Galaxies: Structure, formation and evolution

Lecture 13

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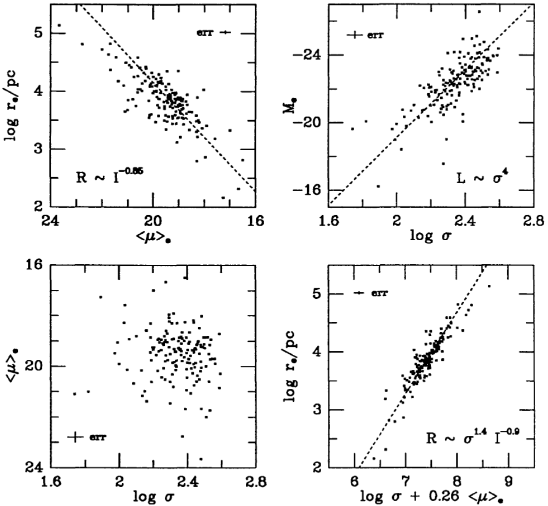
For elliptical galaxies

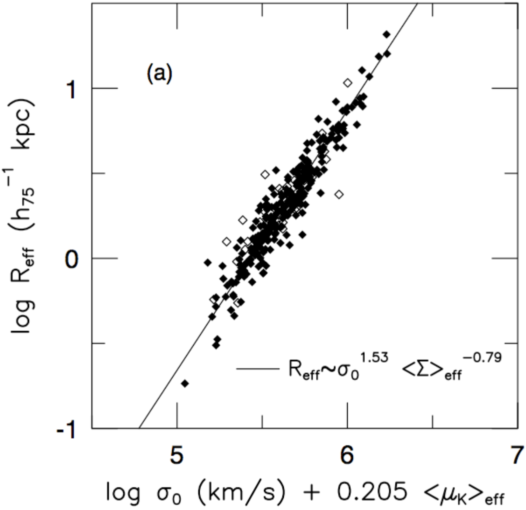
- $L = f(\sigma)$
- $\mu_e = g(r_e)$
- $L = h(\mu_e, r_e)$

Could these correlations be projections of a higher dimensional correlation?

The Fundamental Plane



The Edge-on view of the Fundamental Plane



How will you use the FP as a distance indicator?

FP and the virial theorem

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

the 3D velocity and radius will be some scaled version of the projected version. $R = k_R\langle R\rangle$, $V^2 = k_V\langle V\rangle^2$, $L = k_L I R^2$ Then one can write:

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

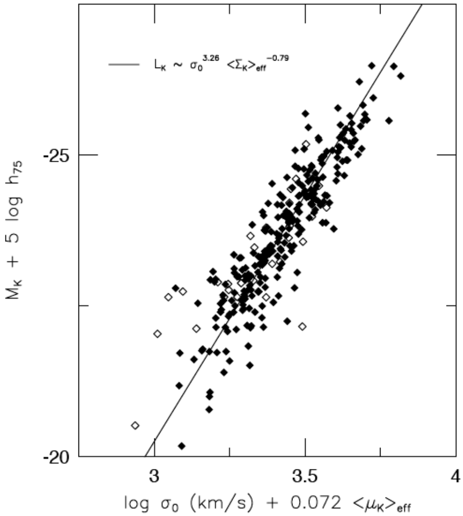
where the structure coeffients

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

Question

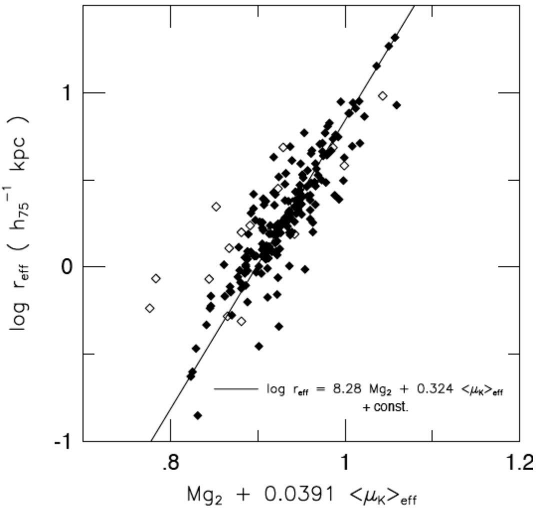
What do deviations of the observed relations from these scalings indicate?

Alternate FP - Luminosity instead of size



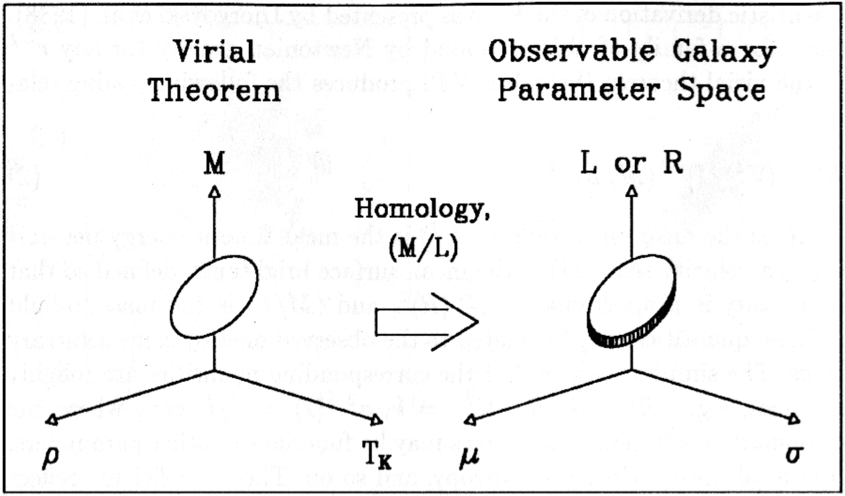
Star formation history connected to structural and dynamical properties

Alternate FP - Metallicity instead of σ



Chemical evolution connected to structural properties

Virial Theorem and the Fundamental Plane



Measuring M/L via the fundamental plane

If we assume homology and attribute all of the FP tilt to the changes in (M/L),

$$(M/L) \sim L^{\alpha}, \alpha \sim 0.2(vis) or \sim 0.1(IR)$$

List two ways of changing M/L in a systematic way

Measuring M/L via the fundamental plane

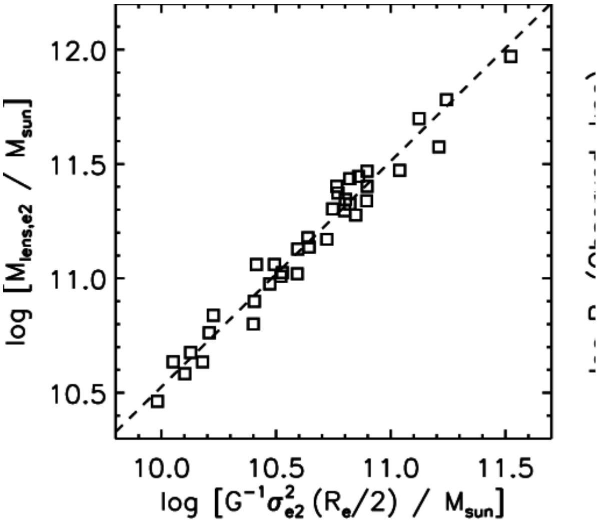
If we assume homology and attribute all of the FP tilt to the changes in (M/L),

$$(M/L) \sim L^{\alpha}, \alpha \sim 0.2 (vis) or \sim 0.1 (IR)$$

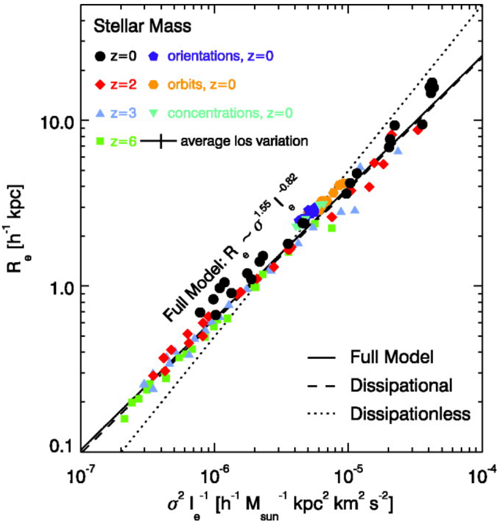
List two ways of changing M/L in a systematic way

1. change the IMF
2. change $M_{\rm visible}/M_{\rm dark}$

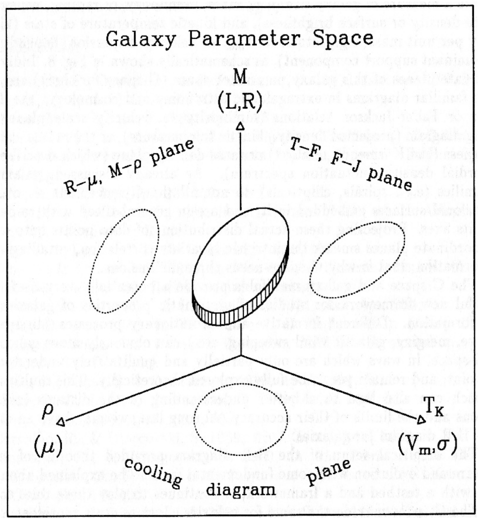
Mass based fundamental plane



FP from numerical simulations



Projections of the FP



For galaxies that fall on FP, just two numbers

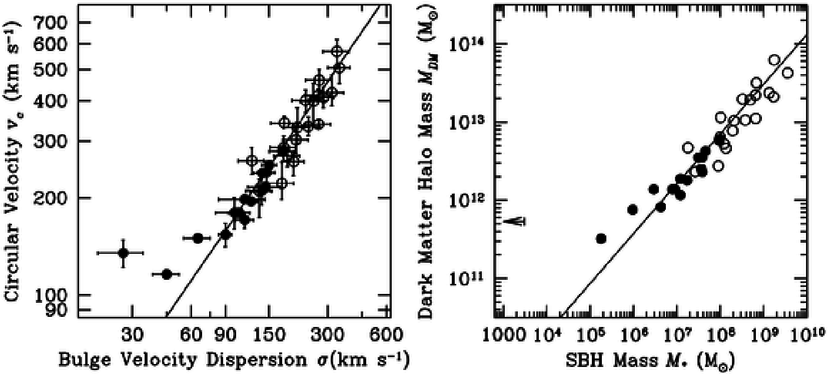
determine to within a few percent or less:

- Mass, luminosity (in any OIR band)
- Any consistently defined radius
- Surface brightness or projected mass density
- Derived 3-d luminosity, mass, or phase-space density
- Central projected radial velocity dispersion
- OIR colors, line strengths, and metallicity
- **Mass of the central black hole**

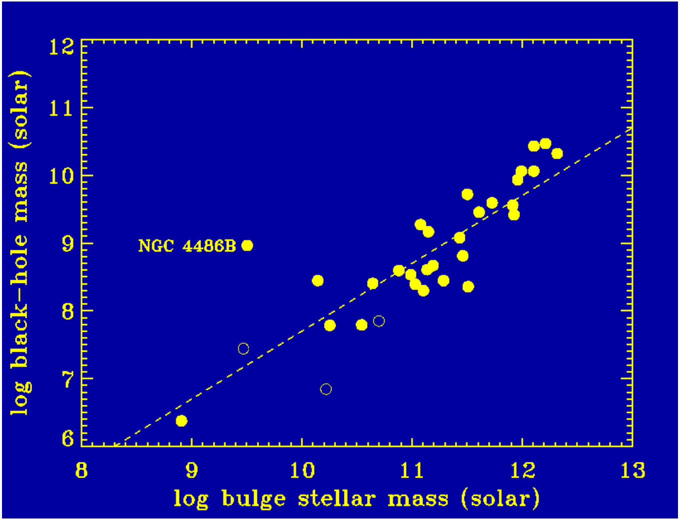
And things that don't matter ...

- Star formation and merging formative/evolutionary history
- Large-scale environment (to within a few %)
- Details of the internal structure and dynamics (including S0's)
- Projection effects (the direction we are looking from)

Central black hole and the bulge



and most interestingly



Extra class at 10 on Tuesday, 12 April?

Dark matter haloes

- Many of galaxy scaling relations may be driven by the properties of their dark halos
- It is possible to infer their properties from detailed dynamical profiles of galaxies and some modeling
- Numerical simulations suggest a universal form of the dark halo density profile (NFW = Navarro, Frenk & White):

$$\rho(r) = \frac{\rho_0}{(r/r_s)(1 + r/r_s)^2}$$

where ρ_0 and the scale radius r_s are parameters that vary from halo to halo.

Dark matter discovered in 1937 by Zwicky

He calculated the mass of the Coma cluster using the virial theorem. $M_{\rm cl} = \sigma^2 R_{\rm cl}/G$. For typical clusters $\sigma \sim 500 - 1500$ km s^{-1},$R{\rm cl} \sim 3 - 5$ Mpc. This gives $M_{\rm cl} \sim 10^{14} - 10^{15} M_{\odot}$. Typical clusters have 100-1000 galaxies and $L_{\rm cl} \sim 10^{12} L_{\odot}$ and $(M/L) \sim 200 - 500$ in solar units.

Dark matter candidates

- Massive neutrinos: Known to exist and to have mass, but how much?
- Weakly Interacting Massive Particles (WIMPs): Not found yet, but possible . A generic category, e.g., the neutralino = the least massive SUSY particle; also include gravitinos, photinos, and higgsino. Possible masses > 10 GeV
- Axions: predicted in some versions of quantum chromodynamics, Could interact electromagnetically, Possible masses 10^{-12} eV to 1 MeV
- Many (many!) other speculative possibilities ...

Two types of dark matter

- Hot (HDM): matter is relativistic, so must involve low-mass particles such as neutrinos. Their streaming erases the small-scale density fluctuations, so big structures form first, then later fragment. This is “top-down” structure formation
- Cold (CDM): matter moves more slowly; includes exotic as yet unknown particles such as axions, WIMPs, etc. Density fluctuations at all scales survive. Small fluctuations collapse first, then larger ones (pulling in the littler ones along the way). This is “bottom-up” structure formation and this is the best match to what we observe.
- There is probably a little bit of HDM and a lot of CDM