TCS-CAIN: NIR SPECTROSPHOTOMETRIC SURVEY OF THE INNER MILKY WAY

C. González-Fernández[1], A. Cabrera-Lavers[2], P. L. Hammersley[3], and F. Garzón[4]

[1]Instituto de Astrofísica de Canarias
[2]GTC Project Office
[3]Instituto de Astrofísica de Canarias
[4]Instituto de Astrofísica de Canarias

ABSTRACT

We present TCS-CAIN, a NIR survey of the Galactic plane, recently made public at the Instituto de Astrofísica de Canarias, and some results derived from it: with star counts derived directly from it the structure of the inner the Milky Way can be dissected, and with low resolution spectra, (part of a follow-up program), its nature, specifically the metallicity distribution in the inner 4 kpc of the Galaxy, further understood.

Key words: Virtual Observatory; Stars: abundances; Galaxy: abundances; Galaxy: structure; Galaxy: bulge.

1. INTRODUCTION

There is now a substantial consensus on the presence of a bar in the inner Galaxy. It was suggested for the first time by de Vaucouleurs (1964) and first evidences were derived from the asymmetries in the infrared (IR) light distribution (e.g., Blitz& Spergel 1991; Dwek et al. 1995) and in the source counts (Weinberg 1992; Hammersley et al. 1994; Stanek et al. 1994), that show a strong increase towards positive longitudes in the Galactic Plane (GP). However, the exact nature and parameters of this structure are still controversial. While some authors refer to a small size bar with a moderated position angle of 15-30 degrees respect to the Sun - Galactic Centre direction (Dwek et al. 1995; Stanek et al. 1997; Binney et al. 1997 and others), other researchers point to a larger bar with a half length of 4 kpc and a position angle around 45 degrees (Hammersley et al. 2000, Benjamin et al. 2005).

To address these issues and gain further understanding of the structure of the Milky Way, TCS-CAIN was born.

2. TCS-CAIN: PHOTOMETRIC SURVEY

TCS-CAIN is a deep multicolour NIR survey. Since the TCS (located at Tenerife, Spain) has a 1.5 m diameter mirror, and large exposure times were chosen, it reaches deeper magnitudes than 2MASS or DENIS, and is less affected by source confusion. The pointings of the survey have been chosen to sample well enough the $0^\circ <$l$< 35^\circ$ strip, were bigger diameter and longer times are more useful. This choice ensures enough coverage of the disk both in l and b, allowing us the study of phenomena such as the warp or the flare.

The body of the catalogue comprises about 500 fields, 4.25’x4.25’ each, obtained using JHKs photometry in the TCS Telescope, and yielding 10 million source points, with limiting magnitudes of 17 (J), 16.5 (H) and 15.2 (Ks), and a photometric accuracy of 0.1 mag (against 2MASS data). The spatial resolution is 1”, with astrometric errors of 0.15” on the position of point sources.

At some selected fields where interstellar extinction or source confusion are specially severe, such at l=24°, a follow-up program using NOT telescope (2.6m, La Palma, Spain) has been carried on, yielding deeper exposures that can overcome these effects.

2.1. Results: Inner structure of the MW

Hammersley et al.(2000) used data obtained from TCS-CAIN to isolate giants in a Colour-Magnitude Diagram (CMD). Analysing star counts along several Lines Of Sights (LOS), they spotted an over-density from l=27° to l=5° at different magnitudes. Assuming an extinction law, the magnitude of this over-densities can be translated into distances along the different LOS. They yield an elongated feature that runs from l=5° to l=27°, with a position angle of $43^\circ\pm7^\circ$ and a half-length of 4kpc, which was interpreted as a bar.

This structure can be further traced making use of the red

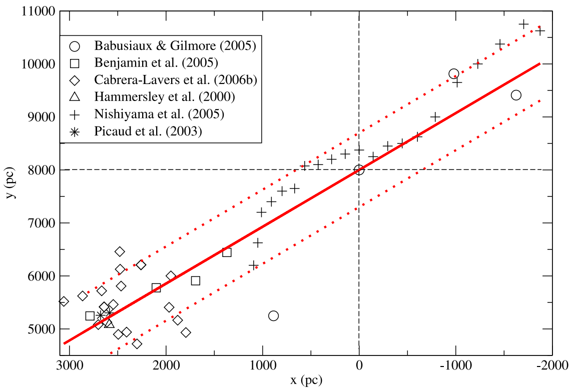

Figure 1. Distance estimations for the red clump giants. Data are taken from Nishiyama et al. (2005), Babusiaux & Gilmore (2005), Benjamin et al. (2005), Picaud et al. (2003), López-Corredoira et al. (2007) and Hammersley et al. (2000). A feature with an angle of 43° and a width of 1 kpc is marked.

clump stars. Since their luminosity function is rather narrow, they present a well defined clump in a CMD. Using this, it is possible to extract star densities and interstellar extinction isolating this clump on a CMD (see López-Corredoira et al. (2002) for details).

We can obtain a magnitude estimate for the red clump stars fitting a second order polynomial plus a Gaussian function to the dereddened magnitude histogram of the selected stars, being the estimate given by the peak value of the Gaussian component. Since with TCS-CAIN we have a good coverage of the inner parts of the Milky Way, we can apply this analysis to several fields along various lines of sight, and compare them with similar studies, as shown in Fig. 1. Clear traces of a long structure appear along the plane, reaching almost l=30° and with an angle of 43°±3°, in agreement with that proposed by Hammersley et al. (2000).

As it can be seen in Fig. 1 there seems to be an elongated structure that touches the disk around l=27°, rather than a short-scale bar. Since this feature is constrained by the Galactic plane (with a scale height of around 150 pc), it cannot be responsible by itself for the observed star counts at $|b| > 0°$. While the effect of this long thin bar is more evident at larger longitudes (15°<l<27°), the effect of the bulge in the red clump counts is predominant at higher latitudes and smaller longitudes ($l < 15°$), thus there are two very different large-scale triaxial structures coexisting in the inner Galaxy (see Cabrera-Lavers et al. 2007 for a more detailed discussion of these issues).

3. TCS-CAIN: SPECTROSCOPIC SURVEY

Spectral analysis of selected sources around this overdensity would yield evidence in favour of one of the two possible configurations of the central part of the Galaxy. Either the disc by itself is responsible for the majority of the observed counts, except for those on the bulge, or there is another structural component that also contributes to the stellar content. The majority of these objects lie very close to the Galactic Plane (GP), and the high value of extinction means that they cannot be observed at visible wavelengths, calling for NIR observations. In the H and K bands, there are a series of molecular lines, OH, H_2O and CO (or more complex carbon molecules in carbon stars) as well as a number of metal lines: Si, Na, Ca, Fe, etc. (see Ramírez et al. 1997). The relative strength of these lines will allow the spectral type to be accurately determined, as well as other physical information, such as the metallicity (Ramírez et al. 1997; Frogel et al. 2001; Schultheis et al. 2003).

As a first step of this follow-up, we have carried two observing runs on the TNG (Telescopio Nazionale Galileo, 3.7m, La Palma), comprising 5 nights of observing time. We obtained ∼100 spectra, over the HK domain ($1.4\mu m < \lambda < 2.4\mu m$), with R=500. This follow-up will evolve into an observational program to be carried with EMIR, the infrared multiobject spectrograph of GTC (10m, La Palma), which will yield ∼1000 spectra of sources selected in a similar fashion as described in 3.1.

3.1. Selection criteria

The sources were chosen according to their locations in the NIR CMD, allowing us to know roughly which Galactic component they belong to. However, in many aspects these diagrams are only partly calibrated; currently we can only be certain of the position of a few spectral types (e.g. the K2III) and even then there are problems. For the more extreme IR sources (as late M giants and carbon stars) their luminosity function is not well known, yet these are the sources that dominate the brighter IR magnitudes. By analysing the spectra of these sources it should be possible to determine which spectral type they have and hence if their position on the CMD is due to extinction or to their intrinsically red colour.

NIR CMDs are obtained from the TCS-CAIN catalogue, and the selected stars are always brighter than K=10.5, so there are no completeness biases in this analysis.

3.2. Spectral analysis

In the K band wavelength range, three are the most prominent features; CaI, NaI and the CO(2,0) bandhead. According to definitions from Frogel et al. (2001), it is possible to obtain the equivalent widths of these features and from them information about the spectral class, temperature (and hence spectral type) and metallicity of the sources.

According to Ramirez et al.(1997) it is possible to define a quantity lg as:

$$lg = \log\left(\frac{EW(CO)}{EW(Na) + EW(Ca)}\right) \qquad (1)$$

This factor has the quality of discriminating between giant and dwarf stars, and between them only. As long as $0.3 \leq lg \leq 0.7$ we are sure to be dealing with giant stars, so applying this filter to our sample we can get rid of reddened dwarfs that passed as giants on the CMD (see Fig. 2).

A relation between the three features and the metallicity can also be established for giant stars (Frogel et al. 2001):

$$\begin{aligned}[Fe/H] = -1.811 + 0.389 \cdot EW(Na) - 0.047 \cdot EW(Na)^2 \\ -0.030 \cdot EW(Ca) + 0.024 \cdot EW(Ca)^2 \\ +0.043 \cdot EW(CO) - 0.001 \cdot EW(CO)^2\end{aligned} \quad (2)$$

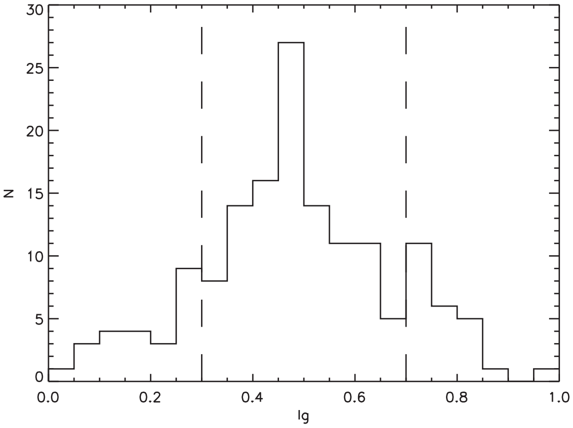

Figure 2. Distribution of lg for our sample of stars. Dashed lines show the limits for the location of the M giants according to Ramirez et al. (1997).

3.3. Results: Metallicity gradient of the inner Milky Way

As can be seen on Fig. 4, at l=7° the metallicities are clearly concentrated around a mean of [Fe/H]=-0.25, well in concordance with previous metallicity estimations for the Galactic bulge (such as Molla et al. 2000, or Schultheis et al. 2003). As one moves towards greater values of Galactic longitude, the mean metallicity becomes smaller, whilst the spread of the successive distributions is clearly greater than at l=7°. It also seems to diminish towards the outer regions, although due to the small size of the samples is hard to tell weather this is a real effect or just a statistical artifact (see Figs. 3 and 4).

This monotone variation of the metallicity with Galactic longitude suggest the existence of a structure spanning from l>7° up until l=27°, at least. If we assume this structure to be a bar, we can infer that the angle it forms with the Galactic Centre-Sun line must be far greater than 20°, since such a small angle would yield the l=26°, 27° sources well within the inner disk. If we adopt an angle of 45°, as proposed by Hammersley et al. (2000), we can translate the longitudes into distances, as shown in Fig. 5.

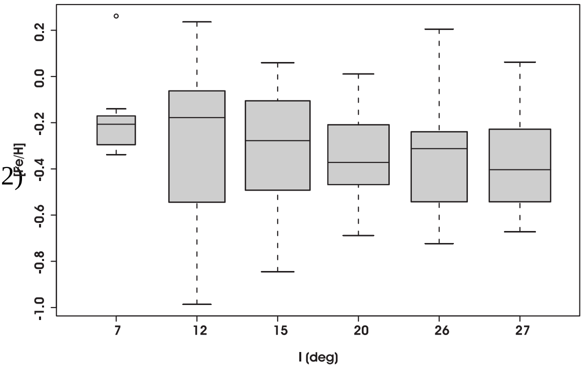

Figure 3. Boxplot of the final metallicity distribution over the different Galactic longitudes. In a box plot each box's sides represent the first and third quartiles, its width varies proportionally to the number of sources within the considered longitude, the central line marks the median and the whiskers account for the maximum and minimum, in absence of outliers.

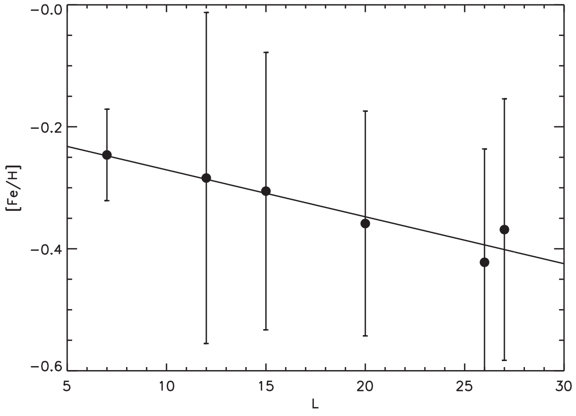

Figure 4. Mean metallicity at each Galactic longitude. Error bars denote the 95% confidence intervals.

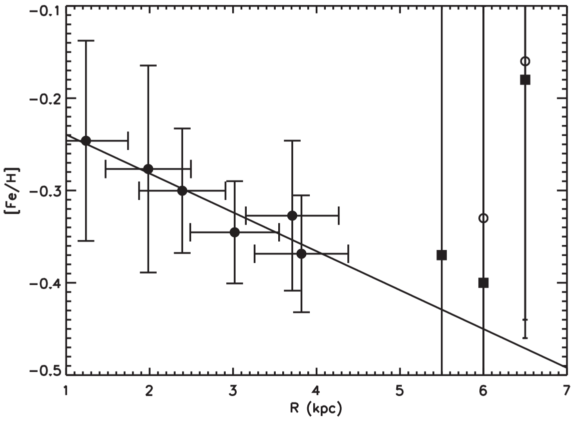

Figure 5. Variation of the mean metallicity with galactocentric distance, assuming an angle for the bar of 45° *with the line Sun-Galactic Centre. For our data, plotted with filled circles, the horizontal error bars denote the width of a 1 kpc bar. The filled squares are data from the Geneva-Copenhagen survey (Nordström et al. 2004) and the open circles data from Rocha-Pinto et al. 2006. The solid line represents the best linear fit to our data, with a -0.04 dex·kpc*$^{-1}$ *slope. Error bars denote the 95% confidence intervals.*

This could be in concordance with results from dynamical simulations, such as Skokos, Patsis & Athanassoula (2002). The authors suggest that the orbital backbone of bars is the 'x1' family of orbits, whose geometry and dynamics could allow for a mixture of the sources from the inner parts of the bar, dominated by bulge sources, with those of the more outer regions. To test this hypothesis, further analysis is required, such as oxygen abundance determination over higher resolution spectra. The [O/Fe] variation with [Fe/H] is different for bulge and disk (both thick and thin disk) sources, due to the different timescales of the star formation in each of the structures (see Cunha & Smith 2006). Since the long bar is primarily a flat structure, with a scale height of $\sim$100 pc (Cabrera-Lavers et al. 2007), its chemical composition should not be very different from that of the thin disk. Thus, oxygen abundances would help tagging the birthplace of the stars in our sample, allowing us to determine the level of mixing over different regions of the bar.

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