Novel kinematic methods to trace Spiral Arms nature using Gaia data

Roca-Fàbrega, S.[1], Figueras, F.[1], Valenzuela, O.[2], Romero-Gómez, M.[1], Antoja, T.[3], Colín, P.[4], Pichardo, B.[2] and Velázquez, H.[5]*

[1]Institut de Ciencies del Cosmos, Universitat de Barcelona (DAM-ICCUB-IEEC) ; [2]Instituto de Astronomía, Universidad Nacional Autónoma de México (IA-CU); [3]Research and Scientific Support Office, European Space Agency (ESA-ESTEC); [4]Centro de Radioastronomía y Astrofísica, Universidad Nacional Autónoma de México (CRyA); [5]Instituto de Astronomía, Universidad Nacional Autónoma (IA-Ensenada)

*sroca@am.ub.es

Abstract

In this work we shed new light in the nature of spiral arm structures in galaxies. We present a disk kinematic and dynamic study of MW like galaxies using complementary approaches: analytical models, test-particle simulations, pure N-body and cosmological N-body plus hydrodynamic simulations. Using collisionless N-body data we have found that models with strong bar present a flat rotation frequency, i.e. rigid body rotation, whereas in the opposite extreme case, i.e. in unbarred systems, spiral arms are disk corotant. Complementary to this work, we discuss how the vertex deviation parameter is a good tracer of corotation (CR) and outer Lindblad resonance radius (OLR). We have succeeded to produce MW like models in fully cosmological N-body plus hydrodynamic simulations with a high resolution. First results concerning disk phase space properties in terms of spiral arm nature using these simulations are presented.

Simulations

Isolated galaxies

TWA analytical approach

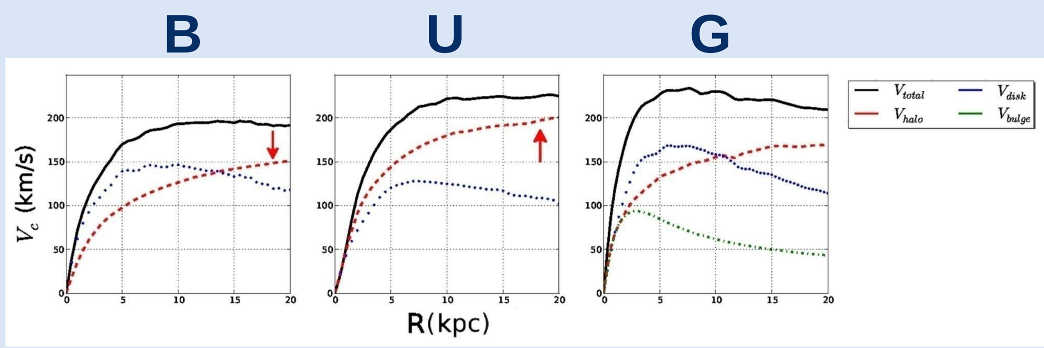
- Full disk vertex deviation map following Mayor (1970)

Test particles

- TWA/PERLAS spiral arm potentials
- Ferrers/quadrupole bar potentials
- Large set of initial conditions

Collisionless N-body

- ART and GADGET3 codes
- Barred models (B, G)
- Unbarred models (U)



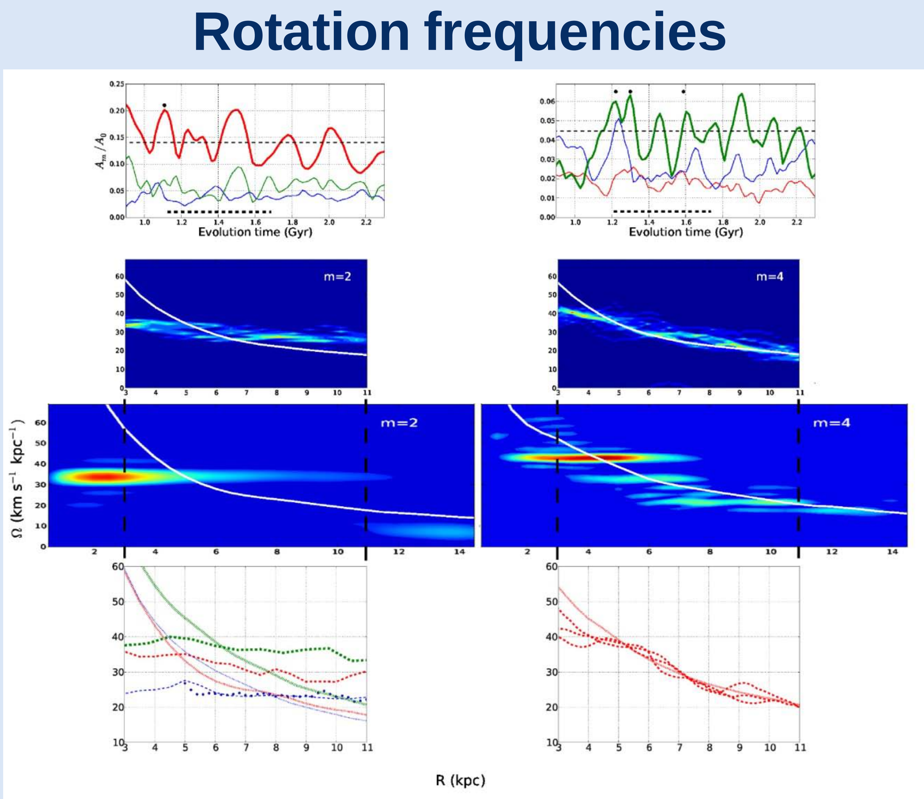
Cosmological N-body + hydrodynamics

- 20 Mpc/h box, "zoom-in technique"
- Cooling/heating mechanisms
- Deterministic star formation
- Feedback: SNIa, II, stellar winds + advection of metals
- Cooling turned off ~40 Myr after SNe
- Spatial, temporal and mass resolutions of 109 pc, 5×10^3 yr, 1000 M_{sun}, respectively.

Results

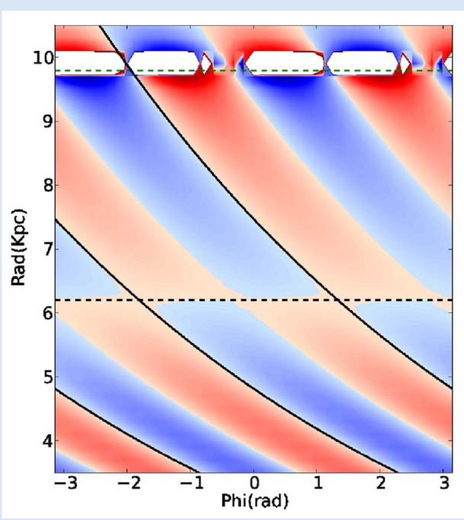
New methods to constrain spiral arms nature

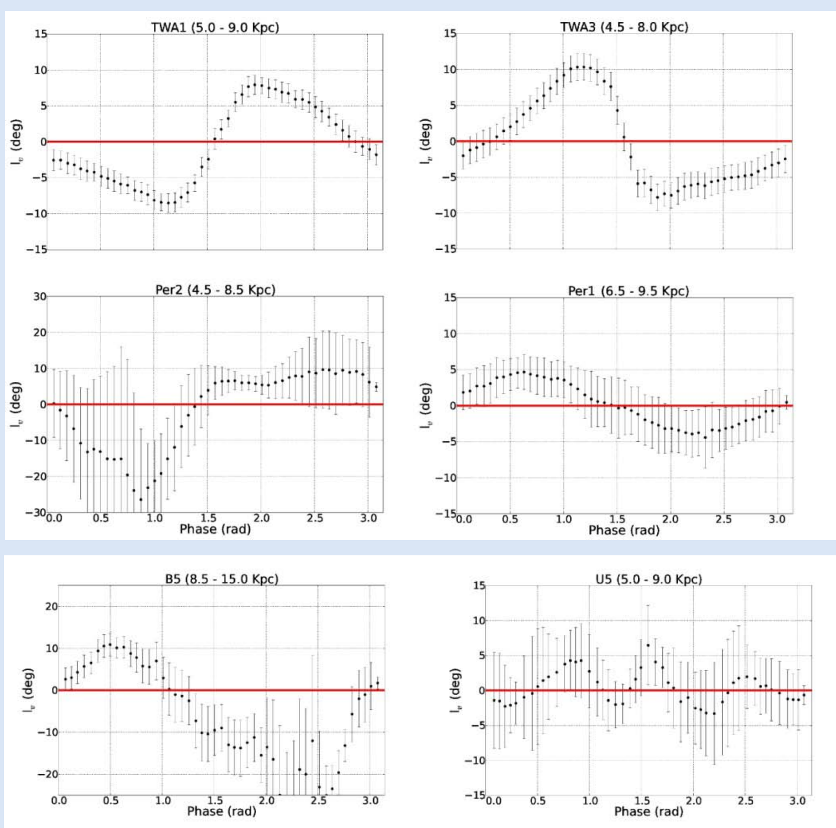
Rotation frequencies



- Collisionless N-body simulations of Barred and Unbarred models
- Different techniques to derive rotation frequencies
- Spirals in strong barred models: rigid body rotation
- Spirals in unbarred models: corotant with disk particles
- Some particles in strong barred models move inside spirals like in a manifold driven scenario

Vertex deviation (lv)



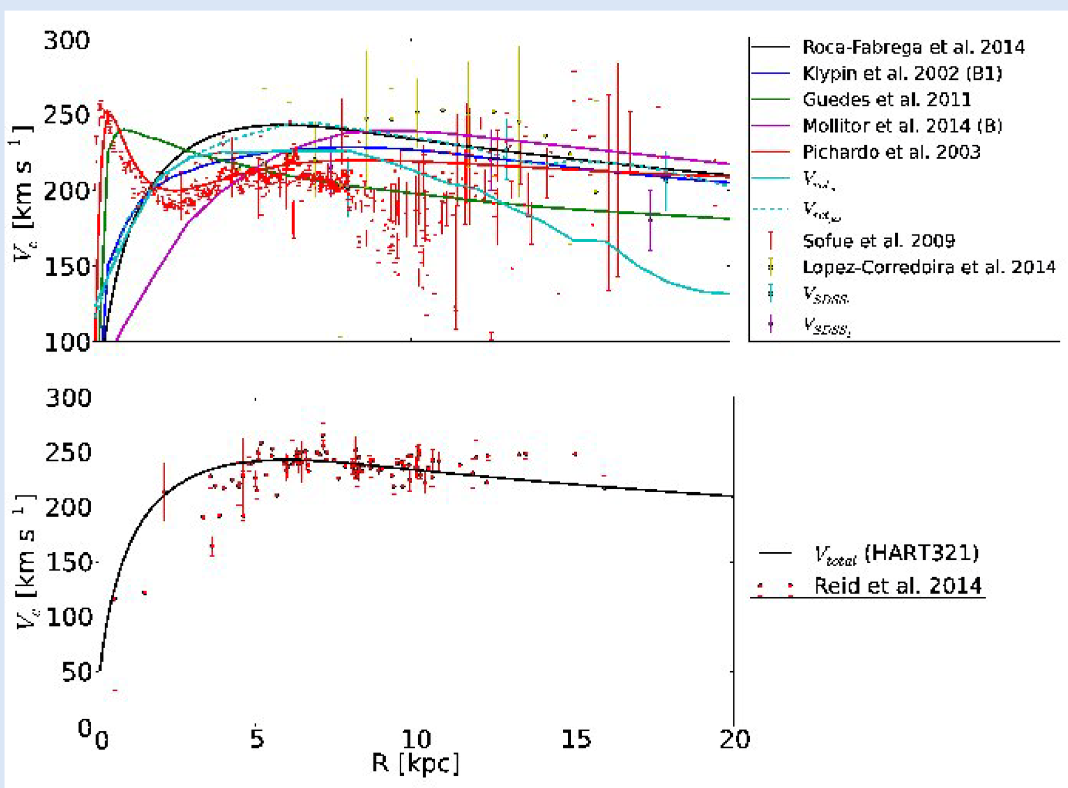


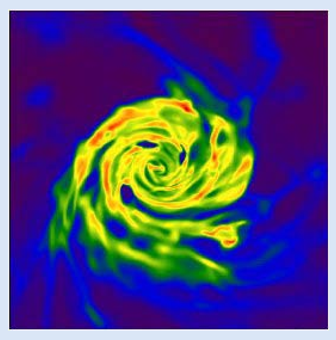
- From analytical, test particle and N-body models: Lv sign change when crossing spiral arm density peak, trace CR and OLR positions

Left: Lv color polar plot of a TWA analytical approach. Solid lines: spiral arm locus. Dashed lines: CR and OLR resonances. Right: Mean vertex deviation (red dots) and normalized density (black) as function of the phase from the spiral density peak. Two first rows: Test particle models. Last row: B and U N-body models.

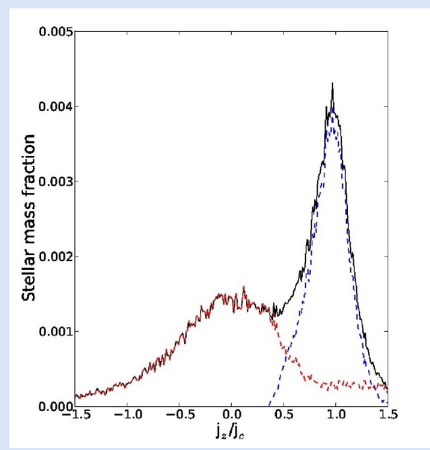
First results from a cosmological based model with reasonable agreement with MW observations

General properties





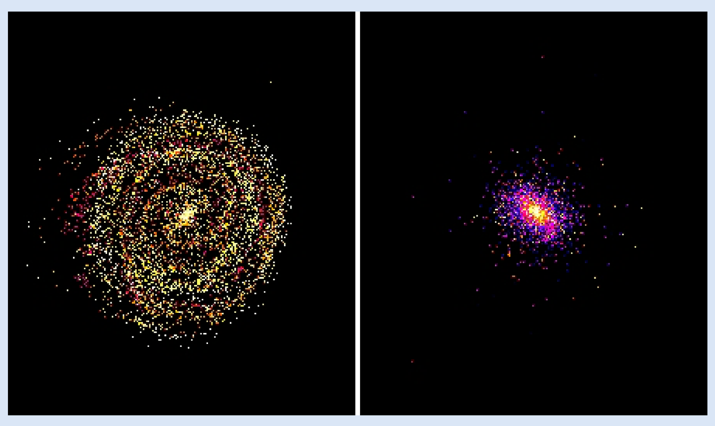
Cold gas



Circularity distribution of stellar particles

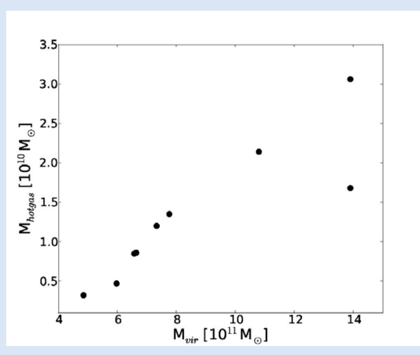
- N_*, N_{DM}, N_{gas} =7.1, 2.34, 6.77 million
- M_{vir}, M_*, M_{gas} =~7.3, ~0.62 ~2.0×10^{11}, M_{sun},
- Rd= 2.5 kpc
- NFW DM profile: c=~27

Baryonic content

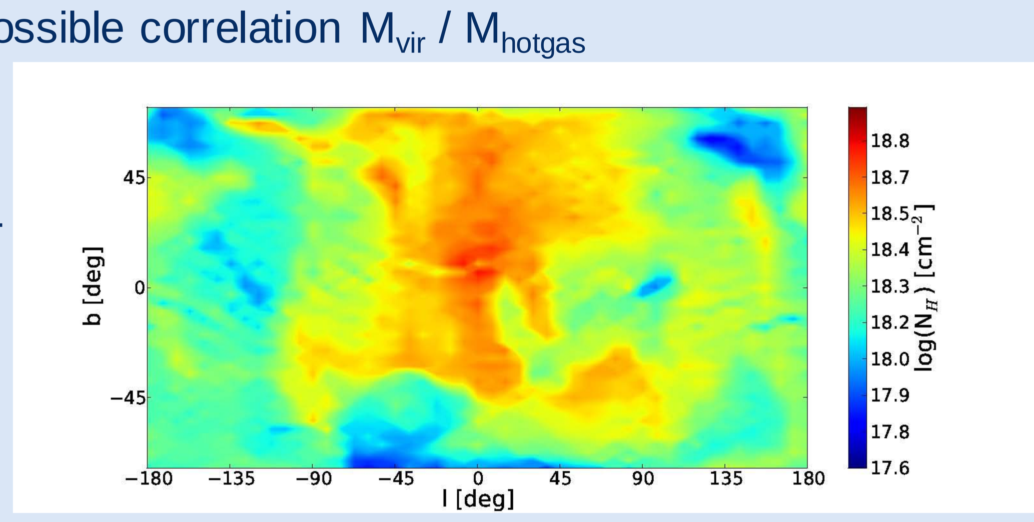


Young stars (0-4 Gyr) Old stars (11-13.467 Gyr)

- Compound bulge: young and old bar components. Different origins: disk vs. z=3 major merger
- Anisotropic hot gas distribution. 50 observations needed to recover $M_{hot\ gas}$ with relative error < 5%
- Possible correlation M_{vir} / M_{hotgas}



Left: Total virial mass vs. total hot gas mass for a set of simulated halos. Right: Full sky hot gas column density plot computed at 8 kpc from de GC of the galactic model.



Conclusions

- We have found two new methods to constrain the spiral arms nature (Roca-Fàbrega et al. (2013, 2014):
  - Spiral arms rotation frequency depends on the strength of the bar:

    The stronger the bar is, the closer the rotation frequency to rigid body rotation.

    The weaker the bar is, the closer the rotation frequency to the disk corotation.
  - Changes in lv sign when crossing spiral arm density peak traces the position of CR and the OLR:

    Inside CR and outside OLR: **Lv>0 ➡ Lv<0** ; Between CR and OLR: **Lv<0 ➡ Lv>0**
- We have generated a new MW-like galaxy simulation that is a perfect dynamical laboratory to study processes of galactic formation and evolution of the MW (Roca-Fàbrega et al 2015, in preparation)