Different models of the Galactic spiral structure: kinematical and morphological aspects

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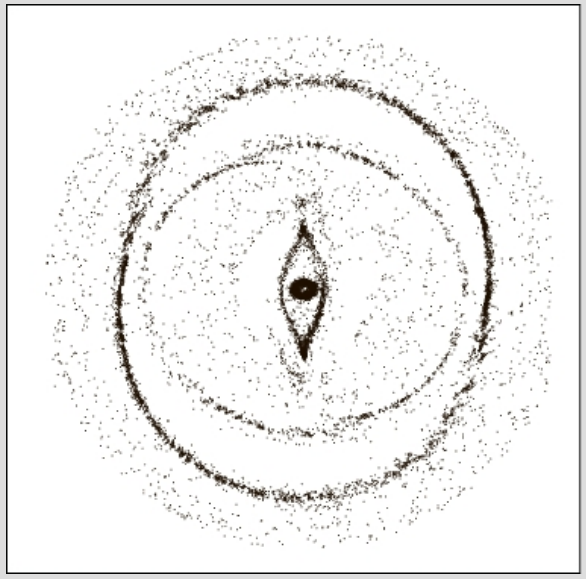
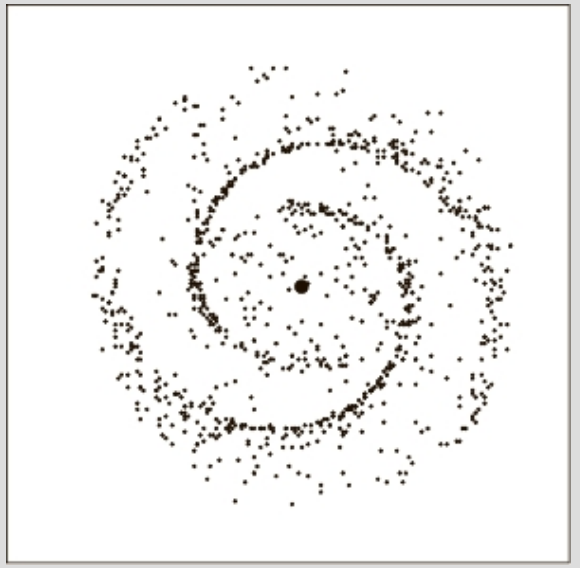
Three different models

Outer ring R1R2



Transient
spiral arms

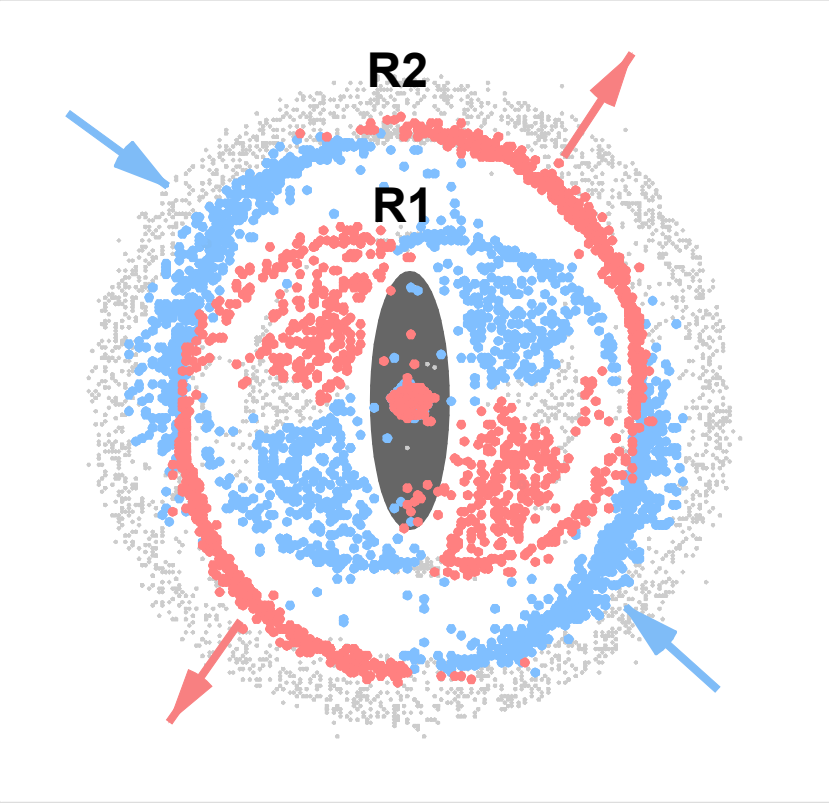
Regular spiral
pattern Ω = const



These models create different patterns in the distribution of velocities in the galactic disk.

Model with the outer ring R1R2
which is often forming near the OLR of the bar

Distribution of model particles with the VR directed toward ● and away ● from the galactic center.

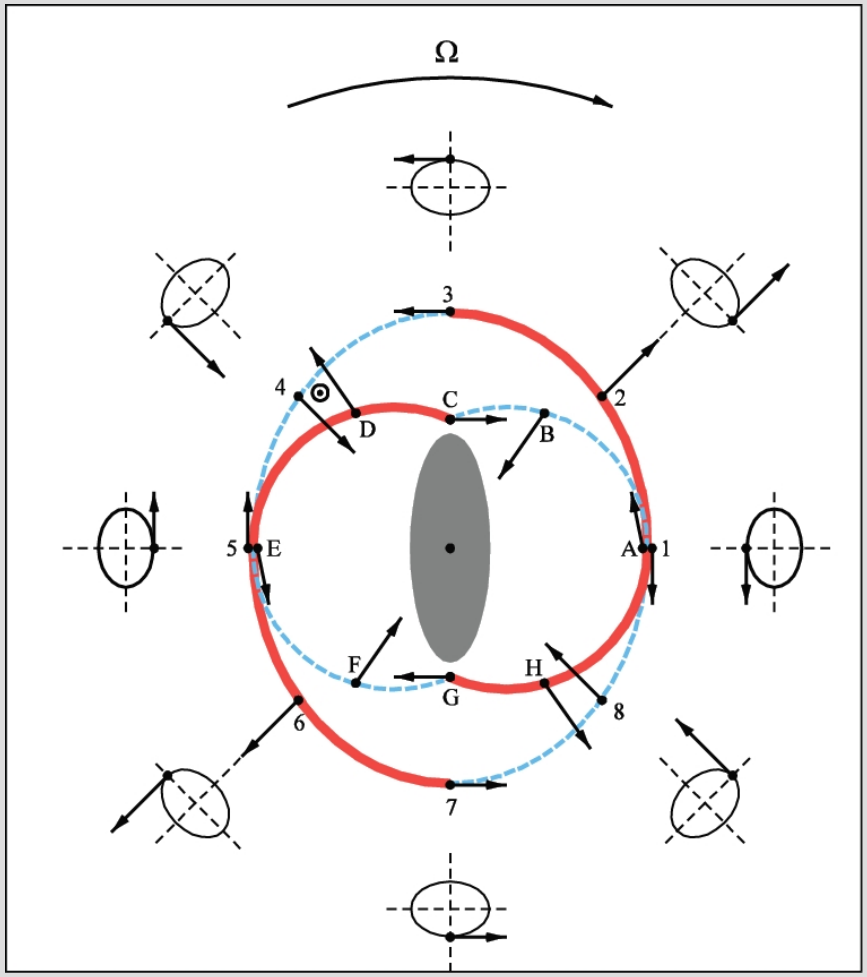


VR velocity
changes its direction
in sectors along
the azimuthal angle.

Analytical bar:
fast bar, T=800 Myr
test particles,
collide inelastically,

(Mel'nik & Rautiainen 2009)

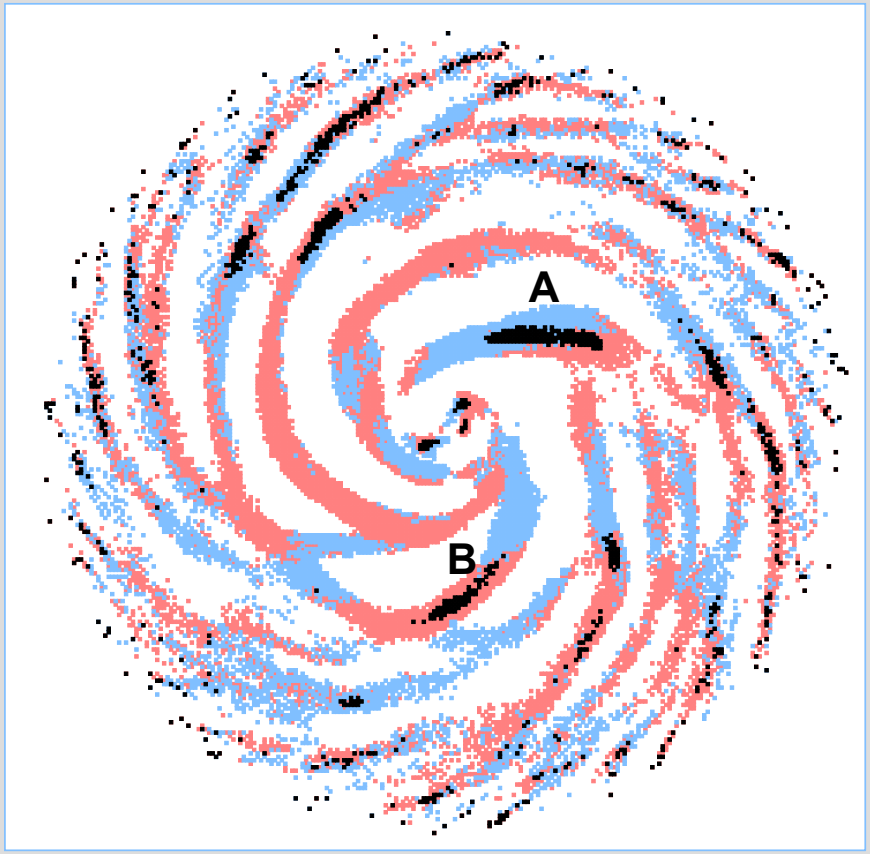
Resonance kinematics



The resonance between the epicyclic and orbital motions adjusts the epicyclic motions in accordance with orbital rotation. That creates systematical non-circular motions whose direction depends on the azimuthal angle of a point with respect to the bar and on the class of the outer ring (R1 or R2)

Kinematics of the transient spiral arms

Distribution of the VR directed toward ■ and away ■ from the galactic center averaged in areas 150 x 150 pc.



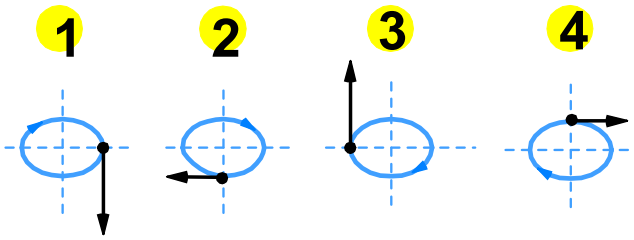
VR changes its direction near the overdensities "A" and "B".

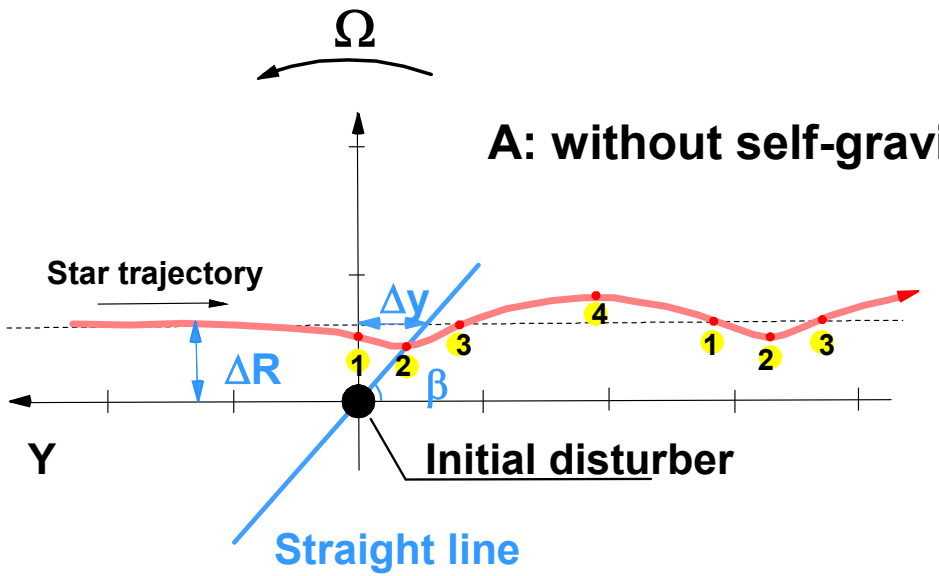
N-body model of the stellar disk with the initial value of QT=1.2 at T=600 Myr, P. Rautiainen.

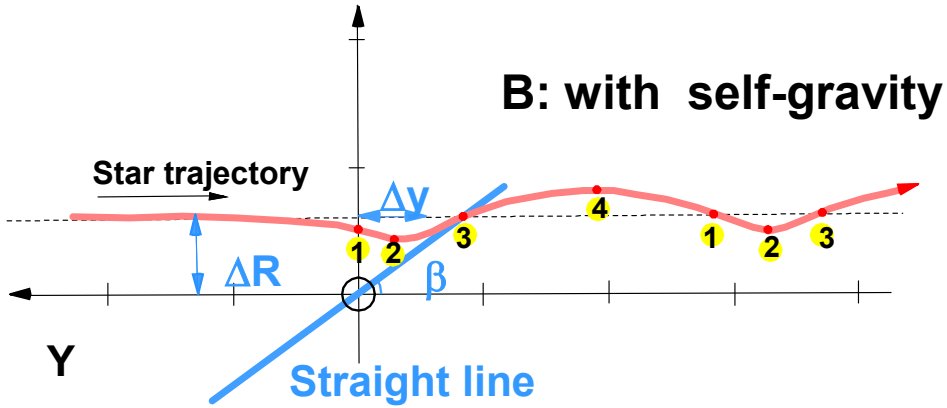
Only areas with n/n0 > 1 are shown. Areas (overdensities) with n/n0 > 2 ■

Some spiral arms consist of the straight lines.

(Mel'nik & Rautiainen 2013)







Formation of
a straight line
near
the initial disturber.

Without self-gravity
the pitch angle β
of straight line is

$$\beta = \arctan\frac{2\sqrt{2}}{\pi} = 42^\circ$$

With self-gravity β is

$$\beta = \arctan\frac{\sqrt{2}}{\pi} = 24^\circ$$

Julian & Toomre (1966)

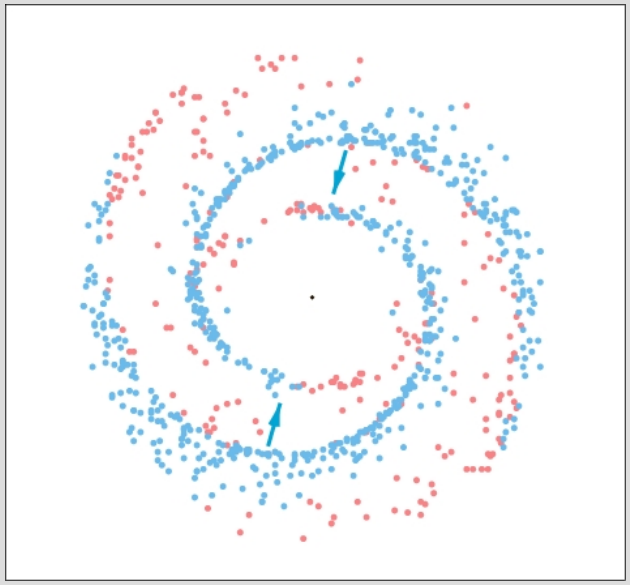
Mel'nik & Rautiainen (2013)
model shows β = 28°

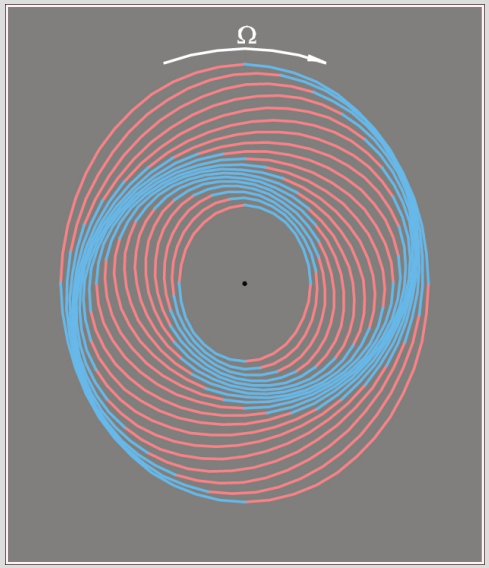
Density-wave kinematics inside the Corotation Radius (CR)

Distribution of OB-particles with the VR directed toward ● and away ● from the galactic center.
Spiral perturbation of the potential rotating with

Ω_s = 20 km/s/kpc, T=100 Myr

Kalnajs (1973)



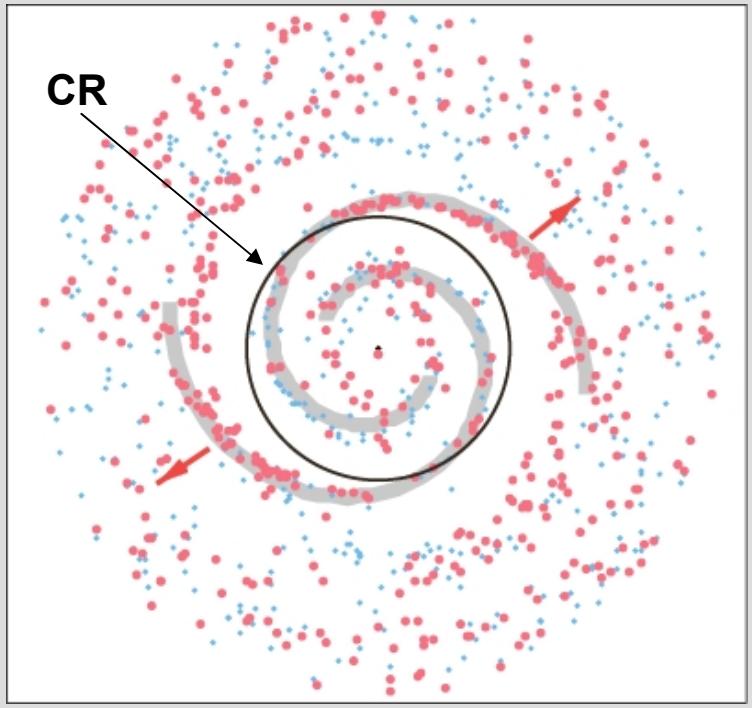


Inside the CR, objects located in spiral arms have the VR directed toward ● the galactic center.

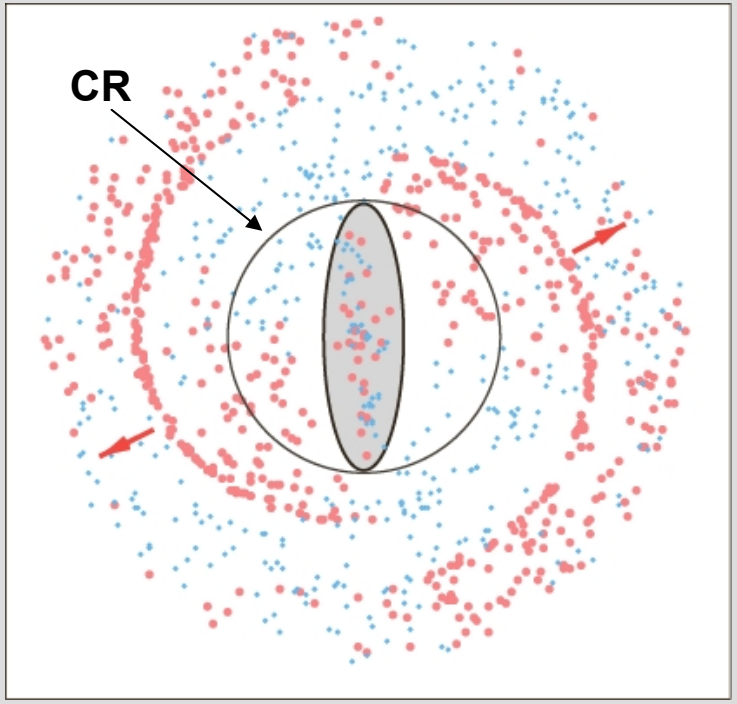
Density-wave kinematics outside the CR

Distribution of OB-particles with the positive ● and negative ● VR

Only spiral perturbation of the potential, no bar, Ω_s = 60 km/s/kpc, T=150 Myr

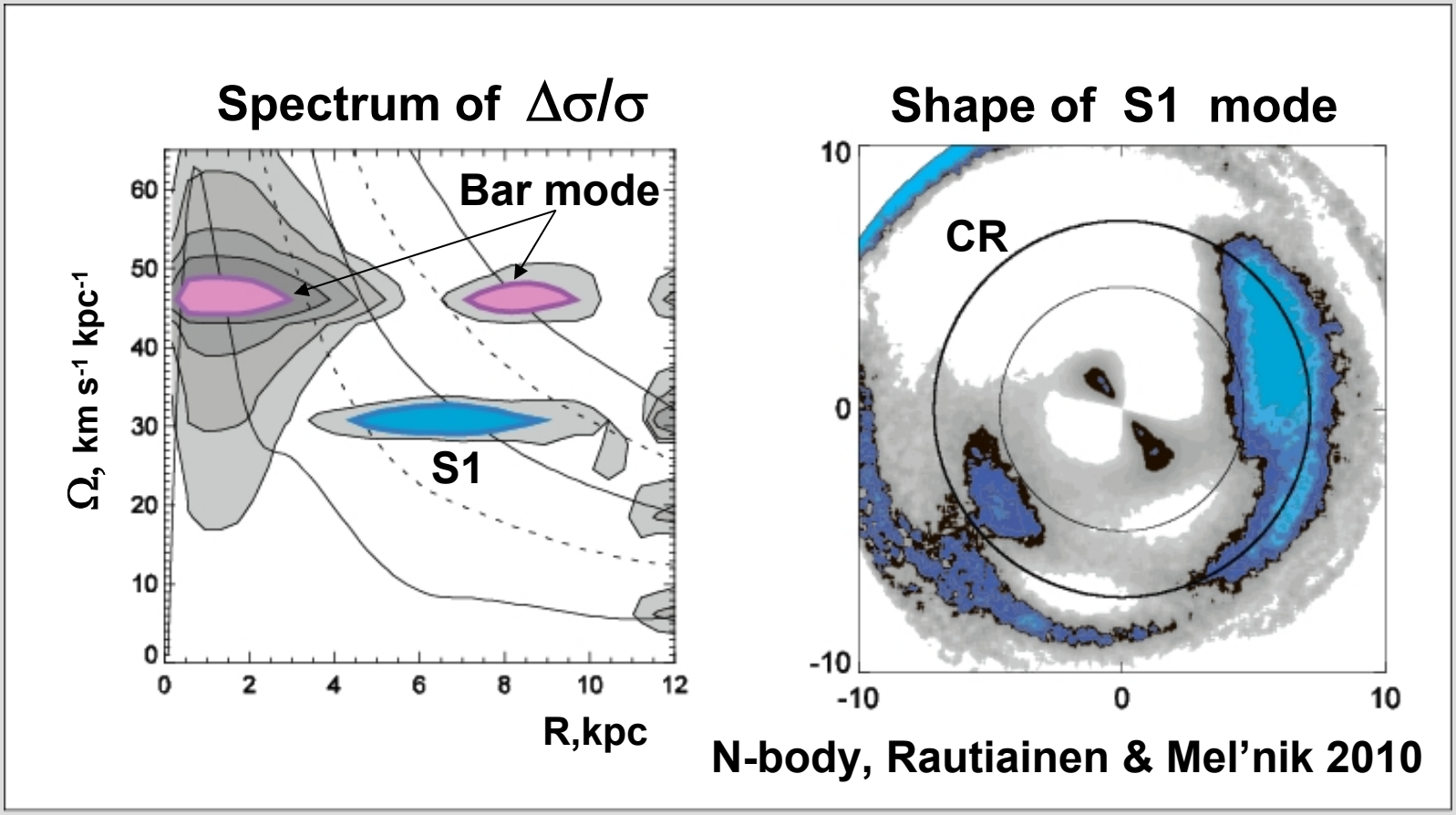


Only analytical bar, no spiral arms, Ω_b = 60 km/s/kpc, T=400 Myr



Outside the CR, objects in spiral arms made by whether the spiral or bar potential have the VR directed away ● from the galactic center.

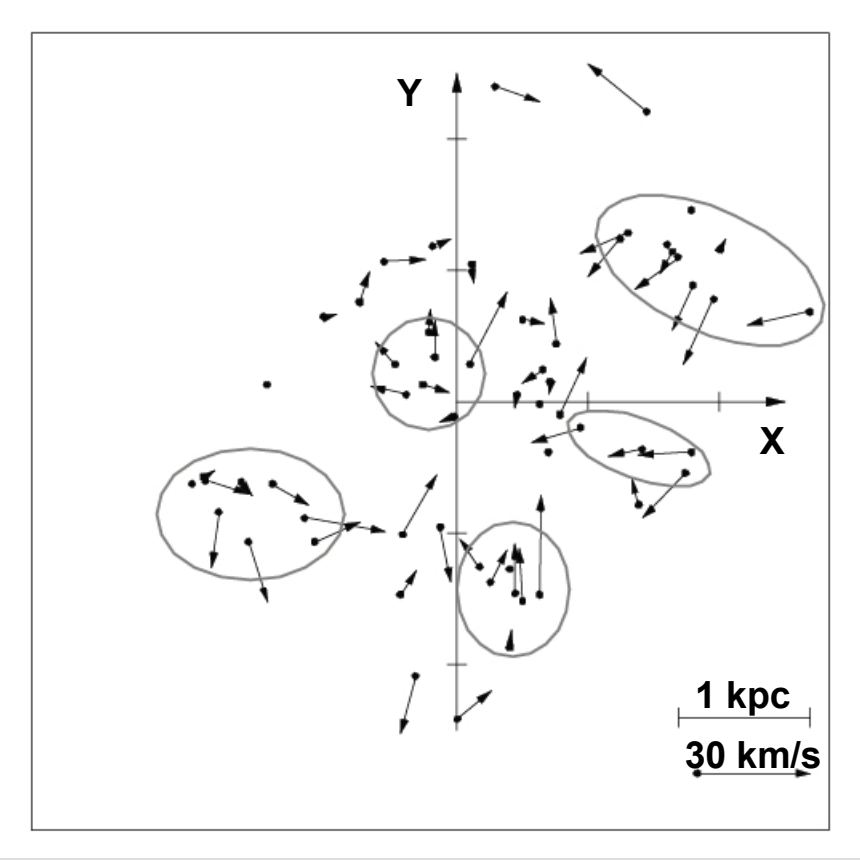
Slow modes – some patterns that rotate slower than the bar



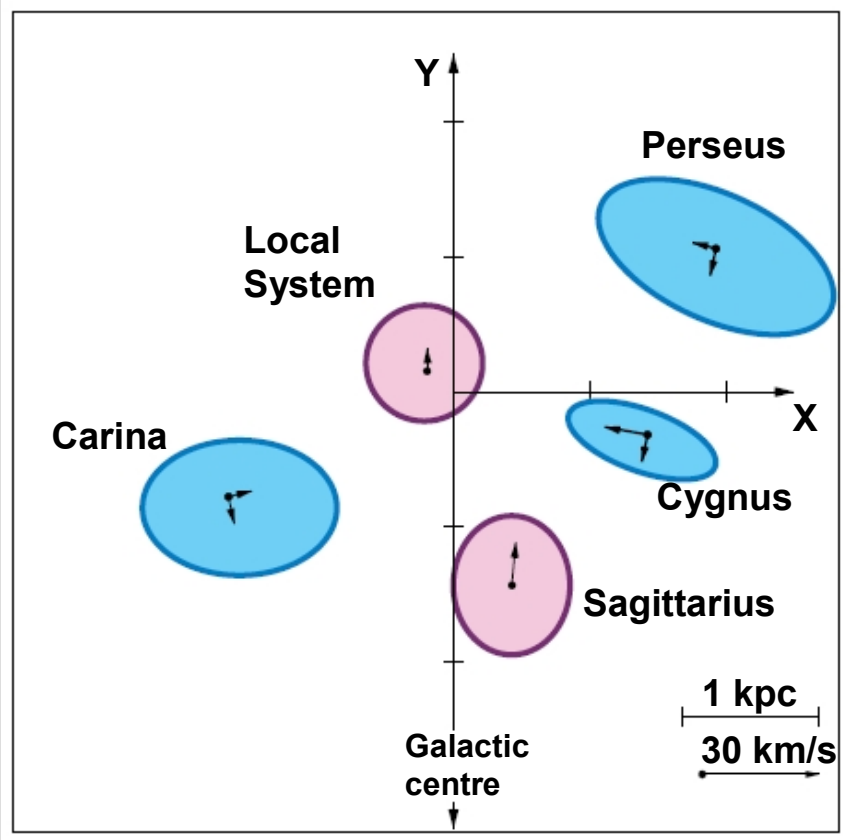
S1 – the strongest slow mode.
Slow modes are not spiral-shaped, they don't show the density-wave kinematics and rather look like overdensities which appear and disappear near the OLR of the bar.

Distribution of residual velocities in the Galactic disk
Vres = Vobs – Vrot – Vapex

OB-associations

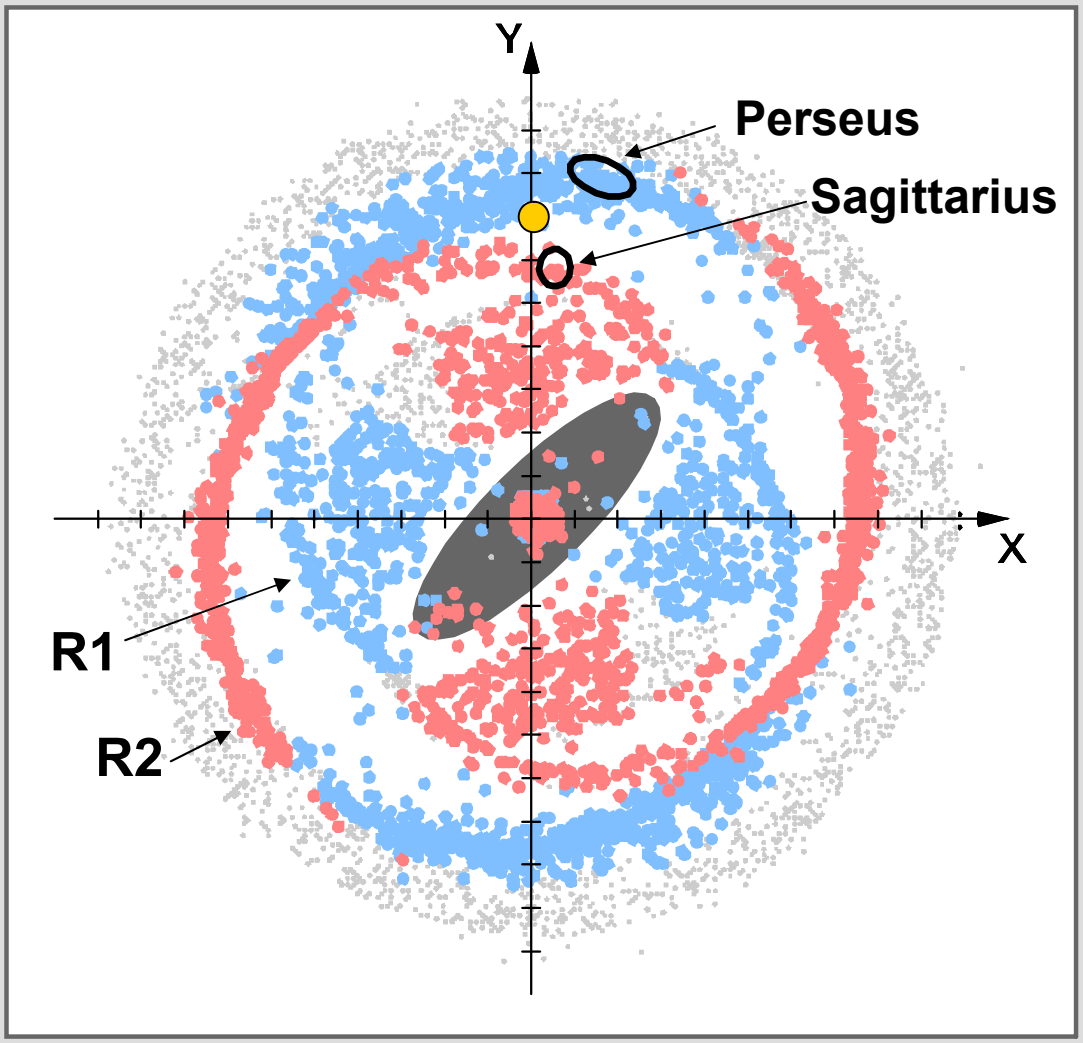


Vres averaged in complexes



Most OB-associations in the Perseus complex have the VR directed toward ● the Galactic center, while most OB-associations in the Sagittarius complex move away ● from the Galactic center (Mel'nik & Dambis 2009).

The positions of the Perseus and Sagittarius complexes with respect to the outer rings R1 and R2



The Perseus complex is related to the ring R2, while the Sagittarius complex lies in the vicinity of the ring R1.

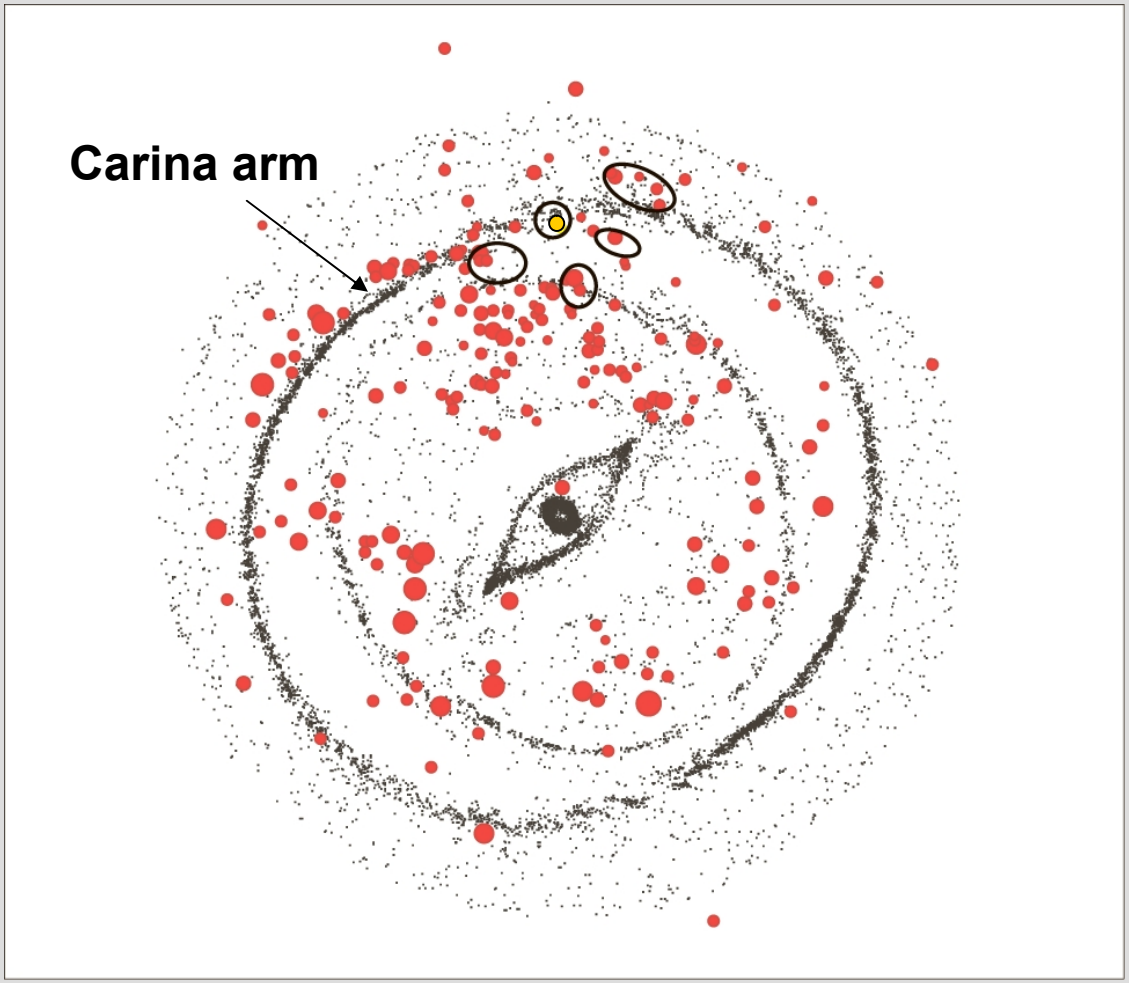
The best agreement corresponds to $\theta_b = 45°$.

($L - V_{LSR}$) diagrams

All three types of models considered are able to reproduce well nearly all main features of observed (L-V_{LSR})-diagrams in the distribution of of ^{12}CO (Dame et al. 2001).

See, for example,
Bissantz, Englmaier & Gerhard 2003;
Mel'nik & Rautiainen 2011;
Pettitt et al. 2015;
Li at al. 2016
and others.

Distribution of giant star-forming complexes from the catalog by Russeil (2003) ○ and OB-particles • in model with analytical bar



Model of the Galaxy with the outer ring R1R2 can easily reproduce the position of the Carina arm whose pitch angle is i=10±3°.

Transient spiral arms (i = 20 -- 30°) seem to be unable to simulate the Carina arm.

Conclusions :

1) Three types of models considered create different patterns in the distribution of velocities in the galactic disk.

2) Model of the Galaxy with the outer ring R1R2 looks most promising because it can reproduce:

a) the long bar (a=4 kpc),
b) the kinematics in the Perseus and Sagittarius complexes,
c) the proper location and pitch angle of the Carina arm.

It should be proved that model with the ring R1R2 can reproduce:

d) the overdensity connected with the Local arm,
e) the kinematics in other star-forming complexes.

3) Model with the transient spiral arms can simulate the Local arm (see, for example, Pettitt et al. 2015).

4) Model with the bar and the spiral pattern rotating rigidly with $\Omega_s < \Omega_b$ has no analogues in N-body simulations of isolated disks.

Thanks for your attention!