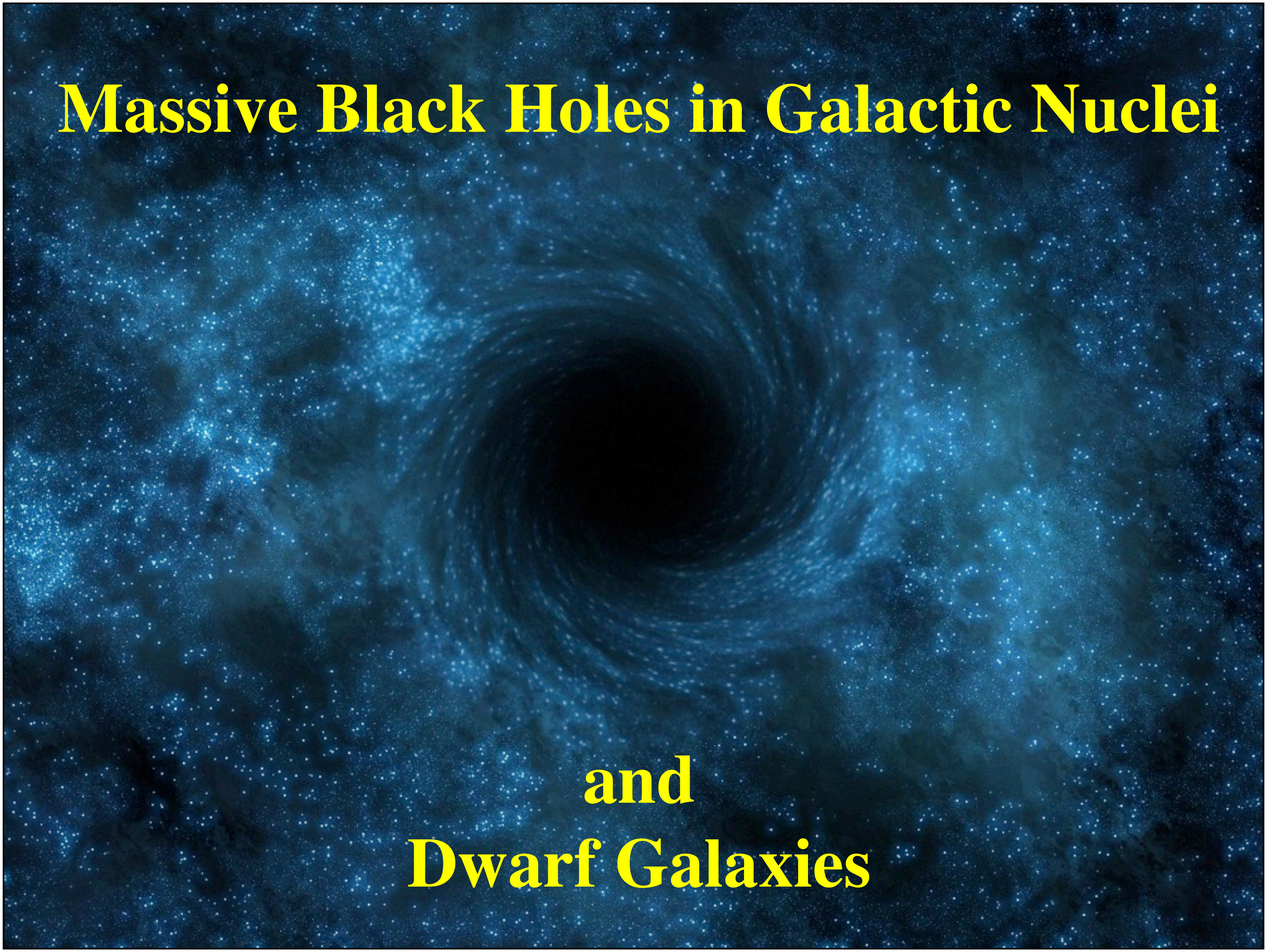
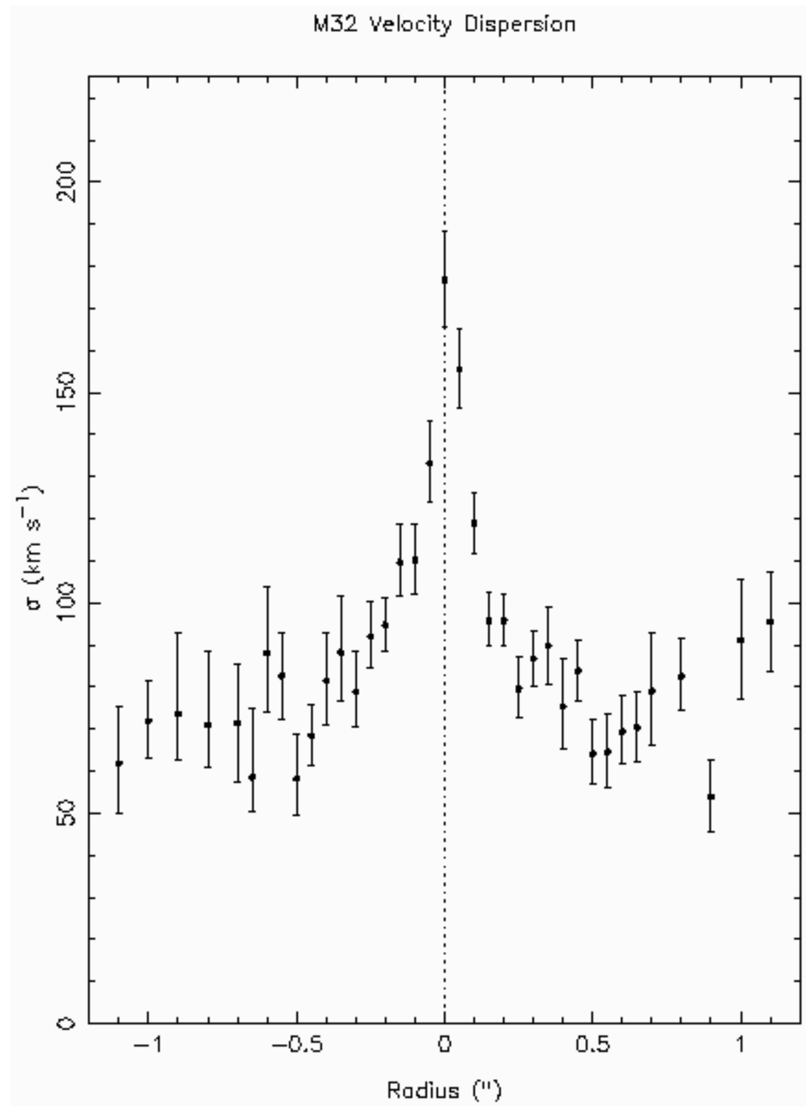

Massive Black Holes in Galactic Nuclei
and
Dwarf Galaxies

Massive Black Holes in Galactic Nuclei

- It turns out that they are ***ubiquitous***: nearly every non-dwarf galaxy seems to have one, but only a small fraction are active today; these super-massive black holes (SMBH) are believed to be the central engines of quasars or other AGN
- They are detected through central velocity dispersion or rotation cusps near the center - requiring more mass than can be reasonably provided by stars
- ***Their masses correlate very well with many of their host galaxy properties***, suggesting a co-formation and/or co-evolution of galaxies (or at least their old stellar spheroid components) and the SMBHs they contain
- Understanding of this connection is still not complete, but dissipative mergers can both drive starbursts and fuel/grow SMBHs

Many (all?) ellipticals (& bulges) have black holes- even compact ones like M32!



Can measure BH masses for galaxies via their velocity dispersion

Fundamental Corrrelations Between SMBH Masses and Their Host Galaxy Properties

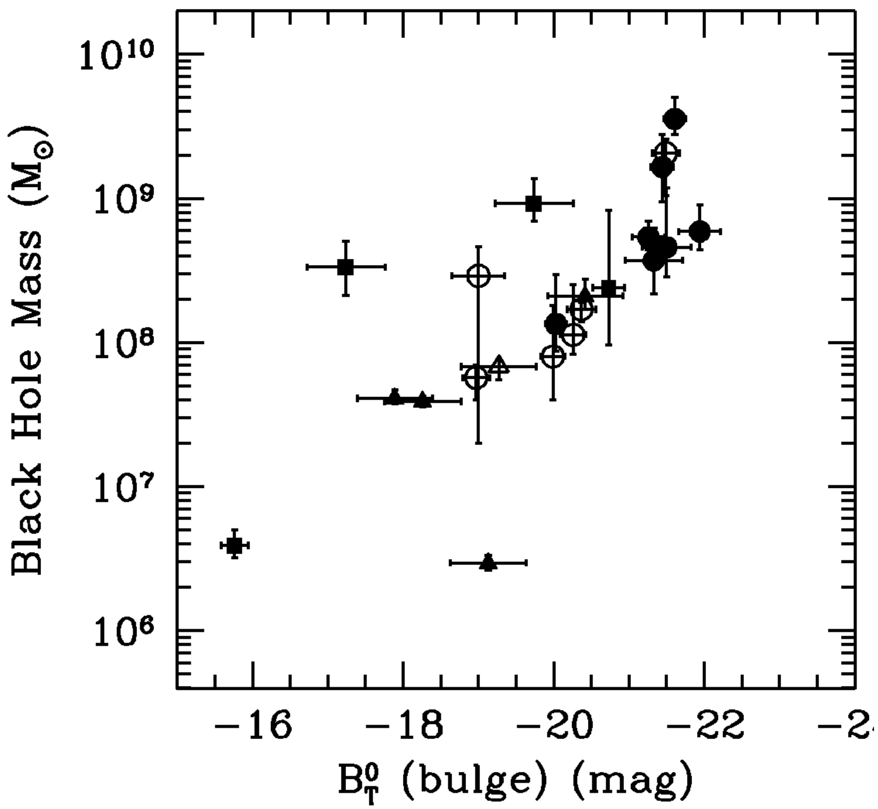
$$\log \frac{M_{BH}}{\mathrm{M}_\odot} = (-0.36 \pm 0.09) B_T^0 + (1.2 \pm 1.9)$$

$$\chi_r^2 = 23$$

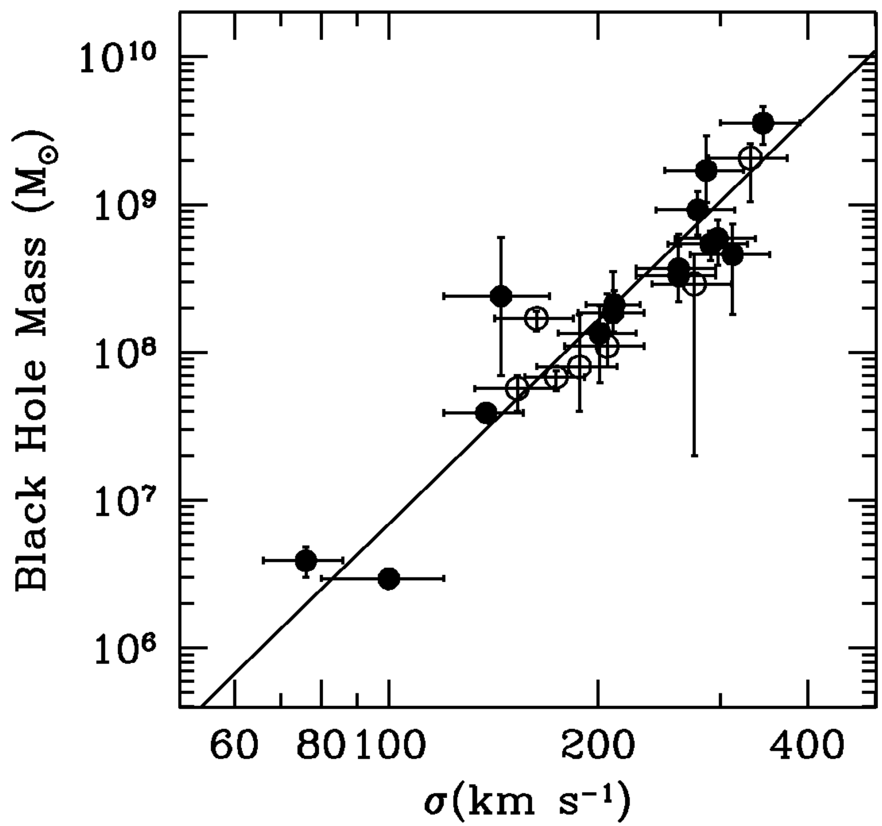
$$\frac{M_{BH}}{\mathrm{M}_\odot} = (1.7 \pm 0.3) \times 10^8 \left(\frac{\sigma_c}{200\,\mathrm{km\ s^{-1}}} \right)^{4.6 \pm 0.5}$$

$$\chi_r^2 = 0.72$$

Kormendy & Richstone 1995



Ferrarese & Merritt 2000; Gebhardt et al. 2000



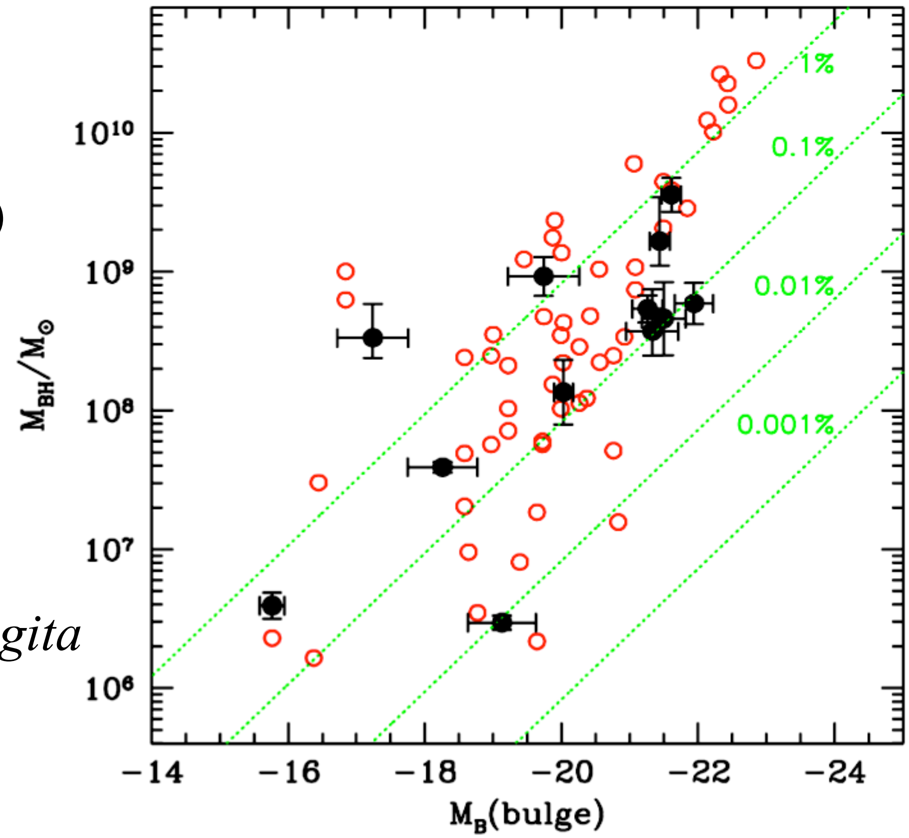
Local SMBH Demographics and Comoving Mass Density

$M_\bullet$ from the $M_\bullet$-σ relation
M_{bulge} from Magorrian et al. (1998)

Mass density in local SMBH:

$\mathbf{x = M_\bullet / M_{bulge} \sim 0.13\%}$

$\boldsymbol{\rho_{bulge} \sim 3.7\times10^8\ M_\odot}$ **Mpc** (*Fukugita et al. 1998*)

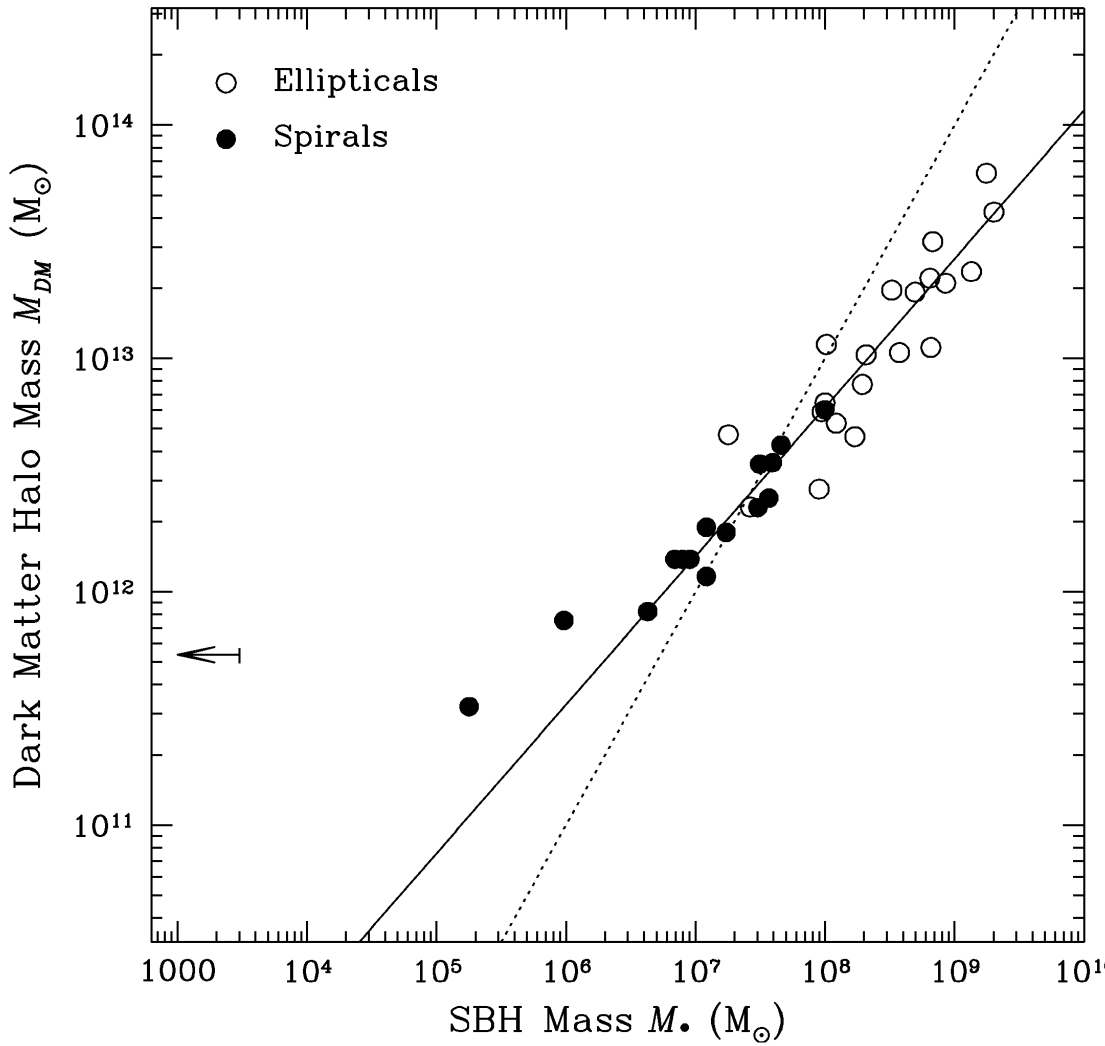


Merritt & Ferrarese 2001

→ $\boldsymbol{\rho_\bullet \sim 4.9\times10^5\ M_\odot\ \mathrm{Mpc}^{-3}}$

Recall that the normalization of the GLF is $\phi_* \sim 10^{-2}$ Mpc^{-3}, so an average galaxy should contain a $\sim$ **10^7 $M_\odot$** black hole!

An even more fundamental relation?

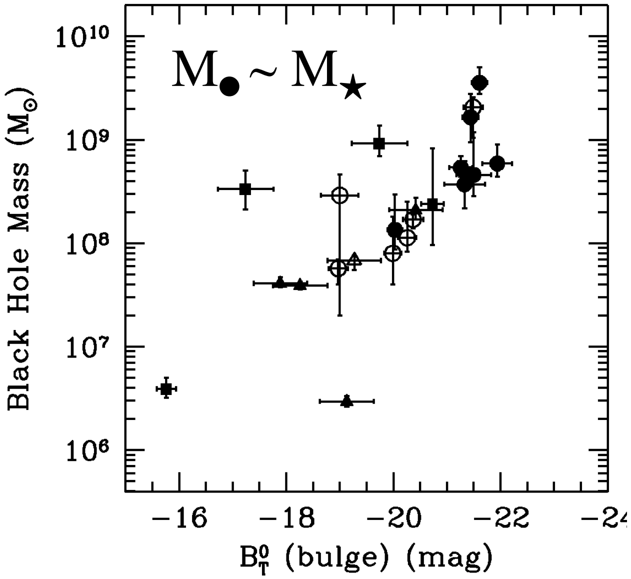


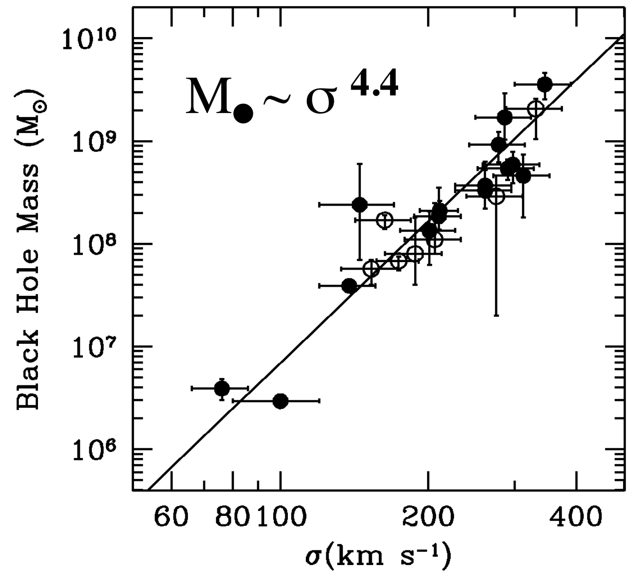
Dark halo mass *vs*. SMBH mass

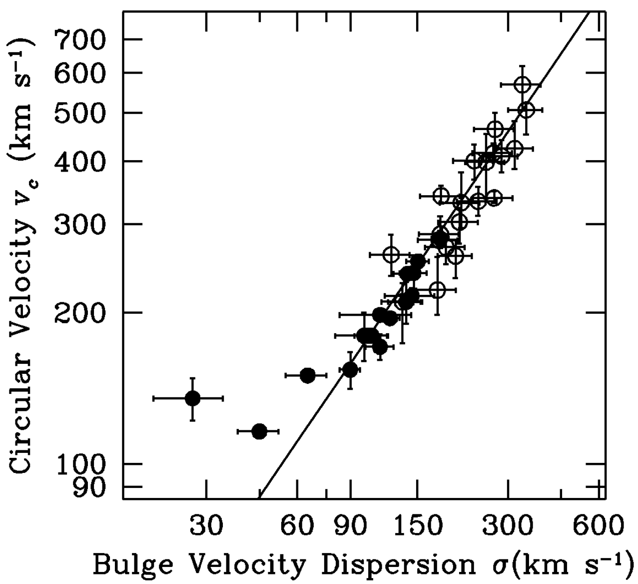
(Ferrarese 2002)

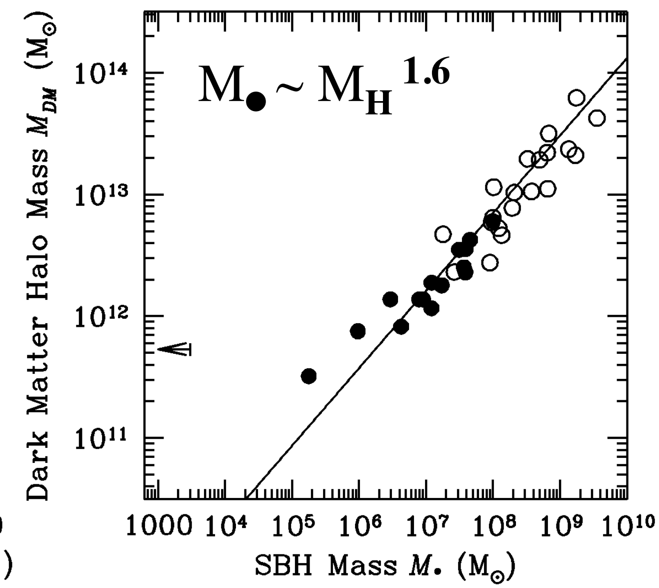
$$\frac{M_\bullet}{10^8 M_\odot} \sim 0.046 \left(\frac{M_{DM}}{10^{12} M_\odot} \right)^{1.57}$$

The SMBH - Host Galaxy Correlations





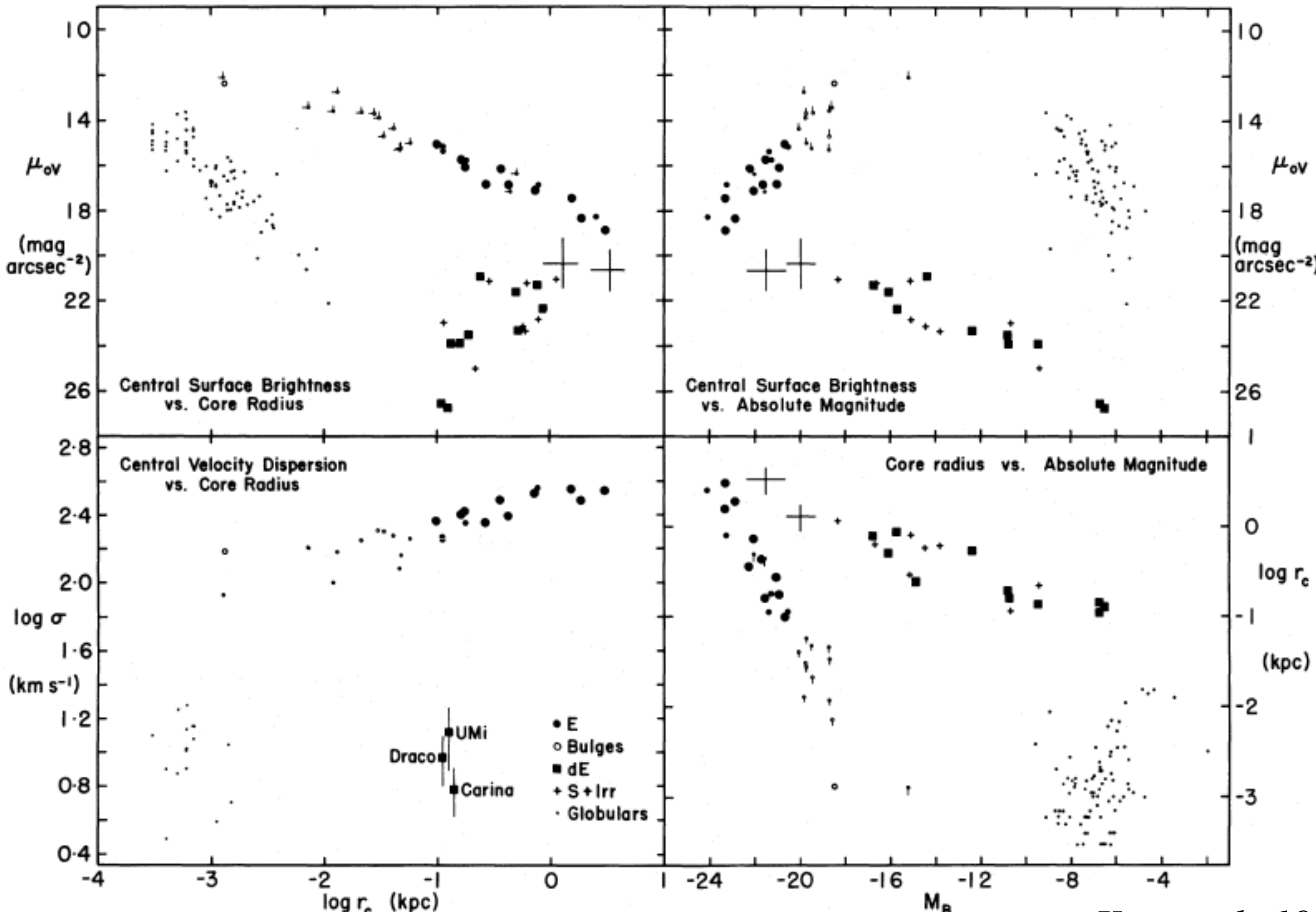




Dwarf Galaxies

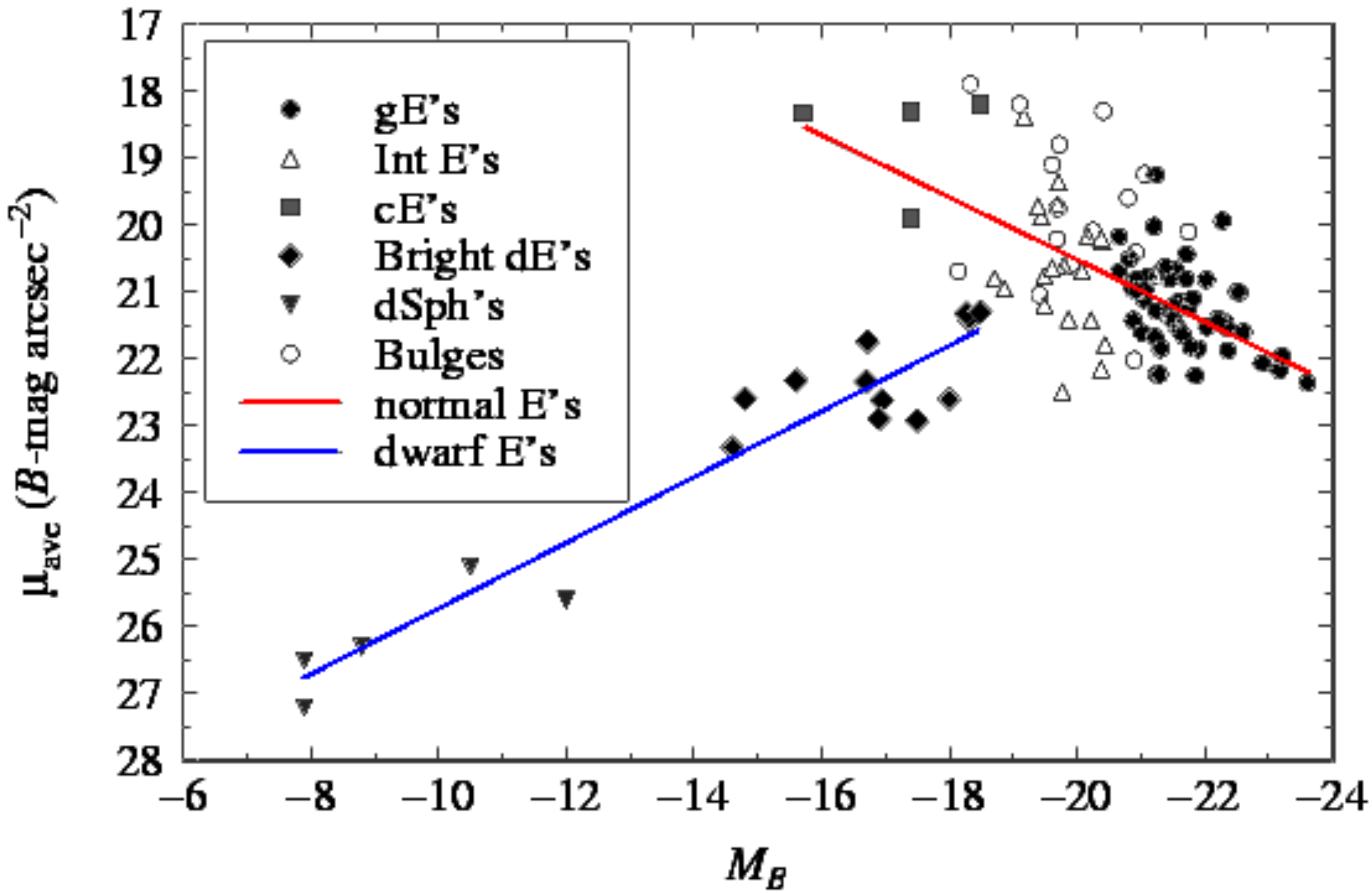
- Dwarf ellipticals (dE) and dwarf spheroidals (dSph) are a completely different family of objects from normal ellipticals - they are not just small E's
- In fact, there may be more than one family of gas-poor dwarf galaxies …
- Dwarfs follow completely different correlations from giant galaxies, suggestive of different formative mechanisms
- They are generally dark matter (DM) dominated, especially at the faint end of the sequence
- One possible scenario is that supernova (SN) winds can remove baryons from these low-mass systems, while leaving the DM, while the more massive galaxies retain and recycle their SN ejecta

Parameter Correlations



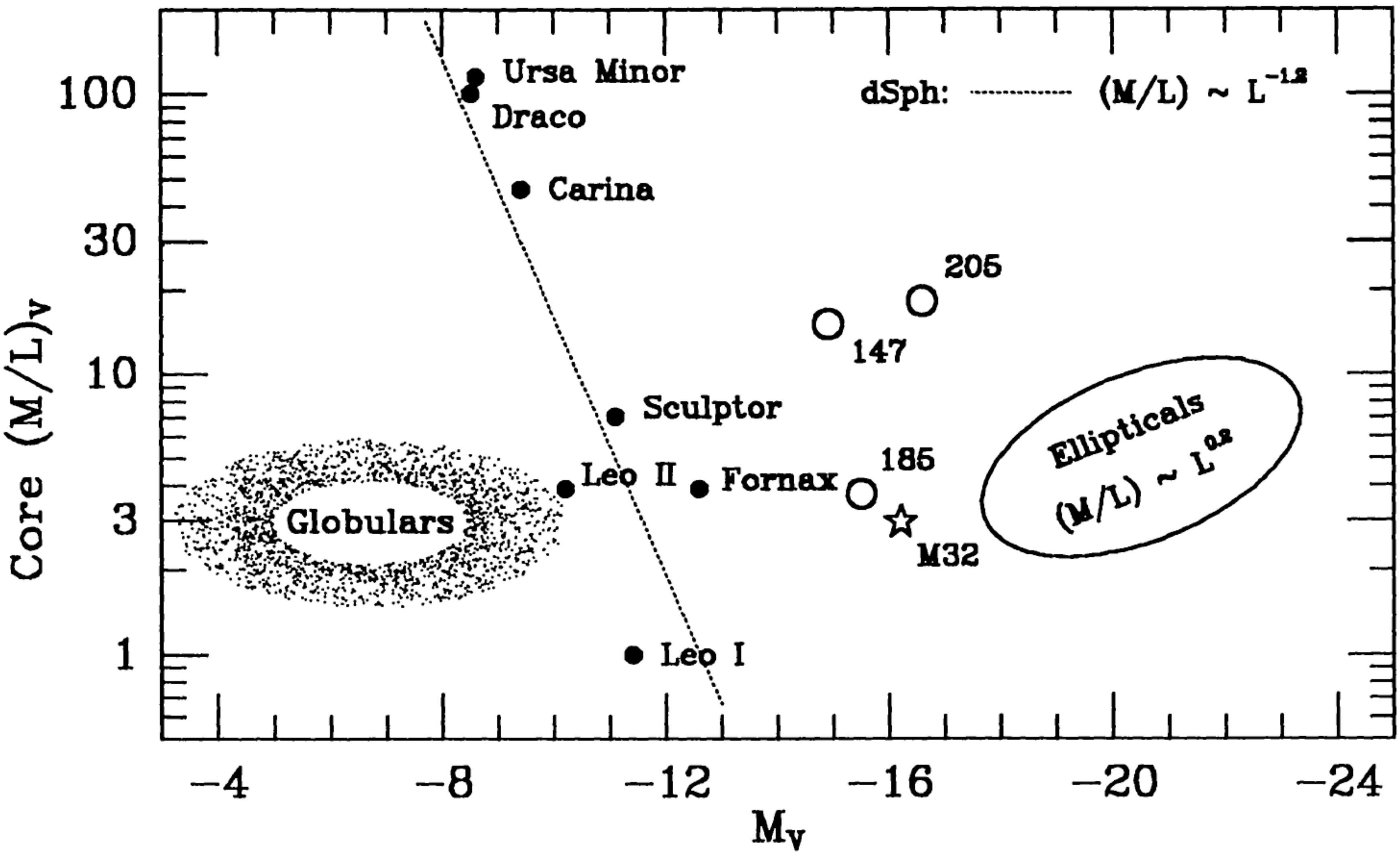
Kormendy 1985

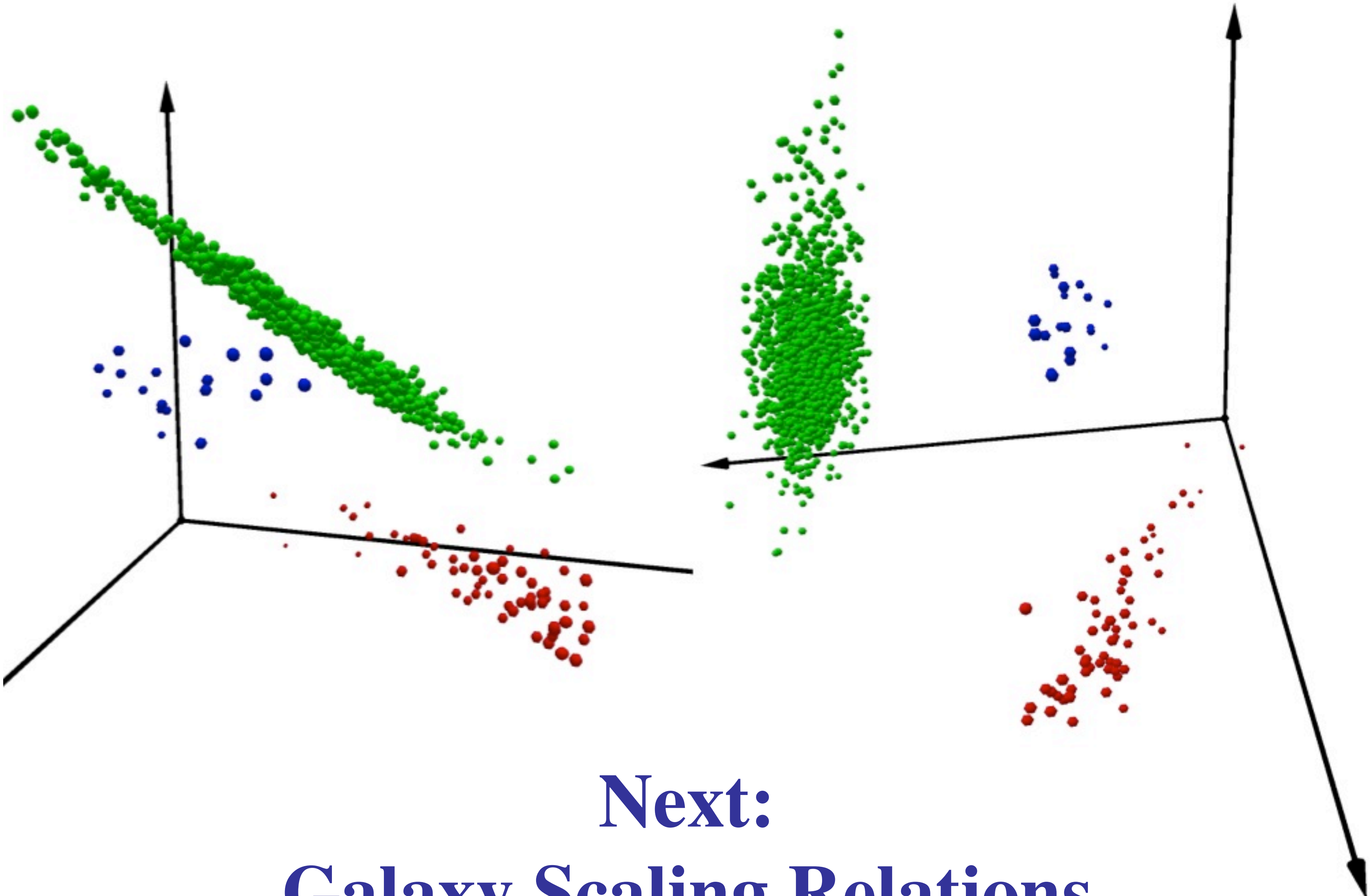
Mean Surface Brightness vs. Absolute Mag.



Mass to Light Ratios

Dwarf Spheroidals





Next:
Galaxy Scaling Relations