Angular momentum shapes disk galaxies

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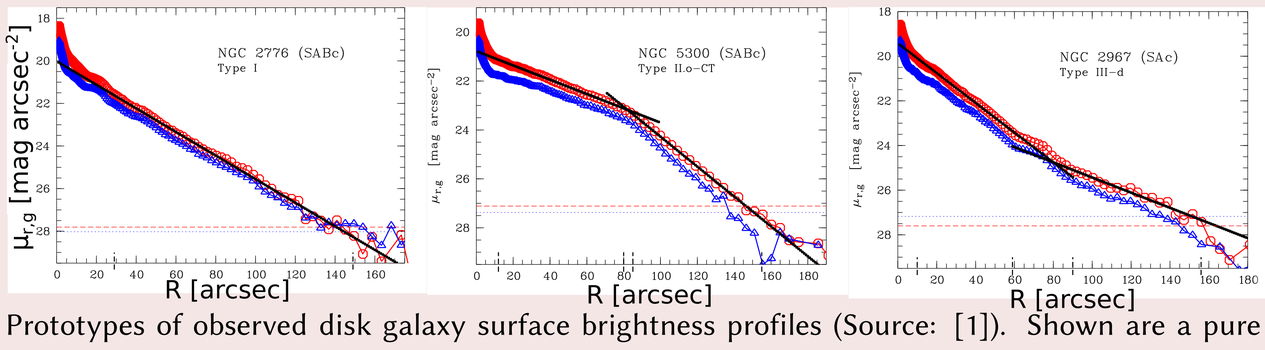
Abstract

We present a simple numerical model of disk galaxy formation which, for the first time, reproduces all observed stellar radial profile types: pure exponential (quite rare), up-bending and down-bending. The model links a galaxies' disk profile type to its host halo's total angular momentum. We find that the outskirts of up-bending disks are dynamically very unusual, i. e. they host stars on very eccentric orbits.

Observational motivation

pure exponential ($\approx 10\%$) down-bending ($\approx 60\%$) up-bending ($\approx 30\%$)



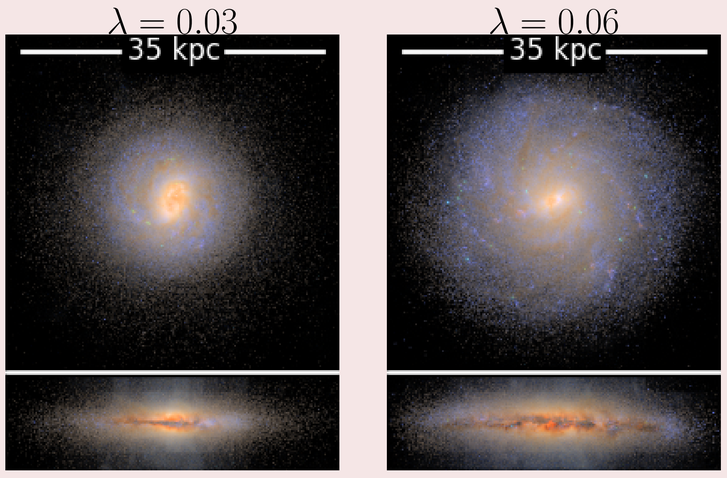
Prototypes of observed disk galaxy surface brightness profiles (Source: [1]). Shown are a pure exponential (left), a down-bending (middle) and an up-bending (right) profile.

Simulations

- Gravity + SPH simulations
- Modified version of ChaNGa
- Initial Conditions:
  - Isolated halos, ($M_{\rm vir} = 10^{12} M_\odot$)
  - Dark matter + spinning gas sphere in hydrostatic equilibrium
  - Cosmologically motivated angular momentum distribution [2]
  - Explore halo spin parameter range $0.02 < \lambda < 0.1$.
- Evolve for 8 Gyr

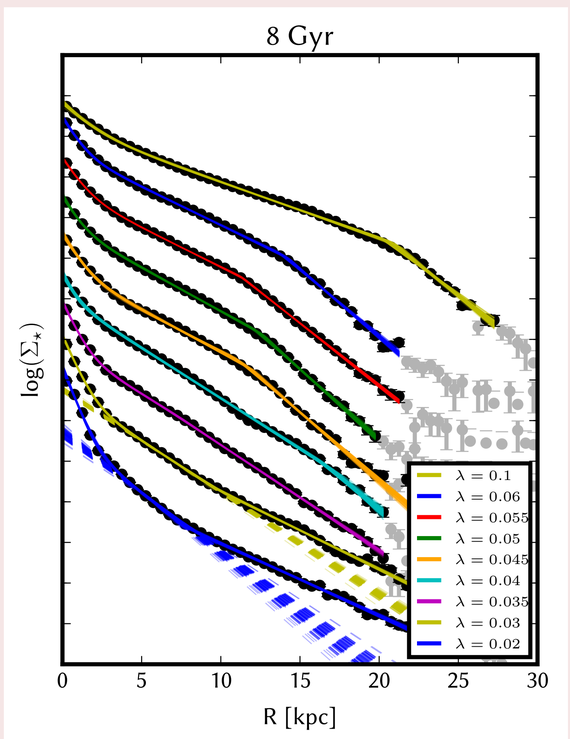
Results

What do the disks look like?



Mock observational images of the low ($\lambda = 0.03$, left) and high spin ($\lambda = 0.06$, right) simulated galaxies. The low spin galaxy appears smaller and more centrally concentrated.

How is stellar mass distributed?



Stellar surface density profiles extracted from low (bottom) to high (top) spin simulations. The profiles are offset by 1 dex.

low spin

($\lambda \lesssim 0.03$), profiles have up-bending break

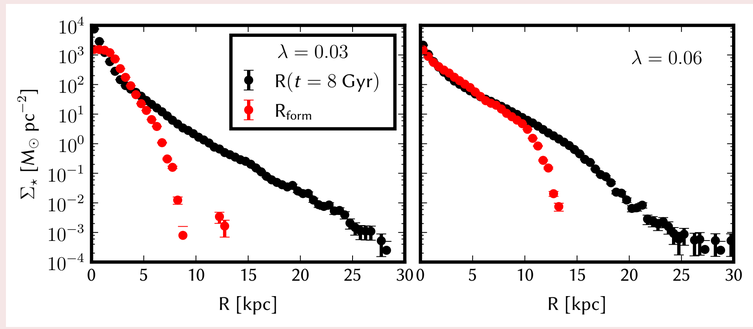
intermediate spin

($\lambda \approx 0.035 - 0.04$), pure exponential profile

high spin

($\lambda \gtrsim 0.045$), profiles have down-bending break

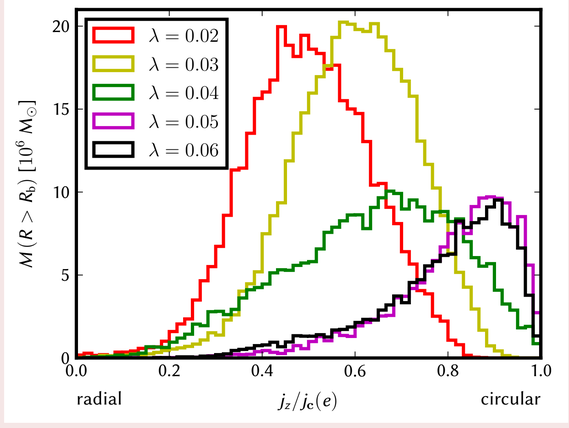
Where are stars in outskirts from?



Final stellar surface density profile (black) vs. profile with respect to position at birth of the respective stars (red). Radial redistribution is much stronger in low spin simulation (left panel).

- Moderate/significant radial mass redistribution in high/low spin case

What are the kinematics in the outskirts?



The circularity parameter distribution of stars in the galaxy outskirts for different spin parameters.

high spin

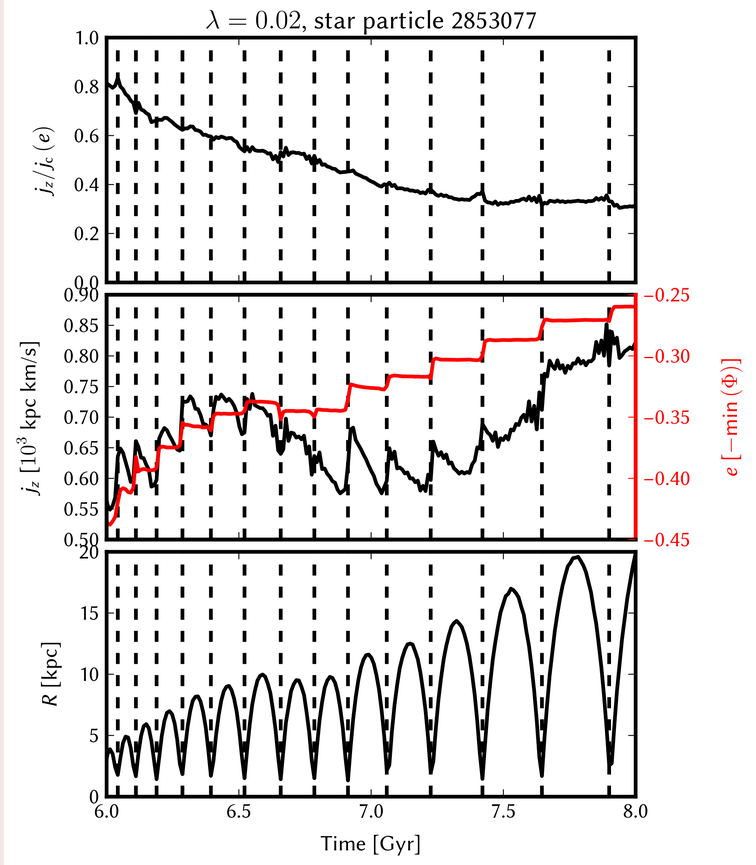
Peaks at $\lesssim 1 \rightarrow$ circular orbits; consistent with radial migration [3]

low spin

Peaks at $\ll 1 \rightarrow$ eccentric orbits; flung out; dynamically unusual

How did stellar orbits in up-bending (low λ) disks evolve?

One individual star:



- Gain energy (and angular momentum) at pericenter
- Gradually loose angular momentum while away form pericenter
- Angular momentum loss turns circular orbits into eccentric orbits

Conclusion

- Gravity + SPH simulations of Milky Way mass galaxy formation
- Disk shape correlates with initial halo spin λ
- Low/high spin: up-/down-bending disks

high spin

Down-bending breaks previously explained: Radial migration [3]

low spin

- Only eccentric orbits in outskirts of up-bending disks
- Dynamically very unusual
- Suggests fundamentally different formation mechanism

References

[1] Pohlen & Trujillo, 2006, A&A, 454, 759
[2] Bullock et al., 2001, ApJ, 555, 240
[3] Roškar et al., 2008, ApJL, 675, 65

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