Evolution of Barred Galaxies in Spinning Dark Matter Halos: High Resolution N-body Simulations at DLX

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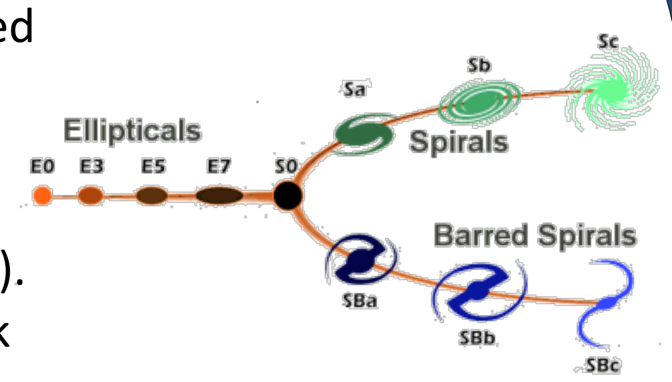
Background:

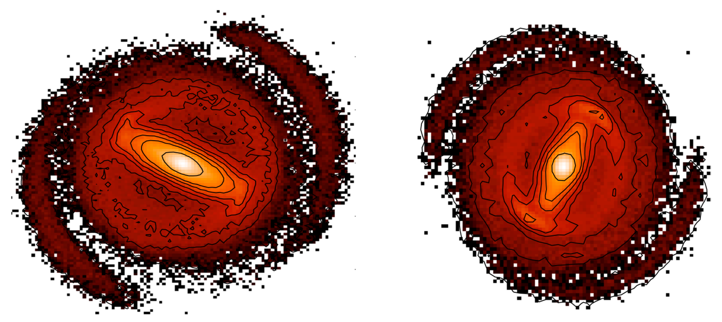
Observations show that galaxies are dominated by stellar disks immersed in much more massive, slowly tumbling dark matter (DM) halos. Large fraction of galactic disks, at least 75%, are barred (see Hubble Fork on the right). Stellar bars form either via spontaneous break of axial symmetry or via galaxy interactions.



The formation and evolution of stellar bars is not fully understood. Stellar bar evolution is highly nonlinear and cannot be treated analytically. The main approach to study these disk-halo systems is via numerical simulations, whose goal is to explain why galaxies have such a wide range of morphologies as shown on the Hubble Fork diagram.

Galaxy observations:[1]

Galaxy simulations:



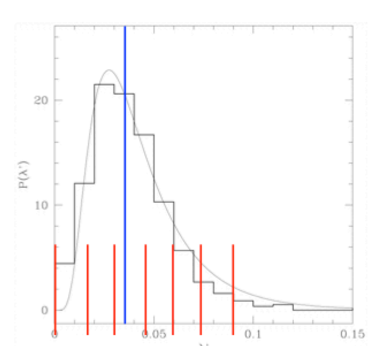
Initial Conditions and Numerics:

We place identical stellar disks inside DM halos of different spin to see what effect this has on the stellar bar. A DM halo spin is expressed as:

Cosmological Spin Parameter

$$\lambda = \frac{J_h}{J_{max}}$$

λ is the total angular momentum inside the halo, compared to the angular momentum in a completely rotationally supported halo. Numerical simulations[3] predict the mean of λ ~ 0.035 ± 0.005.



Numerically measured halo spin (Blue=Average[2]) and those simulated in our work (Red).

Each model is run using the state of the art parallelized N-body code GIZMO[3], a hierarchical TREE code. We compose models of 7.2 million DM halo particles and 0.8 million stellar disk particles.

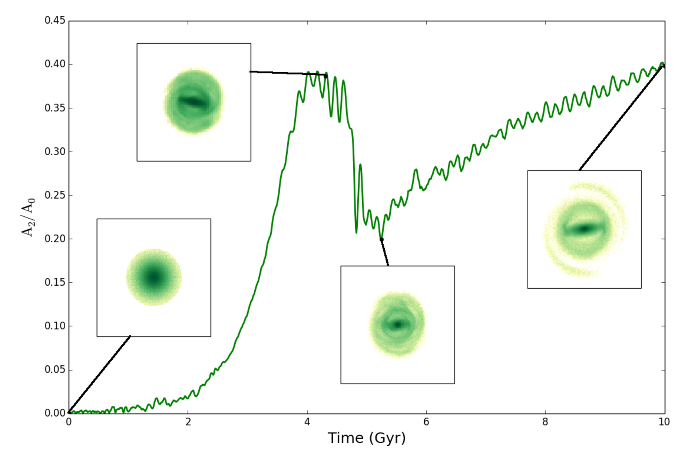
Stellar bars forms and brakes against the DM halo, losing angular momentum to the halo. This process has been studied only in nonrotating halos. Our simulations are the first to ask, **do stellar bars behave the same way in halos of differing spin?**

Results:

Evolution of Stellar Bar Strength and Size:

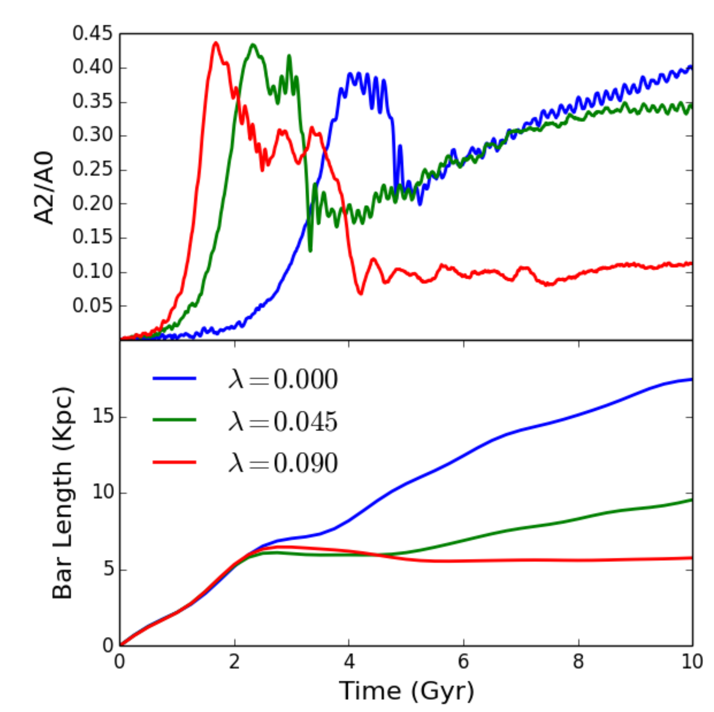
To describe stellar bar evolution over the length of the simulation we measure the bar strength as its departure from axial symmetry normalized to the axisymmetric disk, (A2/A0).

We plot bar strength versus time for the standard (λ =0) model. The insert shows face-on disks at different times of its evolution.

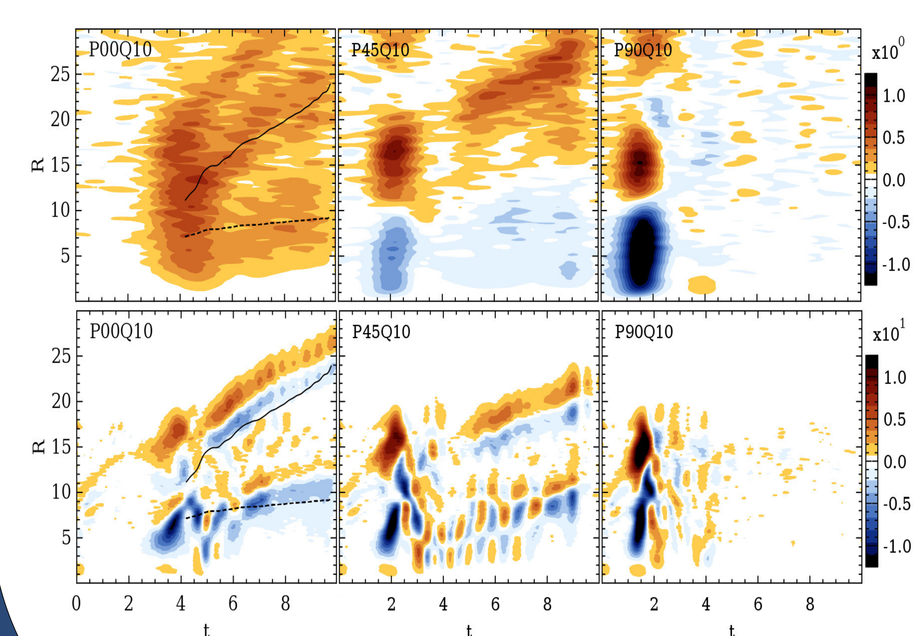


The plot to the right shows trends we observe that scale with λ.

- At early times, larger λ leads to faster bar build up.
- At later times, larger λ damps the bar growth. Faster spinning halo nearly destroys the bar in λ=0.090 model.
- The bar length is also affected. Stellar bars inside the large λ models cease to grow, while bar in λ=0 continues to grow in length for the entire simulation of 10 Gigayears.



Angular Momentum Transfer:

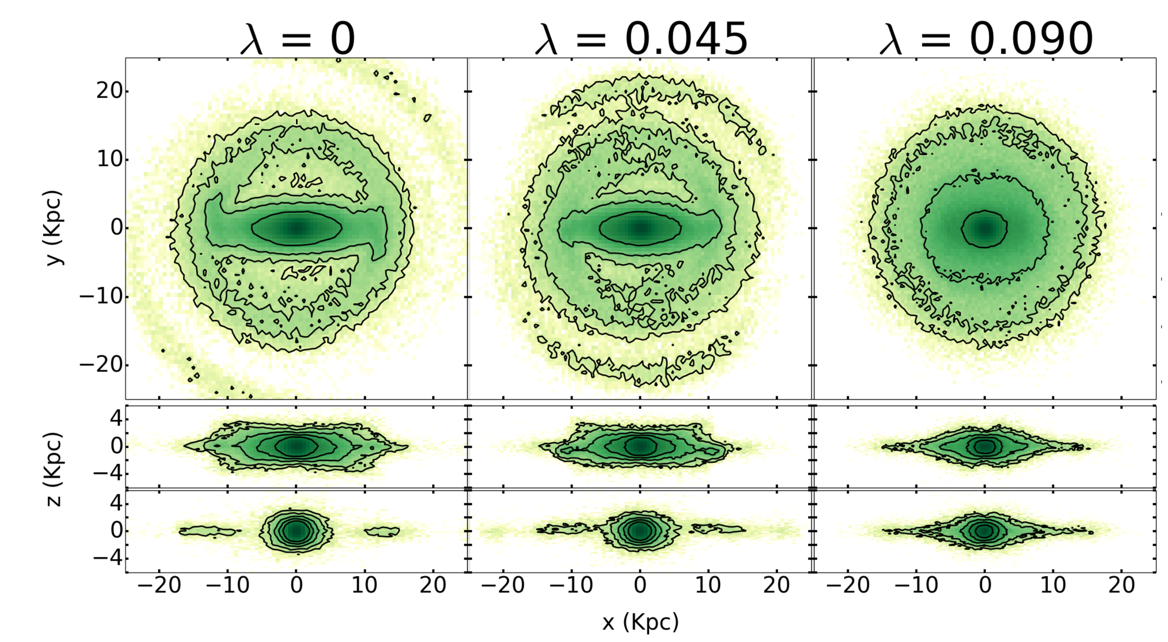


The top row shows angular momentum (J) transfer rate for the halo, the bottom --- for the disk. Red denotes a gain of J and blue shows a loss of J. Lower λ halo acts as a sink of J, while larger λ halos stop interacting with the disk.

Regions of orbital resonance are marked for the λ=0. J is clearly transferred to the halo along these resonances.

Conclusions:

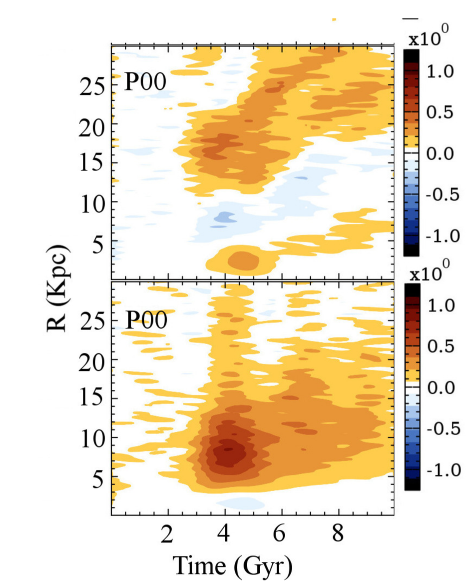
Our results show a new and important effect: the DM halo controls the evolution and morphology of the stellar disk. The end evolution disks are shown for each DM halo:



Stellar bar evolution is substantially more complex when the DM halo spin is taken into account. **We have shown here that bars can be destroyed by internal processes in the galaxy and challenge the idea that stellar bars are robust morphological features.**

Future Work:

- We continue to analyze DM halo evolution, to understand how DM particle orbits affect J transfer. Non-resonant particles contribute more to J transfer than previously expected. (Right Figure: J transfer in halos for retrograde and prograde halo particles.)
- Future simulations will add gas component in addition to stars and DM. The effect of spinning DM halo's on galactic gas is currently unknown.



References:

[1] These photos were taken from NED. The NASA/IPAC Extragalactic Database (NED) is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.
[2] Bullock, J.S., Dekel, A., Kolatt, T.S., A.V., Klypin, A.A., Porciani, C., Primack, .R. 2001, ApJ, 555, 240
[3] Hopkins, P.E., 2015, MNRAS, 450, 53

Acknowledgements:

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