29th ASI Meeting
ASI Conference Series, 2011, Vol. 3, pp 85 – 89
Edited by Pushpa Khare & C. H. Ishwara-Chandra

Multi-wavelength investigations on Galactic star forming regions

L. K. Dewangan[1]*
[1]*Physical Research Laboratory, Navrangpura, Ahmedabad, India*

Abstract. The thesis presents photometric study of several galactic star forming regions including High mass protostellar objects (HMPOs) and Ultracompact HII Regions (UCHIIs). Spectral Energy Distribution (SED) modeling is done for the infrared counterparts of outflow driving engines from HMPO samples and the driving engines of the UCHII regions. We derive the driving engine outflow relationships for a sample of HMPOs and characterize the physical properties of driving engines of the UCHII regions. Our study shows that the modeled disk accretion rates associated with HMPO samples are two orders of magnitude smaller than the envelope accretion rates and can not explain the observed mass loss rates. Therefore it is the mass accreted in the envelope that appears to contribute to the outflow entrainment rate. Our SED modeling results related to the driving engines of the UCHII regions predict very high (envelope) accretion rates, even without taking ionized accretion flows into account. We also present the photometric analysis of archival *Spitzer*-IRAC images, and the ratio maps on three massive star-forming (MSF) regions, which are included in the study of clustering of young stellar objects (YSOs), the interaction and feedback of massive stars to their immediate environments.

Keywords : stars: formation – infrared: stars – infrared: ISM

1. Introduction

The study of star formation has been one of the most fundamental problems in astrophysics. The birth mechanism of low and intermediate mass stars ($M < 8\ M_\odot$) is established by the gravitational collapse and subsequent accretion of their parent

*email: lokeshd@prl.res.in

molecular cloud (Palla & Stahler 1993). But, the exact formation processes of high-mass stars (M $\gtrsim$ 8 $M_{\odot}$) are not well established (Zinnecker & Yorke 2007). Massive stars are usually situated at large distances ($\gtrsim$ 1 kpc) in clustered environment, are deeply embedded and evolve rapidly. All these factors make it difficult to study their earliest phases of their evolution i.e. HMPOs and UCHII regions. These sites are accessible to longer wavelength (such as infrared and sub-mm) observations with very good spatial resolution that can probe very deeply embedded individual objects. In recent years, *Spitzer* Infra-Red Array Camera (IRAC) has provided unprecedented sensitivity and high spatial resolution in mid-infrared wavelength regime that is very useful to identify embedded sources in MSF regions and characterize their associated physical parameters through modeling of their SED using observed data. In addition to, IRAC photometry, ratio maps of IRAC images are very helpful to study the atomic/molecular emission regions created by massive stars due to their interaction with the immediate surroundings. We have utilized the *Spitzer*-IRAC archival images as well as ground based data as basis to study several massive star forming regions. Here, I present some important results associated with MSF regions, which forms a part of my thesis work.

2. Observations

Spitzer Space Telescope (SST) IRAC/Glimpse archival & ground-based observed images from Mt. Abu IR observatory were used for the thesis work. SEDs were constructed using online tool[1] (Robitaille et al. 2006) and analyzed for the sources by using IRAC photometry with combination of 2MASS, MSX, IRAS, and (sub)millimeter data (wherever available).

3. Results

3.1 *Spitzer*-IRAC study of young massive stars

In this section, we present the *Spitzer*-IRAC study of two stages of the young massive stars i.e. HMPOs and UCHII regions.

A. Driving engine outflow relationships for HMPOs samples:

We identified 33 infra-red counterparts (IRCs) which are the possible driving source of molecular outflows associated with HMPOs using IRAC/Glimpse archive images. We compared the physical parameters of HMPOs derived from SED modeling against the observed outflow parameters obtained from the published literature. The outflow mass and momentum are found to be directly proportional to the (proto)stellar

[1] http://caravan.astro.wisc.edu/protostars/

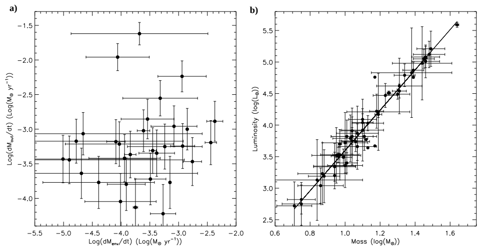

Figure 1. (a) Scatter diagram shows the observed outflow entrainment rate as a function of model-obtained envelope accretion rate of the HMPOs. (b) Figure shows model-derived total luminosity as a function of mass of the driving engines of the sample UCHII regions. The solid line is the linear fit: L $\sim 10^{0.4\pm0.1} \times$ M$^{3.2\pm0.1}$.

mass and inversely proportional to the (proto)stellar age. These results, limited by the dataset, are valid up to a mass of 25 $M_{\odot}$ and an age of 1 Myr. The modeled disk accretion rates are two orders of magnitude smaller than the envelope accretion rates and can not explain the observed mass loss rates. Therefore, it is the mass accreted in the envelope that appears to contribute to the outflow entrainment rate (see Fig. 1a). This allows us to speculate that the massive outflows are launched in the large scale infalling envelopes.

B. Characterization of the physical properties of driving engines of the UCHII regions:

We found 56 infrared counterparts (for a total of 42 UCHII regions) of the driving engines of UCHII regions using of *Spitzer*-IRAC/Glimpse archive and derived their physical parameters through SED modeling using observed imaging data. We obtained average values of mass, age, disk and envelope accretion rate $\sim$ 12.9 $M_{\odot}$, $\sim 10^{4.5}$ yr, $\sim 10^{-5.8}$ and $10^{-3.6}$ $M_{\odot}$ yr^{-1} respectively. Mass and luminosity relation for these sources are found L $\sim 10^{0.4\pm0.1} \times$ M$^{3.2\pm0.1}$ (see Fig. 1b). Our results show that the higher the accretion rate (both disk and envelope), the larger the radii of the sources.

We have compared the physical properties associated with driving engines of HMPOs (33 sources) and UCHII regions (48 regions). We did not find any significant difference between the derived physical parameters of HMPOs and UCHII regions.

3.2 Photometric study of three MSF regions

In this sub-section, we present the photometric study on three MSF regions (i.e. AFGL 437 (2.0 kpc), M8 (1.25 kpc) and S235 (1.8 kpc)) using *Spitzer*-IRAC archive images. We found about 53 %, 60 % and 75 % of the YSOs are present in clusters with surface densities of 10-25 YSOs/pc^2 in AFGL 437, M8 and S235 regions re-

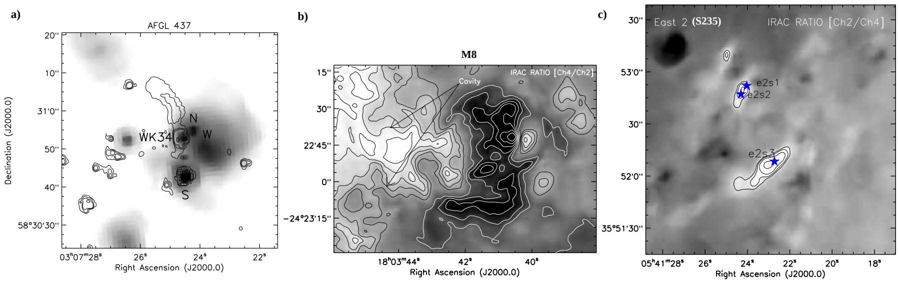

Figure 2. (a) Outflow lobes associated with WK34 in AFGL 437 traced by IRAC ratio Ch2/Ch4 map are shown by contours on IRAC 8 μm image. (b) IRAC ratio image of Ch4/Ch2 of M8 (Lagoon Nebula) is overlaid by the ratio contours. The bright tubular structure within the "cavity" represent possible PAH emission and the dark regions may be due to the Brα emission. (c) IRAC ratio Ch2/Ch4 image of S235 complex revealing the source "e2s3" may be associated with an outflow due to shock-excited H_2 emission.

spectively. The SED modeling and IRAC ratio maps indicate that the sources WK34 (in AFGL 437) & e2s3 (in S235) are young massive protostar and associated with outflows possibly due to molecular hydrogen (see Fig. 2a & 2c) (Kumar Dewangan & Anandarao 2011a, 2011b). Bright emission region in the IRAC ratio Ch4/Ch2 map traces the polycyclic aromatic hydrocarbon (PAH) emission in a cavity east of the Hourglass of M8 region (see Fig. 2b). The dark region reveals Brα (4.05 μm) emission corresponding to the Hourglass HII region powered by Her 36 (see Fig. 2b). Our study suggested that the formation of the sources in M8 could have been triggered by stellar winds or expanding HII regions associated with the massive stars in the region (Kumar Dewangan & Anandarao 2011b).

4. Conclusions

In this thesis work, we found that the mass accreted in the envelope appears to contribute more significantly to the outflow entrainment rate rather than the disk. Our SED modeling results related to the driving engines of the UCHII regions predict very high (envelope) accretion rates, even without taking ionized accretion flows into account. Therefore, it calls for (i) improved SED modeling to take into account the ionized flows, non-spherical accretion and envelope accretion luminosity; and (ii) observations that unambiguously identify and characterize disks and envelopes. Shock-excited molecular hydrogen (H_2), Brα and PAH emission regions are traced in the MSF regions showing the interaction of YSOs with immediate surroundings. The SED modeling and IRAC ratio maps indicate that the sources WK34 (in AFGL 437) & e2s3 (in S235) are young massive protostar and associated with outflows possibly due to H_2.

Acknowledgement

I sincerely thank my thesis supervisor, Prof. B. G. Anandarao (PRL, Ahmedabad), for his guidance and help for my work. Also, I would like to acknowledge Dr. M. S. N. Kumar (CAUP, Porto) for his help and suggestions.

References

Dewangan L. K., Anandarao B. G., 2011a, MNRAS, 402, 2583
Dewangan L. K., Anandarao B. G., 2011b, MNRAS, 407, 1170
Dewangan L. K., Anandarao B. G., 2011c, MNRAS, 414, 1526
Palla F., Stahler S. W., 1993, ApJ, 418, 414
Robitaille T. P. et al., 2006, ApJS, 167, 256
Zinnecker H., Yorke H. W., 2007, ARA&A, 45, 481