Vertex deviation maps to bracked the Milky Way resonant radius

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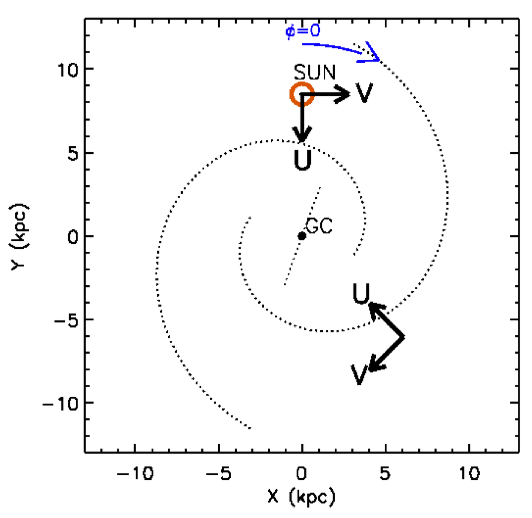
Abstract

We map the kinematics of stars in simulated galaxy disks with spiral arms using the velocity ellipsoid vertex deviation (l_v). We use test particle simulations, and for the first time, fully self-consistent high resolution N-body models. We compare our maps with the Tight Winding Approximation model analytical predictions. We see that for all barred models spiral arms rotate closely to a rigid body manner and the vertex deviation values correlate with the density peaks position bounded by overdense and underdense regions. In such cases, vertex deviation sign changes from negative to positive when crossing the spiral arms in the direction of disk rotation, in regions where the spiral arms are in between corotation (CR) and the Outer Lindblad Resonance (OLR). By contrast, when the arm sections are inside the CR and outside the OLR, l_v changes from negative to positive.We propose that measurements of the vertex deviations pattern can be used to trace the position of the main resonances of the spiral arms. We propose that this technique might exploit future data from Gaia and APOGEE surveys. For unbarred N-body simulations with spiral arms corotating with disk material at all radii, our analysis suggests that no clear correlation exists between l_v and density structures.

Velocity distribution function

Definitions



(p+q+r)th centered moments of the velocity distribution function are computed as follows:

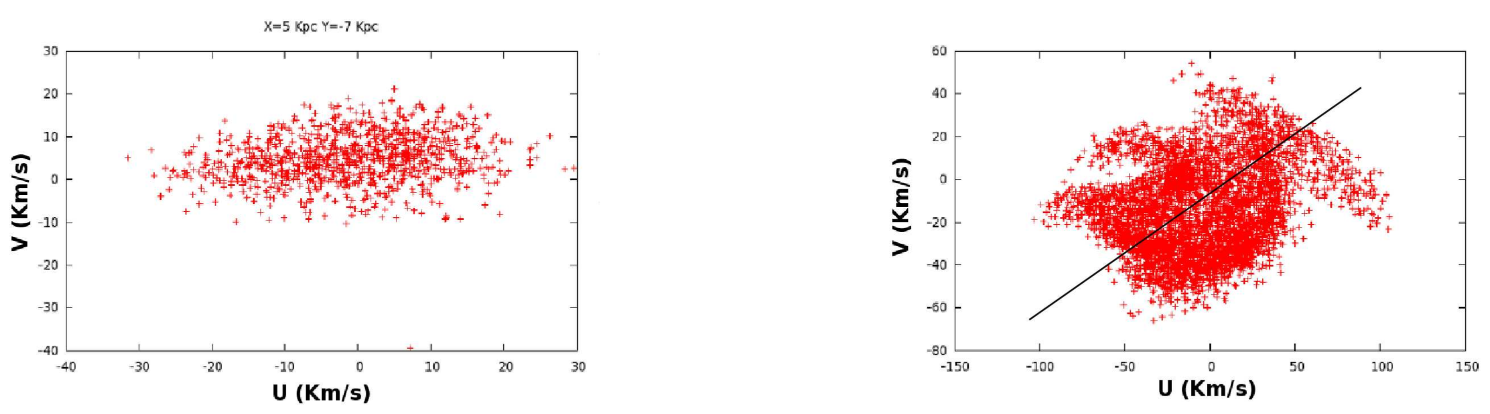
$$\mu_{pqr} = \frac{1}{\mu_{000}}\int d^3\mathbf{v}\,(U-\bar{U})^p\,(V-\bar{V})^q\,(W-\bar{W})^r\,f,$$

, where U,V and W are the radial, tangential and vertical galactocentric velocities as defined in the above figure, and f(**x**,**v**) is the velocity distribution function.

Vertex deviation (l_v)

$$\tilde{l}_v = \frac{1}{2}\mathrm{atan}\left(\frac{2\mu_{110}}{\mu_{200}-\mu_{020}}\right)$$

$$l_v = \begin{cases} \tilde{l}_v & \text{if } \mu_{200} > \mu_{020} \\ \tilde{l}_v + \mathrm{sign}(\mu_{110})\frac{\pi}{2} & \text{if } \mu_{200} < \mu_{020} \end{cases}$$



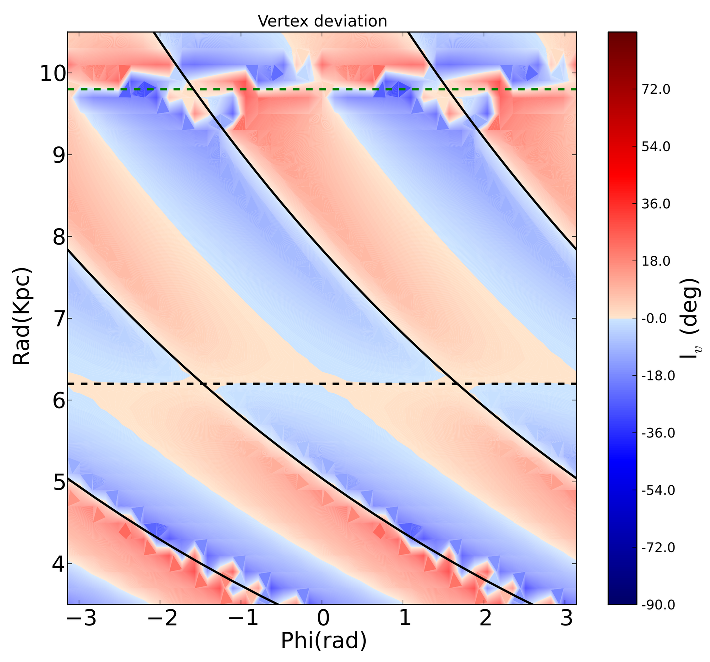
Analytical approach and Test particle simulations

TWA analytical approach

- Lin, Yuan & Shu (1969): first order moments.
- Mayor (1970): second order moments and analysis constrained to the solar neighbourhood.
- We completed the expression for l_v and computed the values for the entire galactic disk.

Assumptions:

- Schwarzschild distribution plus a small perturbation
- Low spiral amplitude
- Small pitch angle
- Low velocity dispersions
- Epicyclic approximation

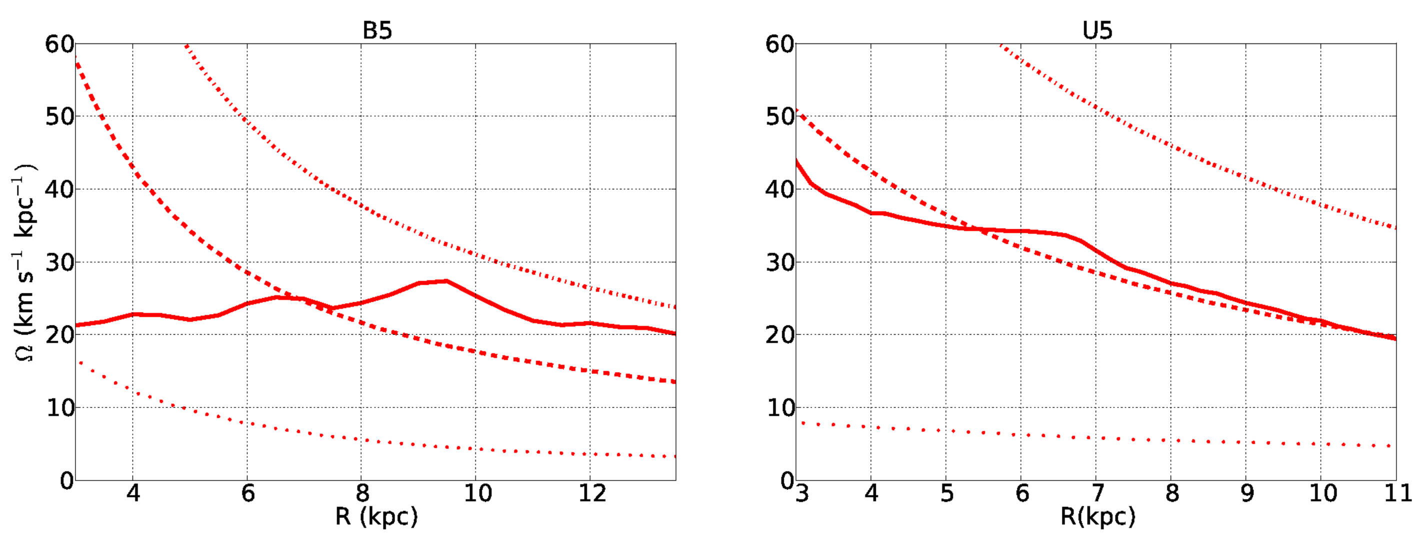


Test particles

Model	i (deg)	Initial Conditions	N (10^6)	Ω_b ($\mathrm{kms^{-1}kpc^{-1}}$)	R_{CR} (kpc)	t_{int}
TWA1	8	ICMN20	5	20	10.2	5 rot.
TWA2	8	ICMN20	5	35	6.2	5 rot.
TWA3	8	ICMN20	5	50	4.04	5 rot.
PER1	8	ICMN20	4.3	35	6.2	5 rot.
PER2	15.5	IC2	4.8	20	10.2	5 rot.
FBar	-	ICMN30	80	50	4.04	18 rot.

TWA, PER and FBar are models with imposed cosine and PERLAS spiral arms and Ferrers' bar potential, respectively. The i values refer to the pitch angle of the imposed spiral structure, Ω_b the pattern speed, R_{CR} its CR and t_{int} the integration time.

N-body Simulations



Parameter	B5	U5
Disk mass ($10^{10}\ M_\odot$)	5.0	3.75
Halo mass ($10^{12}\ M_\odot$)	1.38	1.5
Disk exp. length R_d **(kpc)**	3.86	4.0
Disk exp. height Z_d **(kpc)**	0.2	0.2
Halo NFW R_d **(kpc)**	29.19	16.61
Halo concentration	10	18
N_{eff} (10^7)	13.8	20.0
Min. time step (10^4 yr)	1.6	3.1

Barred (B5) and Unbarred (U5) N-body simulations presented in Roca-Fàbrega et al. (2013). Both models have the following properties:

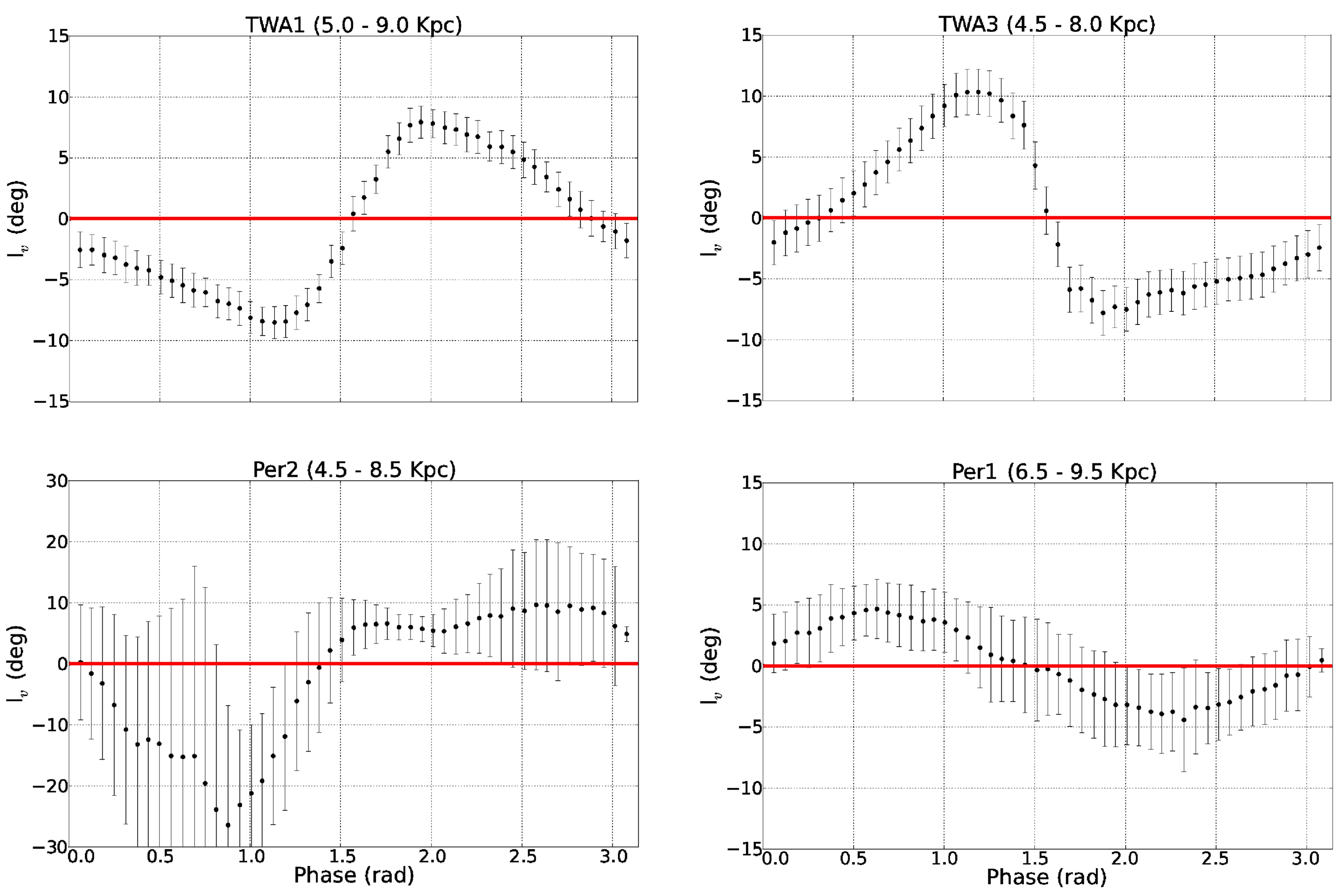
- Live dark matter halo
- 5 million disk particles
- Spatial resolution of 11 pc
- Total integration time of 2.8 Gyrs

Solid red line: Spiral arms rotation frequency (m=2 Fourier mode for B5 model and m=4 Fourier mode for U5). Dashed red thick line: Disk particles rotation frequency.

Results

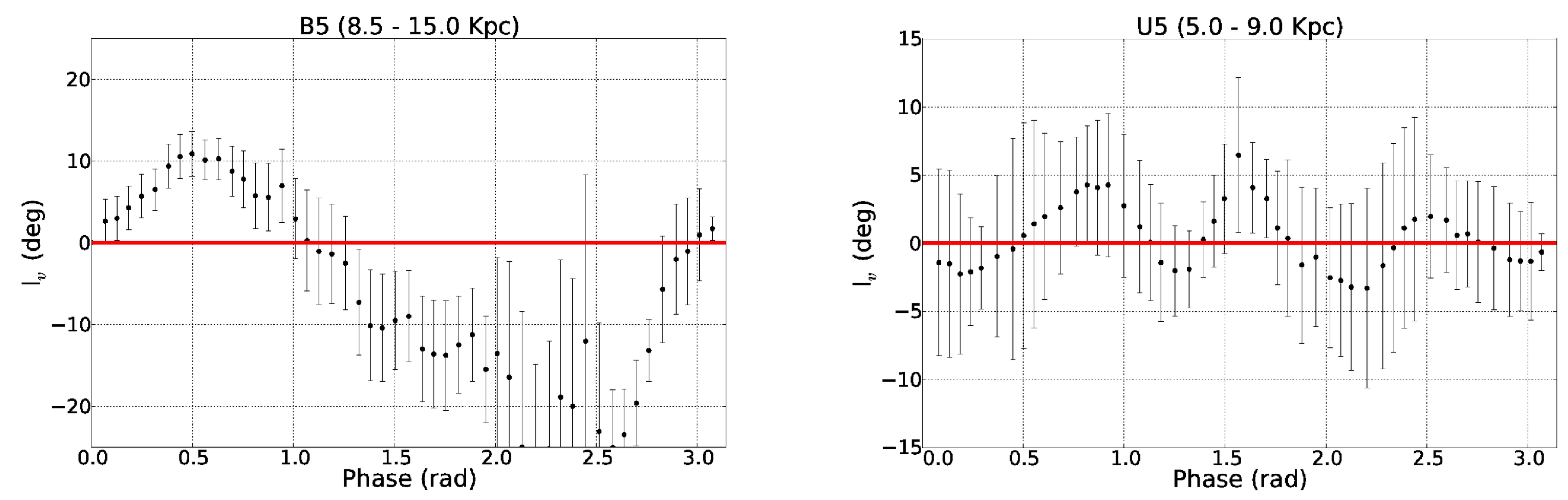
Spiral arms test particles

Inside corotation — Outside corotation



Barred/Unbarred N-body simulations

Outside corotation — All corotating



Description of the figures:

- In these figures we show the average l_v value between radius R_1 and R_2 (see figures' title) as function of the phase from the spiral arm density peak. Spiral arm density peak is placed at phase = 0.
- Due to the symmetry of the system (m=2 or m=4 spiral arms), we have computed l_v as function of the distance to each one of the spiral arms and putted the information all together in a single 0-π phase diagram.
- Errorbars are computed taking into account both, the statistical errors and the errors derived from the vertex deviation computation i.e. the number of particles in the region and the circularity of the velocity ellipsoid.

Conclusions and perspectives

Conclusions

- We confirm l_v is a good tracer of density structures, as proposed by Vorobyov & Theis (2006,2008).
- We find a new method to determine the CR and OLR radius based on changes in l_v sign when crossing density perturbations:

r < CR	CR < r < OLR	OLR < r
$l_v > 0 \Rightarrow l_v < 0$	$l_v < 0 \Rightarrow l_v > 0$	$l_v > 0 \Rightarrow l_v < 0$

- For more information about the method see S. Roca-Fabrega et al. 2014 paper.

Perspectives: Nbody + hydrodynamics

- Hydrodynamics plays an important role in the formation and evolution of galaxies.
- We have a new simulation of a MW like galaxy with resolution high enough to compute the l_v in the disk.
- For more information see S. Roca-Fàbrega talk "Towards a new cosmological Milky Way like galaxy simulation in the Gaia Era" at 10:20 A.M. of Wednesday 10th in "Galaxias y Cosmología" parallel session.

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