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Galactic disc perturbations with Theia

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Outline

- Bulk velocities and asymmetries from RAVE/SDSS
  - In plane motions
  - Bending mode
  - Vertical motions
- Kinematic signatures of perturbations
- Context of Gaia/Theia

Observed departures from axisymmetry

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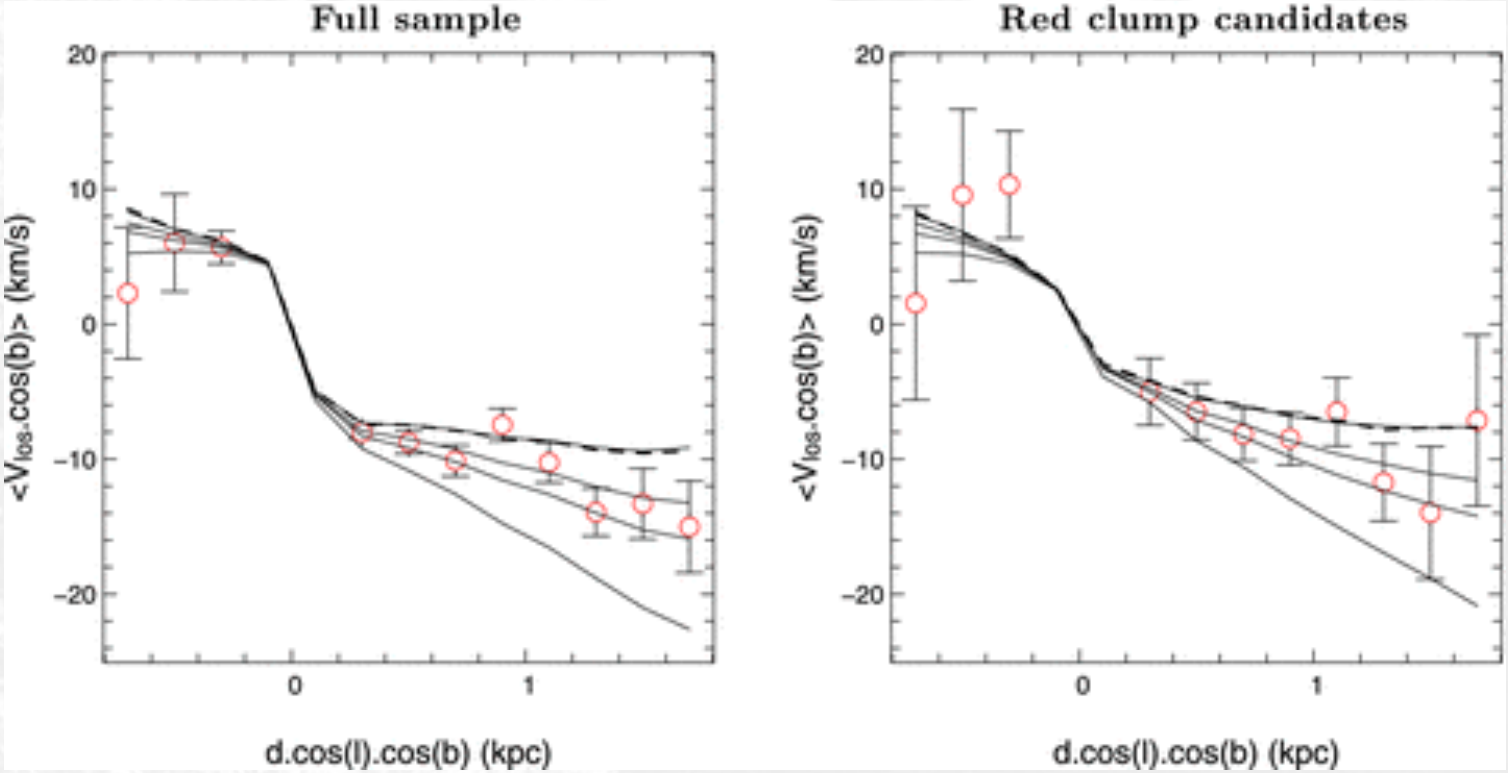
RAVE detection of a radial gradient in $\langle V_R \rangle$

Not compatible with an axisymmetric Galaxy



(Siebert et al. 2011)

2D structure of the RAVE velocity field

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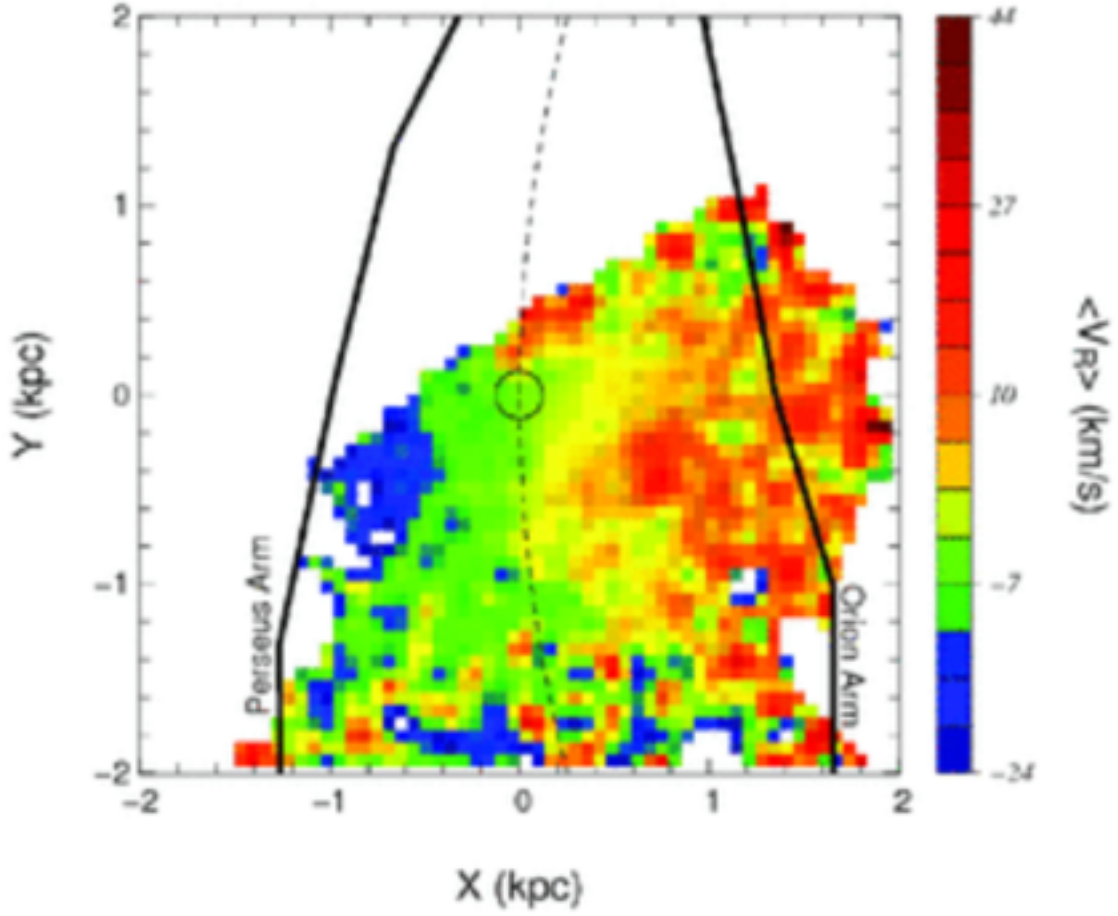
Observed structure implies a gradient -9<K+C<-3 km/s/kpc



Bending modes: SDSS

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Discovery of a north/south asymmetry in density

A=(n(z)-n(-z))/(n(z)+n(-z))

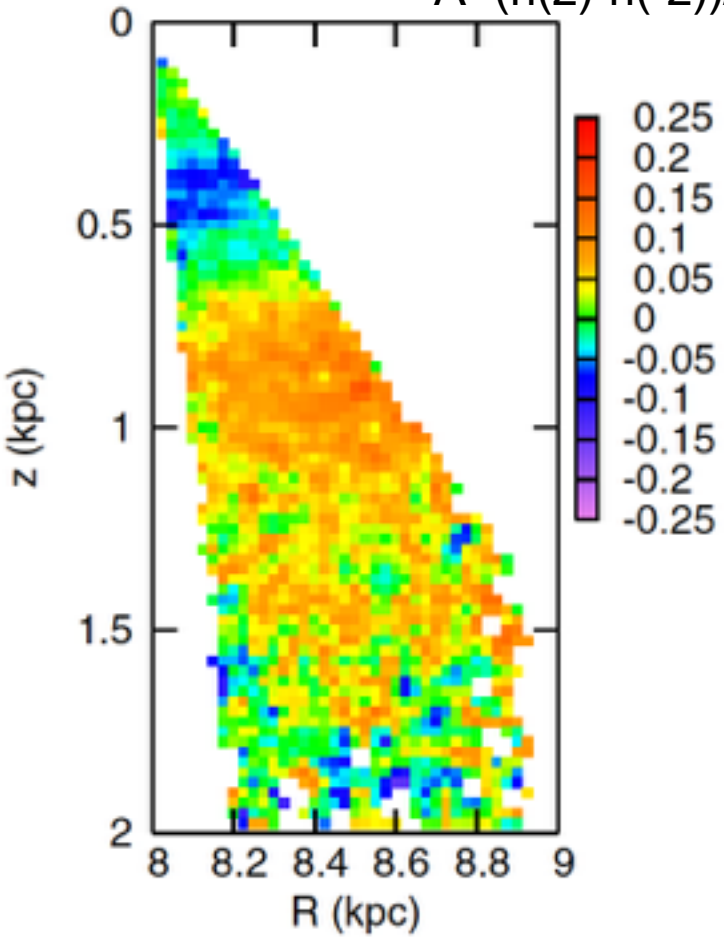

Figure 3. North–South asymmetry A_{2D} as a function of z and the Galactocentric distance R. We assume 8 kpc for the Sun–Galactocenter distance.

Widrow et al. 2012
See also Xu et al. 2015

Vertical bulk motion:

SDSS

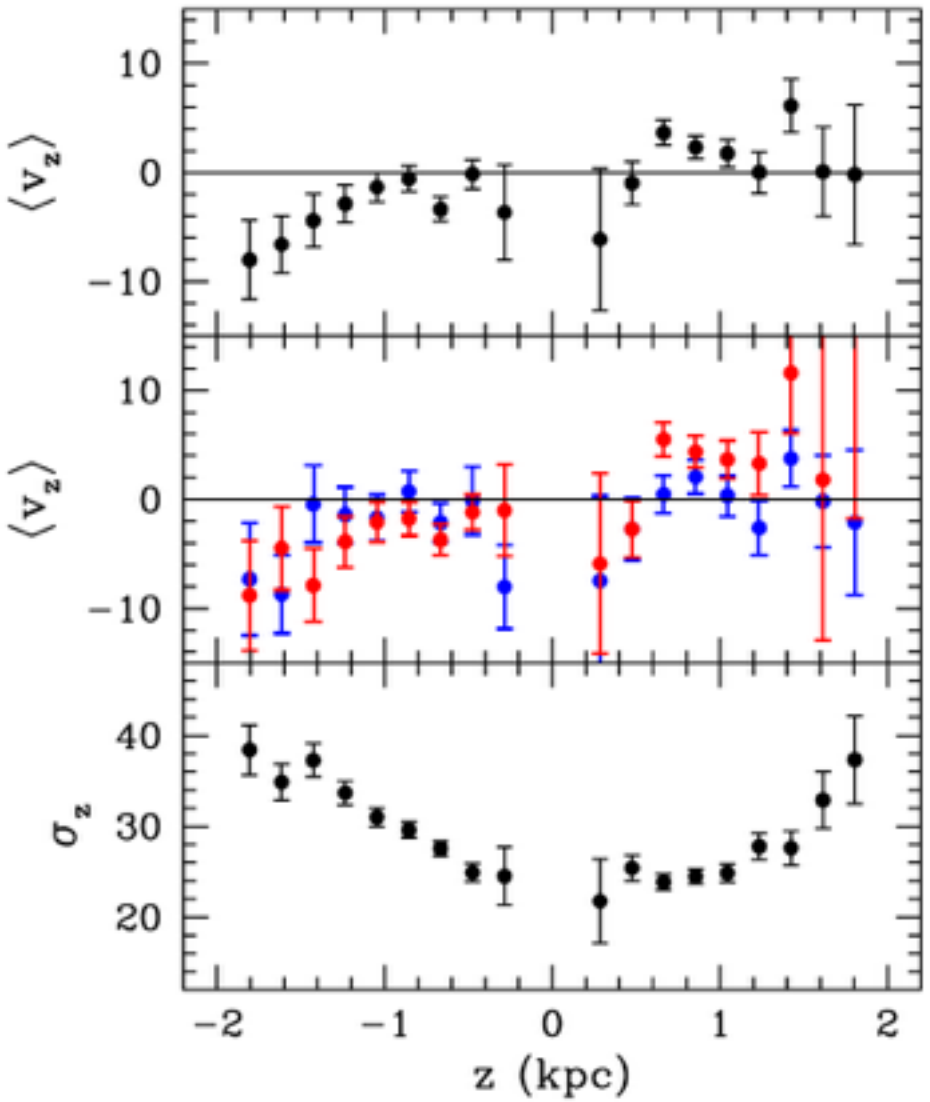

Figure 4. Bulk velocity $\langle v_z \rangle$ and velocity dispersion σ_z as a function of z in units of km s^{-1}. Top panel shows the bulk velocity as a function of z for the entire spectroscopic sample. Middle panel shows the bulk velocity profile for the "red" subsample ($g - r > 1$) and "blue" subsample ($g - r < 1$). The peculiar motion of the Sun ($v_{z,\odot} = 7.2\,\mathrm{km\,s^{-1}}$; Dehnen & Binney 1998) has been subtracted from $\langle v_z \rangle$. Bottom panel shows the velocity dispersion.

Widrow et al. 2012

Vertical bulk motion: RAVE

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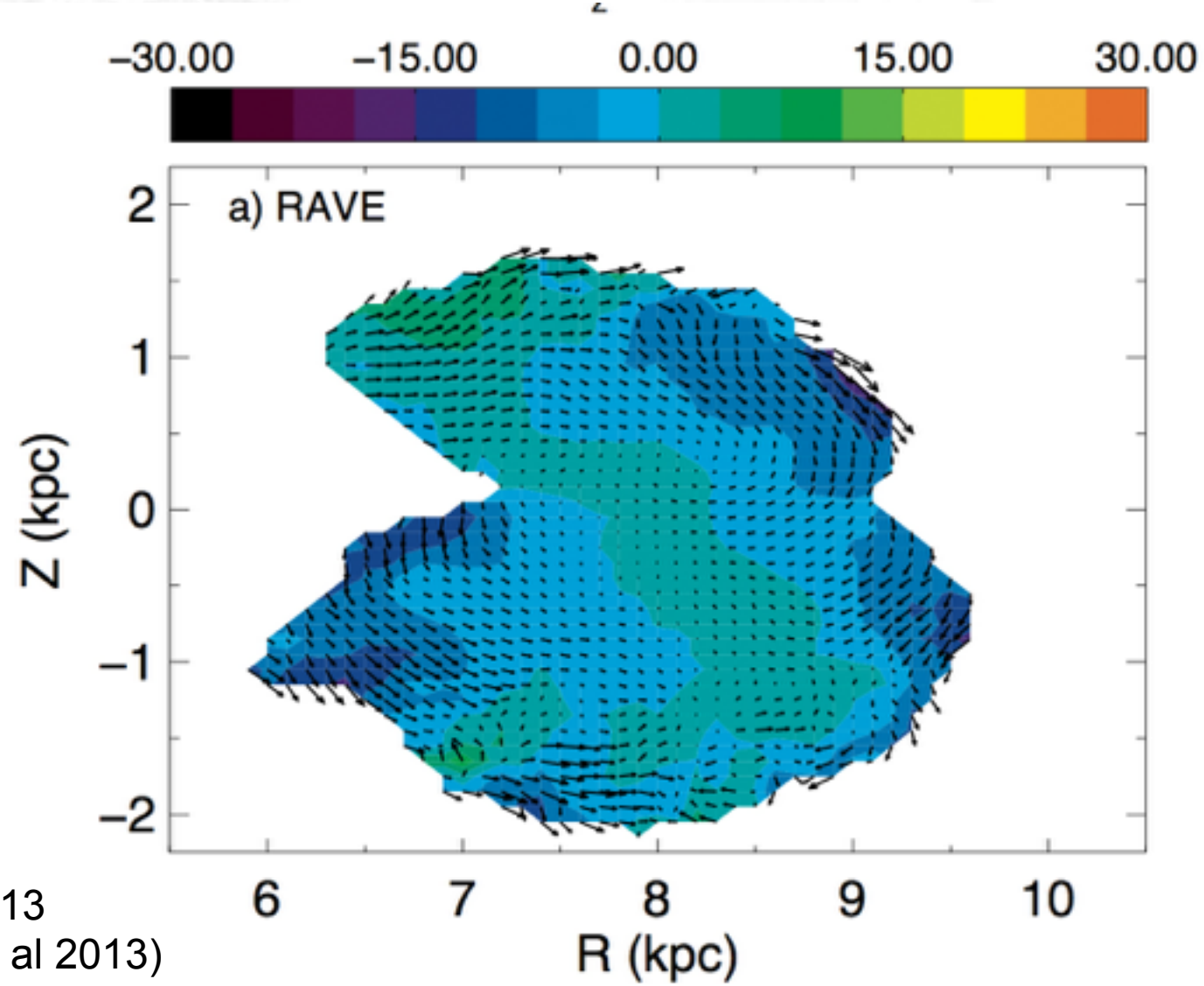

(Williams et al. 2013
See also Carlin et al 2013)

Link to perturbations

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- 2 and 3D velocity fields can be due to internal pertubations :
  - bar and spiral arms are known to affect the velocity distribution in the Solar neighbourhood
- Interactions with satellite galaxies also perturb the disc

Spiral density waves

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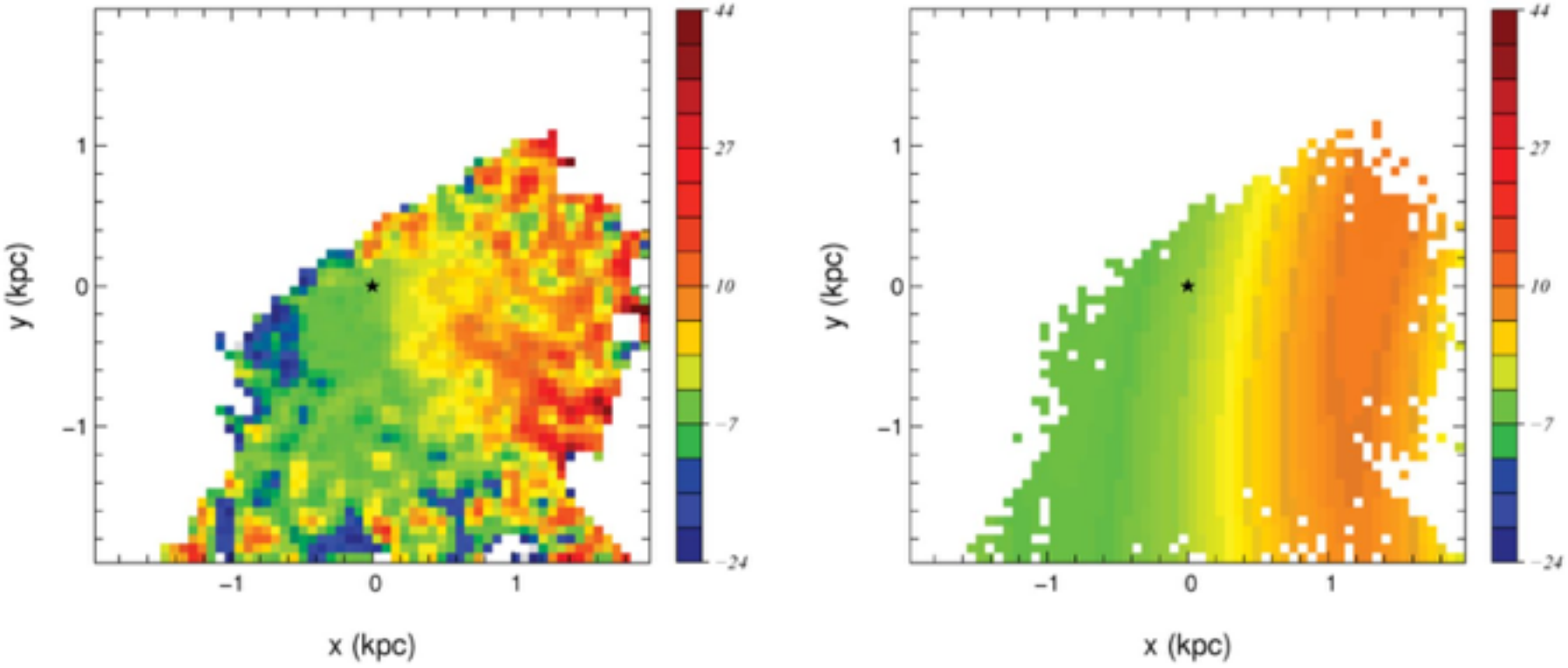
Large scale feature can be reproduced by spiral arms

2D modelisation using logarithmic spirals m=2



(Siebert et al. 2012)

Spiral density waves

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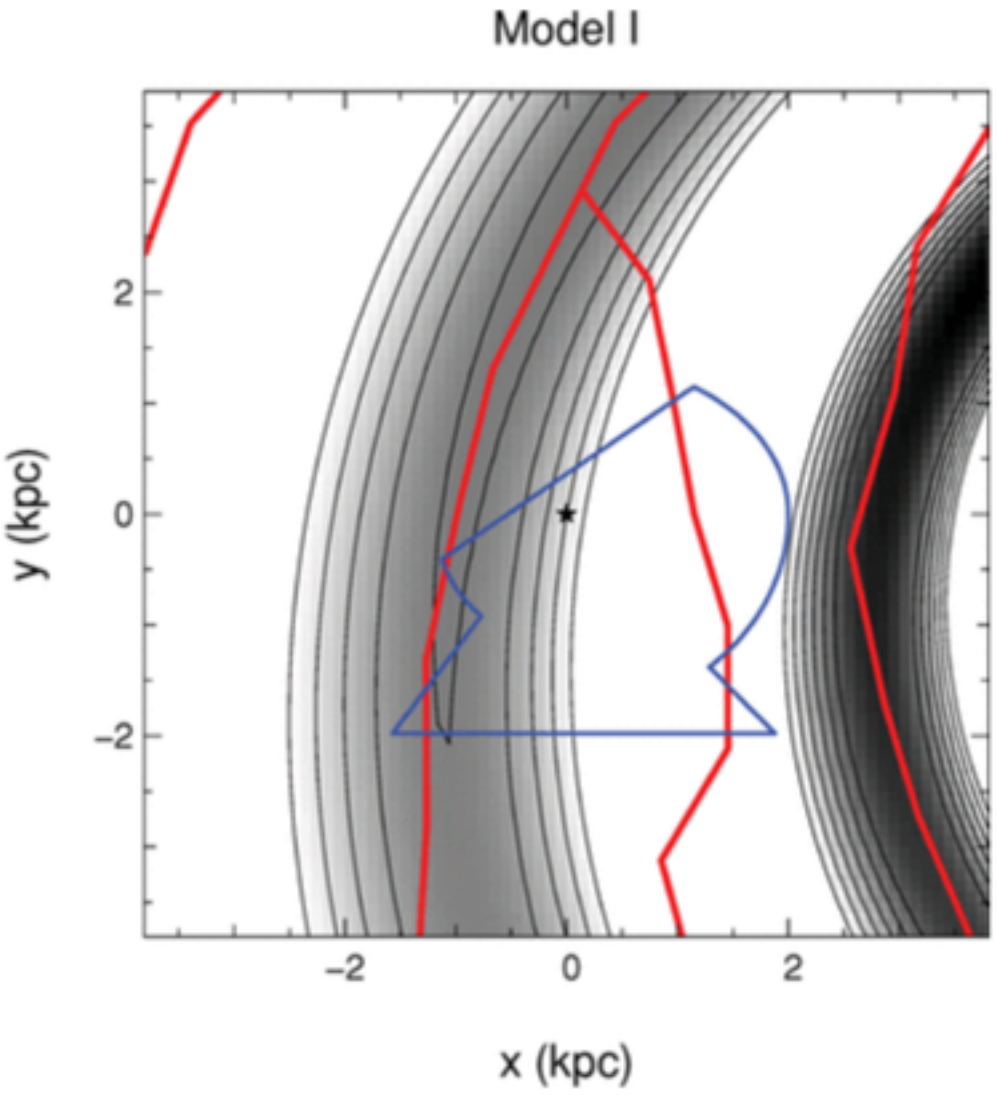
Predicts the proper location of the known spiral pattern in the gas



Siebert et al. 2012

Vertical bulk motion from spiral arms

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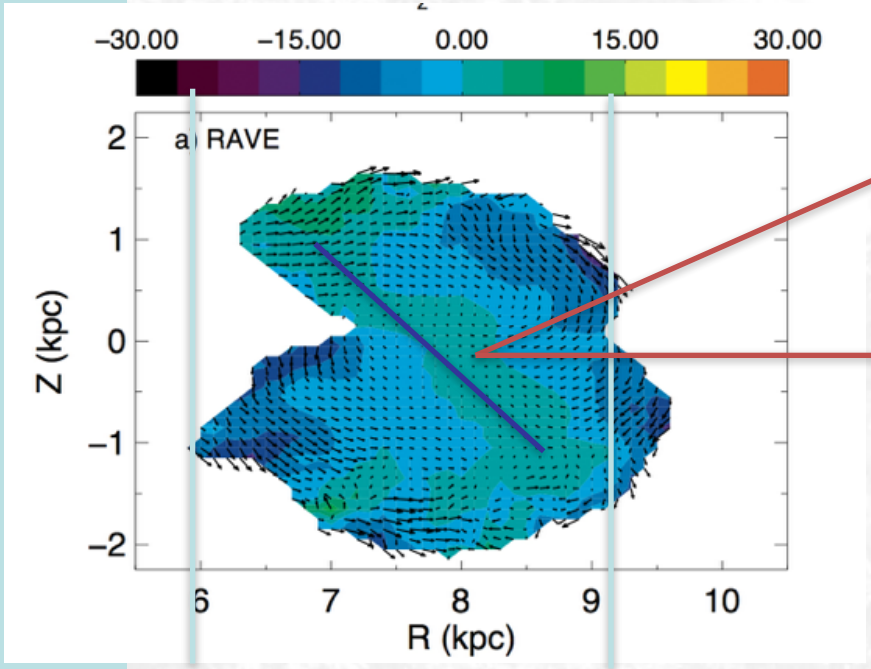
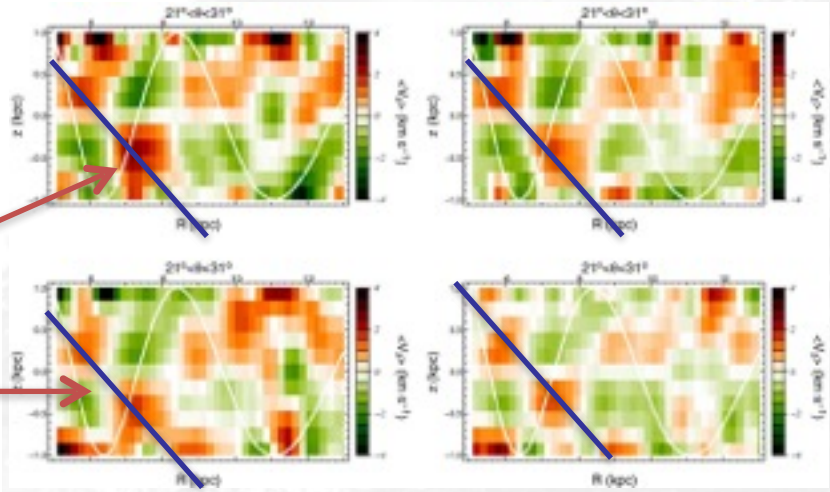
- **RAVE data : 20k red clump giants (Williams et al. 2013)**

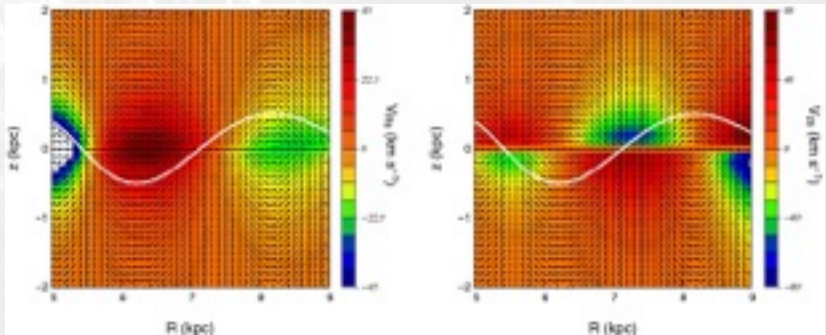


- **Simulation with spiral arms (Faure et al. 2014)**

Particle test simulation



Fluid model



See also Debattista 2014
Grant et al. 2015

Effect of the Galactic bar

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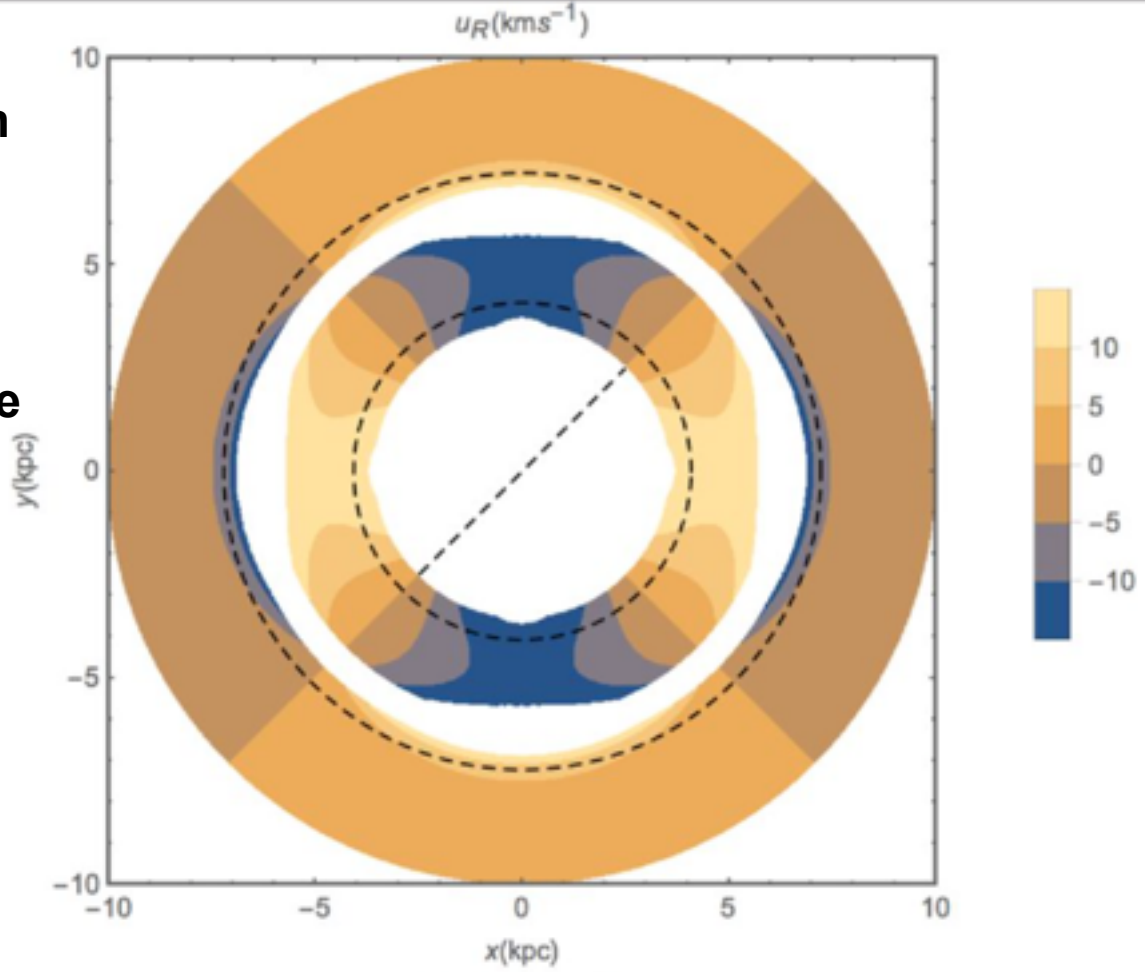
Radial bulk motion

The bar can have an effect of the same order as the spiral arms

However, large scale geometry differs



Monari et al. 2015

Effect of a Galactic bar

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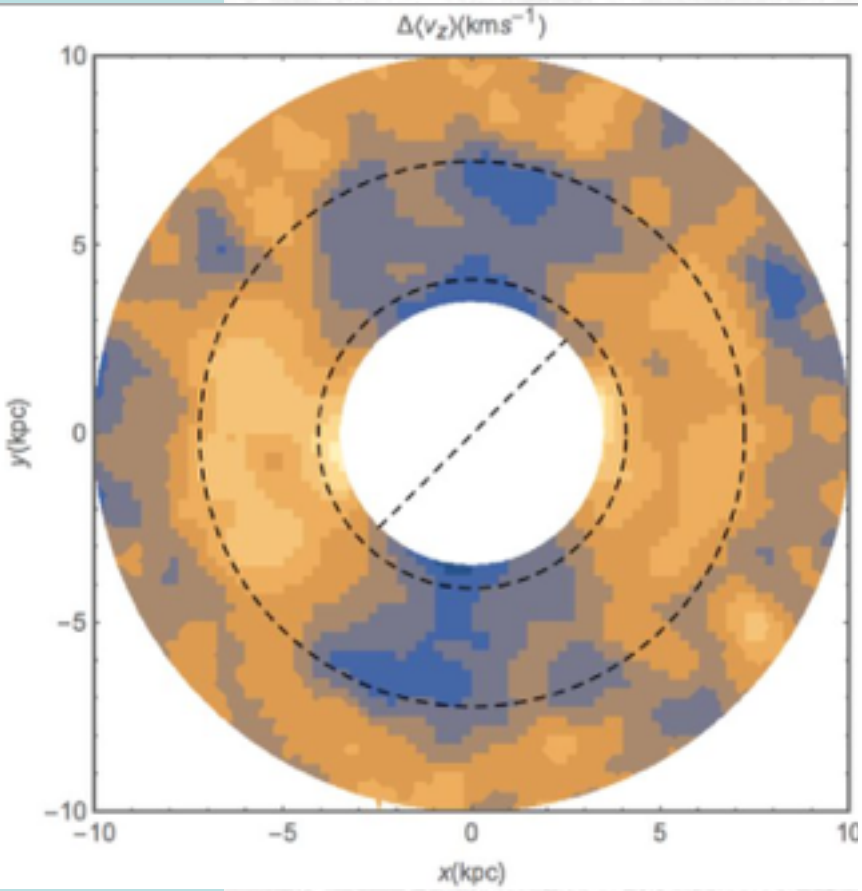
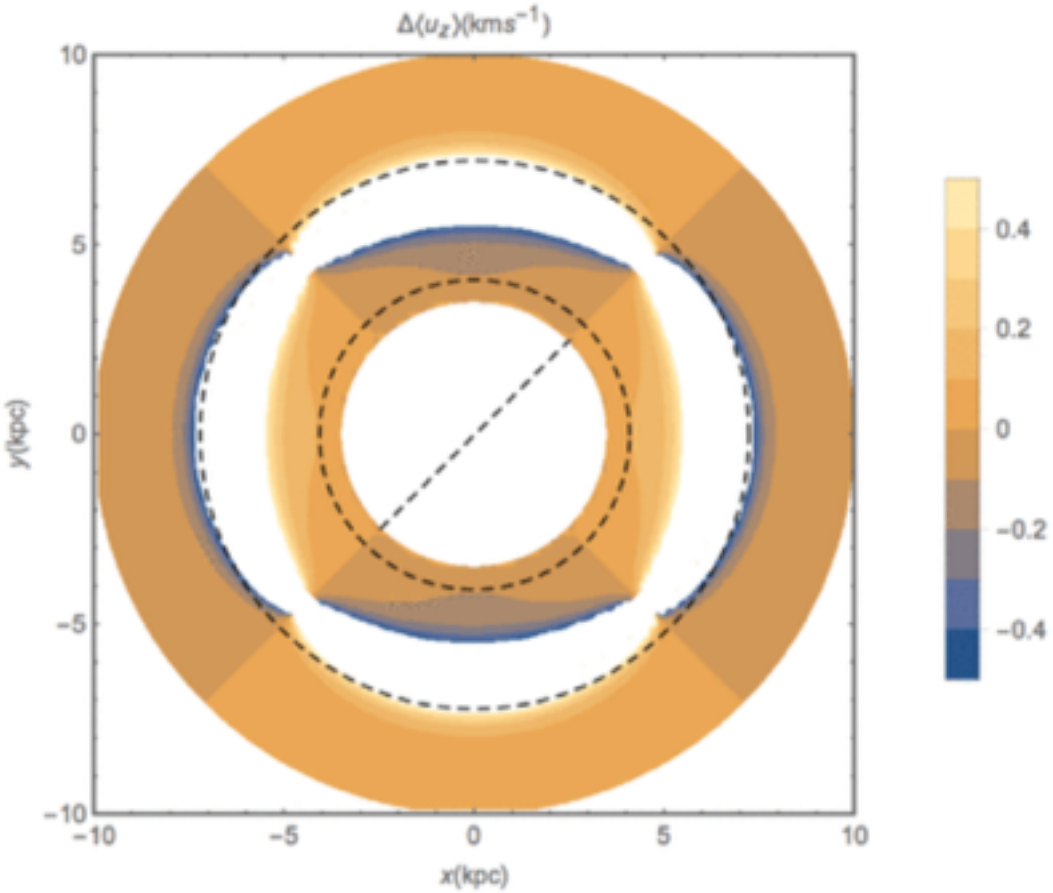
Vertical bulk motion:
The bar does have an effect but is it low





Effect of satellites

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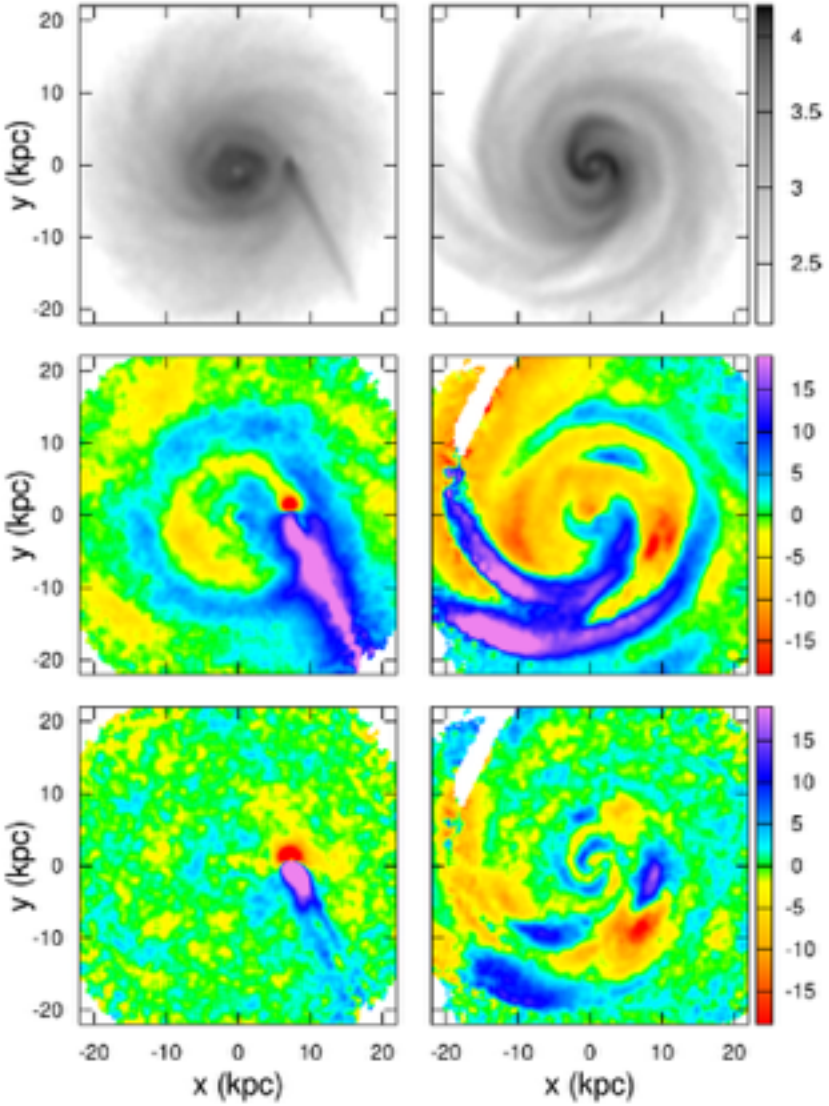

Figure 10. Bending and breathing perturbations induced by a $4 \times 10^9\,M_\odot$ satellite. The left-hand column shows the disc just as the satellite is passing through the mid-plane while the right-hand column shows the disc at $t = 250$ Myr. The top panels show the density map (logarithmic grey-scale shading). The middle panels show the bending-mode parameter B as defined in equation (24). The unit for B is km s^{-1}. The bottom set of panels shows the breathing-mode parameter A in unit of km s^{-1}kpc^{-1}.

$$\bar{v}_z(x,\ y;\ z) = A(x,\ y)\,z + B(x,\ y)\,.$$

Bending mode

Breathing mode

East/West responses are quite different

Widrow et al. 2014

(see also Feldmann & Spolyar 2015)

Effect of satellites

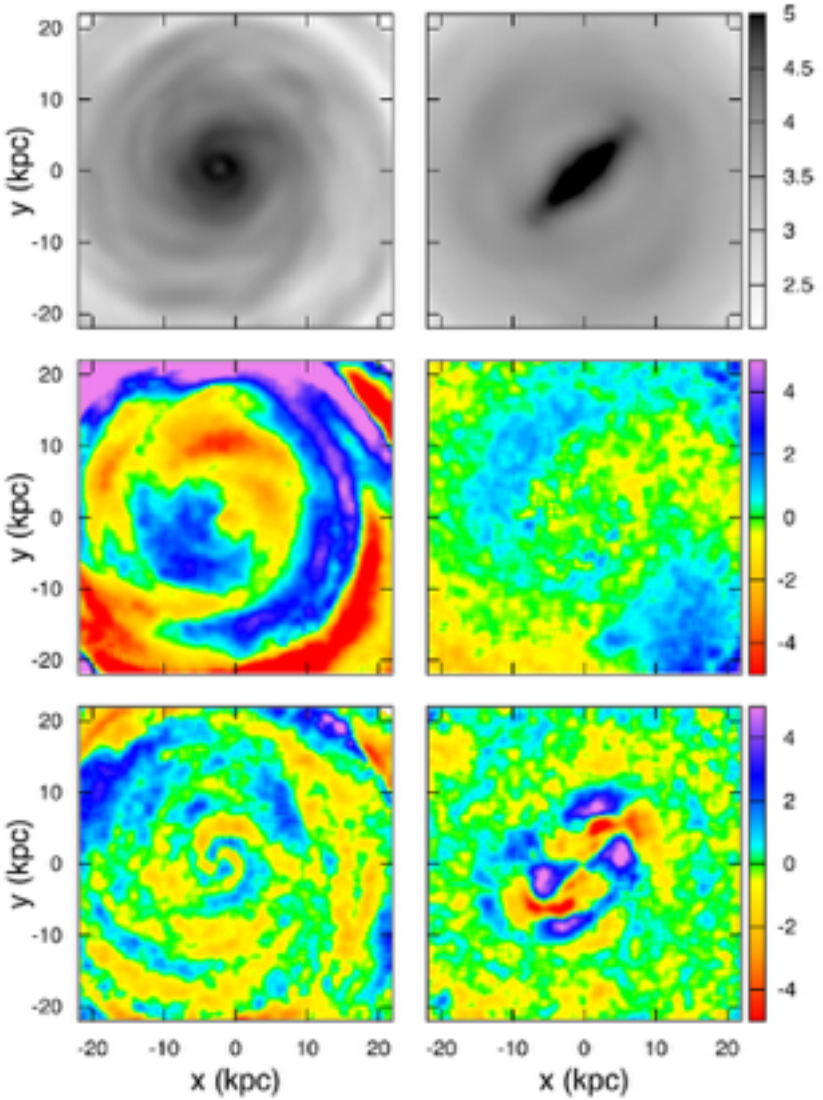

Figure 12. Face-on map of the surface density and the bending- and breathing-mode strengths for the Gauthier et al. (2006) simulation. Left-hand panels show the galaxy at 2.5 Gyr, which is prior to the formation of the bar while the right-hand panels show the galaxy at 10 Gyr, which is well after the bar has formed. The top panels show the logarithmic grey-scale maps of the density. The middle panels show the bending-mode strength in unit of $\mathrm{km\,s^{-1}}$, while the bottom panels show the breathing-mode strength in unit of $\mathrm{km\,s^{-1}\,kpc^{-1}}$.

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$$\bar{v}_z(x,\ y;\ z) = A(x,\ y)\,z + B(x,\ y)\,.$$

Bending mode

Breathing mode

East/West responses are quite different

Widrow et al. 2014

(see also Feldmann & Spolyar 2015)

How can we know

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  - Bending modes -> satellites
  - Breathing modes -> satellites, spiral arms
  - Radial bulk motion -> bar, spiral arms, satellites

- To differentiate the effects of internal perturbations from the effect of satellites: Need for large scale maps and/or precise measurements along selected line of sight.

Particle-test simulations

- 3D simulations, BS integration
- 50×10^6 particles
- Only classical disc perturbations are considered
  - Spiral arms
  - Central bar
  - Spiral + bar

  + no perturbation

Signature in μ_{ell}

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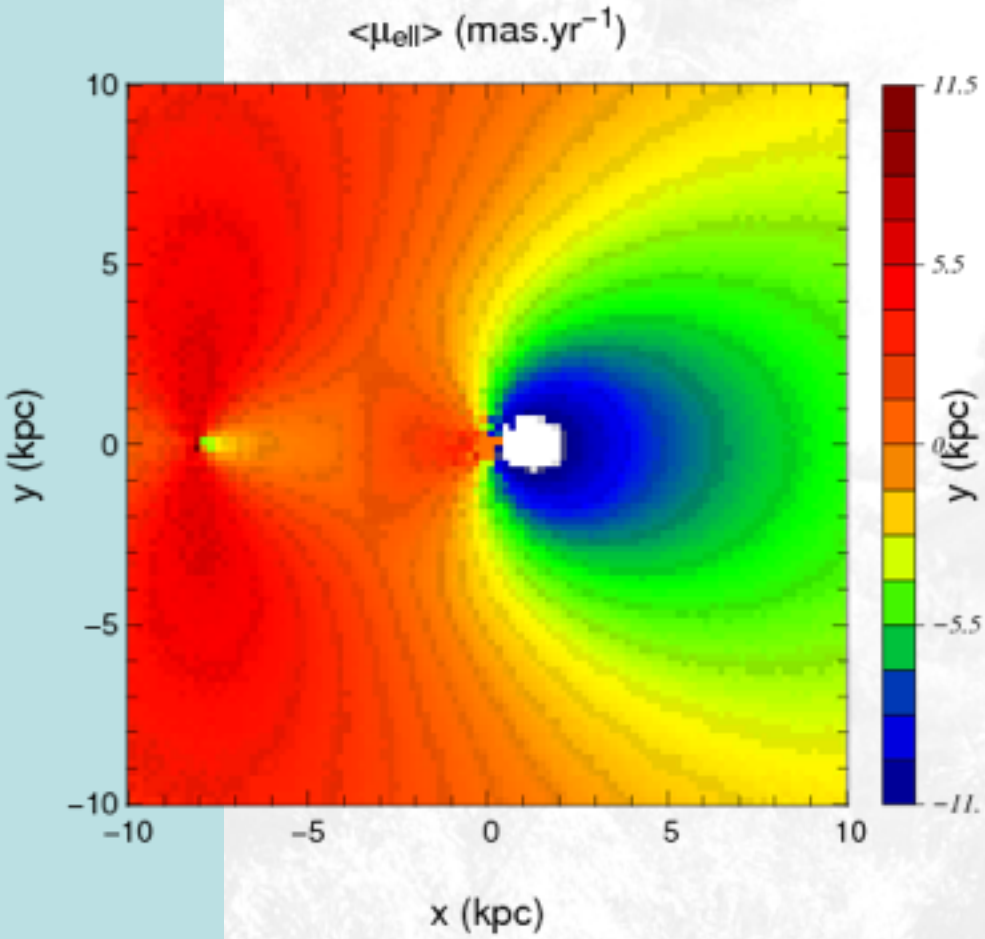
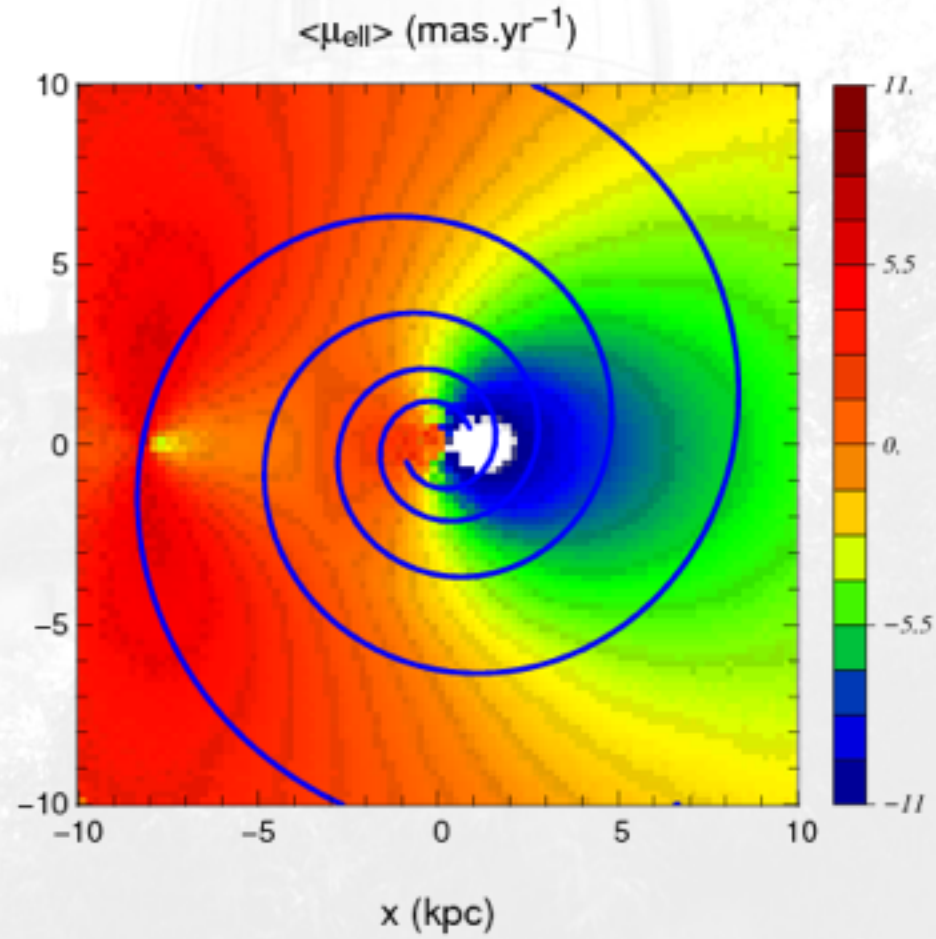
Axisymmetric model



Spiral model



Signature in μ_{ell}

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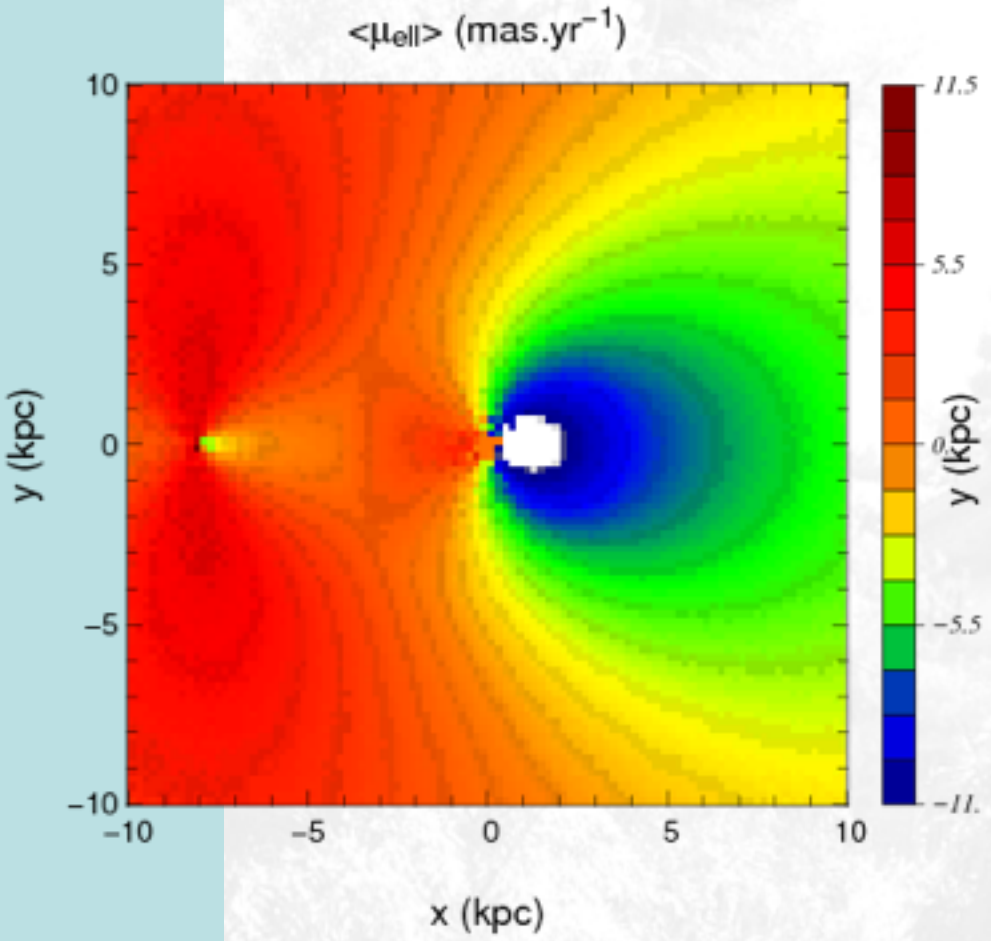
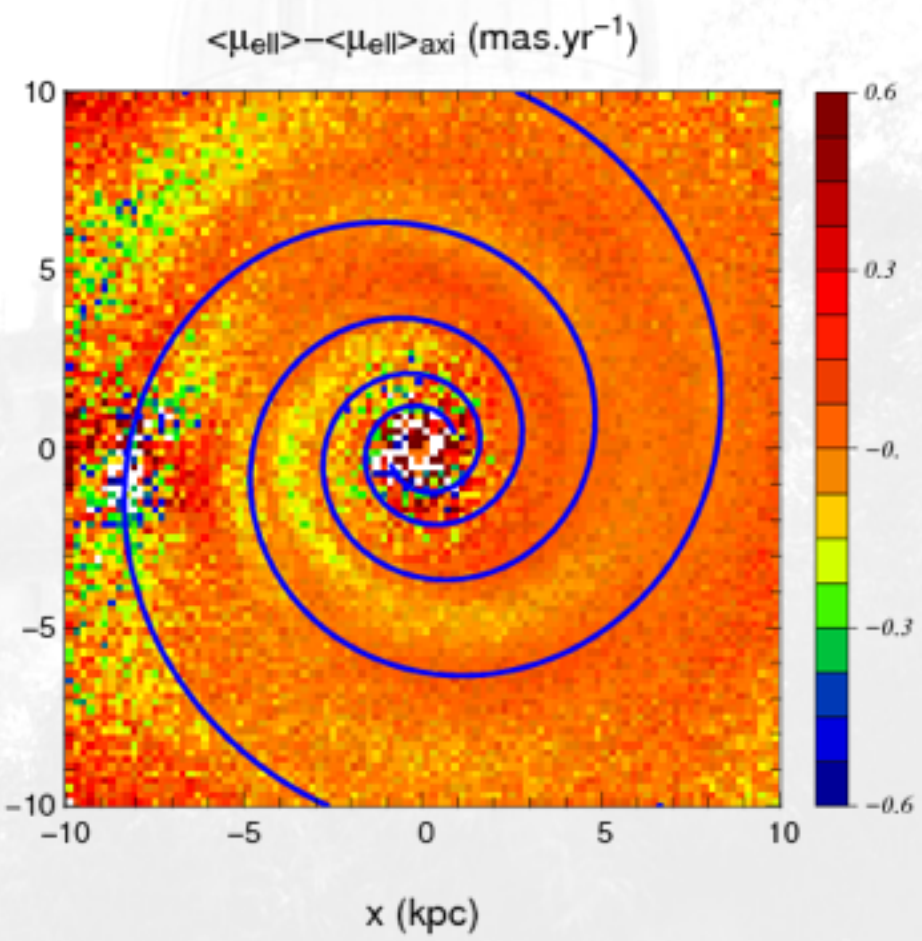
Axisymmetric model



Spiral model



Signature in μ_{ell}

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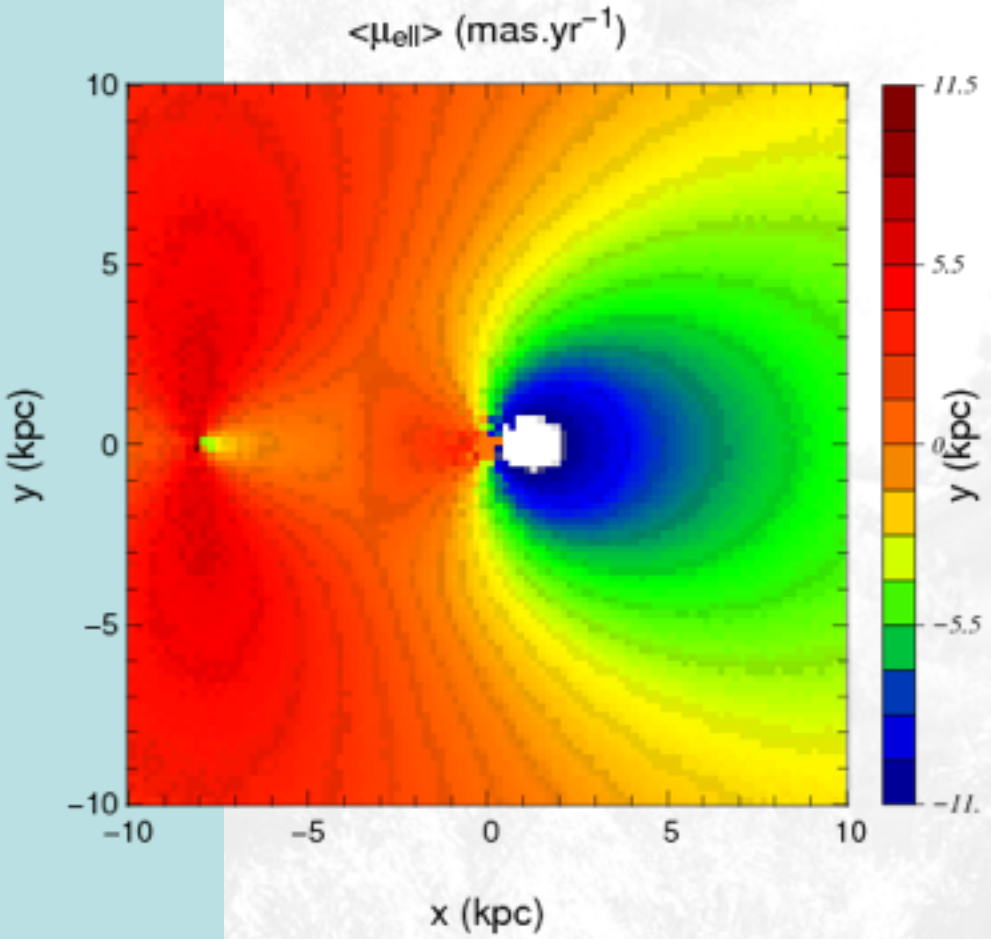
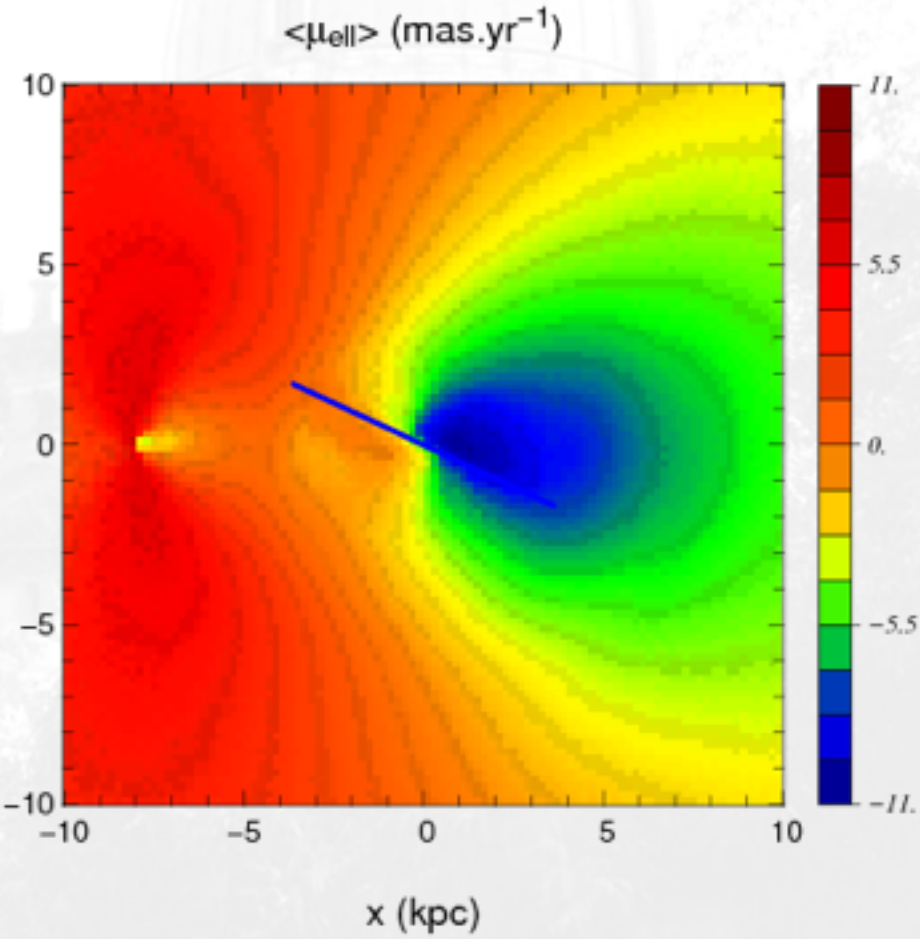
Axisymmetric model



Bar model



Signature in μ_{ell}

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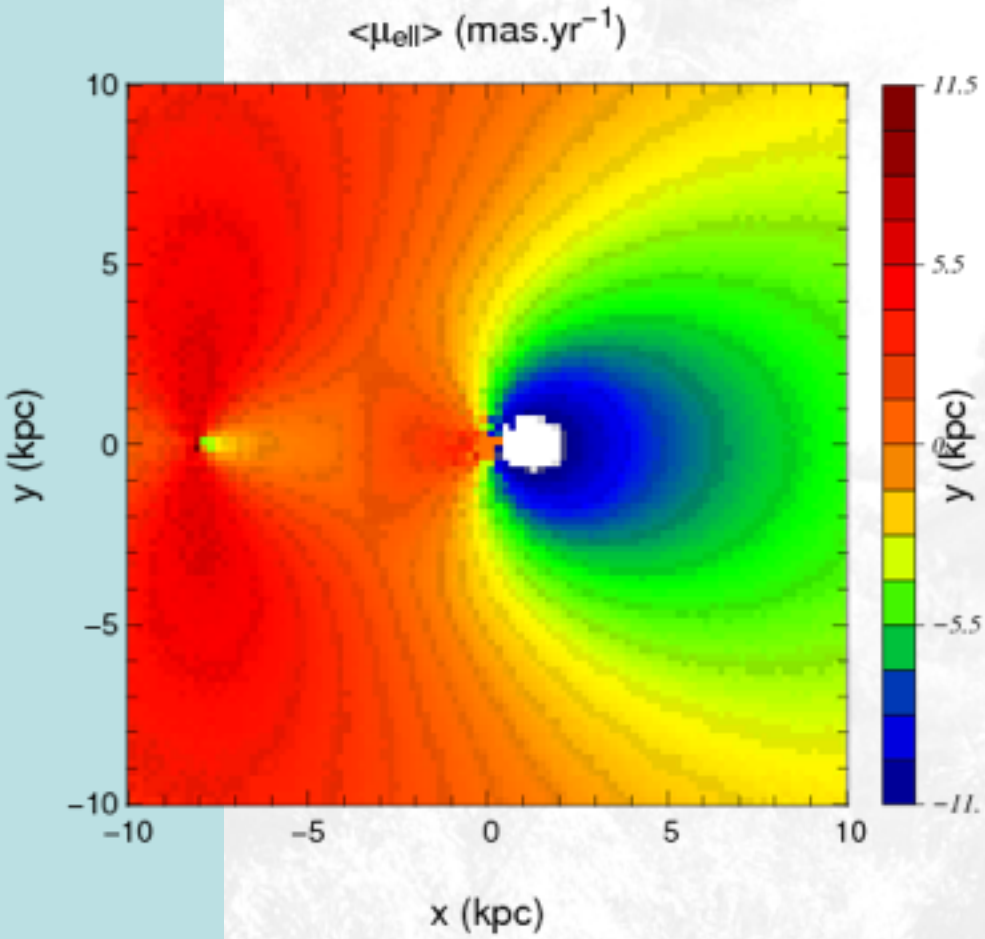
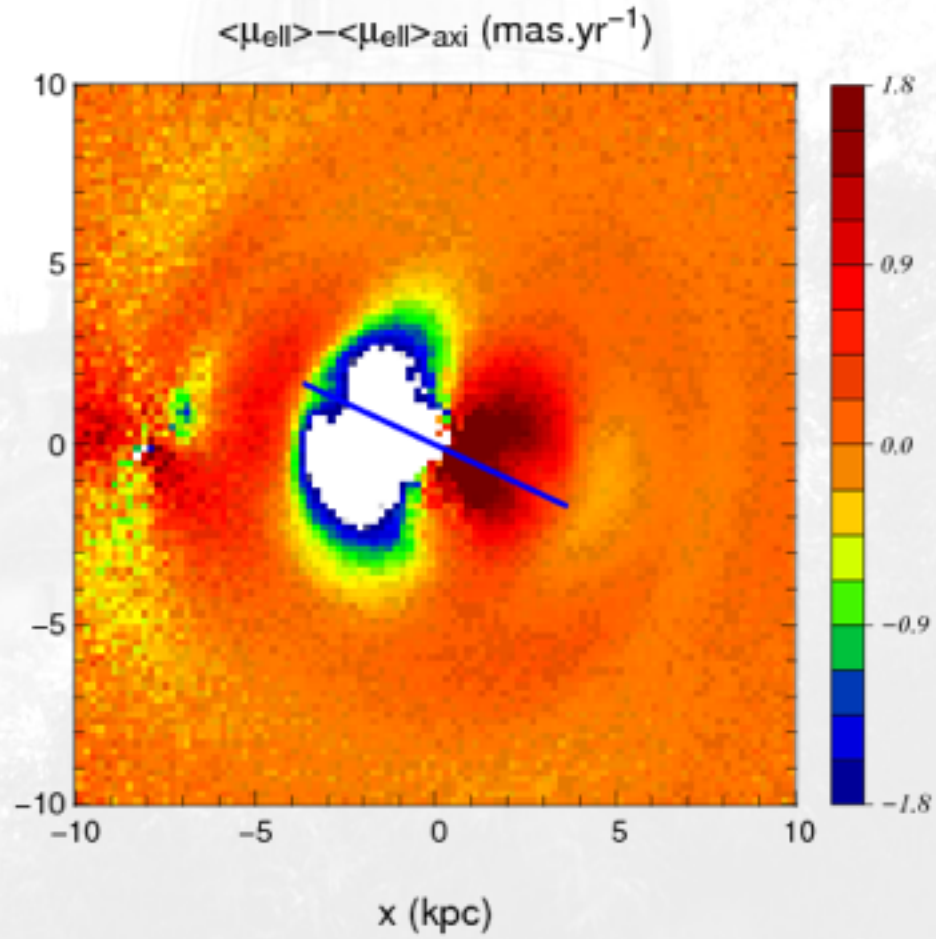
Axisymmetric model



Bar model



Signature in μ_{ell}

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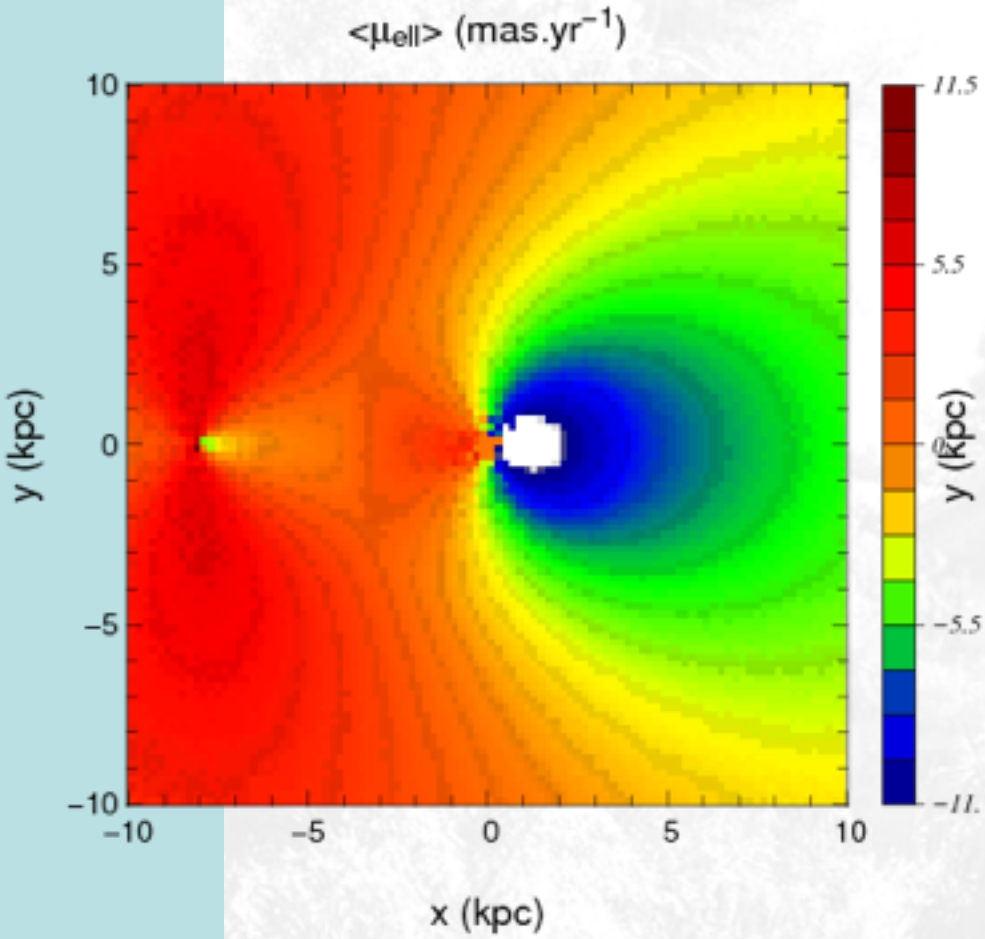
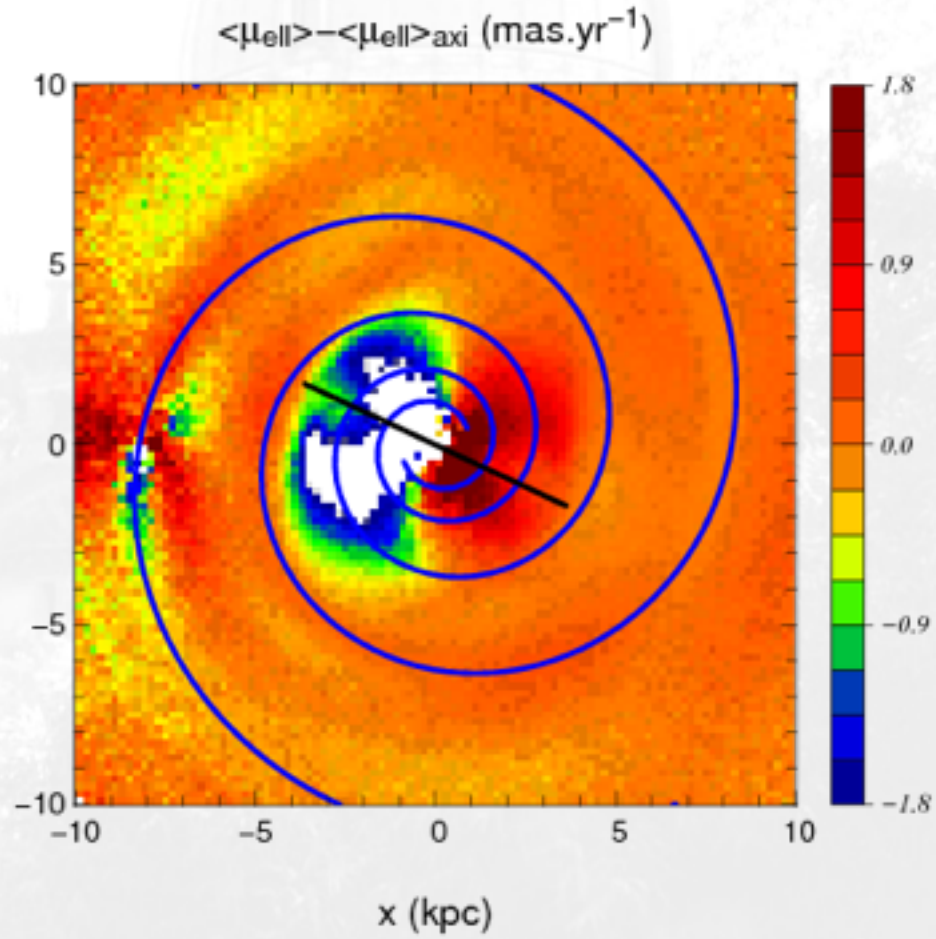
Axisymmetric model



Bar + spiral model



Signature in μ_{ell}

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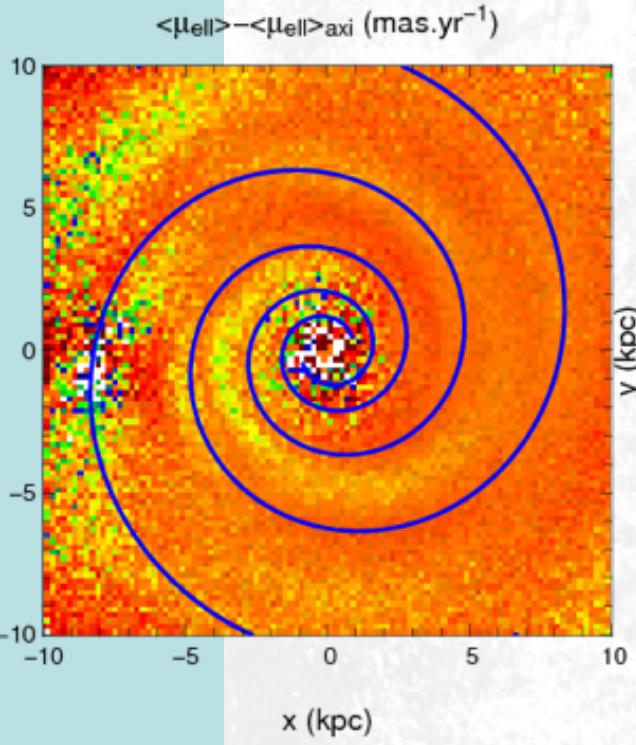
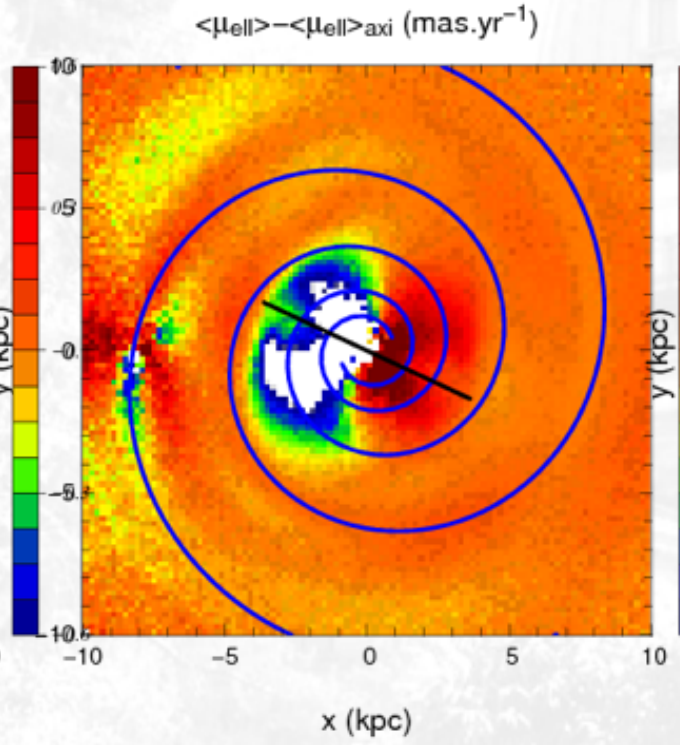
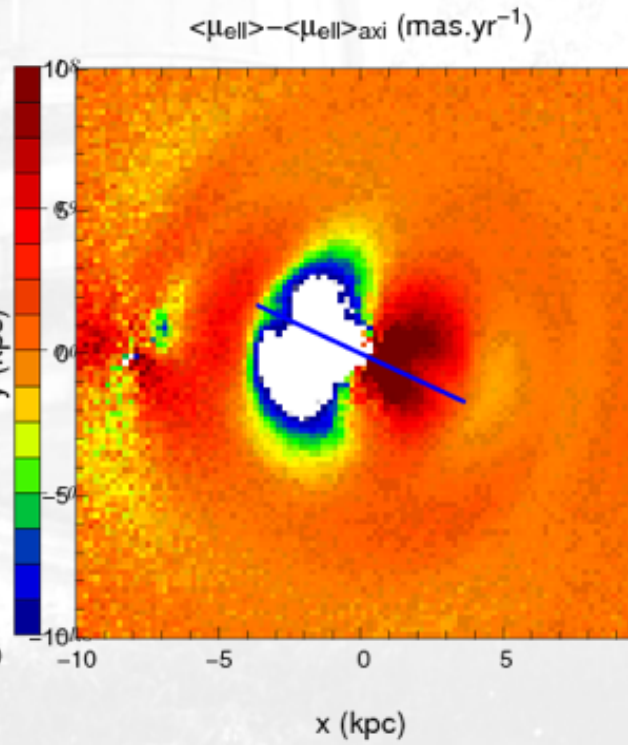
Spiral model



Bar + spiral model



Bar model



Gross features add up

But non linear coupling : ony far away from resonances are the perturbations separable

Signature in μ_b

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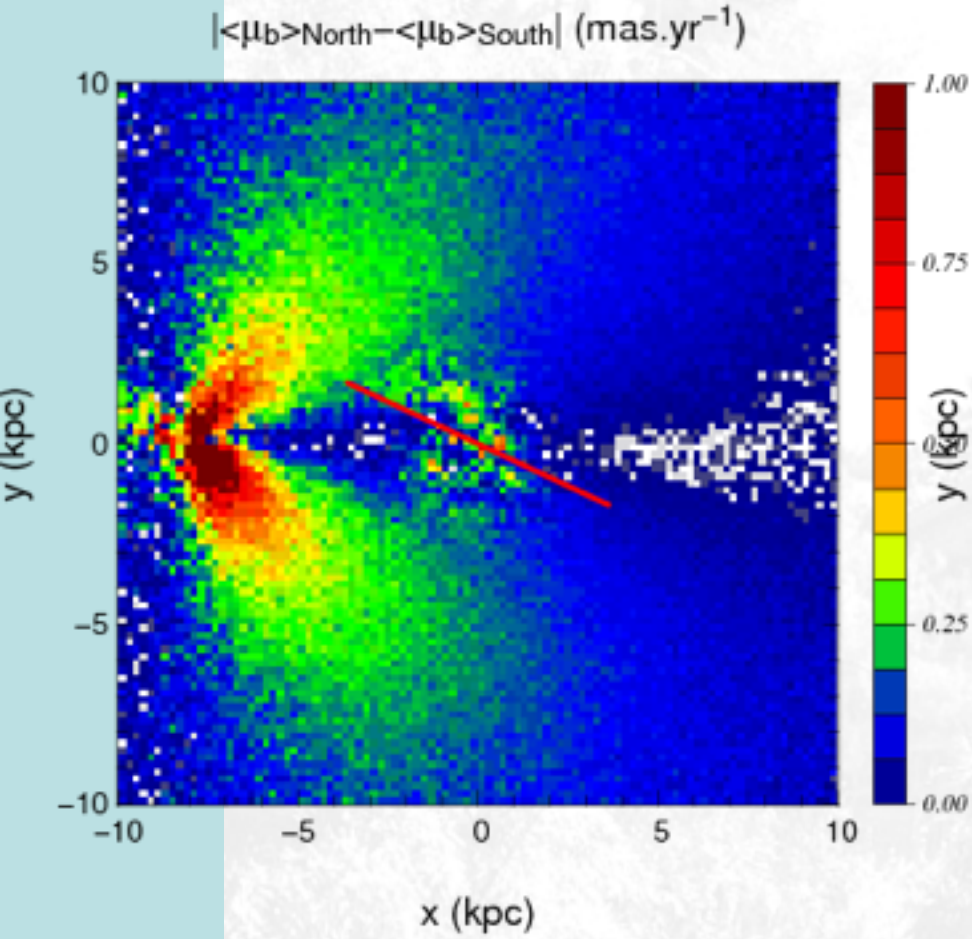
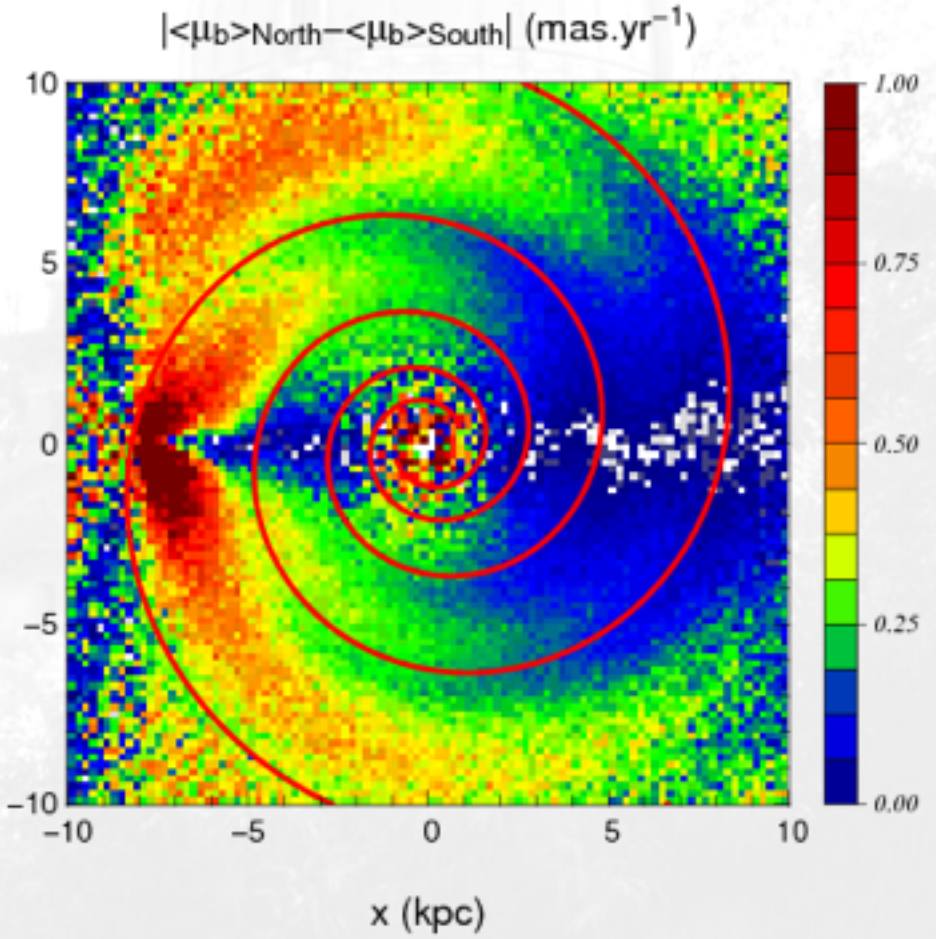
Bar model



Spiral model



Signature in μ_b: bar+spirals

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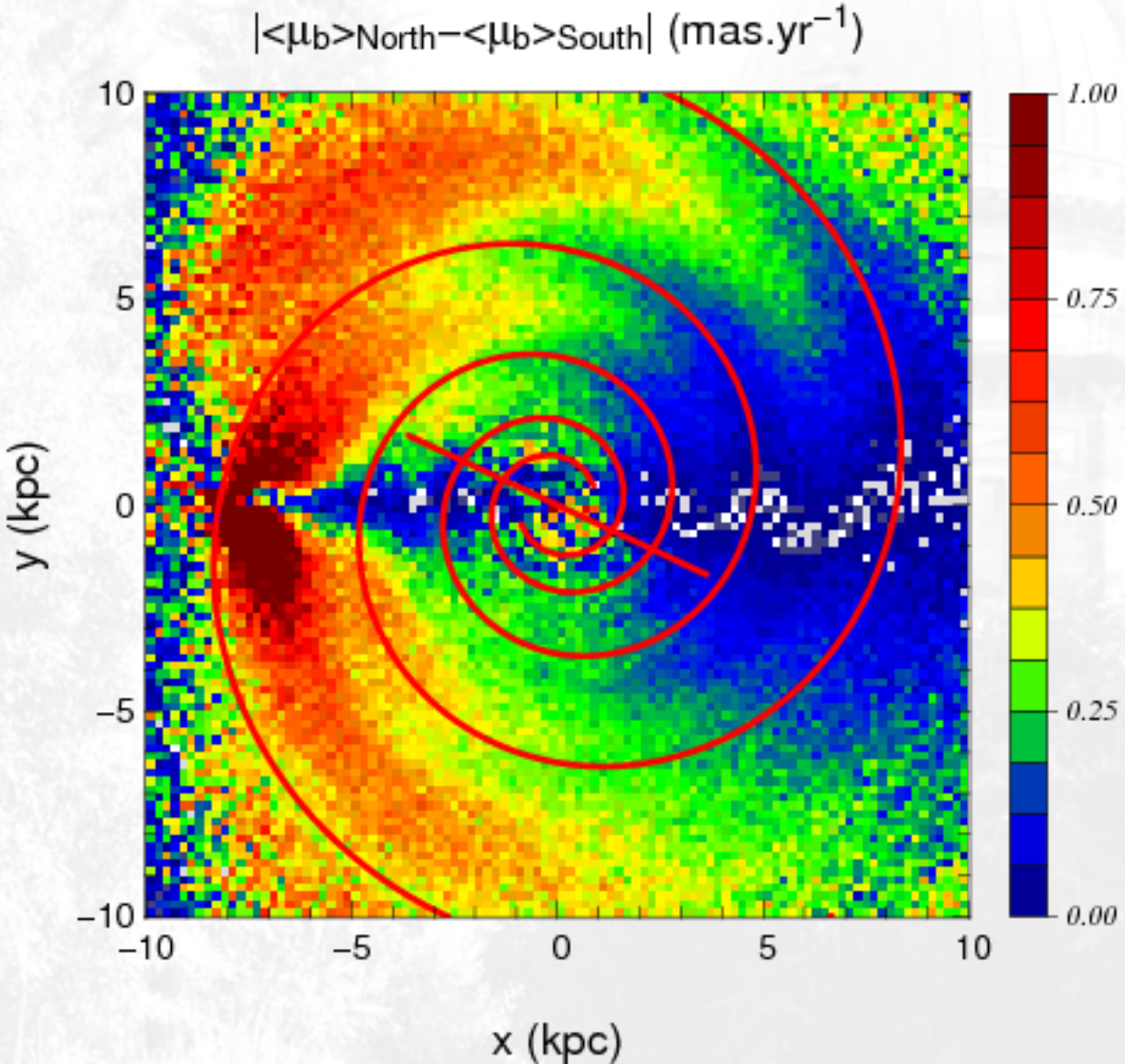

Signature in μ_b

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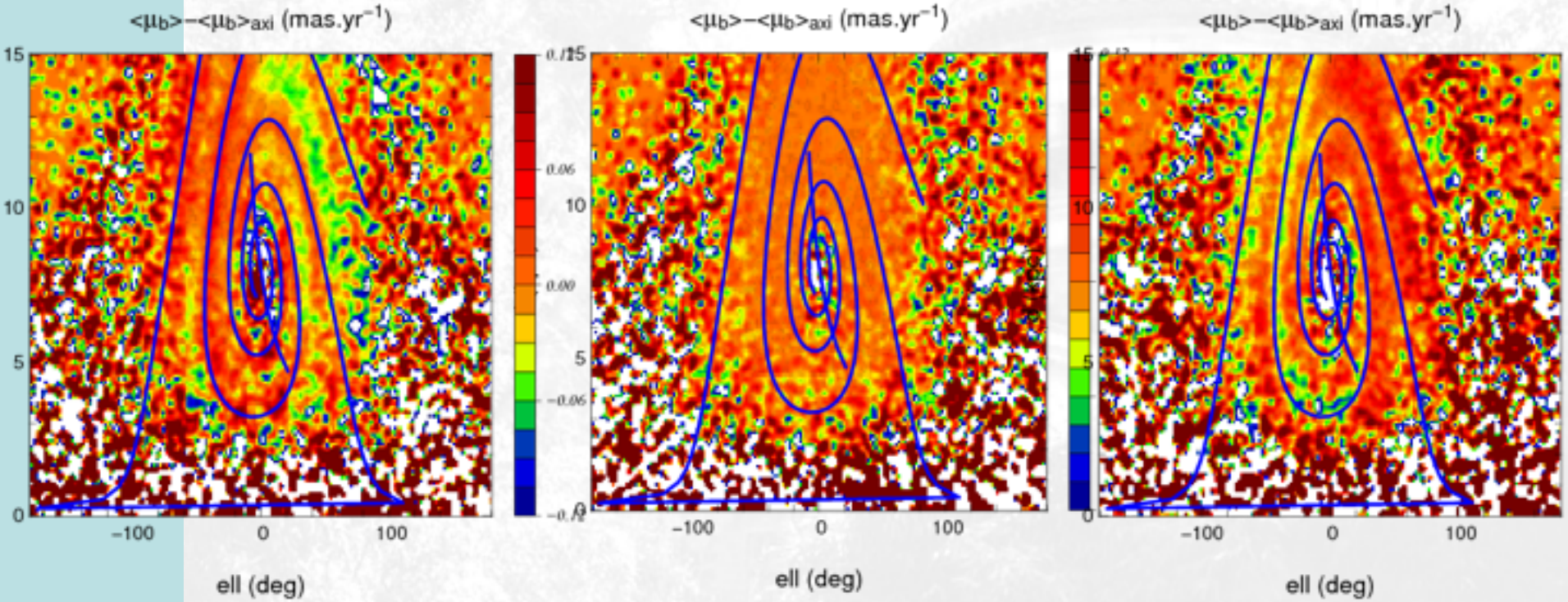
b=-2 **b=0** **b=+2**



Signature in μ_{ell}

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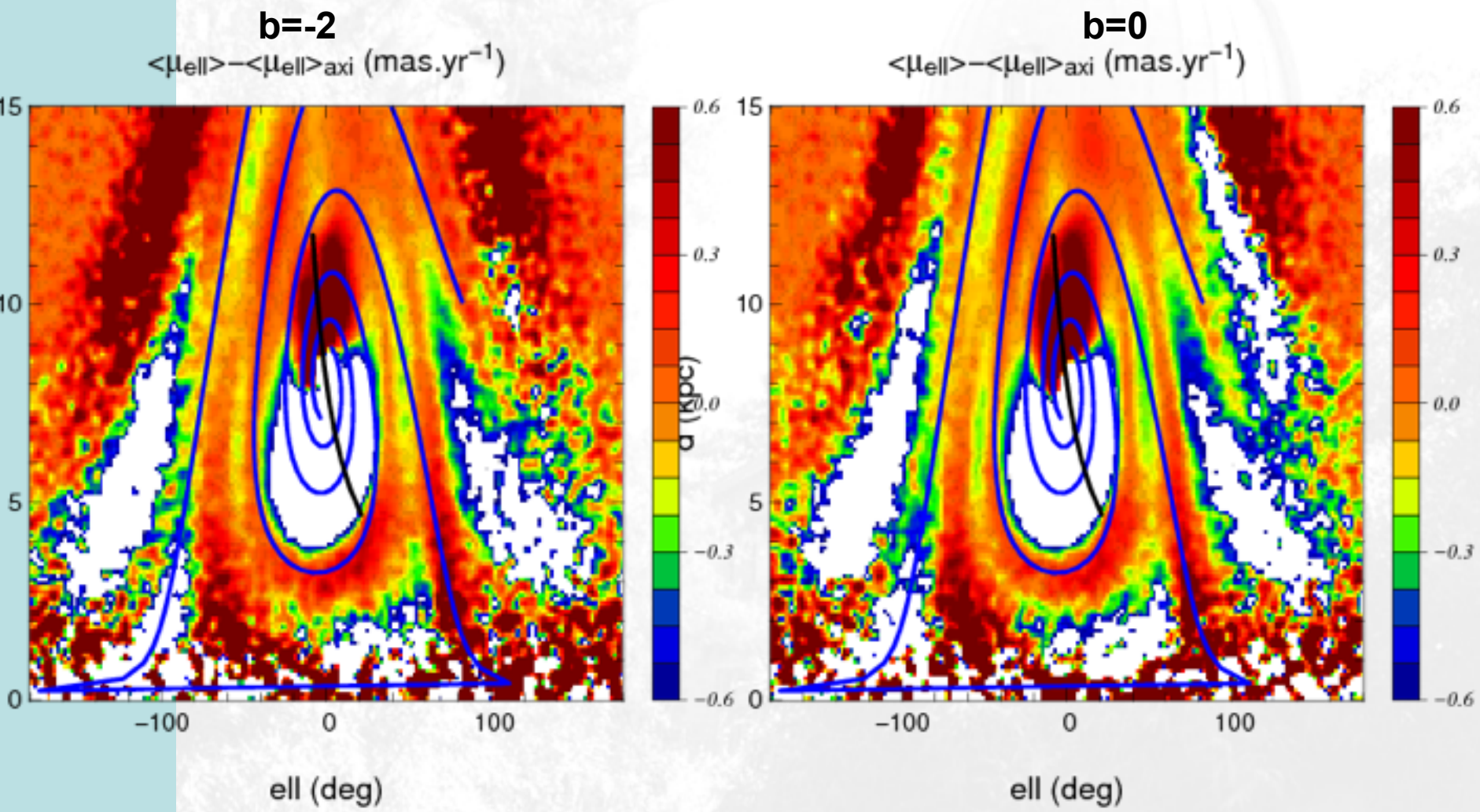

No strong variation with b expected

Summary

- Perturbations in the disc leave imprints at the level of ~100 μas/yr and lower
  - Proper motion to a few μas/yr needed
- Differences between perturbations on large scale
  - Distributed los
  - North/south differences
- Within reach of Theia if crowding and extinction can be handled (NIR?)