Formation of Galaxies: Clues from their Angular Momenta

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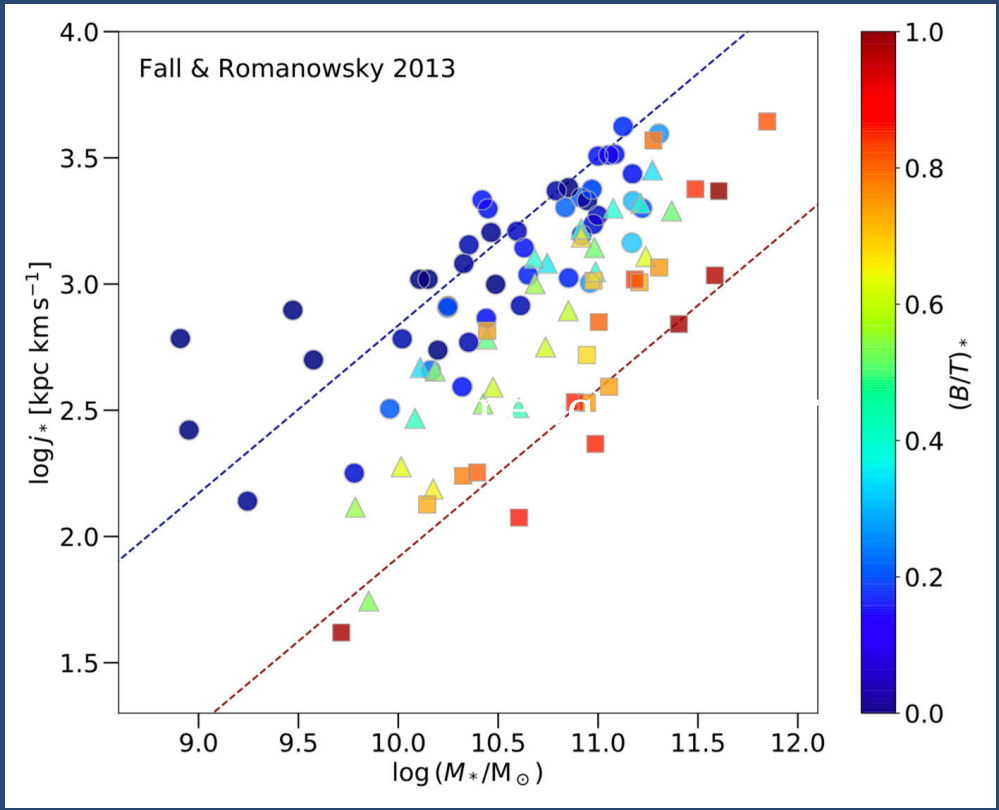
All Galaxy j_* vs M_* (Obs)

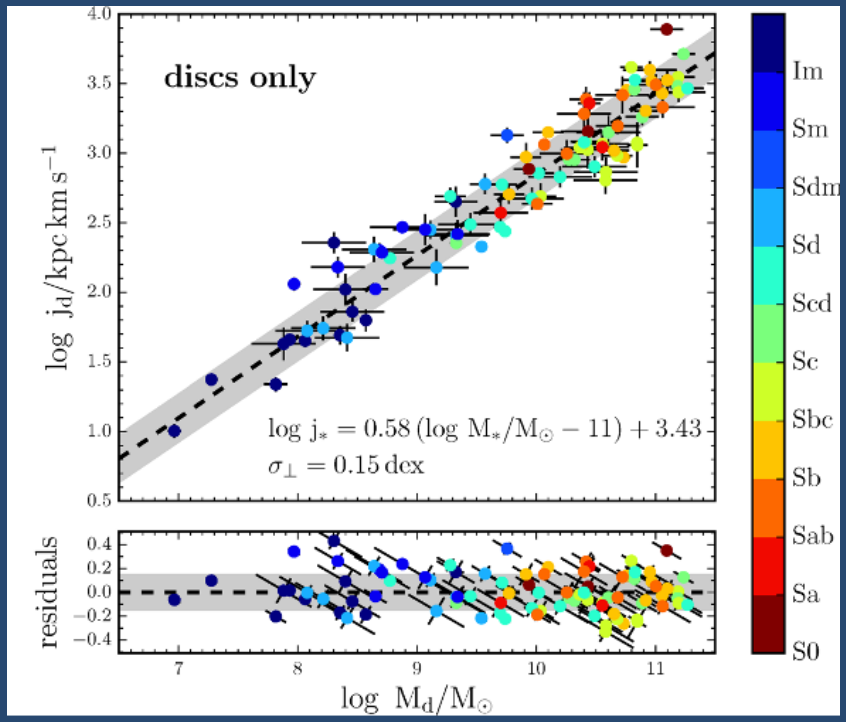


$$j_* \propto M_*^{\alpha} \quad \text{with} \quad \alpha \approx 0.6$$

Note: j_* anti-correlates with bulge fraction $(B/T)_*$

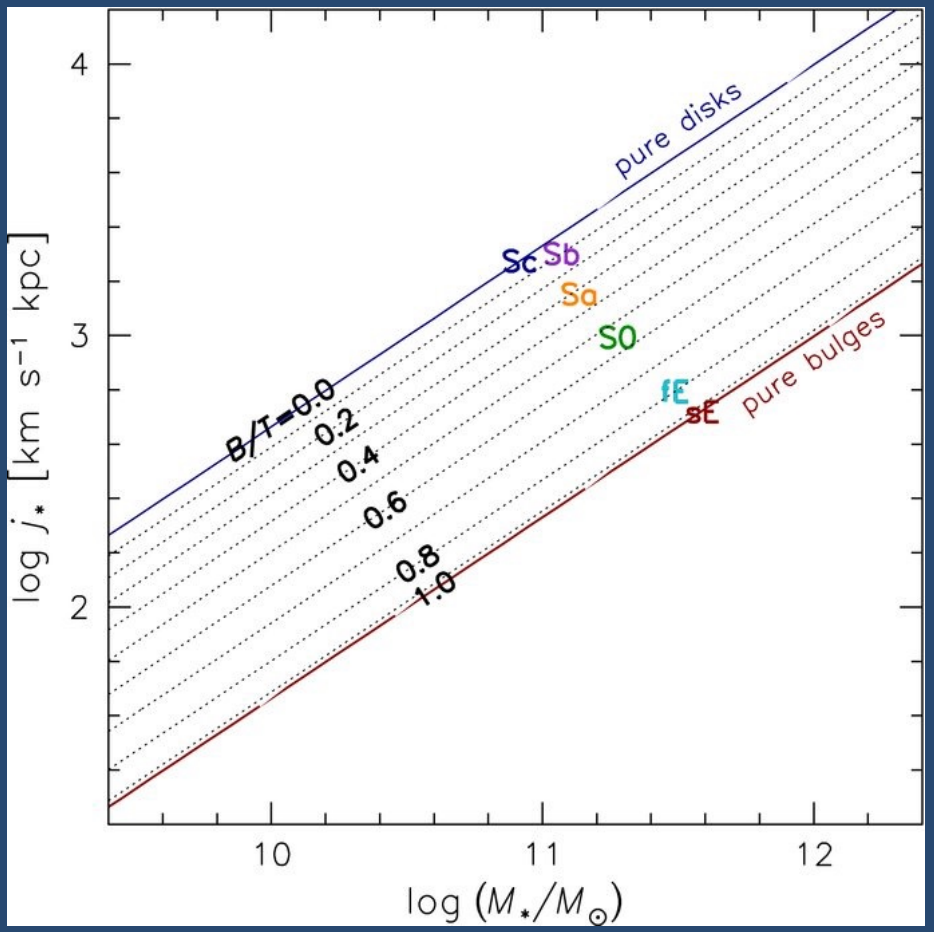
Spiral Disc j_* vs M_* (Obs)

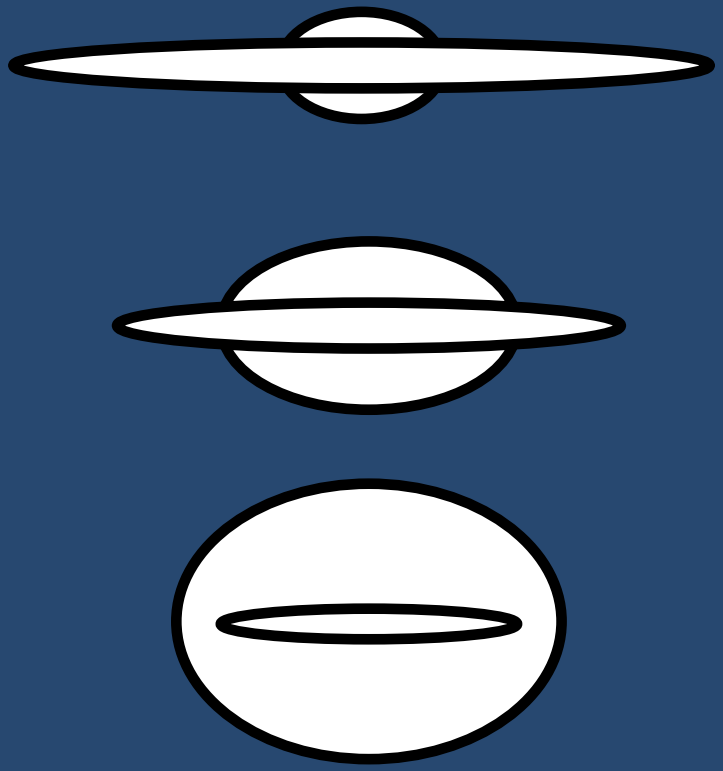
Posti et al 2018



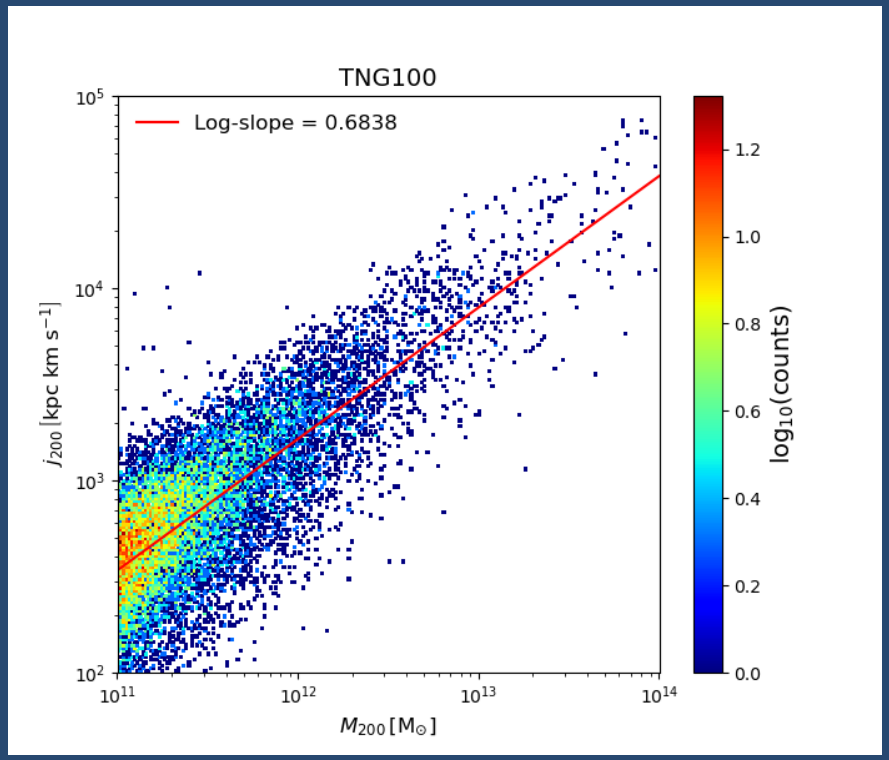
Very tight, linear relation: rivals Tully-Fisher reln -- despite messy formation histories (major mergers, tidal shocks, reforming discs, etc) seen in sims

Alternative to Hubble Classification Scheme Quantitative and Physically Motivated





Dark Halo $j_{\rm h}$ vs $M_{\rm h}$ (Sim)



$$j_{\rm h} \propto M_{\rm h}^{2/3}$$

Equivalent to halo spin λ independent of mass

`Retention Fractions' f_M and f_j Normalize Galaxy Properties by Halo Properties

Mass RF (aka SHMR): $f_M \equiv M_* / M_h$

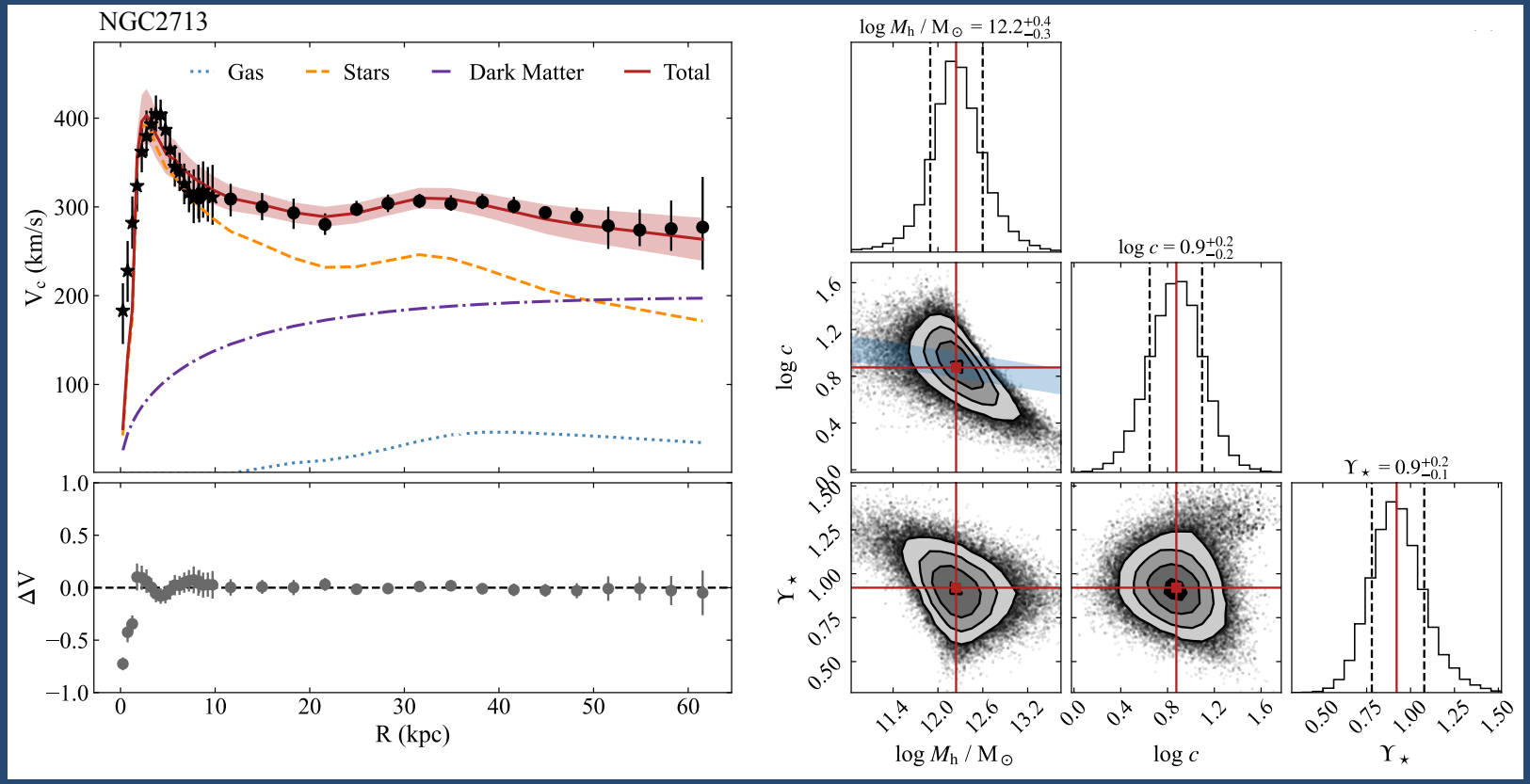
Specific Ang Mtm RF: $f_j \equiv j_* / j_h$

Combining these definitions with the j vs M scaling relations for galaxies and halos gives

$f_M^{2/3} / f_j \propto M_*^{(2/3-\alpha)}$ = weak function of M_*

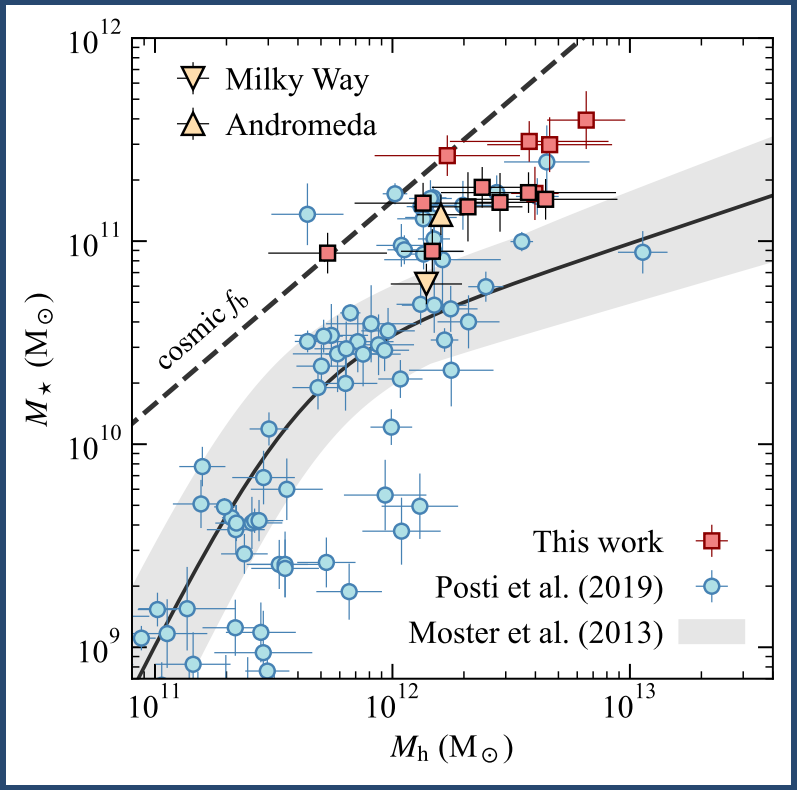
A bend in f_M or f_j implies a bend in the other

Dark Halo Mass Derived from HI Rotation Curve



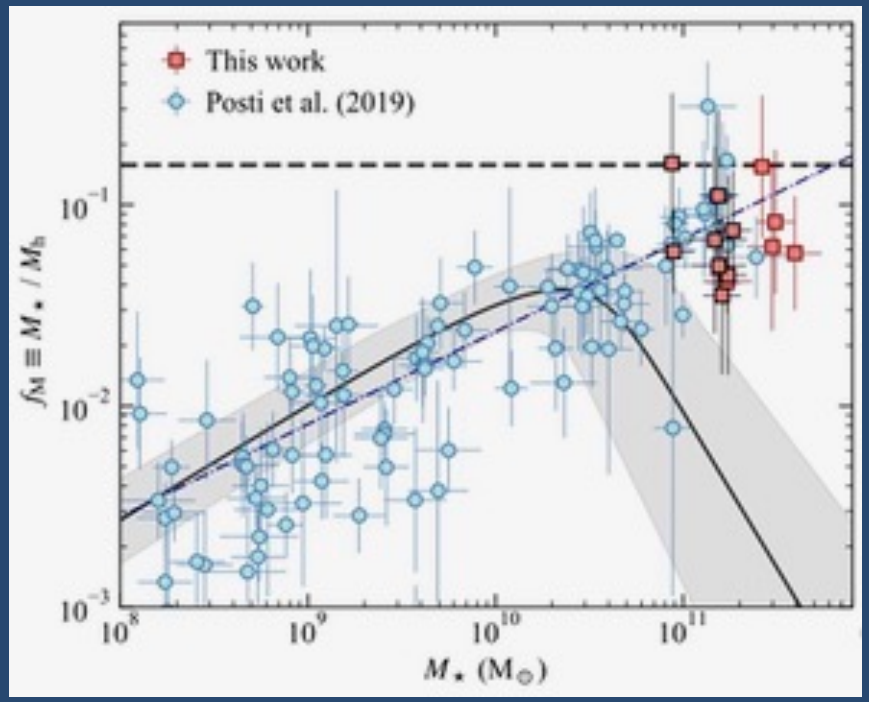
Adopt halo concentration-mass reln from ΛCDM sims

Spiral Galaxy M_* vs M_h (Obs + Sim)



Massive spiral galaxies lie well above the M_* vs M_h relation derived by abundance matching for the general galaxy population and close to $f_{M_*} = f_{baryon}$

Spiral Galaxy f_{M_*} vs M_* (Obs + Sim)

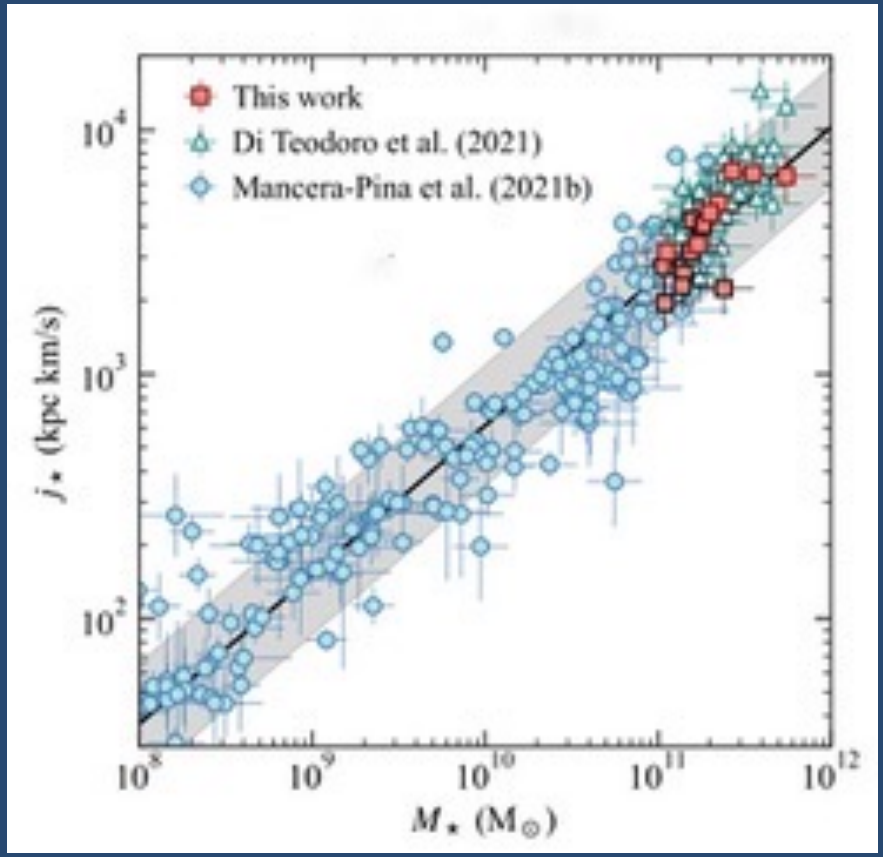


The SHMR of late-type galaxies RISES at all masses,

$$f_{M_*} \propto M_\star{}^{\delta} \quad \text{with} \quad \delta = 0.4 \pm 0.1,$$

while that of early-type galaxies FALLS at M_* > 3 x 10^{10} $M_\odot$

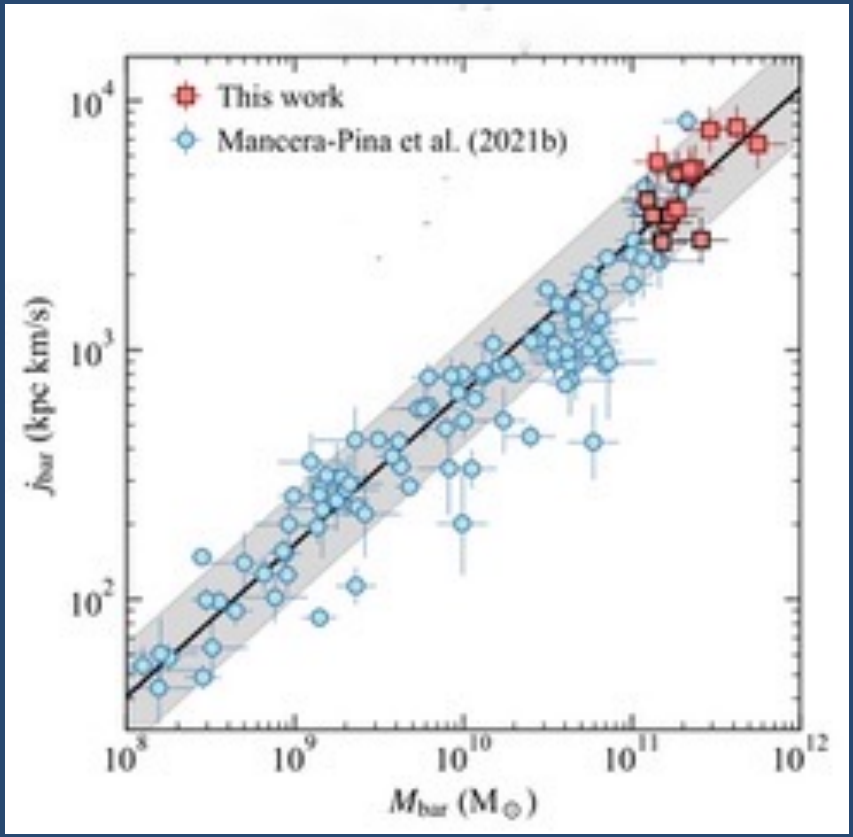
Spiral Galaxy j_* vs M_* (Obs)



Slight bend but not statistically significant

$$j_* \propto M_\star^{\alpha} \quad \text{with} \quad \alpha = 0.61 \pm 0.08$$

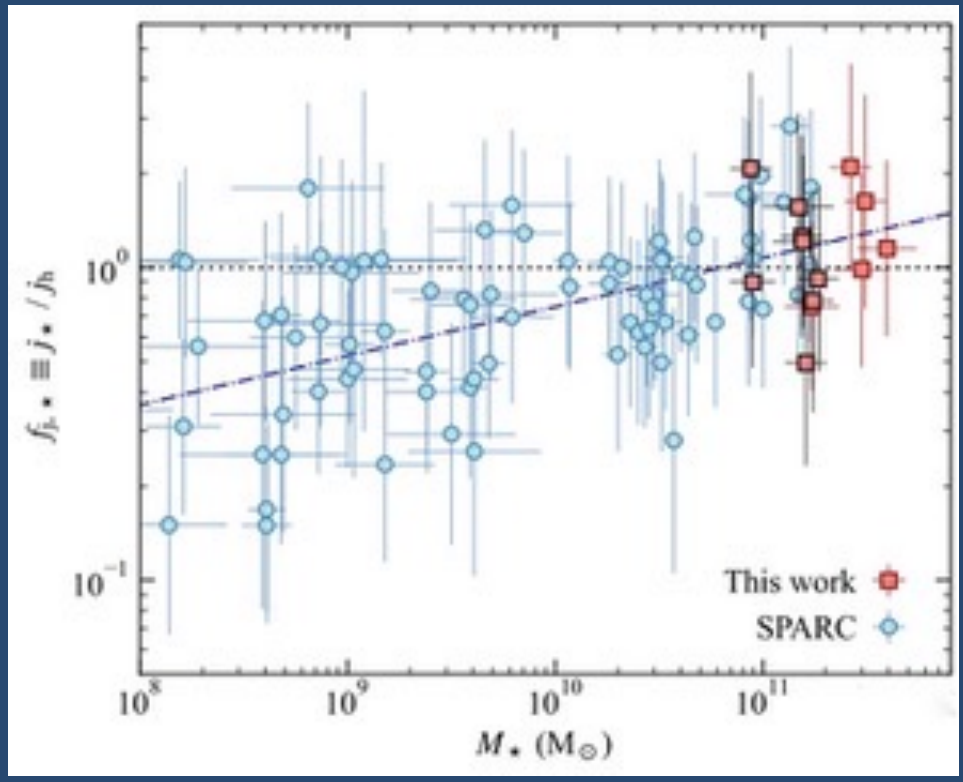
Spiral Galaxy j_b vs M_b (Obs)



`Baryonic' reln (stars + cold gas) is tighter than stellar reln

$j_b \propto M_b{}^{\alpha}$ with $\alpha = 0.61 \pm 0.07$

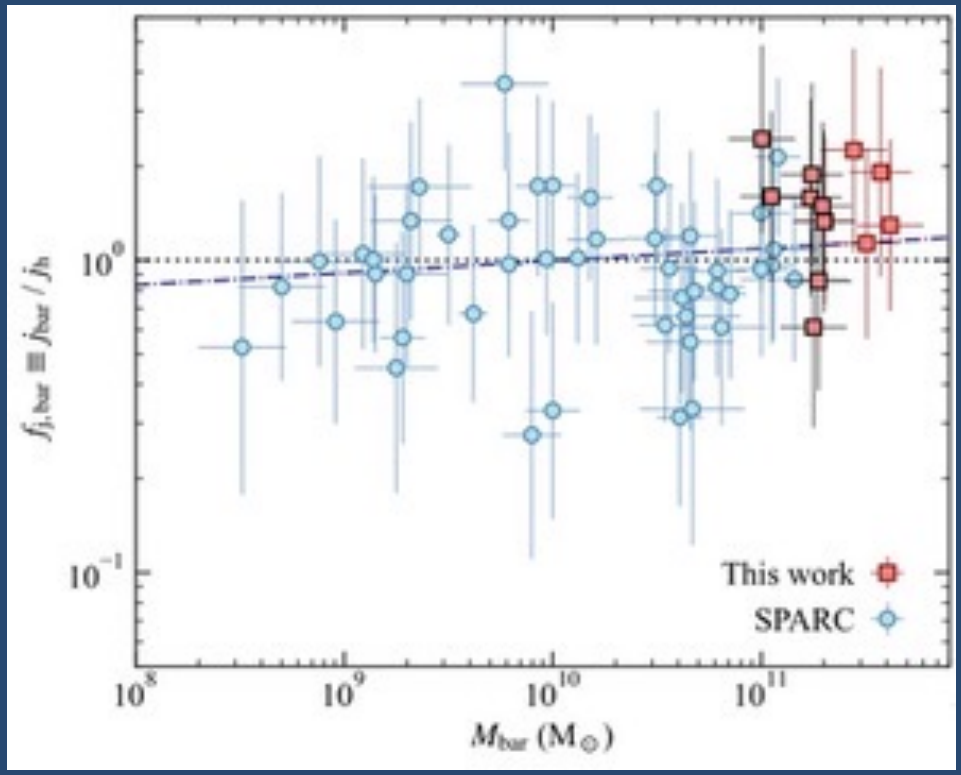
Spiral Galaxy f_{j*} vs M_* (Obs + Sim)



Spiral galaxies have the same specific AM as their dark halos

$$f_{j*} \propto M_\star^{\varepsilon} \quad \text{with} \quad \varepsilon = 0.16 \pm 0.07$$

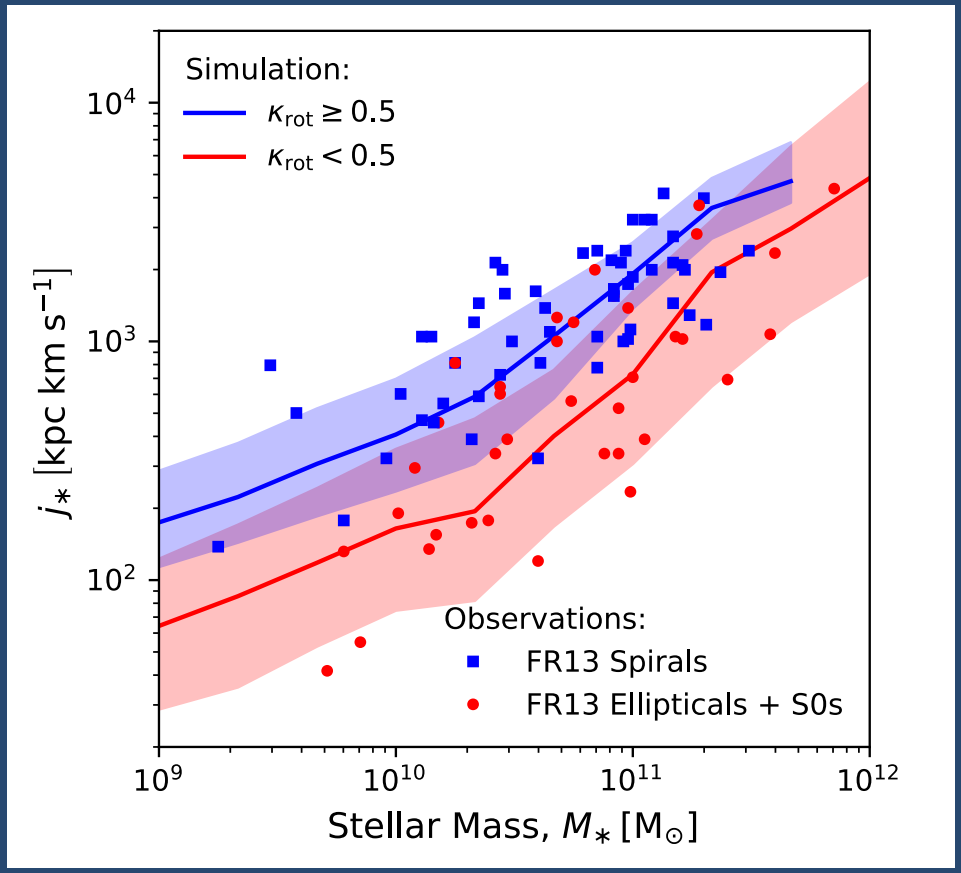
Spiral Galaxy f_{jb} vs M_b (Obs + Sim)



`Baryonic' reln is tighter and flatter than stellar reln

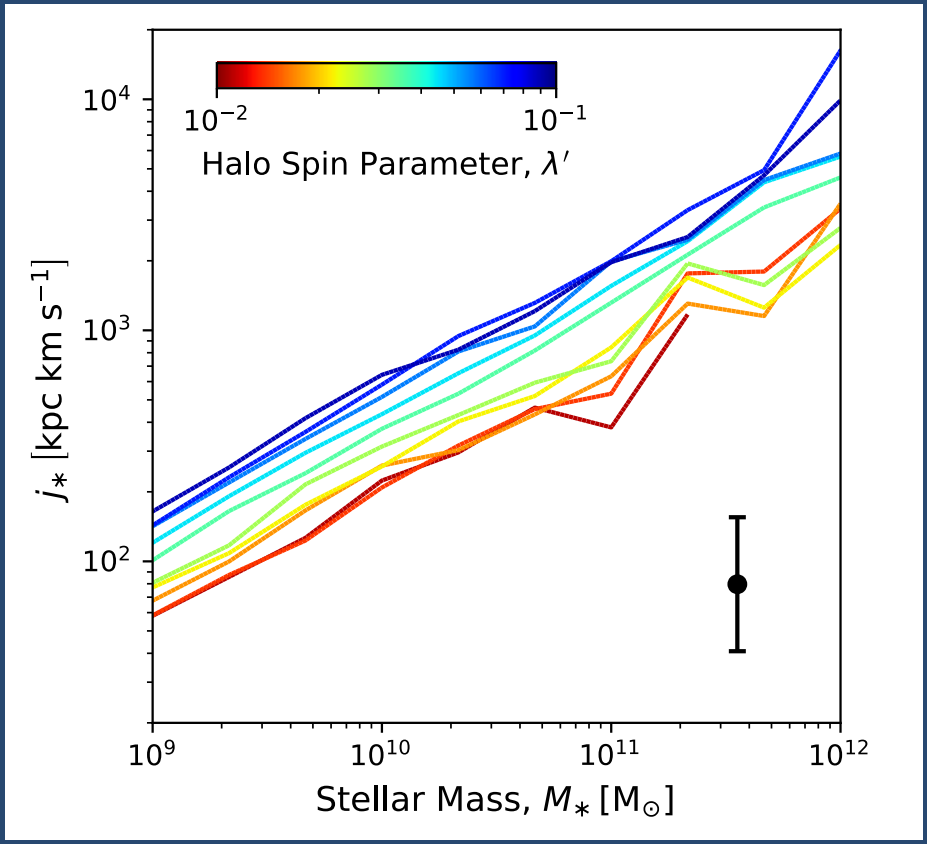
$f_{jb} \propto M_b{}^{\varepsilon}$ with $\varepsilon = 0.04 \pm 0.03$

All Galaxy j_* vs M_* (Sim vs Obs)



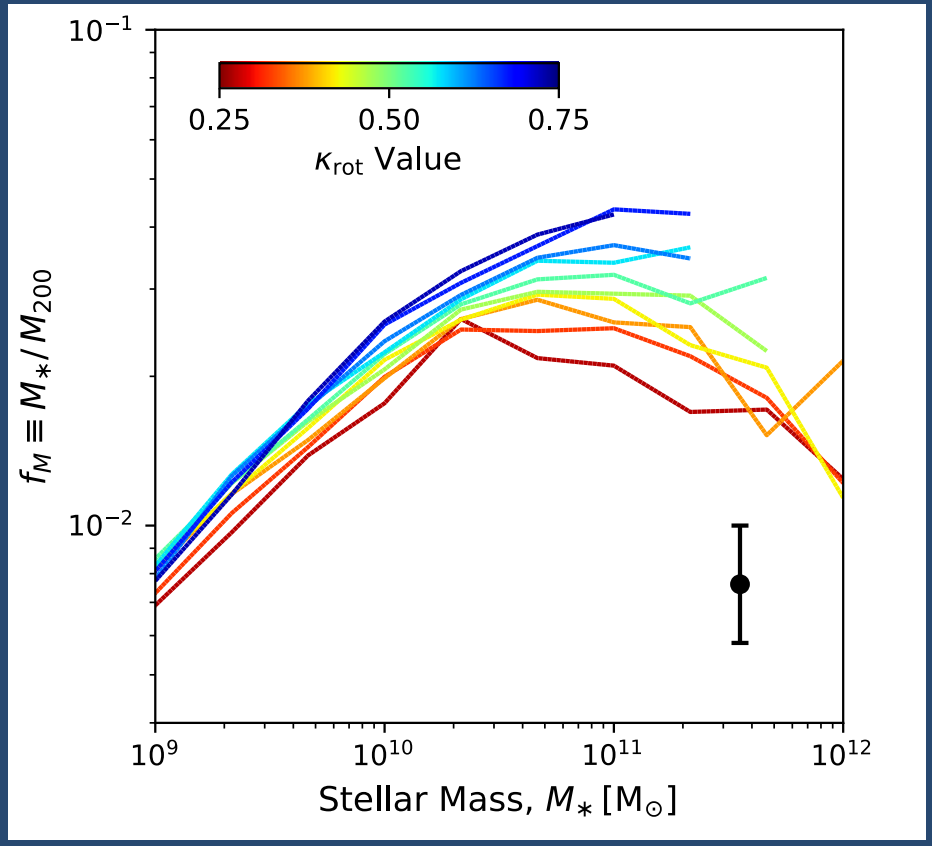
Sims in approximate overall agreement with obs

All Galaxy j_* vs M_* (Sim)



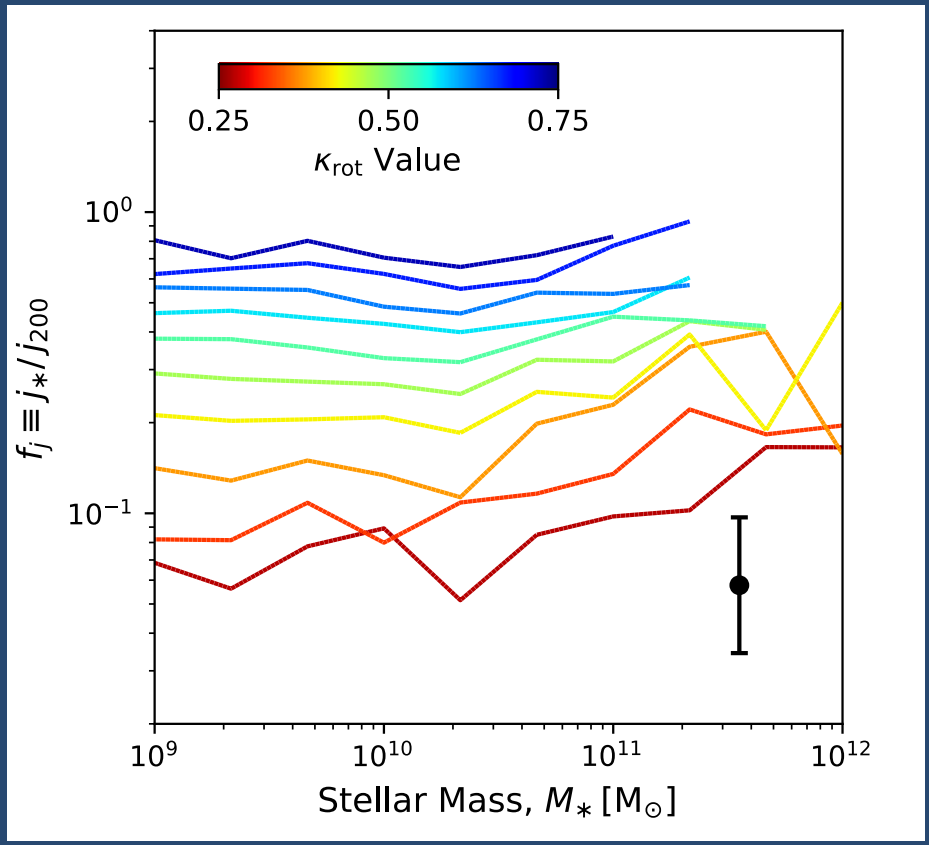
Galaxy specific AM correlates with halo spin at each mass, in contrast to several recent claims of no correlation

All Galaxy f_{M_*} vs M_* (Sim)



Sims in approximate overall agreement with obs: different SHMRs for late- and early-type galaxies

All Galaxy f_{j_*} vs M_* (Sim)



Sims in approximate overall agreement with obs: different AM retention for late- and early-type galaxies

Conclusions

1. Spiral galaxies obey tight j vs M scaling relations despite their messy formation histories

2. The SHMRs of early- and late-type galaxies diverge for $M_* > 3 \times 10^{10} M_\odot$ – stellar vs AGN feedback?

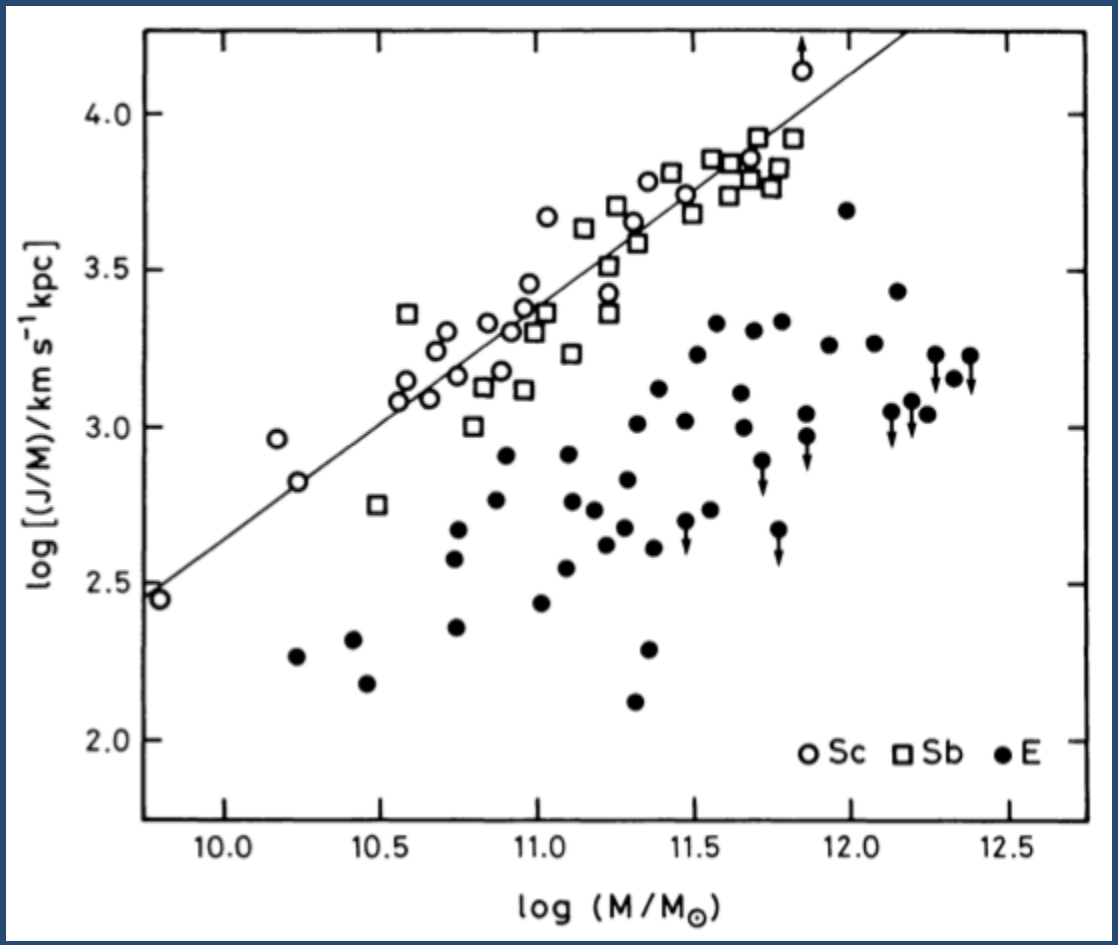
3. Spirals galaxies have the same specific angular momentum as their dark halos (on average)

4. The observed angular momentum relns are broadly reproduced in current cosmo-hydro simulations

Thanks!

Specific Angular Momentum vs Mass

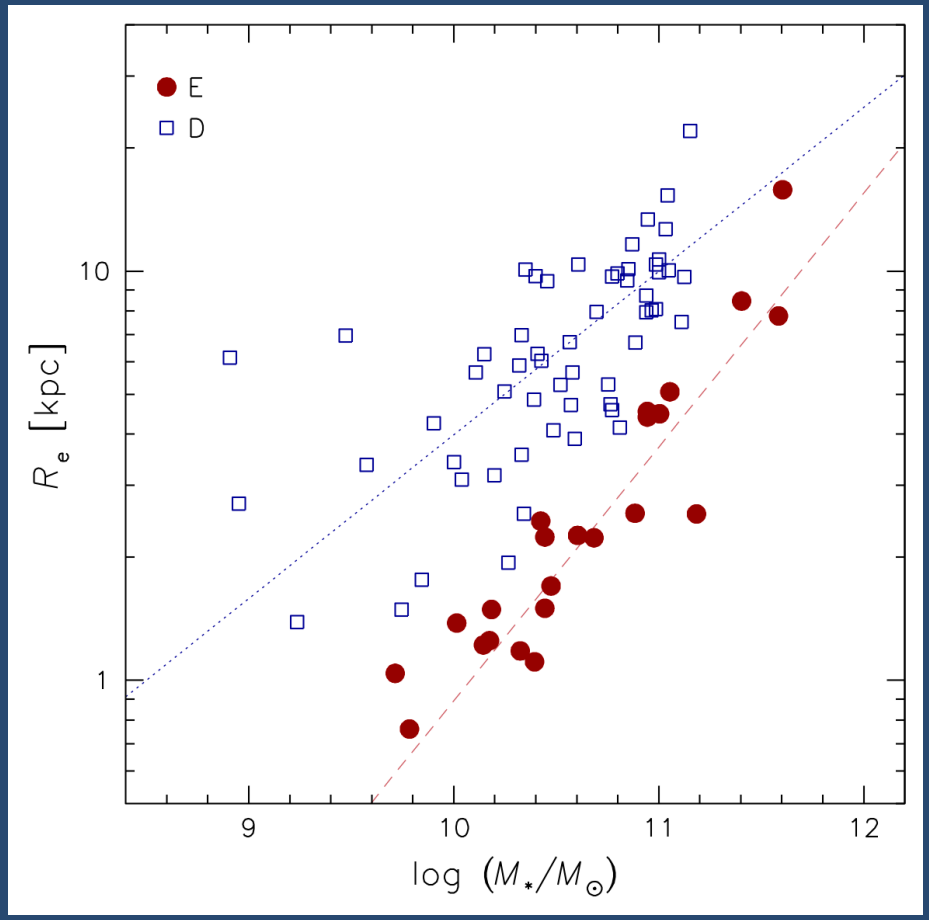
Fall 1983



$j = J/M \propto M^{\alpha}$ with $\alpha \approx 2/3$

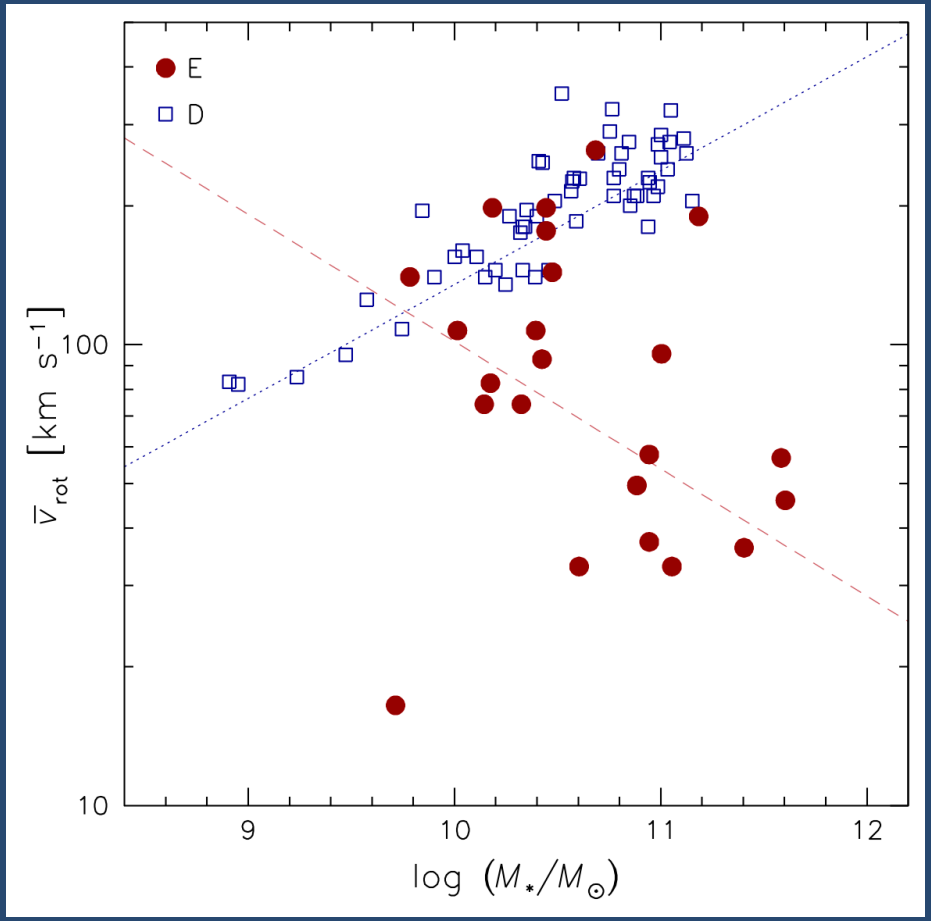
S and E galaxies offset by ~6x

Effective Radius vs Mass



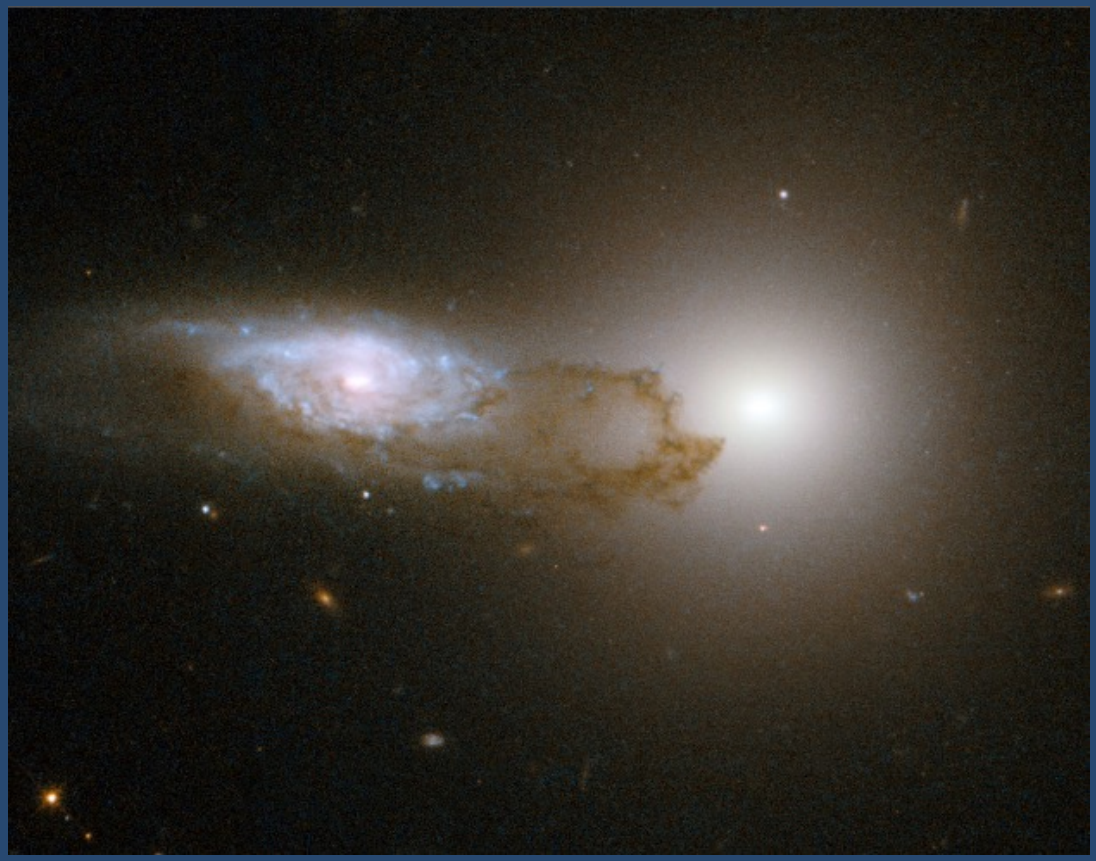
Disks are ~2x larger than E galaxies of the same M_*.

Rotation Velocity vs Mass



For disks, this is essentially the T-F relation.
For E galaxies, it is a scatter plot.

Disks vs Bulges (Spheroids)



Different shapes: flat vs round
Different kinematics: rotation vs dispersion