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Star formation studies at TIFR

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Abstract. Studies of Galactic star forming regions being carried out at TIFR, is summarized. The techniques and typical results from these studies have been described briefly, which include : the balloon borne far infrared mapping in broad photometric bands (150 & 210 μm) as well as spectroscopic imaging in the fine structure [C II] line at 158 μm; near infrared imaging in broad and narrow bands using the Mt. Abu Infrared Telescope & Himalayan Chandra Telescope; high resolution radio interferometric imaging in the 330–1400 MHz bands using GMRT; and use of data products from international space missions like Midcourse Space Experiment (MSX).

Keywords : infrared : ISM – stars: formation – Galaxy: disc

1. Introduction

The major science goals of the infrared astronomy programme at TIFR are related to the study of star formation and interstellar medium in our Galaxy. This involves astronomical measurements in the infrared using ground based, balloon borne as well as satellite borne telescopes. Observations in the radio as well as optical wavebands often supplement these studies.

Section 2 presents the observational facilities and describes results from a few selected studies.

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Figure 1. TIRCAM at the Cassegrain focus of the Mt. Abu Infrared Telescope. The dewar, the drive electronics (on the adjoining rack) as well as the closed cycle cryocooler (cold head on the dewar, Helium gas pipe lines & the compressor on the ground) are visible.

2. Observational facilities and typical results

2.1 Near infrared

The TIFR near Infrared Camera (TIRCAM) based on a SBRC Indium Antimonide focal plane array (58×62 pixels) sensitive over 1–5 μm wavelength has been used at the Cassegrain focus of the 1.2-metre Gurushikhar telescope at Mount Abu. The incoming f/13 beam from the telescope passes through a collimator, selectable filter and the re-imaging optics onto the array. The array is cooled to 35 K for optimum operations using a Helium gas based closed cycle cryo-cooler (Ghosh, Rengarajan and Verma 1996). The pixel size corresponds to 1.0" on the sky. Observations are made in staring mode. Figure 1 shows TIRCAM on Mt. Abu telescope during a typical observing run.

Imaging of Galatic star forming regions are carried out in narrow band filter in the L' band (3.9 μm) in addition to the wide bands of $J/H/K$. In spite of the large thermal background in the L band, it has been possible to achieve a sensivity of L'= 7.2 mag with a total integration time $\sim$ 1200 sec (Ojha et al., 2003). An image of the Trapezium cluster is presented in Fig. 2.

For imaging through the atmospheric windows at shorter wavelengths ($J/H/K$), the infrared cameras based on HgCdTe arrays have been used from Gurushikhar as well as

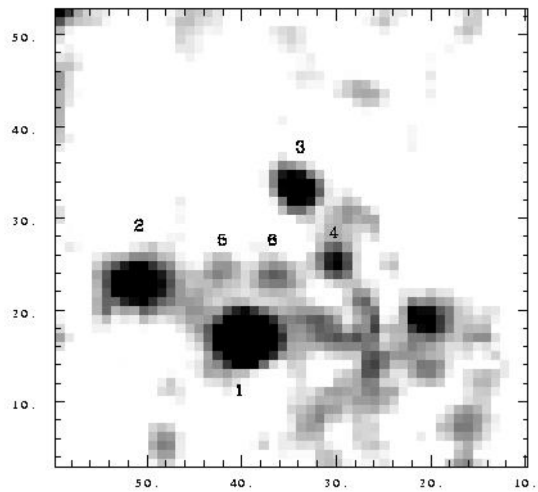

Figure 2. Image of the trapezium cluster in Orion taken by the TIRCAM, in a L' narrow band filter.

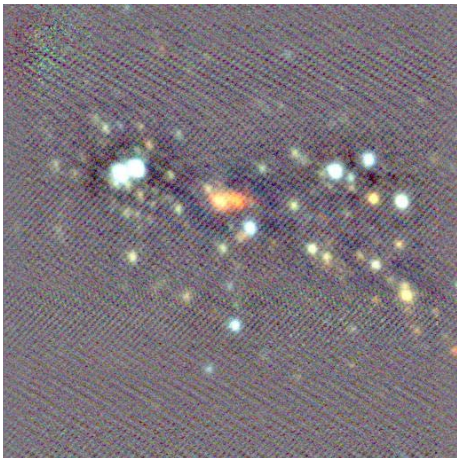

Figure 3. The JHK composite image of Sharpless 269 star forming complex (IRAS 06117+1350).

Himalayan Chandra Telescope at Hanle. A typical image using the Near Infrared Camera on HCT is displayed in Fig. 3. This is the $J, H\&K$ image of the Sharpless 269 region (IRAS 06117+1350), showing evidence of subclustering and massive young stellar objects.

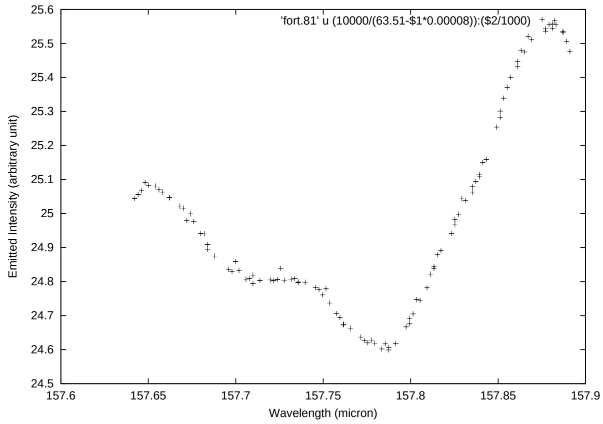

Figure 4. Relative strengths of the [C II] line at 157.7409 μm vis-a-vis atmospheric lines due to O_3 and H_2O for the central $1.'2\times$ $1.'2$ region of RCW 106.

2.2 Far infrared

Far infrared astronomical observations are regularly made using the indigenously built TIFR 100-cm balloon borne telescope (T100) with $\approx 0.5'$ orientation and pointing accuracy (Ghosh et al., 1988). This alongwith a robust image processing scheme allows high resolution (diffraction limited) mapping of Galactic star forming regions in trans-IRAS photometric bands (150 & 210 μm) as well as spectroscopic imaging. The most recent two band photometer used two 3×2 composite Silicon bolometer arrays (FoV $1.'6$ per bolometer) cooled to 0.3 K using a closed cycle ^{3}He dilution refrigerator. The focal plane instrument currently in use is a scanning Fabry Perot Spectrometer (FPS) with spectral resolution $\sim$ 1700, tuned to the astrophysically important fine structure line of [C II] at 158 μm. The FPS can be used in sky chopped or un-chopped (stare) modes, the latter needing the spectral sweep (Fabry Perot scan) to be much faster than the variation in atmospheric emission. The FPS has been used successfully in both these modes. The detection of the [C II] line is very challenging even from balloon altitudes due to the strong atmospheric emission from O_3 and H_2O lines lying spectrally very close. This can be seen from Fig. 4 which shows the relative strength of [C II] line from RCW 106 region (central $1.'2\times$ $1.'2$) vis-a-vis atmospheric emission. The situation would be more difficult from aircraft altitude, e.g. for SOFIA.

2.2.1 *Photometric mapping*

Typical high resolution intensity maps at 150 & 210 μm obtained for the star forming complex associated with IRAS 19181+1349 is presented in Figure 5. Taking advantage of simultaneous observations in the two bands with identical FoVs, reliable spatial dis-

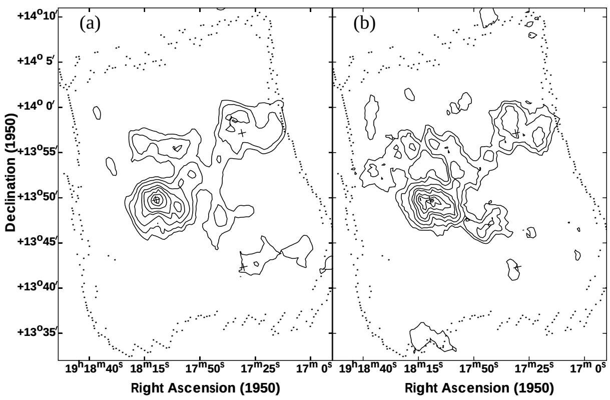

Figure 5. Intensity maps of the region around IRAS 19181+1349 at **(a)** 150 μm and **(b)** 210 μm. The dotted boundary marks the area scanned. Crosses mark the positions of IRAS PSC sources. The contour levels are at 0.90, 0.70, 0.50, 0.30, 0.20, 0.10, 0.05 and 0.025 of the peak intensity. The peak intensities are 723 Jy arcmin^{-2} at 150 μm and 390 Jy arcmin^{-2} at 210 μm.

tribution of interstellar dust temperature and optical depth are generated (Verma et al., 2003).

2.2.2 *Spectroscopic mapping in 158 μm [C II] line*

The Fabry Perot spectrometer alongwith T100 has been used to map a large area ($30' \times 15'$) of the Orion A region using the sky chopped mode (Mookerjea et al., 2003). The use of spectral scanning allows us to obtain maps in the neighbouring continuum also in addition to the 157.7409 μm [C II] line (see Fig. 6). Using the stare (un-chopped) mode, the Photon Dominated Regions (PDRs) associated with the following Galactic star forming complexes have been sucessfully maped in the [C II] line : NGC 2024, RCW 106, RCW 36 and RCW 38.

2.3 Radio

The Giant Metrewave Radio Telescope (GMRT) has been used to map the Galactic star forming regions at 1280, 610 & 325 MHz with angular resolutions of $\sim$ 5", 10" & 15" respectively. These probe the ionised gas component in the associated H II region. The morphology and other geometric details of the radio maps vis-a-vis far infrared maps depicting thermal emission from dust provide insight about these regions. The radio intensity measured for the point-like sources extracted from the 1280 MHz GMRT maps when translated to the stellar spectral types, correlate extremely well with those obtained

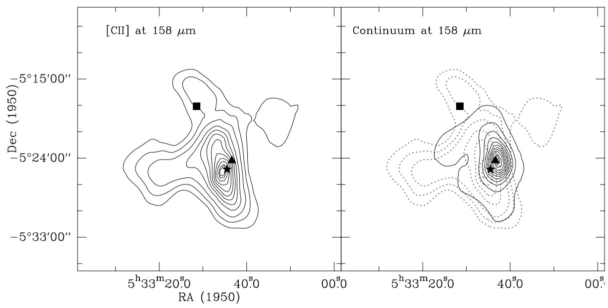

Figure 6. Intensity maps of: *Left* : [C II] at 158μm and *Right* :dust continuum (overlayed with the [C II] map at 158μm contours in dotted lines). Peak of the [C II] intensity map is 3.9×10^{-3} erg s^{-1} cm^{-2} sr^{-1} and that of the continuum is 4.76×10^{-3} erg s^{-1} cm^{-2} sr^{-1}. Marked with the filled triangle is BN/KL, $*$ is θ^1 Ori C and the filled square is M 43.

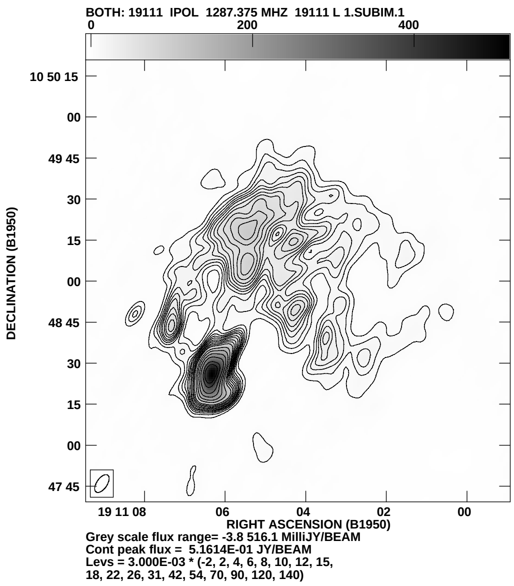

Figure 7. Radio continuum emission at 1280 MHz from IRAS 19111+1048. The beam size is 7.5" $\times$ 3.8" and rms noise level is $\sim$ 0.8 mJy.

from near infrared colours. In order to demonstrate the rich structural details available from the radio maps, in Fig. 7 we present the 1280 MHz map of the star forming region IRAS 19111+1048 (Vig et al., 2005).

2.4 Mid infrared study of Galactic Interstellar Medium

Making use of the recent mid infrared (8–21 μm) survey of the Galactic plane with angular resolution $\sim$ 18" by the Midcourse Space Experiment (MSX; Price et al., 2001), the following results have been obtained : (i) The quantitative success of our scheme modeling the MSX data with emission in the Unidentified Infrared emission Bands (UIBs) alongwith the underlying thermal continuum from the interstellar dust, has been demonstrated by comparison with direct emission in individual UIBs measured by ISOCAM (Ghosh and Ojha, 2002). This scheme promises the potential of the MSX database for the study of large-scale spatial distribution of UIB emission (and the carriers of UIBs) in the entire Galactic plane. (ii) The gross features in the distribution of stars as well as warm (T $>$ 100 K) interstellar dust in the Galactic disk have been investigated and their characteristic angular scales have been quantified. The most favoured values of z_h & R_l for the warm dust have been found to be 80 pc and 2.81 kpc respectively (Vig, Ghosh and Ojha, 2005). The signatures of warp have been detected for the stellar as well as diffuse emission components in all the 4 MSX bands as well as from the DIRBE/COBE data. The amplitude of the warp signature seems to slowly increase with wavelength.

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