



Multi-wavelength study of the Milky Way Galaxy

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Abstract. The inner regions of the Galaxy have remained hidden from view at optical wavelengths due to heavy obscuration by intervening dust clouds. Hence, we do not know the details about how the Milky Way's different components (spiral arms/disc/bulge etc) are related, their formation history etc. One way to know the details is to survey the Galaxy in near and mid-infrared wavelengths (where the obscuring effect of dust is small) and thence to count objects at different distances, classify their stellar population membership and eventually make a map of the Milky Way. Measuring distances in the Milky Way is very difficult due to the extinction along the line of sight. However, the ubiquitous presence of stars such as the giants of the red clump is useful in estimating the distance and the extinction through tracing their presence in the near-infrared colour magnitude diagrams. This thesis has addressed the problem of estimating the extinction, the distance and the stellar populations in various lines of sight. In one direction, polarimetric observations have been carried out to obtain complementary information about the material along the line of sight.

Keywords : Galaxy: general – techniques: photometric – techniques: polarimetric

1. Introduction

The Milky Way Galaxy has been the subject of various surveys in the near and mid-infrared. These surveys attempt to understand the structure of the Milky Way as a galaxy. This thesis (Ganesh 2010) combines data from various surveys to disentangle the extinction and distance ambiguities towards various lines of sight in the inner Galaxy. Chapters in the thesis are summarized in the following sections. Section 2 discusses the interstellar extinction towards the Galactic bulge using data from the

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GLIMPSE-II and 2MASS surveys. The variation in the extinction coefficients in the near-infrared (2MASS bands) are mapped over the entire area observed by the GLIMPSE-II survey. The interstellar extinction (A_V) is mapped for this area using GLIMPSE-II data (mid-infrared CMDs) for the red giants and corresponding theoretical isochrones. Section 3 discusses our deep near-infrared observations of the nuclear bulge of the Milky Way using the Infra Red Survey Facility (IRSF) with the SIRIUS camera at the South African Astronomical Observatory, Sutherland. Stars of the red clump are traced up to and beyond the Galactic centre and their distance and extinction is estimated. Study of the distribution of distance and extinction to these stars provides insight into the structure of the bulge in this line of sight. Section 4 discusses one large ISOGAL field (LN45) in the line of sight tangential to the Scutum-Crux arm (direction of $\ell = 45^\circ$). The red clump stars are used as distance and extinction tracers and the distance and extinction derived for most of the giant population in this field. Section 5 discusses the interstellar extinction and optical polarisation towards a field with relatively low and uniform extinction in the disc of the Galaxy. These observations necessitated an automation of the PRL optical polarimeter and some of the details are presented. The results from the photo-polarimetric observations of stars from the ISOGAL survey of this field are discussed.

2. Interstellar extinction towards the Galactic bulge

The extinction (A_V) is mapped towards the inner bulge with a spatial resolution of 2 *arcmin*, by combining GLIMPSE-II and 2MASS photometry and making use of the latest isochrones (Marigo & Girardi 2007) for evolved stars. The comparison of the A_V map calculated from the IRAC [3.6] and [5.8] bands with the A_V map resulting from the 2MASS J and K_S bands allows us to quantify the interstellar extinction throughout the inner Galactic bulge. A_V is derived using the [3.6] and [5.8] bands for high extinction regions ($A_V > 20$) while for medium and low extinction fields A_V is calculated using 2MASS data. Large values of A_V (up to or beyond $A_V \sim 80$ mag) are found from the GLIMPSE-II data where DENIS (Schultheis et al. 1999) (and 2MASS) only provided lower limits ($A_V \geq 25$). Locations with large number of YSO candidates are also mapped and found to be concentrated near the regions with large A_V . High extinction regions, thus, correspond to regions with very dense ISM similar to that found in dark cloud cores. The availability of the extinction map will be very useful to the community in the study of the stellar populations and to understand individual/peculiar objects or interesting class of objects (such as variable stars) in these regions.

3. A field in the Nuclear Bulge

Distance and extinction have been estimated using red clump locus (RCL) method for over five thousand stars in the direction $\ell = 0, b = 1$, using data from our survey with the SIRIUS camera on the IRSF telescope at the SAAO, Sutherland. From this work,

the extent of the bulge is inferred to be about 4kpc in this line of sight. Interstellar extinction is large in the foreground spiral arm and then there is a drop in the extinction within the bulge, indicating that within the bulge, dust may have been swept away by recent or on-going star forming activity in the nuclear regions.

4. Stellar populations in an ISOGAL field in the Galactic disk

A large ISOGAL field towards the Galactic disc has been studied and a standard mode of studying the large set of ISOGAL observations in conjunction with the other multi-wavelength data on the disc from 2MASS and Spitzer GLIMPSE has been established (Ganesh et al. 2009). The stars of the red clump can be traced along the line of sight using the 2MASS J and K_S data up to the start of the Scutum–Crux arm towards the $\ell = -45^\circ$ direction. The equations describing the locus of the Red Clump in the solar neighbourhood are :

$$J = M_J + 5 \log(d/10) + c_J(d/1000) \quad (1)$$

$$J - K_S = M_J - M_{K_S} + (c_J - c_{K_S})(d/1000) \quad (2)$$

where c_J and c_{K_S} are the average extinction per unit distance in the J and K_S bands. The locally accepted value of the extinction per unit distance, c_J , is sufficient to fit the red clump locus well up to 2.5 kpc in this direction. However, beyond 2.5 kpc, c_J varies with galactic latitude and increases with distance (see left panel of Figure 1). The RCL is used to obtain the distance and extinction towards individual stars assuming them to be red giants and thus following the RGB/AGB isochrone. The distribution of stellar density rises as one hits the spiral arm at 4 kpc. The 2MASS data are not deep enough to detect the stars of the red clump at distances beyond 4 kpc at the lowest galactic latitudes. More luminous AGB stars are seen to greater distances. The $(K_S - [15])_0$ colour provides the mass-loss rates for the AGB stars where [15] refers to 15 μm band magnitude. There are not many AGBs with a high mass-loss rate in this direction. From the mid infrared colour excess a total of 22 YSO candidates are identified in this field. A catalogue of the sources detected by ISOGAL with the estimated extinction and distance is constructed. Also tabulated are the mass-loss rates for several hundred red giants towards this field. This catalogue with distance and extinction determinations provides a good dataset to constrain theoretical models of stellar evolution in the late phases. The catalogue is available publicly from the Vizier database at the CDS url <http://cdsarc.u-strasbg.fr/viz-bin/Cat?J/A%2bA/493/785>.

5. Interstellar extinction and polarisation towards L97 field

To enable the observation of optically faint counterparts of the infrared sources, PRL's optical polarimeter was completely upgraded and automated (Ganesh et al. 2008). Sensitive CCD cameras replaced the eyepieces and microcontrollers were used to implement automation of the parts (filter/aperture etc) traditionally changed by the

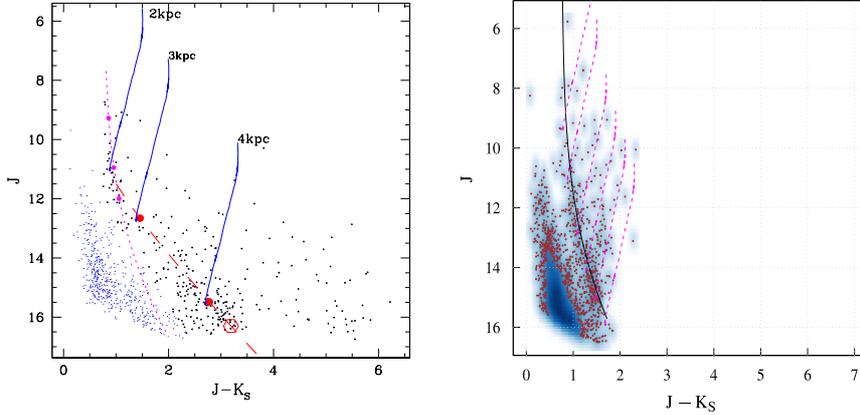


Figure 1. Left panel shows CMD towards the LN45 field (area around $b = 0.0$; from Ganesh et al., 2009). Right panel is CMD towards the L97 field. Figure appears in colour in the electronic version.

observer at the telescope. Optical polarimetric observations were made of stars in ISOGAL L97 field with this instrument on the Mt Abu telescope. The L97 field lies in a direction with uniform extinction. Compared to the inner Galaxy it is a relatively non-crowded field. The interstellar extinction is found to be relatively low and uniform with distance (right panel of Figure 1) over the whole field. The extinction per unit distance towards the $\ell = 97.5$ direction is found to be uniform with distance. A constant value of c_J fits well the observed RC locus in this field. There are not many mass-losing stars in this field. Nearly 65% of the $15\mu\text{m}$ stars have optical counterparts and have been observed for polarisation. They have R band magnitudes ranging from 9.25 to 15.0. Polarisation in the R band goes up to 5%. The position angle is invariant, within the errors, and is parallel to the Galactic plane indicating that the magnetic field is parallel to the plane along this line of sight. There is a linear relation between the observed polarisation and the $R - J$, $J - K_S$ and $K_S - [15]$ colours. The $J - K_S$ colour vs polarisation plot shows the best linear relationship. There is a very small range in the $[7] - [15]$ colour and this colour does not show any systematic relation with the observed polarisation. The degree of optical polarisation exhibited by a star may be a way to disentangle the intrinsic reddening from the interstellar extinction.

Acknowledgements

It is a pleasure to thank Prof U C Joshi, my thesis advisor. I also acknowledge receipt of Marie Curie fellowships during the course of this work. Work at PRL is supported by the Dept. of Space, Govt. of India. I thank my collaborators, colleagues, friends and family for their support.

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