THE ORIGIN OF SPIRAL STRUCTURE IN DISK GALAXIES

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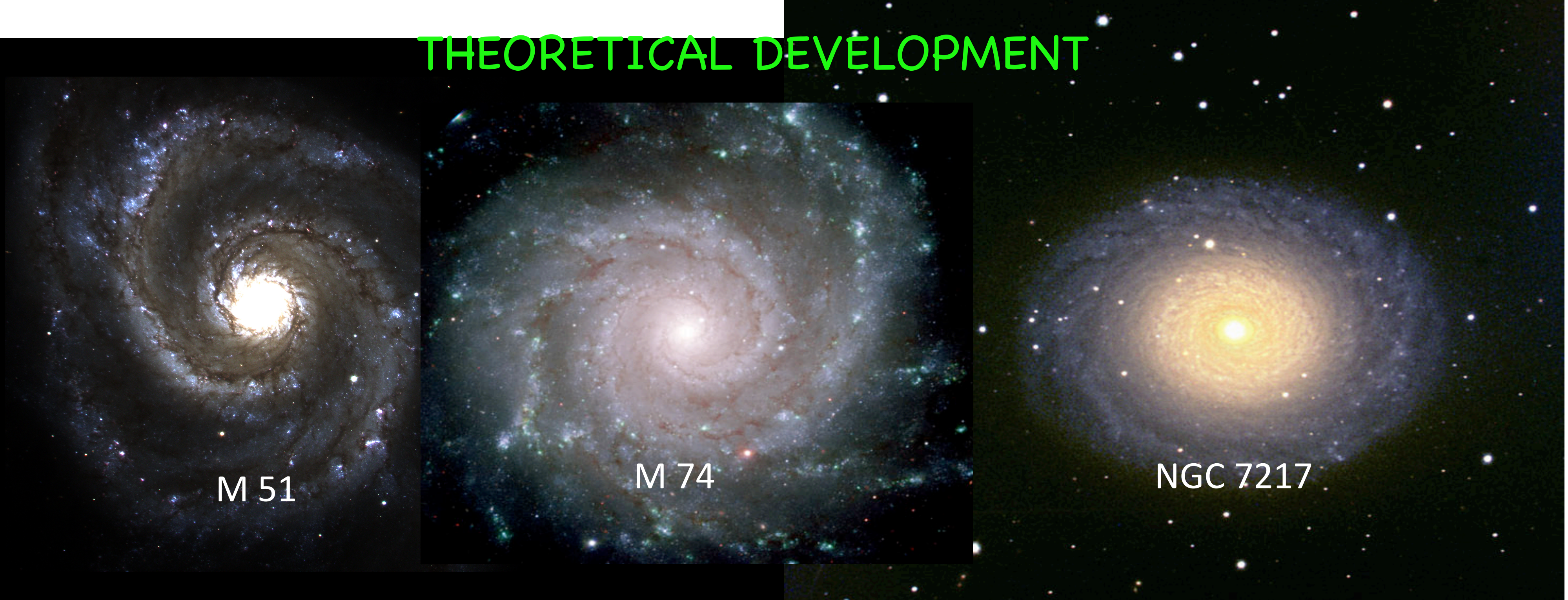
THEORETICAL DEVELOPMENT



- Spiral structure as a "wave" pattern which remains stationary (Lin,Shu 64,66 (Bertin et al. 1989, Bertin 1993)

- "swirling hotch-potch of pieces of spiral arms" result from a variant of Jeans instability affecting their gas (Goldreich & Lynden-Bell 1965).

- Swing amplification: gravity from any massive orbiting aggregate will evoke a strong wake in the stellar medium that shears past it in a differential rotating disk (Julian & Toomre 1966)

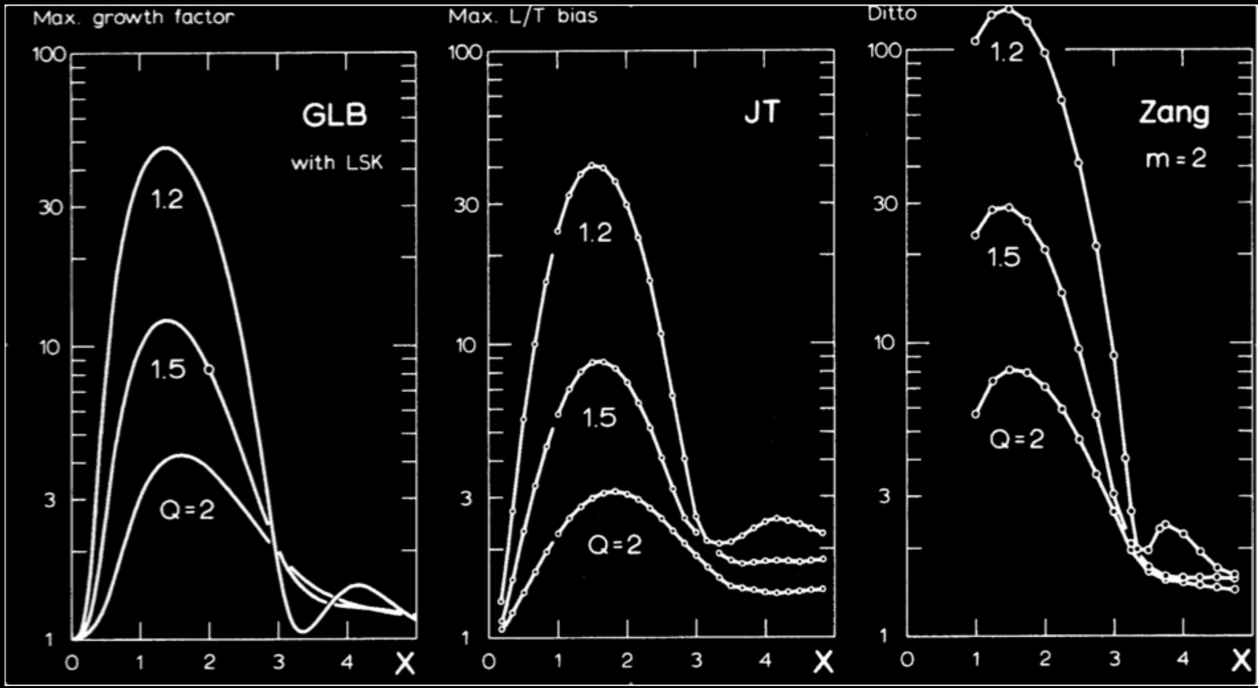
✧ Groove instabilities (Sellwood 1980s)

✧ Coherent unstable modes (Sellwood 2012)

Superposition of long-lived modes.

✧ Invariant Manifolds (Athanassoula 2012; Romero-Gomez 2007 and next talk)

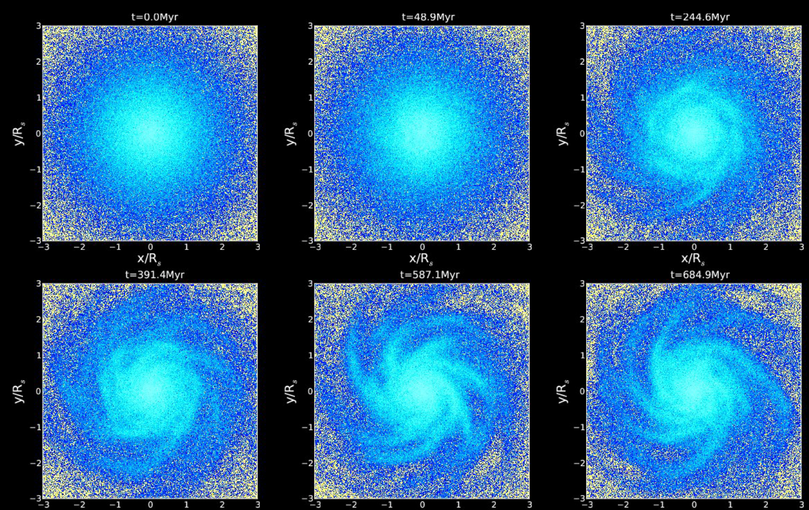
Related to saddle points in non-axisymmetric systems. Manifold are as tubes that drive the motion to the global galaxy forming spirals and rings.

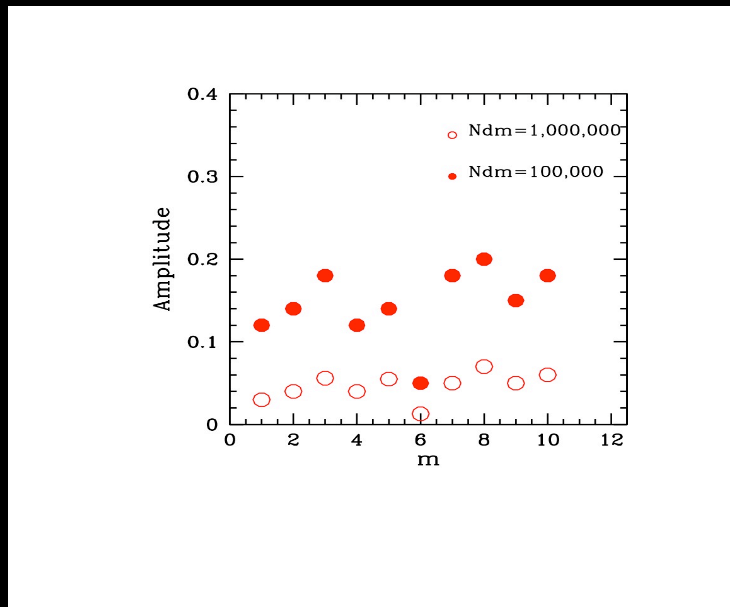


- In N-body simulations trailing arm structures arise from swing amplification of Poisson noise of a random collection of N orbiting stars.

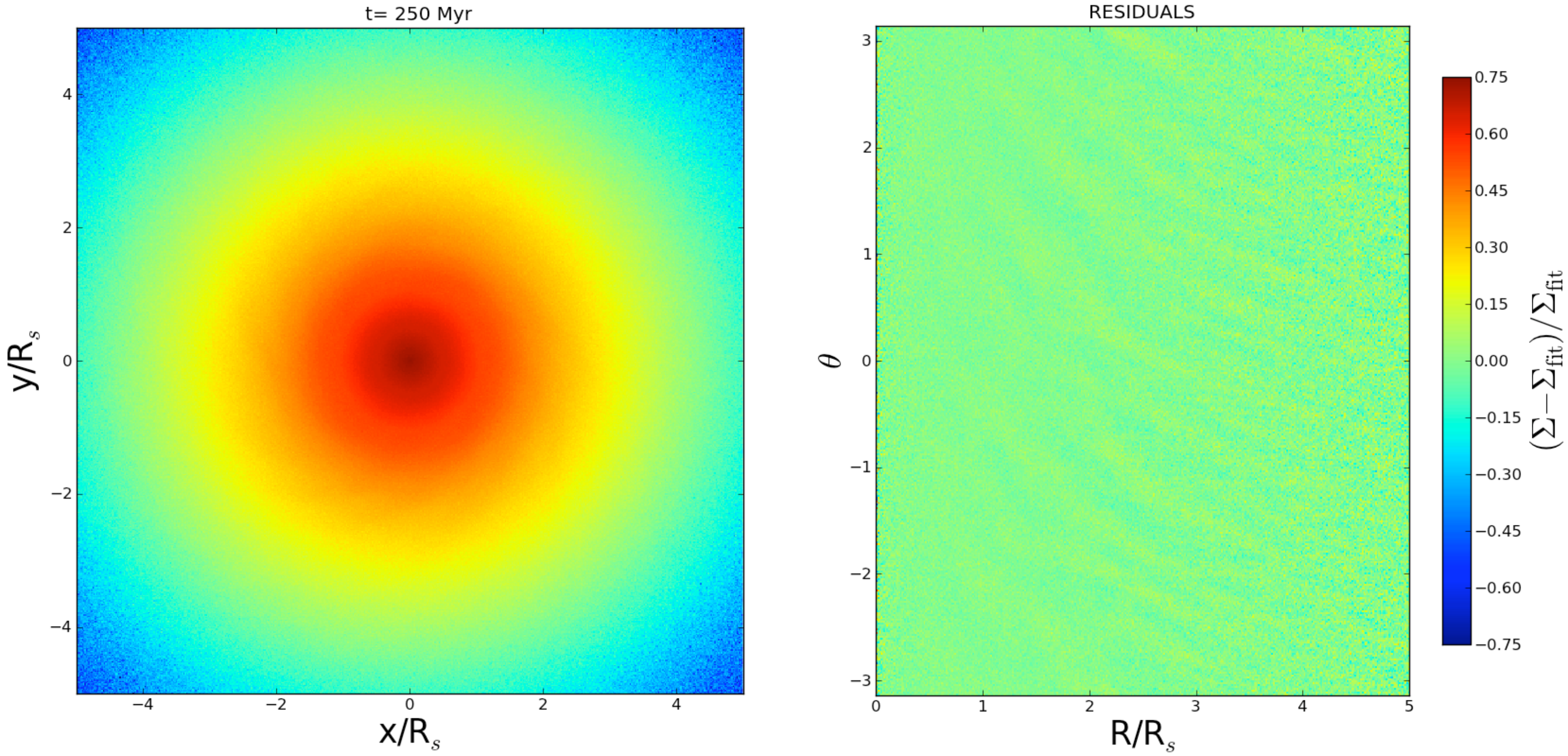
$$X = \frac{\lambda}{\lambda_{crit}} = \frac{\kappa^2}{2\pi G\Sigma}\frac{R}{m}$$

Toomre 1981



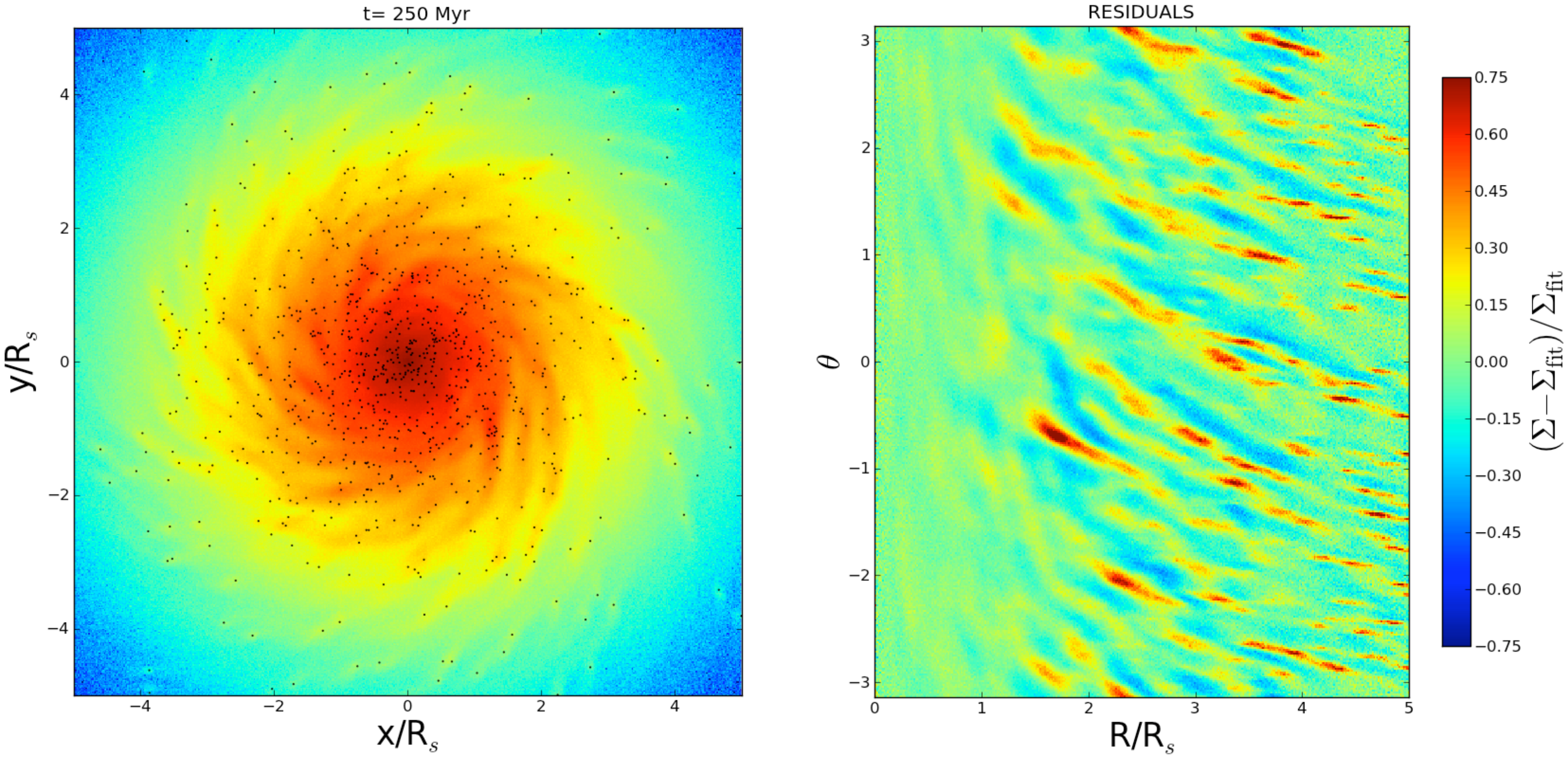


✧ Disk with 100,000,000 of particles rotating in a rigid halo potential



D'Onghia et al. 2013

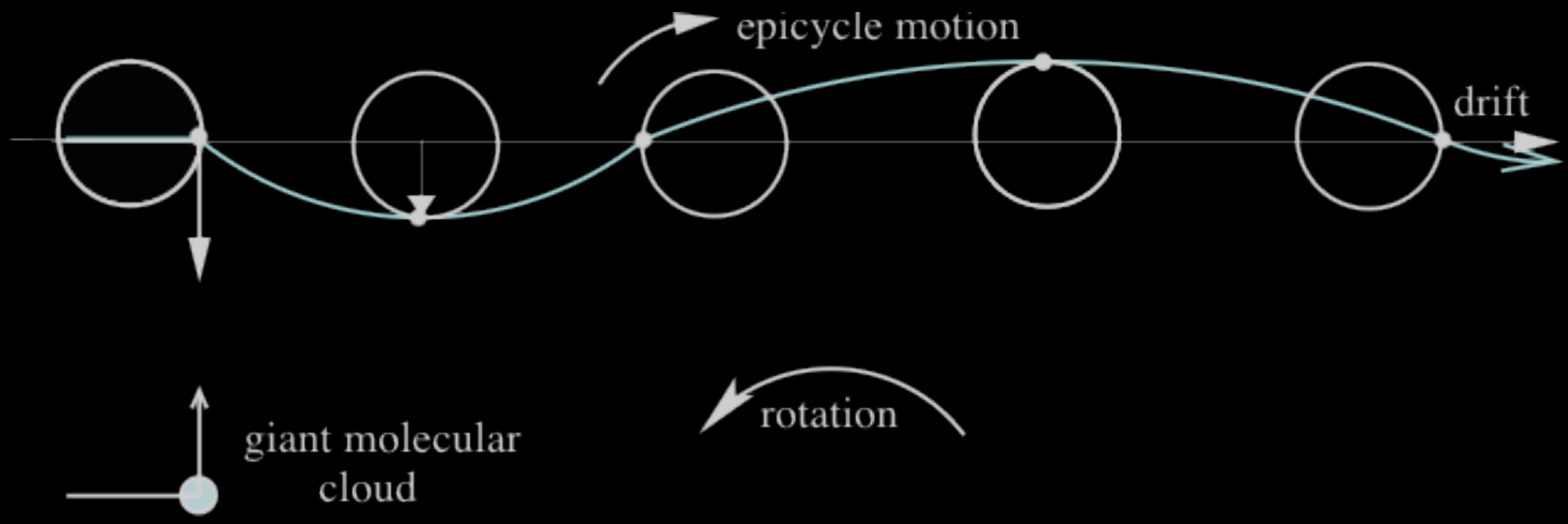
✧ Disk rotating in a rigid halo potential with 1000 massive orbiting aggregates (like corotating giant molecular clouds)



D'Onghia et al. 2013

$$\lambda_{crit} = 4\pi G\Sigma\kappa^{-2}$$

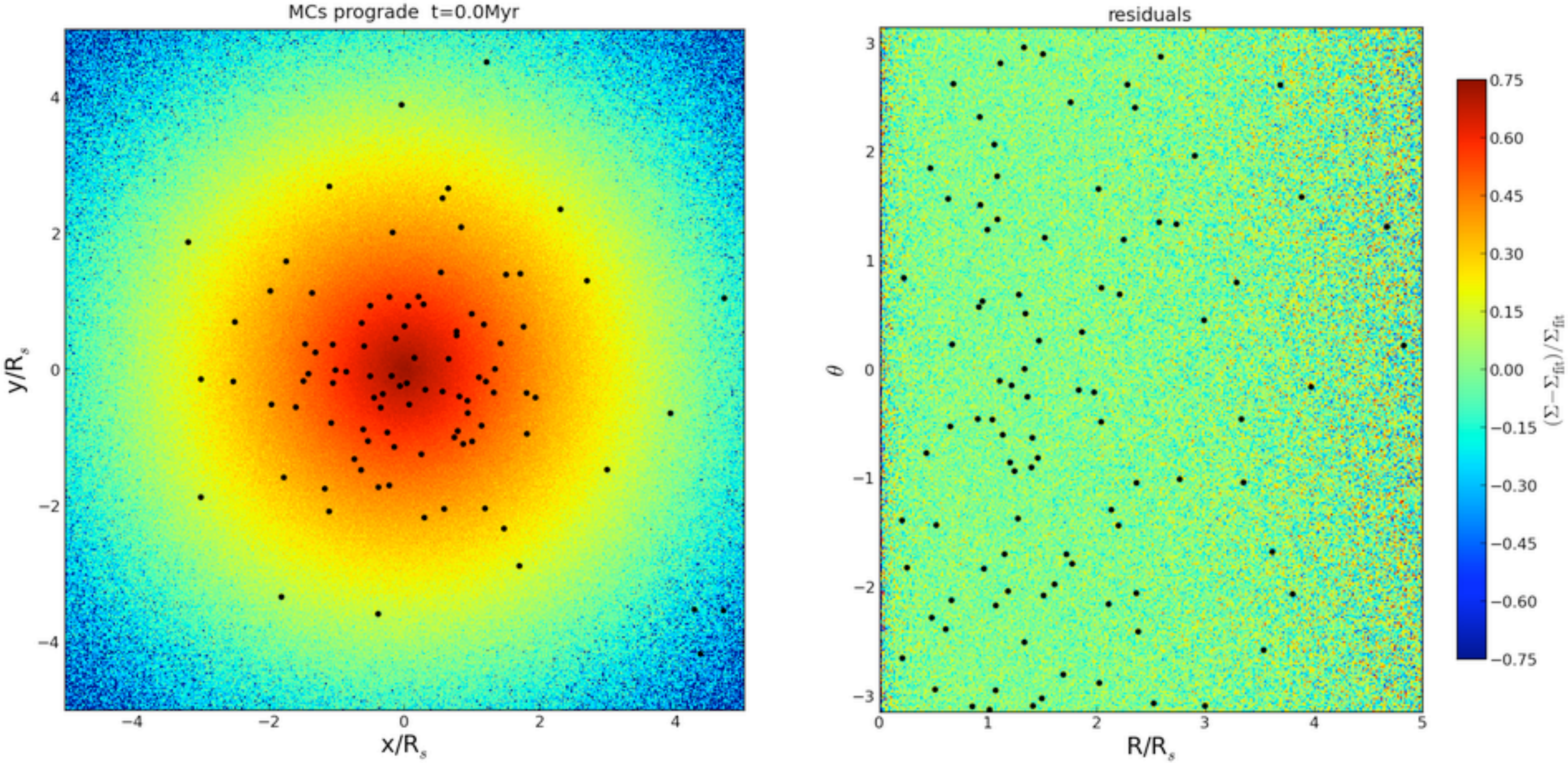
✧ The Swing Amplification (Toomre 1964)



The amplification occurs for wavelengths with $\lambda \approx 1.5\lambda_{crit}$ because of the cooperative effect of :

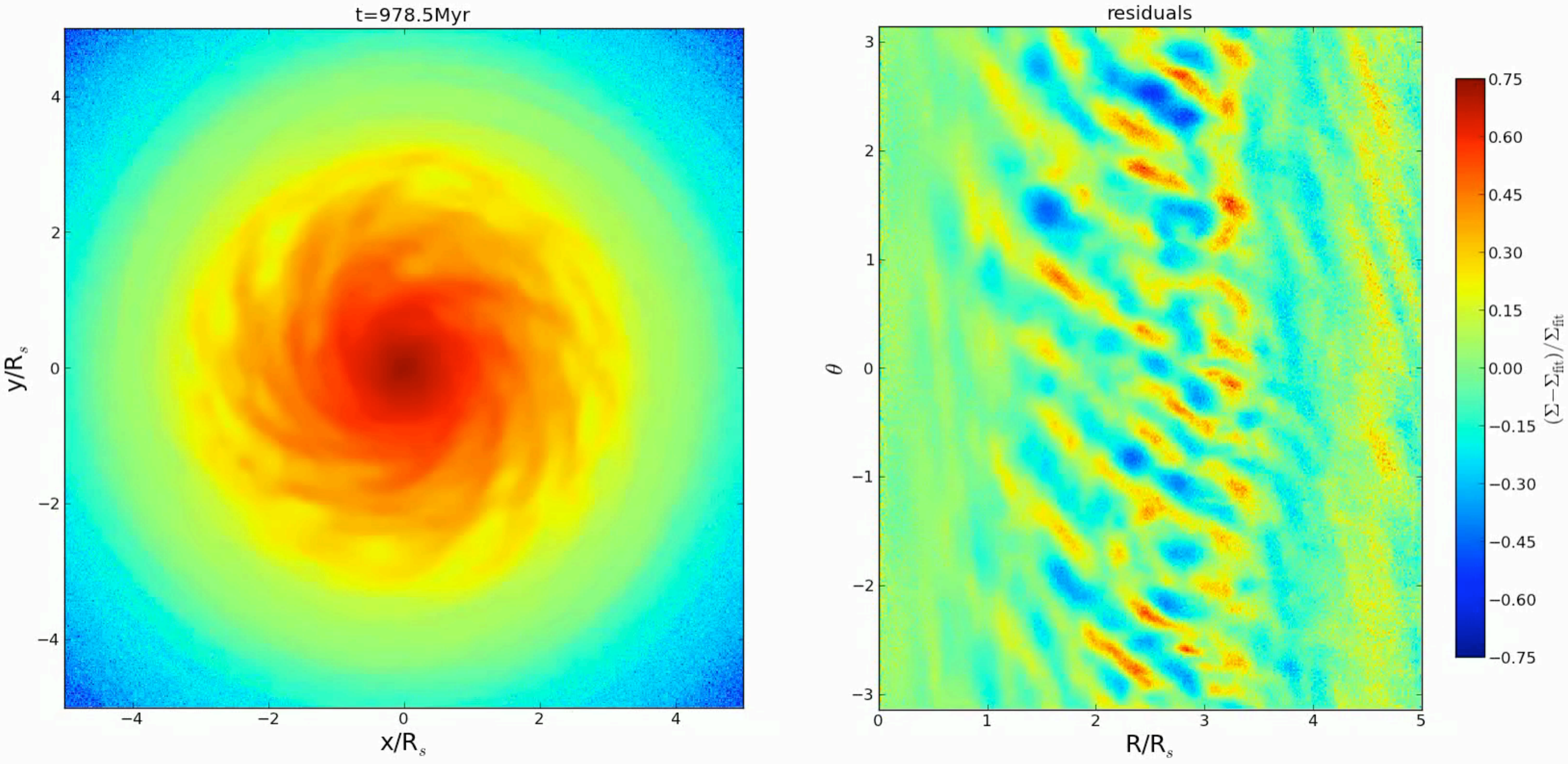
* **shearing flow**
* **random motions**
* **self-gravity**

Non linear effects are dominant on galactic scale and are not anticipated by the theory



Overdense regions depart from the initial perturbers

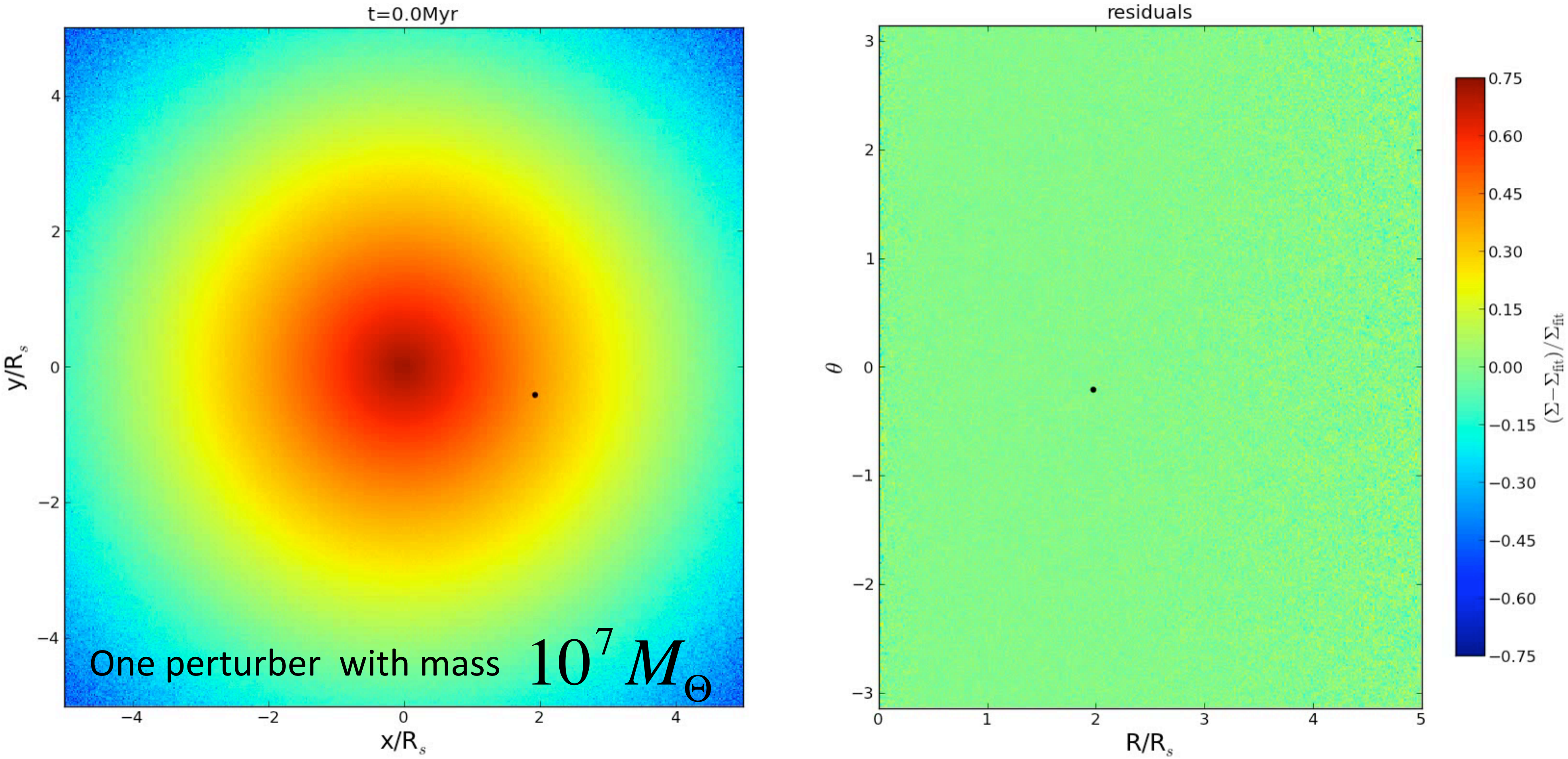
✧ Spiral arms are long-lived: the wakelets take over and become the new perturbers



Density waves are not static but change by time

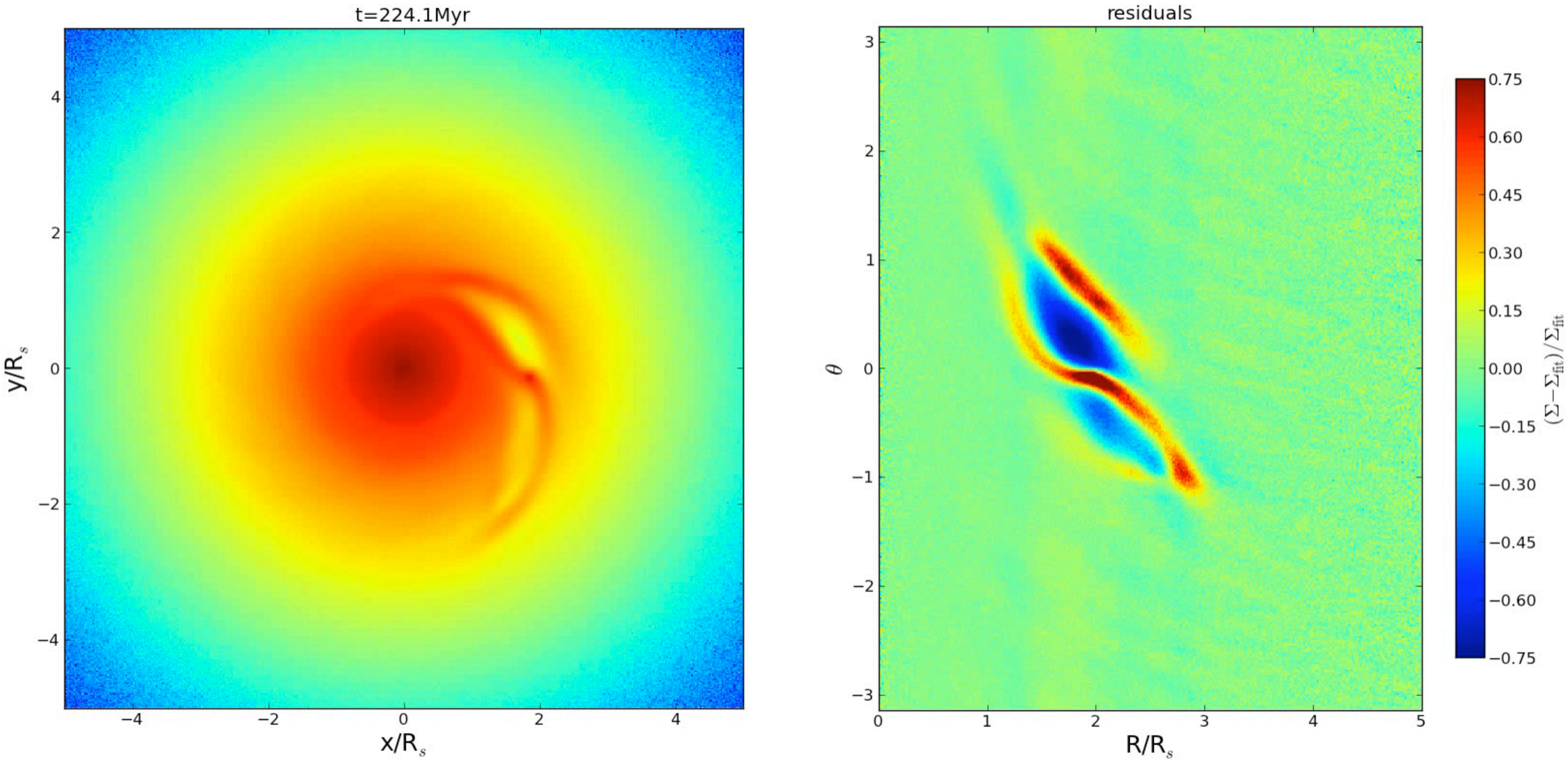
The arms break and reconnect locally by a balance between shear/gravity

✧ NON LINEAR EFFECTS

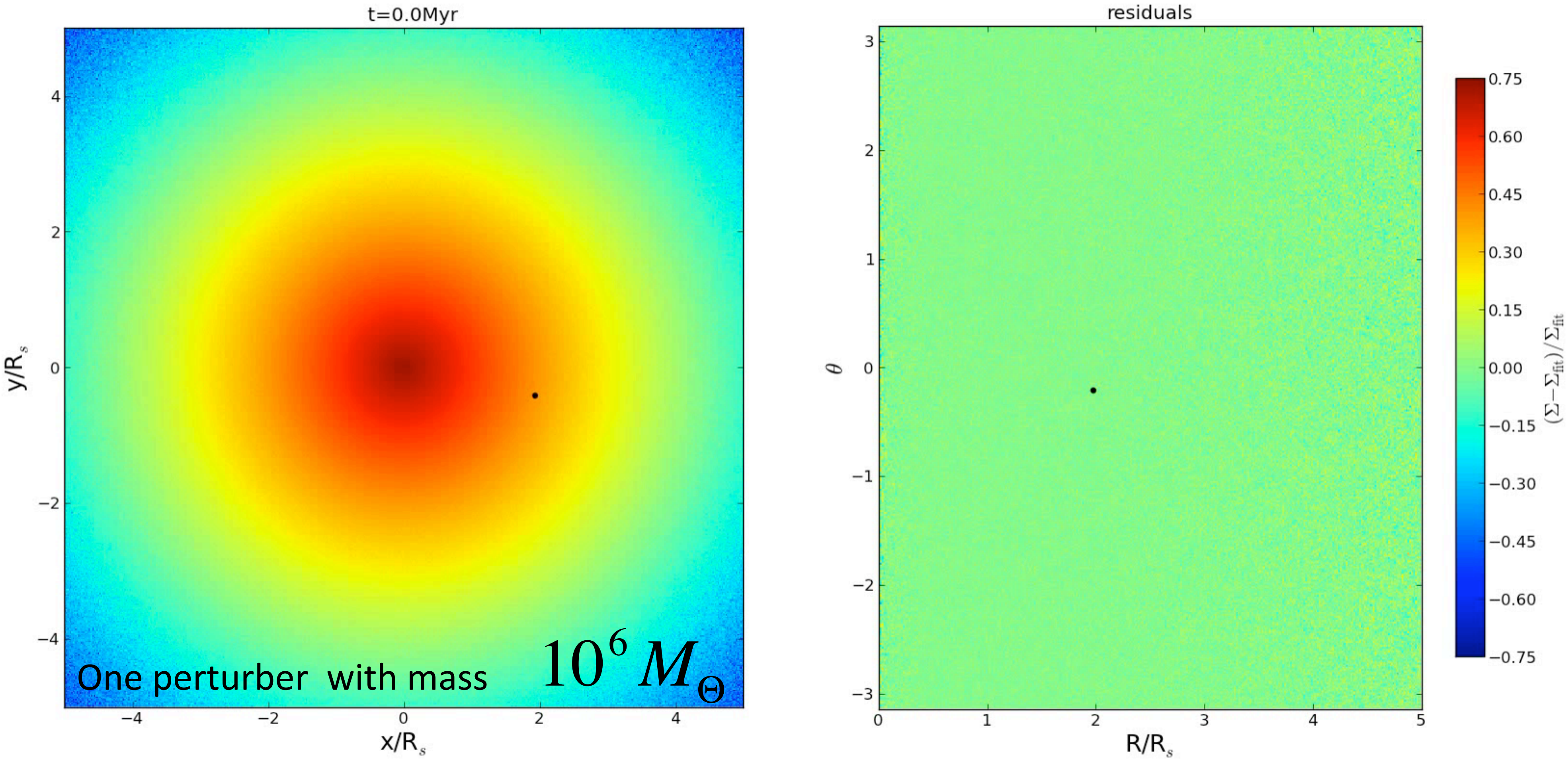


Non linear effects lead to the formation of multi-arms and to a local Jeans instability

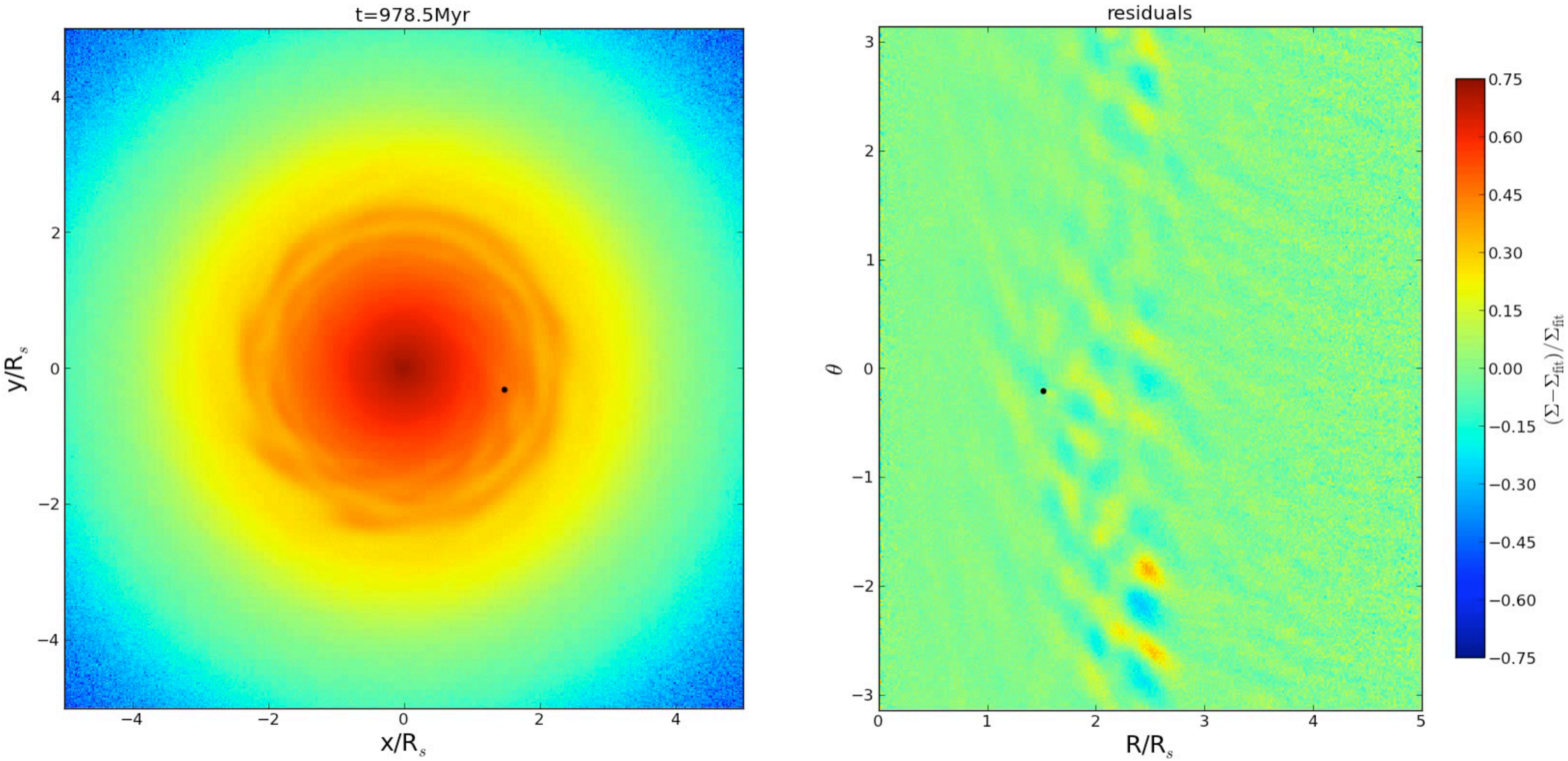
Time evolution of the spiral pattern



* Arms are long-lived
* Formation of holes
* The outer arms wind up (not much self-gravity)



Lower mass perturbers take longer time to develop non linear effects.



Lower mass perturbers take longer time to develop non linear effects.

- Spiral arms can be induced by overdense and underdense regions internal to the disk

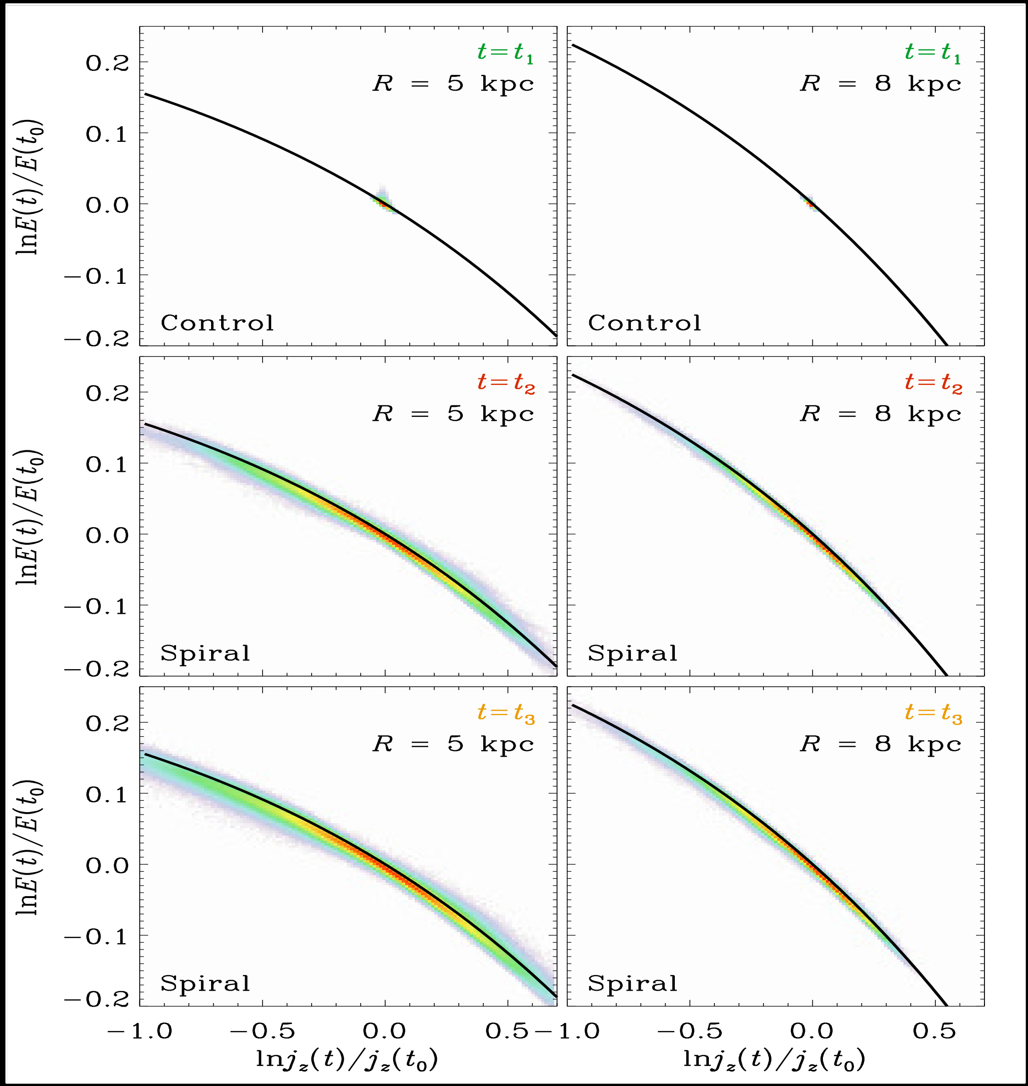
What about radial migration in self-perpetuating spiral arms?
Can stars migrate to produce the thick disk?

We approach it by studying:

* star guiding radii time evolution

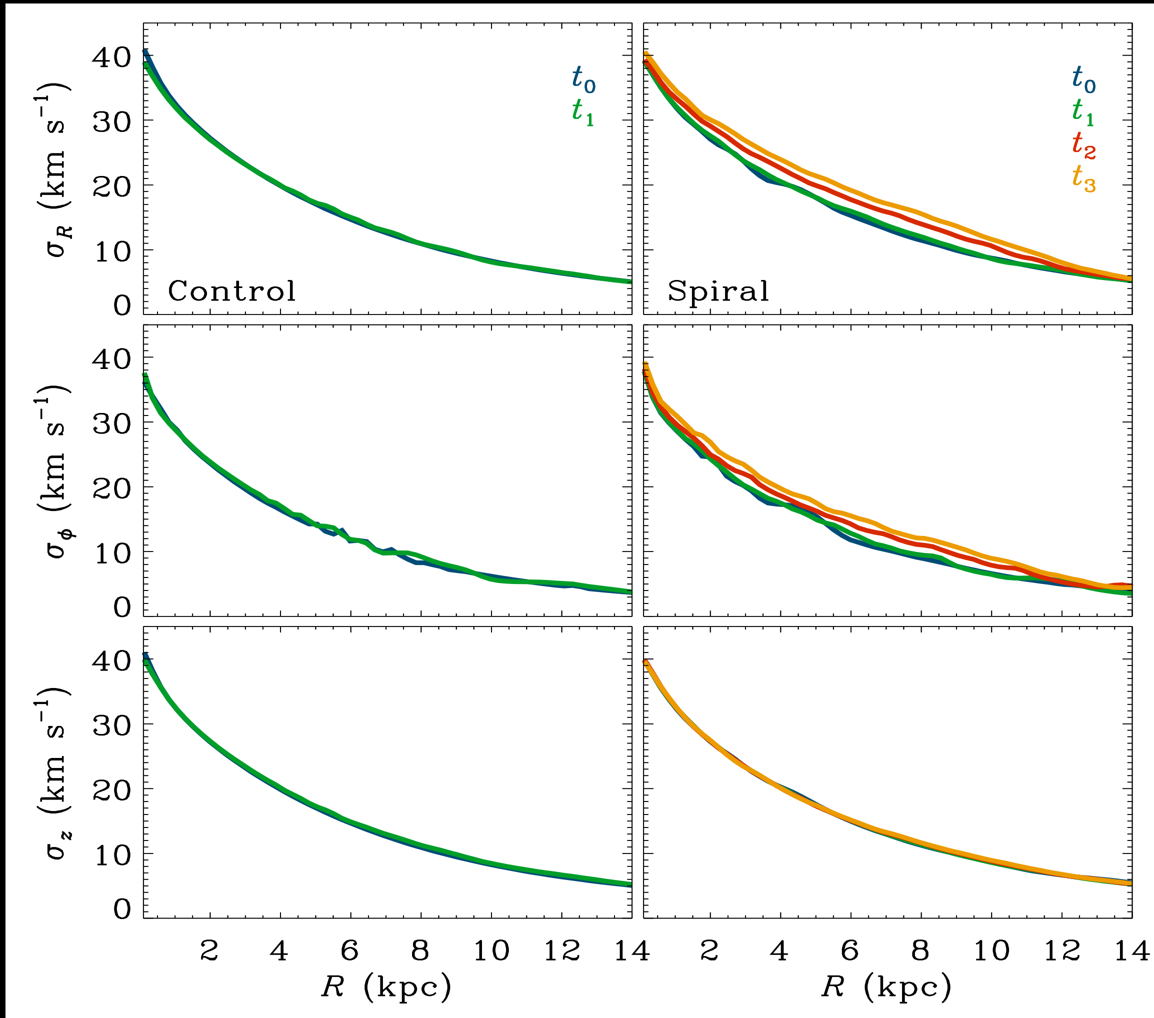
* disk heating

We find lot of stellar mixing



Vera-Ciro, D'Onghia, Navarro, Abadi 2013 in prep

Vertical and radial heating negligible



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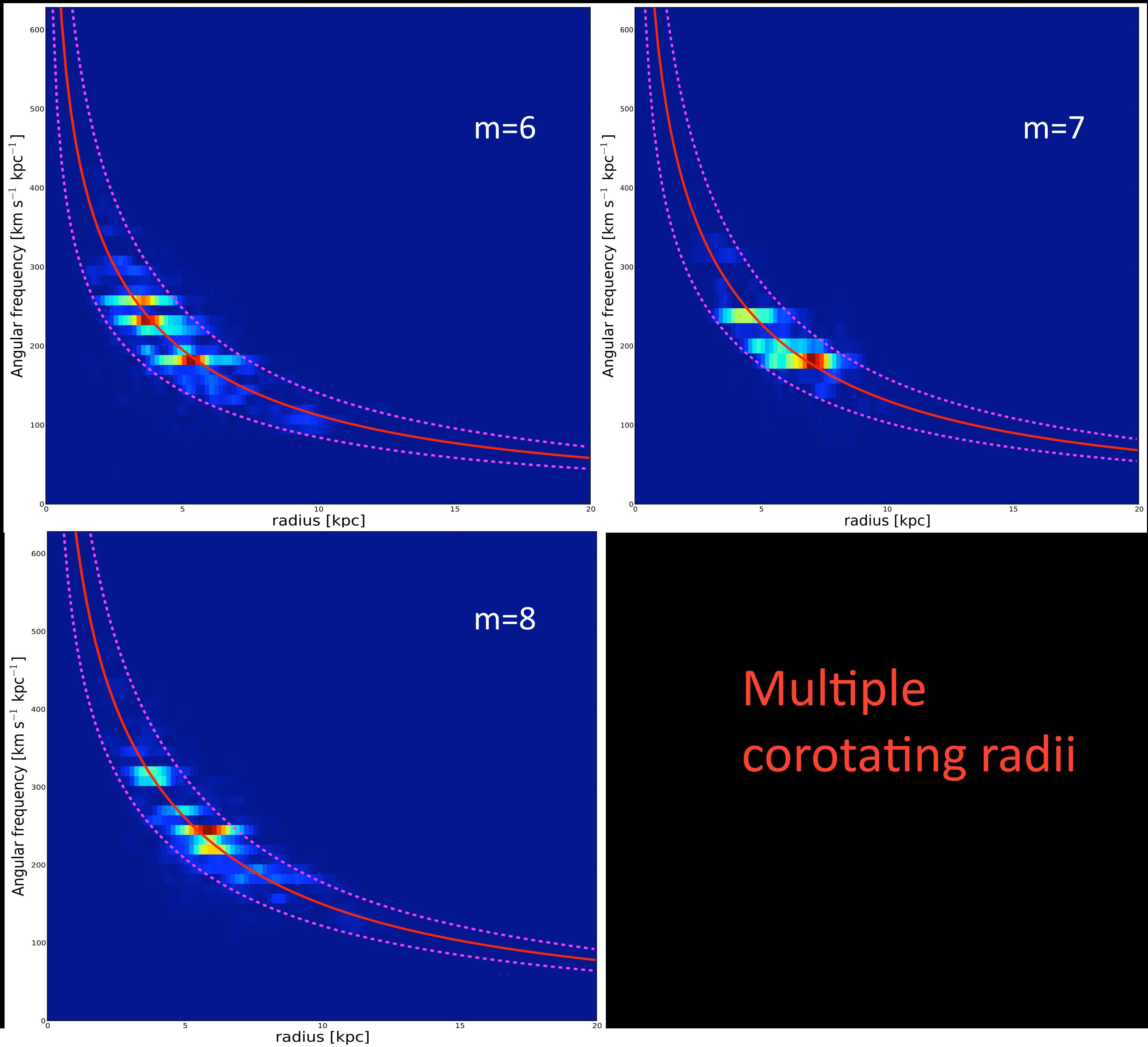
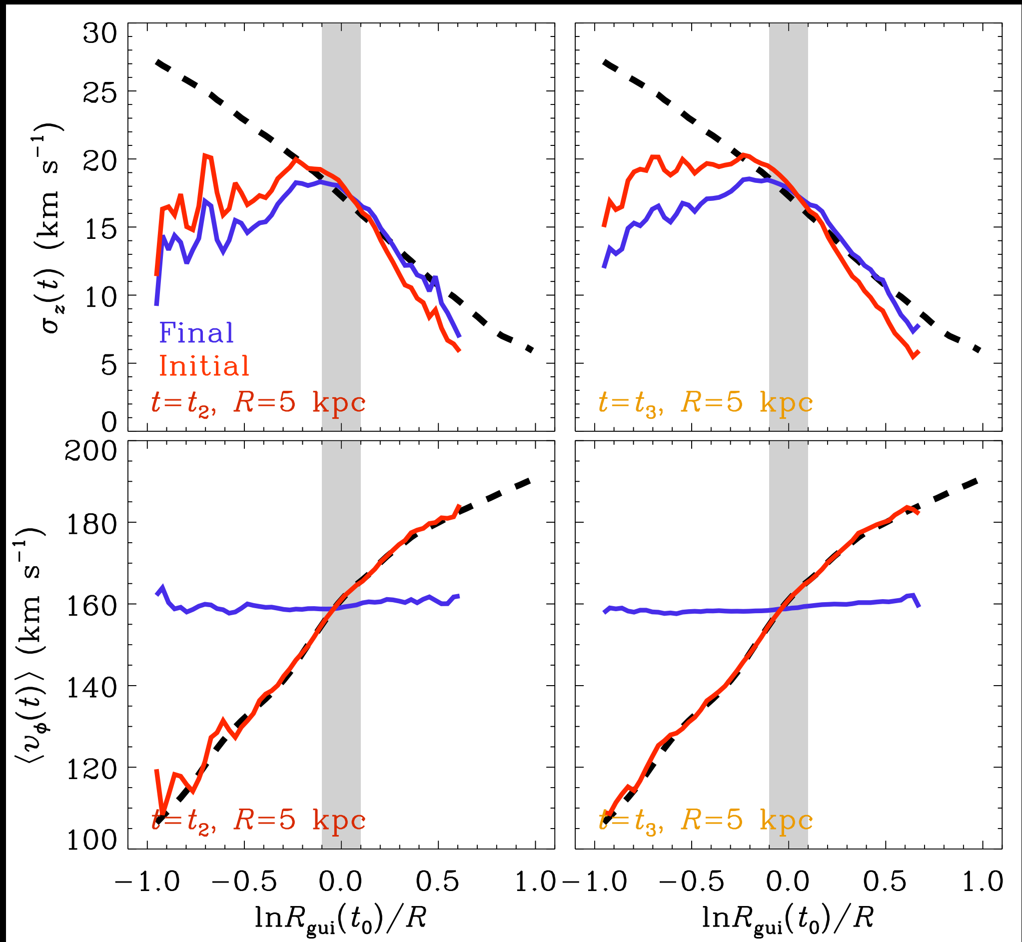


Multiple
corotating radii

Extreme migrators from outside in are much colder than the average



We predict a population of migrators of cold metal poor stars with velocity dispersion of 5 km/s

CONCLUSIONS

- ✧ Successful results for spiral arm formation.

  How a local gravitational response of the disk to perturbers can be **amplified to create spiral patterns through collective effects.**

- ✧ Failure in interpreting the results using current theories based on linear approximations.

  * SPIRAL ARMS ARE statistically LONG-LIVED

- ✧ Picture in which non-linear effects are dominant

  * APPLICATIONS: radial migration: we radial migration of stars but not heating of disk on the vertical plane.

Prediction: extreme migrators from outside in are metal poor cold stars