the spectra of WN and WC stars are given in [139]. From the analysis of these data, the chemical composition of some WN and WC stars were determined. According to these results the content of nitrogen is overestimated in WN stars. Also the investigations revealed that the evolutionary model proposed by Pachinskii [140] for WR stars can be considered as realistic. In [141], the stratification of ions in the envelopes of various WR type stars was studied using ultra-violet lines.
Radiation of WR stars in infrared. The first results of observations of WR IR stars showed that all these stars have large IR excesses. For WN stars, the IR excess is smaller than for WC stars, and for WC9 stars it exhibits extraordinary large values. The IR excesses of WN stars can be explained by the "free-free" and "free-bound" radiation of the hot ionized envelopeand/or the presence of an optically thin emitting dust layer with the temperature of $T \sim 1500$ K. For WC9 stars, they could be explained by the thermal emission of circumstellar dust with the temperature of $T \sim 9500 - 12000$ K. Dusts probably condense from a matter emitted by WR stars. The near-IR spectral atlas of WR stars was published in [142].

9. THE MODERN EVOLUTIONARY STATUS OF WOLF RAYET STARS

After accumulation of sufficient observational (spectral, photometric, polarimetric, etc.) information, bridged with the modern theoretical knowledge, we could propose a reasonable evolutionary path of WR stars. In fact, in our Galaxy we observe: single and binary (WR + O, WR + C and WN + WC) WR stars. It should be noted that, for the formation of WR stars, the original massive star must lose large enough mass. In massive CBS, the mass loss takes place due to the stellar wind and the outflow through the internal Lagrange point after filling the Roche limitof more massive component. In [143–151], the spectral and photometric features of CBS located at different stages of evolution have been investigated.

In the case of single stars, the mass is lost only by the stellar wind. Only very massive single stars could undergo a sufficient strong stellar wind to lose large enough mass to transform to the WR star. From the morphological similarity of the spectra of some WN and Of stars Conti [152, 153] it was, for the first time,proposed that these stars are genetically interrelated. According to this hypothesis, the normal O stars first turn into Of stars and, subsequently, these stars end up with the transient WN7-9 stars [154, 155]. Next, it was found out that only very massive ($\sim 60 - 100 M_\odot$) single O stars can lose a considerable mass by a stellar wind (at the stage of hydrogen burning in the nucleus) to turn into a WR star. However, Maeder [156, 157] showed that with an intensive mass loss and internal mixing, a single star with a mass of 20-60 $M_{\odot}$ can become a WR star by the following evolutionary path: $O \rightarrow Of \rightarrow RSG \rightarrow WNE \rightarrow WC$.

Within solar metallicity, the minimum mass of a star that can turn to a WR star is $\sim 25M_{\odot}$. As noted above in the evolution of stars, the significant factor is the mass of the star. According to modern view, depending on the initial mass, the following evolutionary paths can be realized:

1. $O \rightarrow LBV/RSG \rightarrow WN(H-poor) \rightarrow SNIb$, if the initial mass is in the range 25-40 $M_{\odot}$.
2. $O \rightarrow LBV \rightarrow WN(H-poor) \rightarrow WC \rightarrow SNIc$, if the initial mass is in the range 40-75 $M_{\odot}$
3. $O \rightarrow WN(H-rich) \rightarrow LBV \rightarrow WN(H-poor) \rightarrow WC \rightarrow SNIc$, if the initial mass $\Rightarrow$ 75 $M_{\odot}$.

10. CONCLUSIONS

Albeit many of the problems related to the WR phenomenon have been studied, several significant issues are still to be addressed. Some of the problems awaiting their resolution are listed below:

1. It is hard to explain the existence of a large number WR stars in very low-metallicity Galaxies. This observational fact is at odds with the expectations of single-star evolutionary models without rotational mixing.

2. It is not clear up to now, whether the radiation pressure is sufficient to explain the mass loss rates of WR stars? The reasons for the higher mass loss rates of WR stars compared to their O star progenitors are still controversial.

3. The role of a rotation in formation of WR phenomenon,in mixing processes and masslosses.

4. The contribution of magnetic fields to the massive star evolution, angular momentum losses, and mass-losses.

5. Shape and homogeneity of WR winds. Influence of inhomogeneitiesto the determination of the fundamental stellar parameters. Relation between wind structure and mass loss.

6. The role of binaries in massive starevolution. Are there evidences for WR subtypes to stem only from a binary evolution?

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VOLF-RAYE FENOMENİNİN TƏBİƏTİ HAQQINDA

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Volf-Raye tipli ulduzların spektral, fotometrik və digər müşahidələrdən indiyə kimi aşkar edilmiş fiziki xassələri barədə geniş məlumat verilmişdir. Bu ulduzların spektral təsnifi ilə əlaqədar tarixən irəli sürülən və hal-hazırda istifadə olunan spektral təsnif sxemləri müzakirə edilmişdir. Bu ulduzların təyin olunmuş fiziki parametrləri (temperaturları, kütlələri, radiusları və s.) barədə və hal-hazırda bu ulduzlarla əlaqədar həllini gözləyən problemlər barədə məlumat verilmişdir.

Açar sözlər: Volf-Raye ulduzları – Sıx qoşa sistemlər – Spektral təsnifat – Massiv ulduzlar – Ulduzların təkamülü

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PHOTOPOLARIMETRIC SYSTEM OF ASTEROIDS

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Characterization of asteroids as an assemblage with interdependent optical variables is given. Relationships between phase coefficient and parameters of asteroid polarimetric function make possible to determine their geometric and spherical albedo, as well as the diameter.
Keywords: Asteroids – Polarimetric – Astronomical photometry

1. INTRODUCTION

Illuminance, which is created by the point source of light, in astronomical photometry is usually called by the term brightness, which is usually expressed in terms of the stellar magnitude m = - 2.5 lg E + const. Photometric function, i.e. the asteroid brightness variations in the dependence on the phase angle, was best investigated for a range of the phase angles of 0.5-30 degrees, at which observations of the main belt asteroids from the Earth's orbit are possible. The closer to the opposition of the asteroid to the Earth, the smaller the phase angle, and the brighter the asteroid becomes. As a rule, the brightness of asteroids increases non-linearly for the phase angles less than 8-10 degrees, and begins to decrease almost linearly with increasing the phase angle in the range of approximately 10-25 degrees. The dependence of the asteroid absolute stellar magnitude on the phase angle in the spectral bandpass V is expressed by the following formula:

$$V(1,\alpha) = V(1,0)\text{–}2.5\lg\phi(\alpha) \qquad (1)$$

where the phase angle with the apex at the asteroid, α, is formed by directions to the Sun and to the Earth; V(1,0) is the absolute value of the asteroid at the phase angle $\alpha = 0$; $\phi(\alpha)$ is a photometric function that depends on the light-scattering properties of surface.

Since the generally accepted theory of light scattering of asteroids has not yet been constructed, in practice photometric functions are expressed in terms of

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approximating formulae, which, with a various degree of detail, are reproduced by observational data. For example, V.G. Shevchenko proposed the following simple and fairly precise formula [1, 2]:

$$V(1,\alpha) = V(1,0) - \frac{a_{OE}}{1+\alpha} + b \times a \tag{2}$$

where the parameter a_{OE} characterizes the amplitude of nonlinear increase in brightness at small phase angles (the opposition effect of brightness change), the slope of almost linear part of the photometric function is described by the phase coefficient b, which is measured in units of "magnitude/degree". A typical photometric function of asteroids is shown in Fig. 1 (the left panel). In this example, we selected the average of a_{OE} and b for S-type asteroids, the photometric function is normalized by the condition a_{OE} = V(1,0).

Sunlight, scattered by the surface of asteroids, becomes partially linearly polarized. The degree of linear polarization is estimated by the relation

$$P = -Q/I = (I_{\perp} - I_{\parallel})/(I_{\perp} + I_{\parallel}), \tag{3}$$

where Q and the total intensity I are Stokes parameters; $I_{\parallel}$ and $I_{\perp}$ are the components of the total intensity with the oscillations of electric vector parallel and perpendicular to the scattering plane formed by the Sun-asteroid and asteroid-the Earth directions. The polarization degree, like the photometric function, depends on the phase angle. For a rough asteroid surface (as for all planets and satellites devoid of an atmosphere), since $I_{\parallel} > I_{\perp}$for the phase angles less than $\sim 20°$ the degree of polarization becomes negative for this angle range. The groundbased observations of main belt asteroids are possible for the phase angles less than 30 degrees; therefore we can investigate only the negative branch of the phase polarization curve for them.

The form of polarimetric function is much more complicated than that of photometric function. As can be seen from Fig. 1 (the right panel), the polarization vanishes at zero phase angle and an inversion angle α_i, where the polarization changes sign, and reaches its minimum value P_{min} at a phase angle α_{min}. Thus, the phase curve of polarization degree is described by four parameters: P_{min}, α_{min}, α_i and h, the slope of polarimetric curve at the inversion angle. A generally accepted theory that would explain the appearance of the polarization of light scattered by the surface of planets has not yet been created. Therefore, as for photometry, empirical formulae play an important role for reproducing the phase polarization curve on a set of discrete observational data. Such a formula, valid for a complete interval of phase angles, was proposed in [3] by one of the authors of this paper:

$$P(\alpha) = B(1 - e^{-ma})(1 - e^{-n(\alpha - \alpha_i)})(1 - e^{-l(\alpha - \phi)}) \tag{4}$$

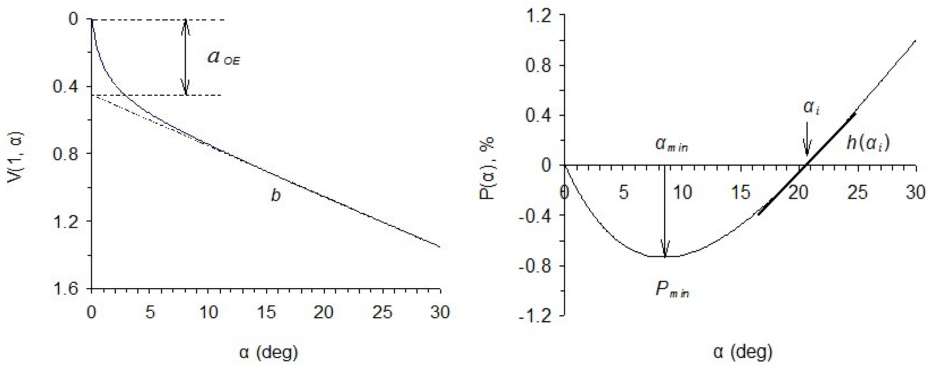

Fig. 1. The typical photometric (left) and polarimetric (right) functions of asteroids. The optical parametrs defining these function are also shown.

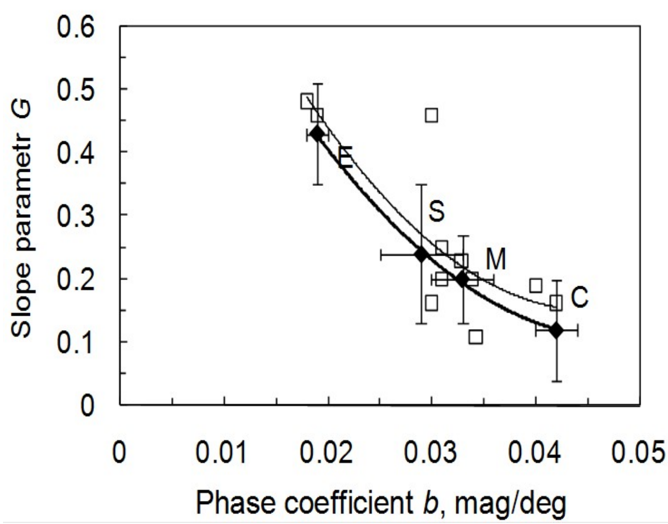

Fig. 2. Interrelation between G parameter of the photometric function and the phase coefficient b for the asteroids of different optical types. Regression lines for the averages (points) and observation data (squares) are shown.

where the scale factor B can be expressed via the slope h of polarization curve at the inversion angle

$$B = \frac{h}{n(1 - e^{-ma_i})(1 - e^{-l(\alpha_i - \phi)})}$$

In formula (3), the phase angle α varies between 0–180°; m, n, l, h, and α_i are free parameters; $P(\alpha)$ vanishes at α= 0, α_i and 180 degrees and has two extrema

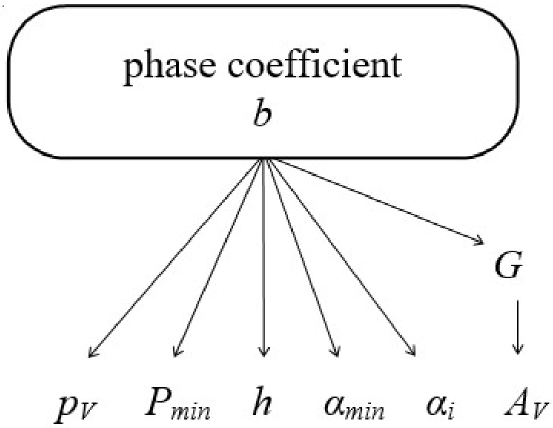

Fig. 3. The photopolarimetric system of asteroids.

(P_{min}, α_{min}) and (P_{max}, α_{max}) similar to what is observed for Mercury and the Moon.

Table 1. Correlation interrelations between the photometric and polarimetric parameters of C-, M-, S-, and E-type asteroids (R^2 is coefficient of determination).

I Regression Y along X	Y=AX^2+BX+C$\pm\Delta$					**Source**
$(Y \rightarrow X)$	A	B	C	$\Delta = \sigma_Y\sqrt{(1-R^2)}$	R^2	
$ln(p_V) \rightarrow b$		-0.01054	0.0125	~0.008	0.7396	[1]
$lg\|P_{min}\| \rightarrow lgb$		1.948139	2.895902	0.045	0.9830	[5]
$lgh \rightarrow lgb$		2.121972	2.330673	0.061	0.9746	[5]
$\alpha_{min} \rightarrow b$	4036.71	357.9341	1.683075	0.30	0.9761	[5]
$\alpha_i \rightarrow b$	-14358.9	973.9197	4.774508	0.53	0.9565	[5]
$G \rightarrow b$	378.8636	-36.4976	0.985728	0.009	0.9986	[this work]
Phase integral$\rightarrow$ G		0.290	0.684	-	-	[7]

In case of asteroids, we are interested in the interval of phase angles less than 30°, so that formula (3) can be simplified by letting the parameters n and l tend to zero (i.e. $0 < (\text{n}, \text{l}) \ll 1$). Then

$$P(\alpha) = \frac{h(1-e^{-m\alpha})(\alpha-\alpha_i)(\alpha-\pi)}{(1-e^{-m\alpha_i})(\alpha_i-\pi)} \tag{5}$$

Using this formula and the polarimetric observations of asteroids collected in the corresponding database [4] and available on the NASA PDS website, we calculated

153 phase polarization curves in different spectral bandpasses for the asteroids of different optical types [5]. The next stage of work was the search for relationships between photometric and polarimetric parameters, which determine the asteroid phase functions of brightness and polarization degree.

2. INTERRELATIONSHIPS BETWEEN PHOTOMETRIC AND POLARIMETRIC PARAMETERS OF ASTEROIDS

Indeed, we have found the number of statistically significant relationships between the phase coefficient and the parameters of the polarimetric function. It should be noted that the first on this way was Louis Bell, who in 1917 came to the conclusion that the phase coefficient b can be used to estimate the geometric albedo of asteroids [10].

The logic of his considerations was the following. A body having a smooth surface, each element of which scatters the incident light uniformly in all directions, will have a phase coefficient independent of the albedo surface. Conversely, a rough, highly textured surface, similar to that of the atmosphereless bodies of the solar system, might have a lower geometric albedo due to the fact that surface irregularities cast multiple shadows. In modern terminology, this effect is called a darkening to the limb of the visible planetary disk. L. Bell also suggested that if the normal albedo of local areas on planetary surface is sufficiently high, then the influence of shadows on the geometric albedo of the planet will become less, since the shaded areas of the surface will be illuminated by the scattered radiation of neighboring illuminated areas. Since the phase coefficient can be considered as some measure of the "degree of shadowing", then, other things being equal, the less shadowing of surface, the higher the geometric albedo and the smaller the phase coefficient.

Using known data on the geometric albedo and phase coefficients in the visible spectral range for the first four asteroids, Mercury and the Moon, as well as the results of his own photometric experiments with an artificial planet, L. Bell found an empirical relationship between the phase coefficient and the geometric albedo. Thus, in historical retrospect, L. Bell was the first to substantiate an indirect method for determining the albedo of asteroids.

For a long time, the ideas of L. Bell were not in demand, because the photographic method of observing asteroids did not allow us to determine the phase coefficients with high accuracy. Only in 1996, V.G. Shevchenko established a fairly accurate correlation between the characteristics under discussion, using, on the one hand, the radiometric albedo of p_V asteroids from IRAS data, and on the other hand, modern high-precision photometric observations of asteroids in order to calculate the value of b [1].

In turn, we confirmed the relationship between b and the maximum degree of negative polarization P_{min}, which was first discovered by us for asteroids in 1983 [5, 6]. We also found the new relationships between b and the other parameters of the negative branch of the polarization curve, namely, the inversion phase angle α_i, the phase angle α_{min}, at which the minimum polarization P_{min} arises, and the slope parameter h of the polarization curve at the inversion angle [5].

Here we present the previously unknown relationship between the phase coefficient b and the parameter G of the photometric Bowell-Lumme function [7], which according to IUE recommendation is used in calculating the ephemerides of minor planets:

$$\phi(\alpha) = (1\text{–}G)\Phi_1(\alpha) + G\Phi_2(\alpha),$$

where $\Phi_1(\alpha) = \exp\text{–}\ 3.33[\tan\ (\alpha/2)]^{0.63}$, $\Phi_2\ (\alpha) = \exp\text{–}\ 1.87[\tan\ (\alpha/2)]^{1.22}$ and G is the only parameter of the function. Fig. 2 shows the relationship between the average values of b and G, which are typical both for asteroids from the optical types C, M, S E and original data. The average data for these optical parameters are taken from [8, 9]. The regression lines shown in this figure are in a statistical sense identical because of the close values of regression equation coefficients and their errors. It was shown in [7] that the phase integral q can be approximately estimated using the parameter G of the photometric function: q = 0.290 + 0.684G. Therefore, taking into account the data in Fig. 2, we can estimate the spherical albedo of the asteroid, $A_S = q \times p_V$ if its phase coefficient is known.

So, knowing only the phase coefficient of an asteroid allows us to estimate with an acceptable accuracy its geometric and spherical albedos, as well as all the parameters of the phase branch of negative polarization and, as a pleasant bonus, the diameter of asteroid. This remarkable property of the regolith of minor planets we called the photopolarimetric system of asteroids, and its schematic representation is shown in Fig. 3 and Table 1 gives the coefficients of correlation equations between the optical parameters under discussion, the errors that accompany the estimation of parameters, and the values of uncertainty coefficient.

3. CONCLUSIONS

The optical properties of asteroid regolith, which determine the photopolarimetric system, can be briefly formulated as follows. The lower the albedo of the rough granulated surface of asteroids with a complex "open" relief, the greater the density of shadow that surface irregularities cast that in turn leads to an increase in the phase coefficient, the amplitude of the negative polarization branch, and the slope parameter. The interrelationships between b and the remaining optical parameters help to attribute an asteroid to the most common optical types E, S, M or C. It is interesting that such a traditional method of astronomical observations, like photometric, allows one not only to determine the shape and dynamic properties of asteroids, but to perform preliminary optical classification and estimate its diameter. Good prospects in this sense open up for the faint asteroids of the main belt and NEA, since for most of them the optical type and diameter, remain unknown.

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ASTEROİDLƏRİN FOTOPOLYARİMETRİK SİSTEMİ

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Asteroidlər, optik dəyişənləri bir-biri ilə qarşılıqlı əlaqəli olan cisimlər toplusu kimi təsvir edilmişdir. Asteroidlərin faza əmsalı ilə polyarimetrik funksiyalarının parametrləri arasındakı qarşılıqlı əlaqə onların həndəsi və sferik albedolarını, həmçinin, diametrlərini təyin etməyə imkan verir.

Açar sözlər: Asteroidlər – Polyarimetrik – Astrofiziki fotometriya

CHRONICLE-2017

1. In January 2017, Shamakhi Astrophysical Observatory named after N. Tusi of ANAS signed an agreement on cooperation with the Institute of Ecology of the National Aerospace Agency on the joint investigations of the structure and transformation of the planet's atmosphere.

2. R. Ismayilli, junior researcher of ShAO, was delegated to the Siegen University, Germany for a period of 90 days from 23 January by the Decree of the Presidium of ANAS No.1/12 dated on 18 January, 2016.

3. Since 2017 ShAO is one of the parties involved in the agreement on scientific-technical cooperation between ANAS and Moscow State University (State Astronomical Institute named after P. Shternberg).

4. The board of the dissertation council FD.01.241 holding the defense of the dissertations submitted for the scientific degree of Doctor of Philosophy approved by the Higher Attestation Commission under the President of the Republic of Azerbaijan by the order No.60 dated 07 March 2017, and the term of office of the council is defined till December 15, 2018.

5. The 80^{th} anniversary of the researcher of ShAO L.S. Salmanova was celebrated on 13 March, 2017 on 13 March, 2017.

6. The 70^{th} anniversary of the leading researcher of ShAO, Ph.D., P. Shustarev was celebrated on 13 March, 2017.

7. By order No.161 dated on March 14, 2017, signed by Presidium of ANAS, Director of ShAO, Corresponding Member of ANAS Namig Dzhalilov was delegated to Moscow, Russia for the period of 20-31 March 2017.

8. By the Decision of the Presidium of ANAS No. 5/5 dated on 15 March 2016, the name of the Department "Solar and Solar-Physical Relations Physics" of ShAOwas changed to "Cosmic Plasma and Heliogeophysical Problems"; "Technical Support of Observations"- to "Astronomical devices and innovative technologies". The departments "Spectroscopy of the Celestial Spheres" and "Photometry and Polarimetry of the Celestial Bodies" have been abolished and new departments of "Star Physics and Magnetism", "Dual Boots and Eruptive Processes" and "Galaxies and Star-building Processes" have been organized.

9. By the decision of Presidium of ANAS the theme "Solar Cyclic Magnetic Activity of the Sun and its Geophysical-Ecological Manifestations" was included in the list of scientific research programs funded by Presidium of

ANAS (Head of the program: Kh. M. Mikayilov; Implementation period: 24 months; Implementing organizations: ShAO, Institute of Physiology, Institute of Geology and Geophysics, Republican Seismological Service Center, Batabat Astrophysical Observatory, IZMIRAN)

10. The Second conference "Physics and Lyrics" on "Novruz calendar: in lyric and astrophysics" was held jointly with the Institute of Literature named after Nizami and the House of Scientists on March 18-19, 2017.

11. From April 3 to 17, 2017, the head of department, Ph.D., associate professor C. Rustamov was sent to the Kazan State University, Russia.

12. On April 5, 2017, an agreement was signed to establish a branch of the Astrophysics chair of Baku State University at ShAO.

13. Corresponding member of ANAS, Professor A. Guliyev was relieved of his membership in the dissertation council FD.01.241 by the order of the Higher Attestation Commission under the President of the Republic of Azerbaijan No.129 dated April 17, 2017 since he was appointed to the post of Deputy Chairman of the Expert Council on Physics and Astronomy.

14. The 65^{th} anniversary of the senior researcher of ShAO, Ph.D., associate professor D. Shestopalov was celebrated on April 22, 2017.

15. On May 19-21, 2017, Professor of the University of Maryland, USA, academician R. Sagdeyev, senior researcher of the Moscow State University named after Lomonosov Y. Popova and professor of the University of Maryland, USA D.Usikov participated and gave a talk in the seminar in ShaO.

16. The 80^{th} anniversary of the leading scientific researcher of ShAO, Ph.D., associate professor R.Zeynalov was celebrated on May 20, 2017.

17. By order No. 200 of the Higher Attestation Commission under the President of the Republic of Azerbaijan dated on May 22, 2017 Professor of the Department of Mathematical Analysis of Baku State University, Ph.D., S. Abdullayev, was included in the dissertation council FD.01.241 at the ShAO on the specialty "2104.01-Planetology".

18. On 24 May, 2017 Director of ShAO N. Dzhalilov made a report at the conference organized by the Caucasian Muslims Office on Ramadan.

19. On May 27, 2017, former chief scientific researcher of ShAO, now living in Russia, Ph.D. Hasanalzadeh gave the books from his personal library to the library of the ShAO (1490 books and journals).

20. On June 9, 2017 the official representative of the Presidential Administration, with the support of the “Bilik” Foundation, A. Abdullayev held a seminar entitled “Ilham Aliyev and the direction of the state policy”.

21. On 26-30 June 2017, the chief scientific officer of the ShAO, N. Ismayilov and the senior researcher, R. Guliyev were sent to participate at the Congress of the European Astronomical Society (EWASS 2017) held in Prague, Czech Republic.

22. On July 12, 2017 Chairman of the State Committee for Religious Affairs under the Cabinet of Ministers of the Republic of Uzbekistan A. Yusupov and chairman of the Uzbek Muslims Office Mufti U. Alimov visited ShAO accompanied by Chairman of the State Committee for Religious Affairs M. Gurbanli and Chairman of the Caucasian Muslims Office A. Pashazadeh.

23. On July 17, 2017, the presentation of the new version of ShAO website was held at the Institute of Information Technology of ANAS.

24. On July 19, 2017, the Scientific Center of the Azerbaijan National Encyclopedia of ANAS was donated two copies of the printed volume of the "National Encyclopedia of Azerbaijan" to ShAO Library.

25. On July 18-28, 2017, Senior Researcher of ShAO H. Adigozalzadeh participated in the international summer school “Space missions: ground-based observations and scientific communications” organized in Vilnius, Lithuania.

26. On July 27, 2017, the International Scientific Conference on “Climate change, air pollution sciences and scientific research opportunities for Azerbaijan” was organized by leading researcher of Earth Sciences Research Laboratory of the US National Oceanic and Atmospheric AdministrationR. Ahmedov.

27. From July 31 to August 4, 2017, vice-director of ShAO for Science, Ph.D., Associate Professor E. Babayev attended a joint event organized by the UN and NASA (United Nations/United States of America Workshop on The International Space Weather Initiative: The Decade After The International Heliophysical Year 2007 is a joint venture between the National Aeronautics and Space Administration and Boston College, Chestnut Hill, Massachusetts, United States of America).

28. On 7-11, August, 2017 the research assistant of ShAO F. Mustafa took part in theinternational astronomy training, organized by the International

Astronomy Center under the auspices of UNESCO and Thailand National Astronomical Research Institute in the Kingdom of Thailand.

29. From August 13 to 20, 2017, Associate Professor, Ph.D., B. Rustamov, and Associate Professor A. Atayi attended the 9th Advanced Astrophysics Workshop of Marageh/Iran, organized by Maragha Astronomy and Astrophysics Scientific Research Institute by the invitation of the Director of Maragha Astronomy and Astrophysics Scientific Research Institute Dr.Hossein Ebadin.

30. On 04-08 September 2017, the chief researcher of ShAO, correspondent member of ANAS A. Guliyev took part in theInternational Conference "VI Bredikhin Conference" in Zavolzhsk, Russia, organized by the Institute of Astronomy of RAS, in honor of the Russian astronomer F.Abdigin, who has a great share in the development of comet and meteorological researches.

31. From 04 to 08 September 2017, researcher of ShAO R. Ismayilli participated in ESPM-15 (15th European Solar Physics Meeting) held in Budapest, Hungary, with the grant support of ANAS and the Youth Foundation under the President of the Republic of Azerbaijan.

32. For the first time in the history two persons were stayed to the Magistracy of ShAO on the specialty 249389-Astrophysics according to the Order of the State Examination Center No.9/Q dated 11.09.2017 and the Order No.620 of the President of ANAS for the 2017/2018 academic year.

33. On September 21-24, 2017, senior researcher of ShAO, Corresponding Member of ANAS A. Guliyev took part in the International Conference organized by the International Meteorological Organization (International Meteor Conference-2017) at the Petnicha Scientific Center in the Republic of Serbia.

34. On 24-30 September 2017, junior researcher R. Ismayilli participated in the 4th International School of Young Scholars of the CIS countries, entitled "Smooth Problems of Physics and Astrophysics in the Greater Particles of Superheavy Energies", organized in Almaty by the Institute of Physics named after Lebedev and supported by the CIS Intergovernmental Humanitarian Cooperation Fund.

35. On September 25-27, 2017, head of department of ShAO A. Atayi, leading researcher, Ph.D. B. Rajabov and researcher U. Gadirova participated in the International Conference "Modern Problems of Astrophysics-III" dedicated to the 110th anniversary of Kharadze in Akhalsixa, Samtskhe-Javakhetia State University, Republic of Georgia.

36. On September 7, 2017 the term of the visit of senior researcher of ShAO, Ph.D., Sh. Nabiyev to the United States Astronomical Institute (Hawaii) (Deadline: 01.09.2016 - 31.08.2017, Decision 9/37 of 29 dated June 2016, Presidium of ANAS), extended to one year (until 31.08.2018) by the decision of FRTEB 8/4 of ANAS.

37. On 04 October 2017, the meeting of the ShAO Trade Union Organization was held and for the next period the members of the Trade Union Committee and the Chairman were elected.

38. On October 13-20, 2017 the leading researcher of ShAO, Ph.D. S. Aliyev visited the Russian Academy of Sciences, Special Astrophysical Observatory.

39. On October 18, 2017 the leading researcher of ShAO, Ph.D. Y. Maharramova was nominated to the Higher Attestation Commission under the President of the Republic of Azerbaijanfor giving the scientific degree of Associate Professor onthe specialty Astrophysics and Star Astronomy-2108.01.

40. On November 1, 2017, the senior researcher of ShAO, Ph.D. H. Adigozalzadeh was nominated to Higher Attestation Commission under the President of the Republic of Azerbaijan for giving the scientific degree of Associate Professor on the specialty Astrophysics and Star Astronomy-2108.01.

41. On November 6, 2017, the results of the photo contest "Discover the universe", organized by the ShAO and supported by the Azerbaijani Photographers Union were announced.

42. On November 07-10, 2017, Associate Professor E. Babayev, Deputy Director of the Research Department, participated in the World Science Forum in Jordan.

43. On November 8, 2017, in ShAO it was held International Astroseminar "Modern Fundamental Science: New Neighbors and Perspectives" organized by Prof. Dr. A.Aliyev from Turkey.

44. On November 18, 2017, 100th year anniversary of prominent scientist and military officer, active participant of the space programs, the Honorary Hero of the Socialist Labor, State and Lenin Prize laureate, Honorary Member of the Azerbaijan National Academy of Sciences, lieutenant-general K. Karimov was celebrated in ShAO. Russian cosmonaut O. Kotov and responsible persons of ANAS took part in the event.

45. By Decision No.10/6 of the National Academy of Sciences of the Republic of Azerbaijan dated November 28, 2010, R. Ismayilli, junior resercher of

ANAS, has been sent to the Siegen University, Federal Republic of Germany for 65 days from November 18, 2017.

46. On November 20-22, 2017, Head of Department, Ph.D. Associate Professor J. Rustamov, participated in the “United Nations / Italy Workshop, on the Open Universe Initiative" event held in the Austrian Republic.

47. On November 20-22, 2017, researcher G. Bahaddinova participated in the conference “Promoting Sustainable Energy Solutions and Clean Technologies in CIS Countries” in the Austrian Republic.

48. On November 8, 2017, the film Sorin Stars ("Sorin Stars") was demonstrated talking about the life and activities of S. Sorin, the head of the Astronomical Society named after Y. Gagarin Pioneer Palace, prepared by the Creative Group of the Russian Information and Cultural Center (RICC) in Baku.

49. On 14-15 November 2017, the annual scientific report presentation of ShAO for 2017 was held.

50. Director’s report on the results of scientific and scientific-organizational activities for the year 2017 in ShAO was presented.

51. By the decree of the Presidium of ANAS No: 14/12 dated December 20, 2017 the laboratory “Physics of cosmos and cosmic space” was established jointly with ShAO, ANAS, Azercosmos OSC.

52. On December 22, 2017, A. Soltanov, who worked as an electronic engineer in the ShAO, died.

53. On December 26, 2017, Director of ShAO, Corresponding Member of ANAS N. Dzhalilov presented a report on the results of the scientific and scientific-organizational activities of ShAO for 2017 in ANAS.

54. The 80^{th} anniversary of the member of an editorial board of the "Astronomical Journal of Azerbaijan", Dr. Prof. V. N. Obridko (Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation // Russian Academy of Sciences) was celebrated.