ANNOTATION

of dissertation for the Philosophy Doctor (PhD) degree on «6D061100 – Physics and Astronomy»

Khokhlov Azamat

Spectral and photometric studies of binary systems with circumstellar envelopes

General description of work

The present work is devoted to the results of the analysis of spectral and photometric observations of the emission star IRAS 07080+0605 (V ~ 12.1), which has one of the strongest IR excesses among objects with the B[e] phenomenon. For the purpose of investigating this object, we collected photometric and spectral observations from various astrophysical observatories, including facilities in Mexico, the United States, Chile, and Kazakhstan. In addition, available data from the literature and information from resources such as ASAS SN, UCAC4, and 2MASS were analyzed. The observations of the star IRAS 07080+0605 span almost two decades, from 2004 to 2021. The second chapter of this thesis presents an extended review of the instruments used, state-of-the-art data analysis techniques in astrophysics, and data collection methods. As a result of this study, the physical parameters of the system were determined. The energy distribution in the spectrum of the system in the optical and IR bands has been modeled. It was found that the positions of the object's absorption lines change with a period of 24±1 days and a semi-amplitude of 10±2 km/s, which indicates the presence of a secondary component with a small mass. Additionally, visual light variations with a stable period of 190 days but with a variable amplitude of approximately 0.2 stellar magnitude were detected in the ASAS SN data. The observational characteristics of the star IRAS 07080+0605 are similar to those of the protoplanetary nebula Red Rectangle (HD 44179). The dust disk of IRAS 07080+0605 shows the presence of carbon particles (~ 10-20% of the total dust content) and emission bands of polycyclic aromatic hydrocarbons (PAHs). Based on a comprehensive analysis of the observational data, we concluded that the star IRAS 07080+0605 is the first (of the detected) objects from the FS CMa group that is on its way to the post-AGB evolution stage, based on its observed characteristics.

Relevance of the topic

Observations by various methods (photometry, spectroscopy, interferometry) obtained since the advent of radiation detectors have shown that more than 70% of stars at various stages of evolution are part of double or multiple systems.

Binary systems, in which stars form close to each other, can interact throughout their lifetime, thus increasing the periods of presence of large amounts of circumstellar matter in the system due to mass transfer in these systems. Periods of such mass transfer change the masses of the stars and can populate regions within

and immediately outside the double system with circumstellar gas. At the same time, dust particles can form in the outer parts of these envelopes, where temperatures are below 1500-2000 K.

In some types of double systems there is such a strong mass transfer between the stellar components that, in addition to significant changes in the masses of the companions, there is formation of large and dense circumstellar gas disks accompanied by condensation of large amounts of circumstellar dust. Such systems show very strong emission lines in the spectra and an excess of visual and infrared emission due to over-emission of stellar photons by circumstellar gas and dust. The above phenomena are observed in double systems with a Wolf-Raye companion star; in double stars of the post-asymptotic giant branch evolving toward a planetary nebula; bright blue variables (LBVs); and FS Canis Majoris (FS CMa) type objects.

FS CMa-type objects were singled out as a separate new group by Prof. Miroshnichenko in 2007. The most likely scenario for the formation of FS CMa objects, according to the confirmed existing data and analysis, is the evolution of a close binary system in which there is a strong mass transfer between the components of the binary system, leading to the loss of some of this mass to the circumstellar space and the formation of a dust shell or disk.

At present, there is significant progress in the study of FS CMa-type stars. A detailed and comprehensive analysis of long time series of observations has allowed us to discover new properties of this group of stars, such as rapid spectral changes; the presence of lithium lines in the stellar spectrum, etc. Orbital periods were determined for a number of objects of this group, physical features of the components of the systems were described, and physical parameters of the stars were determined, which showed a large range of luminosities of the objects, suggesting the existence of a large number of such systems both in our Galaxy and in others. Strong IR excesses indicate that FS CMa group objects represent an unaccounted source of dust in the Galaxy. Such objects have never been considered as dust producers, and a reassessment of Galactic dust "production" is required.

There are challenges in investigating this new group, the main ones being the determination of the physical parameters of the stars and their circumstellar envelopes, and the determination of the evolutionary status of the star. The latter, causes conflicting opinions about the evolutionary status of some objects of the FS CMa group. This is related to the mechanisms of matter formation in circumstellar envelopes. For example, for the brightest objects of the FS CMa group: HD 85567, HD 50138, FS CMa, there are opposing views on the evolutionary status of stars. A number of studies refer the above objects to Herbig Ae/Be (HAeBe) stars at the stage of evolution to the main sequence. At the same time, none of the objects is in the star formation region. The main difference between these objects and true young stars is the sharp flux drop at wavelengths $\lambda > 10$ μm. This feature is caused by the absence of cold/faraway dust in the circumstellar envelope, which formed during previous evolutionary stages. In the neighborhood of stars in the pre-main-sequence stage, circumstellar matter accumulates from large parent clouds and hence contains cold/faraway dust.

Another most likely evolutionary scenario for the above objects is the non-conservative mass transfer between the components of the double system proposed by A.S. Miroshnichenko (described above), and further distinguished by him into a separate class of objects based on the FS CMa prototype. Moreover, signs of duality for HD 85567, HD 50138, and FS CMa were detected in spectro-astrometric observations for all three stars. Despite this, the duality is not taken into account in a number of works, in which the objects HD 85567, HD 50138, and FS CMa are attributed to young Herbig Ae/Be stars..

In addition to the problem of determining the evolutionary status, as mentioned above, there is a problem of determining the luminosity (one of the fundamental parameters of the system) of some FS CMa objects for the following reasons. First, it is not easy to explain the influence of circumstellar matter, since matter both absorbs stellar radiation and re-emits ionizing UV radiation in spectral lines, optical and IR continuum. Second, the distances to objects determined by different methods do not agree with each other in some cases.

At the moment, a number of important questions remain to be answered to unravel the nature and processes in the recently discovered group of FS CMa objects. These include the search for predecessors and successors of the objects of this group, constraints on the time of dust formation onset and its duration, the search for the reasons for the absence of nearby objects, new observed features of the group, at what stages of evolution these objects may be, etc.

A detailed and comprehensive study of each object of this new group is a necessary process in understanding the nature of FS CMa-type stars.

Therefore, IRAS 07080+0605, which has one of the strongest IR excesses among objects with the B[e] phenomenon, was investigated as part of this thesis work. This object was included in the FS CMa group by A.S. Miroshnichenko in 2007, and the dual nature of the system was proposed by him at that time. However, recent works (Arias et al. 2018; Condori et al. 2019) studying the object categorize IRAS 07080+0605 as a pre-main-sequence star. Moreover, for IRAS 07080+0605 there is a scatter in the parameter determination. This is primarily due to the fact that the study of this object is based on single spectroscopic observations in narrow wavelength ranges, except for one spectrum obtained with the FEROS spectrograph in the full optical range, parts of which are shown in Condori et al. 2019. These circumstances prevented a thorough study of the spectral features to determine the exact fundamental parameters of the system.

The aim of the work is a comprehensive study of the emission star IRAS 07080+0605, which included: the study of a large collection of optical spectra (high resolution) of IRAS 07080+0605, modeling of the energy distribution in the spectrum in the optical and infrared ranges, the study of intrinsic multicolor optical and near-infrared photometry to clarify the fundamental parameters, as well as the study of the nature and evolutionary status of the object.

Research objectives

1. On the basis of the analysis of spectral and photometric data of the emission star IRAS 07080+0605, determine the fundamental parameters of the object of study.

2. Modeling of energy distribution in the spectrum of the star IRAS 07080+0605.

3. Based on the analysis of observational characteristics of the star IRAS 07080+0605, to draw a conclusion about its nature and evolutionary status.

Research objects: IRAS 07080+0605 emission star of FS CMa type.

Method of investigation

1. Photometric and spectral observations of the star IRAS 07080+0605.

2. Processing and analysis of the obtained observational data using the IRAF astrophysical data processing package.

3. Modeling of energy distribution in the spectrum of the star IRAS 07080+0605

Main provisions to be protected

1. Using the cross-correlation analysis of the high-resolution spectra of the star IRAS 07080+0605, the presence of an additional stellar component in this system was established.

2. Based on the results of high-resolution spectra, photometry, and RPS modeling, we find that the observed optical luminosity of the star IRAS 07080+0605 is attenuated by the circumstellar disk material by a factor of ~43 in the filter V.

3. Based on a comprehensive study: the study of photometric and spectral variability, modeling of the energy distribution in the spectrum in the optical and IR ranges, estimation of fundamental parameters, and comparison with the properties of the planetary nebula "Red Rectangle", we found that the star IRAS 07080+0605, which has the observed characteristics of the FS CMa group, is on the way to the post-AGB evolution stage.

The scientific novelties of work are:

1. The first object from the FS CMa group, which is on the way to the post-AGB evolution stage, is detected based on the observed characteristics;

2. Changes in the position of absorption lines in the spectrum of the star IRAS 07080+0605 have been detected;

3. Modeling of the energy distribution in the spectrum of the star IRAS 07080+0605 was carried out;

4. A number of properties of IRAS 07080+0605 were found to be similar to those of the post-AGB object Red Rectangle (HD 44179).

Theoretical and practical significance of the work

The results obtained in the thesis can be applied to investigate the causes of dust formation and the evolution of stars and galaxies.

Researches are based on are the original scientific papers listed in the list of references used.

Personal contribution of the author

The results of the analysis were obtained personally by the co-researcher. Problem setting and discussion of the results were carried out jointly with scientific advisors.

The reliability of the results

The reliability of scientific findings of the work is confirmed by consistency with theoretical models, conclusions on the nature of similar objects obtained by other authors.

Approbation of work

Based on the materials of thesis 7 printed works were published.

Articles with a high impact-factor according to the database of Thomson Reuters or in the publications included in the international scientific database Scopus:

1. Khokhlov S. A., Miroshnichenko A. S., Zharikov S. V., Grankin K. N., Zakhozhay O. V., Manset N., Arkharov A. A., Efimova N., Klimanov S., Larionov V M., Khokhlov A. A., Kusakin A. V., Omarov C. T., Kokumbaeva R. I., Reva I. V., and Agishev A. T. Toward Understanding the B[e] Phenomenon. VIII. Nature and Variability of IRAS 07080+0605 //The Astrophysical Journal. – 2022. – Vol.932. – №1.

Articles in publications recommended by the CCNVO of the Ministry of Science and Higher Education of the MSHERK:

1. Сарманбетов С.А., Кожагулов Е.Т., Ибраимов М.К., Хохлов А.А. Классификация спектров нормальных звезд главной последовательности нейронной сетью глубокого очищения // Журнал проблем эволюции открытых систем, выпуск 21 Т1, 2019

2. Жексебай Д.М., Хохлов С.А., Әсілхан Ә.Д., Хохлов А.А. Машиналық оқытудың (Machine learning) көмегімен молекулалық бұлттарды және жұлдыздардың қалыптасуын жіктеу // Журнал вестник «КазНИТУ», №3 (139), 2020г.

3. Ауельбекова Д.О. Амантаева А.Е. Хохлов А.А. Тұтылмалы жұлдызды модельдеу 2MASSJ02253615+2805508 // ҚазҰТЗУ хабаршысы №22021.

Publications in collections of theses of reports:

1. Нодияров А.С., Хохлов А.А. Спектральные изменение звезды IRAS 07080+0605 Материалы международной конференции студентов и молодых ученых «Фараби әлемі». – Алматы, 2019.

2. Ауельбекова Д.О., Хохлов А.А. Фотометрические исследования звезды IRAS 07080+0650 // Материалы международной конференции студентов и молодых ученых «Фараби әлемі». – Алматы, 2020.

3. Хохлов А.А. Природа IRAS 07080 + 0605 // Материалы международной конференции студентов и молодых ученых «Фараби әлемі». – Алматы, 2021.

Relationship of the thesis topic with the plans of scientific works

The dissertation work was carried out in accordance with the plans of fundamental research works of KN MES RK "Grant financing of scientific research" on the theme: "AP08856419 - Observational manifestations of accretion flows in close double star systems and their analysis by computer modeling methods" and "AP19578879 - Study of observational manifestations of stars of FS CMa type by computer modeling methods".

Structure and volume of the thesis

The dissertation consists of an introduction, four sections, conclusion, list of used sources and contains two appendices. The work is set out on 99 pages of

typewritten text, illustrated with 45 figures, 34 formulas, 9 tables, the list of used sources contains 93 names.