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# ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

# PROPERTIES AND EVOLUTION OF CIRCUMSTELLAR DISCS OF THE DIFFERENT MASS YOUNG STARS

Specialization: 2108.01 – Astrophysics, stellar astronomy

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## MAIN CHARACTERISTICS OF THE WORK

**Relevance of the topic and degree of development.** The relevance of studying T Tauri stars (TTS) is due to the fact that these stars currently reflect the initial stage of formation of our Solar System. The study of such stars allows us to refine existing knowledge about the formation and evolution of the solar system. According to current ideas, protoplanetary disks formed in the early stage in rich gas and dust clouds when the T Tauri stars is formed, and then dissipated under the influence of various physical mechanisms at a later stage of evolution, and ultimately lead to the formation of planets around the star[1,2,3]. However, the role of these physical mechanisms and individual stages of disk evolution in different subclasses of TTS stars is still poorly understood.

Intermediate-mass Herbig AeBe (HAeBe) type stars are more massive than TTS stars, so their evolution is expected to be slightly different. Currently, relatively hot stars of spectral class AB in the Galaxy manifest themselves as star clusters with very different physical properties. Examples of these are chemically peculiar Ap type stars, Vega and β Pic type stars. Due to their close spectral classes, these stars should evolve into the indicated type of stars after the disintegration of the protoplanetary disk around HAeBe stars. But until now, there are no studies to confirm or deny this question. Therefore, the study of the mechanisms affecting the dissipation of the very strong circumstellar disk formed around HAeBe stars in the initial stage of formation is one of the most interesting and relevant issues of stellar astrophysics.

Currently, a large amount of observational materials about individual young stars have been collected in international archives.

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[1] Guzmán-Díaz J., Homogeneous study of Herbig Ae/Be stars from spectral energy distributions and Gaia EDR3/J. Guzmán-Díaz, I. Mendigutía, B. Montesinos, [et al.] //Astron&Astrophys., –2021. -650, -p. 182-225.

[2] Hughes AM, Duchêne G., Matthews BC Debris Disks: Structure, Composition, and Variability //Ann.Rev.Astron&Astrophys, –2018. -56, -p. 541-591.

[3] Hasegawa Y., Determining Dispersal Mechanisms of Protoplanetary Disks Using Accretion and Wind Mass Loss Rates/ Y.Hasegawa, JTHaworth, K.Hoadley, [et al.] //Astrophys.J., –2022. -926, -p. 23-35.

At the same time, the extra-atmospheric observations obtained by a number of space missions in different wavelength ranges are very important for the study of protoplanetary disks in young stars. By studying the radiation characteristics of stars based on these materials in the infrared (IR), ultraviolet (UV), radio, X-ray, etc. ranges, it is possible to determine the existing physical state of the circumstellar disk. Thus, the study of the physical properties of stars of different ages can provide more complete information about the evolution of the protoplanetary disk in them.

So far, a number of studies have studied the evolutionary characteristics of stars located in various young star complexes based on the study of spectral energy distribution (SED) curves of young stars. In many cases, the number of research objects taken in these works was not enough to make statistical generalizations. Recently, the characteristics of disks around stars located in groups in various less studied star clusters have been studied [4,5]. Since the ages of the stars in the star clusters selected in these works are about the same, the number of such clusters must be large to generalize the data. However, the number of such cases is not sufficient to make unambiguous generalizations.

**Purpose and tasks of the work.** The purpose of the research conducted in this dissertation is to study the nature of the interaction between the central star and the circumstellar disk of these stars based on the spectral and photometric study of selected young stars of different masses, to classify the spectral energy distribution

SED curves of the program stars in the optical, near and far IR regions, of a statistically significant number of interstellar protoplanetary disks of stars, to determine its morphology, to study the physical parameters of peristellar disks of different ages. The study of the physical condition of the circumstellar disk and the

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[4] Ribas Á., Merín B., Bouy H., & Maud L.T. Disk evolution in the solar neighborhood. I. Disk frequencies from 1 to 100 Myr //Astron&Astrophys., –2014. -561, -p. A54-65.

[5] Avenhaus H., Disks around T Tauri Stars with SPHERE (DARTTS-S). I. SPHERE/IRDIS Polarimetric Imaging of Eight Prominent T Tauri Disks/ H. Avenhaus, SPQuanz, A. Garufi, [et al.] // Astrophys.J., –2018. -863, -p.44-67.

central star of small and medium-mass stars between 1-10 million years old is important for studying the changes in the evolution of stars during this period.

Photometric studies of young stars have shown that their luminosity in the V photometric band varies by 0.1-0.5 mag during one season, and by 1-3 mag during different years. Classification of such changes shows that small amplitude changes are mainly explained by inhomogeneous conditions consisting of cold and hot spots on the stellar surface. Large-amplitude variability can occur through the shielding effect of large-sized gas-dust clouds present in a binary star or in the circumstellar disk. However, despite the fact that these mechanisms are known in general, depending on the parameters of each individual star and the structure of the interstellar medium, its photometric and spectral characteristics vary in its own way. The complexity of the issue is due to the fact that the physical mechanisms listed above cannot be unambiguously accepted for individual stars. Therefore, in order to explain the observed properties of young stars with a general theoretical model, a statistically valuable number of observational materials should be analyzed. Therefore, it is necessary to obtain as much photometric and spectral observation material as possible about each studied object.

One of the goals of the dissertation work is to conduct long-term BVRI photometric observations of two classical CTTS-type stars (AS 205N and V1082 Cyg), analyze the received light curves, and investigate the activity mechanism in these stars. One of the main goals of the dissertation is to construct and analyze the SED curves of a statistically significant number of low-mass (CTTS, WTTS) and intermediate-mass HAeBe stars in the range of 0.36-100 μm to study the physical properties of program stars. Based on these curves, the SED curves of young stars are classified, and the properties characterizing the physical state and chemical composition of the circumstellar disk are studied. By fulfilling the above-mentioned goals, our task is to perform a comparative analysis between the received fundamental physical evolution parameters of program stars and to reveal the nature of variations of the circumstellar protoplanetary disk at different ages.

**The object and topic of the study.** The main object of the study is various types of small and medium-mass CTTS, WTTS and HAeBe stars that have not yet reached the Main Sequence. The main topic of the research is the study of the properties and evolution of the circumstellar disks of young stars of different masses.

**Applied methods.** BVRcIc photometer and FLI CCD 4000x4000 mounted in the 60 cm telescope of the Shamakhy Astrophysical Observatory named after Nasireddin Tusi of Ministry of Science and Education of the Republic of Azerbaijan (ShAO MSE) and its Cassegrain focus were used to observe the two classical T Taurus stars in the standard photometric BVRI Johnson international system. Observations were carried out by the differential method. The observation and the processing of the obtained results were carried out using the standard method in the MaxIm DL program.

To study the SED curves of the selected program stars, the photometric results of 45 WTTS, 49 CTTS, 19 HAeBe stars in the UBVRİJHK, W1, W2, W3, W4, 12, 25, 60, 100 μm bands given in the international catalogs Vizer were used. Since the star brightness and absolute fluxes taken from different sources are expressed in different measurement units, those systems were brought into the same system and SED curves were constructed. The observed results were approximated by the standard star curves given by the theoretical model.

The method given in the Lada[6] classification system was used to classify the obtained SED curves. Based on the value of the parameter α, which expresses the degree of inclination of each SED curve with the abscissa axis, SED curves were classified. Correct determination of the interstellar reddening factor, the distance to the star, and the temperature of the star are important for the correct construction of SED curves. The method of determining all three

[6] Lada CJ Star formation: from OB associations to protostar/IN: Star forming regions; Proceedings of the Symposium, Tokyo, Japan, Nov. 11-15, 1985 (A87-45601 20-90) //IAU Symposium, –1987. -115, -p.1-17.

parameters and the analysis of lines are given in detail in chapter I. In order to determine the obtained fundamental parameters, including the mass and age of the star, the location of those stars on the Herschprüg-Russell (H-R) diagram was determined.

**Main results presented for defense**

1. The period of brightness variation with amplitude ΔV~2 magnitudes was redefined as P=24.71±0.04 days of the CTTS type star AS 205N. The reason for the detected periodic brightness variation is the presence of an eclipsing star in the system. Physical variability of the components of the binary system leads to the appearance of stochastic components in the light curve.

2. SED curves of a statistically significant number of young stars in the range of 0.36-100 μm were constructed, and a method of calculating their integral radiation excess in the ultraviolet and far infrared range was developed.

3. In 22 of the 45 selected WTTS stars, only a weak emission excess in the far-infrared range (60-100 μm) was detected, and these stars were classified as a new subclass IIId.

4. Analysis of the SED curves of 19 HAeBe stars shows that only 3 of those stars have a type III spectrum, that is, a fragmented remnant disk. In these stars, the circumstellar disc shows weak signs of disc accretion.

5. SED curves of 49 CTTS stars show that their stellar disks are richer in gas than WTTS stars. It has been shown that as the age of this type of stars increases, the amount of dust in the circumstellar disk increases.

**Scientific novelty of the research**

1. The previously known P=24.78 day period of the star AS 205N was refined based on a larger number of observational materials and P=24.71±0.04 days was obtained. It was shown for the first time that this period is explained by the variations in the brightness of the stars in the eclipsed binary system. It is shown that the SED curve of the star AS 205N is irradiated by two M-type stars with temperatures of 3500 K and 2000 K and a gas-dust disk.

2. Based on the analysis of the light curve of the star V1082 Cyg, no periodic component of the brightness variations of this star was

detected. The SED curve of a star is formed as a result of radiation from the central star and the surrounding gas-dust disk. The SED curve of the star is attributed to type II.

3. For the first time, the method of calculating the integral radiation excess parameters in the UV and IR region was applied in the SED curves of young stars.

4. The program stars of 45 WTTS all show an emission excess in the far-IR range. Only 15 WTTS stars show a UV excess. It has been shown that none of the 15 WTTS stars with a UV excess have any evidence of accretion.

5. Out of 45 WTTS stars, only 3 stars show an emission difference in the 2.2 μm range. At least two of these 3 WTTS stars have been shown to have disc accretion for the first time. Only 15 of the WTTS program stars show an IR emission excess in the λ 3–12 μm region.

6. Of the 45 WTTS stars, 30 are classified as type III and 15 as type II. The type II SEP curves of WTTS stars are indistinguishable from those of CTTS stars. Some of these stars have an UV excess. The lack of correlation between the luminosity of the Hα line and the UV excess suggests that some of these stars have disk accretion.

7. In 22 out of 30 type III WTTS stars, radiation excess is observed only in the $\lambda \geq 60$ μm range. These stars have a remnant disk that is in the final stages of evolution. Most of such stars show chromospheric activity. This group of stars was first classified by us as subtype IIId.

8. It was shown for the first time that the parameter α, which determines the inclination of the SED curves to the abscissa axis in CTTS stars, increases with the age of the stars. This means that as the age of the stars increases, the radiation excess in the far-IR region increases. This trend is maintained until the age of the stars is 10 million years.

9. Of the 19 HAeBe stars studied, 3 show type III SED curves, and the rest show type II SED curves. A weak correlation between the luminosity of the Hα line and the emission excess in the near-IR range was found. This shows that the variations of the Hα line in these stars is partially determined by the accretion rate.

**Practical and theoretical importance of the work.** New observational materials of AS 205N and V1082 Cyg CTTS type stars in the BVRcIc photometric system were acquired and processed. These observational materials can be used in various studies in the future. The results obtained from the analysis of the light curves of these stars can be used in theoretical work in modeling the photometric variability mechanisms of young stars.

The fundamental parameters and evolutionary status of 45 WTTS stars have been determined. It was found that among the WTTS stars, there is a certain group of stars that have completely dissipated the circumstellar protoplanetary disk and show an excess of radiation only in the far infrared range. This group was classified for the first time as subclass IIId. The practical significance of this result is that it clearly proves the existence of young stars that have completely lost their protoplanetary disk and have a disk consisting only of remnant particles.

The classification of the SED curves of CTTS stars showed that the α coefficient, which characterizes the inclination of the distribution curve to the abscissa axis, also practically expresses a certain relationship with the age of the stars. It is shown that the coefficient α has a normal distribution for the selected program stars. This shows that the value of α coefficient for the selected 49 CTTS stars is random. At the same time, it has been proven that as the age of stars increases, the amount of dust increases. However, this growth rate is not monotonous, but can change at different stages of evolution. These obtained results further enrich the theory of evolution of protoplanetary disks around young stars with small mass and can be used in future theoretical works.

**Veracity of the dissertation.** The photometric observation material studied by the author was obtained using the FLI CCD camera in the 60 cm telescope of the ShAO named after of Shamakhy Astrophysical Observatory named after Nasireddin Tusi of Ministry of Science and Education of the Republic of Azerbaijan. The observations and measurements were carried out using the most modern devices and programs. Measurements of a large number of standard stars have proven that the system works reliably. In addition, archives created by various international space missions were used for photometric measurements of program stars in the near and far infrared range. The method of constructing SED curves of stars in the range of 0.36-100 µm has been tested on a large number of standard stars. The obtained results are in good agreement with the results obtained by other authors for standard stars. All this ensures that the results obtained are honest and reliable.

**Approbation and application of work.** The results obtained in the dissertation work were approved in scientific seminars of the Batabat Astrophysical Observatory of the Ministry of Science and Education of the Republic of Azerbaijan, in scientific seminars of the Tusi Shamakhy Astrophysical Observatory of the Ministry of Science and Education of the Republic of Azerbaijan, and in reports at a number of regional and international scientific conferences listed below:

1. International Conference “Physics of Stars and Planets: Atmospheres, Activity, Magnetic fields”. Shamakhy, 2019;
2. Republican conference dedicated to the 100th anniversary of the great Azerbaijani scientist Lutfi Zade. Shamakhy Astrophysical Observatory named after N. Tusi of ANAS. Shamakhy, 2021;
3. "1st International Congress on Natural Sciences (ICNAS-2021)", Atatürk University, Erzurum (online), Turkey, 2021;
4. The Republic scientific conference on "Modern problems of Physics and Astronomy", NSU, Nakhchivan, 2021;
5. VI international scientific conference of young researchers dedicated to the 99th anniversary of the birth of our national leader Heydar Aliyev. BMU, Baku, 2022;
6. International conference "Alive Universe - from Planets to Galaxies". Shamakhy, October 12-14, 2022.

**The organization where the dissertation work was carried out:** The dissertation work has been fulfilled out at the Batabat Astrophysical Observatory of the Ministry of Science and Education of the Republic of Azerbaijan.

**Personal contribution of the author.** Publication on the author's dissertation topic in the list of his scientific works given in the abstract (p. 25-26) in co-authored scientific articles: in the articles numbered "1, 2, 3, 4, 5, 7, 8, 9, 10, 12, 15, 16, 17, 18, 19" in the list, problem setting, calculations, theoretical interpretation, the share of the claimant and co-authors is equal in receiving results, analyzing, and compiling the text. In the articles numbered "6, 11, 13, 14" in the list, the issues, calculations, theoretical interpretation, obtaining the results, analysis, and drafting of the text belong mainly to the applicant.

**Structure and scope of the dissertation.** The dissertation consists of an introduction, 4 chapters, conclusions, and a bibliography of 230 names. The total volume of the work is 146, the main text is explained on 122 pages. The total volume of the dissertation with marks: 193933 signs.

Title page – 340 characters. Contents – 4547 characters. Entry – 16476 marks. The main content of the dissertation (chapter, paragraph, clause) – 132989 marks. Result – 3443 marks. Reference list – 35350 marks. List of abbreviations and conventional signs – 670.

## BRIEF CONTENT OF THE THESİS

The dissertation consists of an introduction, four chapters, conclusions and a list of cited literature. **In the introduction**, the relevance of the topic, the purpose of the research and the issues raised are justified. The research methods used are explained. Scientific innovations are substantiated, the main provisions defended are given. The practical and theoretical significance of the obtained scientific results is presented.

In the **I Chapter 1.1-1.4** described the devices from which the observation materials are obtained - the CCD photometer installed on the 60 cm telescope of Shamakhy Astrophysical Observatory named after Nasireddin Tusi of Ministry of Science and Education of the Republic of Azerbaijan. It is shown that in a telescope with an aperture a of 600 mm and an equivalent focal length of F=7500 mm, the scale in the focal plane is μ=27.5 "/mm. Considering that the pixel size is 9 μm and the number of pixels per side is 4000, then the dimensions of the useful part in the focal plane are nearly is 17'x17 '. Landolt standards were used to obtain the conversion formulas for our device complex to the international system. From the fields where Landolt standards are shown, those were selected so that the stellar sizes of the standards there were close to the stellar sizes of the stars we studied. Formulas for converting our instrumental system to the international BVRcIc system. B = 0.996b + 0.0827, V = 0.9607v + 0.5599, Rc = 0.9886$r_c$ + 0.1563, Ic = 1.0096$i_c$ – 0.0852. Here, lowercase letters indicate the stellar sizes of the instrumental system.

**Section 1.4** Observations and processing of results were carried out using MaxIm DL software. This section also provides conversion formulas for obtaining the transition coefficients of the instrumental system to the international system based on the observation of standard stars. To the photometric observation program photometry of two stars is included. These are CTTS-type stars AS 205N and V1082 Cyg.

The method of constructing SED curves of young stars is described in Section 1.5 **of Chapter I.** In addition, the Wide-field Infrared Survey Explorer for a wider range of IR (WISE)[7] and Infrared Astronomical Satellite (IRAS) ( https://irsa.ipac.caltech.edu /IRASdocs/exp.sup/ )[8] catalogs were used. The range of research has been significantly expanded by the inclusion of archival observational data from various space missions.

The principle of constructing SED curves for various objects based on stellar measurements obtained in different bands of broadband photometry consists in converting the stellar measurements $m_\lambda$ into the absolute flux $F_\lambda$ according to the well-known expression: It is carried out according to the absolute radiation flux adapted to zero stellar size in all radiation bands of the star[9] .

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[7] SIMBAD-Vizer //Cat. 2012-2311. - p. 0C

[8] Moshir M. et al., IRAS Faint Source Catalogue, version 2.0.//IRASF C, 0M – 1990.

[9] Strayzhis V.L. Multi-color photometry of stars //Mokslas, Vilnius, —1977. - p. 312.

$$F_\lambda = F_0 \cdot 10^{-0.4(m_\lambda - m_0)} \qquad (1)$$

Here $F_0$ - $m_0$ =0 is the adjusted absolute irradiance flux for the zero point of the system.

In the SED curves of young stars, two criteria were used to calculate the energy radiation excess in separate regions. The first of these is the absolute flux difference, ΔK, of the star and the standard in the K (2.2 μm) band. This parameter characterizes the additional radiation caused by gas in the near-infrared range of the disk accretion. The following formula was used to calculate the ΔK parameter:

$$\log\frac{F_\lambda^*}{F_\lambda^m} = log\lambda F_\lambda^* - log\lambda F_\lambda^m (2)$$

Here $F_\lambda^*$ - the absolute radiation flux of the star, $F_\lambda^m$-flux of the standard star, λ-is the corresponding wavelength.

The second parameter characterizing the energy radiation excess is denoted as S(IR) in the infrared (IR) region and S(UV) in the ultraviolet (UV) region. These parameters characterize the integral radiation excess[10]. Integral radiation excess is determined by the energy excess radiated in the area bounded by the initial and final wavelengths where any $\lambda_1$ and $\lambda_2$ radiation excess are observed.

$$S = \int_{\lambda_1}^{\lambda_2} log\frac{F_*}{F_m} d\lambda \quad (3)$$

The quantities S(IR) and S(UV) calculated by this method characterize the areas of integral radiation excess in the SED curves of young stars. The second is based on the determination of the α coefficient, which is known from the Lada method. This coefficient is determined by the slope of the SEP curve to the abscissa axis. To determine the integral irradiance excess S(IR), the standard stellar distribution is subtracted from the known SEP curve of the star, and

[10] Ismailov N.Z., Valiev U.Z. Spectral distribution of energy in stars of type T Taurus with residual disk.//Astron.journ.-2022, No. 11, c. 933-949

the area of the figure obtained from the remaining distribution is determined by the integral method.This methodology was proposed by us for the first time.

In **section 2.1 of Chapter II** an extensive summary of the physical properties of TTS and HAeBe-type young stars is provided. In the summary, the spectral, photometric, polarimetric properties of such stars in the stage of evolution before the main sequence, the existing theoretical models and the main research problems were explained. It is known that planets form in protoplanetar disks around young stars, which leaves a certain imprint on the structure of the disks. Therefore, the scientific community has sought to obtain high-resolution images to study the structure of disks around young stars. To detect substructures present in the disk around young stars, a spatial resolution of ≤0.1 arcsecond is required. Near-IR and ALMA (Atacama Large Millimeter Array) observations, which describe the signs of planet formation, complement each other.

**Section 2.2** provides a brief chronological summary of the study of V1082 Cyg and AS 205N CTTS-type stars. After that, the results of photometric observations of those stars were analyzed. The Scargle[11] method was used to search for periodic variations.

On the light curve of AS 205N revealed the following most probable periods: P1= 6.51±0.06, P2=14.6±0.01 and P3=24.71±0.04. Of these periods, P1 and P3 confirm that there are previously obtained periods with certain accuracy. For the large-amplitude variation period of AS 205N star brightness P3, the value of the newly refined period P3=24.71 days was obtained. The left panel in Fig.1 shows the archived data of two observation seasons and ours to our observations based on the phase light curve of AS 205N is shown. The right panel shows the averaged phases for those points with a step of 0.1P. As can be seen from the Figue 1, the range of variations in brightness of the star is equal to 2 mag in the V band. If taking into account the brightness of the bright component is $L$ =

[11] Scargle JD, Studies in astronomical time series analysis. Fourier transforms. Autocorrelation function and cross-correlation functions of unevenly spaced data // Astrophys. J., -1989. -343, - p. 874-887.

3.98 $L_\odot$[12] , then we get 0.6 $L_\odot$ for the brightness of the second component.

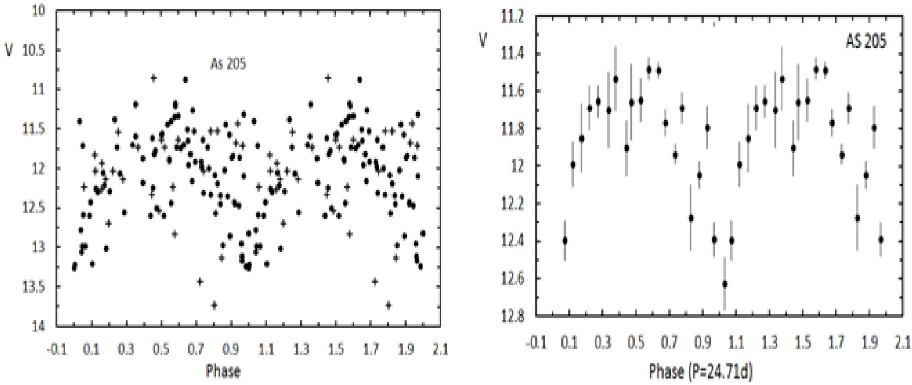


**Figure 1**. **The left panel shows the phase light curve of AS 205N based on archived data from two observing seasons and our observations. The right panel shows the averaged phases for those points with a step of 0.1P. Vertical lines indicate deviation from the mean with statistical weights.**

It is shown that the SED curve of the star AS 205N can be described as a complex system consisting of two different stars with temperatures of 3000K and 2000 K and cold dust radiation.

The analysis of the light curve of the star V1082 Cyg showed that the periodic component of the brightness variations of this star was not detected. The SED curve of the V1082 Cyg star is formed by radiation from the central star and the surrounding gas-dust disk. The SED curve of the star belongs to the second type.

**Section 2.3-2.4** The stars AS 205N and V1082Cyg were observed in the BVRcIc filters for three years from 2019 to 2021, and the results of the measurements taken in each filter were noted. These errors are distributed as follows according to the different filters of the star AS 205N: B (±0.02), V(±0.008), Rc(±0.005), İc(±0.009).

[12] Artemenko SA, Grankin KN, Petrov PP Rotation effects in classical T Tauri stars //Astronomy Letters, –2012, –38(12), –p.783–792.

For the star AS 205N, the number of results obtained in each filter is 35 points. The SEP curve of the star AS 205N, constructed in the range of 0.36-100 μm, showed that there is an excess of radiation in both the UV and IR regions of the spectrum. The excess of ultraviolet radiation is explained by the accretion of the disk, while the excess of IR is caused by the radiation of gas and dust in the disk.

The errors received in our measurements of the star V1082Cyg are as follows: B(±0.03), V(±0.01), Rc(±0.008), İc(±0.01). MaxIm DL software was used for both observation and processing. Observations of the star V1082Cyg were conducted using the same methodology as those for the star AS 205N.

The **Chapter III** is presented the results of study of the SED curves of WTTS-type stars. Based on SED curves of 45 WTTS stars the results of the study of the radiation characteristics of the circumstellar disk are given. The SED curves of the indicated stars were classified and the physical state of the disk was investigated based on them.

In the **sections 3.2 and 3.3 of Chapter III** is considered the analysis and classifications of the SED curves. Integral irradiance excess and other fundamental parameters of program stars were calculated using the rules specified in section 1.6.

During the model approximation, since the energy radiated in the R band in the inner boundary zone of the star's disk is very low, and the interstellar redshift coefficient in the VRI bands is small, these bands were given more priority in fitting the model curve during the approximation. When constructing the SEP curves of the program stars, it was found that WISE W3 (11.6 μm) and W4 (22.1 μm) and IRAS (12 μm) and (25 μm), despite the close wavelengths, in some cases the IRAS observation results show a systematic excess over WISE. In this case, while the WISE W1 (3.35 μm), W2 (4.6 μm), W3 and W4 points in the WISE catalog are described quite well by theoretical curves, the results of IRAS observations are systematically larger. Since IRAS observations are made at a relatively lower resolution, the observed signal may be overestimated by the number of other point sources that typically exist around young stars. Therefore, when constructing the SEP curves, a special correction was made to the IRAS observation results of some program stars to make them consistent with the WISE results. It is shown that the WTTS program stars all show an emission excess in the far-IR range. Only 15 WTTS stars show a UV excess. It has been shown that none of the 15 WTTS stars with a UV excess have any evidence of accretion. Only 3 of these stars show an residual emission in the 2.2 µm range. At least two of these 3 WTTS stars showed signs of disc accretion. SED curves are classified as type III and type II. The type II SED curves observed in WTTS stars do not differ in any way from the SED curves observed in CTTS stars.

It has been shown that 67% of WTTS stars show no emission excess in the near-IR region. Nevertheless, some of these stars have an excess of UV radiation. The lack of correlation between Hα line luminosity and UV excess suggests that some of these stars have disc accretion. 22 out of 30 type III WTTS stars have an emission excess in the far-IR range. These stars have a remnant disk that is in the final stages of evolution. Most of such stars show chromospheric activity. This group of stars was first separated by us as subtype IIId. In the HR diagram, there is no strict boundary between the WTTS stars and the CTTS stars given for comparison. Most of these stars are several million years old, and their masses range from 0.15 to $2.5M_{\odot}$.

It is shown **in paragraphs 3.4 and 3.5** that as a result of various physical processes occurring in the protoplanetary disk, the amount of gas in the disk is seriously reduced due to the dissipation of gas and the formation of planets, the spectrum of stars changes from type II, to type III, and then to type IIId. Finally, the remnants of the protoplanetary disks are observed in a fragmented form. Figure 2 shows the location of the program stars on the HR diagram. It can be seen from the diagram that the ages of the program stars are $10^5$ -$10^8$ years, and some stars lie on the ZAMS (Zero Age Main Sequence) line. Here, the location of type III WTTS stars is indicated by black circles, the location of type II stars is indicated by a colorless triangle, and the CTTS stars given for comparison are indicated by crosses.

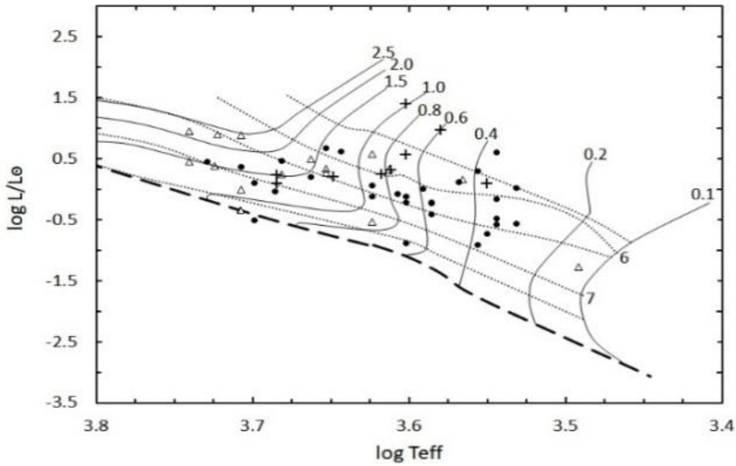


**Figure 2. The location of program stars on the HR diagram. Evolution curves are taken from work[13]. The numbers on the solid curves show the masses, and the dotted curves show the divisions of the logarithm of the age in intervals of 5-8 in 0.5 steps. The thick broken line below is the main sequence boundary (ZAMS). Open triangles indicate WTTS type II stars, black circles indicate type III stars, and crosses indicate CTTS stars**.

The results obtained in this chapter showed that practically all program stars have an excess of radiation in the far-IR range (λ≥12 μm). The results show that both types of WTTS stars show UV excess in some cases. However, only 3 WTTS stars show an excess of radiation in the 2.2 μm band. This indicates that these stars have optically thick disks, analogous to those of regular CTTS stars. In addition, an IR excess is observed in the 3-12 μm range in 15 WTTS stars. Our results prove that a single evolutionary direction of protoplanetary disks is determined:

In the initial stage, the gas-rich disk (type II spectrum) gradually loses gas and the star's type changes to type III, and then to type IIId. However, the H-R diagram shows that there are exceptions to these rules, for example, some stars that are 1 million years old show a

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[13] Siess L., Dufour E., Forestini M. An internet server for pre-main sequence tracks of low- and intermediate-mass stars //Astron.&Astrophys., –2000. -358, -p.593-599

spectrum belonging to type III. It is believed that the evolution of stars is accelerated or slowed down by certain mechanisms unknown to us - some lose gas in the star surroundings disk quickly, while others lose it slowly.

In the section 4.1 of **Chapter IV** protoplanetary disks of CTTS stars have been investigated. To classify the received SED curves according to the Lada[6] scheme, the α parameter was calculated:

$$\alpha = \frac{\log\lambda_2 F_2 - \log\lambda_1 F_1}{\log\lambda_2 - \log\lambda_1}$$

where $\lambda_1$ and $\lambda_2$ , ($\lambda_2 > \lambda_1$ ) are the wavelengths of the corresponding points on the SED curve, and $F_1$ and $F_2$ are the corresponding absolute flux values at that wavelength are floods. The α parameter indicates the slope of the selected interval in the SED curve. The excess radiation in the SEP curves of CTTS stars is not limited to one band, but can be in any two wavelength ranges λ1 and λ2. In this case, it is more convenient to calculate the radiation excess using the integral method to calculate the radiation excess in that interval.

In the **Sections 4.2 and 4.3** is shown that 7 out of 49 CTTS stars show type I and 42 show type II SED curves. Type III SED curves were not detected in these stars. This proves that the gas-dust disks of CTTS stars is optically thick, in other words, rich in gas.

No correlation was found between the luminosity of the Hα line and the radiation excesses in the UV and IR regions. This shows that both disc accretion and chromospheric activity play a major role in the formation of the brightness of the Hα emission line.

It was shown for the first time that the parameter α, which determines the slope of the SED curves, increases with the age of the stars. It has been shown that as the age of stars increases, the radiation excess in the far-IR region increases. This trend is maintained until the age of the stars is 10 million years.

Of the 19 studied HAeBe stars, 3 shows type III SED curves and the rest show type II SED curves. A weak correlation between the luminosity of the Hα line and the emission excess in the near-IR range was found. This shows that the change of the Hα line in these stars is mainly determined by the accretion rate.

In paragraph 4.2 **of the IV Chapter a**n analysis of the physical parameters and results of CTTS stars is presented. In the corresponding table, the luminosity, radius, mass, age and S(IR), S(UV), ΔK values are given. Positions of CTTS stars are determined on the HR diagram and their masses and ages are estimated. It is shown that the masses of CTTS stars exhibit values in the range of $0.3 \leq M/M_{\odot} \leq 2.5$. The HR diagram shows the location of the program stars and the constructed evolution lines.

In section 4.3 and 4.4 of the **Chapter IV** the results of constructing and analyzing the SED curves of HAeBe stars were presented. The fact that some of these stars are much less numerous than TTS, despite their big luminosity, suggests that HAeBe stars, which are relatively big massive, evolution more rapidly. The number of TTS stars discovered currently exceeds 1,000. Therefore, statistical studies of the parameters of HAeBe stars are generally less reliable than those of TTS stars.

Of the 19 program stars, only 3 have α coefficients in the range $-3 < \alpha < -2$. This also indicates that the amount of gas in the surrounding disk of these stars has been significantly reduced (type III). Such stars are at the end of the planet formation phase. In the remaining stars, it is in the range $-1 < \alpha < 0$. This indicates that these stars have a thick optical disk (type II). Studies have shown that, unlike CTTS stars, none of the HAeBe program stars have a type I SEP curve.

The physical parameters of the HAeBe stars selected for the study - absolute balometric stellar sizes Mv, luminosity $L/L_{\odot}$, age t, radiation excess parameters S(IR), ΔK and radii $R/R_{\odot}$ of the stars were calculated. HAeBe indicates the location on the HR diagram of stars that have masses in the range $2 \leq M/M_{\odot} \leq 20$.

Expected precision of lines of this parameter are not more than 20% (Figure 3).

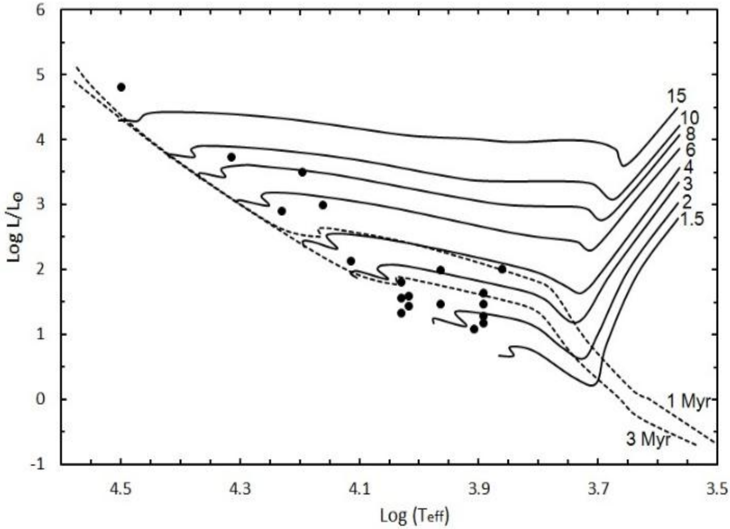


**Figure 3. Location of soft stars on the HR diagram and theoretical evolution tracks[14,15] are shown. Solid lines show masses, broken lines show ages (1-3 million years).**

For HAeBe stars, the dependence of the luminosity of the Hα line on the radiation excess parameters was investigated. It was shown that the correlation coefficient between S(IR) and ΔK quantity was $r = 0.86 \pm 0.12$, and between log (LHα) and ΔK, $r = 0.49 \pm 0.23$. It was shown that the correlation coefficient between S(IR) and ΔK quantity was $r = 0.86 \pm 0.12$, and between log (LHα) and ΔK, $r = 0.49 \pm 0.23$.

[14] Bressan A., PARSEC: stellar tracks and isochrones with the PAdova and TRieste Stellar Evolution Code/ A. Bressan , P. Marigo, L. Girardi [et al.] //Mon. Notice. Roy. Astron. Soc., –2012. -427, -p.127-145.

[15] Marigo P., Girardi, L., Bressan, A., et al, New Generation of PARSEC-COLIBRI Stellar Isochrones Including the TP-AGB Phase/ P. Marigo, L. Girardi, A. Bressan, [et al.] //Astrophys.J., –2017. -835, -p. 77-96.

## MAIN RESULTS OBTAINED IN THE DISSERTATION

1. The value of P3=24.71±0.04 days was obtained for the period of brightness variations of star AS 205N with a large amplitude ($\Delta V \sim 2$ mag). Assuming the captured binarity of the system, the luminosity of the weak component is determined as $0.6 \pm 0.1 L_{\odot}$. The periodic variations of the star brightness with the P3 period is well observed only in certain seasons. Stochastic component of the light curve of the system are explained by the non-stationarity of the stars of the system; It is shown that the SED curve of the star AS 205N consists of two different stars and cold dust radiation with temperatures of 3000 K and 2000 K.

2. As a result of the analysis of the light curve of the star V1082 Cyg, the periodic component of the brightness variations of this star was not detected. The SED curve of the star V1082 Cyg is formed as a result of radiation from the central star and the surrounding gas-dust disk. The SED curve of the star is attributed to type II.

3. All the 45 WTTS program stars show an radiation excess in the far-IR range. Only 15 WTTS stars exhibit an UV excess. It has been shown that none of the 15 WTTS stars with a UV excess have any evidence of accretion. Only 3 stars show an emission excess in the 2.2 μm range . At least two of these 3 WTTS stars are detected by us with signs of disc accretion. Only 15 of the WTTS program stars show an IR emission excess in the λ3–12 μm region.

4. Of the 45 WTTS stars, 30 are type III and 15 are type II. Constructed SED curves were assigned to type III and type II spectra. It has been shown that the type II SED curves in WTTS stars are indistinguishable from those in CTTS stars. 67% of the selected WTTS stars show no radiation excess in the near-IR region. However, some of these stars have excess UV radiation. The lack of correlation between the Hα line luminosity and the UV excess indicates that some of these stars may also have disc accretion.

5. In 22 out of 30 type III WTTS stars, an emission excess was detected only in the far-IR range ($\lambda \geq 60$ μm). This group of stars was first separated by us as subtype IIId. These stars have a faint remnant dust disk that is in the final stages of evolution. Most of such stars show chromospheric activity. There is no strict boundary separating

the WTTS stars and CTTS stars given for comparison in the HR diagram. Most of these stars are several million years old, and their masses range from 0.15 to 2.5$M_{\odot}$

6. Based on the statistical analysis, it was shown that as a result of various mechanisms occurring in the protoplanetary disc, the amount of gas in the disc is seriously reduced due to the dissipation of gas and the formation of planets, the spectrum of stars changes from type II, to type III, and then to type IIId. Finally, the remnants of the protoplanetary disks are observed in a fragmented form. Such stars may have chromospheric activity.

7. 7 out of 49 CTTS stars show type I and 42 show type II SED curves. Type III SED curves were not detected in these stars. This proves that the gas-dust disks of those stars is optically thick.

8. No correlation was found between the luminosity of the Hα line and the radiation excesses in the UV and IR regions in CTTS stars. This shows that both disk accretion and chromospheric activity play a major role in the formation of Hα luminosity. It was shown for the first time that the parameter α, which determines the inclination of the SED curves of CTTS stars to the abscissa axis, increases with the age of the stars. It has been shown that as the age of stars increases, the radiation excess in the far-IR region increases. This trend is maintained until the stars are 10 million years old.

9. Of the 19 studied HAeBe stars, 3 show type III and the rest show type II SED curves. A weak correlation between the luminosity of the Hα line and the emission excess in the near-IR range was found. This shows that the variations of the Hα line in these stars is determined by the accretion rate.

## LIST OF PUBLISHED SCIENTIFIC ARTICLES ON THE DISSERTATION TOPIC


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