THE ROLE OF RESONANCES

IN N-BODY MODELS OF BARRED GALAXIES

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Realistic orbits and resonances

- **Natural frequencies of a general orbit:**

$$\Omega \ , \ K \ , \ \upsilon$$

- **Pattern frequency:** Ω_P

$$l\,K + m_1\,\Omega + n\,\upsilon = m_2\,\Omega_P$$

l , m_i , n **are integers.**

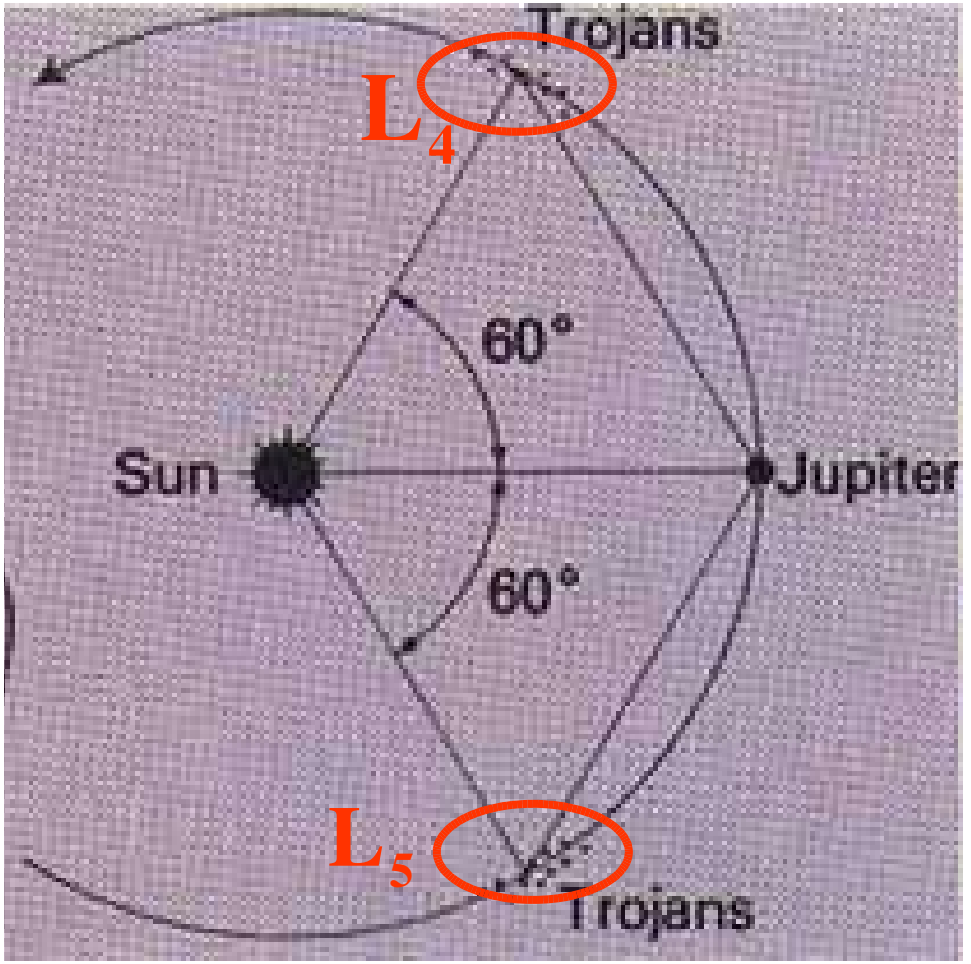
RESONANCE!

- **Linear regime: A resonance produces a dramatic change in the evolution of the orbit.**
- **This is not always the case.**

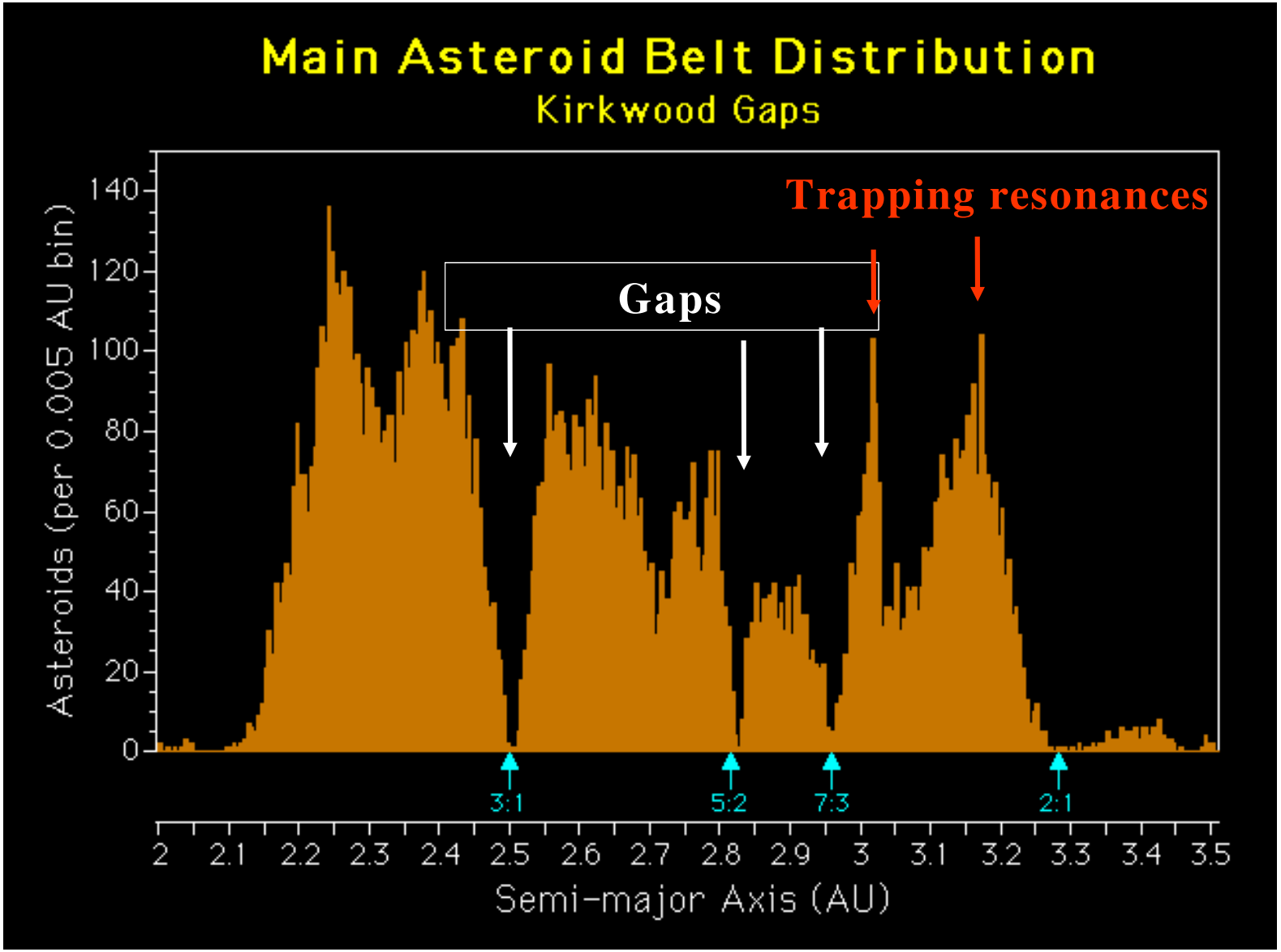
Resonances in the solar system: Trojan asteroids.

- **Libration around Lagrangian points L_4 and L_5 of the system Sun-Jupiter.**

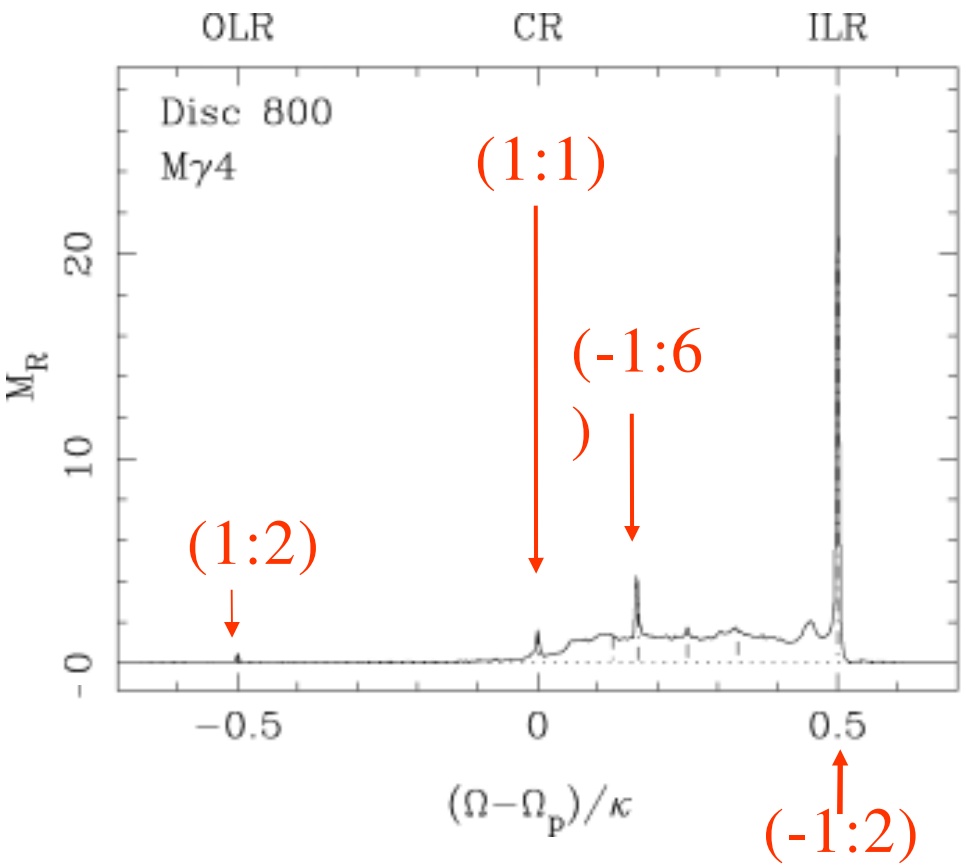
- **Example of a trapping resonance. 1:1 .**



Gaps.


Main Asteroid Belt Distribution
Kirkwood Gaps
Trapping resonances
Gaps
Asteroids (per 0.005 AU bin)
140
120
100
80
60
40
20
0
3:1
5:2
7:3
2:1
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
Semi-major Axis (AU)

Searching resonances in N-body simulations.

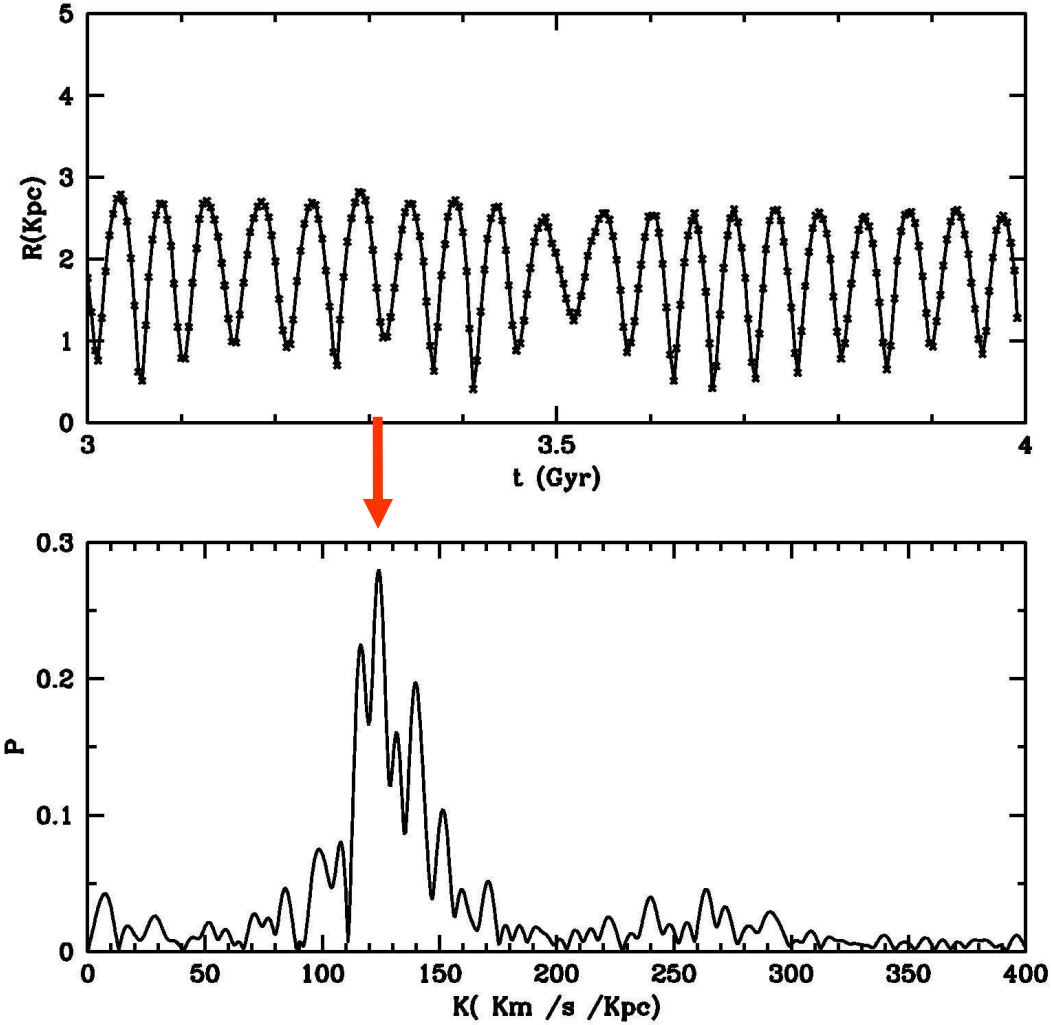


- **Athanassoula 2003:**
  - **Frozen potential.**
  - **Ratio:**

$(\Omega - \Omega_P) / K = -l / m$ **, where l and m are integers**

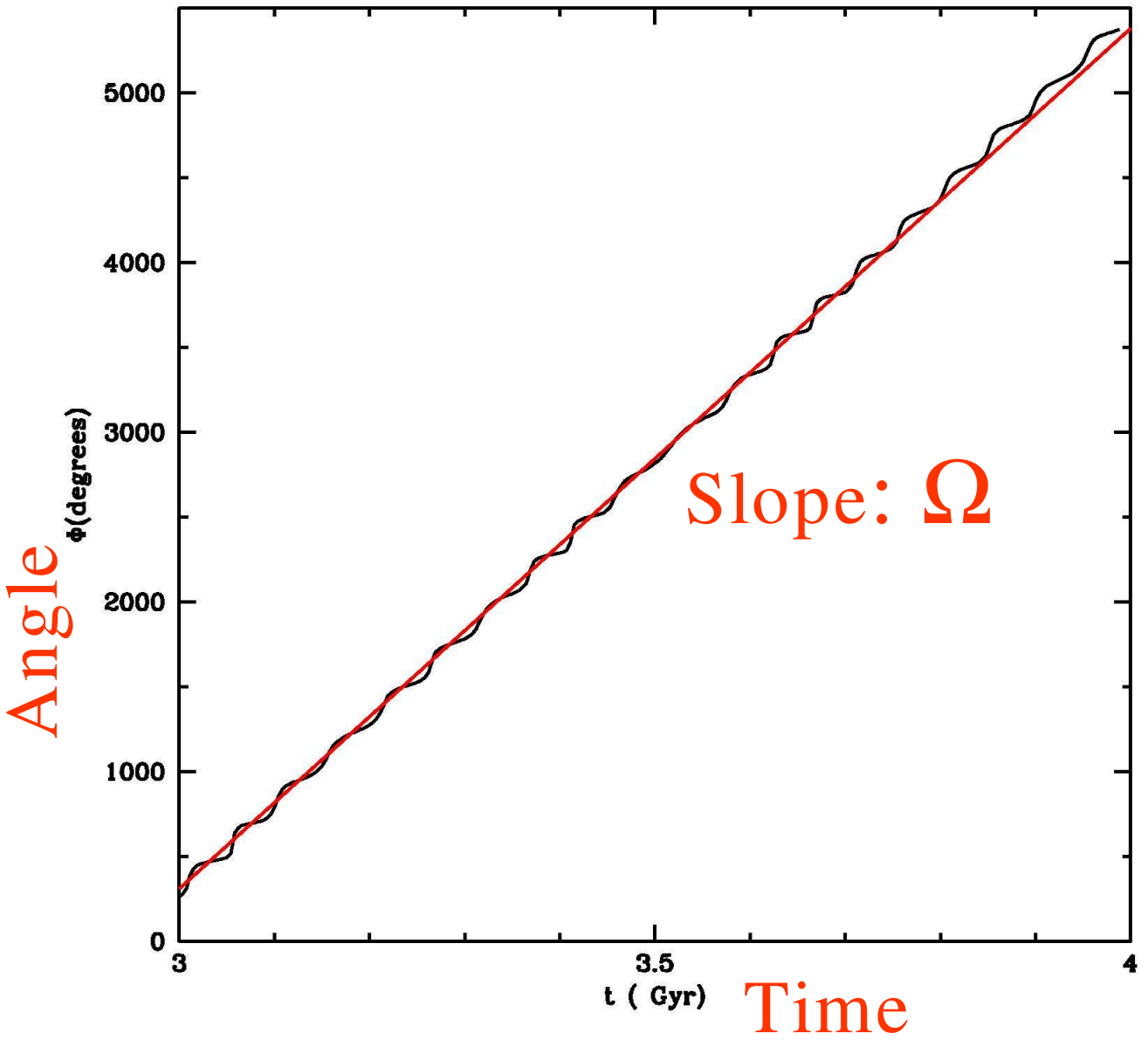
Radial frequency (K) measurements

- **For every particle, we measure the frequencies during a given period of time (1-2 Gyrs) in which the pattern speed is almost constant.**
  - **K: Fourier Analysis of the radial evolution.**

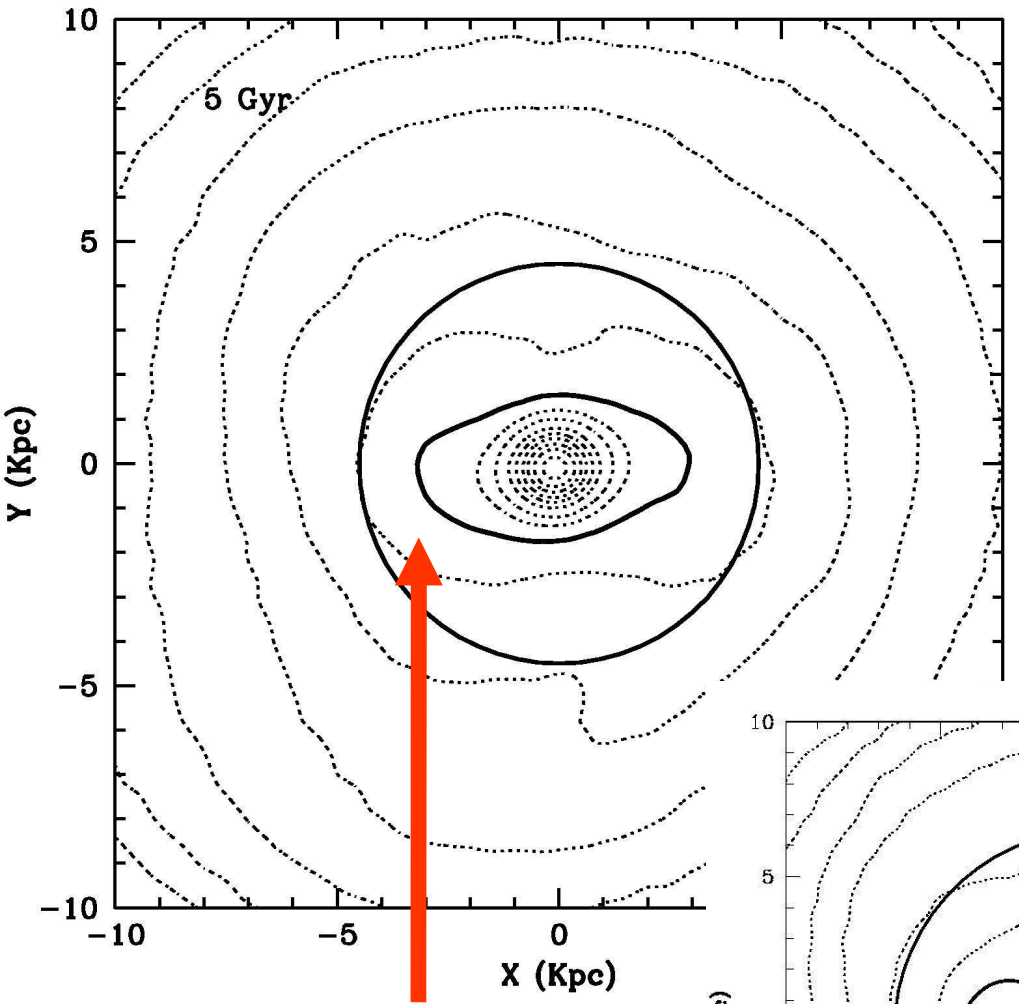


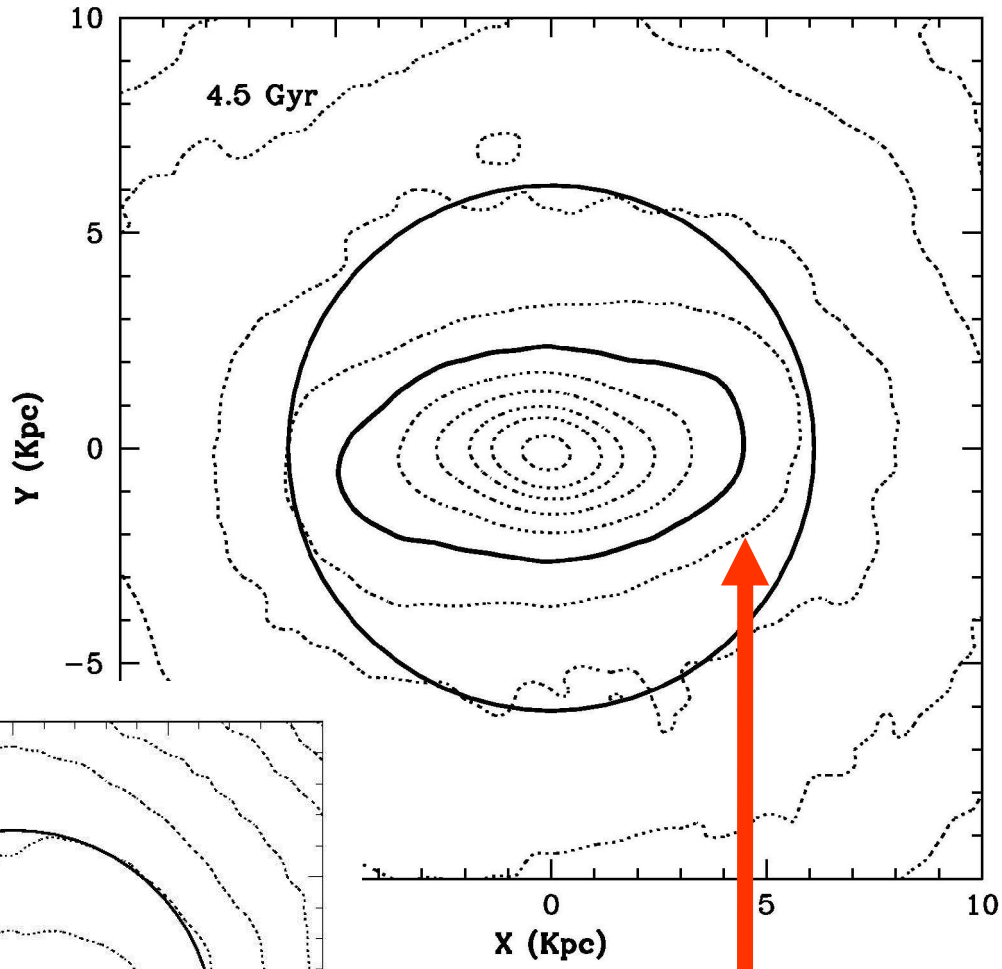
Angular frequency (Ω)

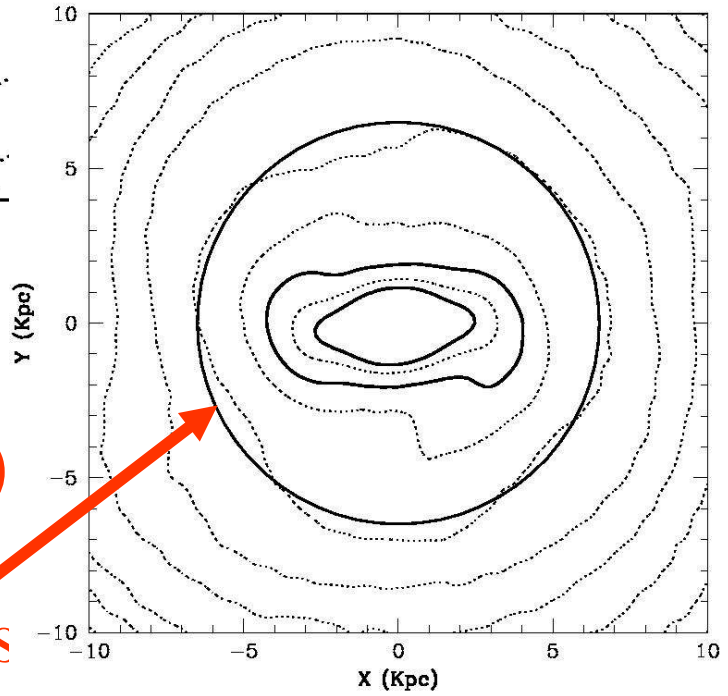
Ω: Averaged time of one angular revolution.



Face-on views of the Models using contours of equal density.







weak bar
(Pseudobulge)

strong bar

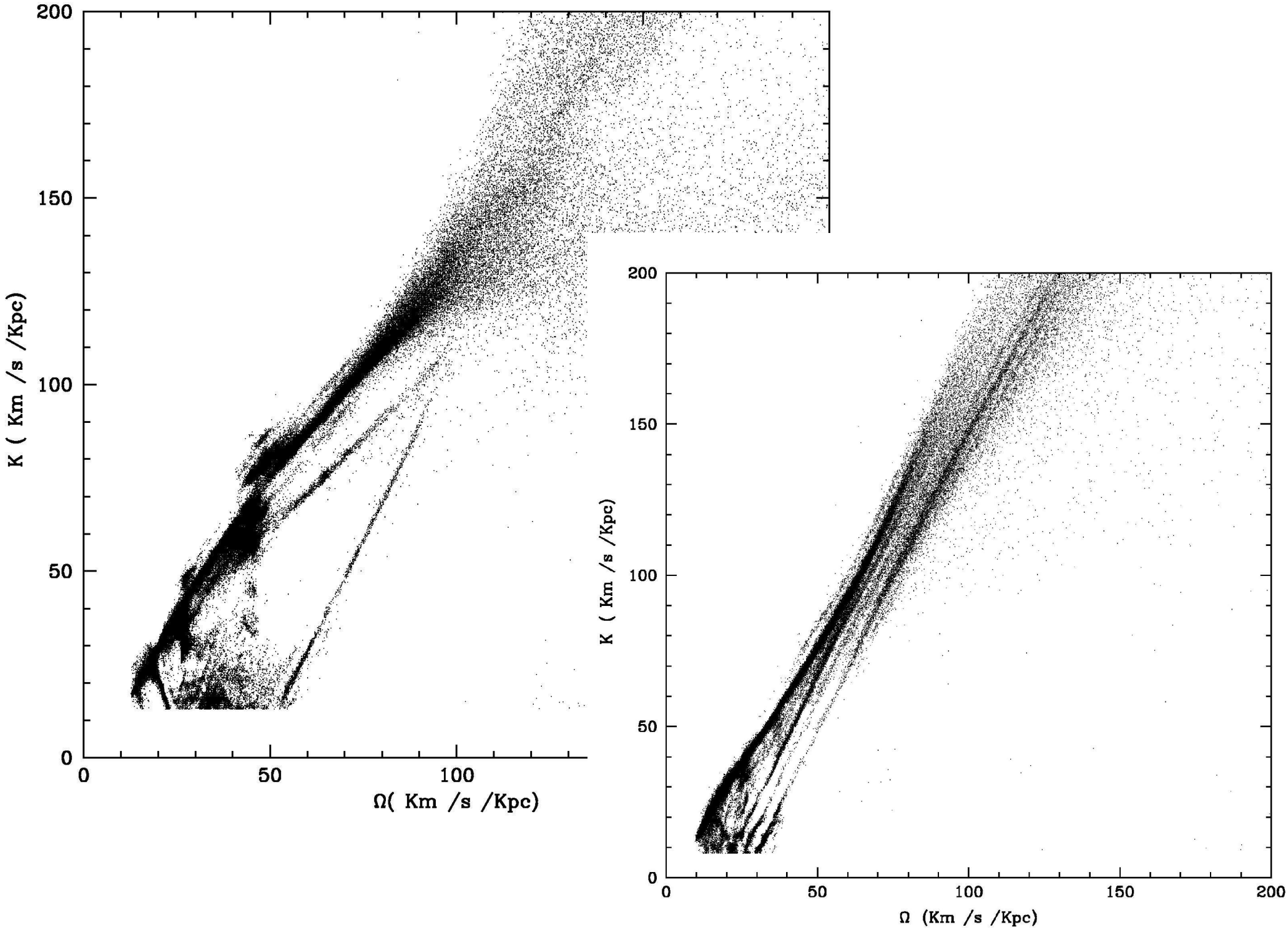
Corotation radius

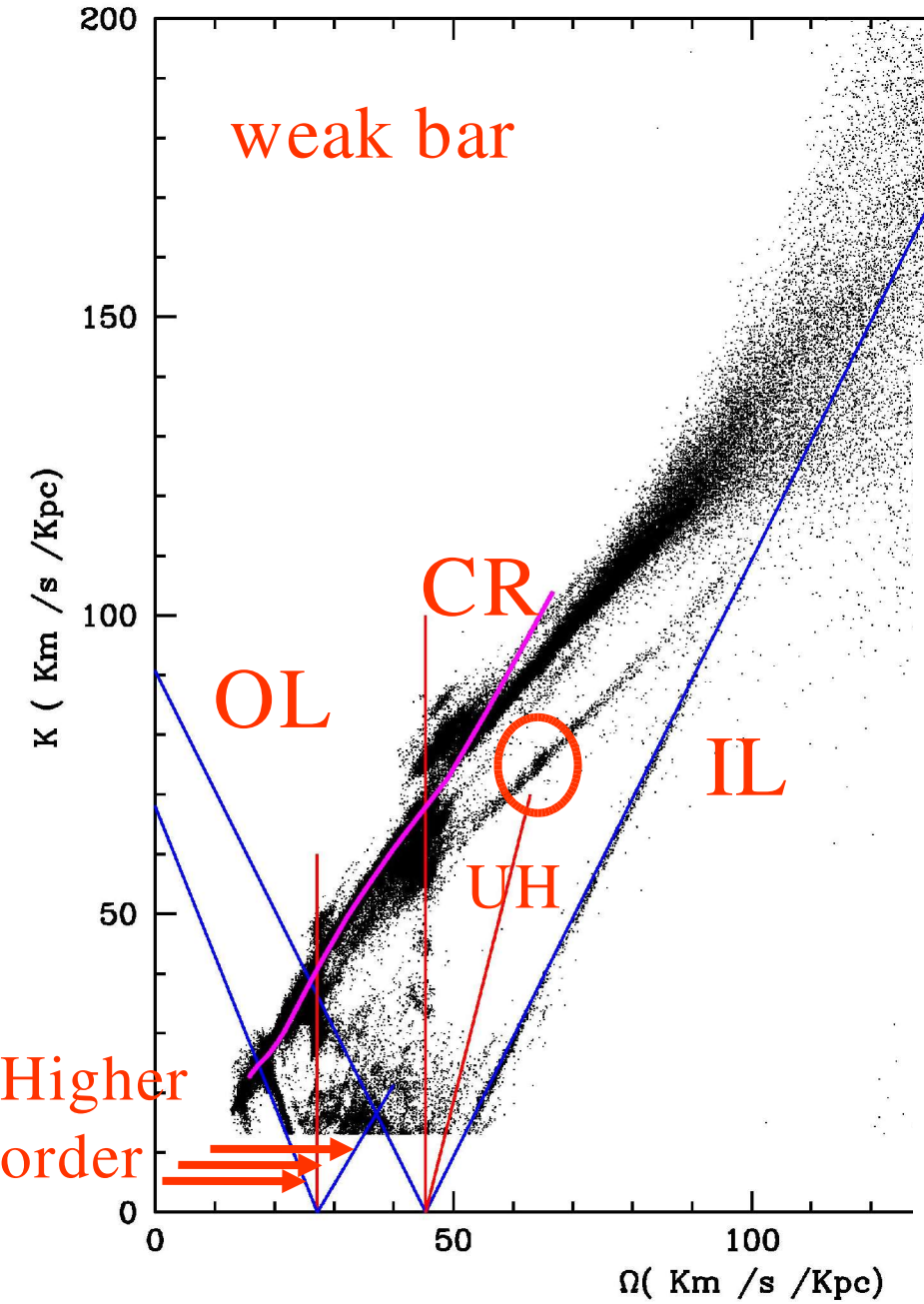
The frequency space: K vs Ω.

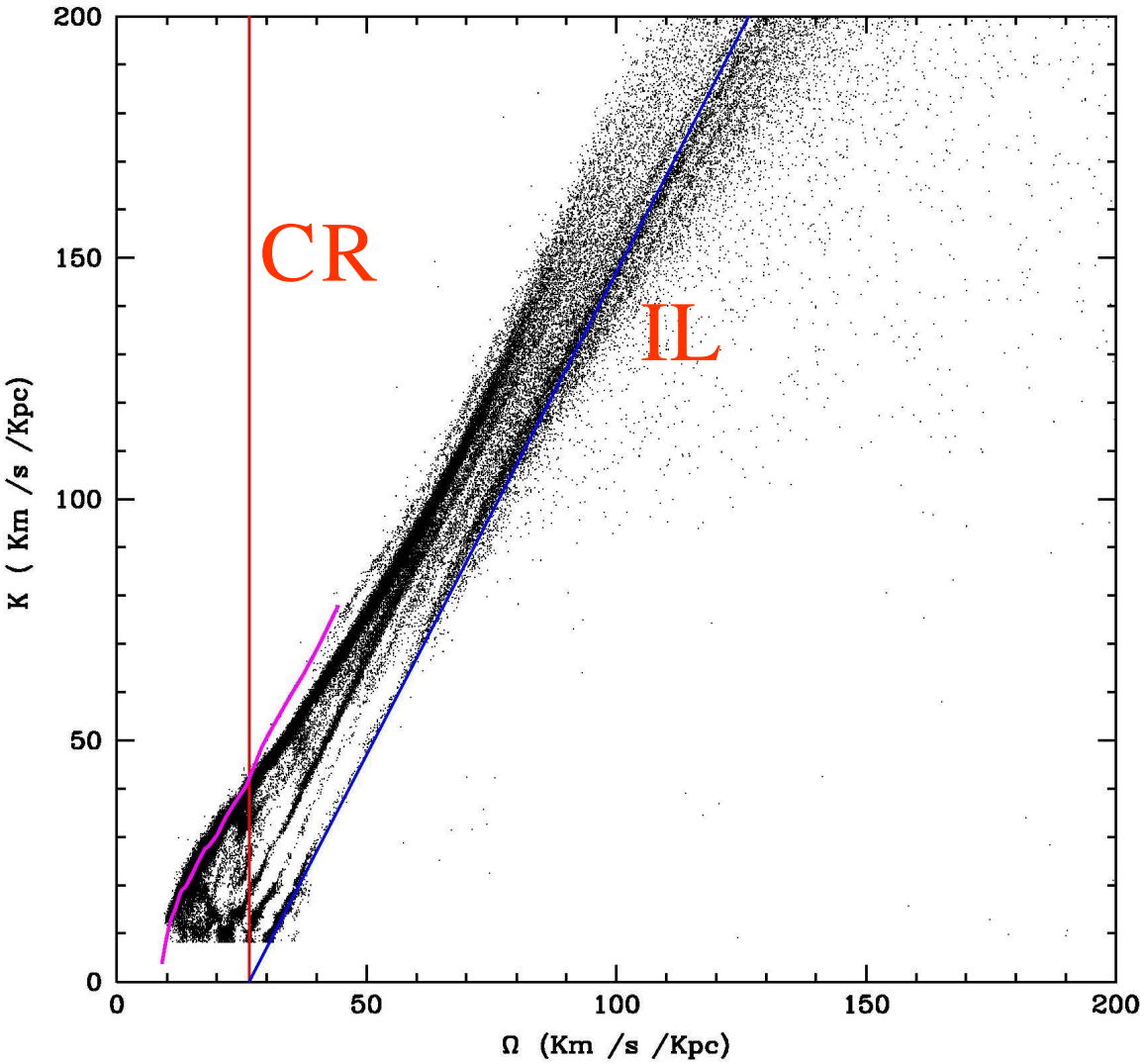
Commonly used in plasma physics and planetary science. (Laskar 1990)

Each point represents the orbit of a particle.

Straight lines with certain slopes define the main resonances.


200
150
100
50
0
K (Km /s /Kpc)
0
50
100
Ω(Km /s /Kpc)
200
150
100
50
0
K (Km /s /Kpc)
0
50
100
150
200
Ω (Km /s /Kpc)

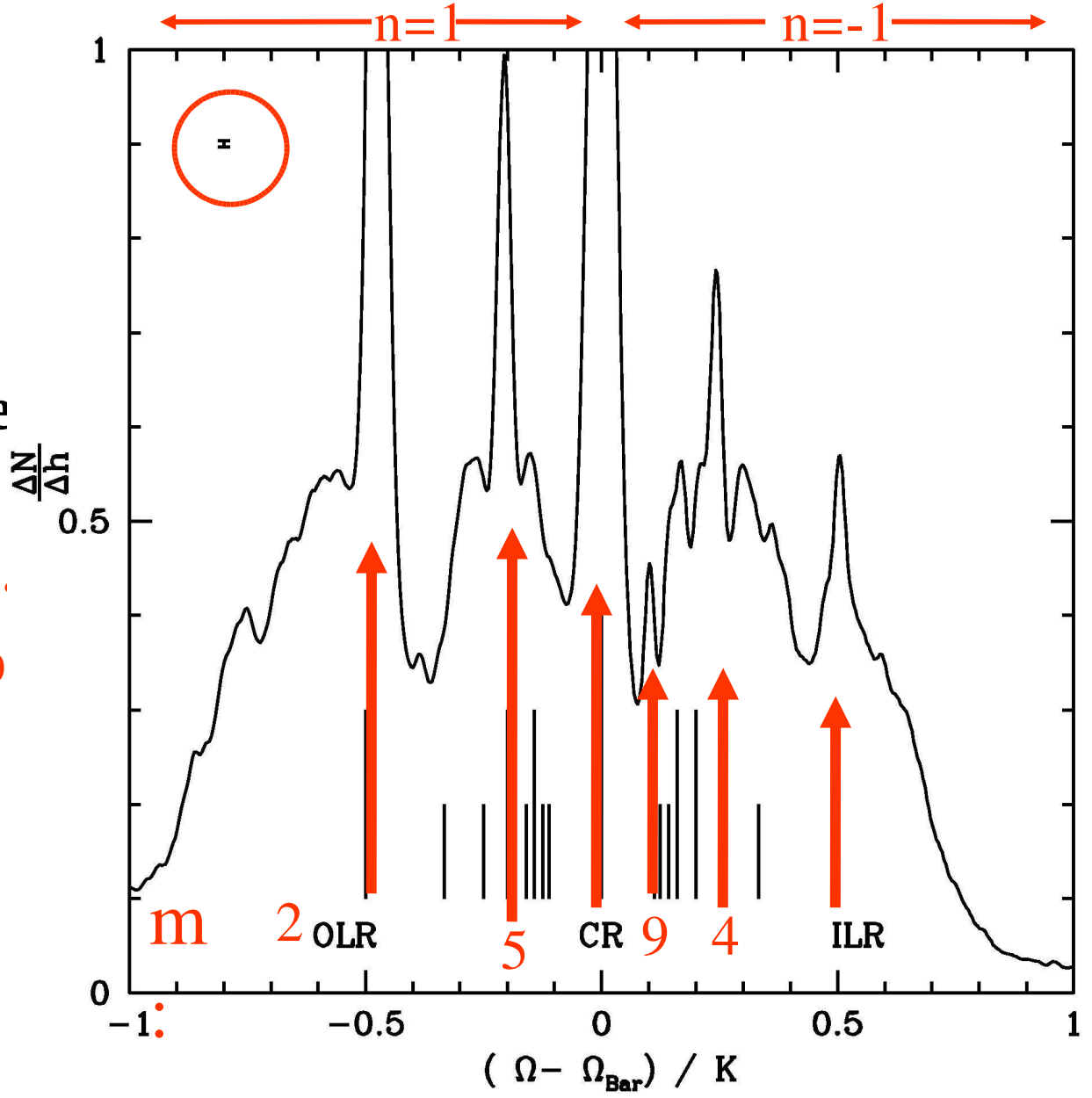




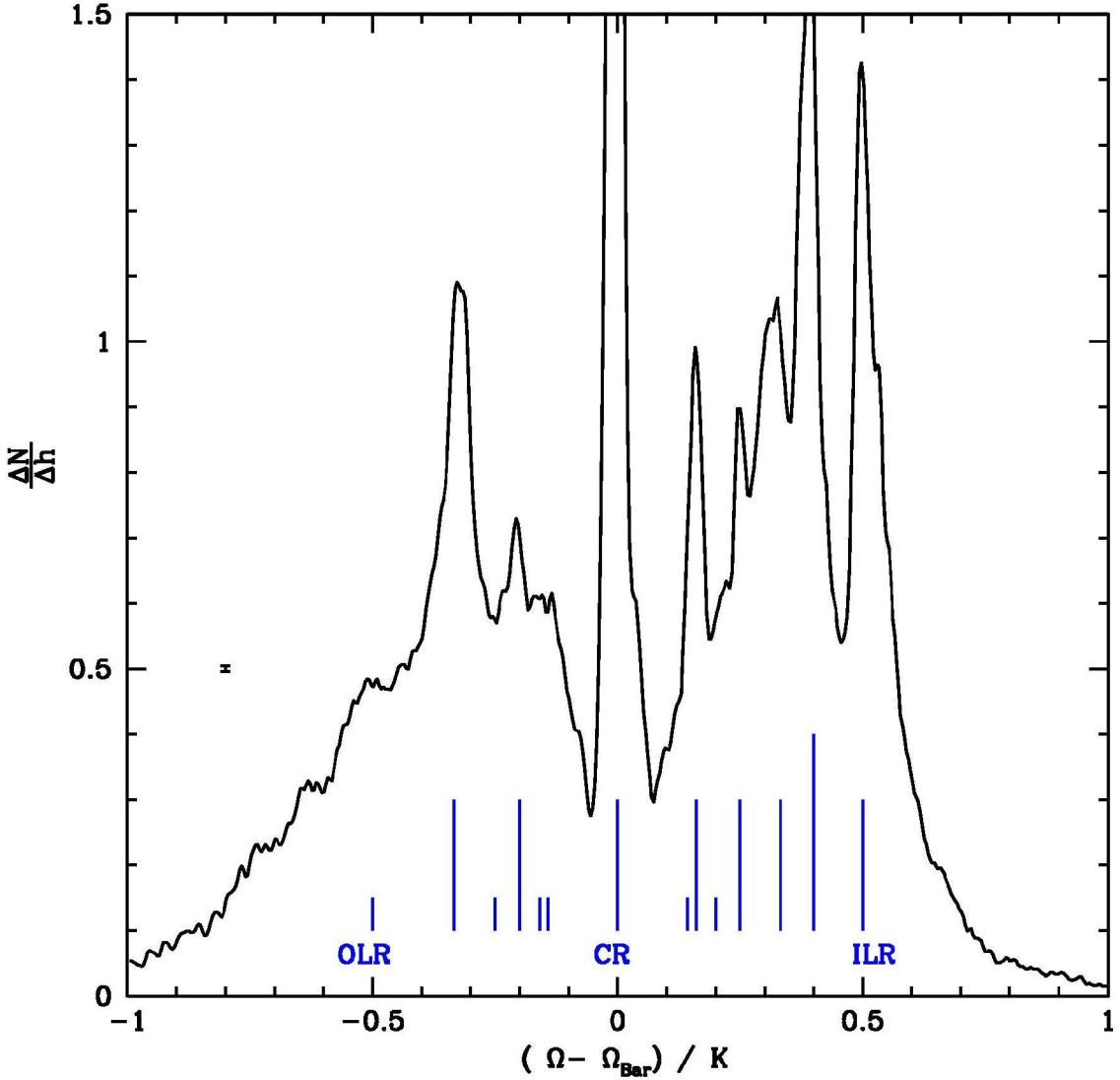
$$K^2 = \left(\frac{\partial^2 \Phi_{Eff}}{\partial^2 R}\right) = \left(R\frac{d\Omega^2}{dR^2} + 4\Omega^2\right)$$

Main resonances (weak bar)

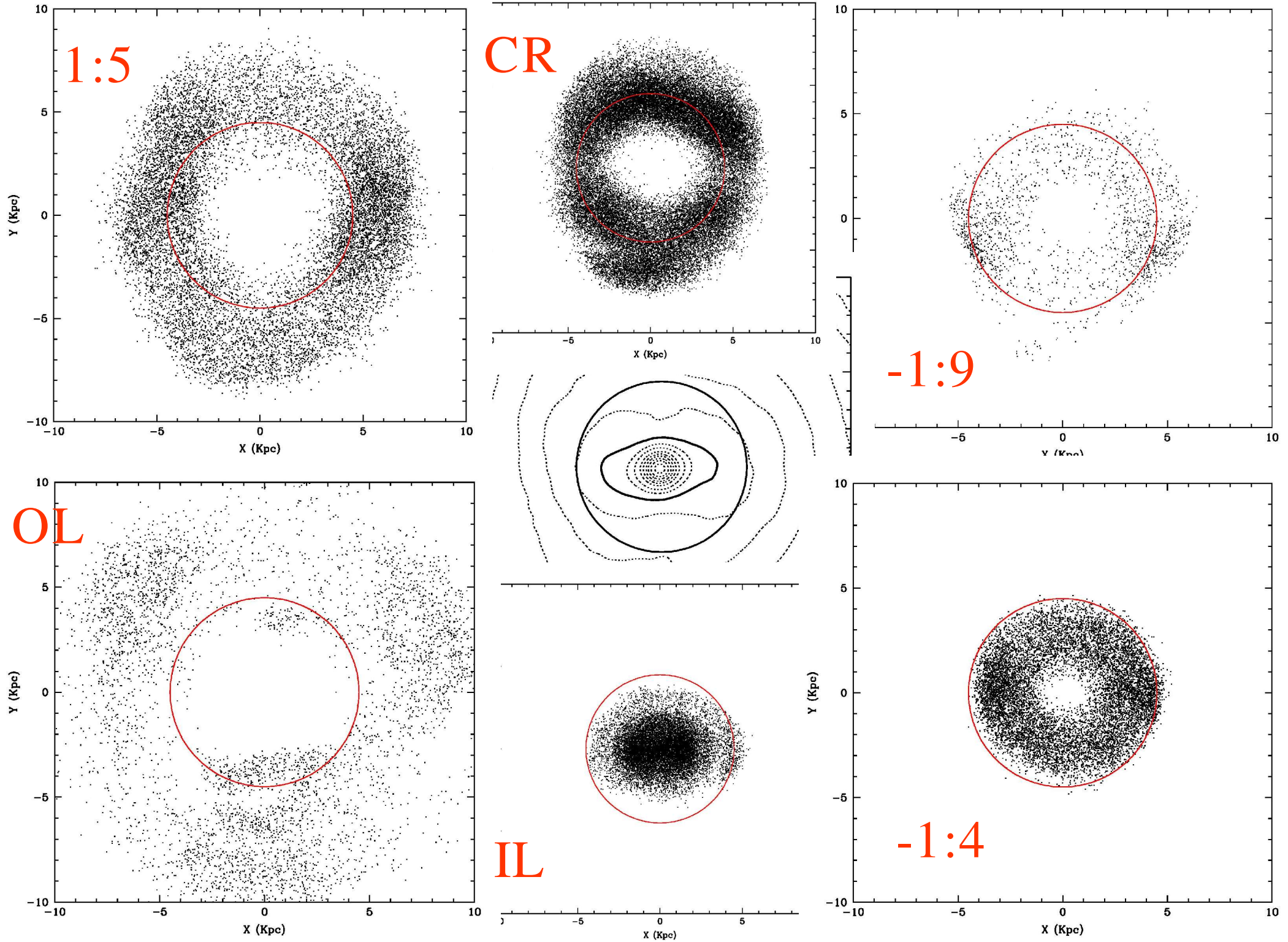
- $(\Omega - \Omega_P)/K = -n/m$
- **Fraction of particles per unit bin.**
- **Low-order resonance (±1:m)**
- **Trapping resonances.**
- **No indications of gap of low-order.**
- **1σ statistical error.**



Main resonances (strong bar)

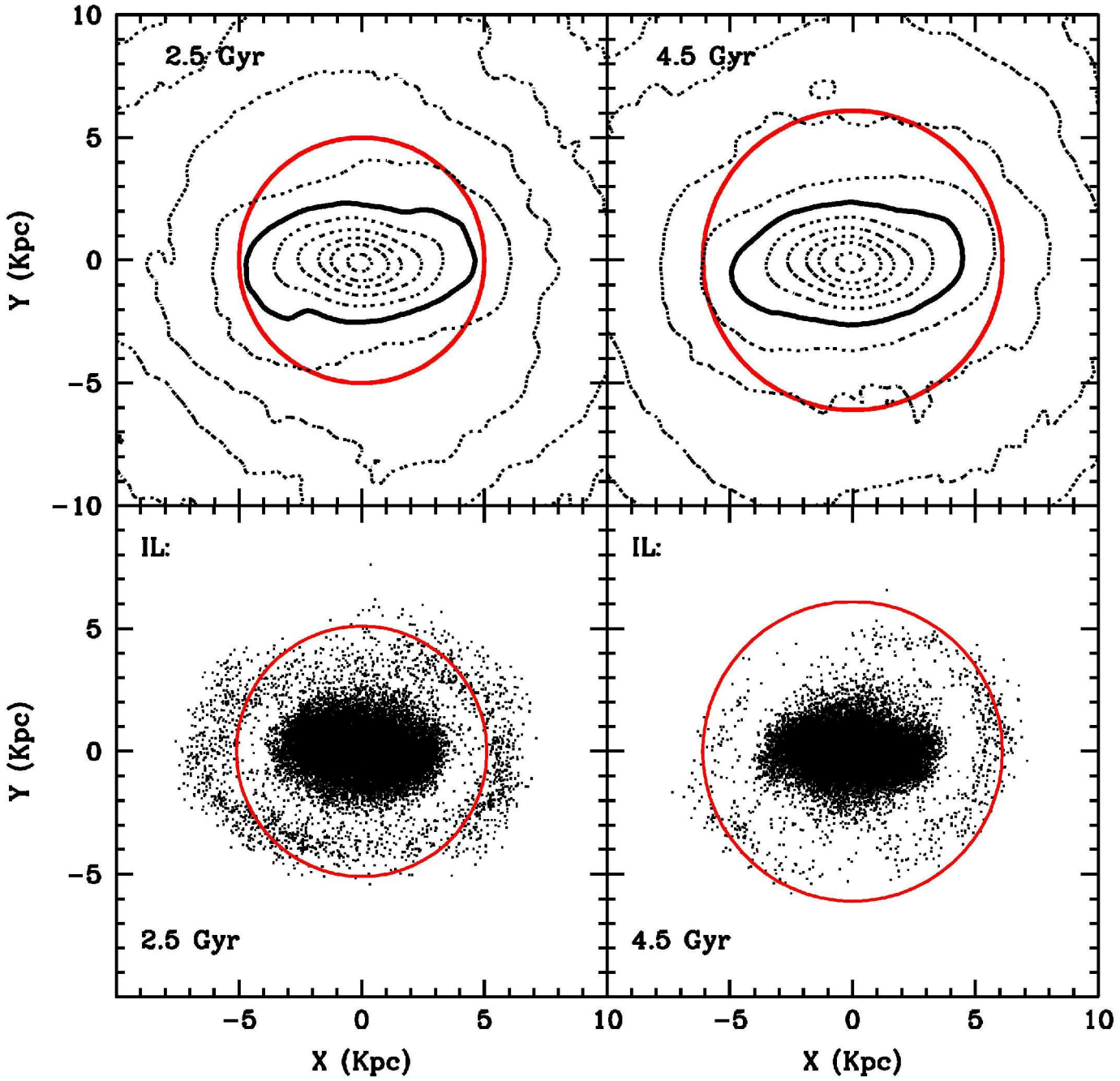


A portrait of resonances for a weak bar.


1:5
CR
-1:9
OL
IL
-1:4
X (Kpc)
Y (Kpc)

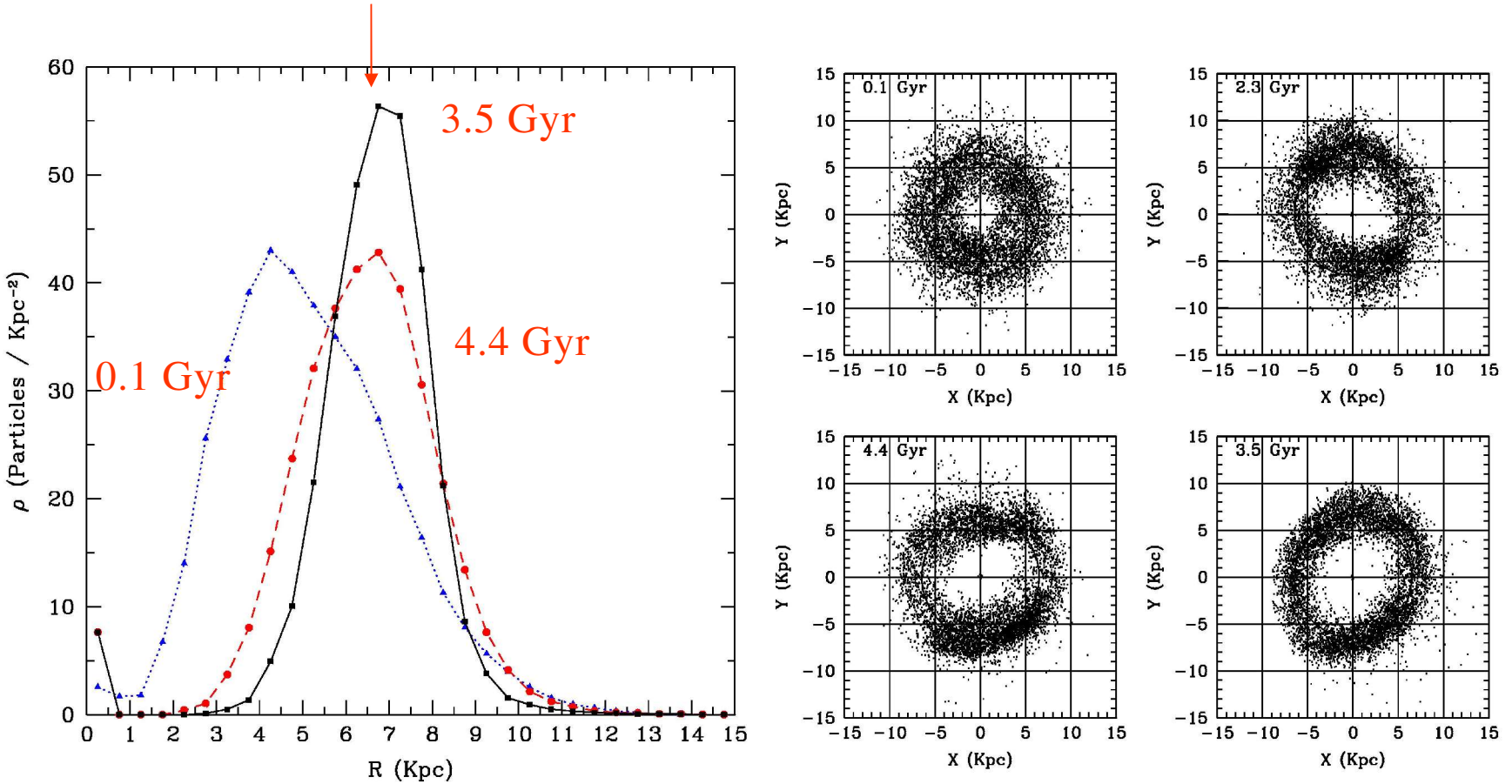
Inner Lindblad

IL is not localized at a given radius



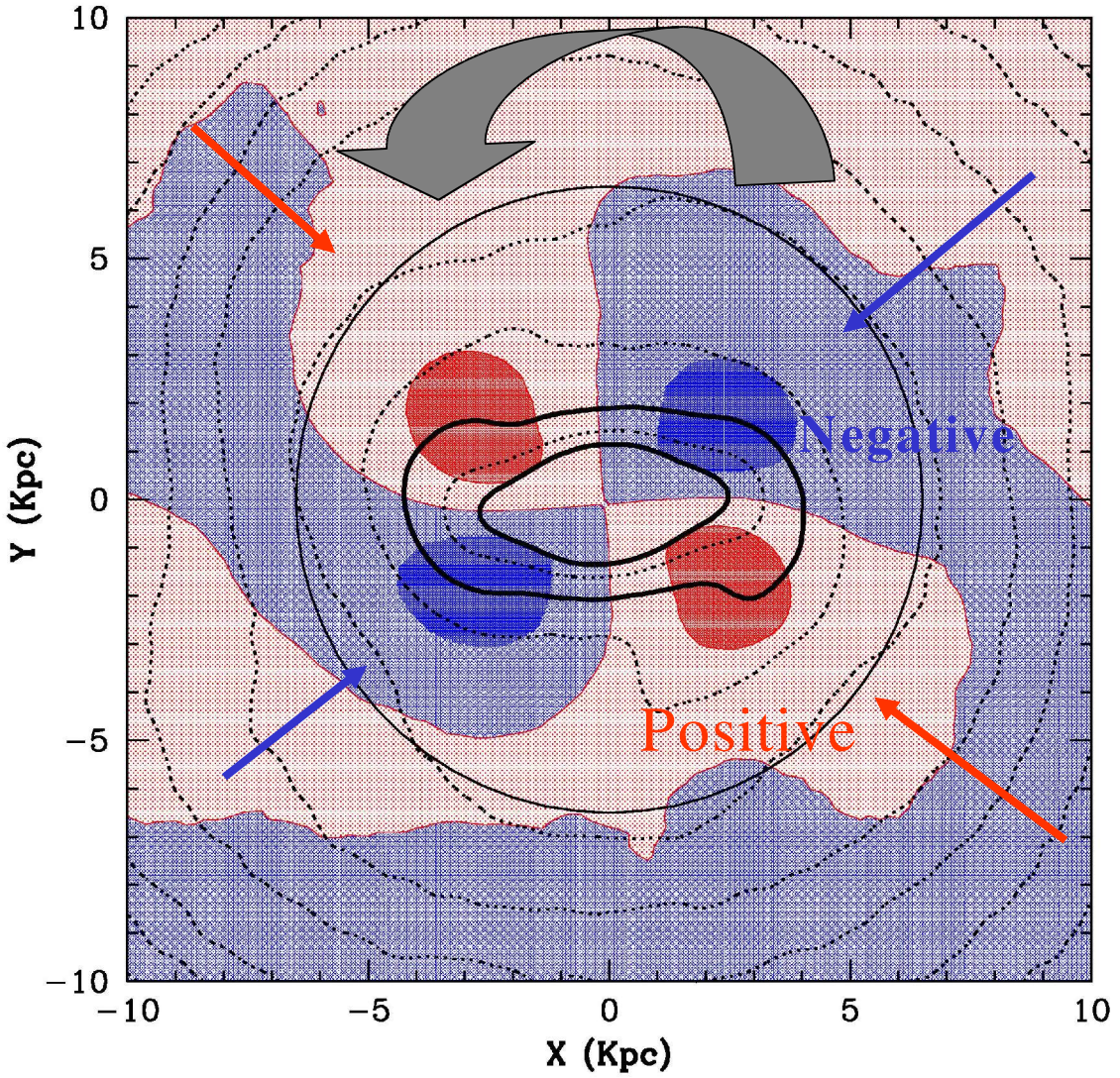
Third model: Corotation.

Selected particles in corotation at 3.5 Gyr



Particles are trapped at corotation.

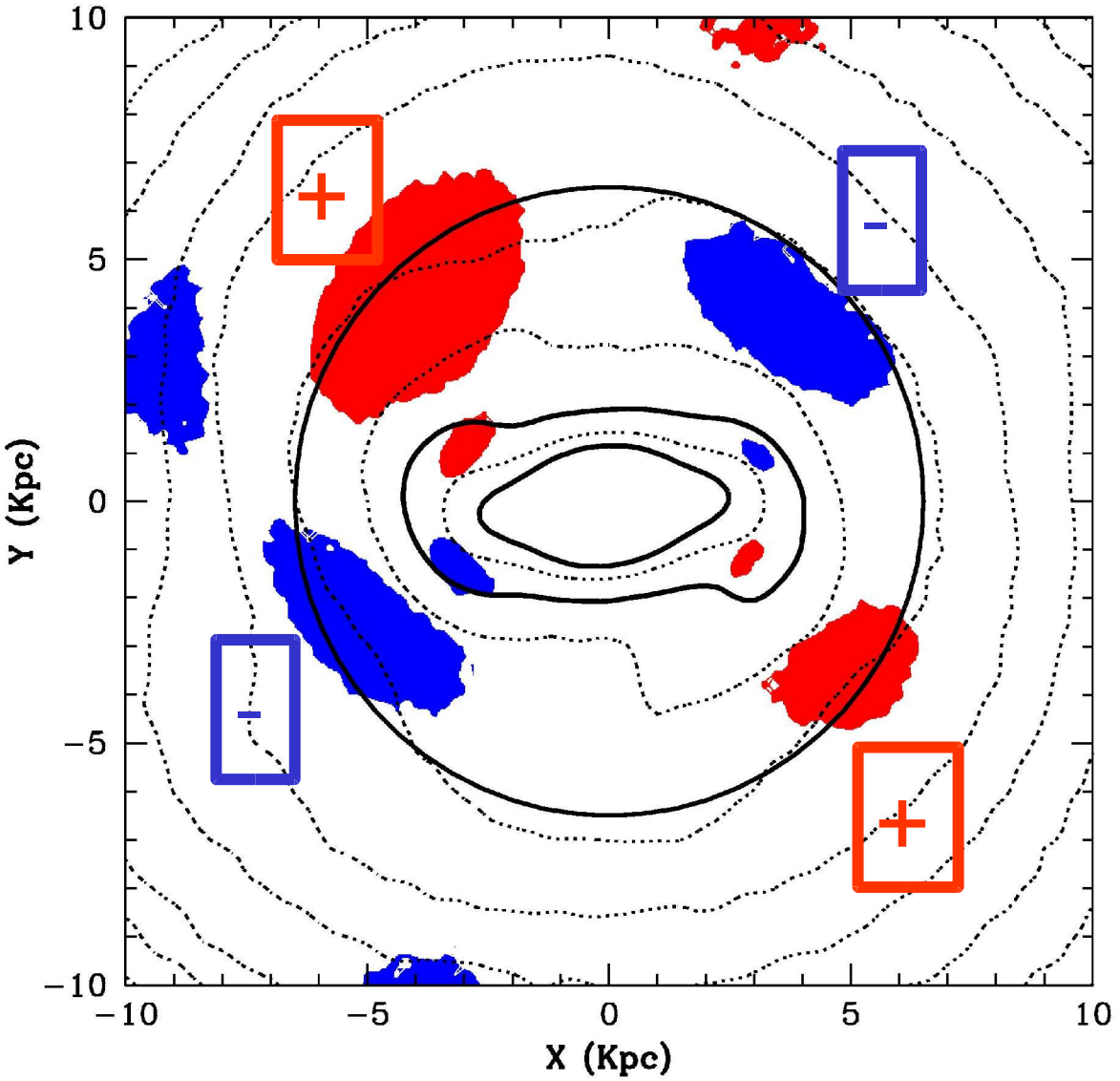
Instantaneous change of angular momentum.



Torque field.

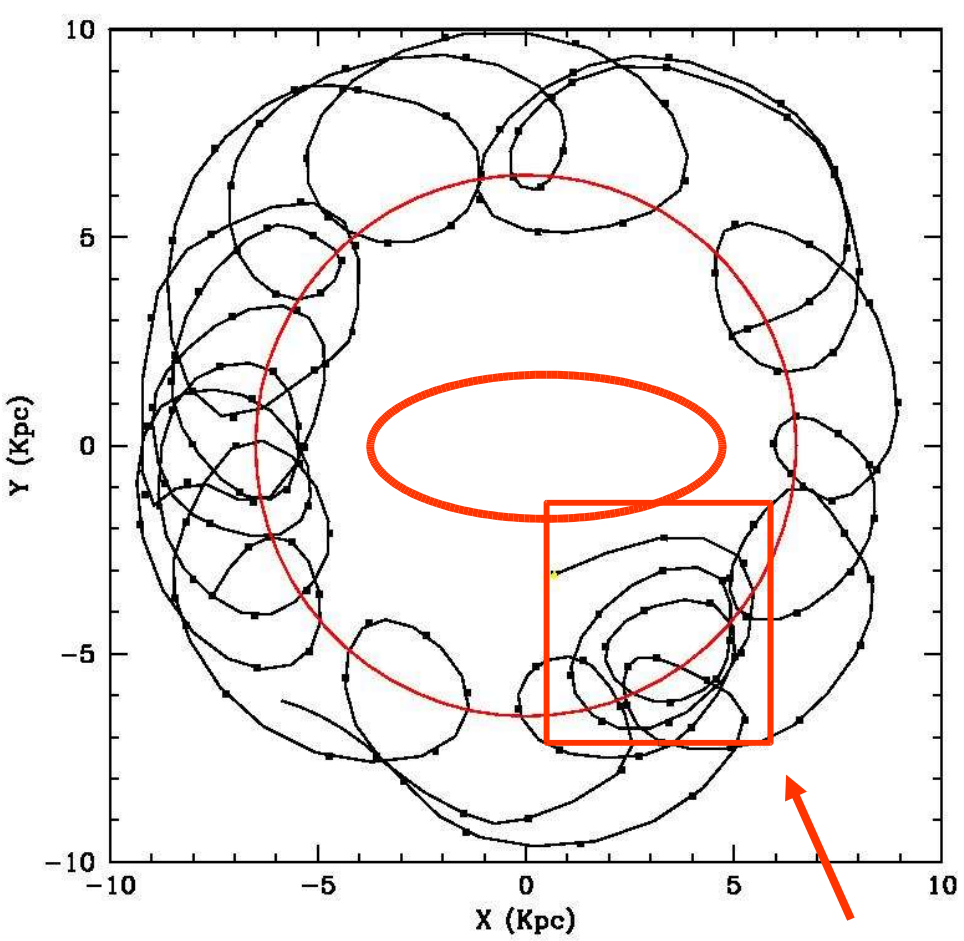
Areas in which the angular momentum of the particles increases (positive torque) or decreases (negative torque).

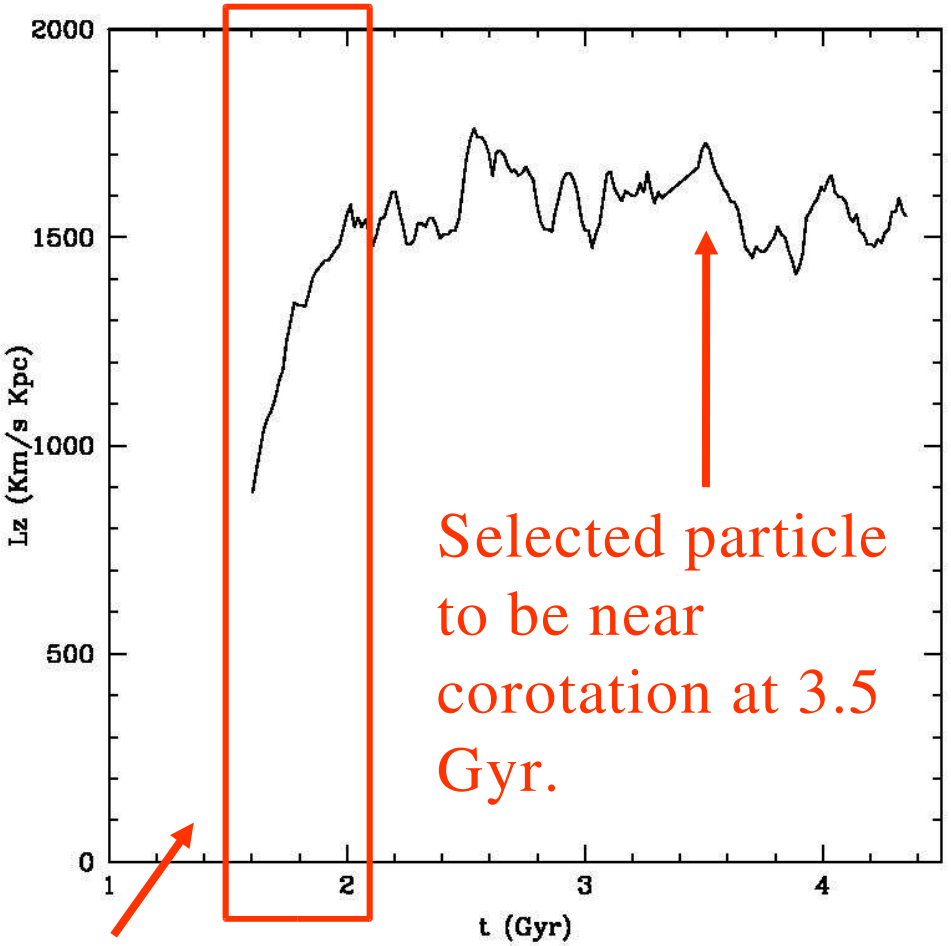
AM change over a longer interval



- Maximum increment and decrement in angular momentum.
- The maximum (positive) and minimum (negative) areas of AM change lie at corotation radius.

A example of a orbit that circulates along corotation.



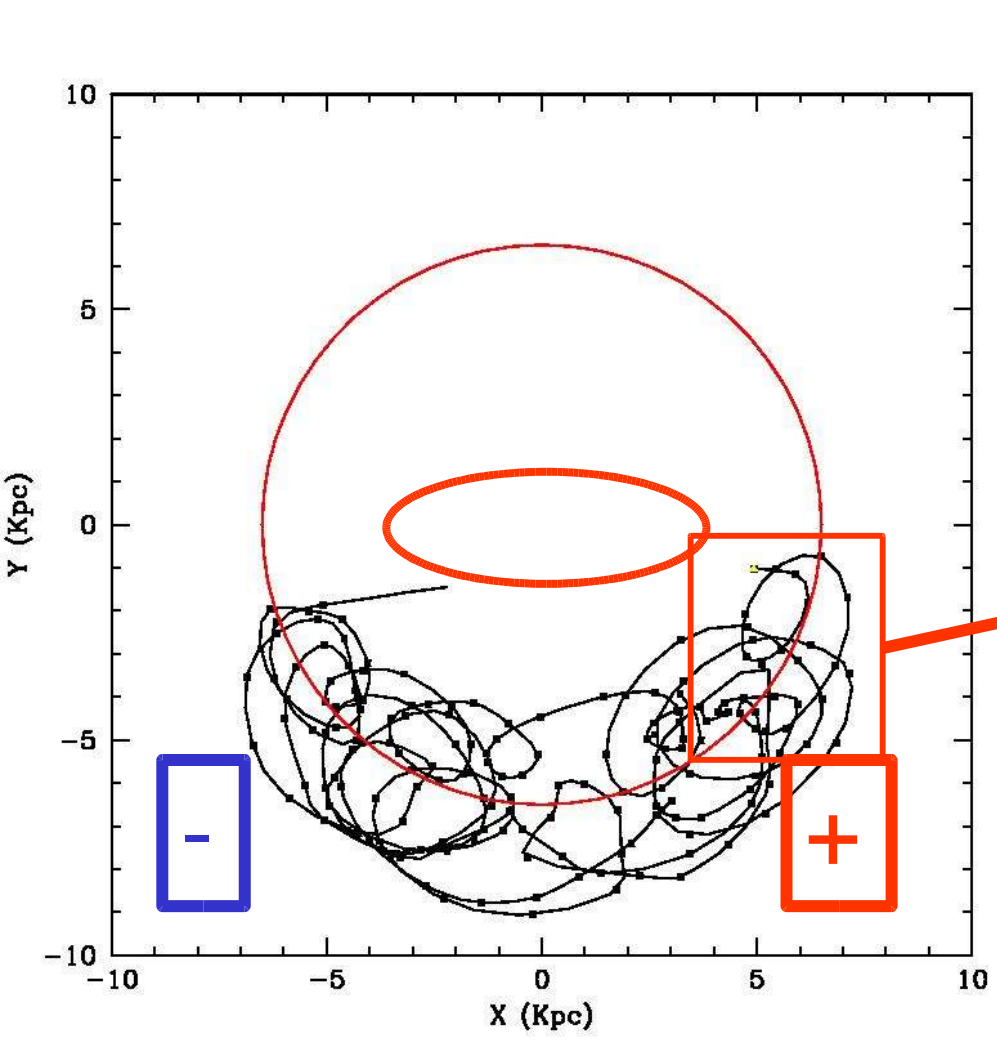


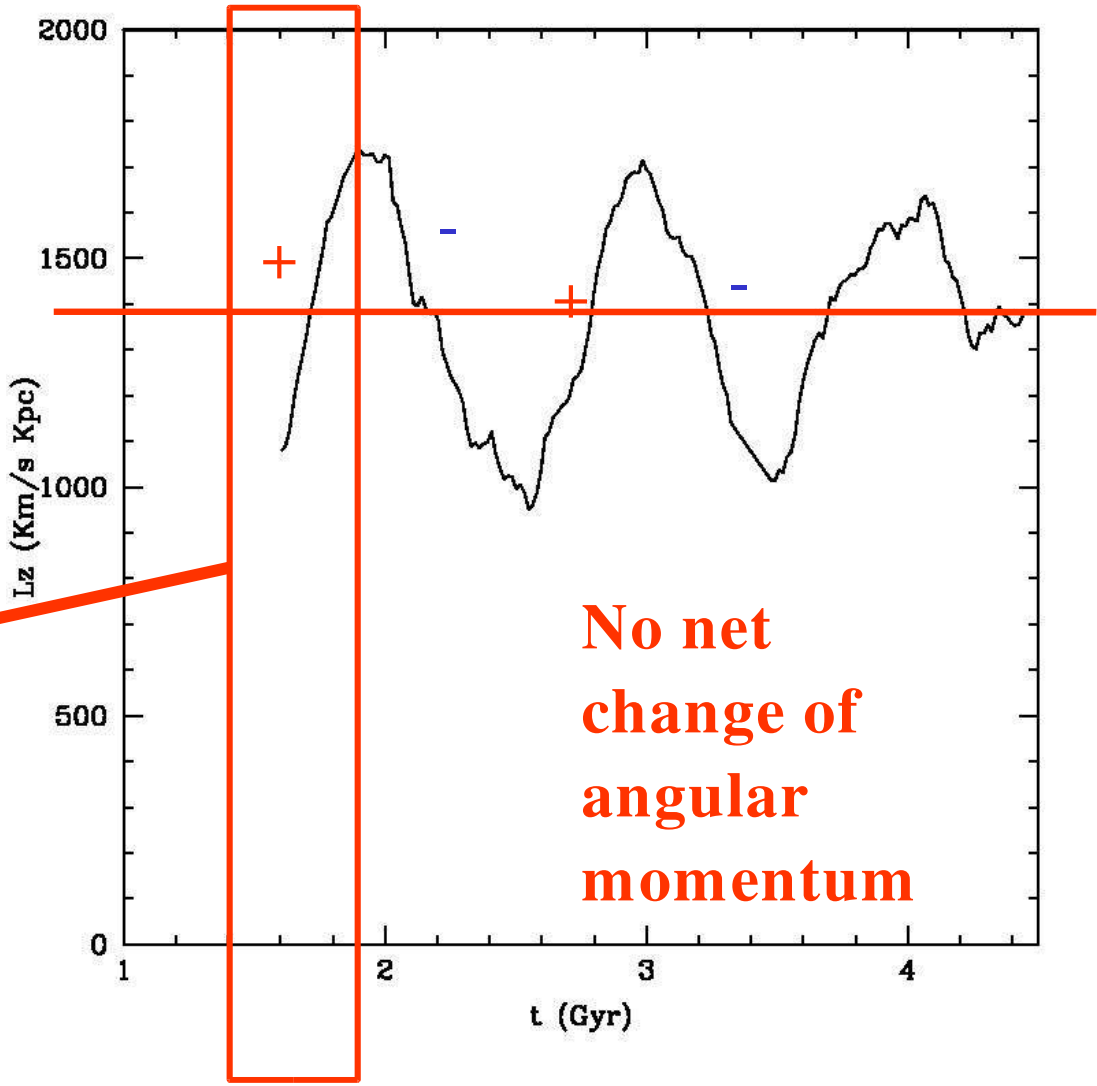
Selected particle to be near corotation at 3.5 Gyr.

The particle is trapped at corotation radius at 1.6 Gyr

reference frame rotating with the bar.

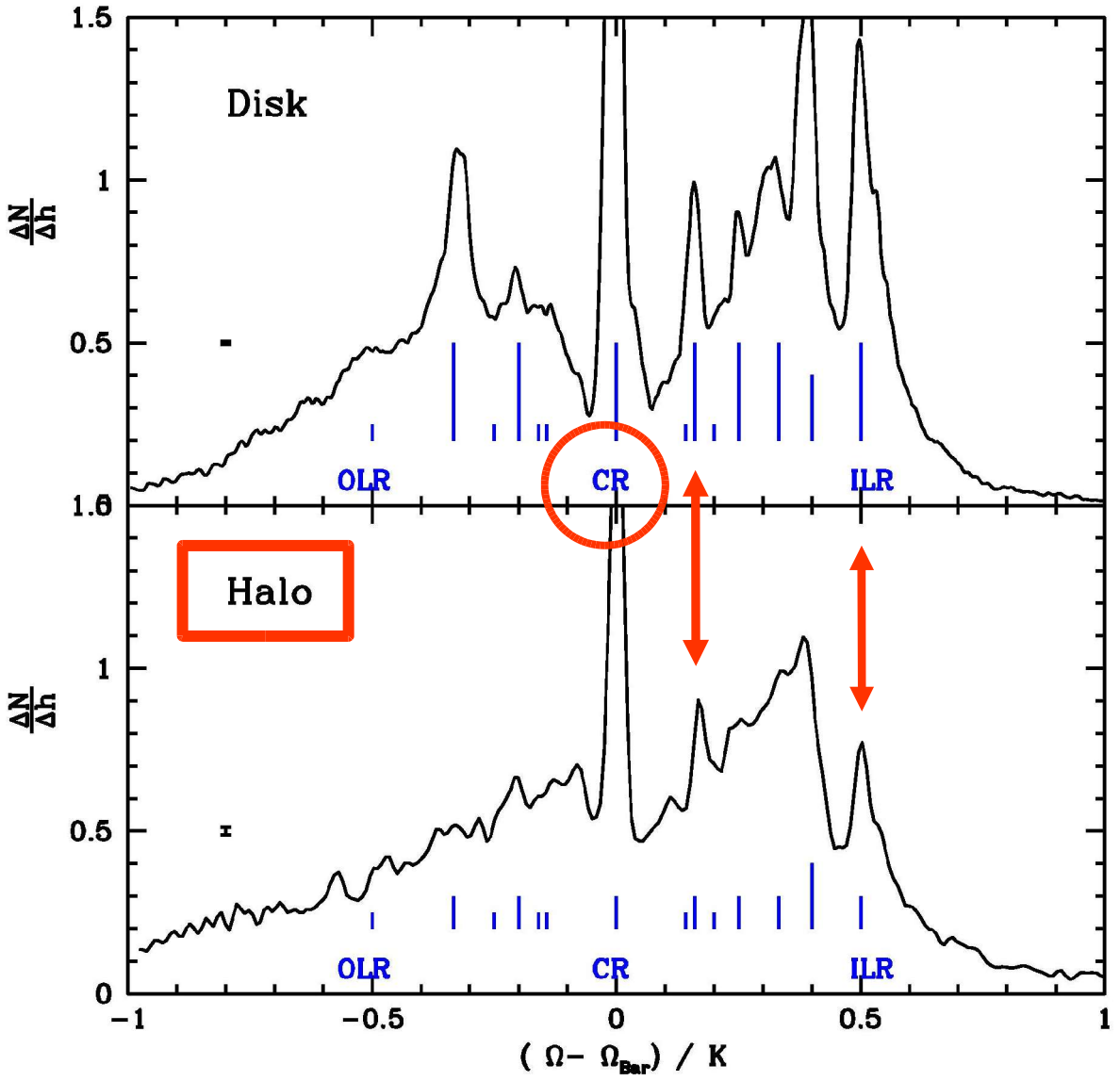
A slow orbit: Libration around a lagrangian point at corotation .





A last result: Resonances in the halo

- Similar pattern of resonances.
- We select halo particles which are close to the disk so the interaction with the bar is stronger.



CONCLUSIONS

- First time that resonances are detected in a N-body simulation with a evolving disk in a living halo using only their trajectories.
- Trapping resonances. No gaps are found.
- There are no evolution after particles get trapped.
- Corotation captures particles in a ring outside the bar.
- Inner Lindblad is not localized at a given radius.
- The halo also exhibits trapping resonances.