MULTIWAVELENGTH STUDY OF THE STAR FORMATION IN THE S237 H II REGION

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ABSTRACT

We present a detailed multiwavelength study of observations from X-ray, near-infrared, and centimeter wavelengths to probe the star formation processes in the S237 region. Multiwavelength images trace an almost sphere-like shell morphology of the region, which is filled with the 0.5–2 keV X-ray emission. The region contains two distinct environments—a bell-shaped cavity-like structure containing the peak of 1.4 GHz emission at center, and elongated filamentary features without any radio detection at edges of the sphere-like shell—where Herschel clumps are detected. Using the 1.4 GHz continuum and 12CO line data, the S237 region is found to be excited by a radio spectral type of B0.5V star and is associated with an expanding H II region. The photoionized gas appears to be responsible for the origin of the bell-shaped structure. The majority of molecular gas is distributed toward a massive clump, which contains the filamentary features and has a noticeable velocity gradient. The photometric analysis traces the clusters of young stellar objects (YSOs) mainly toward the bell-shaped structure and the filamentary features. Considering the lower dynamical age of the H II region (i.e., 0.2–0.8 Myr), these clusters are unlikely to be formed by the expansion of the H II region. Our results also show the existence of a cluster of YSOs and a massive clump at the intersection of filamentary features, indicating that the collisions of these features may have triggered cluster formation, similar to those found in the Serpens South region.

Key words: dust, extinction – H II regions – ISM: clouds – ISM: individual objects (Sh 2–237) – stars: formation – stars: pre-main sequence

1. INTRODUCTION

Massive stars (≥8 M⊙) produce a flood of ultraviolet (UV) photons, radiation pressure, and drive strong winds, which allow them to interact with the surrounding interstellar medium (ISM). In star-forming regions, the radio and infrared observations have revealed the ring/shell/bubble/filamentary features surrounding the H II regions associated with the OB stars, indirectly tracing the signatures of the energetics of powering sources (e.g., Deharveng et al. 2010; Watson et al. 2010; Dewangan et al. 2016). However, the physical processes of their interaction and feedback in their vicinity are still poorly understood (Zinnecker & Yorke 2007; Tan et al. 2014). In recent years, with the availability of Herschel observations, the study of initial conditions of cluster formation toward the filaments, in particular, has received much attention in star formation research. However, the role of filaments in the formation of dense massive star-forming clumps and clusters is still a matter of debate (e.g., Myers 2009; Schneider et al. 2012; Nakamura et al. 2014; Tan et al. 2014).

Located at a distance of 2.3 kpc (Pandey et al. 2013; Lim et al. 2015), the star-forming region Sh 2-237 (hereafter S237; also known as NGC 1931/IRAS 05281+3412/RAFGL 5144/G173.9+0.3; v2000 = 05h 31m 22s 8, δ2000 = +34°13′59″) has a broken or incomplete ring or shell-like appearance at wavelengths longer than 2 μm (see Figure 1 in Pandey et al. 2013). One can find a comprehensive review of this star-forming region in Reipurth (2008). The H II region associated with the S237 region (hereafter S237 H II region) is ionized by a star of spectral type B0.5 (Glushkov et al. 1975) or two B2 main-sequence-type stars (Pandey et al. 2013). Balser et al. (2011) estimated the velocity of ionized gas to be about –0.64 km s−1 in the S237 H II region using a hydrogen radio recombination line (H87-93α). Using CO (J = 1–0) line data, Yang et al. (2002) reported the radial velocity of molecular gas to be about −5.86 km s−1 toward IRAS 05281+3412. Leisawitz et al. (1989) studied the molecular gas content of 34 open star clusters, including S237, using 12CO (1–0) emission and suggested that a part of S237 is obscured by a molecular cloud. In the S237 region, Pandey et al. (2013) reported two separate stellar clusters and estimated a mean age of the young stellar objects (YSOs) to be 2 ± 1 Myr. Based on the morphology of the region, ages of the YSOs, and ionizing sources, they concluded that there is a triggered star formation process in the S237 region. Using the isochrone fitting in the Hertzsprung–Russell diagram, Lim et al. (2015) reported a median age of 2 Myr with a spread of 4.5 Myr for the age distribution of the pre-main-sequence (PMS) members in NGC 1931.

These previous studies suggest the presence of massive star(s) and ongoing star formation activity in the S237 region. The region is a relatively nearby star-forming site and has an interesting morphology, indicating that it is a promising site to explore the impact of ionizing star(s). Despite the availability of different observational data sets, the feedback of massive star(s) is not systematically studied in the S237 region. The physical conditions in the S237 region are yet to be determined, and the velocity structure of molecular gas is also unknown. Recently, Herschel observations have revealed that filaments are often seen in the star-forming regions (e.g., André et al. 2010; Molinari et al. 2010). However, the identification of dense clumps and filaments is still lacking in the S237 region. Furthermore, the star formation toward clumps and filaments in S237 is yet to be probed. A knowledge of the physical
environment of the region is very important for assessing the ongoing physical mechanisms. In the present paper, we study in detail the physical processes responsible for the interaction and feedback effect of massive stars on its surroundings. To understand the ongoing physical mechanisms in S237, we examine the distribution of dust temperature, column density, extinction, ionized emission, hot gas, neutral hydrogen gas, kinematics of molecular gas, and YSOs using the multiwavelength data.

In Section 2, we describe the multiband data sets used in the present work. In Section 3, we provide the details of results obtained. In Section 4, we discuss the possible star formation scenario based on our findings. Finally, the results are summarized and concluded in Section 5.

2. DATA AND ANALYSIS

In the present work, we selected a region of ∼30′6 × 30′6 (central coordinates: l = 173°993; b = 0°273) around the S237 region. In the following, a brief description of the multiband data from X-ray, optical Hα, near-infrared (NIR), and radio wavelengths is presented.

2.1. X-ray Data

The ROSAT 0.5–2 keV X-ray image was obtained from the public archives (observation ID: WG931113P_N1_SI01.N1) maintained at the High Energy Astrophysics Science Archive Research Center (HEASARC) in the USA. The pixel scale of the image is 45″. One can obtain more details about the ROSAT observations in Voges et al. (1999). A single ROSAT source (i.e., J053134.4+341242; Voges et al. 2000) is found in the S237 region. In the catalog, the total X-ray count was reported with an extraction radius of 300″ (Voges et al. 1999), indicating the presence of an extended diffuse X-ray emission.

2.2. Hα Narrowband Image

A narrowband Hα image at 0.6563 μm was obtained from the Isaac Newton Telescope Photometric Hα Survey of the Northern Galactic Plane (IPHAS; Drew et al. 2005) survey database. The survey was made using the Wide Field Camera (WFC) at the 2.5 m INT, located at La Palma. The WFC consists of four 4k × 2k CCDs, in an L-shape configuration. The pixel scale is 0.33″, and the instantaneous field is about 0.3 square degrees. One can find more details about the IPHAS survey in Drew et al. (2005).

2.3. NIR (1–5 μm) Data

NIR photometric JHK magnitudes of point sources have been obtained from the UKIDSS Galactic Plane Survey (GPS; Lawrence et al. 2007) sixth archival data release (UKIDSSDR6plus) and the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006). Note that the UKIDSS GPS data are not available for the entire selected region and are available only for the zone-1 area as highlighted by a dotted line in Figure 1(b). Hence, 2MASS data are employed for the area where UKIDSS GPS observations are absent. The UKIDSS observations (resolution ∼0″8) were taken using the UKIRT Wide Field Camera (WFCAM; Casali et al. 2007). The UKIDSS GPS photometric data were calibrated using the 2MASS data. We obtained only reliable UKIDSS GPS photometric data, following the conditions listed in Lucas et al. (2008) and Dewangan et al. (2015). 2MASS data were also retrieved for bright sources that were saturated in the GPS catalog. To obtain reliable 2MASS photometric data, only those sources from the 2MASS catalog that have photometric magnitude error of 0.1 and less in each band are chosen for the study.

Warm Spitzer IRAC 3.6 and 4.5 μm photometric images (resolution ∼2″) and magnitudes of point sources have been retrieved from the Glimpse360 (Whitney et al. 2011) survey. The photometric magnitudes were obtained from the GLIMPSE360 highly reliable catalog. To obtain further reliable Glimpse360 photometric data, only those sources are selected that have photometric magnitude error of 0.2 and less in each band.

2.4. Mid-infrared (12–22 μm) Data

We utilized the publicly available archival WISE5 (Wright et al. 2010) images at mid-infrared (MIR) 12 μm (spatial resolution ∼6″) and 22 μm (spatial resolution ∼12″). WISE photometric sensitivity6 is reported to be 0.86 and 5.4 mJy (11.3 and 8.0 Vega mag) at 12 and 22 μm, respectively, in unconfused regions on the ecliptic plane. Saturation affects photometry for objects brighter than approximately 3.8 and −0.4 mag at 12 and 22 μm, respectively.

2.5. Far-infrared and Submillimeter Data

Far-infrared (FIR) and submillimeter continuum images were downloaded from the Herschel Space Observatory data archives. The processed level2_5 images at 70 μm, 160 μm, 250 μm, 350 μm, and 500 μm were obtained using the Herschel Interactive Processing Environment (HIPE; Ott 2010). The beam sizes of the Herschel images at 70 μm, 160 μm, 250 μm, 350 μm, and 500 μm are 5″, 12″, 18″, 25″, and 37″, respectively (Griffin et al. 2010; Poglitsch et al. 2010). In this work, Herschel continuum images are utilized to compute the Herschel temperature and column density maps of the S237 region. Following the method described in Mallick et al. (2015), we obtained the Herschel temperature and column density maps from a pixel-by-pixel spectral energy distribution (SED) fit with a modified blackbody to the cold dust emission in the Herschel 160–500 μm wavelengths (also see Dewangan et al. 2015). The Herschel 70 μm data are not used in the analysis, because the 70 μm emission is dominated by the UV-heated warm dust. In the following, a brief step-by-step description of the procedures is described.

The Herschel 160 μm image is calibrated in the units of Jy pixel−1, while the images at 250–500 μm are calibrated in the surface brightness units of MJy sr−1. The plate scales of the 160 μm, 250 μm, 350 μm, and 500 μm images are 3″2, 6″, 10″, and 14″ pixel−1, respectively. In the first step, prior to the SED fit, the 160 μm, 250 μm, and 350 μm images were convolved to the lowest angular resolution of the 500 μm image (∼37″) and were converted into the same flux units (i.e., Jy pixel−1). Furthermore, these images were regridded to the pixel size of the 500 μm image (∼14″). These steps were carried out using the convolution kernels available in the HIPE software. Next,

5 http://www.astro.wisc.edu/sintf/glimpse360/
6 Wide-field Infrared Survey Explorer, which is a joint project of the University of California and the JPL, Caltech, funded by NASA.
7 http://wise2.ipac.caltech.edu/docs/release/allsky/
the sky background flux level was determined to be 0.051, 0.115, 0.182, and −0.0009 Jy pixel$^{-1}$ for the 500 μm, 350 μm, 250 μm, and 160 μm images (size of the selected region ∼5′6 × 7′8; centered at $l = 174°127$, $b = -0°222$), respectively. To avoid diffuse emission associated with the selected target, the featureless dark area away from the S237 region was carefully chosen for the background estimation.

Finally, to obtain the maps, we fitted the observed flux densities at each pixel with the modified blackbody model (see Equations (8) and (9) in Mallick et al. 2015). The fitting was done using the four data points for each pixel, retaining the dust temperature ($T_d$) and the column density ($N(H_2)$) as free parameters. In the analysis, we adopted a mean molecular weight per hydrogen molecule $m_{H_2} = 2.8$ (Kauffmann et al. 2008) and an absorption coefficient $\kappa_\nu = 0.1(\nu/1000\text{ GHz})^3 \text{ cm}^2 \text{ g}^{-1}$, including a gas-to-dust...
2.6. Molecular CO Line Data

The observations of $^{12}$CO(1–0) and $^{13}$CO(1–0) emission were taken using the Five College Radio Astronomy Observatory (FCRAO) 14 m telescope in New Salem, Massachusetts. The FCRAO beam sizes are 45″ (with angular sampling of 22″5) and 46″ (with angular sampling of 22″5) for $^{12}$CO and $^{13}$CO, respectively. Both sets of line data have a velocity resolution of 0.25 km s$^{-1}$. Typical rms values for the spectra are 0.25 K for $^{12}$CO and 0.2 K for $^{13}$CO (e.g., Heyer et al. 1996). The S237 region was observed as part of the Extended Outer Galaxy Survey (E-OGS; Brunt 2004), which extends the coverage of the FCRAO Outer Galaxy Survey (OGS; Heyer et al. 1998) to Galactic longitude $l = 193^°$, over a Galactic latitude range of $-3^°5 \leq b \leq +5^°5$. These $^{12}$CO and $^{13}$CO data cubes were provided by M. Heyer and C. Brunt (private communication). The FCRAO $^{13}$CO profile along the line of sight to the S237 region shows a single velocity component at $v = -4.6$ km s$^{-1}$.

2.7. Radio Continuum Data

A radio continuum map at 1.4 GHz was retrieved from the NRAO VLA Sky Survey (NVSS) archive. The survey covers the sky north of $b_{2000} = -40^°$ at 1.4 GHz with a beam of 45″ and a nearly uniform sensitivity of $\sim 0.45$ mJy beam$^{-1}$ (Condon et al. 1998).

2.8. H$^1$ Line Data

The 21 cm H$^1$ line data were obtained from the Canadian Galactic Plane Survey (CGPS; Taylor et al. 2003). The velocity resolution of H$^1$ line data is 1.32 km s$^{-1}$, sampled every 0.82 km s$^{-1}$. The data have a spatial resolution of 1′ × 1′ csc$\delta$. The line data have a brightness temperature sensitivity of $\Delta T_B = 3.5 \sin \delta$ K. One can find more details about the CGPS observing and data processing strategy in Taylor et al. (2003).

3. RESULTS

3.1. Multiband Picture of S237

3.1.1. Continuum Emission and Gas Distribution in S237

The longer-wavelength data enable us to penetrate deeper into the star-forming cloud despite the high extinction, allowing us to infer the physical environment of a given star-forming region. In this section, we employ multiband data to trace the physical structure of the S237 region. Figure 1(a) shows a two-color composite image using Herschel 70 μm in red and WISE 12.0 μm in green. A three-color composite image (350 μm [red], 250 μm [green], and 22 μm [blue]) is shown in Figure 1(b). The Herschel and WISE images depict a broken or incomplete ring or shell-like appearance of the S237 region at wavelengths longer than 2 μm. The images reveal a prominent bell-shaped cavity-like morphology and elongated filamentary features at the center and the edge of the shell-like structure, respectively (see Figures 1(a) and (b)). The inset on the bottom left shows the zoomed-in view around IRAS 05281+3412 using the Spitzer 3.6 μm image (see Figure 1(a)). The filamentary features are also highlighted in the image. Figure 2 shows the radio continuum and molecular emissions overlaid on the Herschel image at 500 μm. The bulk of the 160–500 μm emission comes from cold dust components (see Section 3.3 for quantitative estimates), while the emission at 22 μm traces the

![Figure 3](image.png)

**Figure 3.** (a) Spitzer ratio map of 4.5 μm/3.6 μm emission. The ratio map is subjected to median filtering with a width of 5 pixels and smoothed by 4 pixels × 4 pixels using a boxcar algorithm. The dot-dashed box (in red) encompasses the area shown in Figure 4. The 4.5 μm/3.6 μm emission contour (gray dot-dashed contour) is also shown on the image with a representative value of 0.75, tracing the shell-like morphology. (b) Contour map of integrated $^{13}$CO emission in the velocity range of $-7$ to $-2$ km s$^{-1}$. The contour levels are similar to the one shown in Figure 2(b). The NVSS contours (red dot-dashed contours) are also superimposed with similar levels to that shown in Figure 2(a). The 0.5–2.0 keV ROSAT X-ray emission contours (solid contours) of S237 are overplotted on both panels. The X-ray image is Gaussian smoothed with a radius of 3 pixels. In both panels, the scale bar at the bottom left corner corresponds to 3 pc (at a distance of 2.3 kpc).
warm dust emission (see Figure 1(b)). In Figure 2(a), we show the spatial distribution of ionized emission traced in the NVSS 1.4 GHz map, concentrating near the bell-shaped cavity-like morphology. This also implies that the ionized emission is located within the shell-like structure. The radio continuum emission is absent toward the elongated filamentary features. In Figure 2(b), we present the molecular \(^{12}\)CO \((J = 1 \rightarrow 0)\) gas emission in the direction of the S237 region, revealing at least four molecular condensations (designated as conds1–4). The \(^{12}\)CO profile traces the region in a velocity range between \(-7\) and \(-2\) km s\(^{-1}\). The molecular condensations are also found toward the filamentary features and the bell-shaped cavity-like morphology. It can be seen that the majority of molecular gas is distributed toward the molecular condensation conds1, where filamentary features are observed. The details of the integrated \(^{12}\)CO map, as well as kinematics of molecular gas, are described in Section 3.4.

Together, Figures 1 and 2 have allowed us to obtain a pictorial multiwavelength view of the environment in the S237 region.

3.1.2. Lyman Continuum Flux

In this section, we estimate the number of Lyman continuum photons using the radio continuum map, which will allow us to derive the spectral type of the powering candidate associated with the S237 \(\text{H}^\text{II}\) region. In Figure 2(a), the NVSS radio map traces a spherical morphology of the S237 \(\text{H}^\text{II}\) region. We used the clumpfind IDL program (Williams et al. 1994) to estimate the integrated flux density, and the radio continuum flux was integrated up to the 0.3% contour level of peak intensity. Using the 1.4 GHz map, we computed the integrated flux density \((S_{\nu})\) and radius \((R_{\text{H}^\text{II}})\) of the \(\text{H}^\text{II}\) region to be 708 mJy and 1.27 pc, respectively. The integrated flux density allows us to compute the number of Lyman continuum photons \((N_{uv})\), using the following equation (Matsakis et al. 1976):

\[
N_{uv}(s^{-1}) = 7.5 \times 10^{46} \left(\frac{S_{\nu}}{\text{Jy}}\right) \left(\frac{D}{\text{kpc}}\right)^2 \left(\frac{T_e}{10^4 \text{K}}\right)^{-0.45} \times \left(\frac{\nu}{\text{GHz}}\right)^{0.1},
\]

where \(S_{\nu}\) is the measured total flux density in Jy, \(D\) is the distance in kpc, \(T_e\) is the electron temperature, and \(\nu\) is the frequency in GHz. This analysis is performed for an electron temperature of 10,000 K and a distance of 2.3 kpc. We obtain an \(N_{uv}\) (or log\(N_{uv}\)) of \(\sim 2.9 \times 10^{47} s^{-1}\) (47.47) for the S237 \(\text{H}^\text{II}\) region, which corresponds to a single ionizing star of spectral type B0.5V–B0V (see Table II in Panagia 1973 for a theoretical value).

The knowledge of \(N_{uv}\) and \(R_{\text{H}^\text{II}}\) values is also used to infer the dynamical age \(t_{\text{dyn}}\) of the S237 \(\text{H}^\text{II}\) region. The age of the \(\text{H}^\text{II}\) region can be computed at a given radius \(R_{\text{H}^\text{II}}\), using the following equation (Dyson & Williams 1980, p. 204):

\[
t_{\text{dyn}} = \left(\frac{4R_e}{7c_s}\right) \left(\frac{R_{\text{H}^\text{II}}}{R_e}\right)^{7/4} - 1
\]
where $c_s$ is the isothermal sound velocity in the ionized gas ($c_s = 11$ km s$^{-1}$; Bisbas et al. 2009), $R_{HI}$ is previously defined, and $R_s$ is the radius of the Strömgren sphere ($= (3N_{HI}/4\pi n_0^2 c_s^3)^{1/3}$), where the radiative recombination coefficient \( c_R = 2.6 \times 10^{-13} (10^4 \text{ K}/T)^{0.7} \text{ cm}^3 \text{s}^{-1} \) Kwan 1997, \( N_{HI} \) is defined earlier, and \( n_0 \) is the initial particle number density of the ambient neutral gas). Assuming a typical value of \( n_0 \) (such as \( 10^3 \text{ [} 10^4 \text{ cm}^{-3} \)), we calculated the dynamical age of the S237 H II region to be \( \sim 0.2 \) (0.8) Myr.

### 3.2. IRAC Ratio Map and H I Gas

To infer the signatures of molecular outflows and the impact of massive stars on their surroundings, the Spitzer IRAC ratio maps have been employed in combination with the radio continuum emission (Povich et al. 2007; Watson et al. 2008; Dewangan & Anandaraao 2011; Dewangan et al. 2012, 2016). Due to almost identical point response functions (PRFs) of IRAC 3.6 \( \mu \)m and 4.5 \( \mu \)m images, a ratio map of 4.5 \( \mu \)m/3.6 \( \mu \)m emission can be obtained directly using the ratio of 4.5 \( \mu \)m to 3.6 \( \mu \)m images. IRAC 4.5 \( \mu \)m band harbors a hydrogen recombination line Br$\alpha$ (4.05 \( \mu \)m) and a prominent molecular hydrogen line emission (\( \nu = 0-0 \) S(9); 4.693 \( \mu \)m), which can be excited by outflow shocks. IRAC 3.6 \( \mu \)m band contains polycyclic aromatic hydrocarbon (PAH) emission at 3.3 \( \mu \)m, as well as a prominent molecular hydrogen feature at 3.234 \( \mu \)m (\( \nu = 1-0 \) O(5)). The ratio map of 4.5 \( \mu \)m/3.6 \( \mu \)m emission is shown in Figure 3(a), tracing the bright and dark/black regions. The shell-like morphology is depicted, and the map traces the edges of the shell (see dark/black regions in Figure 3(a)). The 0.5–2 keV X-ray emission is detected within the shell-like morphology, indicating the presence of hot gas emission in the region (see Figure 3(a)). The prominent bell-shaped cavity and the elongated filamentary features are also seen in the ratio map (see arrows and highlighted dot-dashed box in Figure 3(a)). In Figure 3(b), the distribution of molecular gas, ionized gas, and hot gas emission is shown together. In the ratio 4.5 \( \mu \)m/3.6 \( \mu \)m map, the bright emission regions suggest the domination of 4.5 \( \mu \)m emission, while the black or dark gray regions indicate the excess of 3.6 \( \mu \)m emission. In Figure 4, we present the H$\alpha$ image overlaid with the NVSS 1.4 GHz and Herschel 70 \( \mu \)m emission. The H$\alpha$ image shows the extended diffuse H$\alpha$ emission in the S237 region, which is well distributed within the shell-like morphology. Figure 4 also shows the spatial match between the H$\alpha$ emission and the radio continuum emission. Figures 5(a) and (b) show a zoomed-in ratio map and color composite image toward the radio peak. A bell-shaped cavity is evident, and the peaks of radio continuum 1.4 GHz emission and diffuse H$\alpha$ emission are present within it (see Figures 4 and 5(b)). The warm dust emission traced in the 70 \( \mu \)m image depicts the walls of the bell-shaped cavity (see Figure 5(b)). However, the peak of molecular $^{12}$CO(1–0) emission does not coincide with the radio continuum peak (see Figure 5). This indicates that the bell-shaped cavity can originate from the impact of ionized emission (also see Section 3.6). In the ratio map, there are bright emission regions near the radio continuum emission, indicating the excess of 4.5 \( \mu \)m emission. As mentioned above, the 4.5 \( \mu \)m band contains the Br$\alpha$ feature at 4.05 \( \mu \)m. Hence, due to the presence of ionized emission, these bright emission regions probably trace the Br$\alpha$ features. In Figure 5(a), the excess of 4.5 \( \mu \)m emission is also observed at the bottom of the bell-shaped morphology, which is designated as subreg 1 and is coincident with the 0.5–2 keV X-ray peak emission. We also find a bright emission region near the elongated filamentary features where the radio continuum emission is absent (see arrows in Figure 3(a)). Hence, this emission is probably tracing the outflow activities. Considering the presence of the 3.3 \( \mu \)m PAH feature in the 3.6 \( \mu \)m band, the edges of the shell-like morphology around the H II region appear to depict photo-dissociation regions (or photon-dominated regions, PDRs).

In Figure 6, we present 21 cm H I velocity channel maps of the S237 region. The bright H I feature is seen near the 1.4 GHz emission; however, the sphere-like shell morphology is depicted in black or dark gray regions. It appears that the black or dark gray regions in the H I channel maps trace the H I self-absorption (HISA) features (i.e., shell-like HISA features; e.g., Kerton 2005). It has been suggested that the HISA features are produced by the residual amounts of very cold H I gas in molecular clouds (Burton et al. 1978; Baker & Burton 1979; Burton & Liszt 1981; Liszt et al. 1981). In the S237 region, the...
HISA features are more prominent in a velocity range of $-2.29$ to $-3.11$ km s$^{-1}$. The 21 cm HI line data are presented here only for a morphological comparison with the infrared images. The 0.5–2 keV X-ray emission is also shown in a channel map, allowing us to infer the distribution of cold HI gas and hot gas emission in the region. In Figure 7, to compare the morphology of the S237 region, we have shown infrared images (at 22 μm and 250 μm) and an HI map (at 21 cm). We find that the shell-like HISA feature is spatially correlated with dust emission as traced in the Spitzer, WISE, and Herschel images. The presence of H$\rm{I}$ further indicates the PDRs surrounding the H$\rm{II}$ region and hot gas emission.

3.3. Herschel Temperature and Column Density Maps

The Herschel temperature and column density maps are used to infer the physical conditions present in a given star-forming region. In Figure 8, we show the final temperature and column...
density maps (resolution ~37′′). The procedures for calculating the Herschel temperature and column density maps were mentioned in Section 2.5.

In the Herschel temperature map, the area near the H II region is traced with the considerably warmer gas ($T_d \sim 29$–47 K; see Figure 8(a)). The Herschel temperature map traces the edges of the shell in a temperature range of about 22–28 K. Several condensations are found in the column density map, and one of the condensations (see clump1) has the highest column density (peak $N(H_2) \sim 3.6 \times 10^{21}$ cm$^{-2}$; $A_V \sim 3.8$ mag) located toward the filamentary features (see Figure 8(b)). The relation between optical extinction and hydrogen column density ($A_V = 1.07 \times 10^{-21} N(H_2)$; Bohlin et al. 1978) is used here. Krumholz & McKee (2008) proposed a threshold value of 1 g cm$^{-2}$ (or corresponding column densities of $\sim 3 \times 10^{23}$ cm$^{-2}$) for formation of massive stars. This implies that the formation of massive stars in the identified Herschel clumps is unlikely. The column density structure of S237 appears nonhomogeneous, with higher column density clumps engulfed in a medium with lower column density. The bell-shaped cavity is also seen in the column density map.

In the column density map, we employed the clumpfind algorithm to identify the clumps and their total column densities. We find 13 clumps, which are labeled in Figure 8(b), and their boundaries are also shown in Figure 8(c). Out of the 13 clumps, 7 (e.g., clumps 1, 3, 4, 6, 7, 9, and 13) are found toward the edges of the shell-like structure, while three other clumps (e.g., clumps 2, 5, and 11) are located within the shell-like structure and the remaining three clumps (e.g., clumps 8, 10, and 12) are away from the shell-like structure. To assess the spatial distribution of clumps with respect to the HISA features, these clumps are also marked in the CGPS 21 cm H I single-
channel map at $-3.94$ km s$^{-1}$ (see Figure 6). The mass of each clump is computed using its total column density and can be determined using the formula

$$M_{\text{clump}} = \mu_{H_2} m_H \text{Area}_{\text{pix}} \Sigma N(H_2)$$

where $\mu_{H_2}$ is assumed to be 2.8, Area$_{\text{pix}}$ is the area subtended by 1 pixel, and $\Sigma N(H_2)$ is the total column density. The mass of each Herschel clump is tabulated in Table 1. The table also contains an effective radius of each clump, which is provided by the clumpfind algorithm. The clump masses vary between 10 and 260 $M_\odot$. The most massive clump (i.e., clump1) associated with the molecular condensation conds1 (see Figure 2(b)) is away from the radio peak, while clump2, linked to the molecular condensation conds2 (see Figure 2(b)), is associated with the H II region.

### 3.4. Kinematics of Molecular Gas

In this section, we present distributions of $^{12}$CO ($J = 1-0$) and $^{13}$CO ($J = 1-0$) gas in the S237 region. An inspection of...
Table 1
Summary of the Properties of the Herschel Clumps Identified in the S237 Region (see Figures 8(b) and (c))

| ID | $l$ (deg) | $b$ (deg) | $R_c$ (pc) | $M_{\text{clump}}$ ($M_\odot$) |
|----|----------|-----------|-----------|-----------------|
| 1  | 173.9637 | 0.2325    | 1.8       | 258.6           |
| 2  | 173.8937 | 0.2947    | 1.0       | 84.3            |
| 3  | 173.9054 | 0.2169    | 1.0       | 80.2            |
| 4  | 173.9482 | 0.3842    | 1.3       | 37.4            |
| 5  | 173.8704 | 0.2830    | 0.7       | 35.2            |
| 6  | 173.8471 | 0.2558    | 0.6       | 36.0            |
| 7  | 173.8393 | 0.2830    | 0.6       | 25.0            |
| 8  | 173.8393 | 0.2130    | 1.0       | 37.4            |
| 9  | 173.9054 | 0.2169    | 1.0       | 80.2            |
| 10 | 173.9637 | 0.2325    | 1.8       | 258.6           |
| 11 | 173.8937 | 0.2947    | 1.0       | 84.3            |
| 12 | 173.8471 | 0.2558    | 0.6       | 36.0            |
| 13 | 173.8393 | 0.2830    | 0.6       | 35.2            |

Note. Column (1) lists the IDs given to the clump. The table also contains positions, deconvolved effective radius ($R_c$), and clump mass ($M_{\text{clump}}$).

The $^{12}$CO and $^{13}$CO line profiles reveal that the molecular cloud associated with the S237 region (i.e., S237 molecular cloud) is well traced in a velocity range of $-7$ to $-2$ km s$^{-1}$. In general, $^{12}$CO emission is optically thicker than $^{13}$CO. To study the spatial distribution of the molecular gas in the S237 region, in Figure 9 we present $^{12}$CO ($J = 1-0$) velocity channel maps at different velocities within the velocity range from $-6.25$ to $-1.75$ km s$^{-1}$ in steps of 0.5 km s$^{-1}$. The channel maps show at least four molecular condensations (i.e., clumps$1$–$4$), and the bulk of the molecular gas is found toward the condensation “conds1.” In Figure 10, we show the $^{13}$CO ($J = 1-0$) velocity channel maps as a zoomed-in view toward the condensation “conds1,” where the high- and low-velocity gas distribution is evident toward the Herschel clump$1$. Note that the molecular condensation “conds1” contains the elongated filamentary features and a massive Herschel clump (i.e., clump$1$). In Figure 11, we present the integrated $^{12}$CO and $^{13}$CO intensity maps and the galactic position–velocity maps. In the position–velocity diagrams of the $^{12}$CO emission, we find a noticeable velocity gradient along the condensation “conds1” (see Figures 11(c) and (e)) and an almost inverted C-like structure (see Figure 11(e)). In Figure 11 (see right panels), we also show the integrated $^{13}$CO (1–0) intensity map and the position–velocity maps. The optical depth in $^{13}$CO is much lower than that in $^{12}$CO, and the $^{13}$CO data can trace the dense region ($n(H_2) > 10^5$ cm$^{-3}$). The integrated $^{13}$CO intensity map detects only the condensation “conds1,” which contains the Herschel clump$1$ (see Figure 8(b)). This suggests that the clumps1 is the densest molecular condensation compared to the other three condensations (i.e., clumps$2$–$4$). Using the integrated $^{13}$CO intensity map (see Figure 11(b)), we compute the mass of the molecular condensation “conds1” to be about 242 $M_\odot$, which is in agreement with the clump mass estimated using the Herschel data. In the calculation, we use an excitation temperature of 20 K, an abundance ratio ($N(H_2)/N(^{13}CO))$ of $7 \times 10^7$, and a ratio of gas to hydrogen by mass of about 1.36. One can find more details about the clump mass estimation in Yan et al. (2016) (see Equations (4) and (5) in Yan et al. 2016).

The position–velocity diagrams of the $^{13}$CO emission clearly indicate the presence of a velocity gradient along the condensation “conds1” (see Figures 11(d) and (f)). The condensation “conds1” hosts a cluster of young populations (see Section 3.5.2) and filamentary features. Therefore, one can suspect the presence of molecular outflows in the condensation “conds1” (also see channel maps in Figure 10). The velocity gradient could also be explained as gas flowing through the filamentary features into their intersection. Due to the coarse beam of the FCRAO $^{12}$CO and $^{13}$CO data (beam size $\sim 45''$), we do not further explore this aspect in this work and are also unable to infer the gas distribution toward the filamentary features.

Recently, based on the molecular line data analysis and modeling work, Arce et al. (2011) suggested an inverted C-like or ring-like structure for an expanding shell/bubble in the position–velocity diagrams (see Figure 5 in Arce et al. 2011). In the S237 region, the presence of an inverted C-like structure in the position–velocity diagram can indicate an expanding shell. Additionally, as previously mentioned, the S237 H II region is excited by a single source of radio spectral type B0.5V. Hence, it appears that the S237 region is associated with an expanding H II region with an expansion velocity of the gas $\sim 1.65$ km s$^{-1}$.

Altogether, the FCRAO $^{12}$CO and $^{13}$CO data suggest the presence of an expanding H II region.

3.5. YSOs in S237

3.5.1. Identification of YSOs

The GLIMPSE360, UKIDSS GPS, and 2MASS data allow us to investigate the infrared-excess sources present in the S237 region. In the following, we describe the YSO identification and classification schemes.

1. To identify infrared-excess sources, Gutermuth et al. (2009) described various conditions using the $H$, $K$, $3.6 \mu m$, and $4.5 \mu m$ data and utilized the dereddened color–color space ([K$-[3.6]_0$] and [3.6$-[4.5]_0$]). Using the GLIMPSE360, UKIDSS GPS, and 2MASS catalogs, these dereddened colors were determined using the color-excess ratios given in Flaherty et al. (2007). This dereddened color–color space is also used to identify possible dim extragalactic contaminants from YSOs with additional conditions (i.e., [3.6]$_0$ $<$ 15 mag for Class I and [3.6]$_0$ $<$ 14.5 mag for Class II). The observed color and the reddening laws (from Flaherty et al. 2007) are utilized to compute the dereddened 3.6 $\mu m$ magnitudes. This scheme yields 80 (7 Class I and 73 Class II) YSOs (see Figure 12(a)).

2. We find that some sources have detections only in the $H$ and $K$ bands. To further select infrared-excess sources from this selected population, we utilized a color–magnitude ($H-K/K$) diagram (see Figure 12(b)). The diagram depicts the red sources with $H-K > 0.65$ mag. This color criterion is selected based on the color–magnitude analysis of the nearby control field. We identify 18 additional YSO candidates using this scheme in our selected region.

Using the UKIDSS, 2MASS, and GLIMPSE360 data, a total of 98 YSOs are obtained in the selected region. The positions of all YSOs are shown in Figure 13(a).

3.5.2. Spatial Distribution of YSOs

Using the nearest-neighbor (NN) technique, the surface density analysis of YSOs is a popular method to examine their spatial distribution in a given star-forming region (e.g., Gutermuth et al. 2009; Bressert et al. 2010; Dewangan et al. 2015), which can be used to find the young stellar clusters.
Using the NN method, we obtain the surface density map of YSOs in a manner similar to that described in Dewangan et al. (2015) (also see equation in Dewangan et al. 2015). The surface density map of all the selected 98 YSOs was constructed, using a 5″ grid and six NNs at a distance of 2.3 kpc. In Figure 13(b), the surface density contours of YSOs are presented and are drawn at 3, 5, 7, 10, 15, and 20 YSOs pc\(^{-2}\), increasing from the outer to the inner regions. In Figure 13(b), two clusters of YSOs are observed in the S237 region and are mainly seen toward the Herschel clump1, clump2, and subreg1 (see Figure 13(b)). However, one cluster of YSOs seems to be linked with the Herschel clump2 and the subreg1 together. In Section 3.3, we have seen that the filamentary features and bell-shaped cavity are observed toward the Herschel clump1 and clump2, respectively. Hence, in the S237 region, the star formation activities are found toward the filamentary features, bell-shaped cavity, and subreg1 (see Figure 13(b)). Recently, Pandey et al. (2013) also identified

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**Figure 9.** Velocity channel contour maps of \(^{12}\)CO\((J = 1 \rightarrow 0)\) emission. The molecular emission is integrated over a velocity interval, which is labeled in each panel (in km s\(^{-1}\)). The contour levels are 18%, 25%, 30%, 40%, 55%, 70%, 80%, 90%, and 99% of the peak value (in K km s\(^{-1}\)), which is also given in each panel. In each panel, the positions of IRAS 05281+3412 and Herschel column density peak are marked by a plus sign and a star, respectively. The dot-dashed black box encompasses the area shown in Figures 10 and 14. In the maps, at least four noticeable condensations (i.e., conds1–4) are observed, and the majority of molecular gas is found toward the condensation conds1.
young populations in the S237 region using the optical and NIR (1–5 μm) data. Based on the spatial distribution of young populations, they found most of the YSOs distributed mainly toward the bell-shaped cavity, subreg1, and filamentary features (see Figure 15 in Pandey et al. 2013), which was also reported by Lim et al. (2015; see their Figure 8). Furthermore, Lim et al. (2015) found an elongated shape of the surface density contours of PMS sources that is very similar in morphology to that investigated in this work. Taken together, these previous results are in good agreement with our presented results.

In the molecular condensation conds1, the filamentary features are physically associated with a cluster of YSOs, a massive clump (having the highest column density, i.e., $3.6 \times 10^{21} \text{cm}^{-2}$), and molecular gas (see Figure 14). Interestingly, this result suggests the role of filaments in the star formation process.

### 3.6. Feedback of a Massive Star

Based on the radio continuum data analysis, we find that the S237 region is powered by a radio spectral type of B0.5V star. To study the feedback of a massive star in its vicinity, we compute the three pressure components (i.e., pressure of an H II region $P_{\text{H II}}$, radiation pressure $P_{\text{rad}}$, and stellar wind ram pressure $P_{\text{wind}}$) driven by a massive star. These pressure components ($P_{\text{H II}}$, $P_{\text{rad}}$, and $P_{\text{wind}}$) are defined below (e.g., Bressert et al. 2012):

$$P_{\text{H II}} = \mu m_{\text{H}_2} c_s^2 \left( \frac{3N_{\text{av}}}{4\pi \alpha_B D_s^3} \right).$$

$$P_{\text{rad}} = L_{\text{bol}}/4\pi c D_s^2.\quad (5)$$

$$P_{\text{wind}} = M_v V_w/4\pi D_s^2.\quad (6)$$

In the equations above, $N_{\text{av}}, c_s (=11 \text{ km s}^{-1}$ in the ionized gas; Bisbas et al. 2009), and $\alpha_B$ are previously defined (see Section 3.1.2), $\mu = 0.678$ (in the ionized gas; Bisbas et al. 2009), $n_H$ is the hydrogen atom mass, $M_v$ is the mass-loss rate, $V_w$ is the wind velocity of the ionizing source, $L_{\text{bol}}$ is the bolometric luminosity of the source, and $D_s$ is the projected distance from the location of the B0.5V star where the pressure components are estimated. The pressure components driven by a massive star are evaluated at $D_s = 3.5$ pc (i.e., the separation between the positions of the NVSS peak and clump1).

Adopting $L_{\text{bol}} = 19952 L_\odot$ (for a B0.5V star; Panagia 1973), $M_v = 2.5 \times 10^{-9} M_\odot$ yr$^{-1}$ (for a B0.5V star; Oskinova et al. 2011), and $V_w = 1000$ km s$^{-1}$ (for a B0.5V star; Oskinova et al. 2011) in the above equations, we compute $P_{\text{H II}} \approx 2.0 \times 10^{-11}$ dynes cm$^{-2}$, $P_{\text{rad}} \approx 1.7 \times 10^{-12}$ dynes cm$^{-2}$, and $P_{\text{wind}} \approx 1.1 \times 10^{-14}$ dynes cm$^{-2}$. The comparison of these pressure components indicates that the pressure of the H II region is relatively higher than the radiation pressure and the stellar wind...
We also obtain a total pressure \( P_{\text{total}} = P_{\text{H II}} + P_{\text{rad}} + P_{\text{wind}} \) driven by a massive star of \( \sim 2.2 \times 10^{-11} \) dynes cm\(^{-2}\). \( P_{\text{total}} \) is comparable to the pressure associated with a typical cool molecular cloud \( P_{\text{MC}} \sim 10^{-11} - 10^{-12} \) dynes cm\(^{-2}\) for a temperature of \( \sim 20 \) K and particle density of \( \sim 10^3 - 10^4 \) cm\(^{-3}\); see Table 7.3 of Dyson & Williams (1980, p. 204), suggesting that the clump1 is not destroyed by the impact of the ionized gas.

**Figure 11.** Distribution of \(^{12}\)CO (left) and \(^{13}\)CO (right) emission toward the S237 region. Top panels: contour maps of integrated (a) \(^{12}\)CO and (b) \(^{13}\)CO emission in the velocity range of \(-7 \) to \(-2 \) km s\(^{-1}\). The \(^{12}\)CO map is similar to the one shown in Figure 2(b). In the top panels, the positions of the NVSS 1.4 GHz peak emission and the Herschel column density peak are shown by a blue diamond and a red star, respectively. Middle panels: latitude–velocity diagrams of (c) \(^{12}\)CO and (d) \(^{13}\)CO. In the latitude–velocity diagrams, the molecular emission is integrated over the longitude from 173°75 to 174°25. Bottom panels: longitude–velocity diagrams of (e) \(^{12}\)CO and (f) \(^{13}\)CO. In the longitude–velocity diagrams, the molecular emission is integrated over the latitude from 0°0177 to 0°5175. In the position–velocity diagrams, the dotted blue and dashed red lines show the positions of the NVSS 1.4 GHz peak emission and the Herschel column density peak, respectively. In panel (e), the longitude–velocity diagram depicts an inverted C-like morphology, indicating the expanding shell with an expanding gas velocity of \( \sim 1.65 \) km s\(^{-1}\). The position–velocity diagrams of \(^{12}\)CO and \(^{13}\)CO also trace a noticeable velocity gradient along the Herschel clump1, which contains the Herschel column density peak (also see the text).
and Class positions of all the identified YSOs are shown in Figure 13(a).

### 4. DISCUSSION

In recent years, Spitzer and Herschel data have observed MIR shells or bubbles, infrared filaments, and young star clusters together in many massive star-forming regions, indicating the onset of numerous complex physical processes. The presence of bubbles/shells associated with H II regions is often explained by the feedback mechanisms (such as ionizing radiation, stellar winds, and radiation pressure) of massive stars (e.g., Zinnecker & Yorke 2007; Deharveng et al. 2010; Tan et al. 2014; Dewangan et al. 2015). The multiband images have revealed an almost sphere-like shell morphology as the most prominent structure in the S237 region. The shell-like HISA feature surrounding the ionized emission is also seen in the 21 cm H I line data. The velocity structure of molecular gas has indicated the presence of an expanding H II region associated with the S237 region (see Section 3.4). Additionally, in Section 3.6, based on the pressure calculations ($P_{\text{H II}}$, $P_{\text{rad}}$, and $P_{\text{wind}}$), we find that the photoionized gas linked with the S237 H II region can be considered as the major contributor (against stellar winds and radiation pressure) for the feedback process in the S237 region. Hence, the presence of a bell-shaped cavity-like morphology could be explained by the impact of ionizing photons (see Section 3.2).

In Section 3.5.2, we detect only two clusters of YSOs in the S237 region. Thirteen Herschel clumps are identified in the S237 region, and star formation activities are exclusively found toward the Herschel clump1 and clump2 (see Section 3.5.2). Interestingly, clump1 and clump2 contain the bell-shaped cavity-like structure hosting the peaks of 1.4 GHz emission and diffuse Hα emission and filamentary features without any radio continuum detection, respectively. Lim et al. (2015) also found two groups of PMS stars inferred using their surface density analysis and estimated a median age of PMS members of 2.0 Myr. They also reported the maximum age difference between the stars in the these two groups to be about 0.7 Myr, on average. Considering the presence of the expanding H II region, the spatial locations of the YSO clusters may indicate the triggered star formation scenario in the S237 region. One can obtain more details about different processes of triggered star formation in the review article by Elmegreen (1998). Evans et al. (2009) reported an average age of the Class I and Class II YSOs of ~0.44 Myr and ~1–3 Myr, respectively. Comparing these typical ages of YSOs with the dynamical age of the S237 H II region (i.e., ~0.2–0.8 Myr; see Section 3.1.2), it seems that the S237 H II region is too young for initiating the formation of a new generation of stars. This is also supported by the results obtained by Lim et al. (2015) (see above). Hence, the young clusters are unlikely to have been the product of triggered formation. The $^{13}$CO emission is not detected toward clump2 and subreg1, indicating the absence of dense gas toward these subregions (see Figure 11(b)). Note that the hot gas emission is traced toward subreg1 using the ROSAT X-ray image and is found away (about 2″) from the 1.4 GHz peak emission. The surface density contours are also seen toward subreg1. We suspect that the diffuse X-ray emission could originate from young stars present in the cluster (see subreg1 in Figure 5(a)). Due to coarse resolution of the ROSAT X-ray image, we cannot identify the X-ray-emitting young stars. In general, Elmegreen (2011) mentioned that open cluster complexes could be the remnants of star formation in giant clouds formed by gravitational instabilities in the Milky Way gas layer.

It is also worth mentioning that the Herschel clump1 is the most massive, with about 260 $M_\odot$, contains the filamentary
features, and has a noticeable velocity gradient in both the $^{12}$CO and $^{13}$CO emissions. In Figure 14, there is convincing evidence for a physical association of a cluster of YSOs and a massive clump with the filamentary features, indicating the role of filaments in the star formation process. Recently, Nakamura et al. (2014) studied the filamentary ridges in the Serpens South infrared dark cloud using the molecular line observations and argued that the filamentary ridges appeared to converge toward the protocluster clump. Furthermore, they suggested that the collisions of the filamentary ridges may have triggered cluster formation. Schneider et al. (2012) also carried out Herschel data analysis toward the Rosette Molecular Cloud and suggested that the infrared clusters were preferentially seen at the junction of filaments or filament mergers. They also reported that their outcomes are in agreement with the results obtained in the simulations of Dale & Bonnell (2011). In the present work, due to coarse beam sizes of the molecular line data, we cannot directly probe the converging of filaments toward the protocluster clump. Here, a protocluster clump refers to a massive clump associated with a cluster of YSOs without any radio continuum emission. However, our results indicate the presence of a cluster of YSOs and a massive clump at the intersection of filamentary features, similar to those found in the Serpens South region. Therefore, it seems that the collisions of these features may have influenced the cluster formation. Based on these indicative outcomes, further detailed investigation of this region is encouraged using high-resolution molecular line observations.

In general, the information of the relative orientation of the mean field direction and the filamentary features allows us to infer the role of magnetic fields in the formation and evolution of the filamentary features. Using previous optical polarimetric observations (from Pandey et al. 2013), we find an average value of the equatorial position angle of three stars of 161°5, which are located near the filamentary features (see the positions of these stars in Figure 14(b)), while the equatorial position angle of the filamentary features at their intersection zone is computed to be about 95°. The polarization vectors of background stars indicate the magnetic field direction in the plane of the sky parallel to the direction of polarization (Davis & Greenstein 1951). Hence, these filamentary features seem to be nearly perpendicular to the plane-of-the-sky projection of the magnetic field linked to the molecular condensation clumps in the S237 region, indicating that the magnetic field is likely to have influenced the formation of the filamentary features. Sugitani et al. (2011) studied NIR imaging polarimetry toward the Serpens South cloud and found that the magnetic field is nearly perpendicular to the main filament. In particular, the filamentary features in the S237 region appear to originate from a similar process to that observed in the Serpens South cloud. However, high-resolution polarimetric observations at longer wavelengths will be helpful to further explore the role of magnetic field in the formation of the filamentary features in the S237 region.

5. SUMMARY AND CONCLUSIONS

In order to investigate star formation processes in the S237 region, we have utilized multiwavelength data covering radio, NIR, optical H$_\alpha$, and X-ray wavelengths. Our analysis has been focused on the molecular gas kinematics, ionized
emission, hot gas, cold dust emission, and embedded young populations. Our main findings are as follows:

(1) The S237 region has a broken or incomplete ring- or shell-like appearance at wavelengths longer than 2 μm and contains a prominent bell-shaped cavity-like morphology at the center, where the peak of the radio continuum emission is observed. The elongated filamentary features are also seen at the edge of the shell-like structure, where the radio continuum emission is absent.

(2) The distribution of ionized emission traced in the NVSS 1.4 GHz continuum map is almost spherical, and the S237 H II region is powered by a radio spectral type of B0.5V star. The dynamical age of the S237 H II region is estimated to be ∼0.2 (0.8) Myr for 10³ (10⁴) cm⁻³ ambient density.

(3) The molecular cloud associated with the S237 region (i.e., S237 molecular cloud) is well traced in a velocity range of −7 to −2 km s⁻¹. In the integrated ¹²CO map, at least four molecular condensations (conds1–4) are identified.

**Figure 14.** Zoomed-in view toward the molecular condensation conds1, as traced in the integrated ¹³CO and ¹²CO maps (see dot-dashed box in Figure 9). (a) Spitzer IRAC ratio map of 4.5 μm/3.6 μm emission traces the filamentary features. (b) WISE image at 12 μm also depicts the filamentary features. The positions of three stars having optical polarimetric observations (from Pandey et al. 2013) are marked by cyan circles. (c) Integrated ¹³CO(J = 1–0) emission map of the molecular condensation conds1. The ¹³CO contours are shown with levels of 10%, 18%, 25%, 30%, 40%, 55%, 70%, 80%, 90%, and 99% of the peak value (i.e., 8.251 K km s⁻¹). The YSO surface density contours (dot-dashed; in cyan color) and filamentary features (in red) are also shown in the map. Two filamentary features are highlighted by labels “fl.” (d) Herschel column density map overlaid with the YSO surface density contours, revealing a physical connection between a cluster of YSOs and a massive clump. In the last two panels, the contours are shown at 3, 5, 7, 10, 15, and 20 YSOs pc⁻², from the outer to the inner side. In the first three panels, the position of the Herschel column density peak is marked by a star. The panels exhibit the presence of a cluster of YSOs and a massive clump at the intersection of filamentary features.
(4) In the integrated $^{12}$CO map, the molecular gas is seen only toward the condensation conds1.
(5) Using the 0.5–2 keV X-ray image, the hot gas emission is traced at the center of the shell-like morphology and could be due to young stars present in the cluster.
(6) The position–velocity analysis of $^{12}$CO emission depicts an inverted C-like structure, revealing the signature of an expanding H II region with a velocity of $\sim 1.65$ km s$^{-1}$.
(7) The pressure calculations ($P_{\text{H II}}, P_{\text{ad}},$ and $P_{\text{wind}}$) indicate that the photoionized gas associated with the S237 H II region could be responsible for the origin of the bell-shaped structure seen in the S237 region.

(8) Thirteen Herschel clumps have been traced in the Herschel column density map. The majority of molecular gas is distributed toward the massive Herschel clump1 ($M_{\text{clump}} \sim 260 M_\odot$), which contains the filamentary features. The position–velocity analysis of $^{12}$CO and $^{13}$CO emission traces a noticeable velocity gradient along this Herschel clump1.

(9) The analysis of NIR (1–5 $\mu$m) photometry provides a total of 98 YSOs and also traces the clusters of YSOs mainly toward the bell-shaped structure and the filamentary features.

(10) Toward the elongated filamentary features, a cluster of YSOs is spatially coincident with the massive Herschel clump1 embedded within the molecular condensation conds1. Taking into account the lower dynamical age of the H II region (i.e., 0.2–0.8 Myr), the clusters of YSOs are unlikely to originate from the expansion of the H II region. An interesting outcome of this work is the existence of a cluster of YSOs and a massive clump at the intersection of filamentary features, indirectly illustrating that the collisions of these features may have triggered cluster formation, similar to those seen in the Serpens South star-forming region.

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