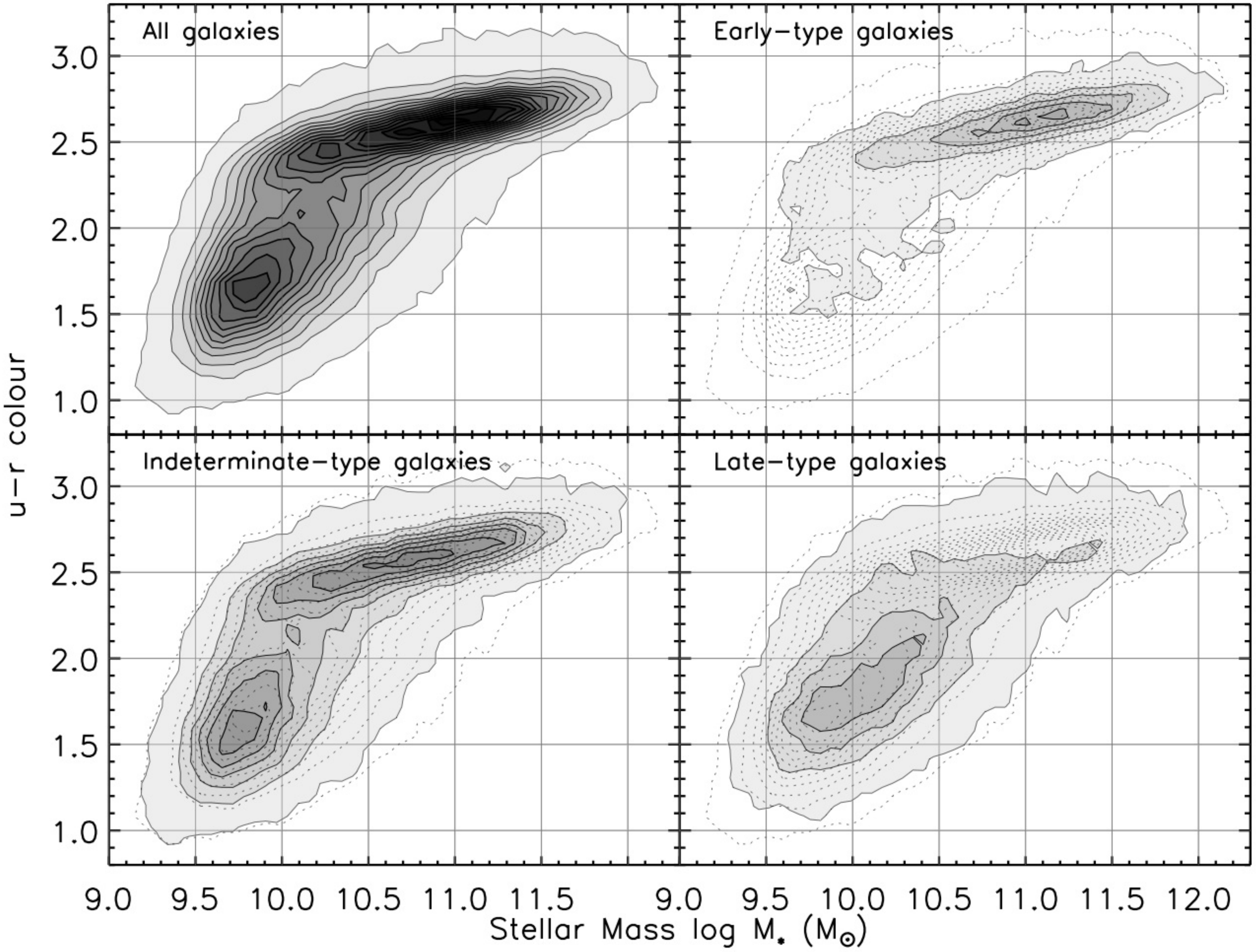
Elliptical galaxies (like spirals) show a color-luminosity relationship: brighter, more massive galaxies are redder. In elliptical galaxies, this is well-established to be a *metallicity effect, not age*. So brighter galaxies are more metal-rich.

The differences between elliptical galaxies and star forming spirals can be seen in plots of color versus luminosity or stellar mass: they form a distinct "red sequence" which is offset from the "blue cloud" of star forming galaxies:



We characterize velocity of populations of stars by

- rotation (v): the net rotational velocity of a group of stars
- dispersion (σ): the characteristic random velocity of stars

In the disk of our galaxy, v=220 km/s, σ=30 km/s, so $v/\sigma \sim 7$.
This is called a cold disk.

Elliptical galaxies have much higher velocity dispersions, 100s of km/s. These are kinematically hot systems.

v/σ ranges (roughly) from 0 to 1.

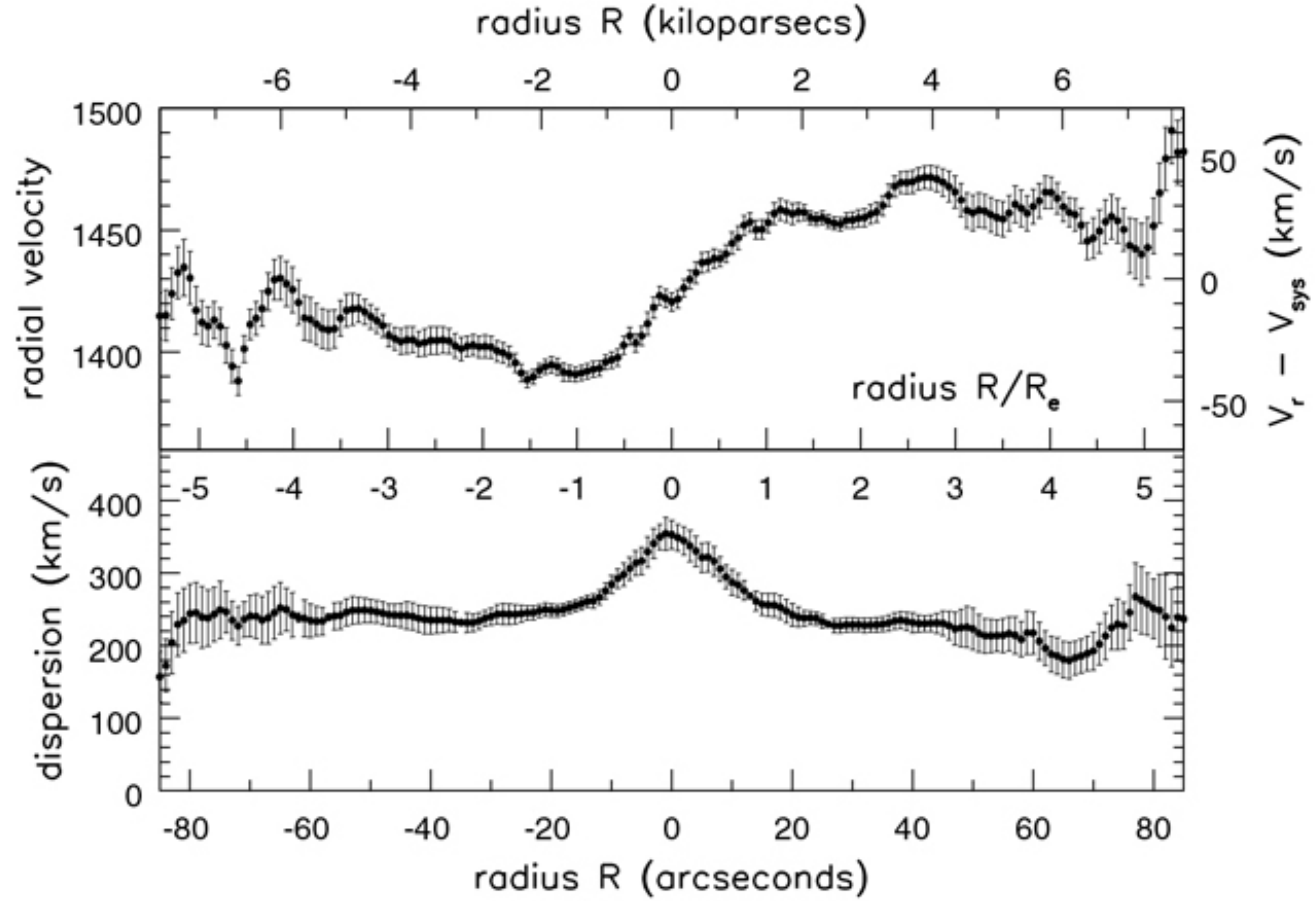


Fig 6.12 (A. Graham) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

v/σ actually correlates with luminosity.

- Lower luminosity ellipticals have higher *v/σ* — rotationally supported.
- Higher luminosity ellipticals have lower *v/σ* — pressure supported.

Stars have different characteristic speeds along different axes.

The figure to the right shows *v/σ* plotted against ellipticity (ε). The line shows expected shape for rotationally supported galaxies. (from [Davies et al 1983](#))

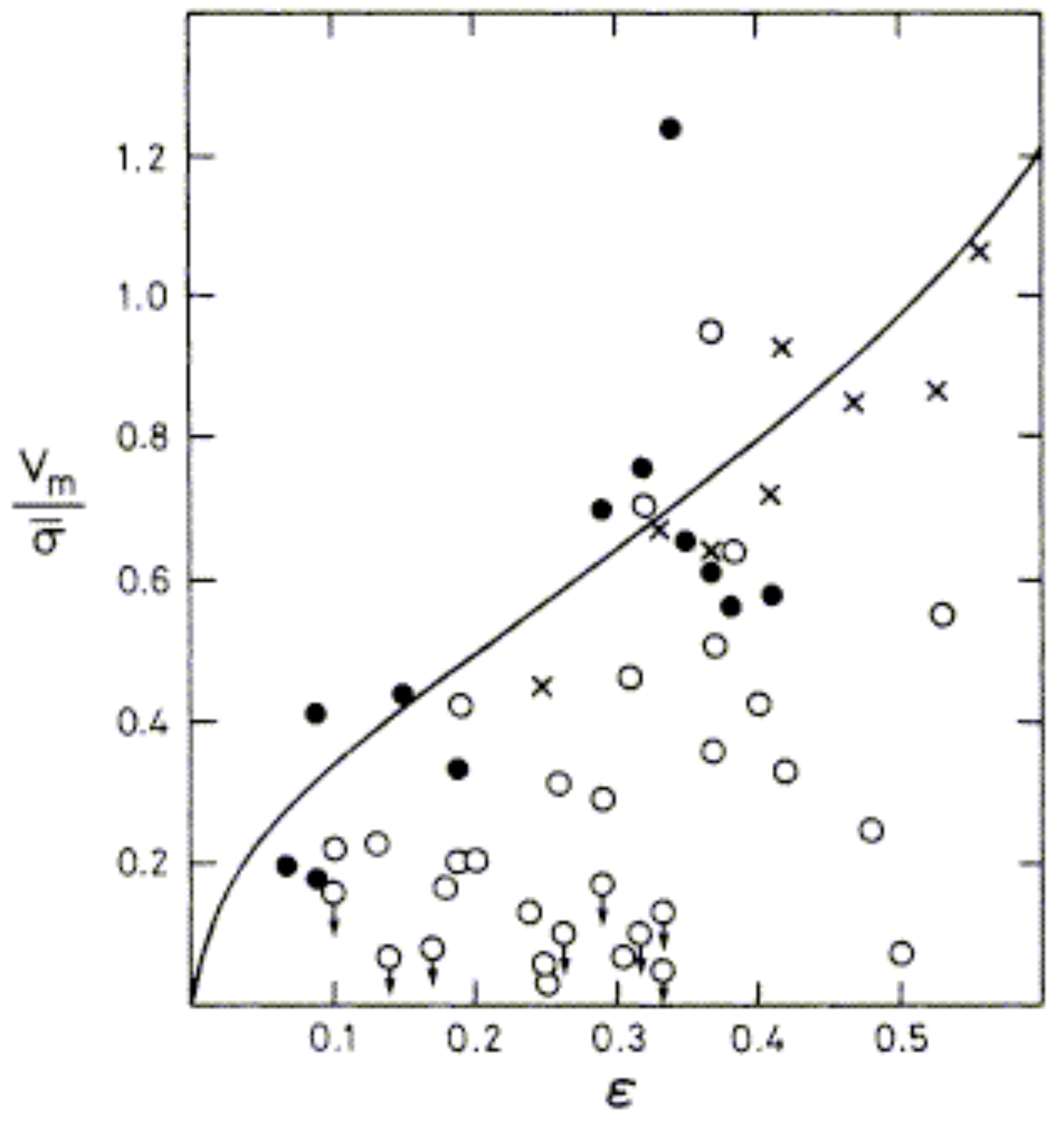


FIG. 3.—The quantity $V_m/\bar{\sigma}$ against ellipticity. Ellipticals with $M_B^{UH} > -20.5$ are shown as filled circles; ellipticals with $M_B^{UH} < -20.5$, as open circles; and the bulges of disk galaxies, as crosses. The solid line shows the $(V/\sigma, \epsilon)$-relation for oblate galaxies with isotropic velocity dispersions (Binney 1978).

Remember the Tully-Fisher law for disk galaxies:

$$L \sim v^4$$

Can we make a similar law for elliptical galaxies using luminosity and velocity *dispersion*?

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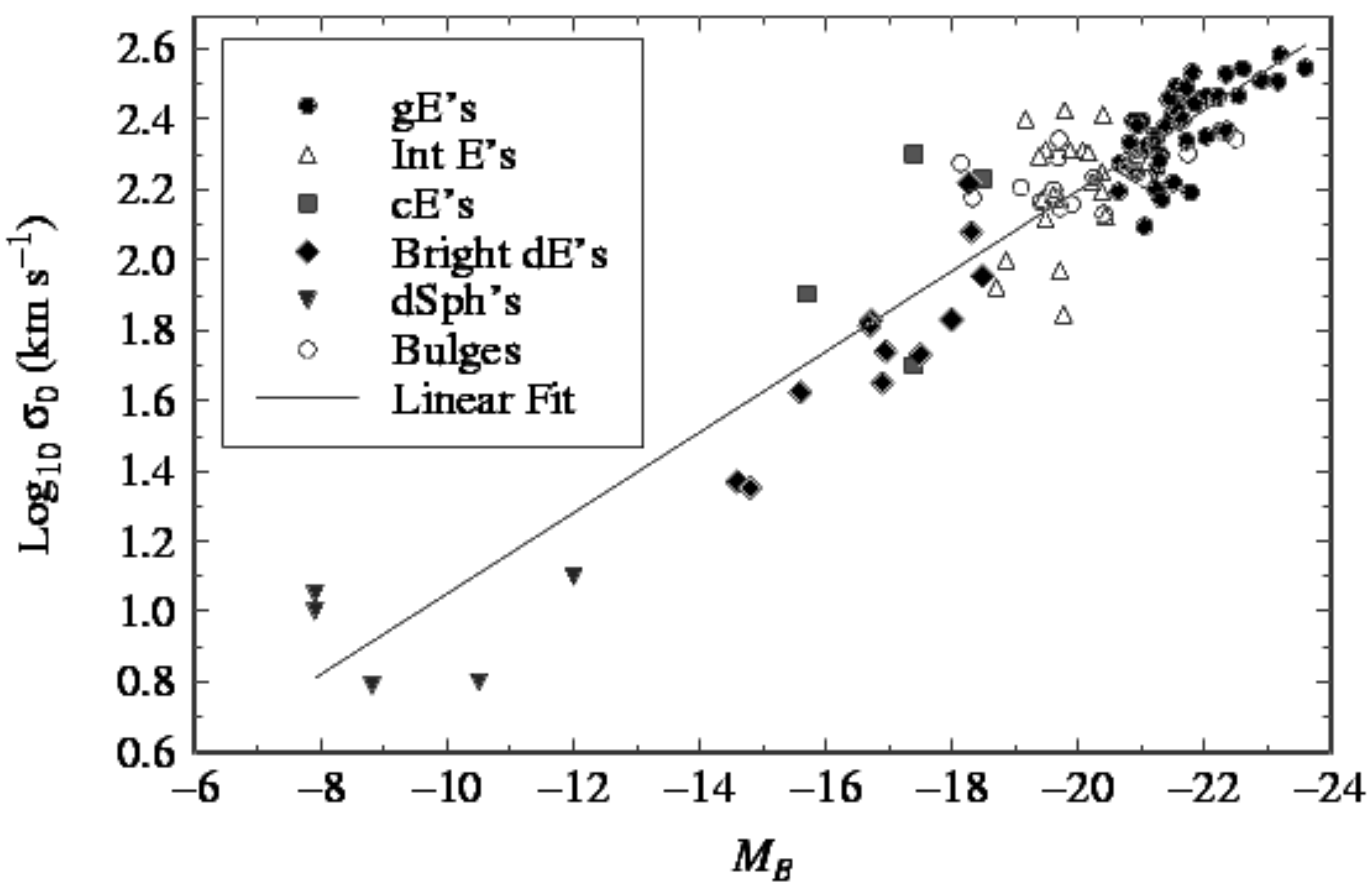
The Faber-Jackson law has a lot of scatter: at a given velocity dispersion, there is a range of +/- 2 magnitudes in luminosity. Compare this to the Tully-Fisher relationship, where at a given circular velocity, there is a range of a few tenths of a magnitude in luminosity.
Clearly, there is something messing with the relationship -- a second parameter.



The Fundamental Plane

In 1987, two teams of astronomers identified the second parameter — the effective radius. Rather than two parameters correlating (in which case you fit a line), there are three parameters correlating (in which case you fit a plane).

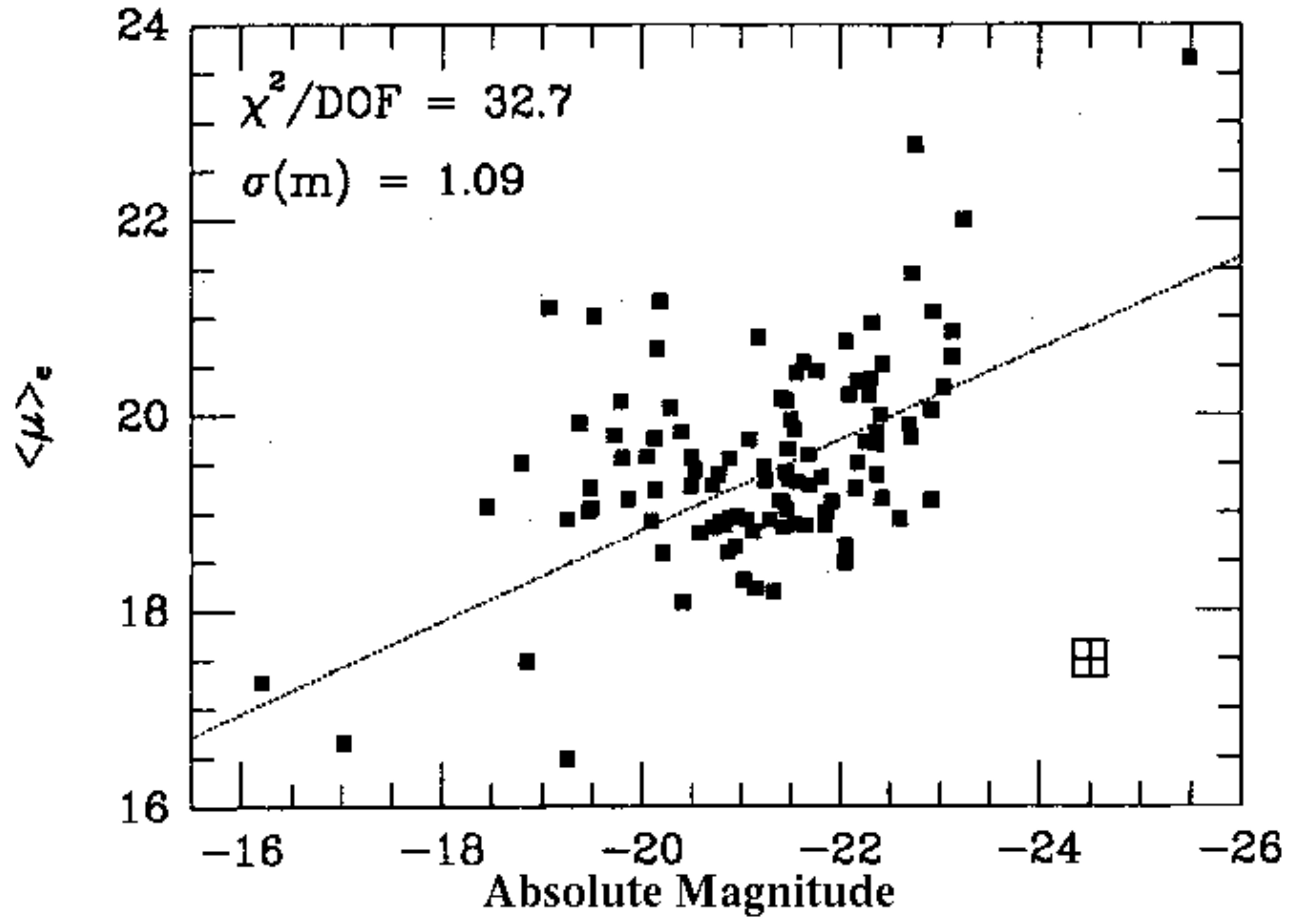
We have 4 things we can measure:

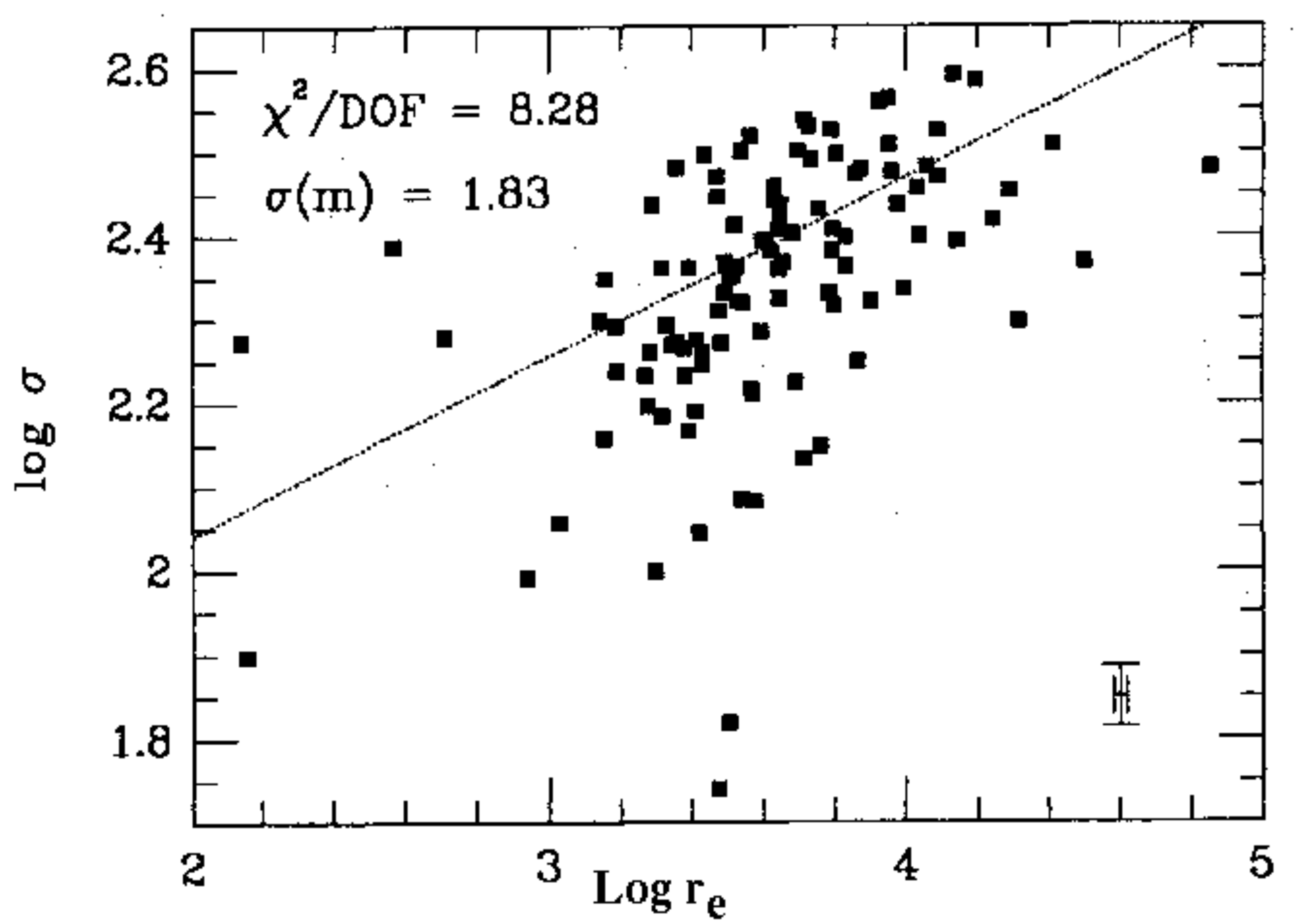
- **Luminosity (*L*)**
- **Effective radius (r_e)**
- **Mean surface brightness ($\langle I_e \rangle$)**
- **Velocity dispersion (σ)**

There are only three independent variables here

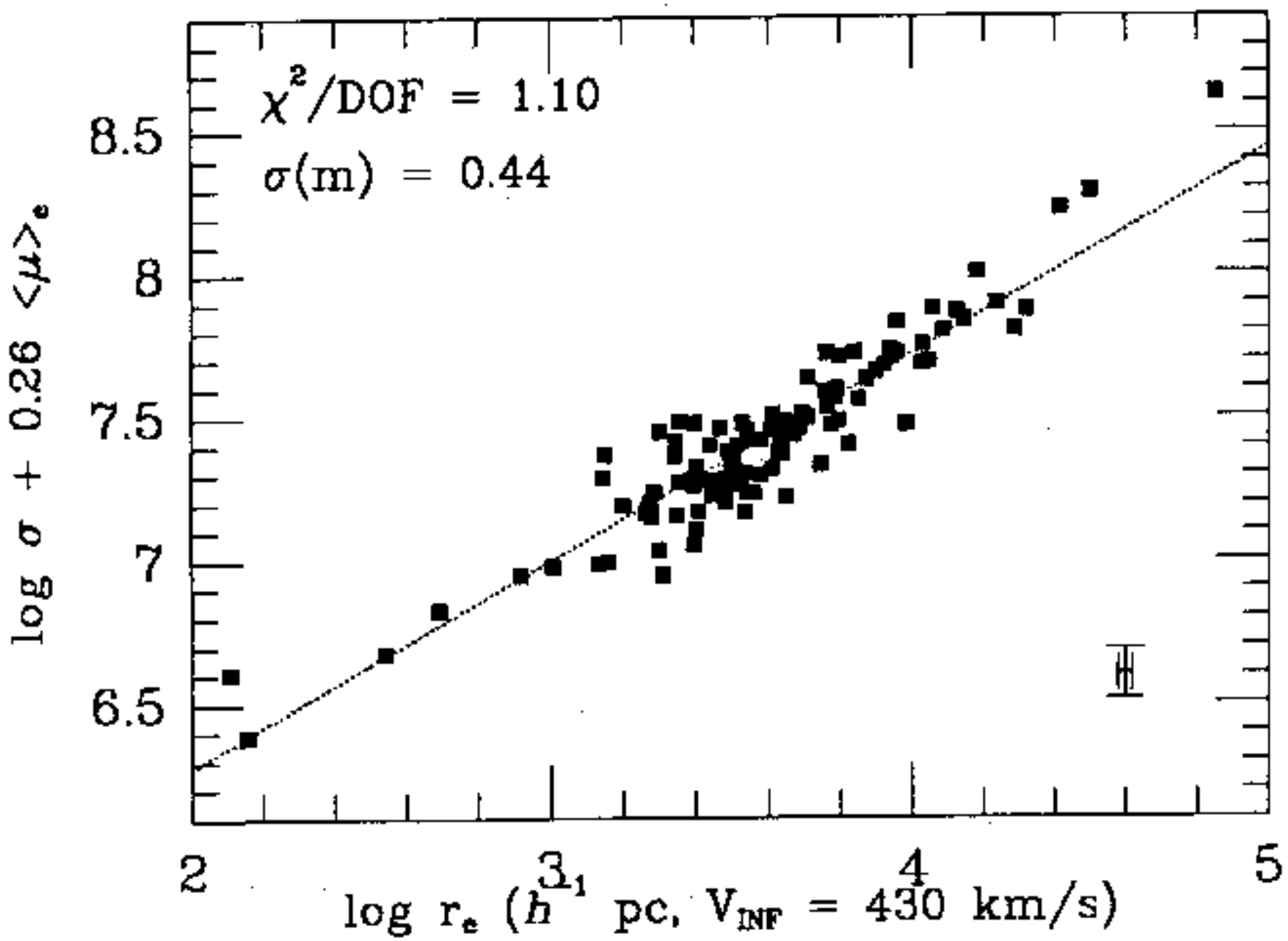
(L, r_e, and $\langle I_e \rangle$ are not all independent).

If you plot one versus another, the third introduces scatter:





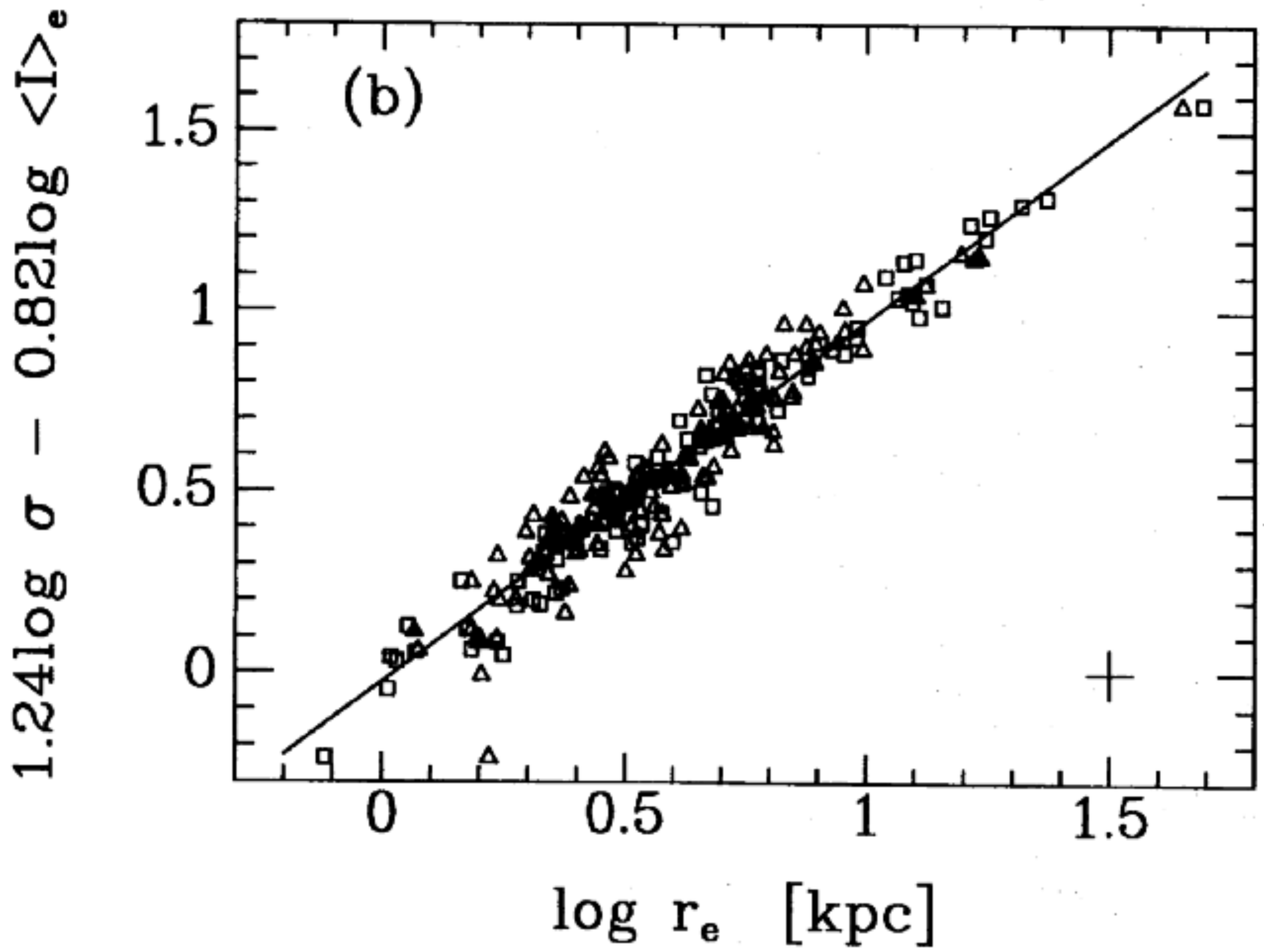
But if you plot one versus a combination of the other two, you can see a very tight correlation:



This correlated plane is now referred to as the fundamental plane. Since we have four observables, only three of which are independent, there are different representations of the FP which are all expressing the same thing. Here is another one:

Put mathematically,

$$r_e \sim \sigma^{1.24} \langle I \rangle^{-0.82}$$



Examples of uses of the Fundamental Plane:

- ***Distance Measuring:*** **In the FP, r_e is measured in physical units: kpc. So if you know the velocity dispersion and effective surface brightness (both of which are distance *independent* measures), you can use the FP to work out the physical size of the galaxy. If you also measure its angular size, you can use trigonometry to solve for the distance to the galaxy.**
- ***Studying Galaxy Structure and Evolution:*** **You can use simple algebra to show that one implication of the fundamental plane is that *total (not stellar) mass-to-light ratio depends on galaxy luminosity*:**

$$\left(\frac{M}{L}\right) \sim L^{0.25}$$

Why would this be? Whatever model we come up with to explain the formation and evolution of galaxies must also explain why more luminous galaxies have higher total mass-to-light ratios.