The angular momentum of simulated galaxy populations

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Genel et al. 2015 with: Fall, Hernquist, Vogelsberger, Snyder, Rodriguez-Gomez, Sijacki, Springel
The observational census

The theoretical challenge:

• Reproduce this in simulations
• For the right reasons
  (with the correct physics)

Navarro et al. 1995
Recent ‘successful’ zoomed-in disks

Agertz et al. 2011

Guedes et al. 2011 - Eris

Marinacci et al. 2013

Aumer et al. 2013

Stinson et al. 2013 - MaGICC
The simulated census

- Specific angular momentum of the stars correlates with galaxy mass
- Separate relations for late-types and early-types, each with a slope close to \((2/3)\)
- Overall relation is shallower, (at least in part) due to changing mix between late- and early-types with mass

Compare:
Teklu et al. 2015 - Magneticum simulations

Genel et al. 2015
Placing $M_{\text{halo}}$ instead of $M_*$ on the x-axis allows comparison with simple theory:

- Late-types are consistent with having 80-100% of the specific angular momentum as the dark matter halo
- Early-types retain ~15-50%
The physics I – tidal torques

• Scaling with redshift approximately matches the scaling for DM halos: \((1+z)^{-1/2}\), i.e. angular momentum retention is approximately redshift-independent.
The simulated census

- The separation is smaller at higher redshift
- Late-types evolve upwards with time
- Early-types evolve little
The simulated census

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In the Magneticum simulation, DM halo spin distribution (in DM-only run!) separates by the galaxy angular momentum:

- The separation is smaller than of the stellar spin difference.
- The separation is large at high redshift, weaker at $z=0$. 

(Teklu et al. 2015)
The physics II - feedback

- Enhancement/addition of feedback always makes galaxies larger
- But while galactic winds boost the angular momentum, radio-mode AGN feedback reduces it

![Graph showing the relationship between angular momentum, size, and mass in galaxies with and without feedback.](image)
The physics II - feedback

- Galactic winds remove early-accreting low-J gas, generating fountain
- Galactic winds do not disrupt the rotation support of the disk
- The result: larger sizes with larger angular momentum
The physics II - feedback

- AGN feedback makes galaxies, and mergers, dry, forcing sizes up
- AGN feedback prevents late-accreting high-j gas, reducing angular momentum
- The result: dispersion-dominated galaxies (see also Dubois+ 2013 & Somerville talk)
Census + physics

\[ z = 2 \]
\[ z = 1 \]
\[ z = 0 \]

\[ \log_{10}(M_{\ast \text{[M_{\odot}]}}) \]
\[ \log_{10}(j [\text{kpc} \cdot \text{km/s}]) \]

no feedback
metals and mass return
galactic winds
AGN but no radio-mode
full model

\[ \text{?} \]
The physics II - feedback

- Only galaxies that significantly quench move towards being ‘less compact’
- In Illustris, this process is very mass-dependent,
  and is a result of AGN feedback
Almost all galaxies have high specific angular momentum \( (j) \) at high redshift.

- Early-type galaxies at \( z=0 \) with low angular momentum may:
  - rapidly lose their \( j \)
  - stop gaining \( j \)

Genel et al. 2015
Conclusion and outlook

• Does the type of dominant feedback determine the galaxy morphology?
  • SF-driven galactic winds make large star-forming rotating disks
  • AGN feedback makes large passive dispersion-dominated spheroids

• What determines the angular momentum retention factors – why approximately unity?
  • Is it really conservation, or something more complicated?

• What is the nature of the connection to halo spin?
  • Does it ‘seed’ the difference at high redshift, then let feedback do the work?