Stellar population and star formation histories of distant Galactic H II regions NGC 2282 and Sh2-149 complex

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Abstract. We present here the recent results on two distant Galactic H II regions, namely NGC 2282 and Sh2-149, obtained with multiwavelength observations. Our optical spectroscopic analysis of the bright sources have been used to identify the massive members, and to derive the fundamental parameters such as age and distance of these regions. Using IR color-color criteria and Hα-emission properties, we have identified and classified the candidate young stellar objects (YSOs) in these regions. The 12CO(1-0) continuum maps along with the K-band extinction maps, and spatial distribution of YSOs are used to investigate the structure and morphology of the molecular cloud associated with these H II regions. Overall analysis of these regions suggests that the star formation occurs at the locations of the denser gas, and we also find possible evidences of the induced star formation due to the feedback from massive stars to its surrounding molecular medium.

1. Introduction

Galactic H II regions are the active formation sites of massive O and B type stars. H II regions are low-density cloud of ionized gas excited by UV radiation from massive stars e.g. O and early B-type (Anderson et al. 2014). H II regions trace active star formations in our galaxy. Galactic H II regions provide us crucial information about the star-formation process, stellar evolution and spiral arm structures etc. Furthermore, strong stellar winds and UV radiation produced by these massive young stars within an H II region control the structure of their surrounding molecular cloud, and might be possible causes of triggering new generation of stars or the destruction of the molecular clouds (Elmegreen & Lada 1977; Yorke 1986; Koenig et al. 2012). Thus, studies of Galactic H II regions containing massive stars provide a platform to understand both high- and low-mass star formations (e.g. Jose et al. 2016).

Massive and low-mass young stars in H II regions are embedded in the natal molecular cloud, which are generally invisible at optical wavelengths. However, these regions can be studied in the infrared wavebands. In general, both massive- and low-mass YSOs are formed, and evolved in dense molecular clouds. Multiwavelength studies of such regions provide census of YSOs, their fundamental parameters e.g. masses, ages, effective temperatures, circumstellar disks around them (if any exists) etc. (Kenyon & Hartmann 1995; Carpenter 2001; Samal et al. 2012; Jose et al. 2012).
From such parameter space, broad pictures emerge on the young star-forming regions (SFRs) viz, star-formation history, star-formation efficiency, formation timescales etc. Here, we present the results of the stellar contents of two distant Galactic H II regions e.g. NGC 2282 and Sh2-149 complex using deep optical, near-infrared, mid-infrared data sets and $^{12}$CO(1-0) molecular line observations.

2. Observations

For this studies, we have used optical photometry from the 1.04-m Sampurnanand Telescope (ST) of ARIES, Nainital, India and the 2-m Himalayan Chandra Telescope (HCT) of IIA, Hanle, India to estimate ages and masses of YSOs associated with these regions. Slit spectroscopy of optically bright members and slitless spectroscopy towards the regions were obtained from HFOSC instrument on HCT to estimate the spectral types of the massive stars, distance of the cluster, extinction towards individual star and $H_\alpha$ emission activities of the stars. Issac Newton Telescope (INT) photometric $H_\alpha$ Survey of the Northern Galactic Plane (IPHAS) were conducted using $H_\alpha$, $r$, $i$ filters. We have taken these photometric data from the archival data release 2 (Barentsen et al. 2011). We have used the archive near-infrared J,H,K photometry from CFHT-WIRCAM (Puget et al. 2004), UKIRT Infrared Deep Sky Survey (UKIDSS, (Lawrence et al. 2007)), Two-micron All-Sky Survey (2MASS, (Cutri et al. 2003)) point source catalogue, along with mid-infrared photometry from Spitzer-IRAC to detect the embedded YSOs. (see Dutta et al. 2015, for details). Molecular observations in $^{12}$CO(1-0) from the 14m Five College Radio Astronomy Observatory (FCRAO) Survey of the Outer Galaxy are used to trace the molecular cloud structure around the H II regions (Heyer et al. 1998).
3. Results

3.1. NGC 2282

The embedded cluster NGC 2282 ($\alpha_{2000} = 06^h46^m50.4^s \delta_{2000} = +01^018^m50^s$) is a reflection nebula in the Monoceros constellation located at distance 1.65 kpc (Dutta et al. 2015, and the references therein). We have analyzed the stellar surface density distribution of $K$-band data using nearest neighborhood technique. The radius of the cluster is estimated as $\sim 3.15'$ from the semi-major axis of the outer most elliptical contour. From spectrophotometry, we estimated the spectral types and membership status of 8 bright sources located within the cluster area using conspicuous lines and comparison of equivalent widths with the spectral standards. Among the bright sources, three sources are identified as early B-type members in the cluster, HD 289120, a B2V type star matches with the previous classification, and two stars (a Herbig Ae/Be star and a B5 V) are newly classified in our study. We estimated the distance to the cluster as $\sim 1.65$ kpc from spectrophotometric analysis of the massive members. The $K$-band extinction map is estimated from $(H - K)$ color excess using nearest neighborhood technique, and the mean extinction within the cluster area is found to be $A_V \sim 3.9$ mag. From slitless spectroscopy, we have identified 16 $H_{\alpha}$ emission line stars. Another 34 $H_{\alpha}$ emission line stars are identified from IPHAS photometry, totaling 50 $H_{\alpha}$ emission line stars towards the region. Using (Gutermuth et al. 2008, 2009) scheme, we have classified 9 Class I and 75 Class II objects using IRAC 3.6 and 4.5 $\mu$m photometry and H and K near-IR photometry. Other candidate YSOs are identified from near-IR $(J - H)/(H - K)$ color-color (CC) diagram. In total we have identified 152 candidate YSOs using IR excess and $H_{\alpha}$ emission properties of the stars towards the region. We characterized these YSOs using various color-magnitude diagrams (CMD). From $V/(V - I)$ CMD, we have estimated the cluster age which is in the range of $\sim 2 - 5$ Myr. From mid-IR data, we have estimated the disk fraction of $\sim 58\%$, which corresponds to an age of $\sim 2 - 5$ Myr. The masses of the candidate YSOs are found to be in the range $\sim 0.1$ to 2.0 $M_\odot$ in the $J/(J - H)$ CMD. The morphology of the region has been studied from spatial distribution of YSOs, stellar density distribution, signature of dust in various optical-infrared images along with the extinction map (Figure 1. left panel). Our results based on ionizing stars, structure of ionized and molecular gas along with the probable YSOs, though not conclusive, indicate that star-formation activity observed at the border is probably influenced by the expansion of the H II region to the surrounding medium. More detailed analysis of those results can be obtained from (Dutta et al. 2015).

3.2. Sh 2-149 complex

The Sh2-149 ($\alpha_{2000} = 22^h56^m16.9^s \delta_{2000} = +58^031^m13^s$) complex located at a distance $\sim 5.6$ kpc in the constellation Cassiopeia, is an optically visible region associated with Sh 2-148, Sh 2-147, YSO 2MASX J22555978+5814424 (Azimlu & Fich 2011, and the references therein). This group of H II regions along with Sh2-152 might be associated to the supernova remnant SNR G109.10-1.0 (Tatematsu et al. 1985). We have identified few optically bright ionizing sources towards the Sh2-149 complex, and their spectral types of massive O7–B0 V are estimated based on optical spectroscopy. We detected several infrared excess stars (candidate YSOs) from NIR and IRAC CC diagrams. These YSOs are spatially distributed along the dust ridge as shown in Figure 1 (right panel), which indicates that the region is an active star formation site. The morphology from $^{12}$CO(1-0) map identifies various clumps including a stream line flow
towards South-West. Mid-IR dust structure suggests that millimeter contours encompass two filamentary structures, one towards East and another towards west, which is an ionized boundary layer towards North-East associated with Sh2-152. The core region of Sh2-149 is extended towards South-East, which is associated to 2MASX J22555978+5814424 via an ionized layer. The morphology and spatial agreement among millimeter-IR observations, distribution of YSOs and ionizing stars indicate that the star-formation activity observed at filaments is probably a tentative example of triggered star formation. More detailed analysis will be presented elsewhere (Dutta et al. 2017, in preparation).

4. Conclusions

We analyzed the star formation scenario within two distant Galactic H II regions, NGC 2282 and Sh 2-149, using multiwavelength data sets. We studied the morphological correlation of gas and dust, nature of the ionizing sources and spatial distribution of young stellar sources and their properties. The $^{12}\text{CO}(1-0)$ maps along with the $K$-band extinction maps and spatial distribution of YSOs are used to investigate the structure and morphology of the molecular cloud associated with the H II regions. Our analysis also suggests that the star formation occurs at the locations of the denser gas, and associate massive members particularly in Sh2-149, might be possible causes of the triggered star formation due to the feedback from massive stars to its surrounding molecular material.

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