




Scaling Relations for Disks & Bulges

Fall & Romanowsky

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Angular Momentum and Galaxy Formation Revisited:
Effects of Variable Mass-to-Light Ratios

Fall & Romanowsky (2013)

Basic Properties of Galaxies

- Angular momentum (J_*)
- Stellar mass (M_*)

$$j_* = J_*/M_*$$



- Specific angular momentum (j_*)
- Stellar mass (M_*)

Disk-dominated galaxies



$$j_* \propto M_*^\alpha \quad (\alpha \approx 0.6)$$

Elliptical galaxies



Similar relation

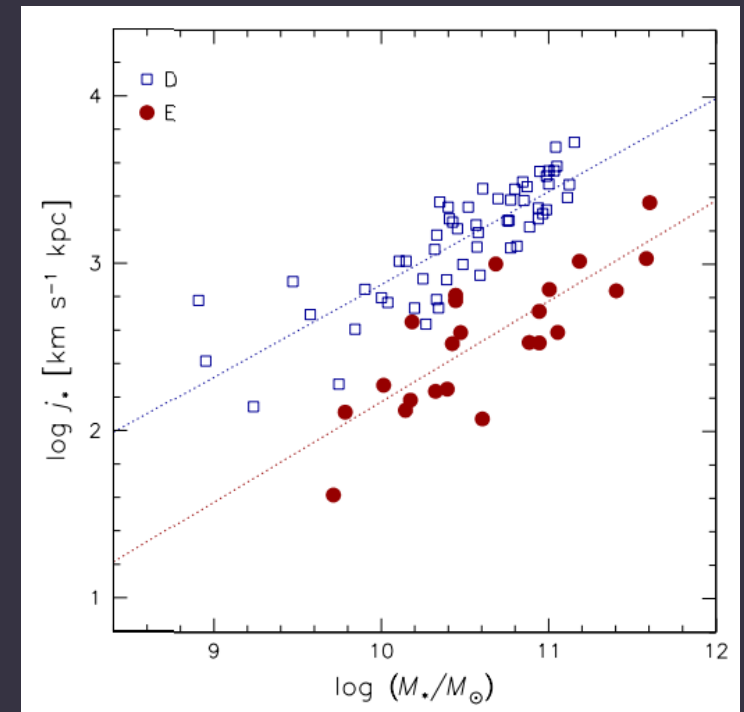
Offset to lower j_* at each M_*

Focus

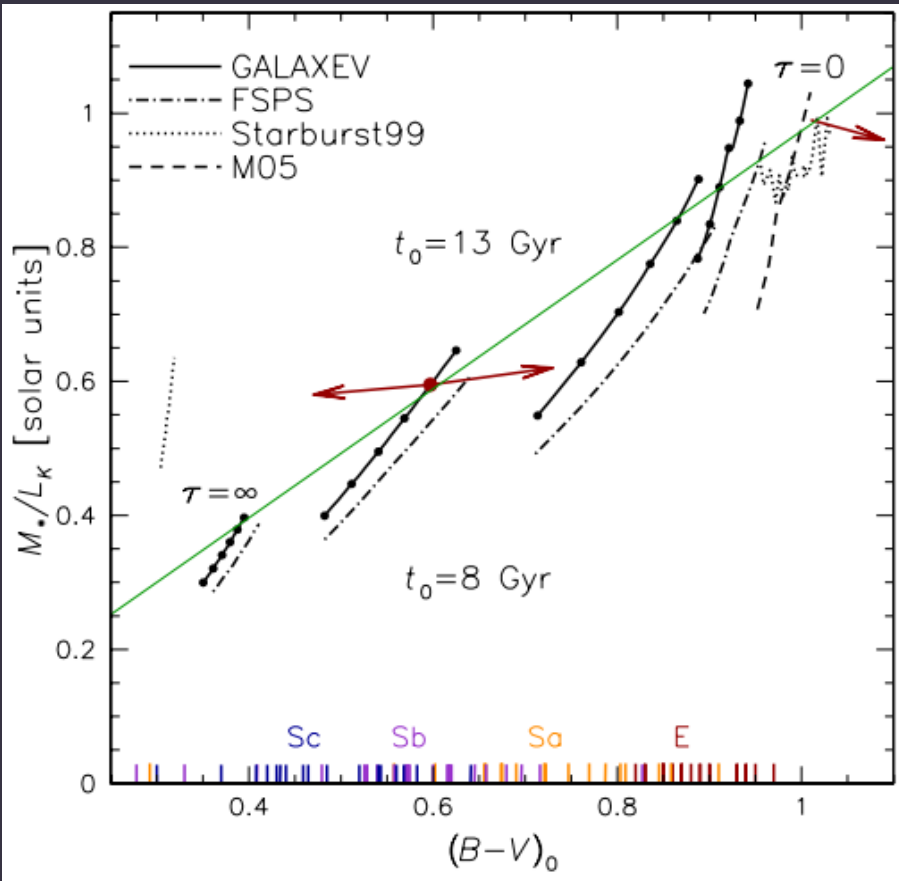
The K-band mass-to-light ratio varies among galaxies



Affects the offset



Fall & Romanowsky 2013



Fall & Romanowsky 2013

- Stellar population models
 - normal initial mass function (IMF)
 - solar metallicity
 - no extinction
- Each curve represent a different star formation history

$$M_* / L_K = 0.96(B - V)_0 + 0.01 \text{ (solar units)}$$

$$M_* = (M_* / L_K) L_K$$

New Approach

disk (d) + bulge (b)

$$J_* = j_{*d} M_{*d} + j_{*b} M_{*b}$$

$$M_* = M_{*d} + M_{*b}$$

$$M_{*d} = f_d (M_* / L_K)_d L_K$$

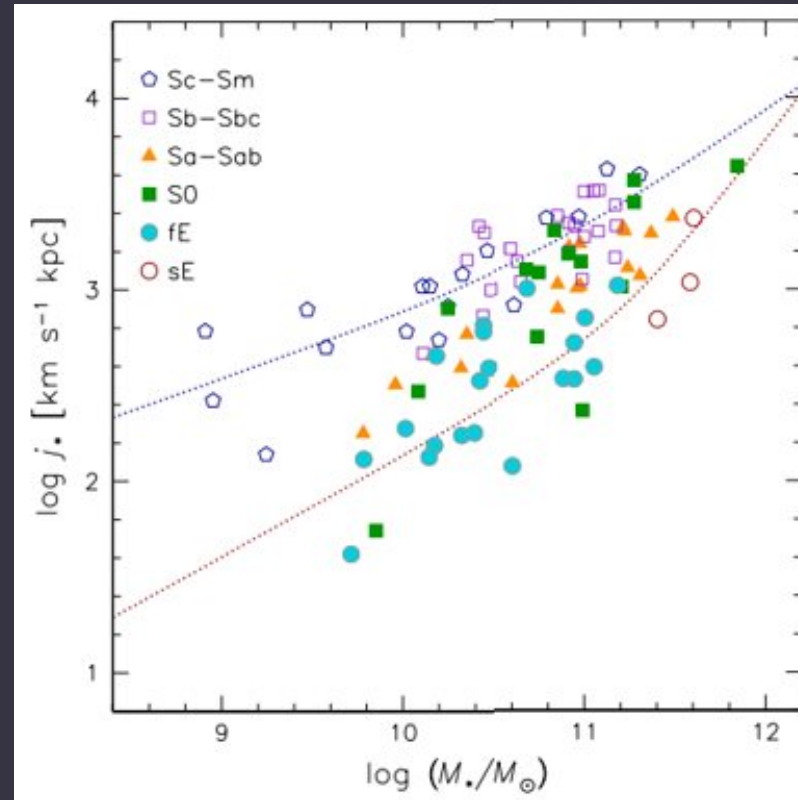
$$M_{*b} = f_b (M_* / L_K)_b L_K$$

f : fractions of the total K-band luminosity L_K

Specific angular
momentum j_*



Observed rotation curves
& surface brightness profiles




Fall & Romanowsky 2013

- $f_j = 0.8$ for disks
- $f_j = 0.1$ for ellipticals

Results

- The offset is a factor of about 5
- The observed $j_* - M_*$ relations for galaxies have nearly the same α as The predicted relation for dark halos ($\alpha_{\text{dh}} = 2/3$)
- Changes in j_* must be almost independent of M_*



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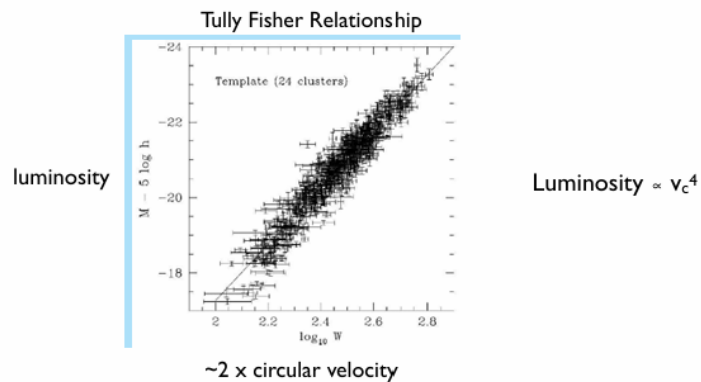
Scaling relations for disks and bulges

What we already know for disk dominated and bulge dominated galaxies

Global Properties of Disk Galaxies

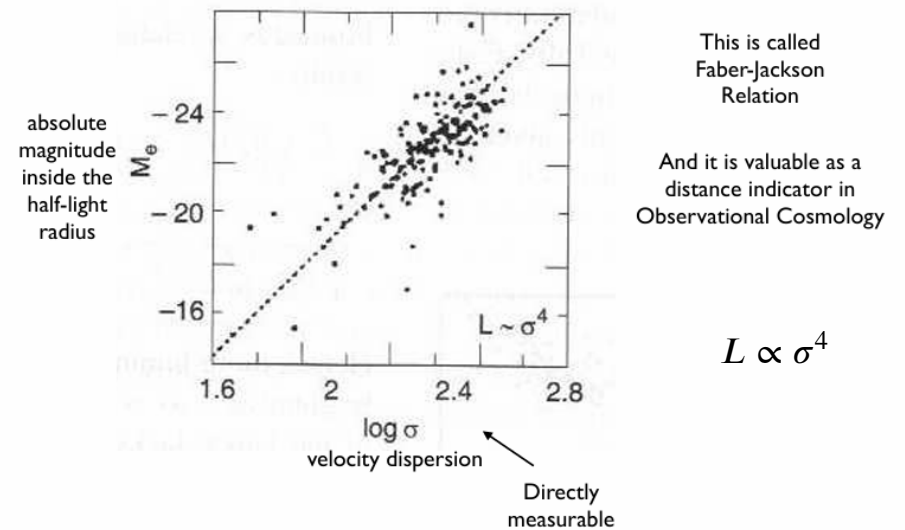
Two variables (mass + angular momentum) of collapsed halos appear to determine most of the physical properties of a spiral galaxy.

And so other variables like their circular velocity appear to closely trace what we observe based on their luminosity and mass



Intrinsic Correlations between Galaxy Properties

Strong correlations are observed between the masses, sizes, and velocity dispersions of elliptical galaxies.



Both have luminosity relation to velocity⁴

Ellipticals and disks but what about in-between?

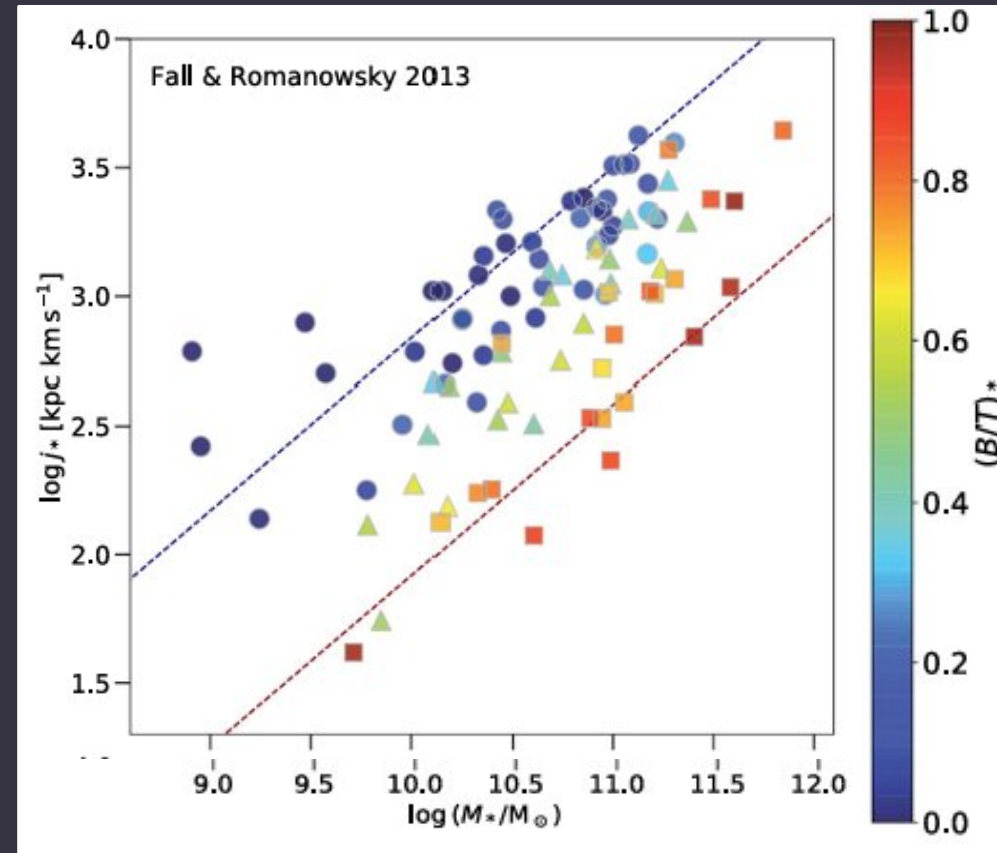
- From 2013 paper $j_{\star} \propto M_{\star}^{0.6 \pm 0.1}$
- Separated for disk and elliptical galaxies by factor of 5
- But for galaxies that have both disks and bulge components what is their distribution?

Need to quantify disk or bulge-ness

$$\beta_{\star} = \frac{M_{\star b}}{M_{\star d} + M_{\star b}} \text{ or } \beta_{\star} = \frac{M_{\star b}}{M_{\star total}}$$

- $\beta = 0$ represent a perfect disk and $\beta = 1$ an elliptical with no disk structure
- Total j_{\star} is the mass weighted sum of independent disk and bulge components, same power law but offset
- Dashed lines represent pure disk and pure bulges

$$j_{\star} = \frac{j_{\star d} M_{\star d} + j_{\star b} M_{\star b}}{M_{\star total}}$$



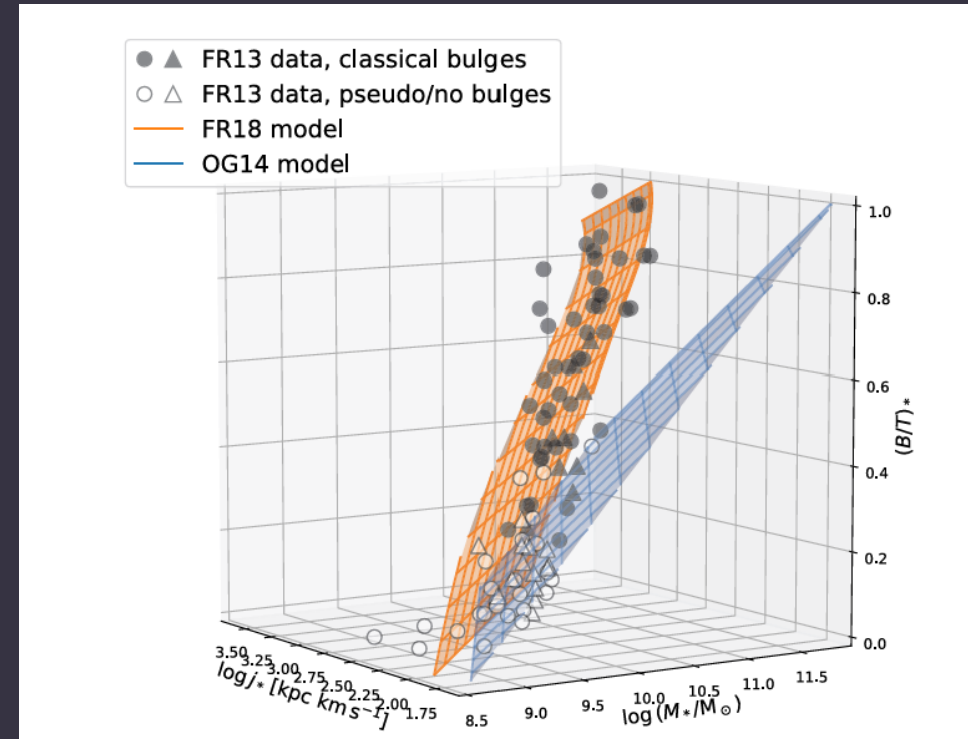
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Galaxies lie on a curved 2D surface in $(j_{\star}, M_{\star}, \beta_{\star})$ space

- The orange surface is the superposition model suggested by this paper predicting a curved 2D surface
- Both classical and pseudo bulges fall on the same surface despite different histories
- The model requires no intrinsic scatter any deviation from surface can be accounted for from measurement error

Galaxy morphology is not a discrete classification but a continuous distribution

This could be used as a quantitative measure of galaxy classification instead of Hubble-de Vaucouleurs system



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What this paper adds and what we did not include

Key takeaways

- Disks and bulges follow the same power law $j_{\star} \propto M_{\star}^{\alpha}$ ($\alpha \approx 0.67$) but offset by a factor of 8
- Simple superposition of bulge and disk can almost fully describe galaxy morphology
- Could allow for objective classification of galaxy type

What we didn't cover

- Comparison of different models from other authors
- Comparison with simulations



Questions?

Thank you!