Are spiral arms in N-body simulations triggered by invariant manifolds?

ABSTRACT:

In this Master's project, we study if spiral arm structures observed in N-body simulations can be triggered or not by invariant manifolds. In this study, we compute the global galactic potential by using the Agama software (Euegene Vasiliev 2018). From the potential, and following our previous work (Romero-Gómez et al. 2006), we plan to determine how many individual stars inside simulated galactic disks (Roca-Fabrega et al. 2013) are found inside invariant manifolds orbits.

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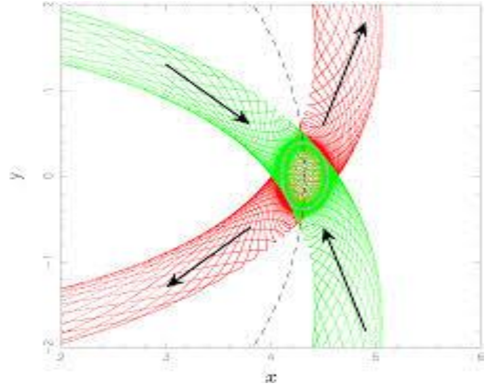
CONTEXT: TRYING TO EXPLAIN SPIRAL GALAXY FORMATIONS WITH N-BODY SIMULATIONS

- The invariant manifold theory was proposed by Romero-Gómez(2006+) as a new way to explain how spiral arms can be formed in barred galaxies. Stars of spiral arms move inside tubes known as invariant manifolds that depart from equilibrium Lagrangian points. It can reproduce multiple observations of external spiral galaxies → Analytic theory

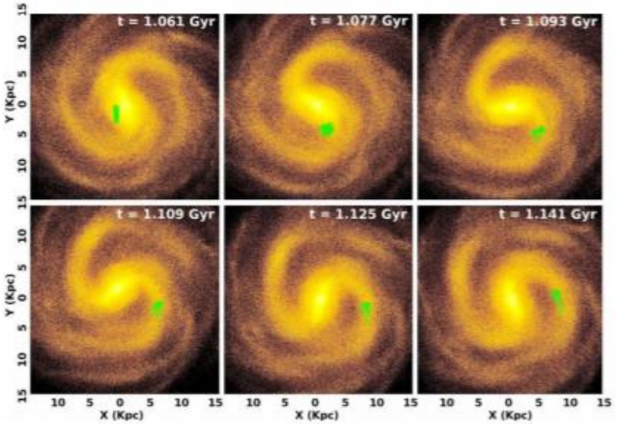


Tubular shape of the invariant manifolds.

What information can N-body simulations gives us?

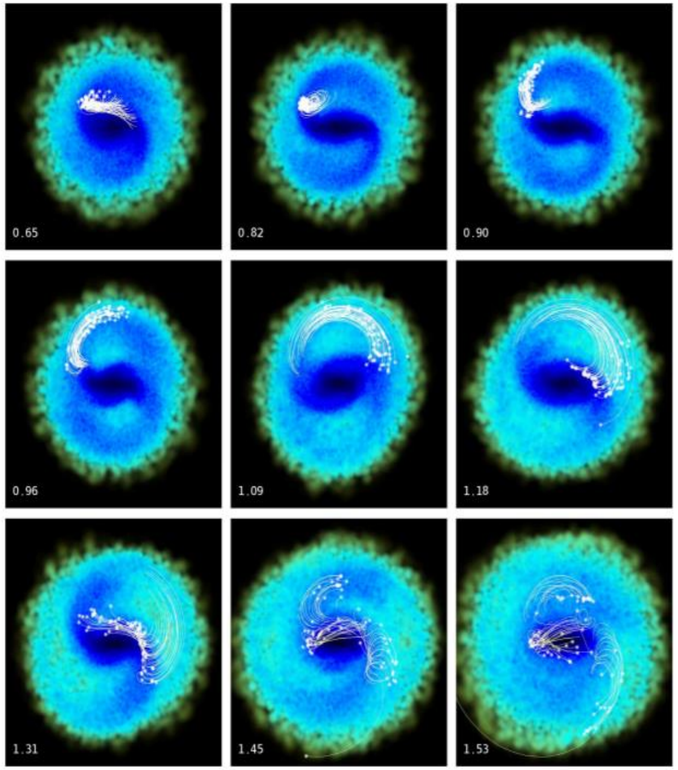
FIRST STEPS!

- Roca-Fábrega+(2013) found that the dominant spiral mode (m = 2) in strong barred models is most of the time connected to the bar and particles in barred models that are placed inside spiral arms move such a way that is compatible with spirals being induced by invariant manifolds.



Evolution of the particles (green) in Roca-Fábrega's +(2013) N-Body Simulation

- Athanassoula+(2012) observed evidences of manifold-driven spirals in a N-body simulation of a barred galaxy. The strongest evidence came from following the trajectories of individual particles.



Evolution of the particles (white) in Ahanassoula's +(2018) N-Body Simulation

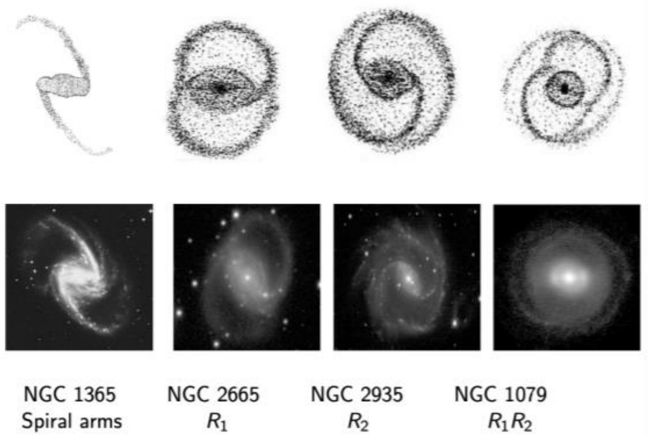
OBJECTIVES AND METHODOLOGY

Main goals

- Test the invariant manifold theory changing the analitycal development by N-body simulations and try to reproduce the basic elements of the theory ➡ equilibrium Lagrangian points and stability behaviour, Lyapunov's orbits, invariant manifolds and, finally, spiral arms.

- Check if through the use of N-body simulations we are able to reproduce the observations, as precise as with the analytical theory.

Predicted observations throught the analytical theory.



Methods

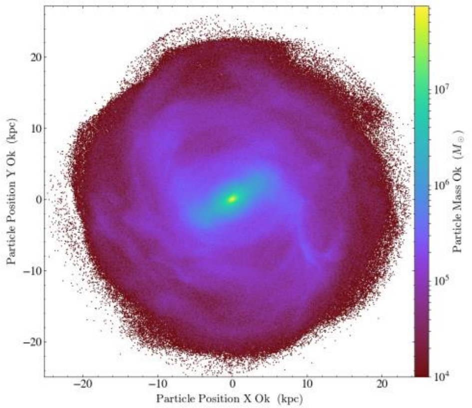
- First, colleting high resolution N-body simulations performed and used by Roca-Fábrega (2013) with ART and GADGET3.

- The use of Agama (Action-based galaxy modelling architecture) framework developed in 2018 by Eugene Vasiliev as an update of Smile. It provides methods for computing the gravitational potential of arbitrary analytic density profiles, N-body models, etc…

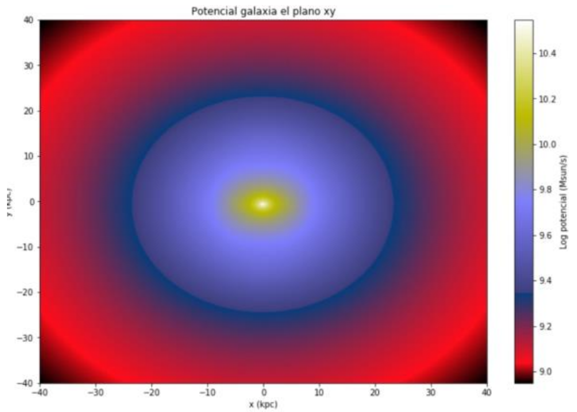
- The code of the calculation needed for the invariant manifold theory elaborated by M.Romero-Gómez, is **applied to extract the potential from AGAMA with a more realistic N-Body simulation instead of an analytical expression.**

FIRST RESULTS

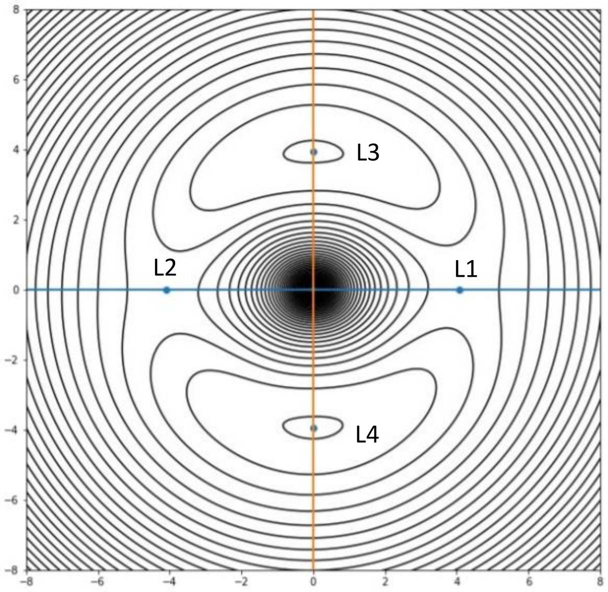
- Extraction of the potential and density of our N-Body simulated galaxy with Agama.
- The plot of the potential isolines contour in the rotating frame and the calculation of the five equilibrium Lagragian points. The behaviour of these points is tested to be correct.



Initial Density of the N-Body Simulation

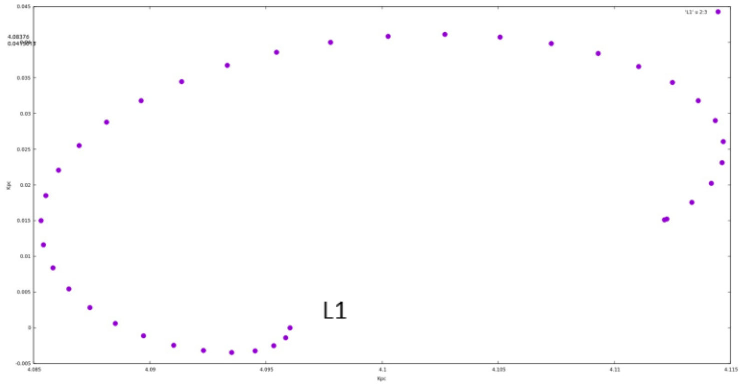


Potential of the N-Body Simultation extracted by AGAMA



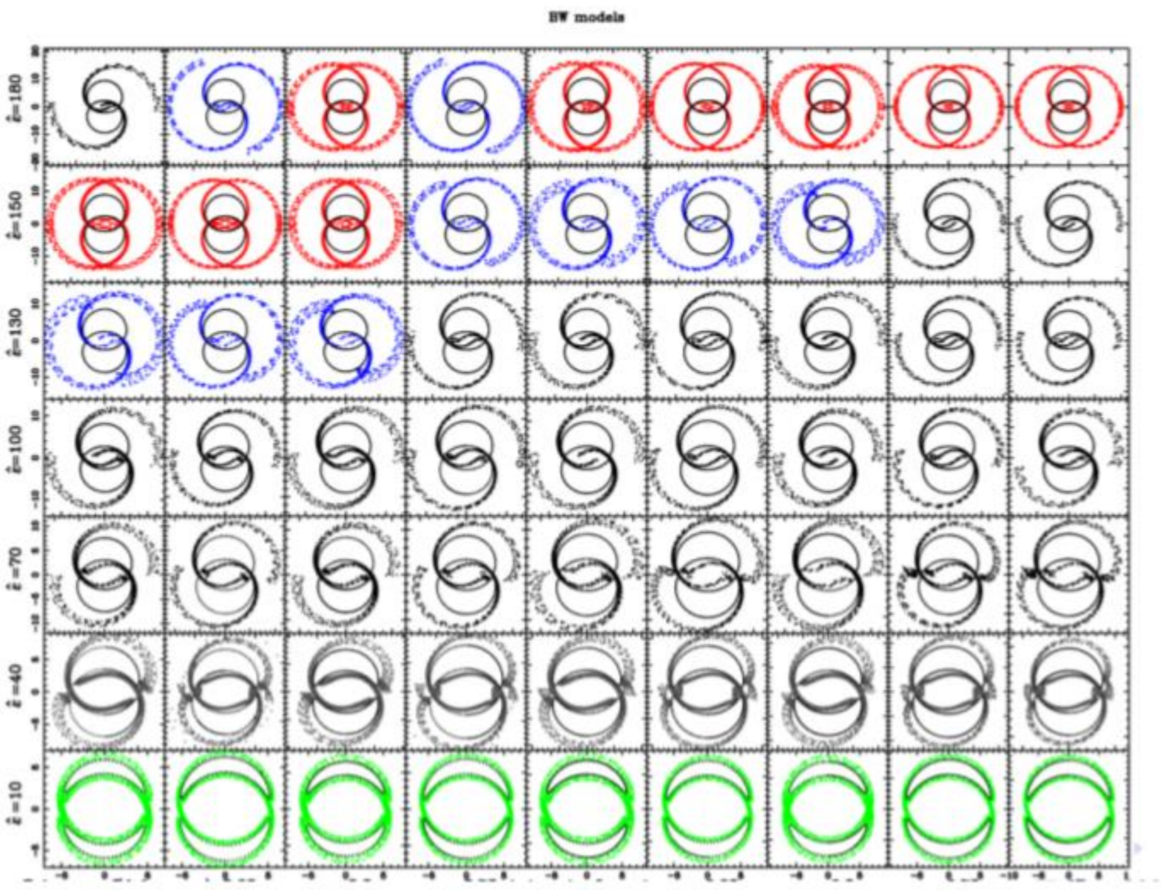
Potential isolines in the rotation frame. Equilibrium Lagrangian points are shown.

- The first calculation of the linear approximation to the Lyapunov's orbit around the unstable equilibrium Lagrangian L1 Y L2 points.



Linear aproximation to the Lyapunov orbit around the equilibrium Lagrangian point L1.

FUTURE WORK



Spirals
rR2 ring
rR1R2 ring
rR1 ring

All the morphologies reproduced through invariant manifolds by changing the parameters.

1. Estimate the fraction of stars located inside the invariant manifolds in relation to the rest of stars.

2. Extend the study from the N-Body isolated simulations to hydrodynamical simulations to see how the gas component is supported.

3. Include time-dependent potentials ➡ Use of Lagrange Coherent Structures (LCS).

4. Study the singular case of spiral arms with a different pattern speed from that of the bar. It is necessary to add again a time dependent potential.