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# Star formation and IMF of young clusters associated with HII regions

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**Abstract.** We are pursuing multi-wavelength studies of a few star-forming regions to study the star formation scenario and effects of massive stars on low-mass star formation. Here I describe our recent results regarding triggered star formation in/ around young star clusters as well as IMF of these regions.

*Keywords* : stars: formation: star clusters – stars: initial mass function

## 1. Introduction

The massive stars of OB associations have strong influence and significantly affect the entire star-forming region. As soon as O stars form, their strong ultraviolet (UV) radiation photoionizes the surrounding gas and develops an expanding HII region, thus dispersing the remaining molecular cloud and consequently terminating star formation. Alternatively, shock waves associated with the ionization front (IF) may squeeze the molecular cloud and induce subsequent star formation either through 'collect and collapse process', which was proposed by Elmegreen & Lada (1977) or through 'radiation driven implosion (RDI)' of molecular cloud condensations. Detailed model calculations of the RDI process have been carried out by several authors (e.g. Lefloch et al. 1997). Observational evidence for this process is often inferred from the spatial distribution of young stars and subgroups of OB associations and their age distribution (see e.g. Sharma et al. 2007, Samal et al. 2007, Pandey et al. 2008).

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To study the star formation scenario in and around young star clusters, we have embarked on multi-wavelength studies of star-forming regions. Here I have reviewed results of our multi-wavelength studies of five star forming regions, namely NGC 1893, Be 59, Sh2-294, Stock 8 and W5 East.

## 2. Data

The optical observations of the regions were obtained using the 105-cm Schmidt telescope of the Kiso Observatory (Japan), 104-cm Sampurnanand telescope of ARIES (Nainital, India) and 200-cm Himalayan *Chandra* Telescope (HCT, Hanle, India) (for details see Sharma et al. 2007, Samal et al. 2007, Pandey et al. 2008). The slitless spectra obtained using the Himalaya Faint Object Spectrograph Camera (HFOSC) instrument at the 2-m HCT were used to identify the emission line stars in the regions.

Near-infrared (NIR, $JHK_s$ ) data for point sources in and around the cluster region have been obtained from the 2MASS Point Source Catalogue (PSC). The Midcourse Space Experiment (MSX) images in four mid-infrared (MIR) bands A (8.28 $\mu$m), C (12.13 $\mu$m), D (14.65 $\mu$m) and E (21.34 $\mu$m) around the cluster regions were used to study the emission from the unidentified infrared bands (UIBs) and to estimate the spatial distribution of optical depth of the warm interstellar dust. The HIRES processed data from the IRAS survey in the four bands (12, 25, 60 and 100 $\mu$m) were used to study the spatial distribution of optical depth of the cold interstellar dust.

## 3. Membership and age determination

The spectra of some of pre-main sequence (PMS) stars, specifically classical T-Tauri stars (CTTSs), show emission lines among which usually H$\alpha$ is the strongest. Therefore H$\alpha$ emission stars have been used to identify the PMS stars associated with the star forming regions. Since many of PMS stars also show NIR excess caused by circumstellar disks, NIR photometric surveys have also emerged as a powerful tool to detect low-mass PMS stars. To identify NIR excess stars from the 2MASS PSC, we used NIR $(J-H)/(H-K)$ colour-colour (NIR-CC) diagram. The age of the identified PMS stars was estimated by using the $V,(V-I)$ colour - magnitude diagram (CMD). The details of the methodology are given by Sharma et al. (2007) and Pandey et al. (2008). Recent studies, e.g. by Preibisch et al. (2005) have shown that YSOs show highly elevated levels of X-ray activity. Therefore we have also used X-ray observations to identify the PMS stars.

The post-main-sequence age of the ionizing sources in these regions was found to be $\sim$ 2 - 4 Myr, whereas the ages of the YSOs range between $<$ 1

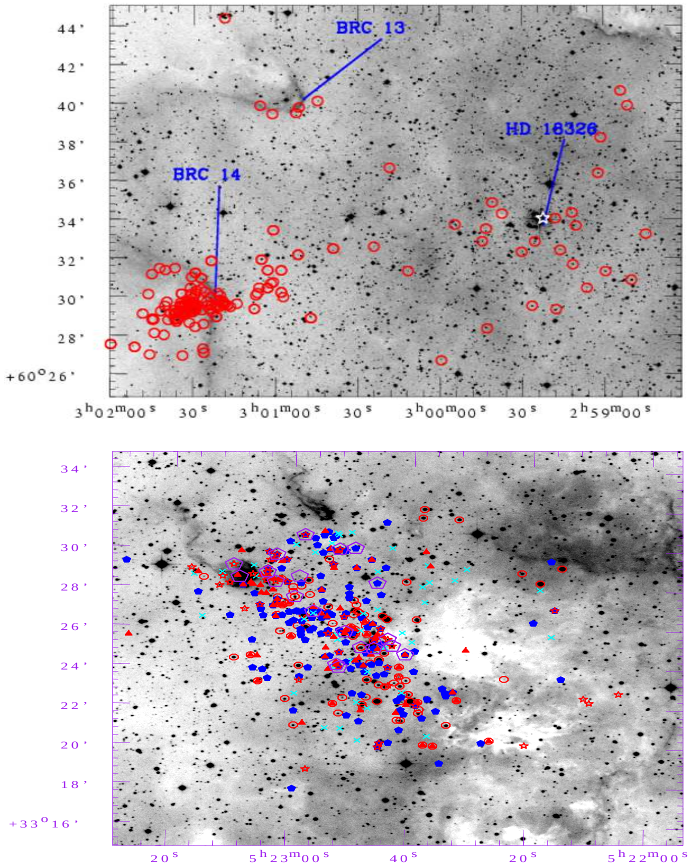


**Figure 1.** Spatial distribution of YSOs in the BRC 14 (*top*) and NGC 1893 regions (*bottom*).

Myr and ∼ 5 Myr (cf. Sharma et al. 2007, Samal et al. 2007, Jose et al. 2008 and Chauhan et al. 2009). The spread in the ages of the YSOs indicates a non-coeval star formation in the clusters.

## 4. Star formation scenario and IMF

Fig. 1 shows the spatial distribution of detected YSOs around BRC 14 region (top panel) and NGC 1893 (bottom panel) on a DSS-II $R$ band image. In both the cases we can see that YSOs are aligned from the vicinity of the ionizing source to the direction of bright rim/ nebulae. A more impressive alignment of the Class II sources in the case of BRC 14, detected using the *Spitzer* observations, can be seen in Fig. 7 of Koenig et al. (2008). To study the age sequence we divided the YSOs associated with BRC 14 into two groups:

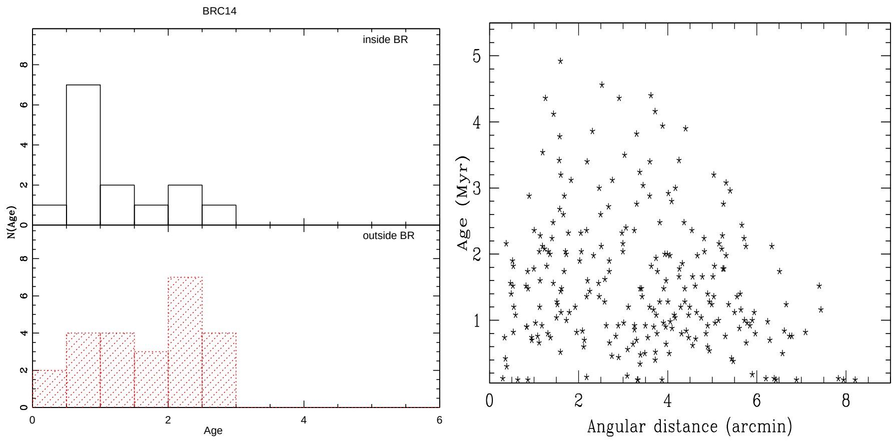


**Figure 2.** Age distribution of YSOs in the BRC 14 (*left*) and NGC 1893 regions (*right*).

those lying on/inside and outside of the rims (for details see Chauhan et al. 2009). Fig. 2 (left) shows the age distribution of these two groups, which manifests that the YSOs lying on/inside the rim (upper panel) are younger than those located outside it (lower panel). A similar trend has been found in the case of several BRCs by Ogura et al. (2007) and Chauhan et al. (2009). Fig. 2 (right) shows the age distribution of YSOs in NGC 1893 as a function of radial distance from the cluster center. It is evident that the age of the YSOs decreases systematically as we move towards the Nebulae Sim 129 and 130.

The age gradient and spatial distribution of YSOs along with the morphology of the ionised gas in these regions discussed here suggest that the star formation activity at the periphery of the star clusters is possibly triggered by expansion of the H II region. The morphological features suggest that the triggered star formation is due to radiation driven implosion. However, the possibility of 'collect-and-collapse' process in the case of Sh2-294 cannot be ruled out, considering the following facts. The radio observation reveals that Sh2-294 is a roughly spherically ionized region and is surrounded by a half ring of MSX dust emission in the mid-IR (cf. Samal et al. 2007). The presence of the dust ring beyond the ionization front indicates that neutral gas surrounds the H II region. There are density enhancements which seem to be distributed symmetrically around the central cluster which contains a B0 V ionization source (cf. Fig. 3 of Samal et al. 2007).

The MF is often expressed by the power law, $N(\log m) \propto m^{\Gamma}$ and the slope of the MF is given as: $\Gamma = d \log N(\log m)/d \log m$, where $N(\log m)$ is the number of stars per unit logarithmic mass interval. The classical value derived by Salpeter (1955) for the slope of IMF is $\Gamma = -1.35$. For the observed mass range $0.6 < M/M_{\odot} \leq 17.7$, the value of the slope of the initial mass function $\Gamma$, in the case of NGC 1893 comes out to be $-1.27 \pm 0.08$ which is in agreement with the Salpeter value of -1.35 in the solar neighborhood. However, the value of $\Gamma$ for PMS phase stars (mass range $0.6 < M/M_{\odot} \leq 2.0$) is found to be $-0.92 \pm 0.09$ which is shallower than the value ($-1.71 \pm 0.20$) obtained for MS stars having mass range $2.5 < M/M_{\odot} \leq 17.7$ indicating a break in the slope of the mass function at $\sim 2M_{\odot}$. In the case of Be 59 the value of $\Gamma$ in the mass range $2.5 < M/M_{\odot} \leq 28$ is found to be $-1.01 \pm 0.11$ which is shallower than the Salpeter value (-1.35), whereas in the mass range $1.5 < M/M_{\odot} \leq 2.5$ the slope is almost flat. In the Stock 8 region, the slope of the mass function (MF) in the mass range $\sim 1.0 \leq M/M_{\odot} < 13.4$ can be represented by $-1.38 \pm 0.12$, which agrees well with Salpeter value (-1.35). In the mass range $0.3 \leq M/M_{\odot} < 1.0$ the MF is found to be shallower with $\Gamma = -0.58 \pm 0.23$ indicating a break in the slope of the IMF at $\sim 1M_{\odot}$. Estimated $\Gamma$ values indicate an effect of mass segregation in the sense that massive stars are preferentially located towards the cluster center. The estimated dynamical evolution time is found to be greater than the age of the clusters, therefore the observed mass segregation in the clusters may be the imprint of the star formation process.

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