ANNOTATION

of dissertation for the Philosophy Doctor (PhD) degree
in specialty "6D061100 - Physics and Astronomy"

MANAPBAYEVA ARAILYM

RADIOASTRONOMIC OBSERVATIONS OF MOLECULAR CLOUD AQUILA AND SEARCH FOR REGIONS OF STAR FORMATION

General description of work. This dissertation work is devoted to radio astronomy studies of the W40 and Serpens South star formation regions of the Aquila molecular cloud, the study of a new Serpens3 star formation region, as well as the search and identification of young stellar objects in the studied regions based on infrared observations. This study is important for radio astronomy, because molecular clouds are considered as birthplaces for stars, and understanding the processes of star formation will help deepen our knowledge about the formation and evolution of stellar systems. For the first time, the analysis of radio astronomy observations of the H_2CO formaldehyde molecule and the $H_{110\alpha}$ recombination radio line toward the southern regions of W40 and Serpens South of the Aquila molecular cloud, obtained using the 26m Nan-Shan radio telescope of the Xinjiang Astronomical Observatory of the Chinese Academy of Sciences was carried out. In this study, a new region of star formation was identified, called Serpens3. The analysis of observations of the recombination radio line $H_{110\alpha}$ in the W40 HII region made it possible to calculate its physical parameters, according to which the ionized hydrogen region is classified as an ultra-compact type. The developed algorithm for the search and identification of young stellar objects based on observations in the near and middle infrared range helps to identify previously unidentified objects in each studied region of star formation. Based on the spectral data, the evolutionary status of the objects was determined.

The relevance of the topic. In recent years, the most important achievement of molecular astrophysics has been the establishment of the basic idea that stars are formed in molecular clouds. The study of molecular clouds and star formation regions is of high relevance in astronomy and has great potential to expand our knowledge about stars, galaxies and the evolution of the universe. Molecular clouds are key objects for studying star formation, as they represent the places of formation of stars and planets. Interstellar molecules are good indicators of the processes of birth and death of stars, their presence is an indicator of various stages of evolution. Traces of interstellar molecules can be found in all kinds of celestial bodies from objects of the early Universe to supernova remnants. Therefore, molecules are considered as indicators of certain processes and conditions that occur in the interstellar medium. An effective method of obtaining data on the kinematics and physical structure of molecular gas clouds is mapping in radio lines. For this purpose, lines of various complex molecules are observed, for example, CO, H_2CO, NH_3, CH_2O, etc. Observations of recombination radio lines provide a unique opportunity to study the physical parameters and processes occurring in the HII

regions that are associated with star formation regions. Determination of density, temperature, mass and other characteristics of the HII regions allows to deepen the understanding of mechanisms of star formation, gas dynamics and the interaction of molecular clouds with the radiation of young stars.

The study of molecular clouds in the infrared range allows us to reveal their structure and characteristics more fully. The identification of young stellar objects emitting in the infrared range is a necessary stage in the study of the evolutionary stages of star formation. Considering that observations play an essential role in the detection of young stellar objects and the study of the most active and interesting star formation zones, celestial surveys of Spitzer, WISE spacecraft and catalogs of infrared radiation sources have recently been widely used. Observations make it possible to analyze energy distributions in the spectra of young stellar objects, as well as to obtain information about their physical properties, temperature, composition and radiation intensity of star formation regions.

The aim of this work is to study the spectral line of the formaldehyde molecule H_2CO and the recombination line $H_{110\alpha}$ toward the Aquila molecular cloud, to determine the physical parameters of star formation regions and to search for young stellar objects.

Research objectives

1. Theoretical studies of molecular clouds and star formation processes in them.
2. Observations of the Aquila molecular cloud at the 26m Nanshan Radio Telescope of the Xinjiang Astronomical Observatory of the Chinese Academy of Sciences and processing of the obtained spectra;
3. Study of emission and absorption lines in spectra, analysis of radio maps, determination of physical parameters of star formation regions;
4. Development of an algorithm for identification of young stellar objects;
5. Studies of star formation regions in the infrared range, search and identification of young stellar objects;
6. Analysis of energy distributions in the spectra of young stellar objects, interpretation of the results obtained and determination of the evolutionary status of objects.

Objects of study: Regions of active star formation in the Aquila molecular cloud: W40, Serpens South and Serpens3.

Subject of study: observational data in the radio and infrared ranges

Research methods: In the dissertation research, experimental and theoretical methods were used to study the star formation regions of the Aquila molecular cloud. To study emission and absorption lines in the spectra, computer software environment for data processing and analysis were used: Gildas, DS9, IDL Astro libraries, Python libraries. A new research algorithm developed in the MatLab software environment was used to identify young stellar objects. SIMBAD, Vizier, IRSA, Aladin v10.0 astronomical databases and infrared catalogs were used to analyze radio maps and compare them with observations of other observatories in the radio and infrared spectral regions: AllWise Data Release (Cutri+ 2013), 2MASS

All-Sky Catalog of Point Sources (Cutri+ 2003), GLIMPSE Source Catalog (I + II + 3D) (IPAC 2008), The Spitzer (SEIP) source list (SSTSL2) (Spitzer Science Center, 2021).

The main results of this dissertation:

1 The distribution of formaldehyde molecule H_2CO absorption lines in the Aquila molecular cloud is consistent with the W40 and Serpens South star-forming regions and also identifies the new star-forming region called Serpens3.

2 Firstly, by means of ^{13}CO spectral line, the excitation temperature T_{ex} of the formaldehyde molecule (H_2CO) was determined, which corresponded to the range of 2-5 K for the W40 region, and 1-2 K for the Serpens South and Serpens3 regions.

3 The $H_{110\alpha}$ radio recombination line is detected in W40 star formation region and corresponds to the HII region which is classified as an ultra-compact type with physical parameters ($T_e^* = 7300K, EM = 7{,}4\times10^6$ pc cm^{-6}, $N_L = 9 \times 10^{47} s^{-1}$, U=28.0 pc cm^{-2}, R = 0.09 pc, M_{HII}=0,15 $M_\odot$).

4 The developed algorithm for searching and identifying young stellar objects made it possible to identify 30 new previously unidentified objects at an early stage of evolution in the Aquila molecular cloud.

Firstly, in the Aquila molecular cloud 30 new objects at an early stage of evolution were identified as young stellar objects: 11 new objects for the W40 region, 7 new objects for Serpens South and 12 new objects for Serpens3.

Scientific novelty of the work

1 The analysis of radio astronomical observations of the H_2CO formaldehyde molecule and the $H_{110\alpha}$ radio recombination line in the direction of the Aquila molecular cloud obtained at the 26m Nan-Shan radio Telescope of the Xinjiang Astronomical Observatory of the Chinese Academy of Sciences was carried out. A new star formation region, designated as Serpens3, which is at an early stage of evolution, has been identified along the absorption lines of the H_2CO formaldehyde molecule.

2 The excitation temperature T_{ex} of the formaldehyde H_2CO molecule in the Aquila molecular cloud is calculated.

3 By analyzing the observations of the $H_{110\alpha}$ radio recombination line, the physical parameters of the W40 HII region were determined.

4 Star formation regions of the Aquila molecular cloud were studied in the infrared wavelength range according to the Wide-field Infrared Survey Explorer (WISE) using the developed algorithm for detecting previously unidentified and at various stages of evolution of young stellar objects.

Theoretical and practical significance of the work

The results obtained in the dissertation work can be applied to the study of both fundamental astrophysical processes and practical aspects of astronomy. This work makes a significant contribution to the expansion of our theoretical understanding of the processes of star formation in molecular clouds. The results obtained can reinforce existing theoretical models and contribute to the development of new concepts aimed at a deeper understanding of star formation processes. They can also be used in further research in the field of astronomy and astrophysics, as

well as in applied tasks related to the study of the evolution and formation of star systems.

The work has practical potential for further development of astronomical methods and instruments. Its results can serve as a basis for the organization of observational programs aimed at studying the processes of star formation in molecular clouds. These practical applications can enhance the efficiency and accuracy of astronomical research related to star formation and the evolution of molecular clouds.

Author's personal contribution

The author of the dissertation participated in the observations of the H_2CO formaldehyde molecule and the $H_{110\alpha}$ recombination line in the direction of the Aquila molecular cloud on the 26m Nan-Shan telescope of the Xinjiang Astronomical Observatory of the Chinese Academy of Sciences. She carried out the processing of observational data, basic calculations of physical characteristics in the software environments Gildas, DS9, IDL Astro libraries and Python, the development of the algorithm and its software implementation in MatLab, search and identification of young stellar objects and interpretation of the results. The statement of tasks and conclusions on the conducted research are coordinated together with scientific consultants.

Reliability of results

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

Approbation of work

The results of the dissertation work were reported and discussed. Based on the materials of the dissertation work, 15 works have been published:

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

1. Komesh T., Esimbek J., Baan W., Zhou J., Li D., Wu G., He Y., Sailanbek S., Tang X., **Manapbayeva A.** H_2CO and $H_{110\alpha}$ Observations toward the Aquila Molecular Cloud // **The Astrophysical Journal**, 2019. – Vol. 874 (172). – PP. 1-10, Quartile: **Q1**. DOI:10.3847/1538-4357/ab0ae3

Publications in the scientific journals, indexed in the database Web of Science:

1. **Manapbayeva A. B.,** Omar A.Zh., Alimgazinova N.Sh., Komesh T., Kyzgarina M.T., Esimbek J., Assembay Zh.. Determination of physical parameters of the W40 HII region using observations of $H_{110\alpha}$ radio recombination line // Recent Contributions to Physics, 2023. - №3 (in print).

2. Nazar A.B., **Manapbayeva A.B.,** Alimgazinova N.Sh., Kyzgarina M.T,. Demessinova A.M. Identification of young star objects near dust bubble N10 // Vestnik KazNU, serija fizicheskaja, 2022. – Vyp.83, №4. – C.13-20.

3. Komesh T., **Manapbayeva A.B.,** Esimbek J., Alimgazinova N.Sh., Kyzgarina M.T., Bagzhan Q. Interpretacija radioastronomicheskih nabljudenij H_2CO i $H_{110\alpha}$ v oblastjah zvezdoobrazovanija W40 i Serpens South molekuljarnogo

oblaka Aquila // Vestnik KazNU, serija fizicheskaja, 2020. – Vyp.74, №3. – S.19-28.

6 articles were published in publications recommended by the Committee for Control in the Sphere of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan and 5 publications were published in abstracts of international conferences.

Connection of the dissertation topic with the plans of scientific investigations

The dissertation work was carried out in accordance with the plans of the Fundamental Research Programs of the Ministry of Science and Higher Education of the Republic of Kazakhstan on the topic "AR13067768 - Radio Astronomy studies of hot nuclei in molecular clouds and the study of star formation regions of massive stars"

The structure and scope of the dissertation

The dissertation consists of an introduction, three sections, a conclusion, a bibliography and contains four appendices. The work is presented on 114 pages of typewritten text, illustrated with 63 figures, 14 formulas, 9 tables, the list of references contains 104 items.