Distribution of early type stars in the galactic anticenter direction

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Abstract

Does the Milky Way have two or four spiral arms? Whereas classical HII region maps suggest a 4-armed spiral structure, COBE/DIRBE K-band indicates a 2-armed pattern. New Spitzer/IRAC results suggest that the Galaxy has two massive/principal stellar/gas arms plus some optically visible gas arms. We propose to resolve this issue by mapping the space density of young stars in the anti-center direction using uvbyHβ photometry to derive accurate distances and ages. A first photometric study of two 2 square degrees in the anti-center direction was carried out with the Wide Field Camera at the Isaac Newton Telescope. We present preliminary results on the stellar population, the distribution of early-type stars as a function of the distance and interstellar reddening in this direction. Our preliminary analysis of 10% of our data shows first indications of density enhancements around 3kpc. That result is not yet significantly statistic, and must be verified with the remaining data.

Does the Milky Way have two or four spiral arms? State of the art

The number of spiral arms in our Galaxy is not fully established. Whereas maps of OB-associations and HII regions (see e.g. Vallée 2005) and the galactic distribution of free electrons (Taylor et al. 1993) show a 4-armed pattern, COBE K-band data (Drimmel 2000) suggest that only two major arms are present in the Galaxy. External galaxies often show a two-armed structure in near-infrared while they may be multi-armed in blue colors (Grosbøl et al. 2004). The spiral model of our Milky Way obtained with the new Spitzer/IRAC infrared data in the galactic center direction (Benjamin, 2008) is in agreement with this extragalactic scenario. Benjamin (2008) proposes that the Milky Way has two major spiral arms (Scutum-Centaurus and Perseus) with the greatest stellar densities and two minor arms (Sagittarius and Norma) filled with gas and pockets of young stars. In the same direction, theoretical models (Martos et al., 2004) demonstrate that it is possible to reproduce these arms of compressed gas without the increase of the stellar surface density. Present project aims to confirm or refuse this up-to-day cartographic model.

Aims & Working plan

Two approaches are proposed here to map the spiral arms in the anti-center direction:

1) To trace the radial space density of young stars up to 5-7 kpc. That will give us a strong, independent determination of the locations of major spiral arms outside the solar radius,
2) To measure stellar radial velocities of the selected stars (towards this direction the influence of galactic rotation is minimal). Systematic radial velocities perturbation along the galactic radius in the range of 5-15 km/s are expected (Melnik et al., 2008). This will enable us to estimate the actual strength of the spiral potential.

We have followed the BGM predictions (see Fig.1) to define the uvbyβ photometric survey needed to get enough statistics to trace the stellar space density up to the Cygnus spiral arm. Our working plan is:

1) A first large 8□º survey complete up to V=15. With this we want to check the presence and position of the Perseus arm.
2) A second deep survey of 4 □º complete up to V=17 -18 to determine if the Cygnus arm is also a major arm.

This survey area is mandatory to ensure the detection of a peak-to-peak variation of 10-20% at the 3-4 sigma level.

Star Counts predictions from the BGM

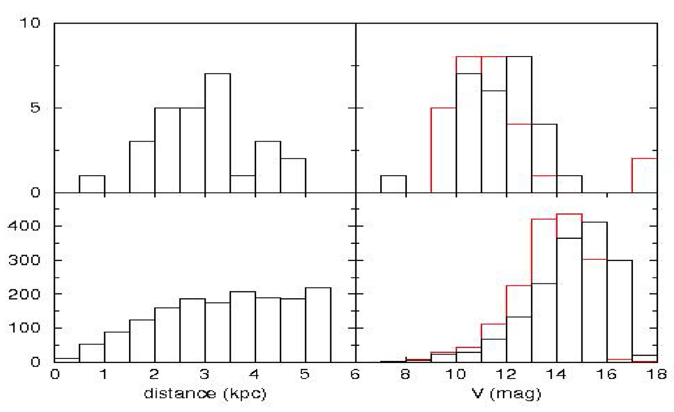


Fig.1 Besançon Galaxy Model predictions (Robin et al. 2003): Number of stars as a function of heliocentric distances and apparent V magnitudes in a solid angle of four square degrees in the region l=[178,182], b=[-0.5,0.5]. Top: O-B3, bottom: B4-A3 type stars. In black, absorption of 0.7mag/kpc; in red, 0.3mag/kpc. Note that in both figures, a 14 kpc disk cut-off is imposed and no spiral arms over-densities are considered in the BGM predictions (Sun galactocentric distance at 8.5 kpc;).

Mapping the space density using uvbyβ photometry: WFC/INT data

Observational Program:

Observations are being performed at La Palma with the Wide Filed Camera at the 2.5m INT. To cover the 8sqd field, and taking into account an overlap between the fields, 48 fields must be observed (see Fig.3). Twelve of these fields were observed during 2009A period with SNR=400 at V=16. Data is still being reduced. Here we present the preliminary results for the central 0.20 square degrees.

Photometric accuracy requirements:

For the final program, we require errors ~0.01-0.02 mag in the indices [u-b], [c1], [m1] and β to determine distances and ages to within 10%. This translates into a SNR=400 for the individual filters.

The Cygnus arm and a disk truncation are expected at 6-7 kpc. Thus, for our deep survey a 10% distance error would be acceptable to locate them to better than 1 kpc, i.e. σ(Mv)=0.23.

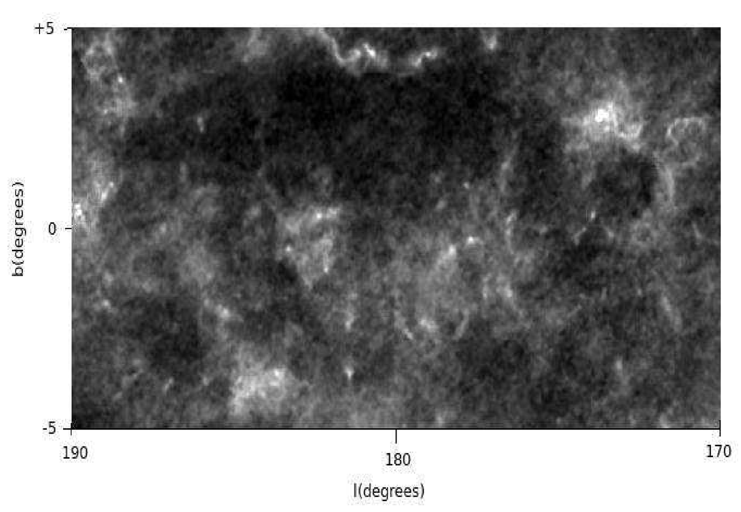


Fig.2 Absorption map of the anti-center direction from Froebrich et al. 2007. Considering absorption and the galactic warp, the center of the observing field has been fixed to (l,b)=(180:41,-0:14) deg. (see Fig. 3).

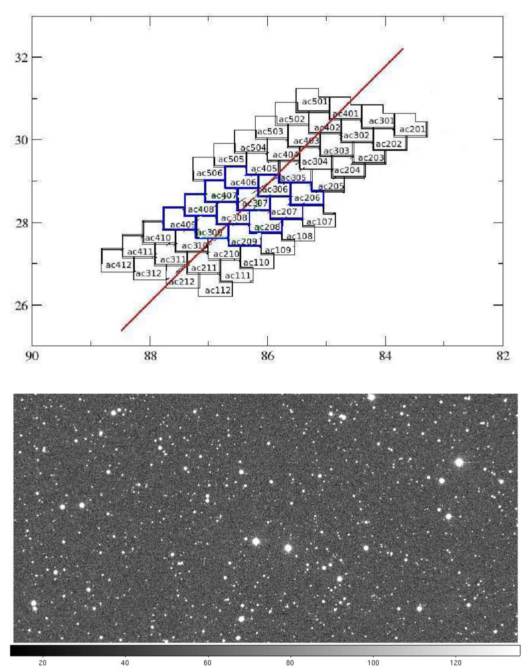
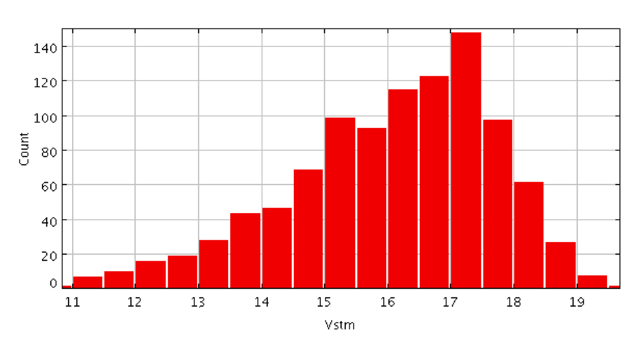


Fig.3 Upper: Scheme of the 48 WFC pointings covering the 8□º around (l,b)=(180:41,-0:14). In blue, fields observed in the 2009A run. Red line is b=-0.5. Bottom: example image of Chip4 WFC for the AC309 area in Hβwide filter.

Calibration field and reduction process:

Calibration has been performed using the open cluster NGC1893 (well measured Strömgren photometry from Marco et al. (2001) and Tapia et al. (1991)).

Instrumental magnitudes were obtained from a PSF fitting using the DaoPhot packages from IRAF. The Moffat25 PSF function, with second order variations through the FoV, was found to provide the best derivation of the total magnitudes both for bright and faint stars. Mean magnitudes and colors have been derived from the three exposures taken for each of our anti-center fields.



Limiting magnitude:

Fig. 5 Histogram of V standard magnitudes for all the stars of our 0.2□º sample. We can see that we reach a limiting magnitude close to V=17.

Young star selection and accurate derivation of distance and extinction

Target selection:

It is likely that our galaxy has a relative weak perturbation (i.e. ~10% variation of the disk density). Then, accurate distances are critical to detect over-densities by statistical means. It is well known that peaks in the space density of very young OB-stars would mark current star formation while an older populations, e.g. late B- or early A-stars, are expected to show a density variation due to the presence of a density wave. These young stars are brighter, so we can reach longer distances. In addition, they have lower peculiar velocity, so the effects of the arm perturbation are easier to be detected. Strömgren uvbyβ photometry is the natural system to identify this population yielding accurate estimates of individual distances and ages.

The uvbyβ photometry has been used to perform accurate two-dimensional classification and to derive accurate distances and ages. The processes described in Figueras et al. (1991) and Masana (1994) have been used. The [m1]-[c1] diagram in our 0.2 square degree field is presented in Fig. 4. Around 85 stars has been classified as Early Region (O-B9 spectral type). These young stars are the ones most useful for our purposes.

[c1]-[m1] diagram

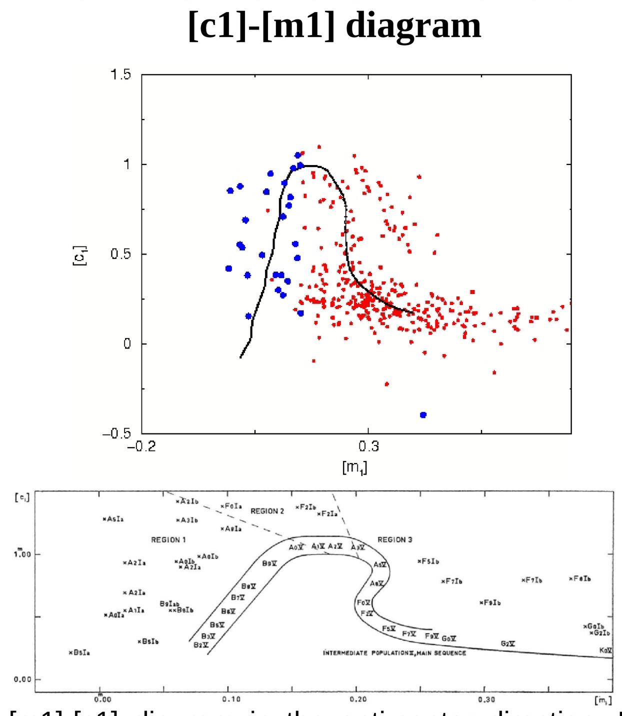


Fig.4 Top) [m1]-[c1] diagram in the anti-center direction. Red points: all stars; superposed blue dots: stars classified as early type (O-B9). Only the stars with errors in [m1] and [c1] lower than 0.05 are plotted. Black line: Crawford's (75,78 and 79) relation for the ZAMS. Bottom) figure [m1]-[c1] Stromgren (1966).

β- [u-b] diagram

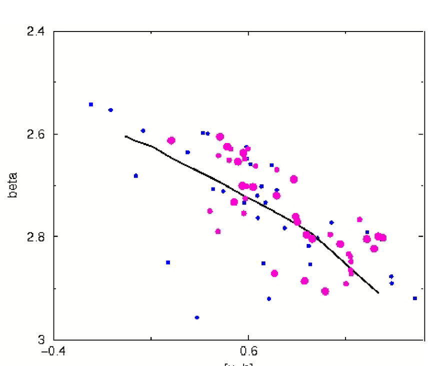


Fig. 5 β-[u-b] diagram. Blue points correspond to the early-type stars. Overploted in magenta we show those stars with error in the β index lower than 0.02 mag. Black line is the ZAMS line from Crawford (1978)

Photometric distances and E(b-y):

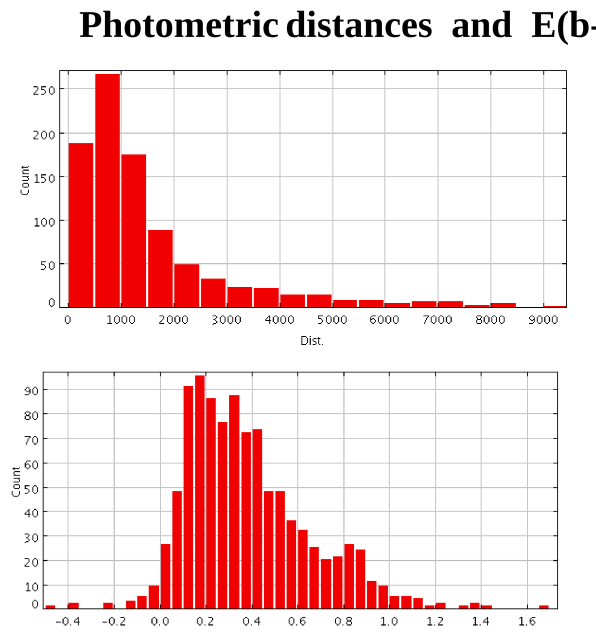


Fig. 6 Number of stars as a function of the distance (top) and color excess E(b-y) for the full sample (998 stars) in the 0.2□º.

The Young stellar Population in the anticenter direction

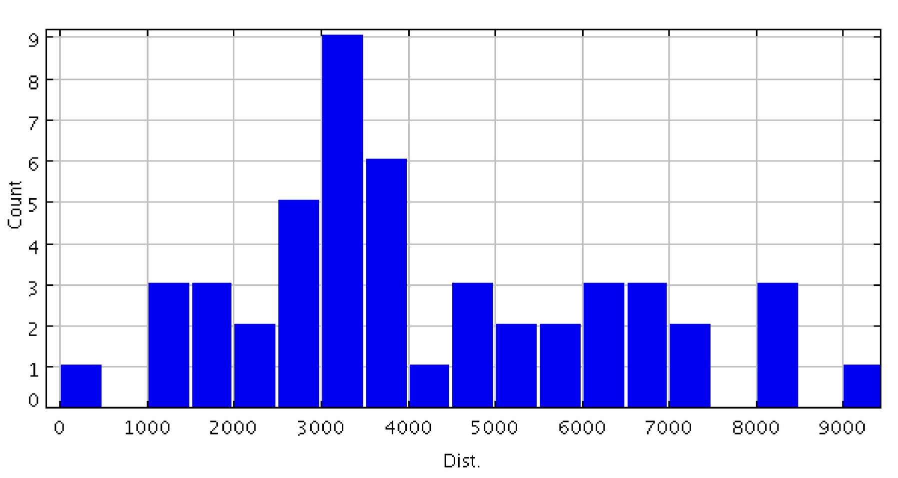


Fig. 7 Distance histogram for O-B9 stars contained in the 0.20□º field.

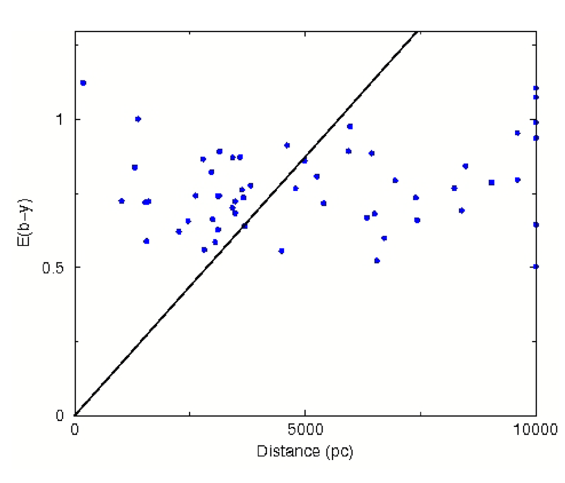


Fig. 8 E(b-y) vs. distance distribution for the O-B9 stars. Black line indicates an absorption of 0.7mag/kpc.

The peak around 3kpc we see in figure 7 is not statistically significant with the amount of analyzed data shown here. Our current full data set is 10 times larger, and once analyzed it will be able to confirm or disconfirm the peak.

In figure 8, we see that our data are not consistent with a constant increase of absorption with distance but rather with a dust screen at 1-2 kpc distance.

The distance to Perseus:

Recently, Reid et al. 2009, from accurate VLBI parallaxes of few stars belonging to star forming regions, has located the Perseus arm at 2 kpc.

Our very preliminary results seem to place an stellar over-density around 3kpc (from Figure 7). This density enhancement could be associated to the Perseus arm, but before reaching a firm conclusion it is mandatory to increase our statistics and to check for possible biases in the photometric calibrations (work in progress).

Conclusions and future work

From our data for 0.20 square degree we have identified a set of around 85 O-B9 type stars in the anti-center direction. Our preliminary results support that the obtained photometric accuracy is enough to detect overdensities around the position expected for the Perseus arm. Two more square degrees are being reduced in order to increase the statistics.
Next steps: 1) Finish the reduction of the 2□º, that will improve the statistics to the present data. 2) Finish the observations for the full 8square degree region 3) Get radial velocities of a subset of these targets to detect the velocity perturbation due to density wave and thereby the amplitude of such wave.

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