# Stellar Membership of RCW 34 HII Star-Forming Region

V.M. Grigoryan *[1], A.L. Samsonyan[2], E.H. Nikoghosyan[2], N.M. Azatyan[2], D.H. Andreasyan[2], and A.A. Khachatryan[1]

[1]Yerevan State University, Yerevan, Armenia
[2]Byurakan Astrophysical Observatory, Byurakan, Aragatsotn Province, Armenia

**Abstract**

The Vel OB1 association, located at a distance of 1.5-1.9 kpc, is one of the most actively studied star formation regions in the southern hemisphere. Our study focuses on an "Arclike" structure within the Vel OB1 association, which may have been formed from a shock wave caused by a supernova explosion about 2-2.5 Myr ago. Optical Gaia data revealed probable stellar members only in the southern part of the Arclike structure, where the RCW34 HII (IRAS 08546-4254) region is located. In contrast, the northeastern part of the Arclike structure, in the vicinity of the IRAS 08563-4225 source, hosts more embedded stellar population. Using near-infrared astrometric and photometric data from the 2MASS survey, we identified well-defined clusters of young stellar objects in the vicinity of both IRAS 08546-4254 and IRAS 08563-4225. The members of the cluster associated with IRAS 08563-4225 exhibit stronger infrared excess.

***Keywords:*** *Open clusters and associations: Vel OB1- stars: formation - stars: early type stars*

## 1. Introduction

Star-forming regions and molecular clouds are intriguing parts of space where new stars are born. These areas, filled with dense, cold gas and dust, appear as dark patches against the bright Milky Way. They play a crucial role in the formation and evolution of stars in our Galaxy and beyond.

Molecular clouds come in two main types: giant molecular clouds (GMCs) and smaller molecular clouds. GMCs have masses ranging from tens of thousands to millions of solar masses and are large enough to birth hundreds of thousands of stars. Meanwhile, smaller molecular clouds, although smaller, still provide the right conditions for new stars to form. Deep within molecular clouds, star formation cores emerge as dense centers of stellar birth. Gravitational forces dominate here, causing gas and dust to collapse and form protostars. In various massive star-forming regions or associations, star formation in these clumps seems to be triggered by compression from external shocks. Other clusters can form by the self-gravitation of dense regions in molecular clouds (e.g. Elmegreen & Lada, 1977, Zinnecker et al., 1993). If star formation is triggered by compression, the age spread of the new generation of stars should be small, while the age spread of young stellar clusters is expected to be larger in self-initiated condensations. Therefore, understanding the characteristics of young stellar populations in star-forming regions is essential for deriving insights into the star formation processes within parent molecular clouds.

Massive stars play a very important role in the star-forming process. They affect their environment by shaping the morphology, energy, and chemistry of the interstellar medium (ISM) through outflows, stellar winds, and supernovae (McKee & Tan, 2003).

The main objective of this study is to search for the young stellar population in the "Arclike" molecular cloud within the Vel OB1 association. Vel OB1, located at a distance of 1.5-1.9 kpc, is one of the largest OB associations and has a complex, multi-component structure (Humphreys, 1978). One of its structures is the RCW 34 emission nebula, located at a distance of about 1.5-1.9 kpc. The age of the RCW 34 HII region is estimated to be around 2 Myr (Bik et al., 2010). Previous studies have shown that RCW34 is located in the southern part of the "Arclike" elongated molecular cloud (Azatyan et al., in preparation). The view of the cloud in WISE wavelengths is shown in Figure 1. In the northern part of the "Arclike" cloud, the IRAS

*vardgesgrigoryan99@gmail.com, Corresponding author


doi: https://doi.org/10.52526/25792776-24.71.1-29

08563-4225 star cluster is located at a distance 1.7 kpc (Beuther et al., 2008). Azatyan et al. suggested that the “Arclike” structure was created by a shock wave resulting from a supernova explosion about 2-2.5 Myr ago. This assumption is evidenced by bow-shock like shape of the cloud.

The paper is organized as follows: Section 2 describes the data used; Section 3 presents the results obtained and their discussion, including the selection of members of the “Arclike” star-forming region in optical range, radial surface density distribution of infrared (IR) point sources, and the identification of young stellar objects (YSOs) using colour-colour (c-c) diagrams. Finally, the conclusions drawn from the obtained results are presented in Section 4.

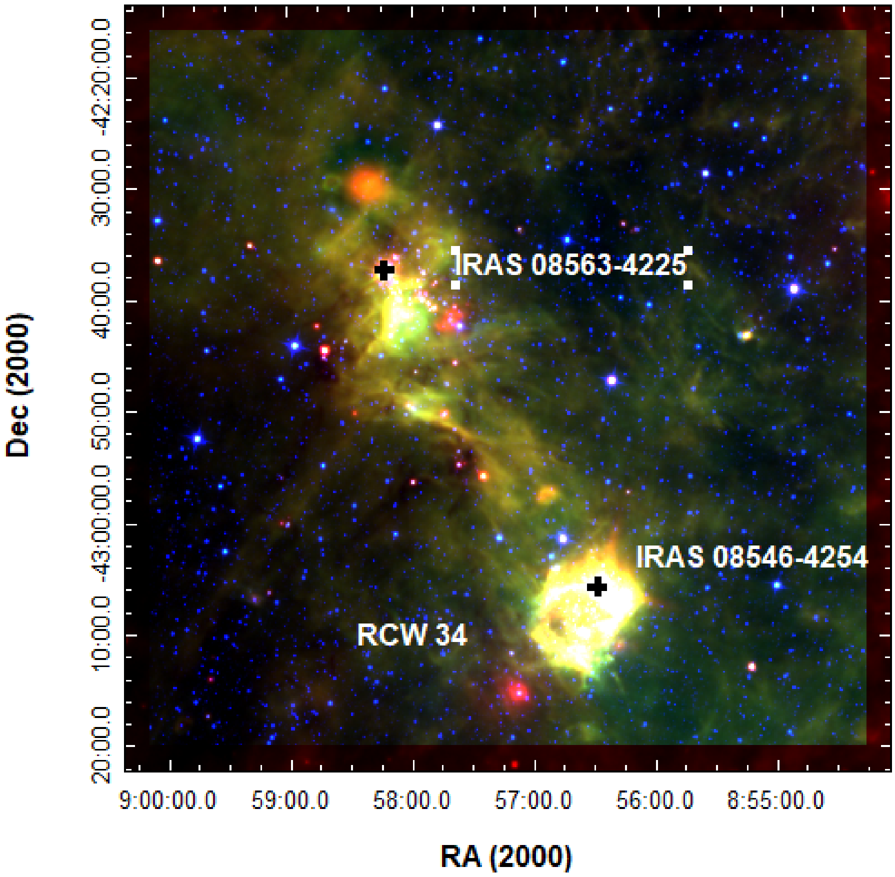


Figure 1. WISE colour-composite image of Arclike molecular clouds (blue - W2, green - W3, and red - W4). The positions IRAS sources are marked by black crosses.

## 2. Used data

To solve the tasks at hand, we used the Gaia Data Release 3 (Gaia DR3) optical database. This database provides the proper motions (pm) and parallaxes of stars, which enable us to estimate their distances and verify their association with the region of interest. We selected the region from the archive defined by the galactic coordinates $263^\circ.89 \leq l \leq 264^\circ.41$ and $1^\circ.3 \leq b \leq 2^\circ.3$, encompassing distances from 500 to 5000 pc. This domain completely covers the “Arclike” molecular cloud. We excluded sources with a fractional parallax uncertainty greater than 5% to ensure reliable parallax measurements.

For IR range, we used near-infrared (NIR) photometric data in the J, H, and K bands from the Two Micron All-Sky Survey (2MASS) with a resolution of 2 arcsec/pix. The photometric limits for point sources with a $5\sigma$ signal-to-noise ratio 16.3 mag in the J band, 15.8 mag in the H band, and 15.0 mag in the $K_s$ band. These limits are essential for studying the structure and composition of star-forming regions (Skrutskie et al., 2006).


doi: https://doi.org/10.52526/25792776-24.71.1-29

# 3. Results

## 3.1. Optical range

Astronomical Data Query Language (ADQL) codes were used to obtain the necessary data from the Gaia archive. Additionally, we used the Tool for OPerations on Catalogs And Tables (TOPCAT) (Pössel, 2020), an interactive desktop application, for searching, analyzing, and managing tabular data. The distribution of stars in the domain according to their pms is given in Figure 2. The distribution clearly reveals a well-defined concentration of stellar objects (black dots) with pms relative to the right ascension (pmra) around -5 mas/yr and relative to the declination (pmdec) around 4.6 mas/yr. The minimum and maximum means of the pmra and pmdec for the selected group are presented in Table 1. This indicates that in the considered region, there is a group of stars moving at nearly the same velocity relative to the interstellar medium. Furthermore, the members of this group have very similar parallaxes, corresponding to a distance of $2200 \pm 500$ pc (see Figure 3 and Table 1). Together, this testifies to the existence of a star cluster located at almost the same distance as RCW 34. The map of the cluster is shown in Figure 4.

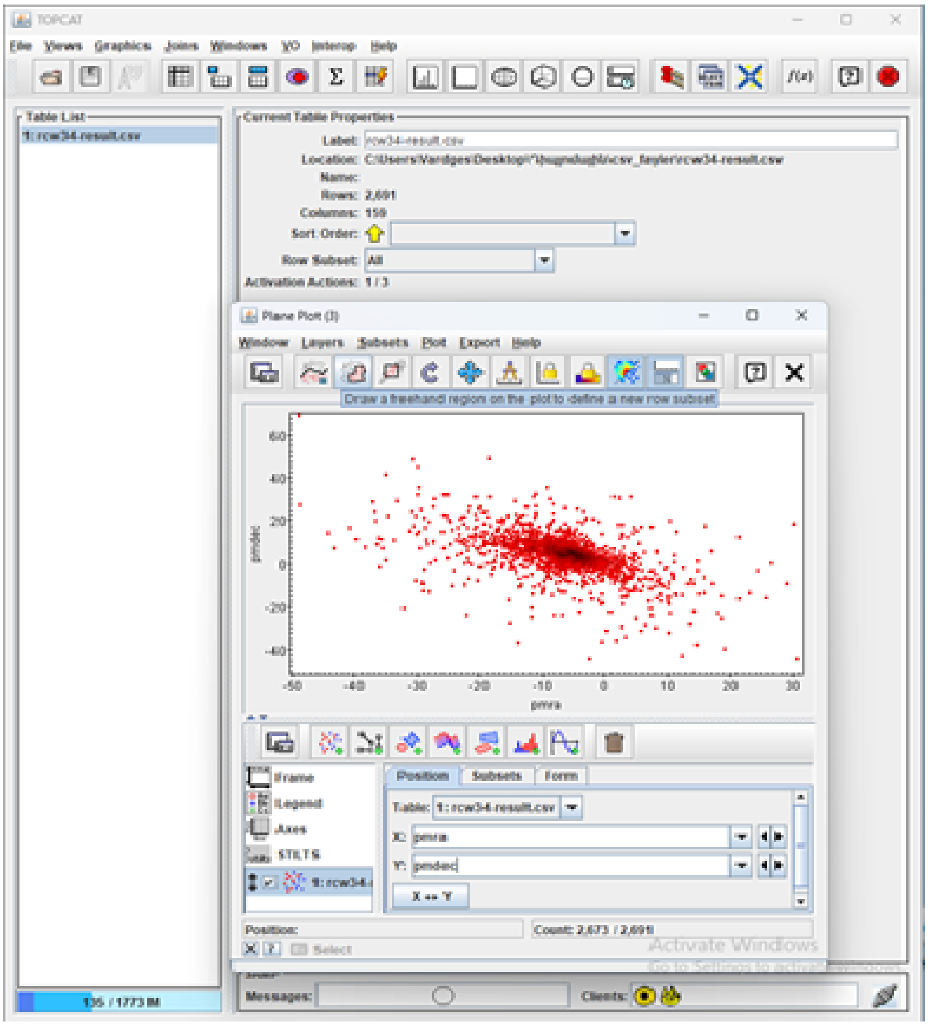


Figure 2. Distribution of the proper motions of the stars in the region defined by the coordinates $263^\circ.89 \leq l \leq 264^\circ.41$ and $1^\circ.3 \leq b \leq 2^\circ.3$.

Table 1. Distance and proper motions of the cluster

| Distance (pc) | pmra min (mas/yr) | pmra max (mas/yr) | pmdec min (mas/yr) | pmdec max (mas/yr) |
|---|---|---|---|---|
| $2200 \pm 500$ | -5.61 | -4.60 | 3.35 | 5.94 |

In Figure 4 we observe that the cluster members form a concentration in the RCW 34 region. However, the clusters members avoid the northern part of the "Arclike" cloud. The most obvious explanation for the absence of optically detected stellar objects in the vicinity of the IRAS 08563-4225 source is the existence of


doi: https://doi.org/10.52526/25792776-24.71.1-29

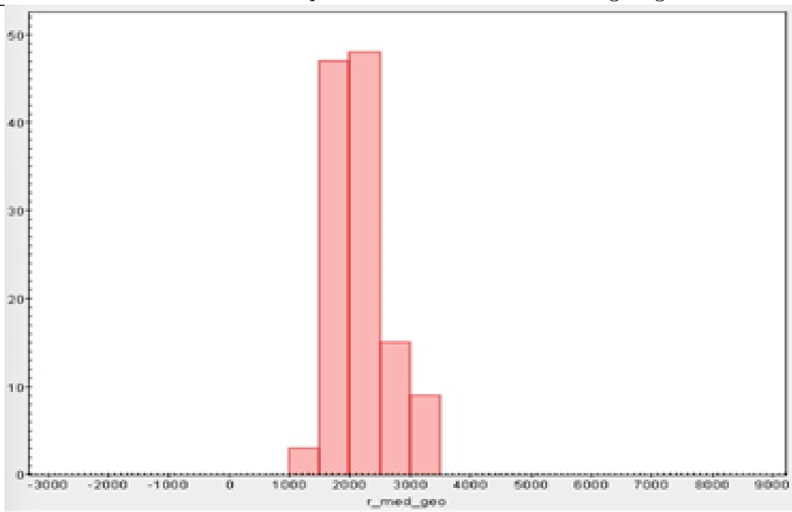


Figure 3. Distribution of the parallaxes of the stars in the region defined by the coordinates $263°.89 \leq l \leq 264°.41$ and $1°.3 \leq b \leq 2°.3$.

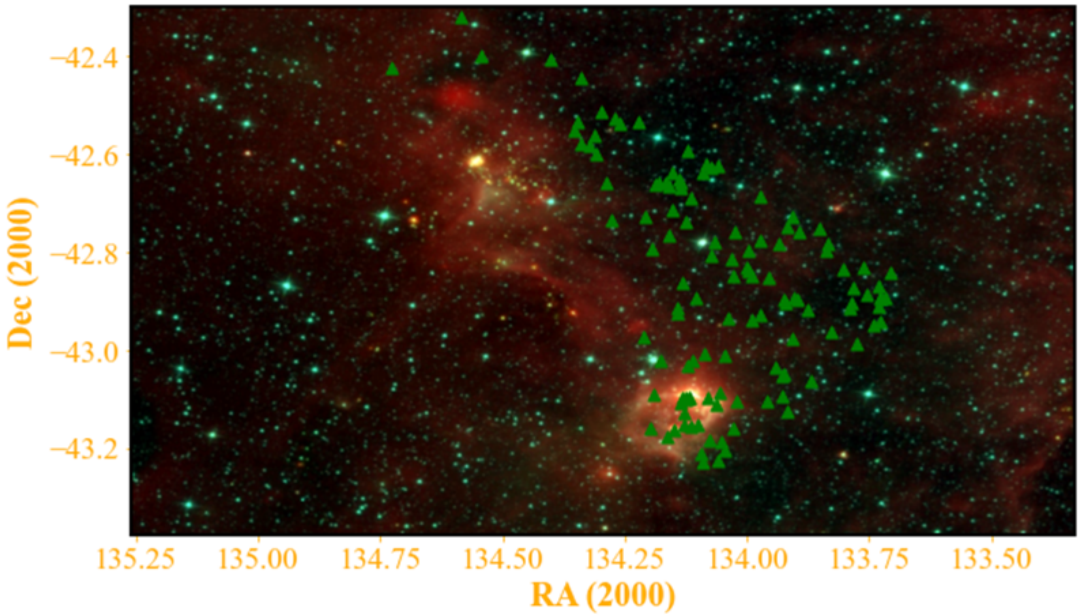


Figure 4. Colour-composite *Herschel* map of the cluster (blue - 160 $\mu$m, green- 350 $\mu$m, and red - 500 $\mu$m). Cluster members marked by green triangles.

a dense foreground molecular cloud which significantly absorbs optical radiation (Yamaguchi et al., 1999). This necessitates the use of the IR range to search for the stellar population in the region.

## 3.2. Infrared range

### 3.2.1. Radial surface stellar density distribution

The first stage of using IR astrometric and photometric data is to confirm the existence of IR clusters in the vicinity of both IRAS sources. For this purpose, we constructed the radial density distributions of the point sources from the 2MASS database with $K_s$ mag < 15.0 in the areas around both IRAS sources. These areas are marked by larger circles in Figure 5. The centers of circles are coinciding with the coordinates of the IRAS sources. To determine the surface density of point source, we divided the regions into rings of a certain width and then divided the number of stars in each ring by the surface of the ring. The standard error of the number of stars in the rings was used as a measure of uncertainty. The stellar density distributions for the clusters are presented in the Figure 5. The radial density distributions show well-defined concentrations of stars around the IRAS sources, confirming the the existence of clusters. Starting from radii of $3'$, and $2.5'$


doi: https://doi.org/10.52526/25792776-24.71.1-29

in the IRAS 08546-4254 and IRAS 08563-4225 regions, respectively, the stellar density does not exceed the average density of the field. These radii can be considered as the cluster radii and are marked by smaller circles in Figure 5.

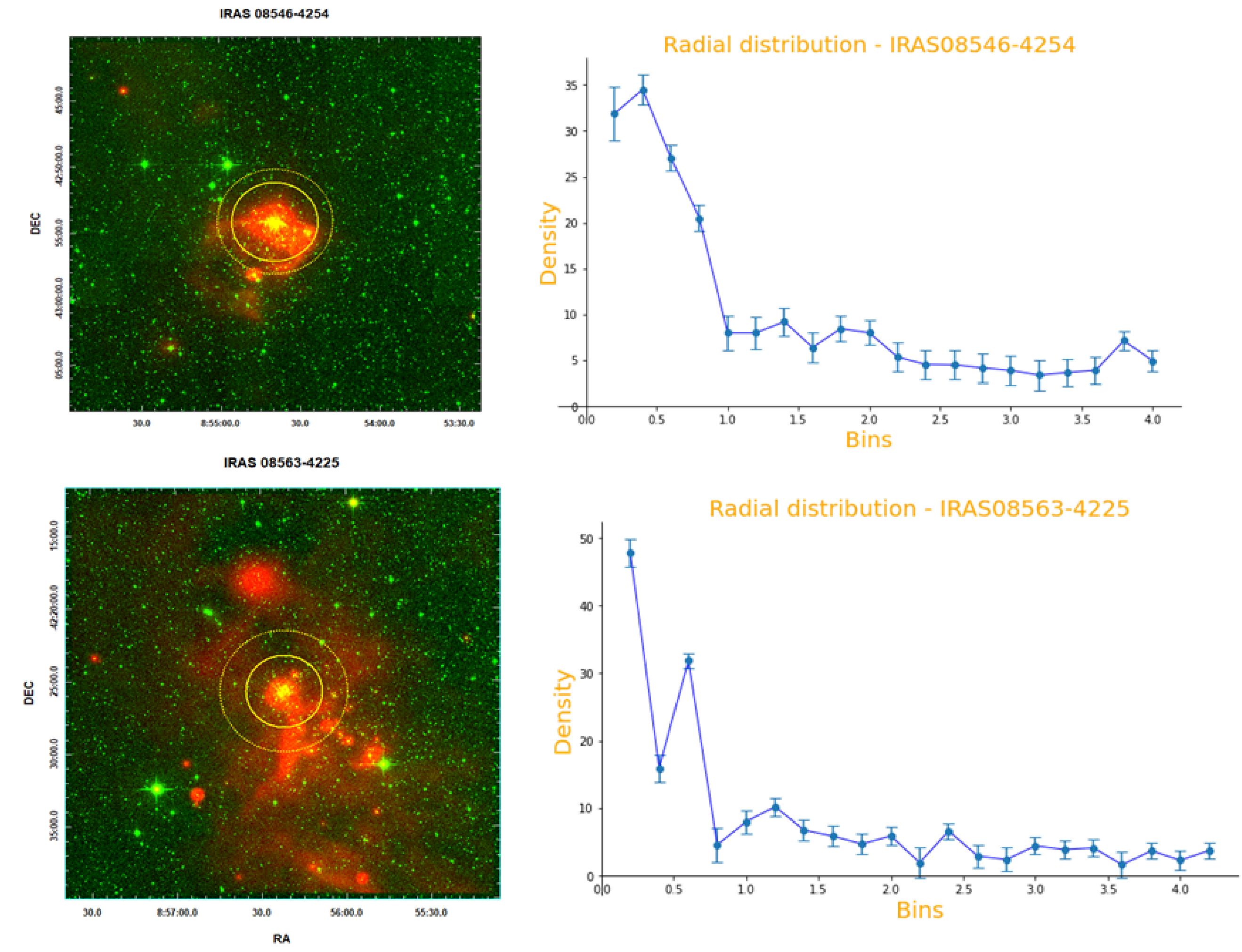


Figure 5. *Left panel*: Colour-composite images of the regions in the vicinity of the IRAS 08546-4254 and 08563-4225 sources (green - 2MASS and red - WISE 22 $\mu$m). The larger circles define the areas in which the radial distributions of stellar surface density were plotted, and the smaller circles outline the regions of increased density. *Right panel*: Radial distribution of surface stellar density (stars/arcmin$^2$) relative to the IRAS sources.

### 3.2.2. Colour-Colour NIR diagram

The next stage of IR research is to show that most of the stellar objects located in the region of increased density belong to the star formation region under consideration. Since, unlike the optical range, we cannot determine the distance of IR sources, we assume that most of the members of the considered active star-forming region are YSOs. One of the main observational characteristics of YSOs is an IR excess due to the presence of circumstellar discs and envelopes (Hartmann, 2009, Lada & Lada, 2003). Furthermore, the measure of the IR excess in the NIR and/or MIR ranges can be used to characterise the evolutionary stage of a YSO (Class I and II). Therefore, YSO candidates can be identified based on their IR colour indices, i. e., their position in c-c IR diagram. Numerous studies have provided theoretical justifications that explain the placement of YSOs in the c-c diagrams, correlating specific positions with different evolutionary stages. For our analysis we employed (J–H) vs. (H–K) c–c NIR diagram (Hernández et al., 2005, Lada & Adams, 1992, Meyer et al., 1997) for the 2MASS IR point sources within the clusters' radii. The diagrams for both regions are presented in Figure 6.

The deviation of stars from the main sequence (MS) on the (J–H) vs. (H–K) c–c NIR diagram can have two reasons: the presence of an IR excess and interstellar absorption, which also leads to reddening of


doi: https://doi.org/10.52526/25792776-24.71.1-29

objects. However, in the latter case, the deviation from the MS will be directed along the reddening vectors. Therefore, the IR excess of objects to the right of the reddening vectors cannot arise solely from interstellar absorption; at least in part, their IR excess must be due to the presence of the disk and envelope surrounding them. Hence, objects to the right of the reddening vectors can be considered as YSO candidates. We also consider objects with $J - K > 3$ as YSO candidates. According to Lada & Adams (1992), those objects may be considered as Class I evolutionary stage YSOs.

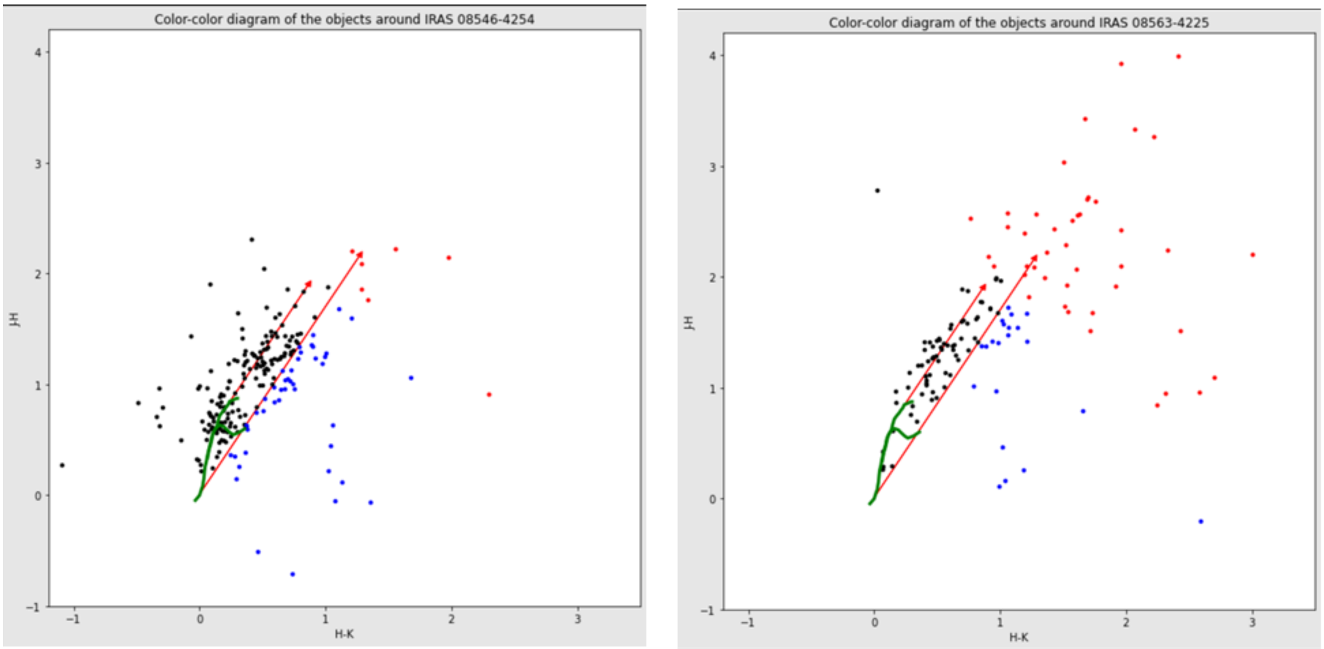


Figure 6. *Left panel*: (J–H) versus (H–K) colour-colour diagrams for the clusters. The green curves represent the positions of dwarfs and giants (Bessell, 1988), converted to the CIT photometric system (Carpenter, 2001). The red vectors are reddening vectors reflecting interstellar absorption (Rieke et al., 1985). Objects with different evolutionary stages are marked by different colors: red for Class I with J-K > 3 (Lada & Adams, 1992), blue for objects with IR excess (Class I/II), and black for objects, which were not selected as potential YSOs.

In total, on the NIR c-c diagram we identified 7 and 65 objects with J-K > 3, as well as 43 and 21 objects located to the right of the reddening vectors in IRAS 08546-4254 and IRAS 08563-4225 regions, respectively. Such a significant number of stars with a distinct IR excess confirms the presence of young star clusters near both IRAS sources. Notably, the IRAS 08563-4225 cluster contains a very large number of YSOs at the Class I evolutionary stage. This may indicate that the cluster is at an earlier stage of evolution and that a dense shielding cloud is present, leading to greater interstellar absorption.

## 4. Conclusion

The main goal of our work is to search for the young stellar population in the “Arclike” molecular cloud within the Vel OB1 association, which may have been formed from a shock wave caused by a supernova explosion about 2-2.5 Myr ago. The molecular cloud includes two subregions around the IRAS 08546-4254 (RCW 34 HII) and IRAS 08563-4225 sources.

Using the Gaia DR3 optical database, we identified a stellar cluster located in the RCW 34 region. However, the optically identified cluster members avoid the northern part of the “Arclike” cloud, around IRAS 08563-4225, most likely due to significant interstellar absorption, necessitating the use of the IR range to search for the stellar population in this region. The radial density distributions of IR point sources from the 2MASS NIR database show well-defined concentrations of objects around the both IRAS sources, confirming the existence of clusters with radii of $3'$ and $2.5'$ in the IRAS 08546-4254 and IRAS 08563-4225 regions, respectively. To identify YSOs in the clusters, we used NIR colour indices. i.e. the positions on the (J–H) vs. (H–K) c-c diagram of point sources within the clusters' radii. In total, we identify 123 YSOs. The significant number of identified YSOs in the clusters further supports that “Arclike” molecular cloud is an


doi: https://doi.org/10.52526/25792776-24.71.1-29

active star-forming region, deserving of much more detailed study. Notably, the IRAS 08563-4225 cluster contains a very large number of YSOs at the Class I evolutionary stage. This may indicate that the cluster is at an earlier stage of evolution and that a dense shielding cloud is present, leading to greater interstellar absorption.

It is important to note that the selection of YSOs is only the initial stage of the overall research. The next step involves determining their parameters, specifically their masses and evolutionary ages, as well as the density and temperature of the ISM. These determinations will enable us to draw comprehensive conclusions about the entire star formation process in the region.

### Acknowledgements

This work was partially supported by a research grant number No 21AG-1C044 from Higher Education and Science Committee of Ministry of Education, Science, Culture and Sport RA. This work presents results from the European Space Agency (ESA) space mission Gaia. Gaia data are being processed by the Gaia Data Processing and Analysis Consortium (DPAC). This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

## References

Bessell M. S., 1988, Astronomy and Astrophysics Supplement Series, 74, 109

Beuther H., Semenov D., Henning T., Linz H., 2008, Astrophys. J. Lett. , 675, L33

Bik A., et al., 2010, Astrophys. J. , 713, 883

Carpenter J. M., 2001, The Astronomical Journal, 121, 3160

Elmegreen B. G., Lada C. J., 1977, Astrophys. J. , 214, 725

Hartmann L., 2009, Annual Review of Astronomy and Astrophysics, 47, 565

Hernández J., Calvet N., Hartmann L., Briceño C., Sicilia-Aguilar A., Berlind P., 2005, Astron. J. , 129, 856

Humphreys R. M., 1978, Astrophys. J. Suppl. Ser. , 38, 309

Lada C. J., Adams F. C., 1992, The Astrophysical Journal, 393, 278

Lada C. J., Lada E. A., 2003, Annual Review of Astronomy and Astrophysics, 41, 57

McKee C. F., Tan J. C., 2003, Astrophys. J. , 585, 850

Meyer M. R., Calvet N., Hillenbrand L. A., 1997, Astron. J. , 114, 288

Pössel M., 2020, The Open Journal of Astrophysics, 3, 2

Rieke G. H., Lebofsky M. J., Low F. J., 1985, The Astrophysical Journal, 288, 618

Skrutskie M. F., et al., 2006, Astron. J. , 131, 1163

Yamaguchi R., Saito H., Mizuno N., Mine Y., Mizuno A., Ogawa H., Fukui Y., 1999, Publ. Astron. Soc. Jpn. , 51, 791

Zinnecker H., McCaughrean M. J., Wilking B. A., 1993, in Levy E. H., Lunine J. I., eds, Protostars and Planets III. p. 429


doi: https://doi.org/10.52526/25792776-24.71.1-29