Infrared Photometric Analysis of Massive Star Forming Regions

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Advances in the observational techniques in infrared and submillimeter and improved theoretical knowledge have revealed a broad range of stellar densities of young stellar objects (YSOs) in star-forming regions. While we have a detailed picture for the formation of low-mass stars, our understanding for massive star formation is still lagging. Since massive stars form and evolve quickly and they produce strong winds and outflows which quickly heat, ionize and disrupt their natal molecular cloud, it is difficult to probe the early evolutionary stages. In addition they are formed in more clustered environments. In order to understand the star formation process as whole, it is necessary to understand the formation of stellar clusters. Therefore, we started a detail investigation of massive star-forming regions (W49, W43, W51) in the Galaxy. We used Spitzer mid-infrared and 2MASS/UKIDSS near-infrared color magnitude relations to identify 232 Class 0/I YSOs, 981 Class II/transition disk candidates in W49, 1177 Class 0/I YSOs, 5358 Class II/transition disk candidates in W43, and 418 Class 0/I YSOs, 1243 Class II/transition disk candidates in W51. We investigated the groups and clusters of YSOs to understand the star formation history in these regions. Based on the morphology of the clusters, which are distributed within the clouds and show relative age differences according to their Class II/I ratios, we argue that there are independent sites of star formation within each complex. We also used SED models to identify massive YSOs and investigated massive star formation tracers such as ultra compact HII regions and masers.

Massive Star-Forming Regions

The vast majority of stars form in massive star-forming regions with complicated star formation histories and within them massive stars play a vital role in the star formation process. However, the process of massive star formation is not well understood yet.

To better understand the massive star formation process, we performed a detailed investigation of W49, W51 and W43 which are among the brightest and massive star-forming regions in the Galaxy. They have similar gas masses (> 10^6 $M_\odot$) but different morphologies and clustering properties which suggests different star formation history.

Source Catalog

We used the mid-infrared Spitzer data from several programs obtained with the Spitzer IRAC instrument and generated the mosaics from the standard basic calibrated data products (see the background for Spitzer mosaic of W51. R: 8.0 μm, G: 4.5 μm, B: 3.6 μm).

After performing the photometry in four IRAC bands (3.6, 4.5, 5.8, and 8.0 μm) detected sources are matched with 2MASS/UKIDSS data (J, H, and K) and then also merged with the MIPSGAL Archive 24 μm data.

Source Classification

To identify and classify the sources, we used color and magnitude criteria as we applied in Saral et al. (2015) [1] for W49 and defined in Gutermuth et al. (2008, 2009) [2,3].

First, we eliminated extragalactic sources such as star-forming galaxies, AGNs, and PAH rich galaxies and also other PAH contaminated sources and AGB stars, separated the photospheres and field stars and then identified YSOs (see Fig 1 and Table 1).

Table 1. Source Classification Summary

	Number of Objects		
Class	W49	W51	W43
Class I	186	302	919
Class II & Transition Disks	981	1243	5358
Class III & Photospheres	247142	157037	429690

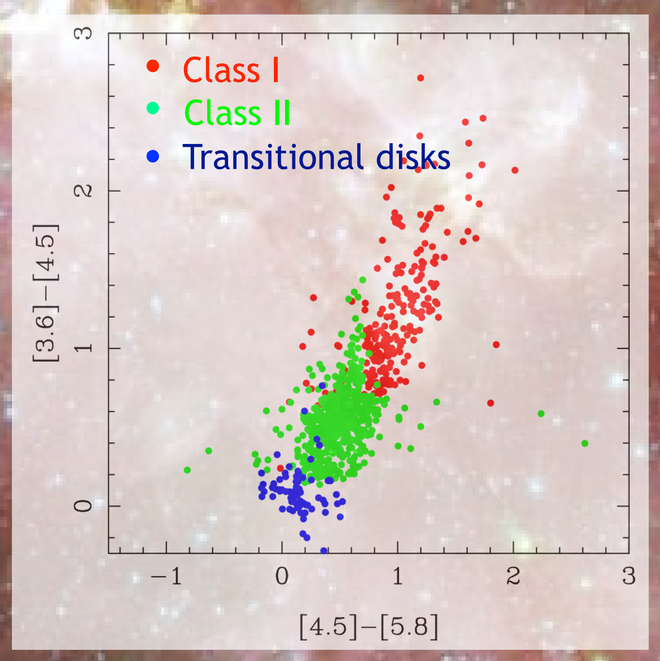

Fig 1. A color-color diagram for W51 region.

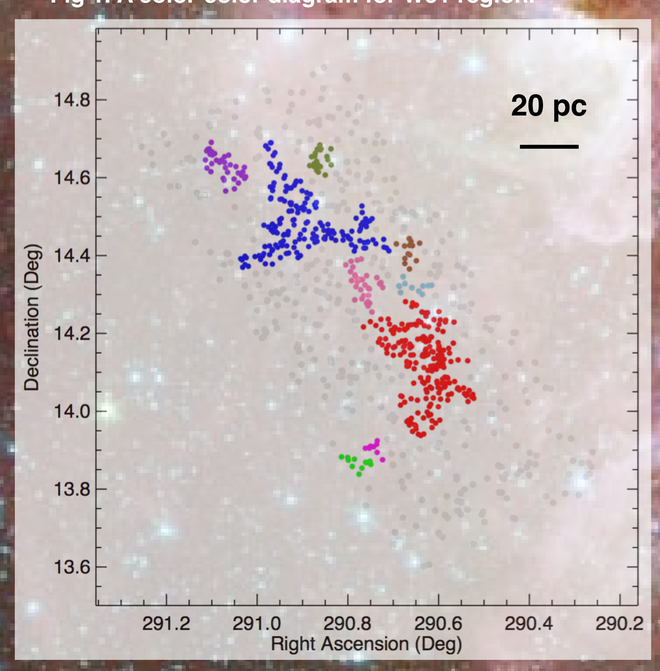

Fig 2: 9 YSO groups are shown in W51.

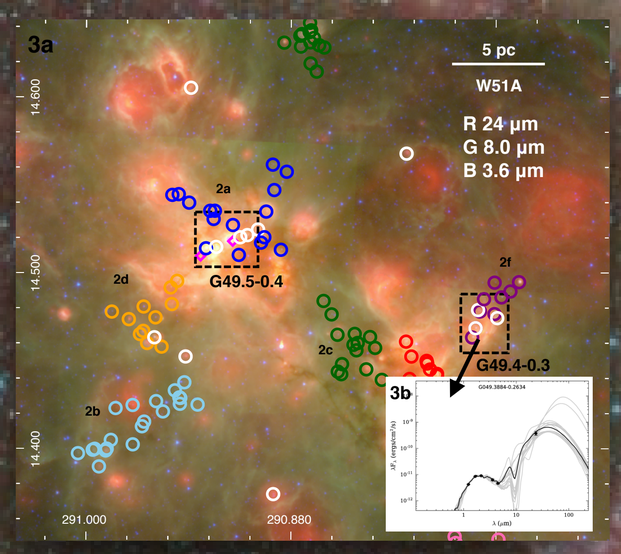

Fig (3a). The distribution of MYSO candidates in W51A. White circles are MYSO candidates, subgroups are shown with different colors. (3b). YSO model SED of a MYSO candidate.

Clustering Analysis

The Minimal Spanning Tree (MST) method [4] was used to examine the substructures such as groups and clusters of YSOs in a similar fashion as in many studies [1,3,5,6].

We identified 3 MST groups and 7 subgroups in W49, 9 MST groups (Fig 2) and 16 subgroups in W51, and 57 MST groups and 102 subgroups in W43. Assuming Class I sources represent relatively early stages of formation, we use the ratio of Class II/I to compare the relative ages of different groups. In both W51 and W43, the Class II/I ratio is suggesting several independent star formation events. The details and comparison with other star forming regions are discussed in the paper [7].

Massive YSO Candidates

We identified 16, 22, and 38 massive YSO (MYSO) candidates ($M \geq 8 M_\odot$) in W49, W51, and W43, respectively according to the SED fitting methods [8,9]. The clustered fraction of MYSO candidates is 100% in W49 and ~90% in W51 and W43.

Star-forming regions host HII regions, UCHII regions and methanol masers which are related to early stages of massive stars. Fig 3 shows two HII regions (G49.5-0.4, G49.4-0.3) which are positionally associated with the subgroups 2a and 2f. Subgroup 2a also hosts 4 MYSO candidates which might be associated with the methanol masers (magenta diamonds). The other main HII region seems associated with subgroup 2f where we identified 11 YSO candidates where 2 of them are MYSO candidates. These are good candidates for follow-up spectroscopic studies.

Conclusion

In this study we generated the photometry catalogs for W49, W51 and W43, classified the YSOs and used SED models to identify the MYSO candidates. By identifying groups of YSOs we tried to understand the star formation histories in these regions.

For more, see the papers [1] and [7].

References:
[1] Saral + 2015, ApJ, 813, 25, [2] Gutermuth + 2008, ApJ, 674, 336, [3] Gutermuth + 2009, ApJS, 184, 18, [4] Cartwright & Whitworth, 2003, MNRS, 348, 589, [5] Koenig + 2008, ApJ, 688, 1142, [6] Beerer + 2010, ApJ, 720, 679, [7] Saral + 2016, ApJ, submitted, [8] Azimlu + 2015, ApJ, 150, 95, [9] Robitaille + 2007, ApJS, 169, 328, * GS acknowledges support from NASA grant NNX12AI60G, Istanbul University grant BAP50195, (ATS) BAP22272, Marie Sklodowska-Curie RISE grant "ASTROSTAT", and Swiss National Science Foundation Sinergia project "STARFORM".