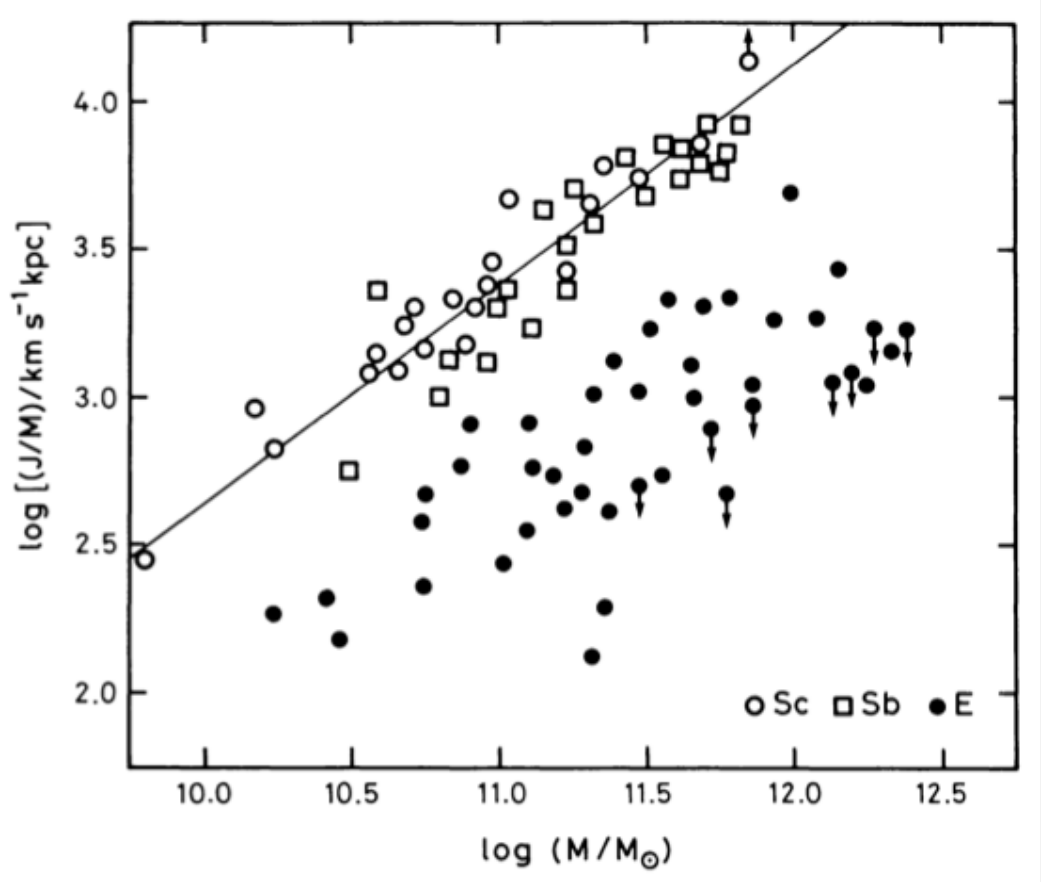
Angular Momentum and Galaxy Formation

Michael Fall

STScI

Specific Angular Momentum vs Mass

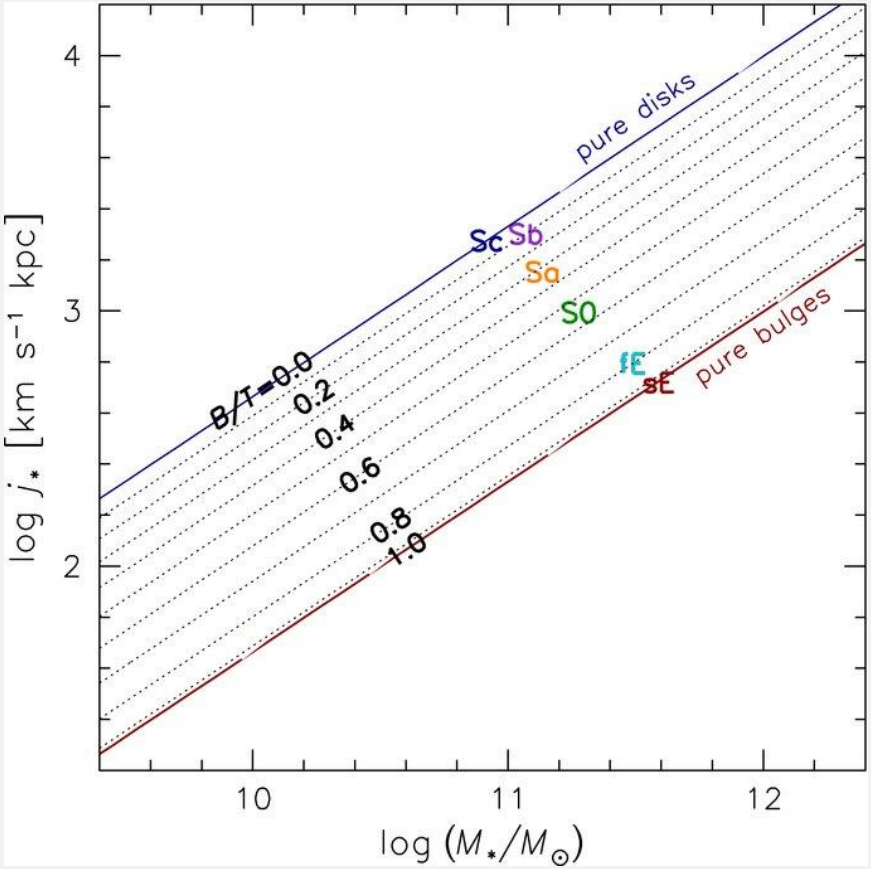
Fall 1983

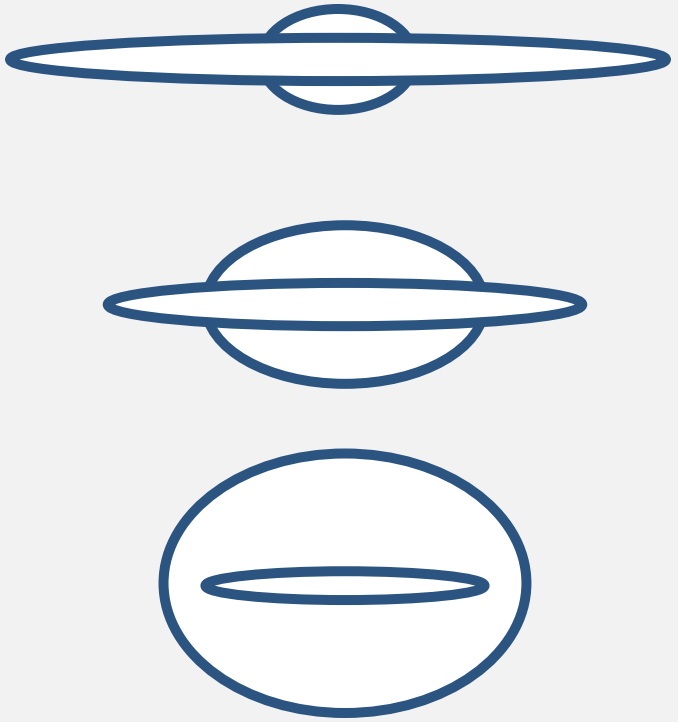


$$j = J/M \ \alpha \ M^{\alpha} \quad \text{with} \quad \alpha \approx 0.7$$

S and E galaxies offset by ~6x

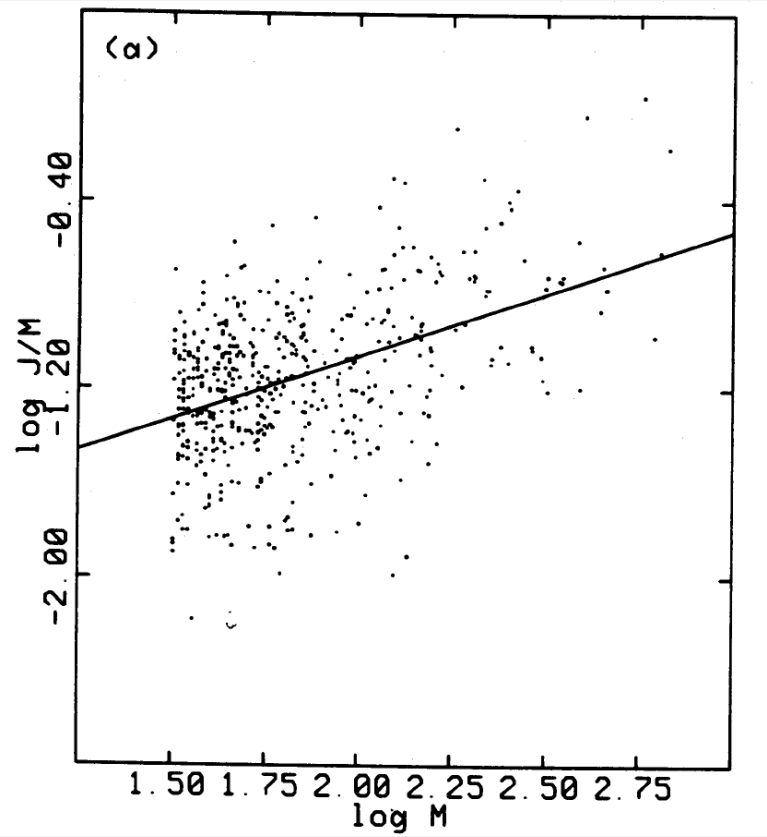
Proposed Connection Between the Hubble Sequence and the *j* vs *M* Diagram





Needs Testing

Dark Matter Simulations



Barnes & Efstathiou 1987

$$j = J/M \ \alpha \ M^{\alpha} \quad \text{with} \quad \alpha \approx 0.7$$

Questions

1. Are the estimates of j accurate for E galaxies (with measured v_{rot} only to ~R_e)?
2. Where do galaxies of intermediate Hubble type (Sa & S0) lie in the j vs M diagram?
3. Does the observed spread in galactic log j at each M match that of DM halos?
4. What causes the ~6x offset between pure disks (Sc galaxies) and pure bulges (E galaxies)?

New Work

Romanowsky & Fall 2012 ApJS
Fall & Romanowsky 2013 ApJL

Sample analyzed: 57 S galaxies, 15 S0 galaxies, 23 E galaxies.

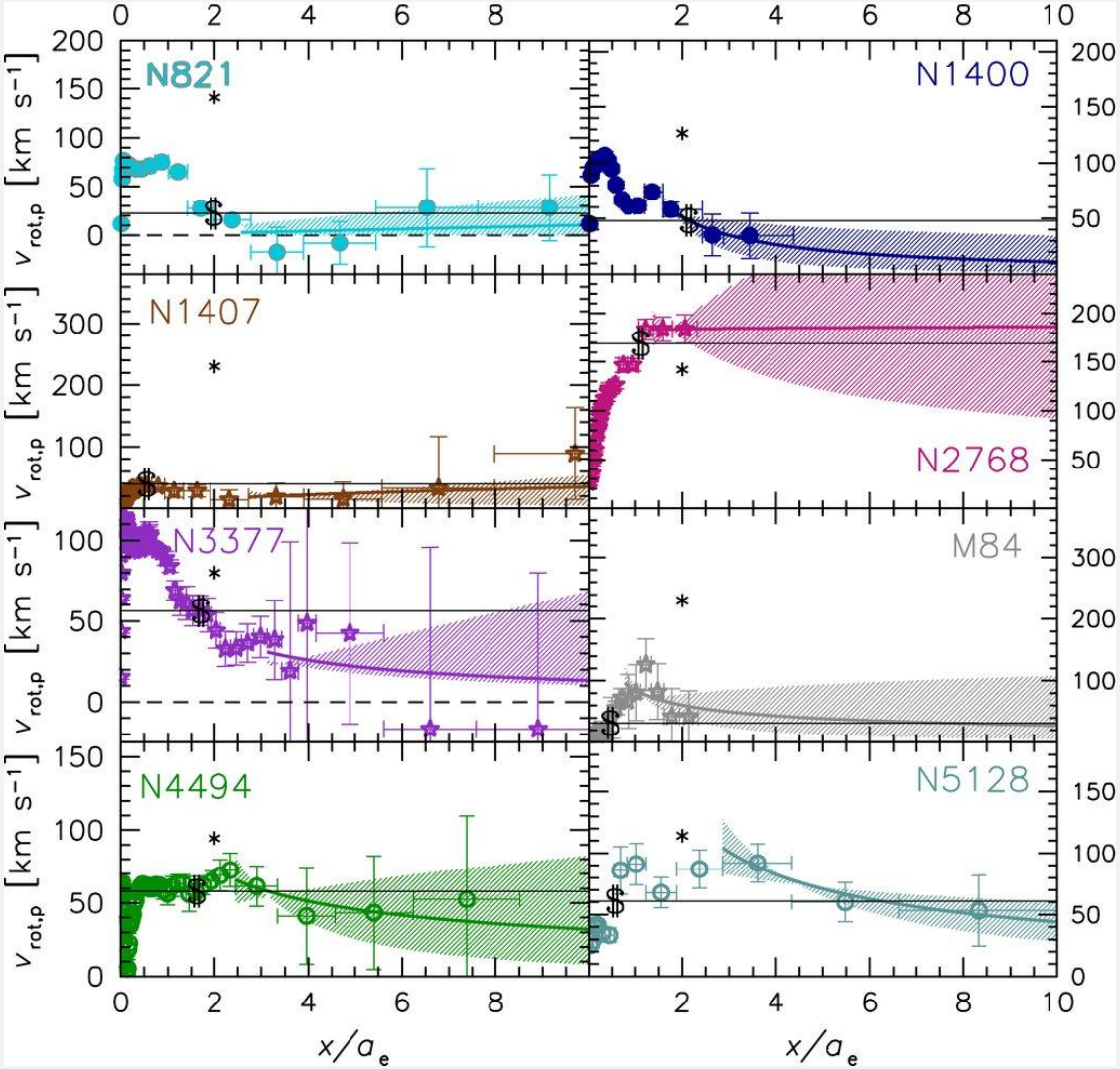
All with surface photometry (including D/B decompositions) and extended kinematics

Analysis of S galaxies is straightforward.

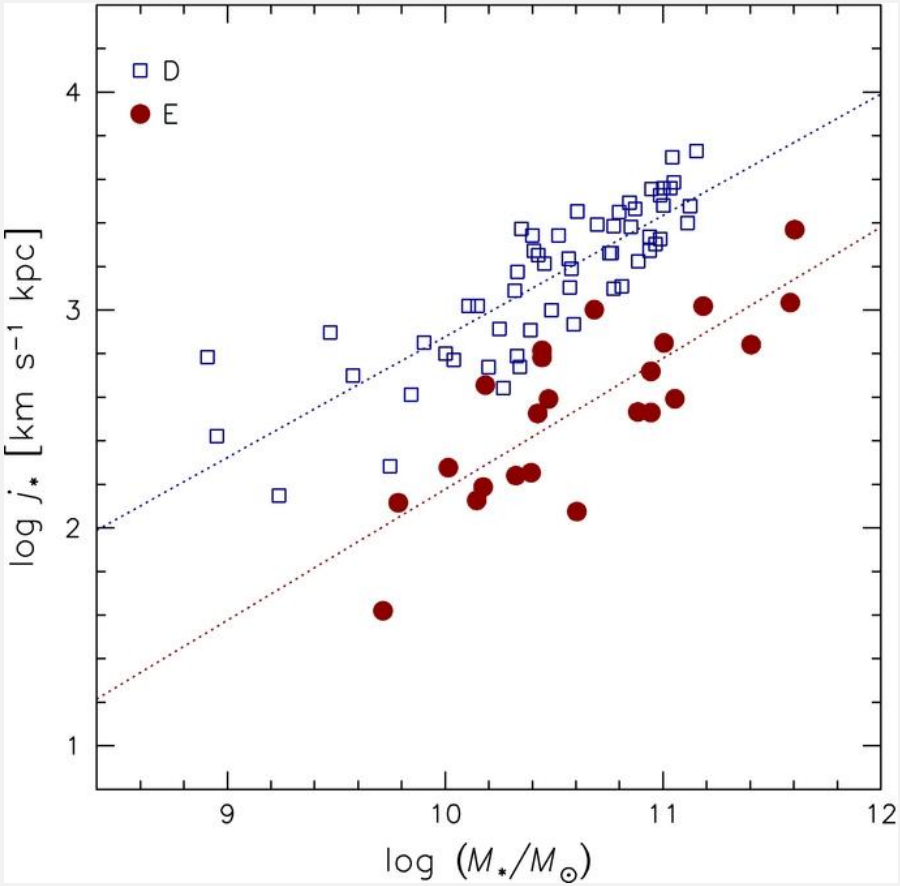
For E and S0 galaxies, kinematic data extend to large radii, $>2R_e$ in all cases, $>4R_e$ in many.

We use data from the SAGES program (Brodie, Romanowsky, Forbes, Arnold, Strader, et al).

New Kinematic Data Extend to 2--10 R_e



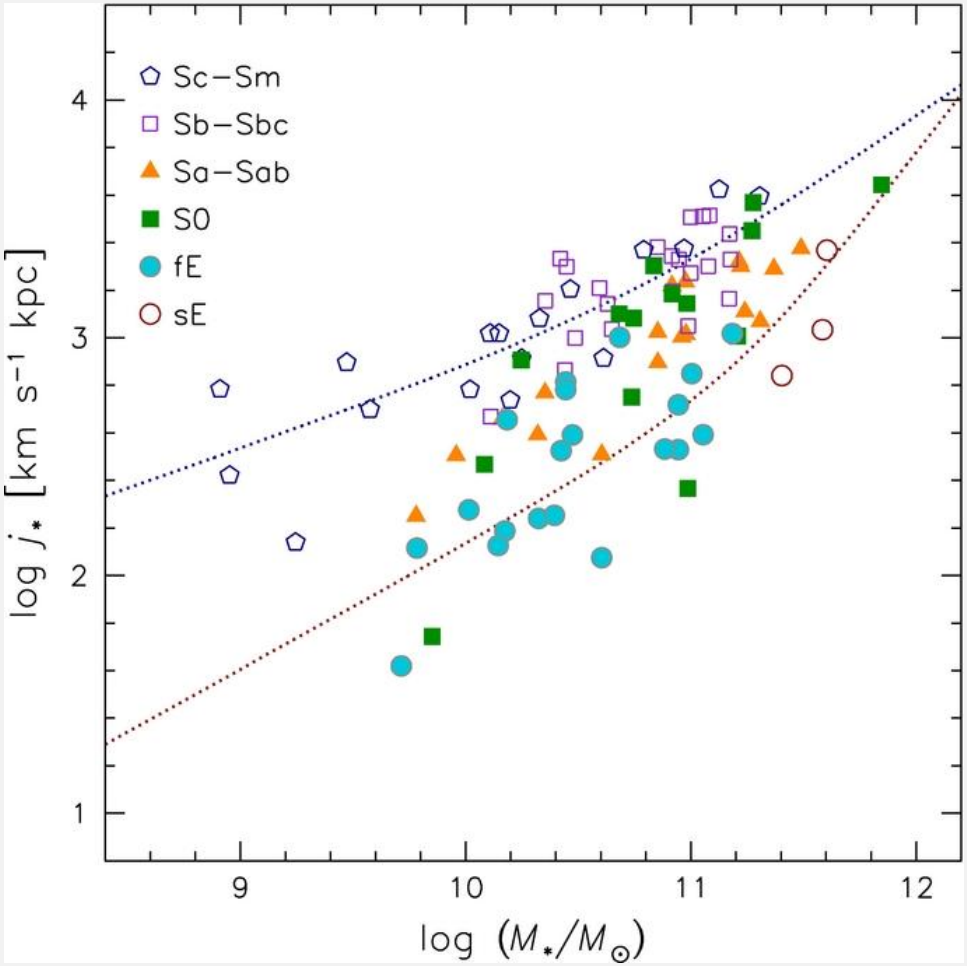
New j vs M Diagram



$$j = J/M \ \alpha \ M^{\alpha} \quad \text{with} \quad \alpha \approx 0.6$$

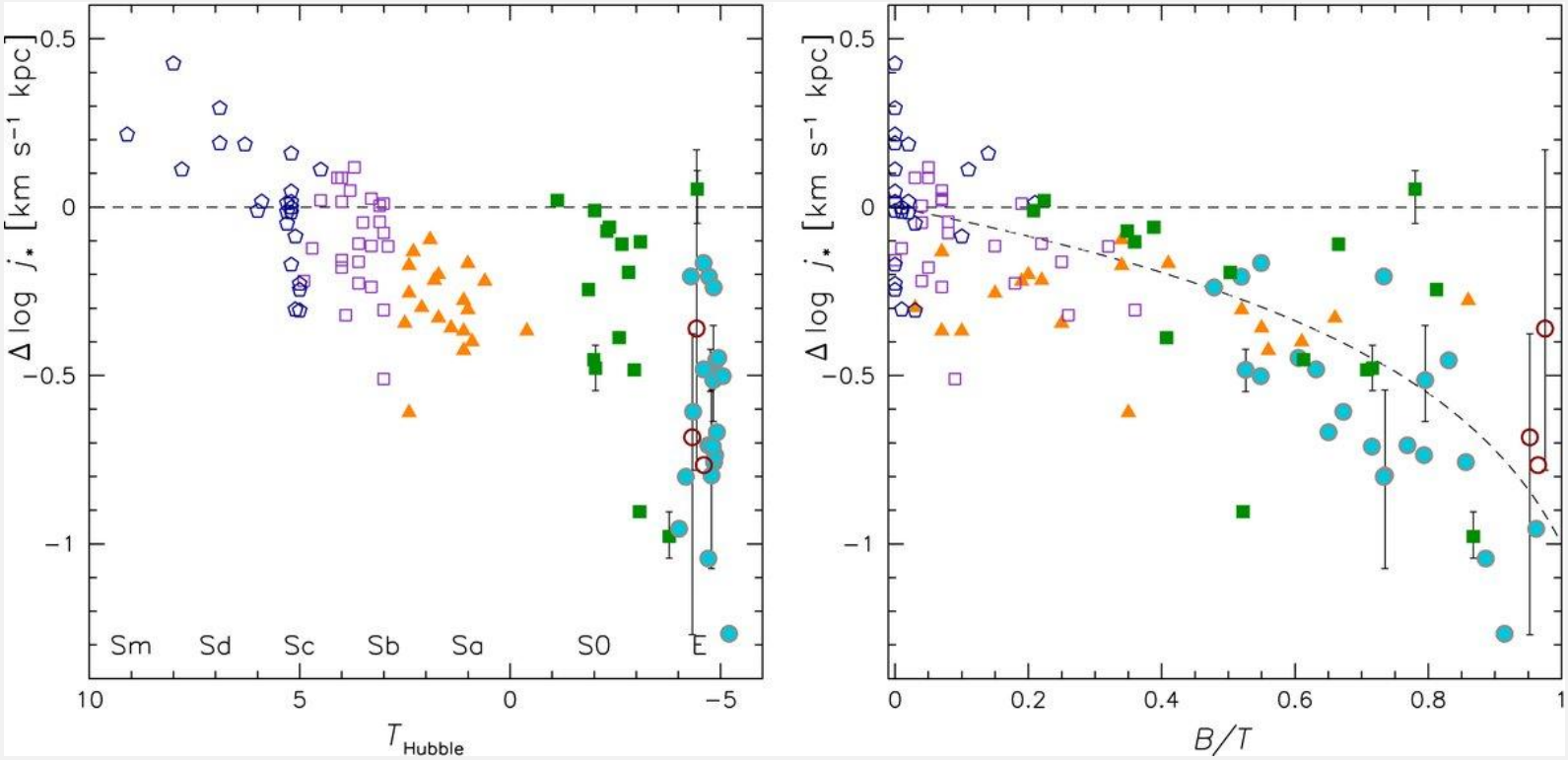
Disks and E galaxies offset by ~5x

New j vs M Diagram



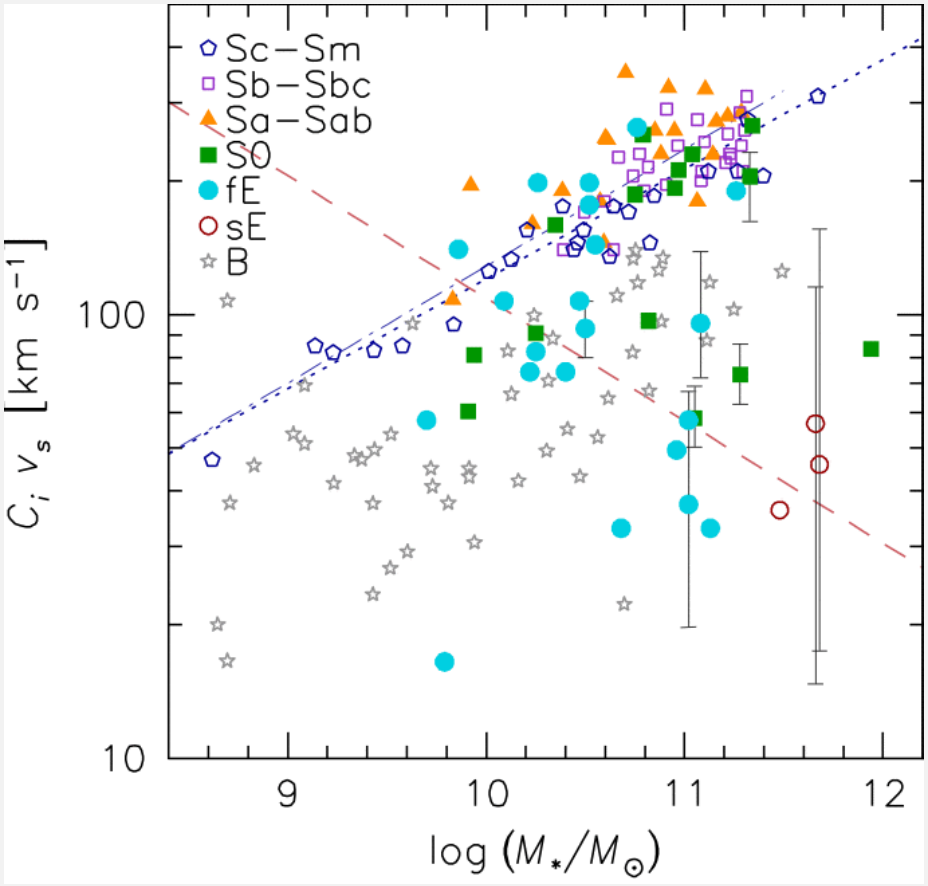
Intermediate-type galaxies lie between D and E sequences.

Offset in log *j* vs Hubble Type and Bulge Fraction



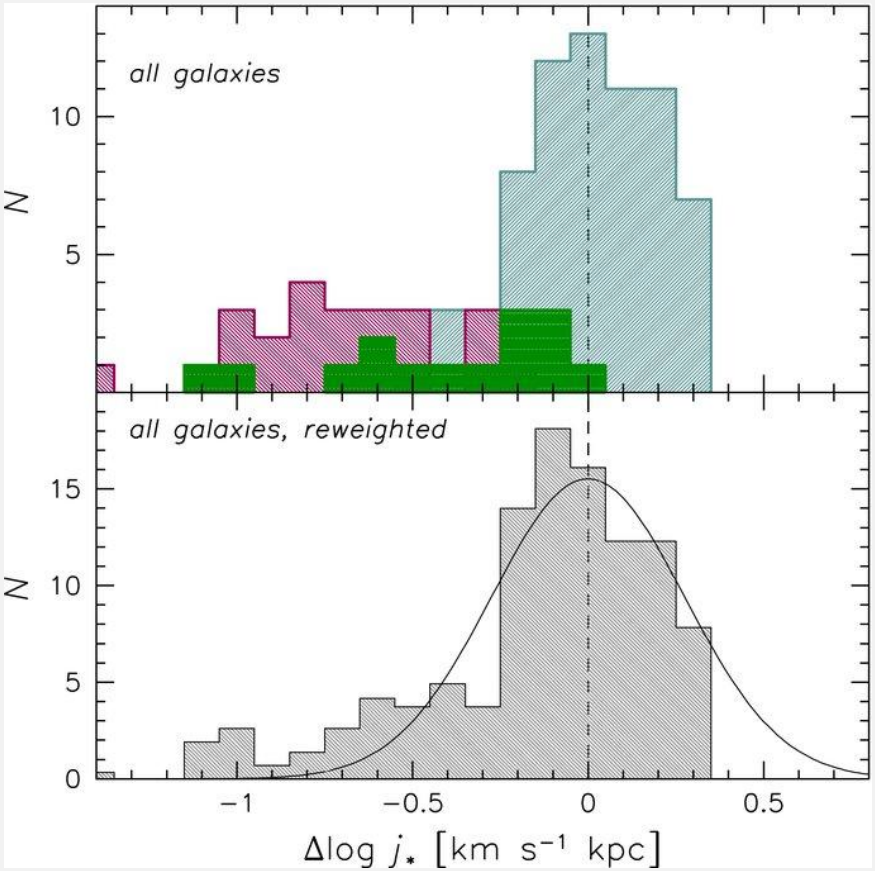
These correlations are highly significant.
We do not know how much of the scatter is real.

Rotation Velocity vs Mass



For S galaxies, this is essentially the T-F relation.
For E galaxies, it is something very different.

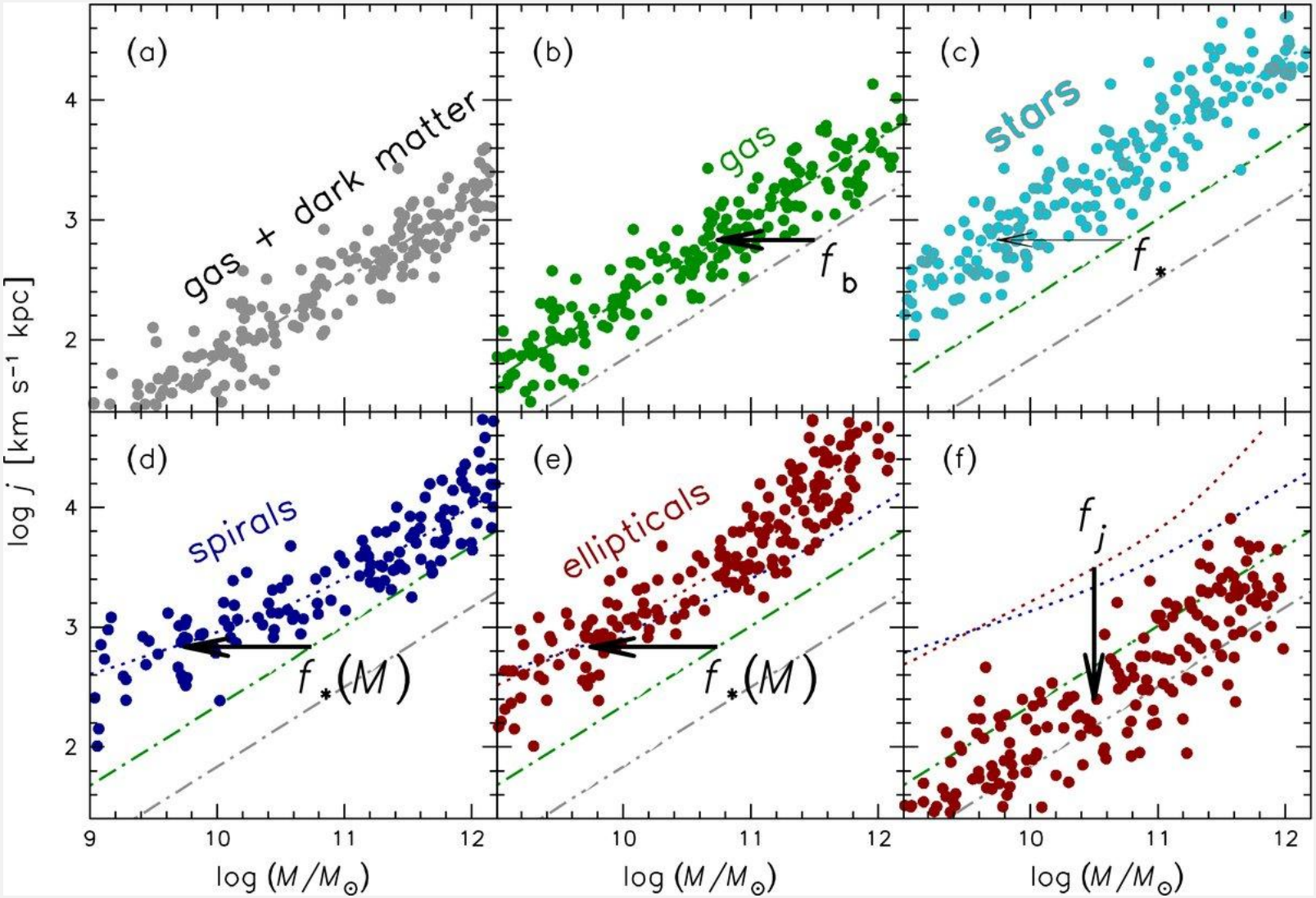
Distribution of Offsets in log *j*



unweighted

weighted
by volume

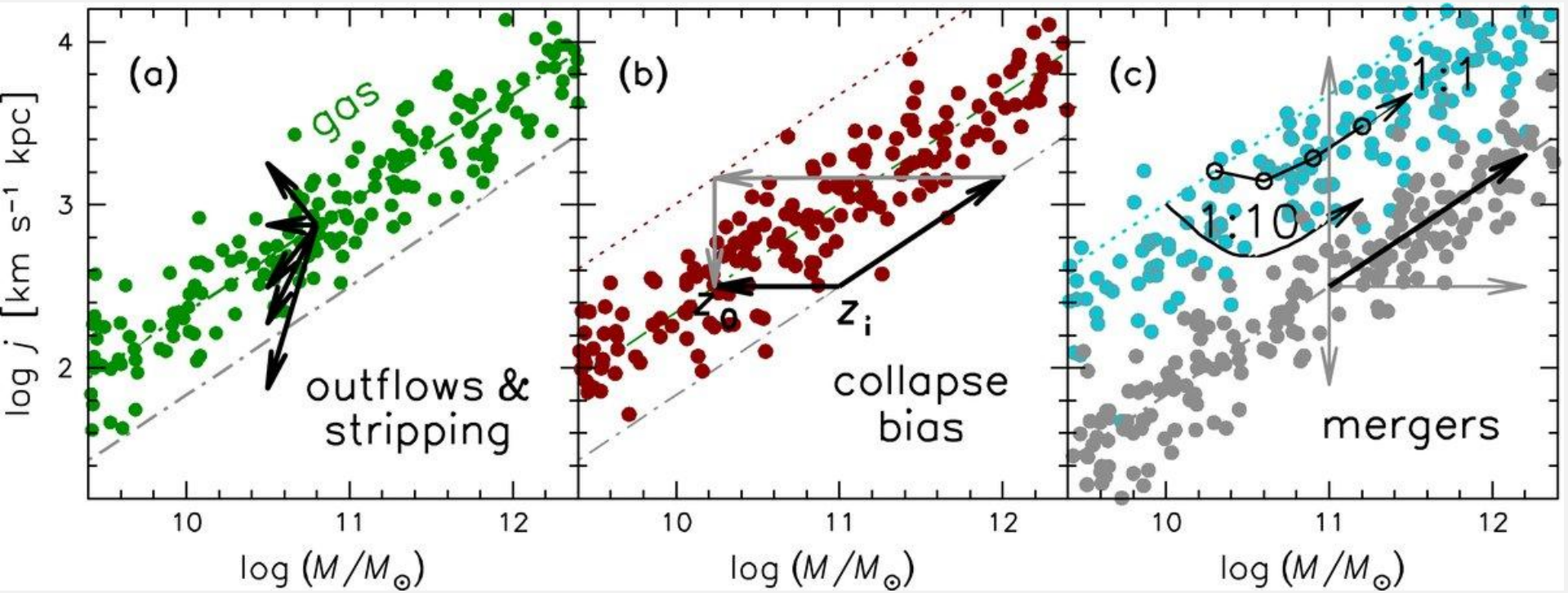
The distribution is different from p(log λ) for DM halos.
For E galaxies, it is broader; for S galaxies, it is narrower.



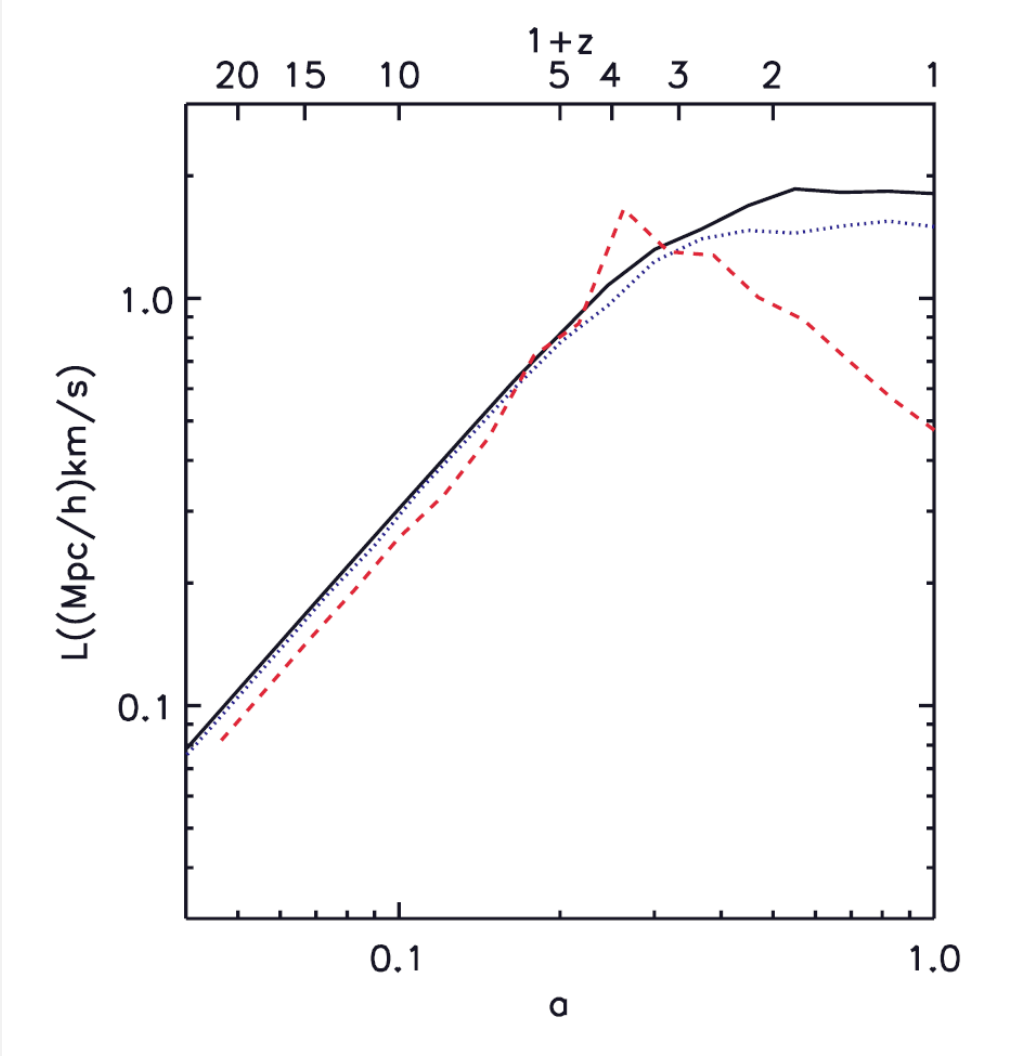
This toy model gives: $f_j \sim 0.8$ for Sc galaxies

$f_j \sim 0.1$ for E galaxies

Other Processes

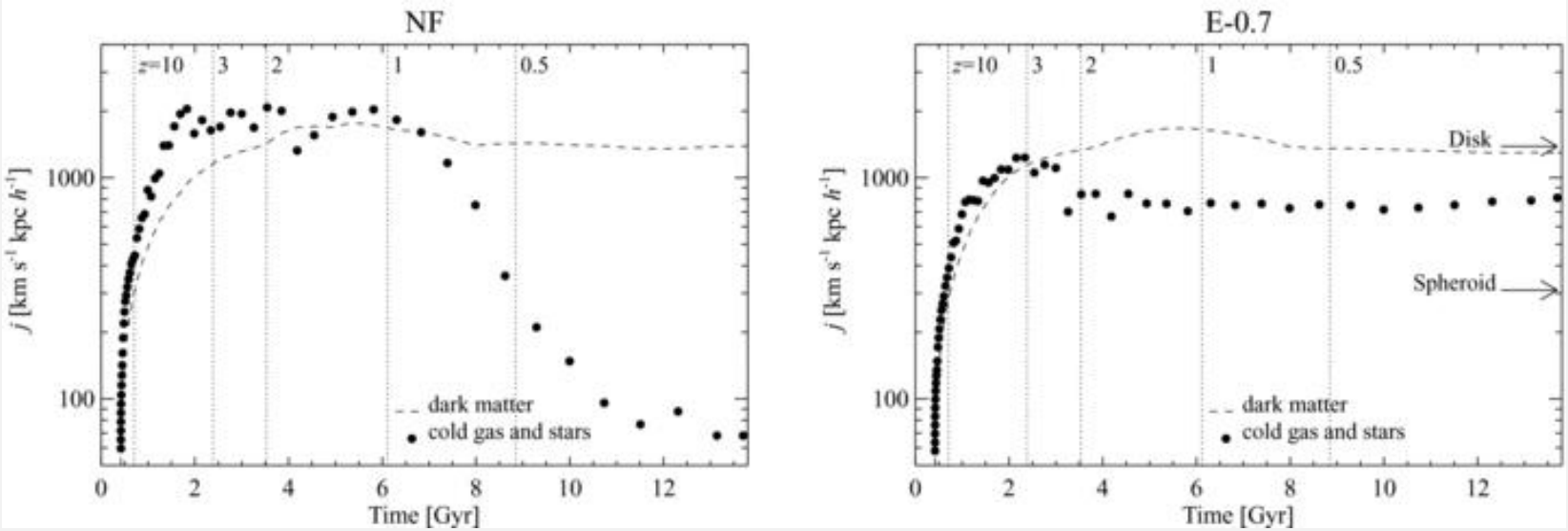


Each process affecting galaxies can be represented by a vector (ΔM, Δj) in the j vs M diagram.
The sum of all these vectors must map the predicted DM halo sequence onto the observed galactic sequences.



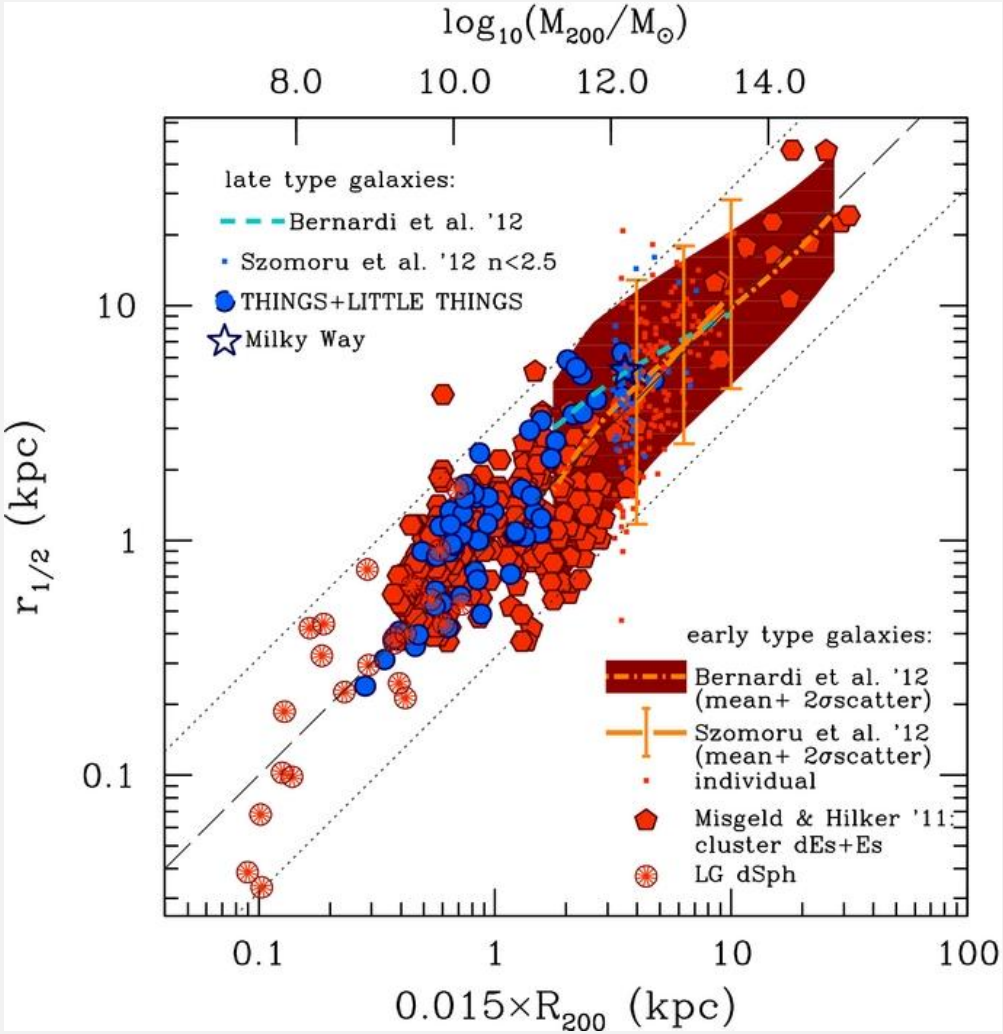
Zavala et al. 2008

Dashed lines show the specific angular momentum as a function of time for the dark matter that, at z= 0, lies within the virial radius of the system for NF (left-hand panel) and E-0.7 (right-hand panel).



Scannapieco C et al. MNRAS 2008;389:1137-1149

MONTHLY NOTICES
of the Royal Astronomical Society



Kravtsov 2013

Summary

1. New *j* vs *M* diagram based on extended kinematic data for E and S0 galaxies.
2. Old *j* vs *M* diagram confirmed, in slopes and offsets between disks and E galaxies.
3. The *j* vs *M* diagram is closely related to the Hubble sequence; galaxies of intermediate types have intermediate *j* at each *M*.
4. The observed sequences in the *j* vs *M* diagram are fundamental “targets’’ for simulations.
5. Recommend plotting trajectories of evolving simulated galaxies in the *j* vs *M* diagram.

Thanks