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A B S T R A C T

of the dissertation for the degree of Doctor of Sciences

SPECTRAL AND PHOTOMETRIC PROPERTIES OF MASSIVE CLOSE BINARY SYSTEMS IN DIFFERENT STAGES OF EVOLUTION

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GENERAL DESCRIPTION OF WORK

Relevance of the research topic. This dissertation is devoted to the spectral and photometric studies of massive close binary systems (MCBS) at different stages of evolution. Due to the fact that MCBS are populated only in spiral galaxies, and these galaxies played an extremely important role in understanding the evolutionary properties of MCBS, we also carried out studies of formation of spiral structures in galaxies.

It is known that the massive components of the MCBS at the end of evolution explode as supernovae, and due to this explosion the interstellar medium of the galaxy enriches with the heavy chemical elements[1, 2]. As a result of this explosion, a huge amount of mechanical energy also transferred to the interstellar medium. The enrichment of the interstellar medium with heavy chemical elements and transferring of enormous mechanical energy to this medium play an important role in the evolution of galaxies.

In the last century, astronomers could not explain why type II supernova explosions occur only in spiral galaxies. After the development of the theory of evolution of MCBS, it became clear that the occurrence of type II supernova explosions in spiral galaxies is directly related to the presence of MCBS in these galaxies. Since, MCBS at the end of evolution explode as type II supernovae. Note that type II supernovae are observed in the spiral arms of spiral galaxies. Supernova explosions of this type do not occur in elliptical galaxies[1, 2].

Despite the fact that numerous works have been devoted to the study of MCBS, there are still a lot of unsolved problems in this area of research. Revealing the new observational facts is important for the testing the conclusions and refining the theory of evolution of MCBS.

[1] Matteucci, F. The role of massive stars in galactic chemical evolution // arXiv:0803.3016 [astro-ph], – 2008, – p.119-130.

[2] Лозинская Т.А. Сверхновые звезды и звездный ветер. Взаимодействие с газом галактики / Москва, издательство Наука, – 1986, – 304 с.

A star is considered as massive if its mass exceeds ~10 $M_\odot$. This value of mass is due to the fact that stars with the masses greater than ~10 $M_\odot$ explode as supernovae at the end of their evolution[3, 4]. More different physical phenomena occur when a massive star is a member of a binary system. According to modern view, more than half of the stars in our Galaxy are members of binary and multiple systems. The binary becomes even more interesting if the binary is close binary. Close binary systems (CBS) are those binary systems in which, at some stage of evolution, takes place an intense exchange of mass between the components[3]. According to theories evolution of MCBS, the more massive component of the binary system evolves faster, since the rate of a star's evolution critically depends on its mass. Consequently, the massive component of the MCBS, evolving faster, first fills its Roche lobe, and begins an intensive process of overflow of mass from a more massive component to another, through the inner Lagrange point. Figure 1 shows a schematic model of MCBS with the masses of component 20 $M_\odot$ and 8 $M_\odot$[3].

The relevance studying of MCBS is associated with the following global problems of modern astrophysics:

1. The formation of exotic astrophysical objects of modern astrophysics, such as Wolf-Rayet (WR) stars, neutron stars and black holes, is associated with the evolution of MCBS[3]. At the end of their evolution, the massive components of the MCBS explode as supernovae and, depending on its initial mass, neutron stars or black holes are formed[3, 4].
2. MCBS exploding as a supernova, at the end of evolution, enriches galaxies with the heavy chemical elements. According to modern view, the Universe was formed ~13.8 billion years ago as a result of the Big Bang (BB). In the era of primary nucleosynthesis of BB

[3]Черепащук А. М. Тесные двойные звезды I часть / Москва, издательство Физматлит, – 2013, – 559 с.

[4]Черепащук А. М. Тесные двойные звезды. II часть / Москва, издательство Физматлит, – 2013, – 570 с.

nuclei of hydrogen (~75%), helium (~25%) and a negligible fraction of lithium were formed[5]. In the epoch of recombination, ~ 380 000 years after the BB, atoms of hydrogen (~75%) and helium (~25%) were formed. The other chemical elements (up to the elements of the iron group) were formed in nuclear reactions occurring in the cores of massive stars. Chemical elements heavier than iron were formed during the explosion of MCBS as a supernova, at the end of their evolution[5].

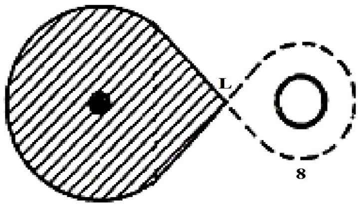

Fig.1. The schematic model of MCBS with the masses of component 20 $M_{\odot}$ and 8 $M_{\odot}$[3]. L is the internal Lagrangian point. The hatched part is a Roche cavity of a component with a mass of 20 $M_{\odot}$.

3. MCBS enriches galaxies with heavy elements, increases the "metallicity" of the interstellar medium[1, 2]. Note that in contrast to chemistry in astronomy, chemical elements, heavy than helium, are called "metals". It is known that the "metallicity" of the interstellar medium plays an important role in the formation of next generations of stars. Taking into account that galaxies are the main fundamental structural elements of the Universe, it can be argued that MCBS play an important role in understanding of evolutionary features of the Universe as a whole.
4. Due to its high luminosity, MCBS are the only sources of information about spiral galaxies located at great distances.

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[5]Gorbunov D.S., Rubakov V.A. Introduction to the Theory of the Early Universe: Hot Big Bang Theory / World Scientific Publishing Co. Pte. Ltd., Singapure 596224, – 2011, – p.471.

Despite the fact that by now several hypotheses have been proposed, with the help of which astronomers try to explain the origin of spiral structures of galaxies, to date, there is no satisfactory theory about the origin of these structures[6, 7]. It is known that the majority (more than 50%) of galaxies in the Universe are spiral galaxies. However, to date, the mechanism formation of spiral structures in galaxies is not fully understood. It is known that the spiral structures of galaxies are quite stable, since this structure does not decay for billions of years[7]. It turns out that the study of the origin of spiral structures of galaxies is one of the actual problems of modern astrophysics. We have proposed an original idea explaining the formation of spiral structures in galaxies. We argue that the "embryos" of the spiral structure of galaxies are forming during the first microseconds after the BB.

Object and subject of research. The main objects of dissertation are MCBS at different stages of evolution (HD 206267, HD 191765, HD 192163, HD 197406, HD 50896, LZ Cep, β Lyr) and spiral galaxies. The subject of research is spectral and photometric studies of MCBS and the origin of spiral structures in galaxies.

The purpose and tasks of the work. The main goal and task of the thesis is the spectral and photometric study of MCBS at different stages of evolution, as well as the study of the origin of spiral structures of galaxies.

The tasks were as follows:

1. Selection of MCBS corresponding to the various stages of evolution. Accordingly, the following objects have been selected: HD 206267, HD 191765, HD 192163, HD 197406, HD 50896, LZ Cep, β Lyr.
2. Carrying out the spectral observations of selected stars at 2-m and the photometric observations at 60-cm telescopes of ShAO.

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[6]Shu F.H. Six decades of spiral density wave theory // Annual Review of Astronomy and Astrophysics, – 2016, 54, – p.667-724.

[7]Naab T., Ostriker P.J. Theoretical challenges in galactic formation / Annual Review of Astronomy and Astrophysics, – 2017, 55, – p.59-109.

3. The choice programs for processing and analysis of the obtained spectral and photometric observational data. The spectral and photometric data were processed by using the DECH and MaxIm DL software correspondingly.
4. Analysis of the possible origin of spiral structures of galaxies, considering the possibility of the formation of these structures in the first microseconds of BB. Search for possible methods for the revealing the spiral structures.
5. Processing, analysis and interpretation of the data obtained.

Research methods. In processing spectral and photometric observations, the DECH and MaxIm DL software packages were used. The study of the spiral structure of galaxies was carried out by using self-similarity. A method for the revealing the spiral structures are proposed.

The main provisions submitted to the defense: The following provisions are submitted to the defense.

1. The unusual photometric variability of WR type star HD 191765. From photometric observations it was revealed that, the magnitude of this star varies from $8^m.0$ to $8^m.1$ within ~ 10 minutes.
2. The revealed WR stars with the probable compact components which are progenitors of X-ray binaries with the "normal" low-mass (K-M) components. As a result of studies of stars HD 192163, HD 191765, HD 50896 and HD 197406, we have confirmed that these stars are WR + (K-M) binaries. According to the theory of evolution of MCBS, WR + (K-M) binaries are evolutionary progenitors of X-ray binaries, with the "normal" low-mass (K-M) components.
3. Contribution of the Ring Nebula NGC 6888, surrounding the stars HD 192163, to the formation of the lines NaI 5890 and NaI 5896.
4. The revealed difference in the spectral classification of WR stars, HD 191765 and HD 192163. Since the star HD 192163 more closely corresponds to the subtype WN6, and the star HD 191765 is located on the border between WN5 and WN6.

5. Stable weak emission in the violet wing of line H_α, the appearance and motion of Discrete Absorption Components (DACs) in the core of line H_α in the spectrum of the star HD 206267. DACs appeared in the red side of core of the line H_α and within about 1.5 h moved to the violet side.
6. The asymmetry of the H_α and H_β lines in the spectrum of the star HD 206267, and the change of these asymmetries over time. For the H_α and H_β lines, the opposite asymmetry was found, i.e. when the line H_α is asymmetric on the violet wing, the line H_β is asymmetric on the red wing and vice versa.
7. The determined value of the orbital period of the star β Lyr corresponding to our observational season (July-August of 2016) as 12.9414 days. It is known that due to the intense mass loss of the main component of the star β Lyr, the value of the orbital period of this system increases by ~19 seconds in one year. Consequently, when studying this star, it is necessary to determine the value of the orbital period corresponding to the observational season.
8. Additional observational argument indicating the presence of two hot spots near phases 0.4 and 0.8 of the orbital period on the disk, surrounding secondary component of the star β Lyr. We revealed two maxima in the dependence of the ratio of the intensities of the violet and red components of H_α and HeI 6678 lines on the phase of the orbital period, at phases of about 0.4 and 0.8.
9. The forming of the “embryos” of the spiral structures of galaxies during the first microseconds of the BB. In the first microseconds of BP, near the critical point during the transition from quark gluon plasma to hadron, the spiral structure formed as a result of the correlation length approaching infinity becomes the “embryo” of the spiral structure of galaxies.
10. A new indicator for the second type of phase transition. The spiral structure formed near the critical point is an indicator of the second type of phase transition.

Scientific novelty of the research. The scientific novelty of the work is determined by the following results:

1. Revealed unusual photometric variability of the WR star, HD 191765. From photometric observations of this star, an increase in the magnitude of the star HD 191765 by $0^m.1$ during ~ 10 minutes was found.
2. It was revealed that some WR stars with the probable compact components may be the progenitors of X-ray binaries with the low-mass (K-M) components. As a result of spectral and photometric study of HD 192163 and HD 191765 stars and by analysing of scientific literature for HD 50896, HD 197406 stars, it was revealed that these stars are WR + (K-M) binary systems. According to the theory of evolution of MCBS the WR star in the WR + (K-M) binary system explodes as an supernova at the end of evolution and forms a source of X-ray radiation with a low mass (K-M) component.
3. The stable weak emission in the violet wing of the line H_α, the appearance and motion of DACs in the core of the line H_α in the spectrum of the star HD 206267 was revealed. DACs appeared in the red side of the core of line H_α and within about 1.5 h moved to the violet side.
4. The additional observational fact, indicating the presence of two hot spots near the phase of ~0.4 and ~0.8 of the orbital period, on the disk, surrounding secondary component of the star β Lyr was revealed.
5. Conclusion on the formation of the “embryo” of the spiral structure of galaxies in the first microseconds of BP. If the collision of particles occurs near a critical point, due to the correlation length approaches infinity, the system becomes self-similar and fractalized. It is known that the most perfect self-similar figure is a logarithmic spiral. So, if the collision of particles takes place near a critical point, a spiral structure is formed, and this spiral structure becomes the “embryo” of galaxies.
6. The new indicator (spiral structure) has been revealed for a second order phase transition.

The practical and theoretical value of the work. The practical and theoretical value of the work is as follows:

1. The applied method of processing and analyzing of observational (spectral and photometric) data as well as the interpretation of results can be used in similar studies.
2. The results of spectral and photometric studies are a source of data for corresponding catalogs.
3. The results obtained by us are important in theoretical studies of the evolutionary properties of MCBS. Our observational data are important sources of information for the plotting of physical models of MCBS.
4. Our hypothesis that the "embryos" of the spiral structure of galaxies were formed during the first microseconds after the BB is a subject for further comprehensive studies in the field of understanding the origin of spiral structures of galaxies.
5. The indicator for the second order phase transition revealed by us is important for the detection of second order phase transitions.

The credibility of the thesis. The reliability of the thesis is connected by the using of precise methods in obtaining and processing of observational data. Were used the software packages (DECH, MaxIm DL, etc.), widely used, by the astronomers in various advanced observatories in the world. Our results have been repeatedly reported in Republican and International scientific conferences, and received positive feedbacks.

Approbation of work. The main results of the dissertation were reported and discussed at the following Republican, International conferences and scientific seminars:

1. I Republican Scientific Conference "Modern Problems of Physics", Baku State University, Baku, December 6-8, 2007.
2. International Conference on Physical, Mathematical and Technical Sciences, Nakhichevan, November 07-08, 2008
3. International Conference on Astronomy, Physics and Mathematics, dedicated to the International Year of Astronomy, Nakhichevan, November 16-17, 2009.
4. International conference dedicated to the 90th anniversary of Baku State University, Baku, October 30-31, 2009.

5. III Republican Scientific Conference "Modern Problems of Physics", Baku State University, Baku, December 17-18, 2009.
6. VI Republican Scientific Conference "Actual Problems of Physics", Baku State University, Baku, November 20, 2010.
7. VII Republican Scientific Conference "Actual Problems of Physics", BSU, Azerbaijan, November 26, 2012.
8. VI Republican Scientific Conference "Modern Problems of Physics", Baku State University, Baku, December 14-15, 2012.
9. International Scientific Conference "Actual Problems of Physics" dedicated to the 80th anniversary of the birth of acad. B.M. Askerova, Baku State University, Baku, December 6, 2013.
10. VII Republican Scientific Conference "Modern Problems of Physics", Baku State University, Baku, December 14-15, 2013.
11. II International Scientific Conference dedicated to the 91st anniversary of the National Leader of the Azerbaijani people G. Aliyev, Baku, April 18-19, 2014.
12. All-Union Scientific Conference, Astronomical School of Young Scientists, Ukraine, Kiev, May 20-22, 2015.
13. III International Scientific Conference dedicated to the 92 nd anniversary of the National Leader of the Azerbaijani people G. Aliyev, Baku, April 17-18, 2015.
14. IV International Scientific Conference dedicated to the 93 rd anniversary of the National Leader of the Azerbaijani people G. Aliyev, Baku, April 29-30, 2016.
15. All-Union Scientific Conference, Astronomical School of Young Scientists, Ukraine, Kiev, May 26-27, 2016.
16. I scientific-practical conference "Creative potential of youth in solving aerospace problems", February 29 - March 01, 2016.
17. International Astronomical Conference "Physics of Stars: from Collapse to Collapse", Special Astrophysical Observatory of the Russian Academy of Sciences, Nizhny Arkhyz, Russia, October 3-7, 2016.
18. International conference "Physics of stars and planets: atmospheres, activity, magnetic fields", Shamakhy Astrophysical Observatory, Shamakhy, September 16-20, 2019

19. I scientific-practical conference "Creative potential of youth in solving aerospace problems", Baku, February 02-04, 2021.
20. General Scientific “Astroseminars” of the Shamakhy Astrophysical Observatory.
21. At scientific seminars of the State Astronomical Institute. P.K. Sternberg (GAISH) at the Moscow State University of Russia.
22. At scientific seminars of the Department of Astronomy and Space Geodesy of the Kazan Federal University of Russia.
23. At scientific seminars at the Montreal University of Canada.
24. At scientific seminars of the European Center for Nuclear Research (CERN).

Publications on the topic of the dissertation. 39 scientific articles in scientific journals recommended by the Supreme Attestation Commission under the President of the Azerbaijan Republic, 17 abstracts of reports at conferences and one monograph were published on the topic of the dissertation. 8 scientific articles were published in foreign journals with the high impact factor. 17 articles and 5 abstracts are without coauthors.

The name of the organization in which the dissertation work was performed: The work was performed in the department “Physics of stellar atmospheres and magnetism”, of Shamakhy Astrophysical Observatory named after N. Tusi of the Azerbaijan National Academy of Sciences.

Personal contribution of the author. All spectral observations at 2-m telescope and photometric observations at 60-cm telescope of ShAO named after N. Tusi of the Azerbaijan National Academy of Sciences were performed by the author. Photometric data processing was also carried out by the author. A.F. Abdulkerimova, an employee of the Department of “Physics of stellar atmospheres and magnetism”, partly participated in the processing of the spectral data for the star HD 206267. The processing of spectral data of the remaining stars was carried out by the author. The author gave an analysis of the data obtained, prepared articles for publication.

The volume and structure of the thesis. The thesis consists of the introduction of 71 978 signs (title page - 351 signs, table of contents - 5428 signs) from six chapters (chapter I – 83 300 signs, chapter II – 28 997 signs, chapter III – 29 935 signs, chapter IV – 44 573 signs, chapter V – 54 534 signs, chapter VI – 76 376 signs), results - 4674 signs and a list of cited literature, numbering 305 titles. The total volume (without tables, graphs and figures) of the thesis is 400 146 signs.

The author is deeply grateful to academician of the Russian Academy of Sciences A.M.Cherepashchuk and to the staff of the department of "Stellar Astronomy" of the State Astronomical Institute named after P.K.Sternberg, at Moscow State University, with whom many of the results presented in the thesis were discussed.

The author is deeply grateful to all scientific researchers of ShAO for useful discussions of the results presented in the thesis and valuable comments that stimulated the performing of this work.

THE MAIN CONTENT OF THE DISSERTATION

The dissertation consists of an introduction, six chapters and a list of cited references.

In the introduction, substantiates the relevance of the topic, shows the unsolved problems in this area of research, formulates the goals and objectives of the research, sets out the provisions for defense, the scientific novelty and practical value of the results obtained, and the methodology used. The list of Republican and International scientific conferences, as well as scientific seminars, at which the results of the dissertation were discussed is given and the structure of the dissertation is described.

The first chapter describes the evolutionary features of MCBS and the mechanism of formation of WR-type stars in these systems. According to the results of theoretical research[8] the evolution of MCBS takes place through the following five stages:

$$O_1 + O_2 \rightarrow WR_1 + O_{2*} \rightarrow C + O_{2*} \rightarrow C + WR_2 \rightarrow C + C$$

[8]Масевич А.Г., Тутуков А.В. Эволюция звезд: теория и наблюдения / Изд-во Москва, Наука, – 1988, – 280 с.

At the initial stage, the system consists of two O stars: O_1 + O_2. It is known that the rate of evolution of a star critically depends on its mass[8]. Therefore, the more massive component of the MCBS (for example, O_1), evolving faster, fills its Roche lobe and begins intensively lose mass through the inner Lagrange point (Fig. 1). This process is called the primary mass exchange[8]. The massive component O_1, losing its hydrogen abundant outer shell, turns into the WR star and the $WR_1 + O_{2*}$ system is formed. The sign * in the subscript of O_2 indicates the fact that the mass of this star has increased due to the star O_1 during the primary mass exchange. Note that dozens of WR binary stars with O components are known from the observations.

During the subsequent evolution, the star WR_1 explodes as a supernova and, depending on the initial mass of this star, a neutron star or a black hole is formed. The binary $WR_1 + O_{2*}$ system transforms into $C + O_{2*}$ system, which is called the O star with a compact component. The compact component (C) could be a neutron star or a black hole. O stars with compact components are called "runaway" stars in the scientific literature. This name is due to the fact that they are mainly located at great distances from the galactic plane. After some time, the O_{2*} star in the $C + O_{2*}$ binary system fills its Roche lobe and undergoes intense mass loss through the inner Lagrange point. This process is called the process of secondary mass exchange in MCBS. After the secondary mass exchange, a WR star with a compact component is formed: $C + WR_2$.

Note that the existence of WR stars with the compact components was first predicted theoretically. Observational search for these objects has revealed only one WR star with a compact component in our galaxy: Cyg X-3 (WN3-7 + C)[9].

Ultimately, in binary system $C + WR_2$ the star WR_2 explodes as a supernova. Theorists believed that in this case the binary system should disintegrate, since the more massive component of this

[9]Van Kerkwijk M.N., Charles, P.A., Geballe, T.R., et al. Infrared helium emission lines from Cygnus X-3 suggesting a Wolf-Rayet companion // Nature, – 1992, 355, – p.703-705.

system explodes. However, contrary to theoretical statements, to date, a large number of double pulsars have been discovered from the observations[10].

The main properties of WR stars revealed from observations are presented. The spectra of these stars contain very strong and broad emission lines of nitrogen, carbon, oxygen, helium and hydrogen corresponding to different stages of ionization (NII-NV, CII-CIV, OIV-OVI, HeI, HeII, HI)[10]. According to the ratios of intensities, selected lines of nitrogen, carbon and oxygen ions, WR stars are subdivided into three types: nitrogen (WN), carbon (WC), and oxygen (WO). The spectra of WN stars mainly contain nitrogen lines, the spectra of WC stars mainly contain carbon lines, and the spectra of WO stars contain oxygen and carbon lines. The spectra of WR stars of all types contain helium and hydrogen lines. However, the hydrogen lines are weak; the number of hydrogen atoms in the envelopes of these stars is several times smaller than the number of helium atoms[10].

About half of the WR stars are part of close binary systems (CBS), which makes it possible to determine their masses. The masses of WR stars determined from binary stars are in the range from 10 $M_\odot$ to 83 $M_\odot$[3, 4]. However, the WR star R136a1 with a mass of 265 $M_\odot$ was discovered in the Large Magellanic Cloud (LMC), which seriously contradicts the theory of the internal structure of stars. Since the value of the mass of this star is greatly high from the upper mass limit (~ 140 $M_\odot$) of a theoretically possible star[11].

The mechanism of formation of WR stars in binary and single systems is different[3, 4, 10]. In the MCBS, consisting of two O stars, at some stage of evolution, by the losing of mass through the inner Lagrange point, a more massive O star, losing its hydrogen abundant

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[10]Crowther, P.A. Physical properties of Wolf-Rayet stars / Annual Review of Astronomy and Astrophysics, – 2007, 45, – p.177-219.

[11]Crowther, P. A., Schnurr, O., Hirschi, R., et al. The R136 star cluster hosts several stars whose individual masses greatly exceed the accepted 150 $M_\odot$ stellar mass limit // Monthly Notices of the Royal Astron. Soc., – 2010, 408, – p. 731-751.

outer envelope, turns into a WR star[3, 4, 10]. A single star with a mass of about more than 60 $M_{\odot}$ also transforms to WR stars as a result of intense mass loss by stellar wind[10].

According to modern view, WR stars are at the final stage of evolution, at the stage of exhaustion of nuclear energy reserves, after which the collapse of the star should follow with the formation of a neutron star or black hole, depending on its initial mass. Hence, WR stars are potential progenitors of neutron stars and black holes[3, 4, 10].

WN, WC and WO stars are subdivided into subtypes. The criteria by which these subtypes are determined are given. The various classification schemes proposed for WR stars to date have been comprehensively discussed. The spectral features of WR stars of various types are analyzed.

The second chapter presents the main properties of various galaxies, the classification scheme of galaxies proposed by the American astronomer E.Hubble, the presence of MCBS in spiral galaxies, and observational facts related to the presence of MCBS in spiral galaxies.

A brief historical review of the development of ideas from observations of mysterious "nebulae" to the elucidation of the true nature of these "nebulae" is given. In 1927, E. Hubble proposed the classification scheme of galaxies, according to which galaxies with the regular shapes were separated into elliptical, spiral and lenticular, galaxies that do not have the regular shape have been called irregular galaxies[12].

According to the Hubble classification, spiral galaxies are subdivided into normal (S) and bar spirals (SB). In S type spiral galaxies, spiral arms emerge from the core, and in SB-type spiral galaxies, spiral arms emerge from the ends of an oblong formation (bar), in the center of which the galactic nucleus is located. On going from Sa to Sc, we find a development from tightly twisted spiral arms to a more open one[12].

Elliptical galaxies are divided into 8 subtypes, from E0 to E7.

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[12] Hubble E.P. The classification of spiral nebulae // The Observatory, – 1927, 50, – p.276-281.

The numbers determine the degree of ellipticity of the galaxy. In the photographs of these galaxies, have no structure, the brightness smoothly decreases from the center to the periphery, there is a uniform distribution of stars without a core[12].

Lenticular galaxies are designated as S0. In photographs, these galaxies have a board-like shape with a pronounced, central bulge (core) and spiral arms are not found[12].

Irregular galaxies are designated as Irr, and a characteristic feature of these galaxies is a weakly expressed core and bulge. In some cases, the core is completely absent. The luminosity of these galaxies is very low. Typical examples of irregular galaxies are LMC and SMC, satellites of our galaxy[12].

Some interesting observational facts related to the presence of MCBS in spiral galaxies are presented. These facts played a decisive role in understanding the evolutionary properties of spiral galaxies and MCBS. One of these facts is the occurrence of type II supernovae only in spiral galaxies. For astronomers were difficult to explain why a type II supernova explosion occurs only in spiral galaxies.

Supernovae are subdivided into two types[2, 13]: type I and II. The light curves of type I supernovae are very similar to each other: within 2-3 days takes place a sharp rise in brightness, then a significant decrease occurs within 25-40 days, after which a linear weakening of brightness occurs over a long period of time. The absolute magnitude of Ib\c supernovae at the maximum brightness are on average – $19^m.5$, and – $18^m.0$, respectively[2, 13].

However, the light curves of type II supernovae are quite different[2, 13]. The light curves of some supernovae of this type are similar to the light curves of type I supernovae, with the difference that a slower decrease in brightness occurs before the beginning of the linear stage. However, some type II supernovae, having reached their maximum brightness, remain in this stage for up to 100 days, after which rapidly decrease in brightness and approaches the

[13] Архипова В.П., Блинников С.И., Ламзин С.А., и др. Звезды / Москва, издательство Физматлит, – 2009, – с.427

linear end. The absolute magnitude of type II supernovae at maximum brightness varies in a very wide range, from -20^m to -13^m.

According to modern view, the mechanism of supernova explosions of type I and II are different. Type I supernovae takes place as a result of a thermonuclear explosion, and type II supernovae as a result of gravitational collapse at the end of the evolution of massive star[2, 13].

Type II supernova explosions are associated with the evolution of massive stars, i.e. massive stars complete their evolution by exploding as type II supernovae. A brief evolutionary path of a massive star is outlined.

The energy released by the conversion of hydrogen to helium in the core of stars creates pressure that keeps the star from gravitational collapse and the star is in hydrostatic equilibrium[13]. However, when hydrogen is depleted in a star's core, the gravity forces the core to shrink. As a result of this compression, the core temperature rises and reaches to a level sufficient for a thermonuclear reaction involving helium. After exhaustion of helium in the core, due to the next compression, the carbon in the core of the star begins to enter a fusion reaction. When the thermonuclear synthesis of the next chemical element stops in the core of a star, the core of the star shrinks until the pressure and temperature become sufficient to start the next stage of synthesis, which stops the contraction of the star. Obviously, the amount of energy released from thermonuclear fusion depends on the binding energy that holds the nucleons in the atomic nucleus. When heavier nuclei are formed in the core of a star, less and less energy is released during fusion. Thermonuclear combustion continues until the chemical element Ni-56 is formed, which radioactively decays into cobalt-56, and then into Fe-56 over several months[13]. Due to the fact that Fe and Ni have the highest binding energy per nucleon, among all chemical elements, the release of energy in the star due to thermonuclear fusion stops and the formed iron core is under tremendous gravitational pressure. Due to the lack of an energy source to further increase the temperature of the star, the gravitational contraction is constrained only by the repulsion pressure of electrons. When the mass of the forming iron core of the star exceeds the Chandrasekhar limit (~1.4 $M_\odot$), the repulsive pressure of electrons can't stop the compression, and a catastrophic collapse occurs. As a result of catastrophic compression, the temperature of the nucleus increases, emits high-energy gamma rays, takes place fission the iron nuclei through the nuclear photoelectric effect, and at the same time the nuclei of helium and free neutrons are emitted. As the density of the nucleus increases, the neutronization reaction becomes energetically efficient, in which neutrons and neutrinos are formed. The loss of energy due to the escape of neutrinos accelerates the collapse of the star, which occurs within milliseconds. When the density reaches the density of the atomic nucleus, the collapse is stopped by the repulsive forces of neutrons. As a result of these processes, a neutron star or a black hole is formed, depending on the initial mass of the massive star. This is a type II supernova explosion[13].

Hence, the explosion of type II supernovae is closely related to the evolution of the MCBS. The mystery has been solved; the occurrence of type II supernovae in spiral galaxies is associated with the presence of MCBS in these galaxies.

The third chapter describes the observational equipment and the technique used in obtaining and processing of spectral and photometric observations. The spectral material used in the thesis was obtained at the Cassegrain focus of 2-m telescope of ShAO by using the following equipments:

- echelle spectrometer[14];
- fiber echelle spectrograph ShAFES (Shamakhy Fiber Echelle Spectrograph)[15].

In obtaining echelle spectrograms by using an echelle spectrometer and a fiber echelle spectrograph ShAFES the DECH software package developed at SAO RAS and the Owl 3.01 software

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[14]Микаилов Х.М., Халилов В.М., Алекберов И.А., и др. Эщелле-спектрометр фокуса кассегрена 2-х метрового телескопа ШАО НАН Азербайджана // Циркуляр ШАО, – 2005, 109, – с. 21-29.

[15]Mikayilov, Kh.M., Musayev, F.A., Alakbarov I.A., et al. ShAFES: Shamakhy fibre echelle spectrograph // Astronomical Journal of Azerbaijan, – 2017, 12, 1, – p.4-27.

package were used correspondingly. The processing of the obtained echelle spectrograms was carried out by using the DECH software package.

The echelle spectrometer of the Cassegrain focus of the 2-m telescope of ShAO was made on the basis of a universal diffraction astrospectrograph - UAGS (Universal Astro Grid Spectrograph). The UAGS was previously mainly used to obtain low and medium dispersion spectra of celestial objects. The main goal of constructing an echelle spectrometer was to increase the spectral resolution of the UAGS astrospectrograph by using an echelle grating.

In echelle spectrometer uses a CCD light detector, with the 530x580 pixel matrix cooled by liquid nitrogen. With this echelle spectrometer, echelle spectrograms of the studied stars were obtained in the spectral range of λλ 4000-7000 ÅÅ, with a spectral resolution of R = 14000, the signal-to-noise ratio is S/N ~ 100.

It should be noted that the size and weight of the suspended echelle spectrometer, which we used, fully meets modern requirements and one of important properties is its stability. The echelle spectrograms obtained by using this equipment allow us to determine the physical parameters of spectral lines with a high accuracy. To date, with the help of this spectrometer, tens of thousands of echelle spectrograms have been obtained, and based on the analysis of this observational material, dozens of thesis have been defended.

The ShAFES fiber echelle spectrograph is described. At present, in astronomical observations, high-resolution echelle spectrometers are often used, in which light from celestial bodies is directed to the echelle spectrometer through an optical fiber.

In fiber echelle spectrograph of the ShAFES uses a CCD light detector, with the 4000×4000 pixel matrix cooled by liquid nitrogen. With the help of this echelle spectrograph, echelle spectrograms of the studied stars were obtained, with the spectral resolution R = 56000, the wavelength range is λλ 3800–8500 ÅÅ.

A technique for performing observations with the echelle spectrometer of the Cassegrain focus of a 2-m telescope and processing of the echelle spectrograms obtained are described. One of the important stages of processing is the plotting of the dispersion curve. The accuracy of measuring the radial velocities of spectral lines critically depends on the accuracy of plotting the dispersion curve. To plot the dispersion curve, the spectra of the daytime sky are used, which are obtained in the dates of obtaining the spectrum of the studied stars.

A technique for the performing observations with the fiber-optic echelle spectrograph ShAFES and processing of the obtained echelle spectrograms are described. Note that the processing of the obtained spectra by using a fiber echelle spectrograph and the spectra obtained with the echelle spectrometer were carried out by using the DECH software package.

Photometric observations of investigating stars were carried out with a 60-cm ShAO telescope by using an Apogee Alta U-47 CCD photometer. The main characteristics of this photometer are presented. The MaxIm DL program was used to obtain and processing the photometric observational material. The main stages of processing photometric images of stars by using this program are outlined. Before starting the observation, without turning on the telescope, the CCD was checked. Flat images were obtained in the evening twilight. The telescope is directed to the north-west of the sky, where there are no clouds, the stars are not yet visible.

When processing photometric data, firstly it is necessary to calibrate the images of investigating star. For this purpose, by using the Sbias, Sdark, and Sflat the images are calibrated. The calibrated images of the star can already be processed. First you need to choose the correct aperture. The correct choice of the radius of the inner circle is necessary, since the measurement is carried out in this circle. Therefore, the radius of this circle must be accurate. The object must be completely inside the inner circle. If the circle is larger than the object, then the radius of the inner circle must be reduced and vice versa, if the object is not placed inside the circle, the radius is increased. After that, you should to select an outer circle, in which the background of the sky around the object is taken. By subtracting the outer part from the inner, by using Maxim DL software, we get a star image cleared from the background. The outer circle should be chosen so that there is a lot of background. After that, all the calibrated spectra of the object under study are opened in the MaxIm DL window, and by using the Photometry subroutine located in the Analyze menu, the photometry of the object under study was carried out.

The fourth chapter presents the results of spectral studies of MCBS: HD 206267, LZ Cep and β Lyr.

The star HD 206267 (O6.5V + O9V, V = 5.6) is a spectral binary system with the 3.709784 day period. In connection with the discovery of the X-ray source Ser X-4 (GS 2138 + 56) in the vicinity of this star in 1972, interest in it increased greatly[16, 17]. However, the study of this star in the wavelength range λλ 3750-6680 ÅÅ did not reveal emission lines that could be indicators of X-ray radiation[18].

The star HD 206267 has some interesting properties. One of them is that this system is a member of a multiple trapezoidal stellar system - Trap 857[19]. Trapezoidal systems are very similar to open clusters but differ from them by presence a small number of members. The trapezoid Trap 857 is a member of the young (~ 3 million years old) open star cluster Trumpler 37. This cluster, in turn, is a member of the Cep OB2 association[19].

Another distinctive feature of this star is its high rate of mass loss. The star HD 206267 has a high wind velocity. For the star HD 206267, the wind velocity is 3225 km/s, i.e. the terminal wind velocity is the maximum among the 181 studied O stars[20].

The spectral observations of this star were carried out during 2011-2014 at the Cassegrain focus of the 2-m telescope of ShAO.

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[16]Crampton, D., Redman, R.O. Binary O star HR 8281 // Astron. Journal, – 1975, 80, – p.454-457.

[17]Ulmer, M.P., Baity, W.A., Wheaton, W.A., et al. New Transient Source, Cepheus X-4, Observed by OSO-7 // Astroph. Journal, – 1973, 184, – p.L117-L120.

[18]Галкина, Т.С. Спектральные наблюдения HD 206267, отождествляемой с рентгеновским источником Cep X-4 // Известия КрАО, – 1981, 63, – c.86-92.

[19]Abt, H.A. The ages and dimensions of Trapezium systems // Astrophys. Journal, – 1986, 304, – p. 688-694.

[20]Prinja, R.K., Barlow, M.J., Howarth, I.D. Terminal velocities for a large sample of O stars, B supergiants, and Wolf-Rayet stars // Astroph. Journal, – 1990, 361, – p.607-620.

Echelle spectrograms were obtained and processed by using the DECH software packages developed at SAO RAS. The observation was carried out by using the Cassegrain focus echelle spectrometer of a 2-m telescope with the CCD matrix 530x580 pixels (page 19). Spectral range λλ 4700-6700 ÅÅ, spectral resolution R = 14000, signal-to-noise ratio S/N~100. By analyzing the echelle spectrograms of star HD 206267, the following results were obtained:

1. A stable weak emission was found in the violet wing of line H_{α}.
2. The DAC (discrete absorption components) lines in the core of the line H_{α} have been revealed. The DAC appears in the red part of the core of line H_{α} and within about 1.5 hours moves to the violet part of the core. The DAC in the core of line H_{α} in the spectrum of HD 206267 were revealed by us for the first time.
3. The spectral feature (for example, strong emission) has not been found, according to which this star can be identified with the X-ray source CepX-4.
4. The asymmetry of lines H_{α}, H_{β} and the change of these asymmetries over time (approximately one hour) were revealed. Note that the asymmetry of both lines is mainly observed at residual intensities above 0.90 (line wings). Below the residual intensity values of 0.90 (line core), the profiles of both lines are approximately symmetric. Note that the opposite asymmetry was detected for the H_{α} and H_{β} lines; when the line H_{α} is asymmetric on the violet wing; the H_{β} line is asymmetric on the red wing and vice versa.
5. In those cases when DAC is not observed, the H_{β} line width at different levels of residual intensity hardly changes with time, but the H_{α} line widths undergo significant changes, there is no correlation between changes in H_{α} and H_{β} line widths.
6. In those cases when DAC are observed, significant variability of both lines (H_{α} and H_{β}) is observed, the widths of both lines change almost synchronously (if we do not take into account the level of residual intensity 0.80).

7. The largest changes in the width of the H_α and H_β lines are observed at the residual intensity levels 0.90–0.95, in the wings of the line.
8. The radial velocity of the main component varies from approximately +80 km/s to -110 km/s for the lines H_α and H_β, from +60 km/s to -100 km/s for the line HeII 5411. The amplitude of changes of radial velocities of the main component does not differ significantly for the lines H_α, H_β and HeII 5411.
9. The radial velocity and the equivalent width of line H_α change in antiphase, the equivalent widths of the H_β and HeI 5875 lines do not depend on the phase of the orbital period, the radial velocity and the equivalent width of line HeII 5411 change synchronously.

The star LZ Cep (O9 III + ON9.7V, V = 5.54) is an eclipsing binary, with the 3.070507 day period[21]. The LZ Cep binary is in a more advanced evolutionary stage compared with the star HD 206267. Since the star LZ Cep is almost at the final stage of primary mass exchange, and the star HD 206267 is at the stage of forming an envelope around the main component. Signs of nitrogen sequence WR stars are already appearing in the main component of the star LZ Cep.

The light curve of the star LZ Cep shows the ellipsoidal variability with an amplitude of $\Delta m < 0.1$ magnitude. The value $i = 48^0$ was found from the light curve for the inclination of the orbit to the line of sight. The ellipsoidal light curve of this star indicates the deformation of at least one of the components of this binary system[21, 22]. Two models for the star LZ Cep are tested: a contact and a semi-separated binary system. A semi-separated system, in which a less massive component filled its Roche lobe, was in good agreement with the results of observations[22].

[21]Petrie, R.M. The O type spectroscopic binary 14 Cephei // Publications of Dominion Astrophysical Observatory of Victoria, – 1962, 12, – p.111-116.
[22]Harries, T.J., Hilditch, R.W., Hill, G. Interacting OB star binaries: LZ Cep, SZ Cam and IU Aur. Monthly Notices of the Royal Astron. Soc., – 1998, 295, – p. 386-396.

The spectral observations of the star LZ Cep were also carried out with the Cassegrain focus echelle spectrometer (page 19) and the parameters of the echelle spectrograms obtained are identical to those for the star HD 206267.

As a result of investigation of the star LZ Cep, the following results were obtained:

1. Near the phase $\phi = 0.00$ (when the low-mass component of the binary system approaches us with the maximum speed) of 3.709784 day orbital period, the H_α line profile is strongly distorted: the core of this line consists of red and highly distorted violet parts.
2. The variability of the parameters of the LZ Cep line was investigated by using 23 echelle spectrograms obtained during one night near the phase $\phi = 0.00$. It is shown that the equivalent width of the line H_α shows the rapid variability. Despite the fact that the radial velocity determined at the half-width level changes in a chaotic manner, the radial velocity determined from the red component of the nucleus reflects the orbital motion better.
3. A jump is revealed in the radial-velocity curve near the phase $\phi = 0.25$ (when the low-mass component is between us and the massive component).
4. In the spectrum of this star, at some phases, the profile of the HeI 5875 line doubles; at a phase of about $\phi = 0.00$, the secondary component of this line appears in the violet side of line HeI 5875, and at a phase of about $\phi = 0.50$, the secondary component of this line appears in the red side. In other phases, the profiles of this line are strongly distorted by the presence of a secondary component.
5. The H_β line profile does not double, however, at some phases, the H_β line exhibits a component; at a phase of about $\phi= 0.00$, the secondary component of this line appears in the violet side of line H_β, and at a phase of about $\phi = 0.50$, the secondary component of this line appears in the red side. In other phases, the profiles of this line are strongly distorted by the presence of a secondary component.

The star β Lyr is a bright ($V_{max} = 3^m.4$, $B - V = 0^m.0$) semi-separated, eclipsing, closely-binary system with an orbital period of 12.9414 days. The star β Lyr consists of a main component (B8 III), which fills its Roche lobe, and a secondary, invisible, surrounded by a thick accretion disk[23].

One of the interesting features of this star is the fact that the main component has a lower mass (~ 2.9 $M_\odot$) than the secondary (~ 13$M_\odot$). The temperatures of the main and secondary components are 13 3000 K and 23 0000 K, respectively. The inclination of the orbital plane to the line of sight is ~81^0 and the orbit is almost circular[23].

Optical and spectropolarimetric observations revealed the presence of bipolar jets in binary star β Lyr, which are perpendicular to the orbital plane, and the H_α and HeI 6678 emission lines are mainly formed in these jets[23, 24]. Due to the fact that the main component of the star, β Lyr, is losing mass at a high rate, the value of the orbital period of this binary system increases by about 19 seconds over the course of the year[23, 24].

The binary star β Lyr is at the stage of rapid mass exchange between its components. Therefore, in this star, stronger spectral changes are observed, in contrast to the stars HD 206267 and LZ Cep.

One of the interesting features of this star is the fact that the main component has a lower mass (~ 2.9 $M_\odot$) than the secondary (~ 13$M_\odot$). The mass of the main and secondary components are determined by the expressions[24]:

$$M_1 \sin \iota = (2.88 \pm 0.10)\ M_\odot$$

$$M_2 \sin \iota = (12.94 \pm 0.05)\ M_\odot$$

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[23]Skulskyy, M. Yu. Formation of magnetized spatial structures in the Beta Lyrae system I. Observation as a research background of this phenomenon // Contributions of the Astronomical Observatory Skalnaté Pleso, – 2020, 50, – p. 681-703.

[24]Harmanec, P., Scholz, G. Orbital elements of beta Lyrae after the first 100 years of investigation // Astronomy and Astrophysics, – 1993, 279, – p.131-147.

Here M_1 and M_2 are the masses of the primary and secondary components, respectively, ι - is the inclination of the orbital plane of the binary system to the line of sight of the observer. Assuming a conservative mass loss and taking into account the detected increase of the period, the value for the rate of mass loss by the main component was found to be $20 \cdot 10^{-6}$ $M_{\odot}$ per year[24].

The lower mass of the main component is explained by the fact that, filling its Roche lobe, it underwent an intense loss of mass through the inner Lagrange point. As usual, we call the massive component of the binary system the primary and the low-mass mass secondary. However, in the case of the star β Lyr, the inverse ratio of the masses of the components is observed.

According to modern view, the low-mass main component of the star β Lyr, in fact, was originally a massive star. It is known that the rate of evolution of stars depends critically on their mass. Therefore, the more massive (main) component of the binary system, evolving rapidly, fills its Roche lobe. After that, the main component begins intensively lose matter through the innner Lagrange points and, over time, the mass of this component decreases, and the mass of the secondary increases. At the end of this process, the so-called “paradox of Algol” is formed, i.e. the less massive component of the binary system is more evolved.

The spectral observations of the star β Lyr were carried out at the Cassegrain focus of 2-m telescope of ShAO in July-August of 2019 and 40 spectrum have been obtained. The ShAFES fiber echelle spectrograph with CCD (4000x4000 px), cooled with liquid nitrogen was used (page 19). The spectral range is λλ 3800–8500 ÅÅ, the spectral resolution is 56 000, the signal-to-noise ratio (S/N) is ~300. The processing of the echelle spectrograms were carried out by using the DECH20T software package developed at SAO RAS. The root-mean-square errors of determining the equivalent widths and radial velocities were 5% and 300 m/s respectively. The following results were obtained from the analysis of echelle spectrograms of the star β Lyr:

1. To plot the radial velocity curve of the main component, we used the measured radial velocities of the SiII 6347, MgII 4481, and FeII 4233 lines. The choice of these lines is due to the fact that these lines are narrower and symmetric, which allows us to determine the radial velocities of these lines with high precision.
2. The value of the orbital period corresponding to our observational season was determined as 12.9414 days. Due to the intense mass loss of the main component of star β Lyr, the value of the orbital period of this system increases by 19 sec. in one year. Consequently, when studying this star, it is necessary to determine the value of the period corresponding to the observation season.
3. It was revealed that the line H_α consists of narrow violet (V - violet), wide red (R-red) components and absorption between them. In all phases of the orbital period, the so-called S-wave emission is also observed in the H_α line. Note that S-wave emission is characteristic for cataclysmic variables.
4. The dependences of the radial velocity, central intensities, equivalent widths and half-widths of the H_α and HeI 6678 lines on the phase of the orbital period were plotted. All these dependences are in fairly good agreement with these plotted by other researchers.
5. An additional observational fact indicating the presence of two hot spots at phases ~0.4 and ~0.8 of the orbital period on the disk surrounding secondary component was revealed. The temperature of these spots is 10% and 20% higher than in the environment, respectively. We found two maxima in the dependence of the ratio of the intensities of the violet and red components of H_α and HeI 6678 lines on the phase of the orbital period, at phases of about 0.4 and 0.8. It is known that the emission lines H_α and HeI 6678 are formed mainly in bipolar jets. The jets are directed perpendicular to the orbital plane in the region where the wind from the main component collides with the disk. A comparison of the curves for H_α and HeI 6678 shows that the maximum for the line H_α is more distinct. This fact may be connected with that the jets contribute more in the formation of line H_α than of HeI 6678.

Note that the circumstellar envelope and the wind from the main star also contribute to the formation of these lines.

6. It was revealed that the dependence of the radial velocities of the S wave emission changes approximately synchronously with the radial velocity curve of the main component, but with a smaller amplitude.

These results are important for the understanding the physical nature of the processes taking place in star β Lyr and should be taken into account in plotting the physical model of this star.

The fifth chapter presents the results of a study of WR stars, with the probable compact components. In the 1980s, the spectral and photometric variability of 16 "single" WR stars was discovered, which were surrounded by ring nebulae and located at large distances from the galactic plane[25]. These objects were considered as WR stars with the probable compact components (WR + C). The compact component could be a neutron star or a black hole. The periodic variability of the radial velocities of some spectral lines and brightness revealed for these "single" WR stars was an argument in favor of the binarity of these stars. However, further research did not confirm that the above mentioned 16 stars can be WR + C systems. First, the observed spectral and photometric periodicities for most of these objects turned out to be not strictly periodic, but quasiperiodic. On the other hand, X-ray observations have shown that the X-ray luminosity of these stars is too low ($L_x \leq 10^{33}$ erg/s) for accreting neutron stars. In fact, if these stars were indeed WR + C systems, their X-ray brightness should be ~ 10^{38} erg/s[26]. After that, the physical nature of these 16 stars turned out to be uncertain.

The first attempt to explain the physical nature of these 16 stars was made by academician A.M. Cherepashchuk[26]. According to A.M. Cherepashchuk, "single" WR stars located in the centers of ring nebulae can be CBS containing low-mass "normal" K-M stars

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[25] Асланов А.А., Колосов Д.Е., Липунова Н.А. и др. Каталог тесных двойных звезд на поздних стадиях эволюции / Москва, издательство МГУ, – 1989, – 240 с.

[26] Cherepashchuk, A.M. X-ray nova binary systems // Space Sci. Review, – 2000, 93, – p.473-580.

as components[26].

The basis for this hypothesis is that, several dozen low-mass X-ray Binaries (LMXB) have been discovered, consisting of a low-mass optical star of spectral type K - M, filling its Roshe lobe and an accreting relativistic object (neutron stars or black holes). The orbital periods and eccentricities of orbit of these objects are P ~ 0.2 - 33.5 days and e = 0 correspondingly. Spectral types of optical components: B, A, K, M. According to the luminosity class, these components correspond to dwarfs, subgiants, and giants. The duration of the LMXB X-ray flares is on the order of months. During an X-ray flare, their X-ray luminosity increases by a factor of 10^2-10^6 and reaches the value of $L_x \sim 10^{37}$-10^{38} erg/s. The quiescent X-ray luminosity is $L_x \sim 10^{31}$-10^{33} erg/s. The duration of a quiet state can be up to several years. The relativistic components of the LMXB are neutron stars or black holes[26].

According to the theory of evolution of MCBS, the progenitors of low-mass X-ray binaries should be WR stars with low-mass K-M stars. The WR + (K-M) system is formed after the primary mass exchange. The subsequent explosion of the WR star as a supernova formed after the initial mass exchange leads to the formation of an X-ray binary system with a relativistic object and a low-mass K-M star.

To test A.M. Cherepashchuk's hypothesis, it is necessary to answer the question: does the periodic variability of these 16 stars persist during very long time. To answer this question, we examined four of these stars: HD 191765, HD 192163, HD50896, and HD197406.

The spectral observations of the stars HD 191765 and HD 192163 were carried out at the Cassegrain focus of 2-m telescope of ShAO during 2005-2010. The echelle spectrometer of the Cassegrain focus of 2-m telescope was used (page 19). The spectral range λλ 4000-7000 ÅÅ, spectral resolution R = 14000, signal-to-noise ratio S/N ~ 100. Echelle spectrograms were obtained and processed by using the DECH software packages developed at SAO RAS.

The photometric observations of the star HD 191765 were carried out with the 60-cm telescope of ShAO in July-September of

2010. The Apogee Alta U-27 1024x1024 pixel CCD photometer was used. The filter V was chosed because the contribution of emission lines in this filter is about 7% and the variability in this filter is mainly related to the variability of the continuous spectrum. Photometric data were obtained and processed by using the MaxIm DL program. The photometric variability of the star HD 191765 was revealed, both during the night and from night to night. The root-mean-square error of one measurement, determined from the control star, varies from $0^m.0006$ to $0^m.0009$.

The information concerning on the revealed variability of the profiles of the (HeII + H_α) 6560 emission band in the spectra of the stars HD 191765 and HD 192163 is given. It is known that the H_α emission is formed in the outer regions of the expanding envelope of the WR star, and the orbital motion of the K-M star can lead to the perturbation of the region of formation of the H_α emission, which should cause variability of the profile shape of this line. The variability of the profile of the (HeII + H_α) 6560 emission band may serve as an additional indication of the presence of a companion near the star WR, which, according to A.M. Cherepashchuk, is the low-mass K-M star[26].

Among the 17 profiles of the (HeII + H_α) 6560 emission band studied by us in the spectrum of the star HD 191765, only in one case a more or less symmetric profile was detected, and in other cases the asymmetry of different degrees are observed. The signal-to-noise ratio is the same for all investigated echelle spectrograms and is equal to S/N ~ 100.

By comparison the profiles of the (HeII + H_α) 6560 emission band in the spectrum of the star, HD 192163, obtained on different dates, revealed the profile variability in the violet wing (the region from ~ 6496 Å to ~ 6532 Å). In this region, sometimes narrow emission features appear (mainly at a wavelength of ~ 6510 Å), the height of which is three times higher than the error (0.9%).

By using the measured radial velocities of (HeII + H_α) 6560 emission band for the star HD 192163, we carried out a frequency spectral analysis of the radial velocities to reveal the possible periodicity. By using the method proposed by Scargle[27] and the "clean" algorithm[28] obtained the period as 5.1287 days. This period is interpreted by the binarity of HD 192163 with the "normal" low-mass K-M component.

The frequency spectral analysis of the photometric data of the star HD 191765 is performed to reveal the possible periodicity. By using the method proposed by Scargle[27] and the "clean" algorithm[28] obtained the period as 1.887 days. This period is interpreted by the binarity of HD 191765 with the "normal" low-mass K-M component.

By analyzing the data published in the scientific literature for the stars HD50896 and HD197406, it was revealed that their periodic variability persists for a long time. Thus, we came to the conclusion that four stars (HD 192163, HD191765, HD50896 and HD197406) are a binary WR + (K-M) system. According to the modern theory of evolution of the MCBS, these binary systems are progenitors of X-ray sources with low-mass K-M components.

As a result of spectral and photometric studies of the stars HD 191765 and HD 192163, we have confirmed the preservation of the periodic variability of these two stars during long time.

Note that the orbital periods for the stars HD 191765 (P = $1^d.887$), HD 192163 (P = $5^d.218$), HD50896 (P = $3^d.766$), and HD197406 (P = $4^d.31364$) fall into the intervals that were determined for X-ray sources with the low-mass components. The assumed masses of the low-mass components are ~ 1 $M_\odot$ and 4 $M_\odot$ for the stars HD 50896 and HD 197406, respectively[29, 30]. These masses are

[27]Scargle, J.D. Studies in astronomical time series analysis. II. Statistical aspects of spectral analysis of unevenly spaced data // Astrophys. Journal, – 1982, 263, – p.835-853.

[28]Roberts, D.H., Lehar, J., Dreher, J.W. Time series with clean. I. Derivation of a spectrum // Astronomical Journal, – 1987, 93, – p.968-989.

[29]Cherepashchuk, A.M. Periodic variability of HD 50896 – a Wolf Rayet star associated with a ring nebula // Monthly Notices of the Royal Astronomical Society, – 1981, 194, – p.755-759.

[30]Moffat, A.F.J., Seggewiss, W. The intrinsically bright Wolf-Rayet stars of type WN 7. V - The single-line runaway binary HD 197406 // Astron. and Astrophysics, – 1980, 86, – p.87-90.

in very good agreement with the masses of the low-mass components of X-ray sourses[26]. Taking into account the above indicated observational facts we concluded that the stars HD 191765, HD 192163, HD50896, and HD197406 are evolutionary precursors of X-ray sources with the low-mass K-M components.

A study of the interstellar lines NaI 5890 and NaI 5896 in the spectrum of a WR star, HD 192163, have been investigated in order to reveal the possible contribution of the Ring Nebula NGC 6888 to the formation of these lines. Note that the star HD 192163 is located in the center of the Ring Nebula NGC 6888. Note that the lines NaI 5890 and NaI 5896 are formed mainly in the interstellar medium and should be symmetric. The asymmetry of these lines is an argument in favor of the contribution of other sources to the formation of these lines. In our case, it is reasonable to assume that the Ring Nebula NGC 6888 contributes to the formation of these lines. The asymmetry of these lines was not detected by us in the spectra of another WR star, HD 191765, and the standard star HD 189847. This observational fact is an additional argument in favor of the reality of the revealed asymmetry of the studied absorption lines NaI 5890 and NaI 5896 in the spectrum of the star HD 192163, since the spectra of all stars were obtained and processed under the same conditions.

The results on the study of the ionization structure of the envelopes and the spectral classification of the WR, HD 191765 and HD 192163 stars is given. The ionization structure of the envelopes of these stars is studied by plotting the dependence between the emission line half-widths and the ionization potentials. It is shown that the structures of the envelopes of these stars are different. These differences may be related to the difference in their evolutionary states.

By using the logarithm of the ratio of line intensities, the dependence of log (CIV5808/HeI5875) on log (HeII5411/HeI5875) was plotted. It is known that this dependence is used for the spectral classification of WR stars of nitrogen sequence. Despite the fact that both stars in this dependence fall into the region corresponding to the WN6 subtype, there are differences between them. HD 192163 more accurately corresponds to the WN6 subtype, while HD 191765 is located on the border between WN5 and WN6. Note that the atmosphere of the star HD 192163 contains hydrogen, while the star HD 191765 has completely lost its outer hydrogen envelope[31]. The difference between these stars may be due to both this circumstance and the fact that the initial mass of these stars was different[31].

The sixth chapter presents the results of studies the origin of spiral galaxies. The idea proposed by us concerning to the origin of spiral galaxies is explained.

According to the classification scheme proposed by the American astronomer E. Hubble, by the degree of development of spiral arms and its size, the spiral galaxies are subdivided into subtypes: Sa, Sв, and Sc. Along this sequence the core of galaxy decreases and the spiral arms become stronger[12].

The separation of galaxies into spiral and elliptical is connected with the rotation (angular momentum) of galaxies. Galaxies with the high angular momentum, had a favorable condition for the development of a spiral structure, however, galaxies with a low angular momentum were formed as elliptical galaxies, galaxies with the least angular momentum remained shapeless (irregular)[12].

It is known that the majority (more than 50%) of galaxies in the Universe is spiral galaxies and the spiral structures of galaxies are quite stable, since this structure does not decay for billions of years. Despite the fact that several hypotheses have been proposed, with the help of which astronomers try to explain the origin of spiral structures of galaxies, to date, there is no satisfactory theory about the origin and evolution of these structures[6, 7]. We argue that the "embryos" of the spiral structure of galaxies are formed in the first microseconds of Big Bang (BB).

According to modern view, the Universe was formed ~13.8 billion years ago from a singular state as a result of BB, and has been expanding and cooling since then[5]. BB is a generally accepted cosmological model, which successfully describes the physical

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[31]Hamann, W.R. Wessolowski, U., Koesterke, L. Non-LTE spectral analyses of Wolf-Rayet stars: The nitrogen spectrum of the WN6 prototype HD 192163 (WR136) // Astronomy and Astrophysics, – 1994, 281, – p.184-198.

properties of the early stages of the evolution of the Universe.

BB is subdivided into the following epoch: Planck, Grand Unification, Inflation, Electroweak, Quark, Hadrons, Leptons, Nucleosynthesis, Photon, Recombination (Recombination/Decoupling), Dark Ages, Formation of stars and galaxies. The properties of these epochs are briefly outlined.

At present, in modern particle accelerators, it has been possible to create a state of matter that corresponds to the first microseconds of the Universe after the BB. In the Large Hadron Collider (LHC), it was possible to reach up to 10^{-12} seconds after the BB. This state approximately corresponds to the post-inflationary era of the BB. According to modern view in this era, the Universe consisted of a quark-gluon plasma and experiments carried out at the LHC showed that this quark-gluon plasma behaves more like a liquid than a gas. After revealing this fact, it became possible to apply van der Waals curves to quark-gluon plasma[32].

Numerous experiments have shown that the state of the liquid near the critical point is extremely unstable. Physically, this means that at the critical point, the correlation length approaches infinity, fractality and self-similarity appear.

If the collision of particles occurs near the critical point, self-similarity appears due to approaching the correlation length to the infinity. Any object is called self-similar if this object exactly or approximately coincides with a part of itself. Self-similarity is a characteristic property of a fractal. A fractal is a self-similarity set. It is known that the most suitable figure of a self-similar object is a logarithmic spiral. We have proposed a method for the revealing the spiral structure. It is known that the equation of the logarithmic spiral in polar coordinates has the form[33]:

$$r(\phi) = r_0 e^{k\phi}$$

[32]Cashmore R., Maiani, L., Revol, J.P. Prestigious Discoveries at CERN / Springer, – 2004, –190 p.

[33]Сильванович О.В. Лабораторный практикум по высшей математике. Специальные кривые / Санкт Петербург, издательство Университет ИТМО, – 2018. – 62 с.

where, ϕ - is the polar angle of the points on the spiral, r - is the radius vector of these points, r_0 and k are the coefficients by which the radius and distance between the turns is determined correspondingly.

If we take the logarithm of the spiral equation we get:

$$\ln(r(\phi)) = \ln(r_0) + k \times \phi$$

After this transformation, the equation of the logarithmic spiral is transformed to the equation of a straight line, which can be easily identified from the experiment by plotting the dependence of the logarithm of the radius vector on the polar angle.

The logarithmic spiral has some interesting features. Among the various properties of the logarithmic spiral, the following features are more important for our problem[32]:

- with an increase in the size of the turns of the logarithmic spiral, its shape remains unchanged;
- after various transformations, the logarithmic spiral has the ability to restore its shape;
- the tangent at any point to the logarithmic spiral forms the same angle with the radius vector;
- polar angles that correspond to different points of the logarithmic spiral are proportional to the logarithms of the radius vectors of these points.

Namely these features of the logarithmic spiral make it a suitable self-similar figure[32].

So we conclude:

- in the first microseconds of the BB during the transition from quark-gluon plasma to hadron (proton and neutron) matter, due to approaching infinity of correlation length, near the critical point, a spiral structure develops;
- this spiral structure is “embryo” of spiral structures of galaxies;
- a spiral structure, which, formed near the critical point, can be used as one of the signs of second-order phase transitions.

Though most of the galaxies in the universe are spiral galaxies, there are also elliptical and irregular ones. To clarify the possible evolutionary relationships between types of galaxies, it is necessary to compare the distinctive properties of these objects. We believe that angular momentum plays a critical role in the division of galaxies into different types. As noted above, near the critical point, due to approaching infinity of correlation length, the fractality appears and a spiral structure develops. In this case, infinitely many spiral structures are formed. Different spirals differ from each other by the value of angular momentum, and these spiral structures can be divided into three groups:

- spiral structures with the high angular momentum;
- spiral structures with the average angular momentum;
- spiral structures with the low angular momentum.

We argue that spiral galaxies are formed from the spiral structures with the high angular momentum. Elliptical and irregular galaxies are formed from the spiral structures with average and low angular momentum, respectively. Therefore, we argue that the "embryos" not only of spiral galaxies, but also of all galaxies are formed during the first microseconds of the BB. This leads to another idea that the galaxies were formed first, and then its main components - the stars.

In 2012, the oldest galaxy Q2343-BX442 with the well-formed spiral arms was discovered[34]. The redshift of galaxy Q2343-BX442 is z = 2.1765, which corresponds to a distance of approximately 10.7 billion light years. Consequently, this galaxy was formed ~ 3 billion years after BB. Astronomers believe that "the fact that such a galaxy exists is surprising, because modern common sense says that such spiral galaxies simply should not exist in such early epochs of the universe"[34].

However, according to our assumptions, the presence of such a galaxy in the early epochs of universe is quite reasonable, since the

[34]Law, D.R., Shapley A.E., Steidel C.C., et al. High Velocity Dispersion in A Rare Grand Design Spiral Galaxy at Redshift z = 2.18 // Nature, – 2012, 487, – p.338–340.

“embryos” of spiral structures were formed during the first microseconds of BB. This observational fact is also in favor of our assumption that galaxies were formed first, and then its main components - stars.

REZULTS

The results of the dissertation are as follows:

1. An unusual photometric variability of the WR of the star HD191765 has been revealed. From photometric observations, it was found that the magnitude of the star HD 191765 varied from $8^m.0$ to $8^m.1$ within ~ 10 minutes. Such a brightness change the first time has been observed for this star [19, c.33-35].
2. It was revealed that WR stars with the probable compact components (HD 191765, HD 192163, HD 50896, and HD 197406) are evolutionary precursors of X-ray binaries with “normal” low-mass K-M components. As a result of spectral and photometric studies of the stars HD 192163 and HD 191765, and from an analysis of the literature data for the stars HD 50896 and HD 197406, we concluded that these stars are WR + (K-M) binaries. According to the theory of evolution of MCBS, WR + (K-M) binaries are precursors of X-ray binaries, with “normal” low-mass K-M components [18, c.380-392], [50, c.109-110].
3. The contribution of the Ring Nebula NGC 6888 surrounding the star HD 192163 to the formation of the lines NaI 5890 and NaI 5896 was revealed. The asymmetry of these profiles is an argument in favor of the contribution of other sources to the formation of these lines. By investigating the high-resolution spectra, we revealed the asymmetry of the lines NaI 5890 and NaI 5896 in the spectrum of the star HD 192163. We argue that the in formation of these lines there is contribution of Ring Nebula NGC 6888, surrounding the star HD 192163 [23, c.14-16], [45, c.75-76].
4. The revealed difference between subtypes of WR type stars, HD 191765 and HD 192163. By using the logarithm of the line intensity ratio, the dependence of log (CIV5808/HeI5875) on log (HeII5411/HeI5875) was plotted. In this dependence the star HD

192163 more distinctly corresponds to the WN6 subtype, while HD 191765 is located on the border between WN5 and WN6. The difference between these stars may be due to the fact that the initial masses of these stars were different [43, c.142-143], [48, c.308-309].

5. A stable weak emission in the violet wing of the H_α line, the appearance and movement of Discrete Absorption Components (DAC) in the core of line H_α in the spectrum of HD 206267 was revealed. The DAC appeared in the red part of the nucleus of line H_α and within about 1.5 h moved to the violet part [43, c.142-143], [48, c.308-309].
6. The interval of variation of the radial velocities of the main component of the star HD 206267 was determined for the different lines. It was found that the radial velocity of the main component varies from approximately +80 km/s to -110 km/s for the H_α and H_β lines, from +60 km/s to -100 km/s for the line HeII 5411 [32, c.50-56].
7. The asymmetry of the H_α and H_β lines in the spectrum of the star HD 206267 and variation this asymmetry over time was revealed. For the lines H_α and H_β, the opposite asymmetry was found, i.e. when the line H_α is asymmetric in the violet wing, the line H_β line is asymmetric in the red wing, and vice versa [29, c.13-15], [55, c.79-80].
8. The value of the orbital period of the star β Lyr corresponding to the observational season (July-August 2016) was determined as 12.9414 days. It is known that due to the intense loss of mass of the main component of the star β Lyr, the value of the orbital period of this system increases by ~19 second in year. When studying this star, it is necessary to determine the value of the period corresponding to the observational season [39, c.18-23].
9. An additional observational fact has been revealed that shows the presence of two hot spots in phases 0.4 and 0.8 of the orbital period on the disk, the surrounding secondary component of the star β Lyr. We found two maxima in the dependence of the ratio of the intensities of the violet and red components of the H_α and

HeI 6678 lines on the phase of the orbital period, at phases of about 0.4 and 0.8 [39, c.18-23], [40, c.145-147].

10. Conclusion that the "embryo" of the spiral structure of galaxies formed in the first microseconds of the Big Bang. If the collision of particles takes place near a critical point, due to the correlation length approaches infinity, self-similarity and fractality are formed. The most accurate self-similar figure is a logarithmic spiral. Thus, in the first microseconds of BP, a spiral structure is formed near the critical point during the transition from quark gluon plasma to hadron. This spiral structure is the "embryo" of galaxies [30, c.2-4], [36, c.75-78].
11. The spiral structure, which forms near the critical point, is the sign of second-order phase transitions, i.e. the spiral structure can be used as an indicator in revealing of second-order phase transitions [30, c.2-4], [36, c.75-78].

The results of the dissertation are published in the following works:

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