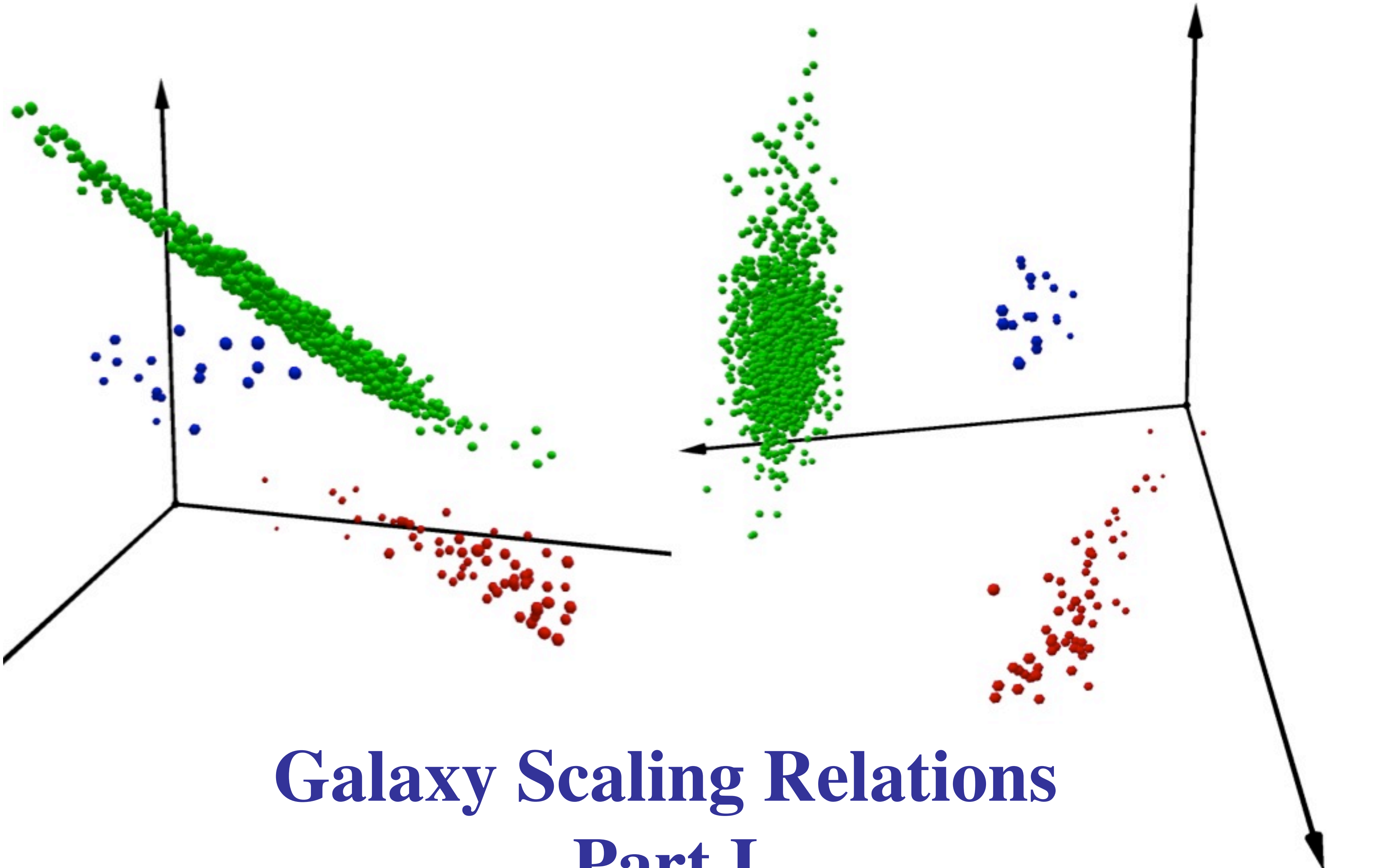


Galaxy Scaling Relations
Part I

Galaxy Scaling Laws

- When correlated, global properties of galaxies tend to do so as power-laws; thus "scaling laws"
- They provide a quantitative means of examining physical properties of galaxies and their systematics
- They reflect the internal physics of galaxies, and are a product of the formative and evolutionary histories
  - Thus, they could be (and are) different for different galaxy families
  - We can use them as a fossil evidence of galaxy formation
- When expressed as correlations between distance-dependent and distance-independent quantities, they can be used to measure relative distances of galaxies and peculiar velocities: thus, it is really important to understand their intrinsic limitations of accuracy, e.g., environmental dependences

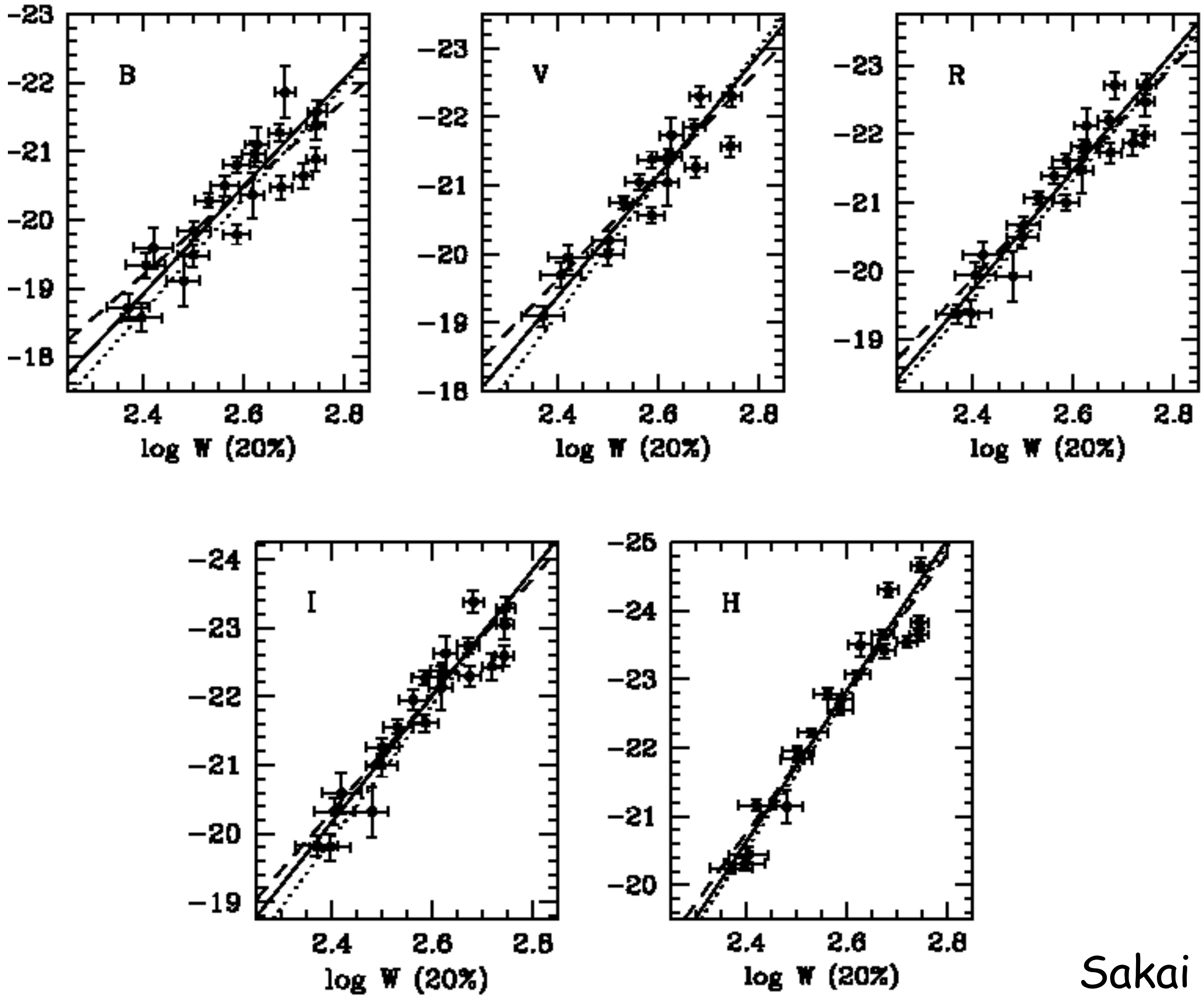
The Tully-Fisher Relation

- A well-defined luminosity vs. rotational speed (often measured as a H I 21 cm line width) relation for spirals:

$$\boldsymbol{L \sim V_{rot}}^{\gamma}\ , \gamma \approx 4, \text{ varies with wavelength}$$

  Or: $M = b \log(W) + c$, where:
  - M is the absolute magnitude
  - W is the Doppler broadened line width, typically measured using the HI 21cm line, corrected for inclination $W_{true} = W_{obs} / \sin(i)$
  - Both the slope b and the zero-point c can be measured from a set of nearby spiral galaxies with well-known distances
  - The slope b can be also measured from any set of galaxies with roughly the same distance - e.g., galaxies in a cluster - even if that distance is not known
- Scatter is ~ 10-20% at best, better in the redder bands

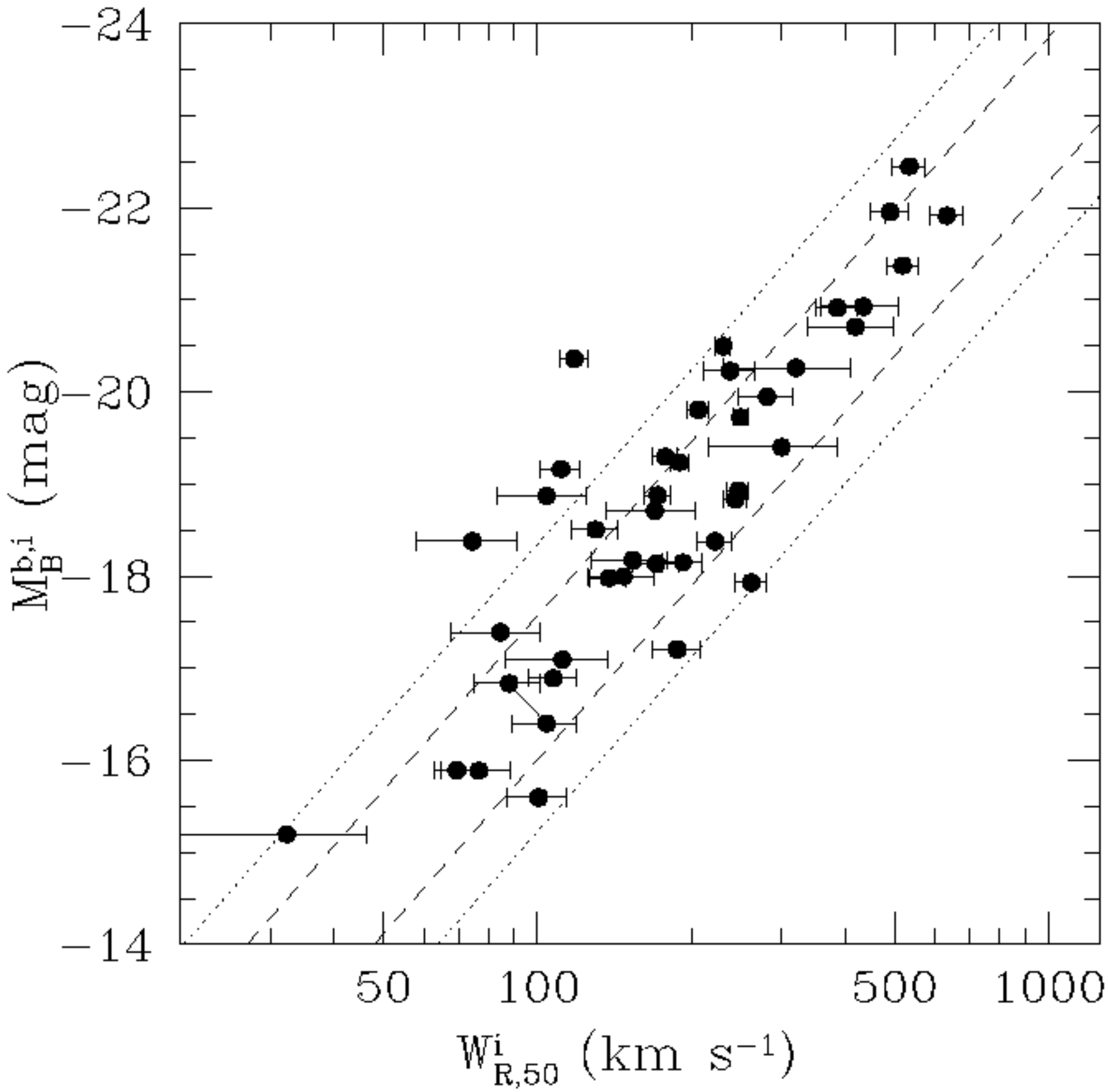
Tully-Fisher Relation in Diferent Bands



Sakai et al 1999

Why is the TFR So Remarkable?

- Because it connects a property of the dark halo - the maximum circular speed - with the product of the net integrated star formation history, i.e., the luminosity of the disk
- Halo-regulated galaxy formation/evolution?
- The scatter is remarkably low - even though the conditions for this to happen are known not to be satisfied
- There is some important feedback mechanism involved, which we do not understand yet
- Thus, the TFR offers some important insights into the physics of disk galaxy formation

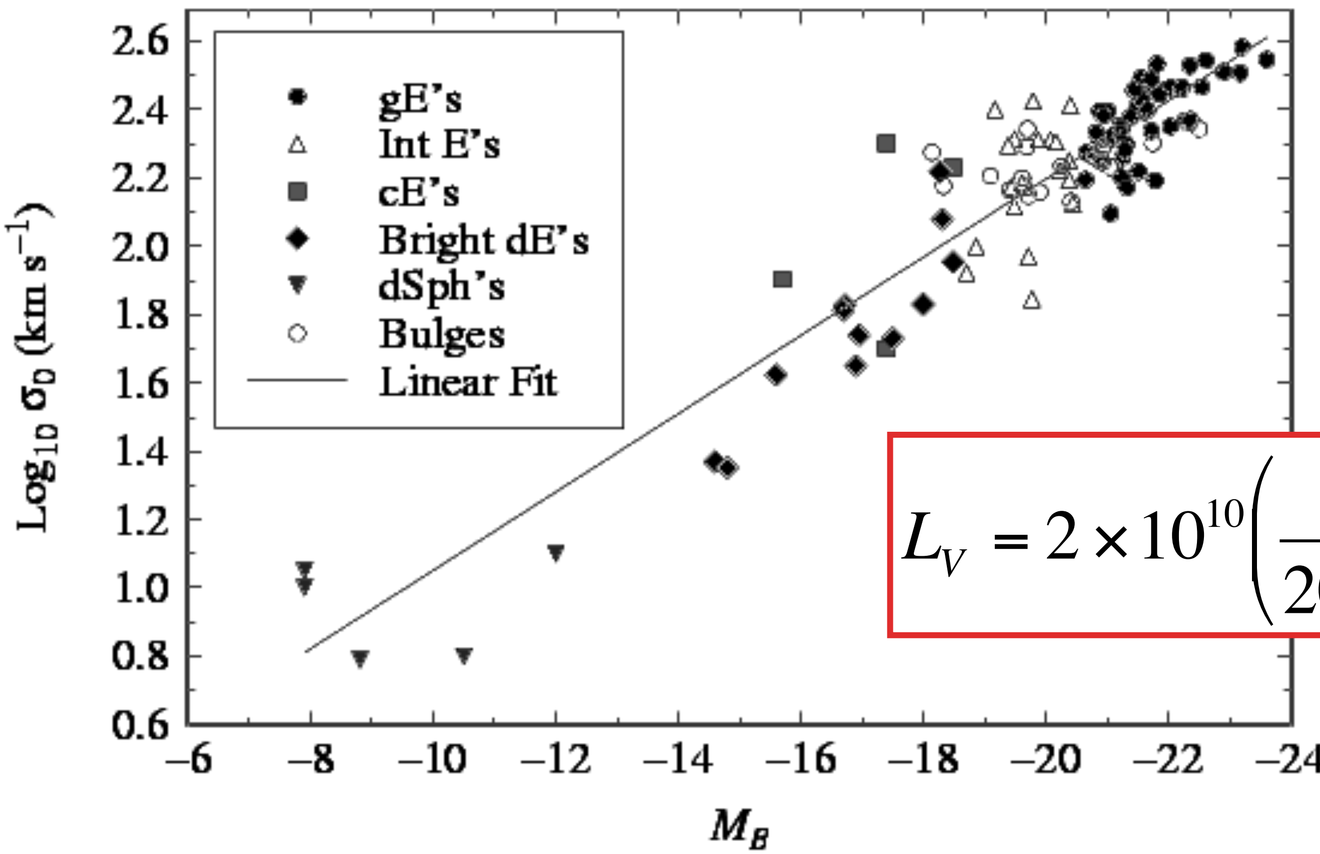


Low surface brightness galaxies follow the <u>same</u> TF law as the regular spirals: so it is really relating the baryonic mass to the dark halo

Zwaan et al. 1995

The Faber-Jackson Relation for Ellipticals

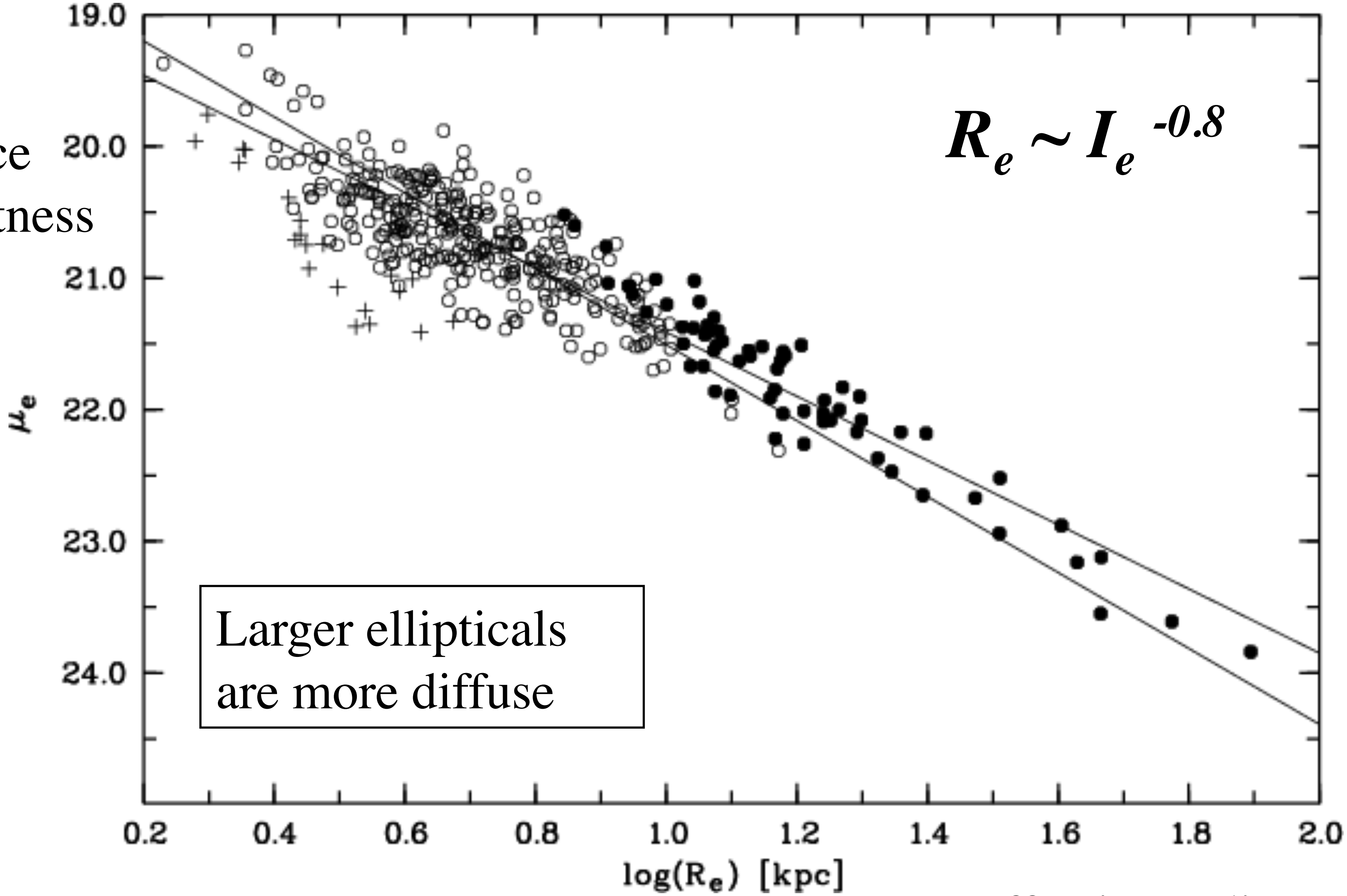
Analog of the Tully-Fisher relation for spirals, but instead of the peak rotation speed V_{max}, measure the velocity dispersion. This is correlated with the total luminosity:



$$L_V = 2 \times 10^{10} \left(\frac{\sigma}{200 \text{ kms}^{-1}} \right)^4 L_{sun}$$

The Kormendy Relation for Ellipticals

Mean surface brightness



$R_e \sim I_e^{-0.8}$

Larger ellipticals are more diffuse

Effective radius

Can We Learn Something About the Formation of Ellipticals From the Kormendy Relation?

From the Virial Theorem, $m\sigma^2 \sim GmM/R$

Thus, the dynamical mass scales as $M \sim R\sigma^2$

Luminosity $L \sim I\,R^2$, where I is the mean surface brightness

Assuming $(M/L) = const.$, $M \sim I\,R^2 \sim R\sigma^2$ and $I\,R \sim \sigma^2$

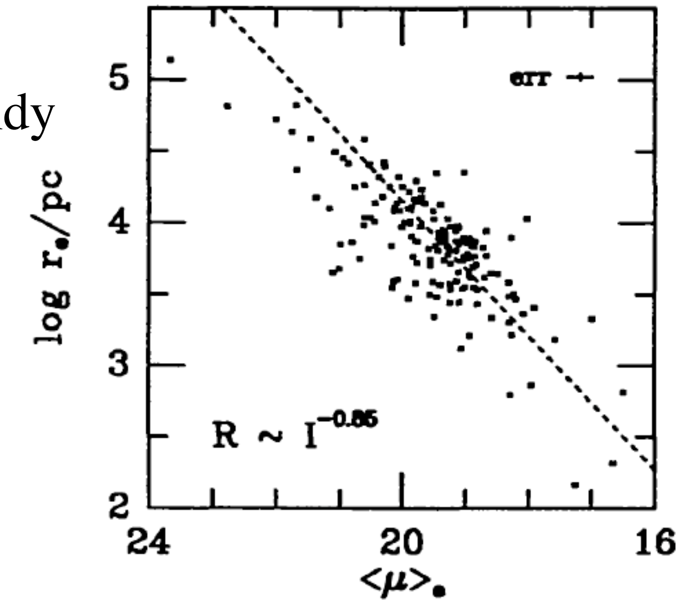
Now, if ellipticals form via dissipationless merging, the kinetic energy per unit mass $\sim \sigma^2 \sim const.$, and thus we would predict the scaling to be $R \sim I^{-1}$

If, on the other hand, ellipticals form via dissipative collapse, then $M = const.$, surface brightness $I \sim M\,R^{-2}$, and thus we would predict the scaling to be $R \sim I^{-0.5}$

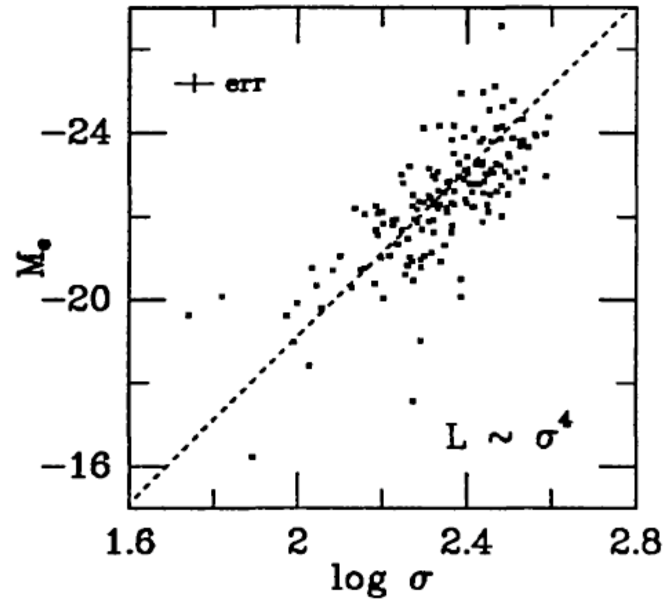
The observed scaling is $R \sim I^{-0.8}$. Thus, ***both*** dissipative collapse and dissipationless merging probably play a role

Scaling Relations for Ellipticals

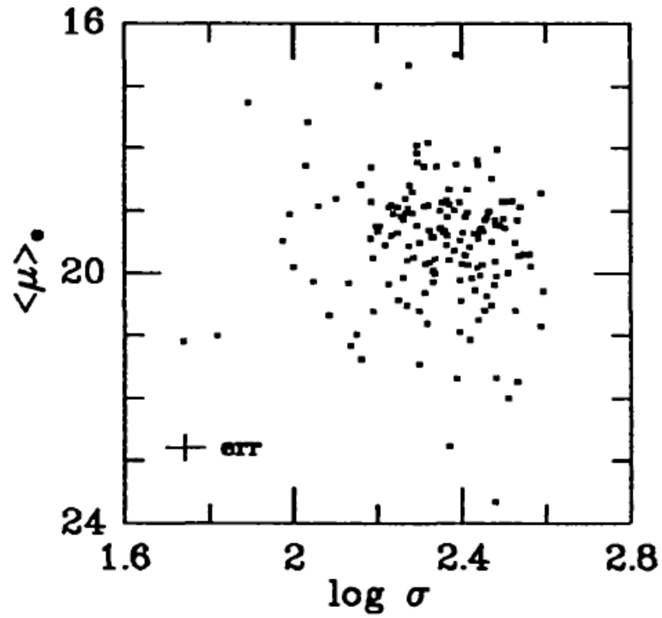
Kormendy rel'n



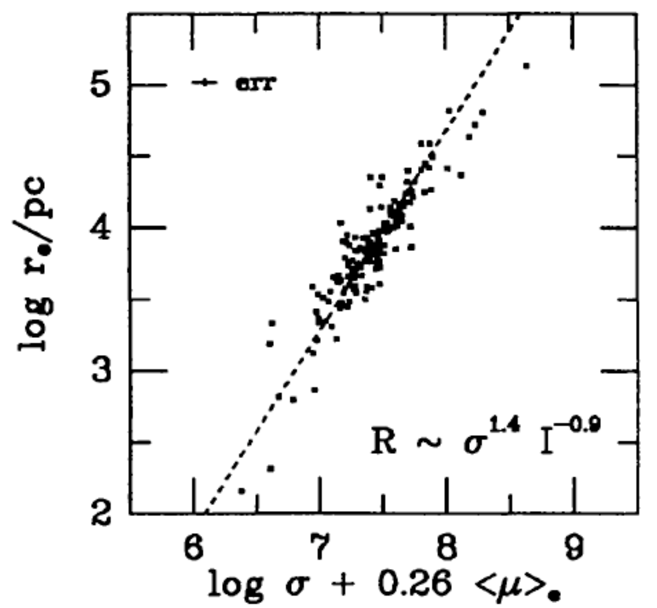
Faber-Jackson rel'n



Cooling diagram



Fundam. Plane



Deriving the Scaling Relations

Start with the Virial Theorem:

$$\frac{GM}{\langle R \rangle} = k_E \frac{\langle V^2 \rangle}{2}$$

Now relate the observable values of ***R***, ***V*** (or ***σ***), ***L***, etc., to their "true" mean 3-dim. values by simple scalings:

$$R = k_R \langle R \rangle \qquad V^2 = k_V \langle V^2 \rangle \qquad L = k_L I R^2$$

One can then derive the "virial" versions of the FP and the TFR:

$$R = K_{SR} V^2 I^{-1} (M/L)^{-1}$$

$$L = K_{SL} V^4 I^{-1} (M/L)^{-2}$$

Where the "structure" coefficients are:

$$K_{SR} = \frac{k_E}{2G k_R k_L k_V}$$

$$K_{SL} = \frac{k_E^2}{4G^2 k_R^2 k_L k_V^2}$$

Deviations of the observed relations from these scalings must indicate that either some ***k'***s and/or the ***(M/L)*** are changing

Galaxy Scaling Relations Will Continue in Part II