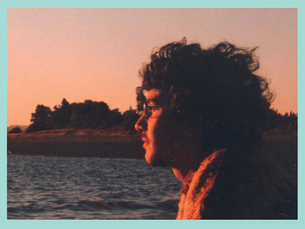
SPITZER-IRAC, NIR and CO study of the Massive Star Forming Complex S254-S258



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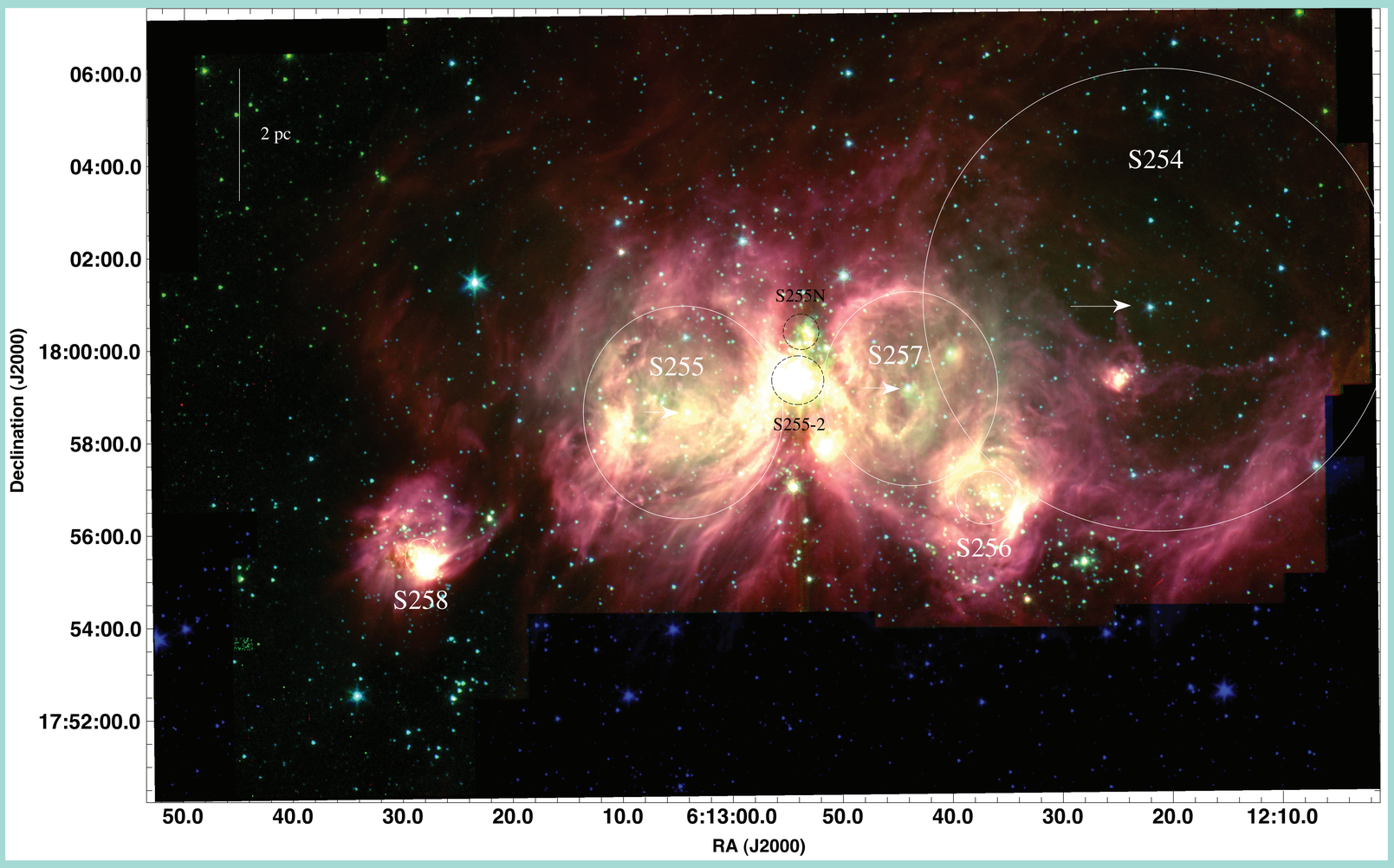


Figure 1: IRAC color image of the S254-S258 complex (blue: 3.6 μm, green: 4.5 μm, red: 8.0 μm). White areas enclose the HII regions (Mizuno 1982). Clusters S255-2 and S255N are enclosed by black circles. Known ionizing stars are indicated with arrows.

ABSTRACT

We present Spitzer-IRAC, 2.1meter-Flamingos, Keck-NIRC, and FCRAO-SEQUOIA observations of the massive star forming complex S254-S258. Using a combination of the IRAC and NIR data, we identified and classified the YSO in the complex. We detected 62 Class 0/I, 136 Class II, and 115 stellar photospheres. We also identified 449 sources with IR-excess. The YSO are found in clusters surrounded by isolated YSO in a low-density distributed population. The ratio of isolated to clustered YSO is ~ 1/5. We identify three new clusters in the complex. The structure of the molecular cloud is examined using 12CO and 13CO, as well as a near-IR extinction map.

S254-S258

The S254-S258 complex (see Figure 1) is a star forming region described for the first time by Sharpless (1959) as a group of five HII regions (S254 to S258), with sizes between 0.4 to 4 pc at a distance of 2.4 kpc (Evans et al. 1977).

Between HII regions S255 and S257, there is a young cluster called S255-2. This cluster has been studied by several authors, and contains signatures of star formation like infrared sources, OH, H2O and methanol masers, as well as HH like objects and compact HII regions, indicating that massive stars are forming in S255-2. The location of S255-2 between the HII regions suggest that the formation of the cluster was triggered by the expansion of HII regions S255 and S257. North from S255-2 is located the region S255N where star formation is in an early stage than in S255-2 (Minier et al. 2005).

More young clusters of stars have been identified in S256, S258, and another inside S254. Until now, there was no compilation of the number of cluster members and percentage of sources with IR-excess in the complex.

In this work, we present Spitzer-IRAC, 2.1meter-Flamingos, and Keck-NIRC imaging covering the whole complex S254-S258. The combination of IRAC and NIR data will allow us to identify and classify the YSOs in the complex. We will also combine our data with CO emmision in order to understand how massive stars interact with the interstellar medium.

Identifying and classifying YSO

Sources with IRAC 4-band detections

We use the IRAC SED slope (α_{IRAC}) to classify the YSOs according to the following criteria: Class I/0 ($0 < \alpha_{IRAC}$), Class II ($-2 < \alpha_{IRAC} < 0$), and stellar photospheres ($-2 > \alpha_{IRAC}$). We estimate α_{IRAC} using a minimum square fit regression over the fluxes in the IRAC bands at 3.6, 4.5, 5.8 and 8.0 μm.

Sources with 7-band detections

We classified the sources with 7-band detections (J, H, K, IRAC 1 to 4) using the derreddened value of α_{IRAC}. The sources were derreddened using the reddening law from Flaherty et al. (2007) by moving them to their main sequence color in the H-K vs. J-H color-color diagram. Then, we classified the sources using the derreddened α_{IRAC} and the criteria explained previously.

Identifying more YSOs

We used the combined (H, and K bands plus IRAC 4.5) color-color diagram to detect more sources with IR-excess (see Figure 2).

We detected 61 Class I/0, 139 Class II, and 115 Class III sources in the complex. In total, we found 494 stars with IR excess. Of those, 121 correspond to sources detected in the 4 IRAC bands.

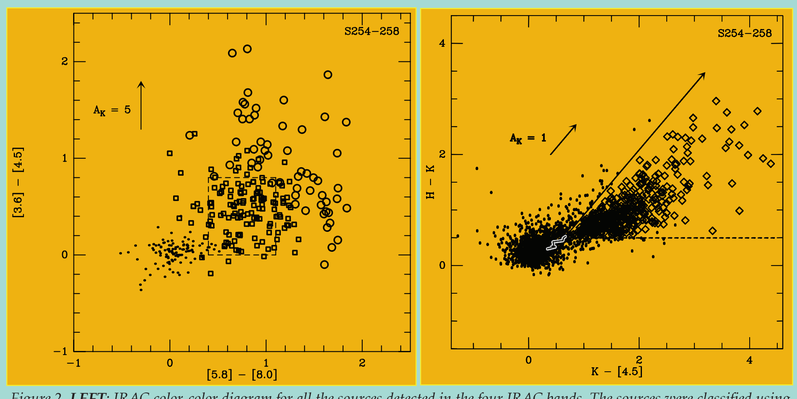


*Figure 2. **LEFT**: IRAC color-color diagram for all the sources detected in the four IRAC bands. The sources were classified using their observed α_{IRAC} value in Class I/0 ($\alpha_{IRAC} > 0$, shown in circles), Class II ($-2 < \alpha_{IRAC} < 0$, shown in squares), or Class III ($\alpha_{IRAC} < -2$, shown in points). Sources that were also detected in JHK, were classified using their derreddened α_{IRAC} value. Big dashed square indicates the position of Class II sources from Allen et al. 2004. The reddening vector is from Flaherty et al. 2007. **RIGHT**: Flamingos H, K and IRAC 4.5μm band color-color diagram in S254-S258. The black line shows the main sequence path for a late type dwarf star (Patten et al. 2004). The long arrow corresponds to the reddening vector (from Flaherty et al. 2007). Segmented line delimits the region for stars with infrared excess, which are shown as diamonds.*

Spatial distribution of YSO

Figure 3 shows the spatial distribution of Class I/0 and Class II sources. In general Class II sources are more dispersed than Class I/0. There is a clear concentration of Class I/0 sources around S255-2 that is extended north-south, forming a filament between S255 and S257.

To determine the amount of members in clusters, we used the nearest-neighbor cummulative distribution (see Figure 4). We also impose a minimum number of members per cluster of 5. Figure 5 Shows the cluster members.

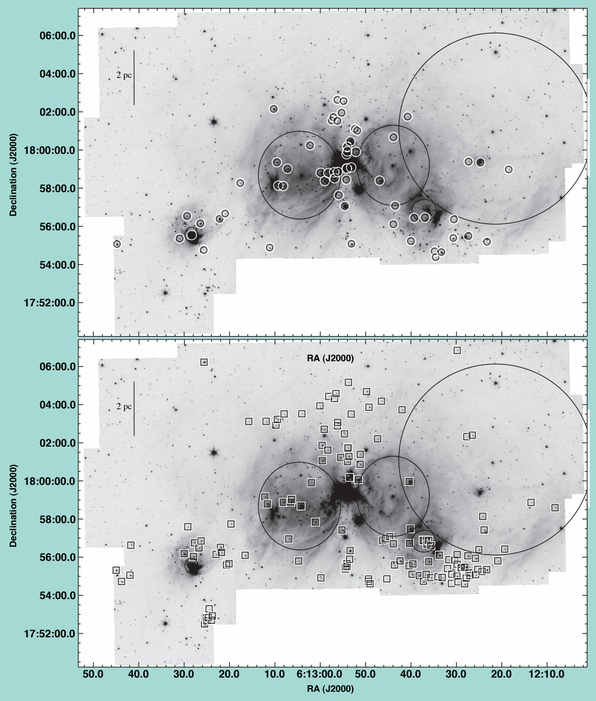


*Figure 3: **UPPER**: Sources identified as Class I are shown marked on the IRAC 4.5 μm mosaic. **LOWER**: Sources identified as Class II. The areas marked correspond to the HII regions in the complex (from Mizuno 1982).*

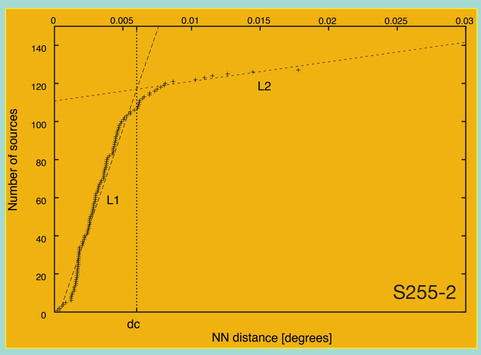


Figure 4: Criteria used to estimate the maximum distance between cluster members (dc) for S255-2. The nearest-neighbor (NN) distance raises smoothly for sources included in the cluster, represented by L1. The NN distance increases for sources more isolated in the outer parts of the cluster, represented by L2. The distance "dc" is defined by the intersection of L1 and L2. The intersection correspond to a physical length of 0.2 pc.

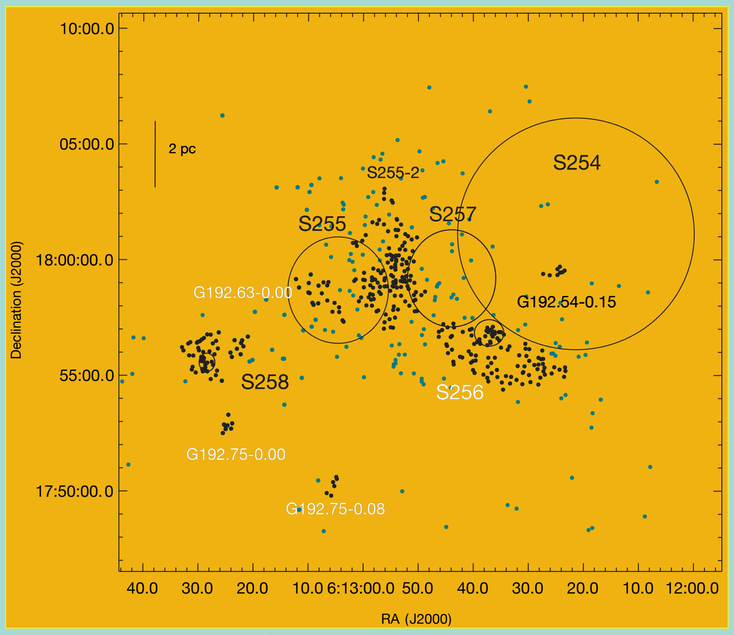


Figure 5: Cluster members. Sources identified as cluster members are shown in black, the rest of the sources are shown in gray. The areas marked correspond to the HII regions in the complex (from Mizuno 1982). New clusters are named in white. For S256, the new members are located to the south from the HII region.

Cloud structure

The K-band extinction map of the complex is shown in Figure 6. The map was created using the mean value of the K-band extinction of the nearest 10 stars over a uniform 30'' grid. The A_K values were estimated by derredening the sources with no IR-excess in the H-K v/s J-H color-color diagram. Finally, we convolved the resulting map with a 30'' Gaussian kernel. The total number of sources used to build the map was 1735.

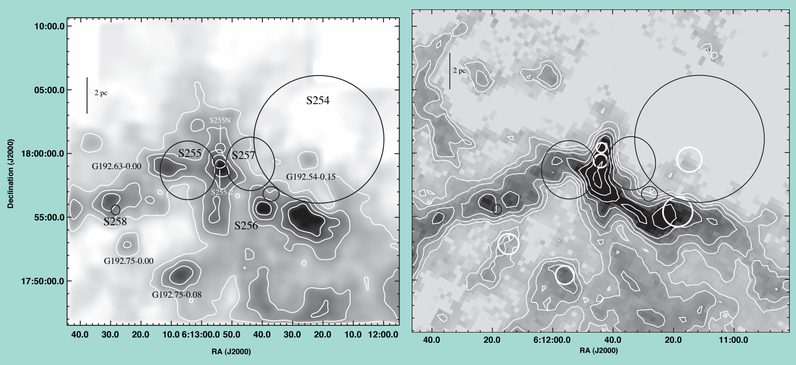
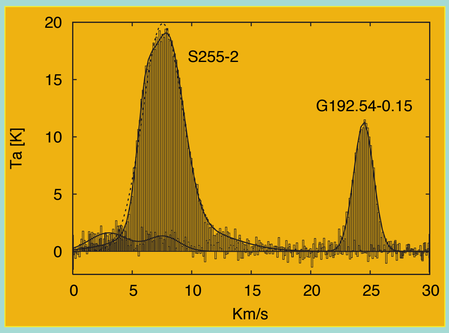


*Figure 6. **LEFT**: K-band extinction map. Contours begin at 0.4 A_K and increase by 0.2. **RIGHT**: Map of 13CO column density derived from the ratio of 12CO and 13CO intensities. Contours are spaced logarithmically between $5x10^{15}$ and $5x10^{16}$ cm^{-2}. HII regions and clusters are also indicated.*

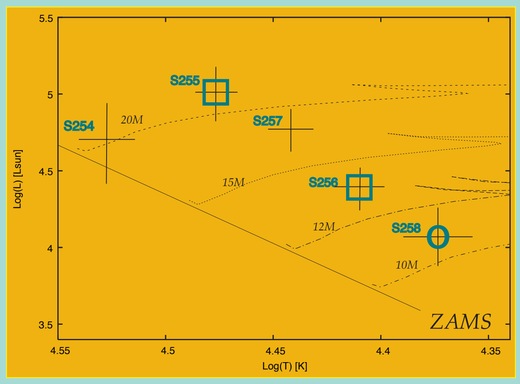
Figure 7: integrated 12CO velocity spectra for S255-2 and G192.54-0.15. Continuous lines show Gaussian fitting. We note that all the clusters peak at velocities between 7-9 km/s with the exception of G192.54-0.15, which peaks at 25 km/s.



HR diagram of ionizing stars

We used Optical-Hectospec and NIR-SpeX spectra to estimate the spectral type of the ionizing sources in the complex. Figure 8 shows the resulting HR diagram. We used the spectral type to estimate the ages of the ionizing stars using the expansion of the Stromgren sphere. The estimated ages in ascending order are: S258 ($1x10^5$ yr), S256 ($2x10^5$ yr), S255 and S257 ($1.5x10^6$ yr), and S254 ($5x10^6$ yr).

Figure 8: Position of the ionizing stars in the HR diagram. The size of the points indicate the errors. Circles or squares indicate IRAC Class I/0 or Class II respectively. The spectral type of S257 was taken from Reed et al. (2005). Model evolutionary tracks from Lejeune et al. (2001) .



Conclusions

We used Spitzer-IRAC and Flamingos-NIR data to classify and identify YSOs in the massive star forming complex S254-S258. We used the IRAC slope of the SED to classify YSOs in Class I/0 and Class II sources, and the K-4.5 v/s H-K color-color diagram to identify sources with IR-excess. We detected in total 61 Class I/0, 139 Class II, and 115 stellar photospheres. Also, we identified 496 sources with IR-excess.

Using the surface density map of sources with IR-excess, and the nearest-neighbor distances, we studied the spatial distribution of YSOs in the complex. We found that 70% of the IR-excess sources are located in clusters, while the rest are distributed in a more isolated component.

We discovered 3 new young clusters in the complex: G192.63-0.00, G192.75-0.00, G192.75-0.08, and a southern component of the cluster S256.

The ages of the ionizing stars suggest three stages in the evolution of the HII regions. The oldest one includes S254, then S255 and S257, and finally the younger S256 and S258.

The structure of the molecular cloud suggests that the high density of dust in the lower part of HII regions S255 and S254 was accumulated by the expansion of those HII regions.

The CO data suggest that cluster G192.54-0.15 may be located in the background of the complex.

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