Tracing the Milky way spiral arms. Now and in the Gaia era

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Abstract

The cartography and dynamics of the spiral structure of the Milky Way is still, nowadays, highly controversial. Different spiral tracers lead to different conclusions about geometric basic parameters such as the strength and number of arms and, more important, we are far from understanding the mechanisms acting to create this kinematic perturbation on the galactic disk.

Two complementary approaches are presented here aiming to shed light on that issue: 1) a photometric and spectroscopic survey in the anticenter direction is ongoing to detect the overdensity and kinematic perturbation of the outer Perseus arm and, 2) detailed simulations are being performed to evaluate the capabilities of the future Gaia database to undertake this study. We show how the preliminary young stars distance distribution obtained from the first 3 sqr photometric survey completed up to now (INT/WFC, La Palma) suggests an overdensity around 1.5-2kpc probably associated with the outer Perseus major arm. Complementary, using actual expectations on the Gaia mission accuracy on astrometric and spectroscopic data, we present a first and very preliminary simulation code to evaluate how Gaia data will help in establishing a definitive cartography and a velocity distribution function through the galactic disk.

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-date cartographic model.

Observational survey

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

Photometric survey

Tracing the radial space density of young stars up to ~3-4kpc we will obtain a strong, independent determination of the location of the Perseus spiral arm outside the solar radius. We plan to complete a 8□º Stromgren (uvbyβ) photometric survey up to V=17. Good precision in the distance determination is needed.

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

For the moment, a 3□º survey have been completed using the Wide Field Camera at 2.5m Issac Newton Telescope (La Palma), from which a sample of around 1000 B3-A5 stars has been obtained.

Spectroscopic survey

Measuring stellar radial velocities of our photometrically selected sample of young stars we plan to detect the velocity perturbation introduced by a density wave associated to Perseus arm. The anticenter direction is optimal for this purpose because it minimizes the influence of galactic rotation. Young stars have small velocity dispersion and a high response to density wave perturbation; so they are ideal candidates for this study. Systematic radial velocities perturbation along the galactic radius in the range of 5-15 km/s are expected (Melnik et al., 2008).

A spectroscopic survey using AF2/WYFFOS multi-object fiber spectrograph working at the Prime focus of the 4.2m William Herschel Telescope (La Palma) will start next Nov. 2010.

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. We plan to cover 8□º field around (l,b)=(180.8,-0.25) (see ~3 □º, have been already observed up to V=16-17 in Fig.1).

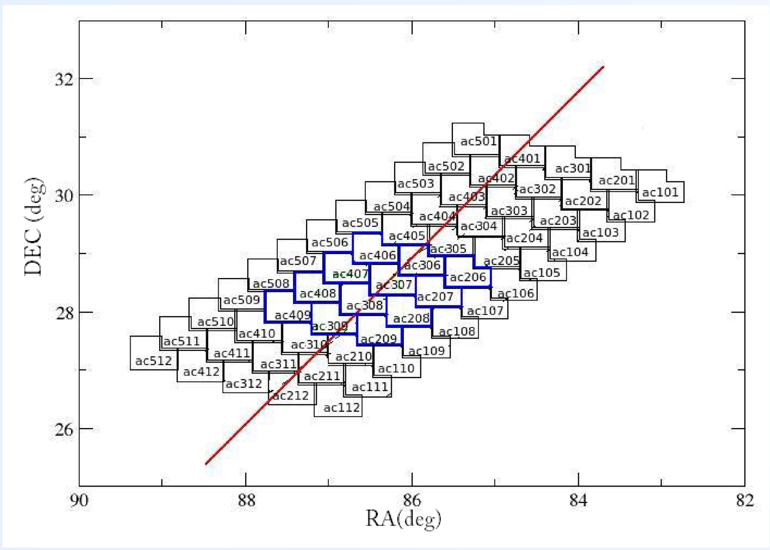


Figure 1: Scheme of the 48 WFC pointings Red line is b=-0.5.

Photometric accuracy:
Errors ~0.01-0.02 mag in the indices [u-b], [c1], [m1] and β have been obtained (Fig.2). Extinction is presented in fig. 3.

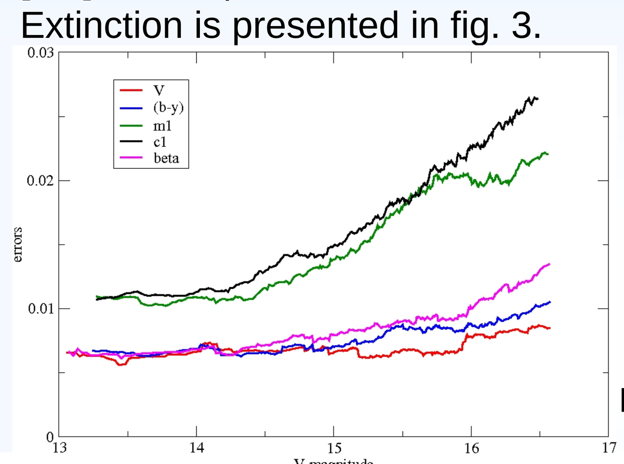


Figure 2

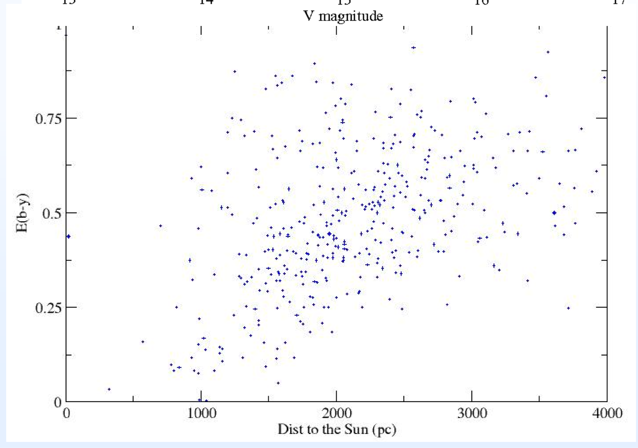
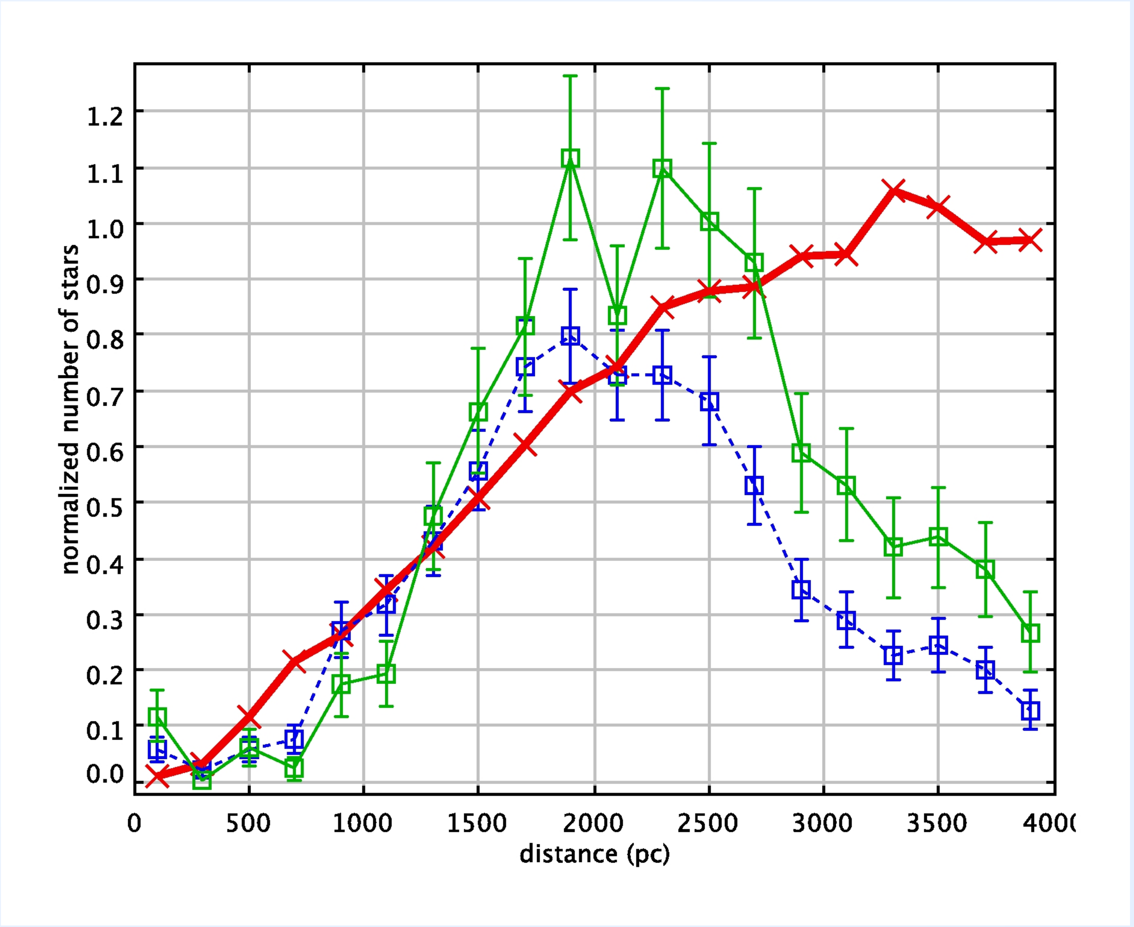


Figure 3

Figure 4: number of stars (normalized) as a function of distance in the anticenter direction. Red line: simulated stars assuming a radial scale length hr=2.5kpc (no spiral arm overdensity). Blue line: real B3-A5. Green line: real B3-A3 stars. Star counts are normalized using the number of stars between 1-1.5kpc.



We can hint a possible overdensity around 1.5-2kpc, probably associated to the Perseus arm.

Work is in progress to increase the limiting magnitude and the statistics.

Simulations: Spiral arms as seen by Gaia

Main objective and steps

We simulate how Gaia will see the spiral arms of the Milky Way, and the precision we expect to find in the derivation of the parameters of this large scale structure. For the moment only B5V stars have been used for the simulations. To develop these simulations we create three different codes:

1.-Star generator (positions and kinematics):

- Random azimutal angle θ in the galactic plane.
- Galactocentric distance following an exponential disk (hr=2.5kpc) plus a spiral arm overdensity:

$$F(R)=\exp^{\frac{-R}{h_r}}\left(1+\sigma\cos\left(\psi_{Sun}-m\theta+\frac{m}{\tan i}\log\frac{R}{R_{Sun}}\right)\right)$$

- Distance to the disk following (Z_{exp}=0.2kpc):

$$f(Z)=\sec h^2\left(\frac{Z}{Z_{exp}}\right)$$

- Intrinsic velocity dispersion (RSR):

$$\sigma_U(R)=\sigma_{USun}\exp\left(\frac{-(R-R_{Sun})}{R_{sigma}}\right)\quad \sigma_V(R)=\sigma_U(R)\sqrt{\frac{-B}{A-B}}\quad \sigma_W=\sigma_{WSun}$$

- Galactic rotation and asymmetric drift.
- Sun velocity.
- Spiral arms kinematics following Lin & Shu density wave theory (i, m, Ωp, Ψ_{Sun}, σ)

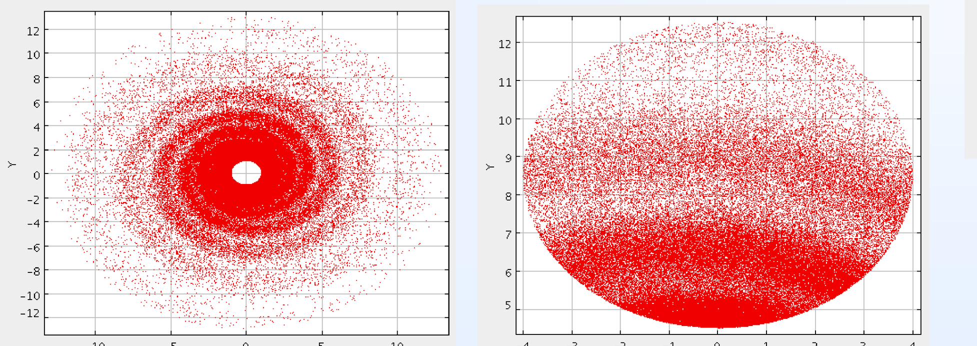


Figure 5: Left) X-Y plot of the star position in the plane. 10^5 stars simulated between 1 and 13kpc. Right) 10^5 stars simulated in 4kpc around the Sun position.

2.-Gaia errors

We add the expected Gaia errors for parallax, proper motion (Gaia web page) and radial velocities (Katz et al. 2004) according to the G magnitude and (V-I) colour. A 1.3mag/kpc extinction has been assumed (Fig. 3).

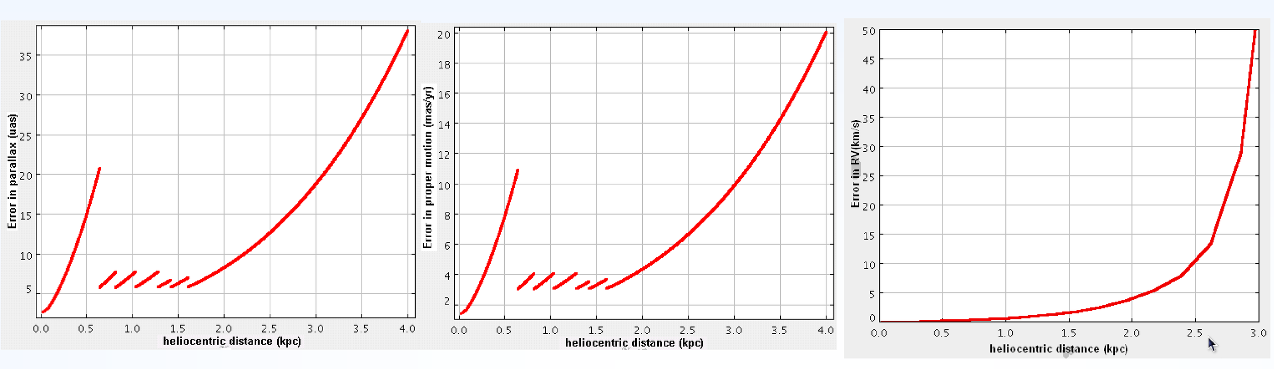


Figure 7: Expected Gaia errors for B5V stars (Mv=-1, $(V-I)_0$=-0.33) as a function of heliocentric distance our B5V simulated stars. Left: parallax error. Center: proper motion error. Right: radial velocity error (errors in Vr > 50 km/s for r > 3 kpc)

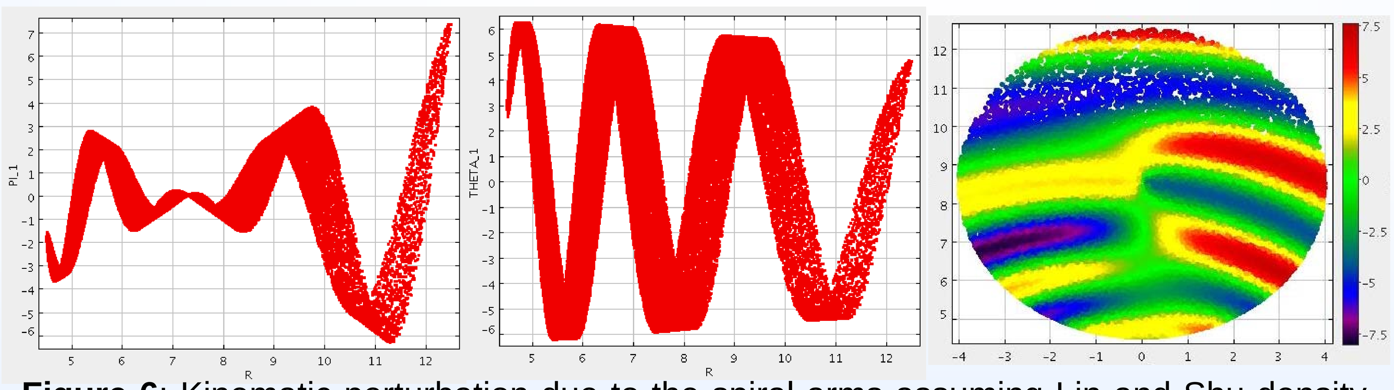


Figure 6: Kinematic perturbation due to the spiral arms assuming Lin and Shu density way model. Left) Radial contribution (Π_1= $\Pi_b$cosΨ) as a function of heliocentric distance. Center). Tangential contribution (Θ_1= $\Theta_b$cosΨ). Right) X-Y plot. Colour scale indicates the contribution of the spiral perturbation to the heliocentric radial velocity for each star. Sun galactocentric distance is 8.5kpc.

3.- Simplified kinematic model at the Solar Neighbourhood. Least square fit:

As a first step, a very simplified model developed by the team for the solar neighborhood (Fernández et al. 2001) has been applied to the generated observed catalogue. A least square fit is solved considering simultaneously radial velocities and proper motion equations. The fixed inputs parameters, assumed to be known, are the number of spirals (m=2), the pich angle (i=-6º) and Rsun. The parameters to be derived from the fit are:

- Sun motion with respect to the LSR ($U_\odot$, $V_\odot$, $W_\odot$)
- First and second order terms of the rotation curve: a(r), b(r)
- The expansion term parameter (Oort constant): K
- The spiral structure parameters: Πb, Θb, Ψsun, fr.

The obtained fit results for 10^5 stars closer than 1kpc and 4kpc are:

PARAMETER	Input value	Output (r<1kpc)	Output (r<4kpc)
$U_\odot$	10.0 km/s	10.64 ± 0.03	10.90 ± 0.34
$V_\odot$	5.25 km/s	6.67 ± 0.11	6.57 ± 0.46
$W_\odot$	7.17 km/s	7.16 ± 0.03	7.17 ± 0.27
A Oort *	(12.94) km/s/kpc	12.92 ± 0.11	12.79 ± 0.12
B Oort *	(-12.92) km/s/kpc	-11.28 ± 0.24	-12.66 ± 0.04
K	0.0 km/s/kpc	0.12 ± 0.04	0.62 ± 0.12
Ψsun	90 º	90.24 ±1.17	93.99 ± 3.56
Πb *	(1.85) km/s	1.82 ± 0.05	-0.82 ± 0.38
Θb *	(5.77) km/s	7.28 ± 0.26	6.58 ± 0.39
Ωp	30 km/s/kpc	29.13 ± 0.15	24.24 ± 0.77
Corrotat. radius	7.3 kpc	7.42 ± 0.04	9.07 ± 0.29
$f_\odot$ *	(0.3)	0.54 ± 0.00	0.55 ± 0.00

Parameters with asterisk are assumed constant in this simplified model (up to now applied to solar neighborhood). Looking at fig. 6, a correct scientific exploitation of the Gaia data require a more complex model to take into account the radial and azimutal variation of the kinematic parameters of the spiral perturbation.

References

Benjamin,R.A., 2008, ASPC 387, 375
Drimmel,R., 2000, A&A 458, 13
Fernández, D., Figueras, F., Torra, J. , 2001, A&A,372, 833
Figueras, F., Torra, J., Jordi, C. , 1991, A&AS 87, 319
Grosbøl,P., Patsis,P., Pompei,E., 2004 A&A 423, 849
Marco,A., Bernabeu,G.,Negueruela,I., 2001 AJ 121, 2075
Tapia,M., Costero,R., Echevarria,J., Roth,M., 1991 MNRAS 253 649
Taylor,J.H:, Cordes,J.M. 1993, ApJ, 411, 674
Vallée,J.P, 2005, AJ, 130,569
Martos, M: Yañez,M.,Hernández,X., et al. 2004 JKAS,37,199
Melnik, A., Dambis, A.K., et al. 2008: arXiv:0809.3381
Stromgren,B., 1966 ARA&A, 4, 433
Gaia web page:
http://www.rssd.esa.int/index.php?project=GAIA&page=Science_Performance