TITLE
*ASP Conference Series, Vol. **VOLUME**, **PUBLICATION YEAR***
EDITORS

Near-infrared surveys and the shape of the Galactic Disc

S. Derriere

CDS, Observatoire de Strasbourg, 11, rue de l'Université, Strasbourg, F-67000, France

A.C. Robin

Observatoire de Besançon, BP 1615, F-25010, Besançon cedex, France

Abstract.
We present results from the comparison of selected fields observed in the near-infrared by DENIS with predictions from a modified version of the Besançon synthetic model, taking into account a possibly warped and flaring galactic disc. We find evidence for a warp and flare in the stellar disc. The warp starts approximately at the solar circle, whereas the galactocentric radius for the beginning of the flare depends on the galactic longitude.

1. Introduction

The near-infrared surveys currently under completion (DENIS and 2MASS) will provide 3-colors observations of thousands of square degrees with much fainter magnitudes than that achieved before. The lower extinction at those wavelengths makes these surveys well suited for studying galactic structure. In this paper, we will focus on the study of a warp and flare of the Milky Way disc, using DENIS data.

Warps are quite a common feature in external galaxies (Bosma 1991). Since radio observations allowed to peer into dust clouds, it has been known that the Milky Way itself hosts a warped and flaring disc. Maps of the gas distribution were obtained with 21 cm observations (Burton & te Lintel Hekkert 1986; Burton 1988). The warp and flare in the Galaxy have also been detected in the interstellar dust (Freudenreich et al. 1994), in molecular clouds (May et al. 1997), in IRAS sources (Djorgovski & Sosin 1989), or in the distribution of O–B stars (Miyamoto et al. 1988; Reed 1996; Drimmel et al. 2000).

In order to study the warp in the stellar disc, we used a modified version of the Besançon stellar population synthesis model (Robin & Crézé 1986; Bienaymé et al. 1987; Haywood et al. 1997). We performed comparisons, in selected regions, with DENIS data.

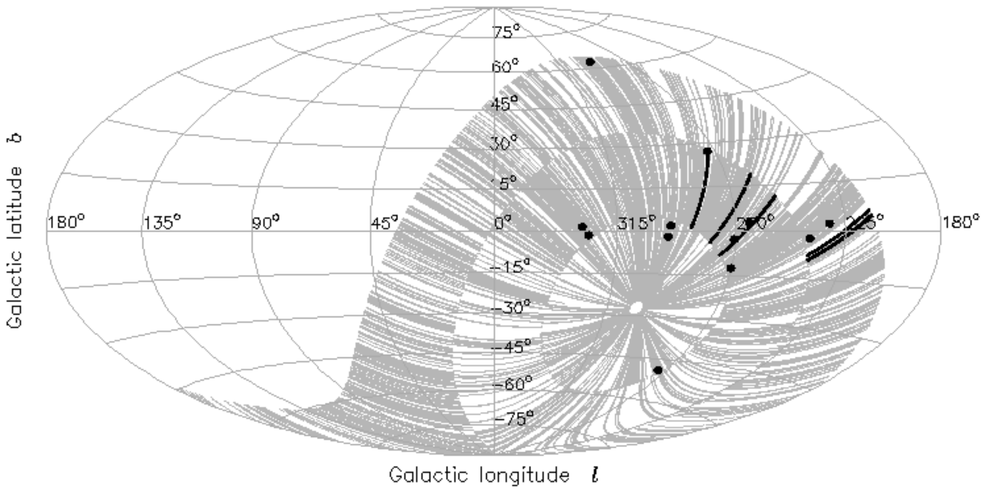

Figure 1. Location of the selected regions with DENIS data. Circles stand for small regions, and lines are DENIS selected strips. Prereduced strips appear as a grey background.

2. Data selection

The DENIS survey (Epchtein 1997) is conducted on a 1 m telescope at La Silla. Observations are made simultaneously in three bands: I, J and K_S (Fouqué et al. 2000). The limiting magnitudes are respectively 18.5, 16.5 and 14.0, with photometric accuracy better than 0.1 mag.

The Paris Data Analysis Center (PDAC) deals with image processing (Borsenberger 1997). We used DENIS data point sources recently extracted at PDAC, with photometric values derived from a PSF fit procedure.

The sun lies within 10° of the warp's line of nodes. This implies that the maximum displacement of the disc below the plane in the south will occur between the 3rd and 4th quadrants.

We have thus selected two kinds of data sets: small regions symmetrically distributed around the plane, and DENIS strips (30°× 12' regions) crossing the plane at various longitudes. These are plotted on Fig. 1. The small regions will be used to constrain global parameters, before using the strips for constraining the warp and the flare.

3. Warping and flaring the disc

We compared these data to a model of stellar population synthesis of the Galaxy, in which we introduced parameters describing a possibly warped and flaring disc.

The Besançon model (Robin & Crézé 1986; Bienaymé et al. 1987; Haywood et al. 1997), taking into account the stellar evolution, the galactic evolution and galactic dynamics, can produce catalogues of stars which are to be compared directly with observations.

We modelled the warp of both the thin and thick discs with a tilted ring model, such as that described in (Porcel et al. 1997). For galactocentric radii $R > R_{\rm warp}$, the mid-disc is shifted perpendicular to the plane by a value

$$z_{\rm warp} = z_c \cos(\theta - \theta_{\rm max}) \; . \tag{1}$$

The warp has its maximum amplitude z_c towards $\theta_{\rm max}$, and this amplitude increases linearly as $z_c = \gamma_{\rm warp}(R - R_{\rm warp})$.

As in Gyuk et al. (1999), we model the flaring of the discs by increasing the scale heights by a factor $k_{\rm flare}$, beyond a galactocentric radius $R_{\rm flare}$, with

$$k_{\rm flare} = 1 + \gamma_{\rm flare}(R - R_{\rm flare}) \; . \tag{2}$$

We must ensure that the surface density remains constant in this process. One must compute a normalization factor f, when increasing the scale height from h_z to $k_{\rm flare} h_z$. For the thick disc, for example, the spatial density is a truncated exponential:

$$\rho = \rho_0 \exp\left(-\frac{R}{h_R}\right) \begin{cases} 1 - \frac{z^2}{2h_z h_c + h_c^2} & \text{for } |z| < h_c \\ \frac{\exp(h_c/h_z)}{1 + h_c/2h_z} \exp\left(-\frac{|z|}{h_z}\right) & \text{for } |z| > h_c. \end{cases} \tag{3}$$

With a flaring disc, ρ is to be corrected by a factor:

$$f = \frac{(2h_z + h_c)(3k_{\rm flare} h_z h_c + 3k_{\rm flare}^2 h_z^2 + h_c^2)}{(2k_{\rm flare} h_z + h_c)(3h_z h_c + 3h_z^2 + h_c^2)} \; . \tag{4}$$

We assumed in the following that the sun exactly lies on the line of nodes ($\theta_{\rm max} = 90°$).

4. Dealing with extinction

The stellar warp can be detected only at low galactic latitudes, where the extinction plays a very important role. The use of near-infrared data benefits from the lower absorption at those wavelengths (Bessel & Brett (1988) give $A_I/A_V = 0.60$, $A_J/A_V = 0.29$, and $A_{K_s}/A_V = 0.11$), but extinction cannot be neglected.

The absorption law in the Besançon model corresponds to material distributed in a disc, with an Einasto (1979) density law of scale length 140 pc and scale length 5000 pc. Absorbing clouds can also be added on the line of sight.

This model is valid for high galactic latitudes. For some of the small selected regions at low latitudes, there are some strong discrepancies between the data and catalogues produced with this simplistic absorption model, suggesting a strongest absorption (see Fig. 2).

We tried to model the absorption along the line of sight for those regions. We compute, on one hand, various observables from the DENIS data ([I-J] or [J-K] histograms, K vs. [J-K] diagram, ...). On the other hand, we have a catalogue from the model with a simple Einasto absorbing disc.

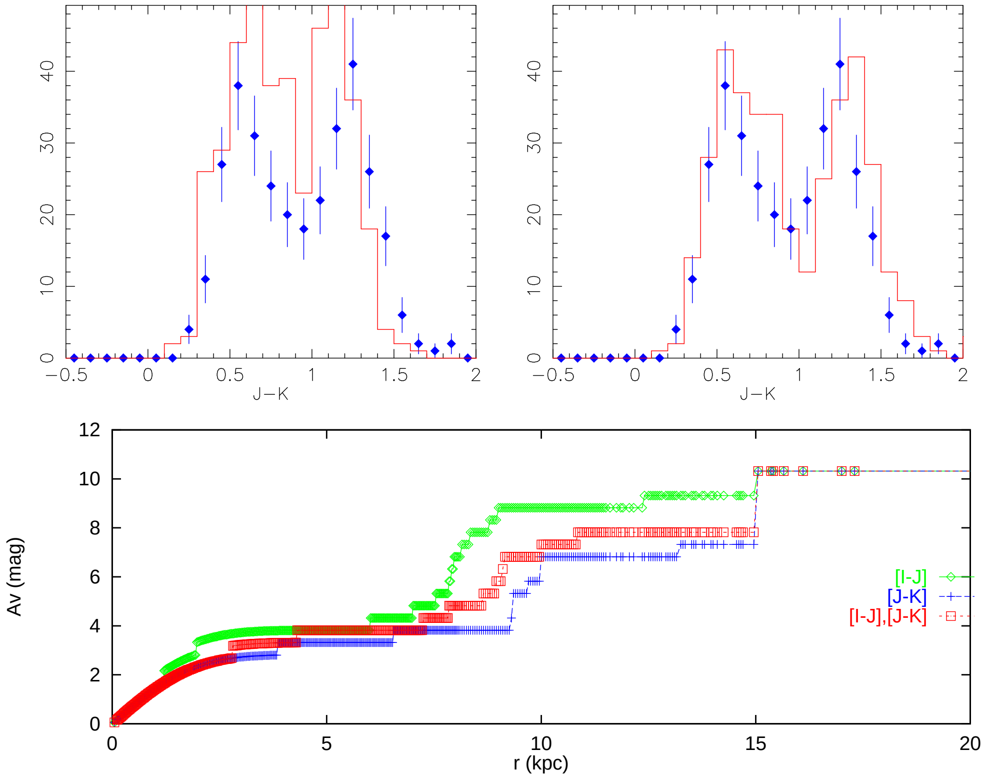

Figure 2. Effect of the extinction towards $l = 264°, b = +2.7°$. The two upper graphs show DENIS [J-K] histogram for sources with $12 < K < 13$ (symbols) , and the model (solid line) before (left) and after (right) adjusting the extinction. The bottom graph displays the absorption distribution fitted for 3 different observables.

We progressively add, in this catalogue, clouds of variable visual absorption at different distances along the line of sight, in order to minimize the χ^2 between the observed histogram and the modelled one. Using clouds of decreasing absorption, this iterative procedure converges, and a new distribution of the absorbing material is found.

In Fig. 2, we applied this method to a field located at $l = 264°$ and $b = +2.7°$. The lower figure represents the reconstructed absorption: there is a steep increase (nearly 4 visual magnitudes) at distances of 7–9 kpc. This is right where we expect to find the Perseus arm (Vallée 1995).

5. Results on galactic structure

Using for the warp and for the flare a distribution similar to that of the gas, we made comparisons on small regions to put constraints on structure parameters (with a fitted absorption when necessary). We find for the thin disc a scale length $h_R = 2.5$ kpc, and a radial cutoff $R_{\mathrm{cut}} = 14$ kpc (Ruphy et al. (1996)

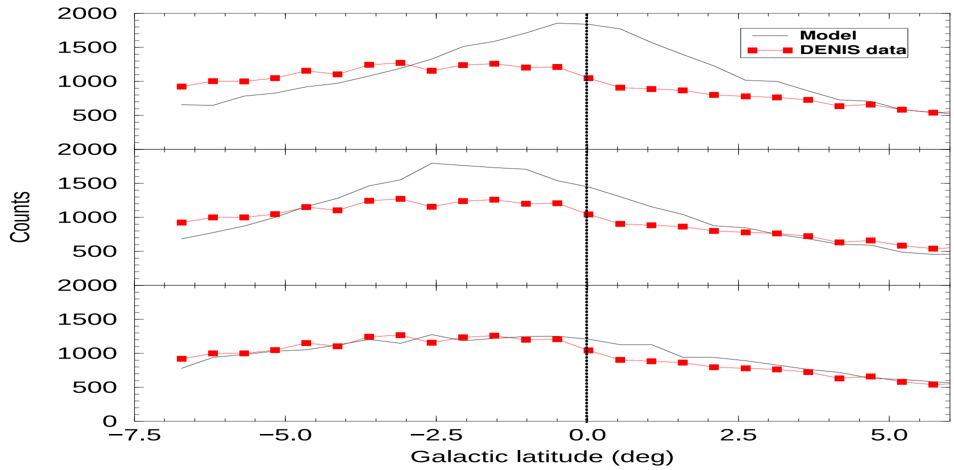

Figure 3. Latitude profile, crossing $b = 0°$ at $l = 266.1°$ (counts in $0.8°$ bins in declination, in the strip). Top panel: flat disc. Middle panel: warped disc. Bottom panel: warped and flaring disc.

found $h_R = 2.3$ kpc and $R_{\rm cut} = 15$ kpc with the first DENIS data). The local normalization of the thick disc is 6%.

For all small regions symmetrically distributed around $b = 0°$, the density of sources is higher at negative latitudes. We have plotted on Fig. 3 the effect of a warp and flare (identical to the gas layer) on a given latitude profile. Introducing a warp shifts the peak of the star counts towards negative latitudes, and the flaring spreads the overall profile.

We have attempted to fit latitude profiles (star counts for bright objects detected in the K band) in the selected strips, with various galactocentric radii for the start of the warp and flare. It becomes impossible to constrain $R_{\rm warp}$ towards $l = 225°$, as the amplitude is very small. The strips around $l = 270°$ favour a warp starting at $R_{\rm warp} = (8400 \pm 200)$ pc, very close to the distance adopted for the Sun ($R_\odot = 8500$ pc).

The starting position for the flare shows a dependance on galactic longitude. We find it to start further towards the anticenter: $R_{\rm flare} = 8800$ pc at $270°$, and $R_{\rm flare} = 10500$ pc at $225°$.

We have assumed here uniform scale lengths for the discs. Any dependance of the scale length on longitude, or deviations from the exponential distribution might contribute to this effect.

6. Conclusions

We have introduced into the Besançon model the possibility to study a warped and flaring disc. Basic star counts and latitude profiles show a strong evidence for a warp and flare in the stellar disc.

This stellar warp is found to start at $R_{\rm warp} = (8400 \pm 200)$ pc, while the flare might depend on longitude ($R_{\rm flare}$ ranging from 8800 to 10500 pc).

Further work on an extended set of zones should allow to tighten the constraints on the structural parameters of the stellar warp and flare.

References

Bessell, M. S. & Brett, J. M. 1988, PASP, 100, 1134

Bienaymé, O., Robin, A. C., & Crézé, M. 1987, A&A, 180, 94

Borsenberger, J. 1997, The Impact of Large Scale Near-IR Sky Surveys, ASSL 230, Kluwer ed., p. 181

Bosma, A. 1991, in Warped Disks and Inclined Rings around Galaxies, Knudsen ed., p. 181

Burton, W. B. 1988, in Galactic and Extragalactic Radio Astronomy, Springer-Verlag, p. 295

Burton, W. B. & te Lintel Hekkert, P. 1986, A&AS, 65, 427

Djorgovski, S. & Sosin, C. 1989, ApJ, 341, L13

Drimmel, R., Smart, R. L., & Lattanzi, M. G. 2000, A&A, 354, 67

Einasto, J. 1979, IAU Symposia, 84, 451

Epchtein, N. 1997, The Impact of Large Scale Near-IR Sky Surveys, p. 15, Springer-Verlag

Fouqué, P., Chevallier, L., Cohen, M., Galliano, E., Loup, C., Alard, C., de Batz, B., Bertin, E., Borsenberger, J., Cioni, M. R., Copet, E., Dennefeld, M., Derriere, S., Deul, E., Duc, P., Egret, D., Epchtein, N., Forveille, T., Garzón, F., Habing, H. J., Hron, J., Kimeswenger, S., Lacombe, F., Le Bertre, T., Mamon, G. A., Omont, A., Paturel, G., Pau, S., Persi, P., Robin, A. C., Rouan, D., Schultheis, M., Simon, G., Tiphène, D., Vauglin, I., & Wagner, S. J. 2000, A&AS, 141, 313

Freudenreich, H. T., Berriman, G. B., Dwek, E., Hauser, M. G., Kelsall, T., Moseley, S. H., Silverberg, R. F., Sodroski, T. J., Toller, G. N., & Weiland, J. L. 1994, ApJ, 429, L69

Gyuk, G., Flynn, C., & Evans, N. W. 1999, ApJ, 521, 190

Haywood, M., Robin, A. C., & Crézé, M. 1997,A&A, 320, 428

May, J., Alvarez, H., & Bronfman, L. 1997, A&A, 327, 325

Miyamoto, M., Yoshizawa, M., & Suzuki, S. 1988, A&A, 194, 107

Porcel, C., Battaner, E., & Jimenez-Vicente, J. 1997, A&A, 322, 103

Reed, B. C. 1996, AJ, 111, 804

Robin, A. C. & Crézé, M. 1986, A&A, 157, 71

Ruphy, S., Robin, A. C., Epchtein, N., Copet, E., Bertin, E., Fouque, P. & Guglielmo, F. 1996, A&A, 313, L21

Vallee, J. P. 1995, ApJ, 454, 119