Red Giants in ISOGAL: Tracers of the Evolution of the Galaxy

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Abstract.

The DENIS/ISOGAL near/mid-IR survey of the Milky Way for the first time probes stellar populations in the innermost obscured regions of our galaxy. Ages, metallicities and extinction-corrected luminosities are derived for these stars individually by isochrone fitting to the preliminary IR photometry. A few hundred AGB stars with thick circumstellar dust envelopes are identified. An old metal-rich population dominates in the inner galactic Bulge, but there are indications for the presence of a younger population. The inner Bulge has a tri-axial shape, as traced by depth effects on the observed luminosity distributions.

1. Introduction

Attempts to understand the evolution of galaxies by studies of their stellar populations as a function of redshift are limited by sensitivity and angular resolution. Our nearest galaxy, the Milky Way, has the potential to provide many important clues on the evolution of galaxies: ages and metallicities may be measured for individual stars, and the spatial and kinematic distributions of the different stellar populations may be observed. Astrophysical problems such as the evolution and mass loss of Asymptotic Giant Branch (AGB) stars, which are relevant for the (chemical) evolution of galaxies, may be addressed. For the innermost parts of the Milky Way, however, where most stellar light and mass are and where most activity is happening, this has not yet been the case. Due to the location of the Sun in the galactic Plane, our view of the central few hundred pc of the galactic Bulge and the inner few kpc of the galactic Disk is obscured by tens of magnitudes extinction at visual wavelengths.

Recent near- and mid-IR surveys of the Milky Way, both from the ground (DENIS, 2MASS, TMGS) and from space (ISOGAL, MSX), for the first time probe large numbers of stars located deep within the obscured regions of our Galaxy (Fig. 1). The preliminary catalogue of IR point sources from the DENIS/ISOGAL 0.8–15 µm survey (Omont et al. 1999; see also the contributions of Omont et al. and Blommaert et al. to these proceedings) is used here to derive the ages, metallicities, luminosities and extinction for \( \sim 3 \times 10^4 \) individual stars in the inner galactic Bulge, and the implications for the structure and evolution of the galactic Bulge (cf. Wyse et al. 1997) are discussed.
2. Data and methods

The ISOGAL 7 and 15 µm images are typically 20' × 20', at pixel scales of 3'' or 6''. Different filters were used: LW2, LW5 and LW6 at 7 µm, and LW3 and LW9 at 15 µm. All photometry has been transformed to the LW5 and LW9 filters (that best sample the continuum) by applying small offsets. The fields cover regions along the galactic Plane, as well as fields at higher latitude including the Large Magellanic Cloud. The Milky Way is especially well-sampled for −10° < l_II < +10° and −2° < b_II < +2°, which is the region studied here (Fig. 2). Preliminary mid-IR photometry for point sources is complemented by DENIS I,J and K_s-band photometry.

An example of an IR colour-magnitude diagram for two fields is given in Fig. 3, together with an isochrone for a 10 Gyr old population of solar metallicity (Bertelli et al. 1994). The red colours of the stars are predominantly due to severe interstellar extinction. The age, metallicity and extinction (adopting Mathis 1990) are derived for each individual star by comparing its location with respect to isochrones (Bertelli et al. 1994) in various IR colour-magnitude diagrams, after proper computation of bolometric corrections from a combination of Kurucz (1993) and MARCS II (Fluks et al. 1994) synthetic spectra. For stars without sufficient photometry to solve for all three variables, the extinction is assigned as derived for neighbouring stars. The luminosity and effective temperature are obtained as well. All stars are assumed to be located at the distance of the galactic Centre, for which 8 kpc is adopted.
Figure 2. Galactic map of the ISOGAL fields studied here.

Figure 3. The \([7]\) versus \((K-[7])\) diagram of the stellar populations in two fields in the inner Galaxy that suffer from different amounts of (severe) extinction. An isochrone for a 10 Gyr population of solar metallicity is plotted for illustration.
3. Interstellar extinction

Derived extinction ranges from $A_V \sim 0$ in some areas at $b_\Pi > 3^\circ$ to $A_V > 30$ mag in the galactic Plane at $|l_\Pi| \lesssim 1^\circ$ (Fig. 4). The extinction map of the inner galactic Plane and Bulge based on DENIS photometry alone (Schultheis et al. 1999), although unsurpassed in its spatial detail and depth, cannot quantify extinction of $A_V \gtrsim 20$ mag, which comprises half our sample of stars. The apparent bimodality of the extinction distribution suggests at least two major extinction components exist in the inner Galaxy. The stars without sufficient photometry are predominantly found in regions of high extinction, as can be seen in the distribution of the assigned extinction values.

4. Stellar populations

As a first result, the luminosity distribution of the stars is plotted in Fig. 5. The Asymptotic Giant Branch (AGB) is detected even in the obscured galactic core region. In most regions the Red Giant Branch (RGB) is detected down to a few
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Figure 5. Luminosity distribution derived from the comparison of IR photometry and isochrones. All of the AGB, and a significant portion of the RGB are detected.

$10^2 \, L_\odot$. The derived effective temperatures are generally $T_{\text{eff}} \sim 2500$ to 4000 K, confirming the red giant nature of most of the stars. A few hundred bright mid-IR sources have been identified that are interpreted as mass-losing AGB stars, some of which are associated with OH maser emission (see also Omont et al. 1999; Glass et al. 1999; Ortiz et al. 2000). The AGB stars thus make an excellent sample for the study of the evolution and mass-loss of intermediate-mass populations, whilst the RGB stars are ideally suited for the study of the early evolution and chemical enrichment of the inner Galaxy.

5. Ages and metallicities

The metallicity distribution covers the wide range of $[M/H] \in [-1.7, 0.4]$. Although solar and super-solar metallicity stars amongst these are more common, many of the stars have metallicities that are not much higher than of stars in the galactic Halo. There is only a very marginal indication for a negative metallicity gradient over the inner $\sim 400$ pc from the galactic Centre, suggesting that the inner galactic Bulge is rather — but not entirely — homogeneous.
Figure 6. Ages of inner Bulge stars derived from the comparison of IR photometry and isochrones. Three populations are present: old ($t \gtrsim 10$ Gyr), intermediate ($t \sim 1$ Gyr) and young ($t \lesssim 100$ Myr).

The dominant population of the inner Bulge is old, $t \gtrsim 10$ Gyr, but there are indications for the presence of a significant intermediate-age population, $t \sim 1$ Gyr, and possibly an even younger population of $t \lesssim 100$ Myr too. The age distribution is fairly uniform over the inner Bulge, although the average age of the youngest component may slightly increase outwards of the galactic Plane (traced up to $z = \pm 400$ pc). Hence there is no strong signature of an inner Disk component distinct from the inner Bulge.

This would suggest that in the galactic Bulge star formation did not switch off completely after the first generations of stars were born and that we now see as the old, metal-rich population. Instead, the intermediate-age population of AGB stars would imply on-going star formation over most of the galactic history, while the young population might represent a recent epoch of enhanced star formation, possibly due to a minor merger event.

The derived ages should be taken with caution, though, until the final ISOGAL photometry is analysed, and the results can be confirmed when spectroscopic information is taken into account.
6. Three-dimensional structure of the inner galactic Bulge

The extinction-corrected luminosity function shows a clear asymmetry in the galactic Plane at either side of the galactic Centre: it is brighter at $l_{\Pi} \sim -6^\circ$ than at $l_{\Pi} \sim +6^\circ$ (Fig. 6). This can be understood in terms of differential depth effects, if the inner Bulge has a tri-axial shape on a radial scale of $R \sim 1.4$ kpc under an angle $i \sim 53^\circ$, with the near side at negative galactic longitude. This geometry is much alike that proposed for the larger scale Bar, which is, however, rather a disk phenomenon. Within the inner $|l_{\Pi}| < 2^\circ$ there is a hint of an asymmetry in the opposite sense. If confirmed, this would make the Bulge resemble a spiral pattern instead. The structure of the inner few kpc of the Galaxy thus seems to be highly complex. The analysis presented here gives a preview of what future deep IR surveys may do in terms of mapping the Milky Way in three dimensions. The results should be combined with kinematic data to construct a complete and coherent picture of what the inner Milky Way really looks like, before any firm conclusions can be drawn.
7. Future prospects

The definitive results of the analysis presented here will make use of the final ISOGAL photometric catalogue, which is envisaged to be completed in Autumn 2000. Good quality spectroscopic data in the 0.6–2.3 \( \mu \)m range have been obtained for > 200 mass-losing AGB stars and other heavily obscured IR objects in the innermost regions of the Galaxy. A deep near-IR survey with the Cambridge IR Survey Instrument has just started at Las Campanas Observatory, and will detect many more Bulge stars than with DENIS, including stars as faint as the red clump. These new data will improve greatly our understanding of the nature of the stellar populations, and better constrain their metallicities and ages. The resulting view on the structure and evolution of the inner parts of our own Milky Way galaxy may then serve as an important template for the study of the structure and evolution of more distant galaxies and the Universe as a whole.

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