The Morphology and Pattern Speed of Spiral Structure

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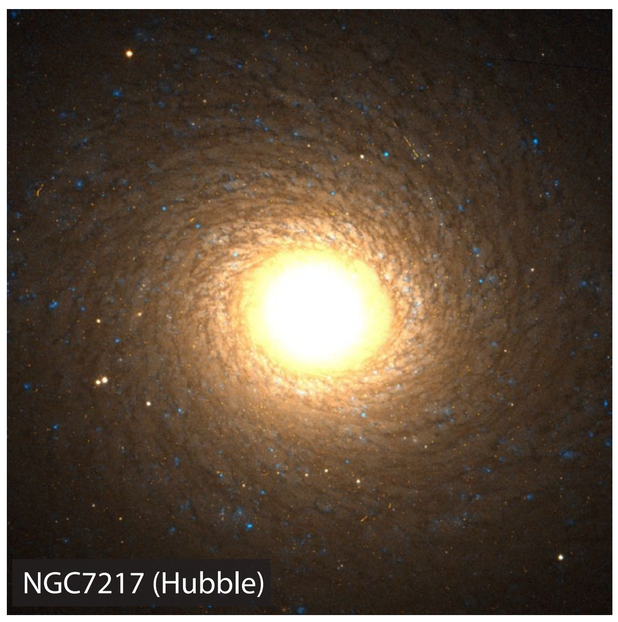
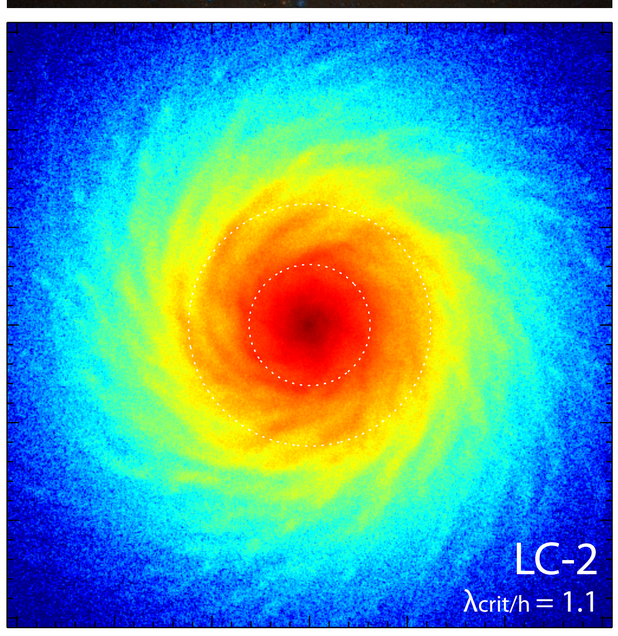
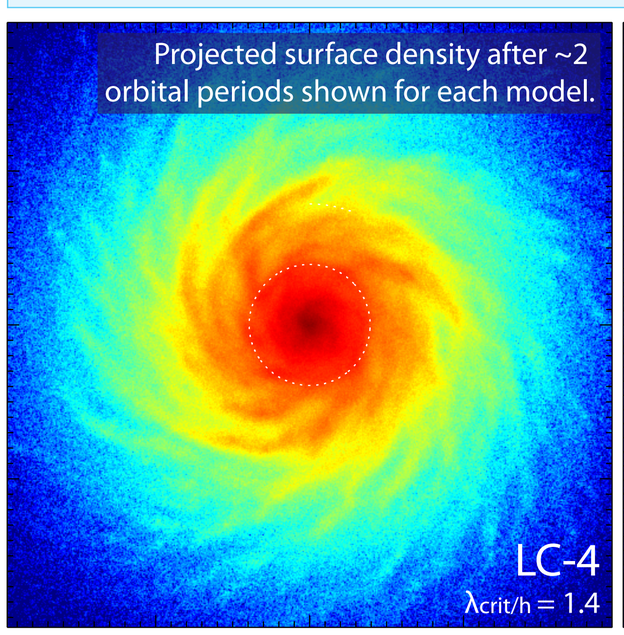

NGC7217 (Hubble)

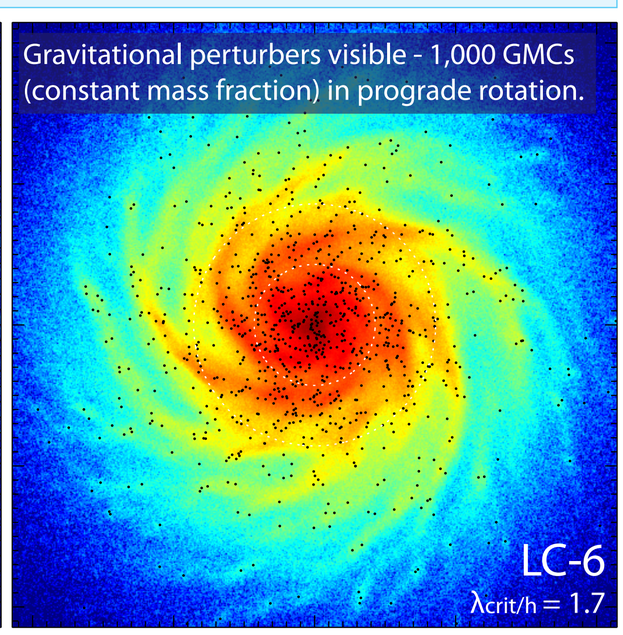
We consider the spiral structure arising from the gravitational influence of massive perturbers, for instance giant molecular clouds, corotating in a stellar disk. Within a single rotation period our simulations develop a prominent, large-scale response in an initially smooth disk.

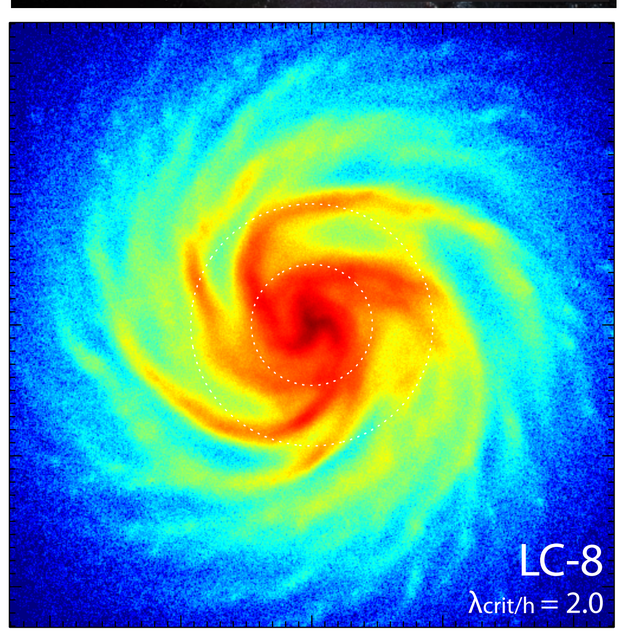
We explore the spectrum of spiral morphologies generated by this mechanism by varying the critical wavelength parameter (λ_{crit}). We make quantitative correlations between spiral structure and host galaxy and halo properties, and construct a catalog of arm morphologies to compare to spatially resolved observations of nearby galaxies. We measure radial variation of the spiral pattern speed using a modified Tremaine-Weinberg method, and find that the pattern speed both decreases with radius and appears to track the circular velocity of the disk.


M101 (NASA/ESA)

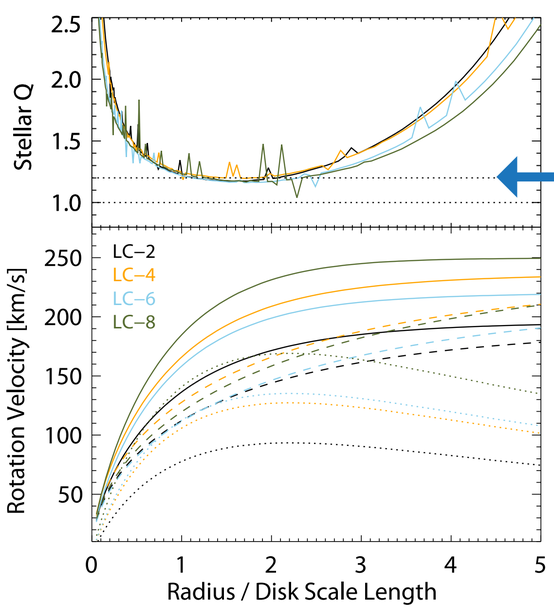








1. Model Construction and Simulation



Models locally stable (Q>1) against axisymmetric instability at all radii.

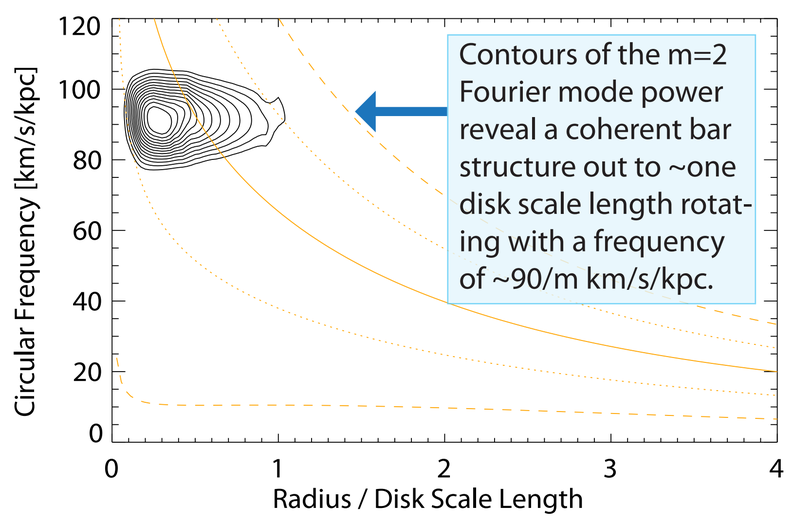
1. We construct a suite of stable, live exponential stellar disks embedded in rigid dark matter halos (following Hernquist 1993).

2. Chosen to have varying λ_{crit}, the maximum wavelength stable against axisymmetric instability, and the natural length scale in the swing amplifier solution:

$$\lambda_{crit} = \frac{4\pi^2 G \Sigma_\star}{\kappa^2}$$

3. N-body forces evolved using the hierarchical Barnes-Hut tree code implemented in GADGET-3.

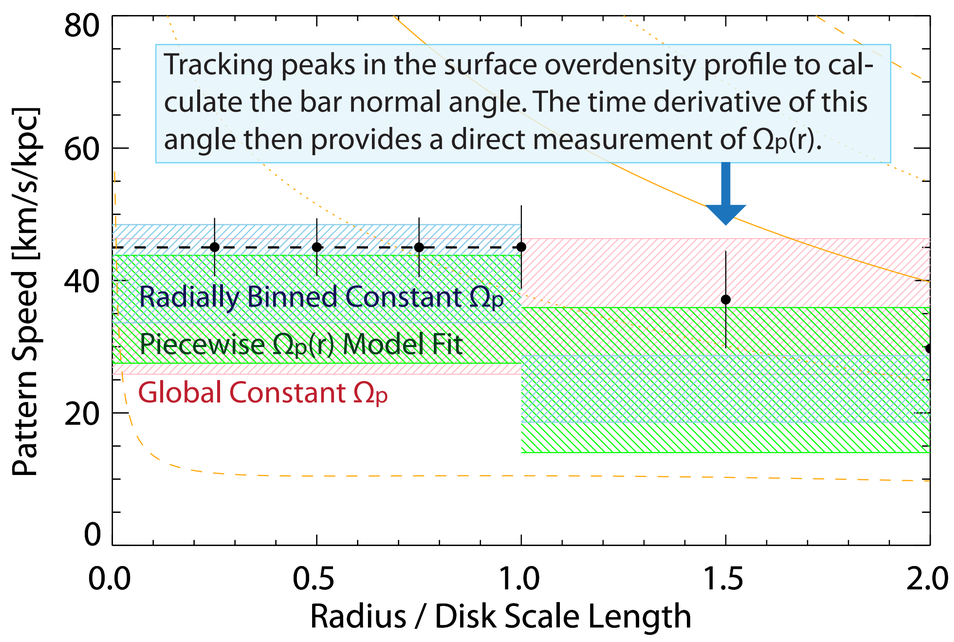
2. Verification of the TW Method with a Barred Galaxy



1. Adopt techniques used observationally to measure the structural properties of disk galaxies: modified Tremaine-Weinberg (TW) method for measuring spiral pattern speeds.

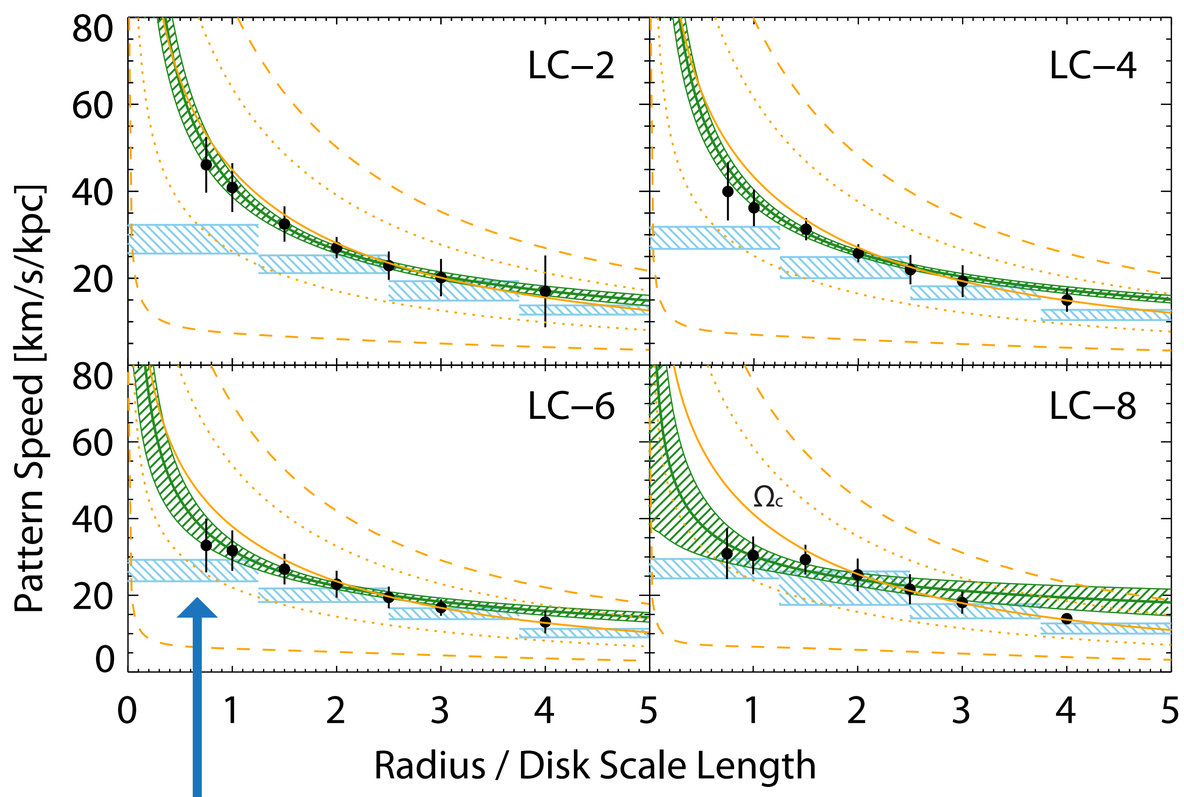
2. Verify the methods using time-domain information available in the simulations, and compare directly with observations.

Observational methods (colored regions) based on the TW method are consistent with direct simulation measurements of the pattern speed, though they exhibit significant scatter with time (shown as vertical errors).



Five methods to measure Ωp(r) for the bar simulation.

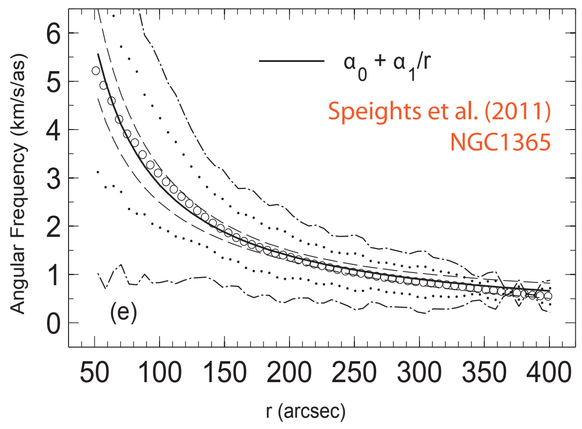
3. Measuring the Pattern Speed of Simulated Spiral Galaxies

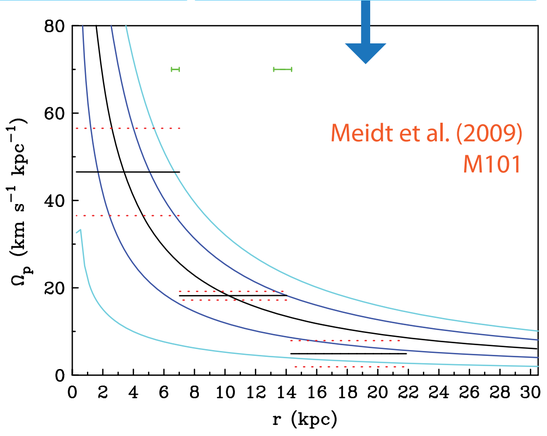


1. Best fit powerlaw models using the Radial Tremaine-Weinberg method (green) in excellent agreement with direct measurements (points).

2. Pattern speed decreases with radius and closely follows the circular velocity of the disk (solid orange line).

3. Radial behavior in broad agremeent with recent observational work, and inconsistent with constant Ω_p.





4. Main Conclusions and Future Work

- The proposed mechanism (collective swing amplification of a large number of perturbers co-rotating within the disk) can **recreate a broad range of spiral morphologies**.
- Measurements made with the observationally based Tremaine-Weinberg method are consistent with the true feature pattern speeds, though with large scatter.
- The **spiral pattern speeds of our model spiral galaxies decrease with radius**, consistent with recent observational work (e.g. Merrifield+ 2006, Meidt+ 2009, Speights+ 2011).
- Furthermore, the **pattern speed closely tracks the disk circular velocity**, a natural consequence for a local response arising around a collection of co-orbiting perturbers.
- **Our results are fundamentally inconsistent with the quasi-steady density wave theory of Lin and Shu (1964), and rather imply that spiral structure is not steady in time.**

Additional visualization and movies available at www.cfa.harvard.edu/~dnelson/