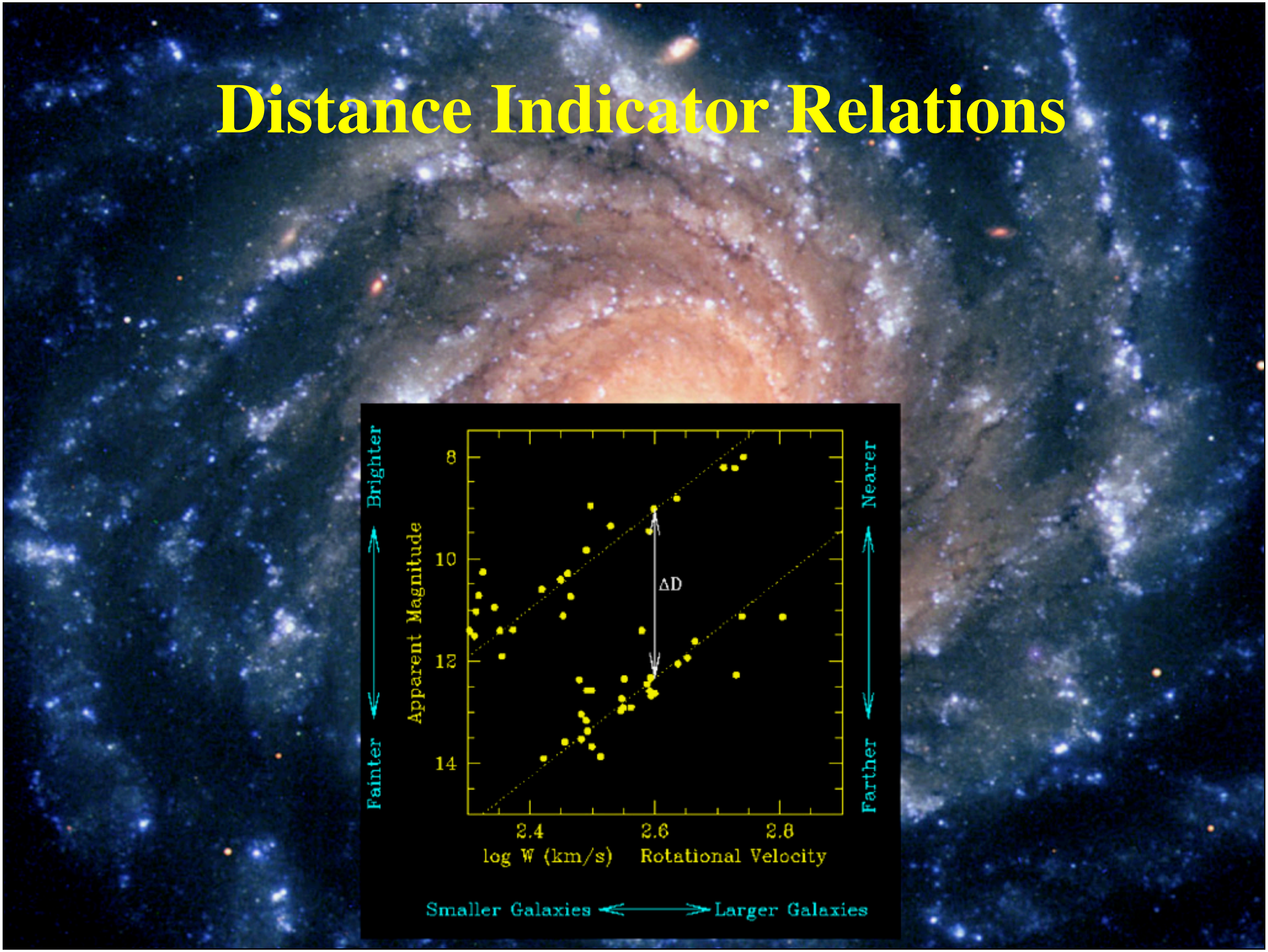
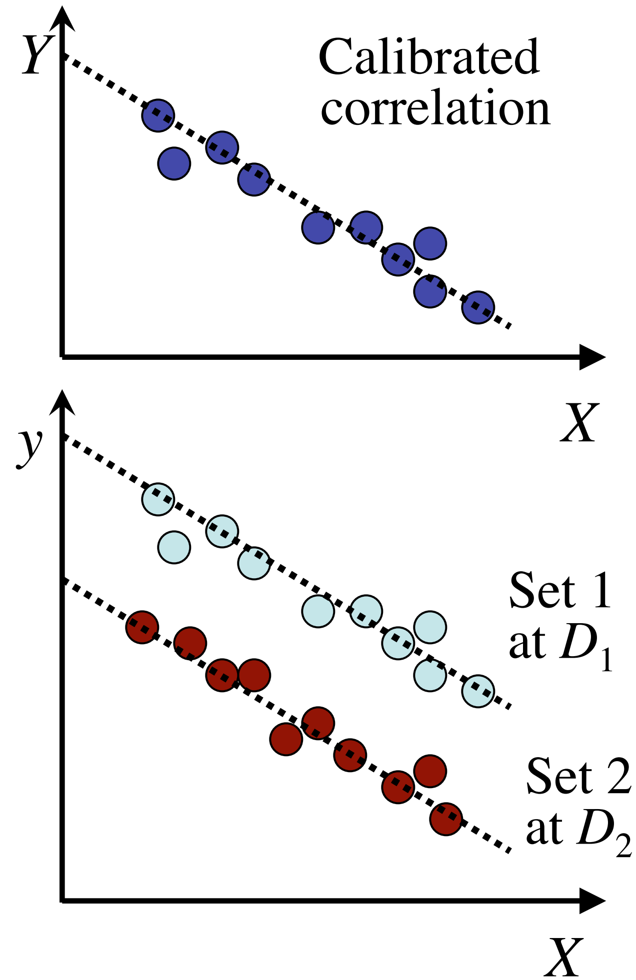
Distance Indicator Relations



The Basic Idea:

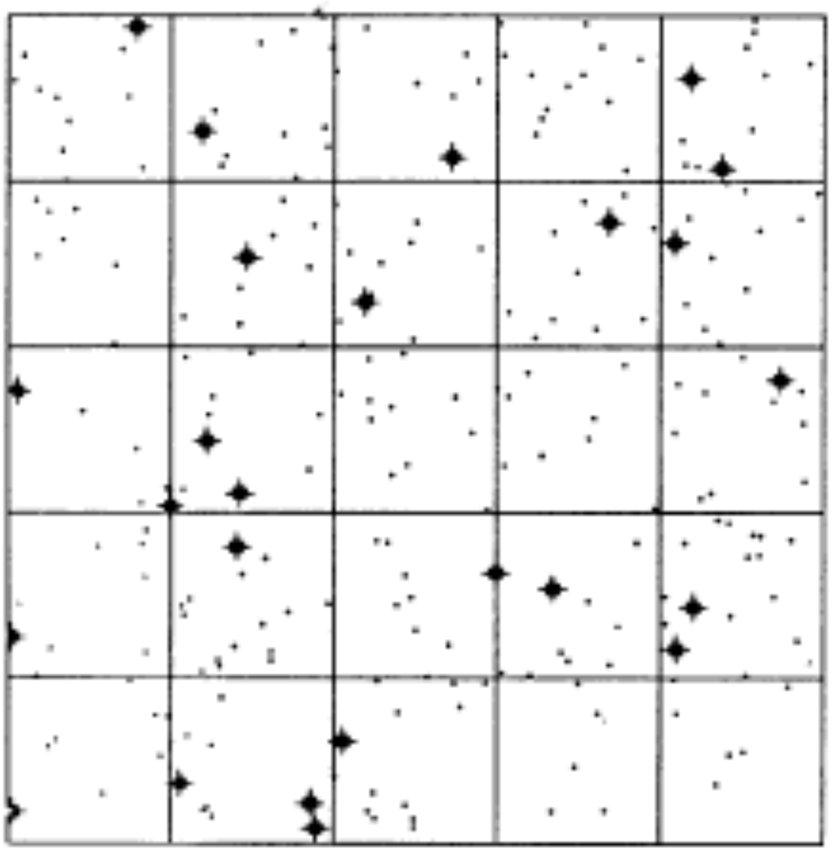
- Need a correlation between a distance-independent quantity, "X", (e.g., temperature or color for stars in the H-R diagram, or the period for Cepheids), and a distance-dependent one, "Y", (e.g., stellar absolute magnitude, *M*)
- Two sets of objects at different distances will have a systematic shift in the *apparent* versions of "y" (e.g., stellar apparent magnitude, *m*), from which we can deduce their ***relative distance***



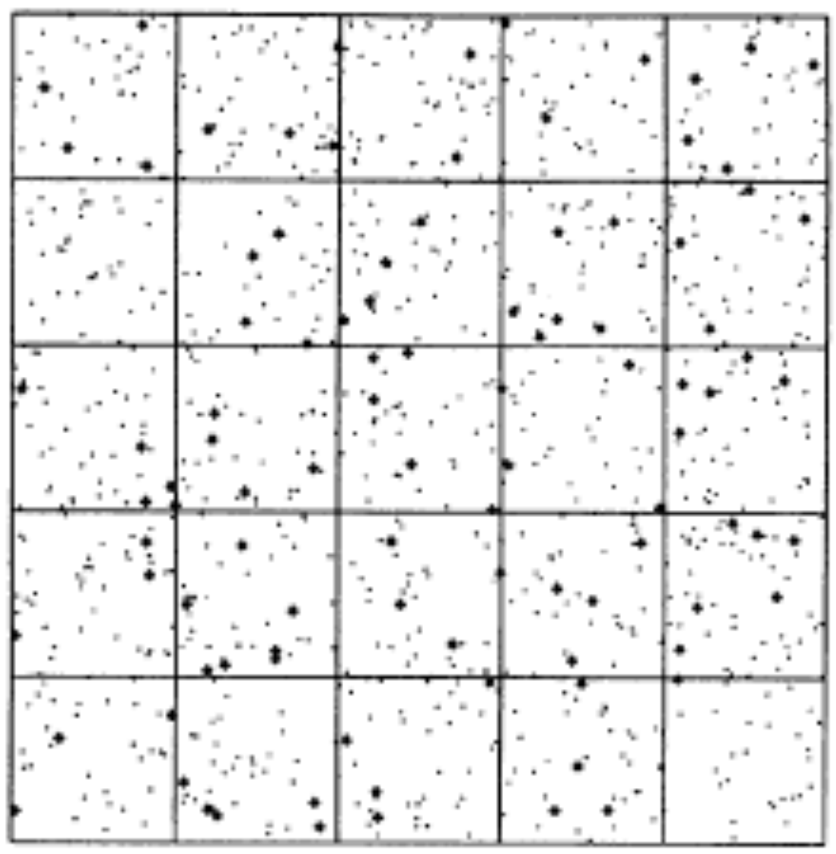
- This obviously works for stars (main sequence fitting, period-luminosity relations), but can we find such relations for galaxies?

Surface Brightness Fluctuations

Consider stars projected onto a pixel grid of your detector:



Nearby Galaxy

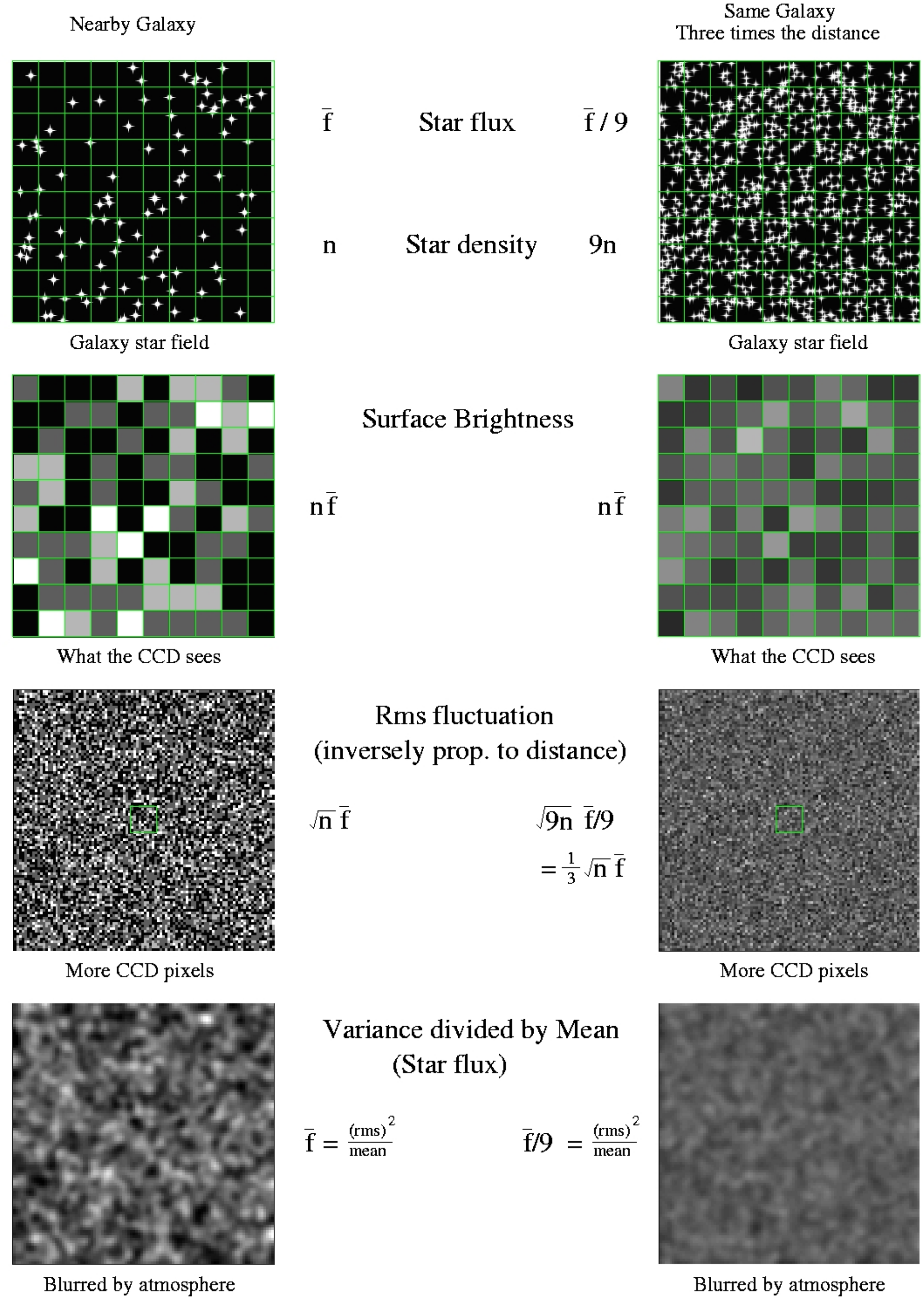


A galaxy twice farther away is “smoother”

Surface Brightness Fluctuations

- Surface brightness fluctuations for old stellar populations (E’s, SO’s and bulges) are based primarily on their giant stars
- Assume typical average flux per star $\langle f \rangle$, the average flux per pixel is then $N\langle f \rangle$, and the variance per pixel is $N\langle f^2 \rangle$. But the number of stars per pixel N scales as D^2 and the flux per star decreases as D^{-2}. Thus the variance scales as D^{-2} and the RMS scales as D^{-1}. Thus a galaxy twice as far away appears twice as smooth. The average flux $\langle f \rangle$ can be measured as the ratio of the variance and the mean flux per pixel. If we know the average L (or M) we can measure D
- $\langle M \rangle$ is roughly the absolute magnitude of a giant star and can be calibrated empirically using the bulge of M31, although there is a color-luminosity relation, so $\langle M_I \rangle = -1.74 + 4.5\,[(V-I)_0 - 1.15]$
- Have to model and remove contamination from foreground stars, background galaxies, and globular clusters
- Can be used out to ~100 Mpc in the IR, using the HST

Surface Brightness Fluctuations



Pushing Into the Hubble Flow

- Hubble's law: $\boldsymbol{D = H_0 v}$
- But the total observed velocity v is a combination of the cosmological expansion, and the *peculiar velocity* of any given galaxy, $\boldsymbol{v = v_{cosmo} + v_{pec}}$
- Typically $v_{pec} \sim$ a few hundred km/s, and it is produced by gravitational infall into the local large scale structures (e.g., the local supercluster), with characteristic scales of tens of Mpc
- Thus, one wants to measure H_0 on scales greater than tens of Mpc, and where $\boldsymbol{v_{cosmo} >> v_{pec}}$. This is the Hubble flow regime
- This requires *luminous standard candles* - galaxies or Supernovae

Galaxy Scaling Relations

- Once a set of distances to galaxies of some type is obtained, one finds correlations between distance-dependent quantities (e.g., luminosity, radius) and distance-independent ones (e.g., rotational speeds for disks, or velocity dispersions for ellipticals and bulges, surface brightness, etc.). These are called ***distance indicator relations***
- Examples:
  - Tully-Fisher relation for spirals (luminosity vs. rotation speed)
  - Fundamental Plane relations for ellipticals
- These relations must be calibrated locally using other distance indicators, e.g. Cepheids or surface brightness fluctuations; then they can be extended into the general Hubble flow regime
- Their origins - and thus their universality - are not yet well understood. Caveat emptor!

The Tully-Fisher Relation

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

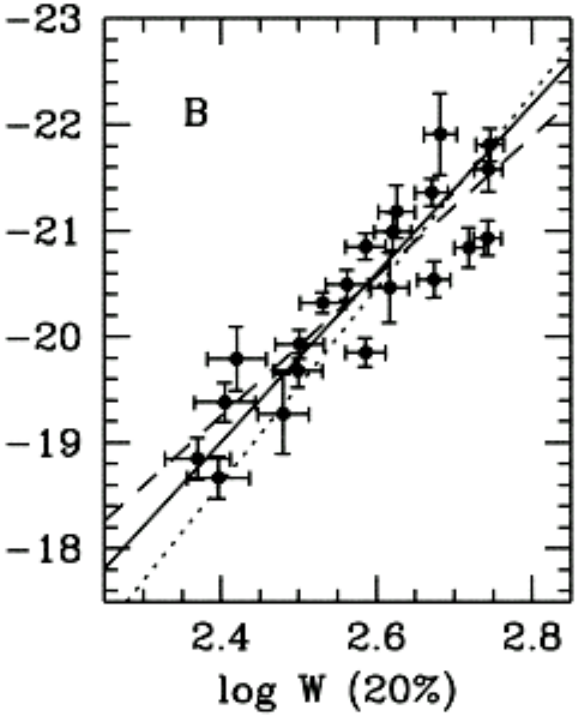
$$L \sim v_{rot}^{\gamma}, \gamma \approx 4, \text{ varies with wavelength}$$

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, which limits the accuracy
- Problems include dust extinction, so working in the redded bands is better

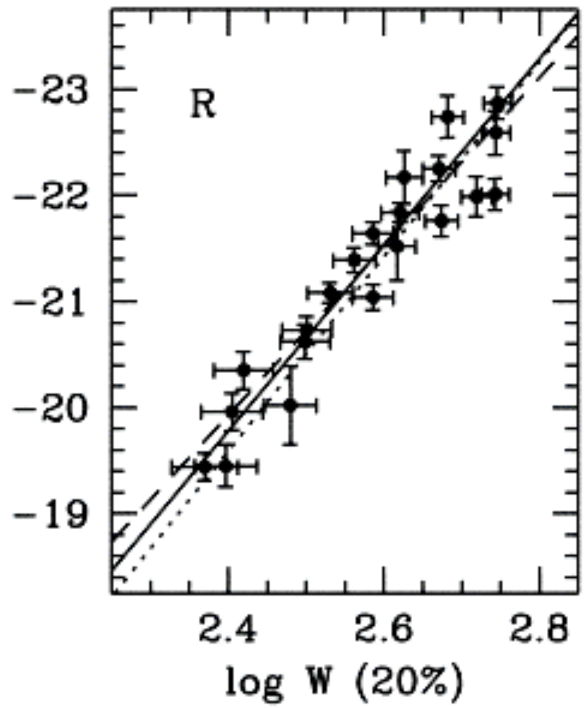
Tully-Fisher Relation at Various Wavelengths

Blue



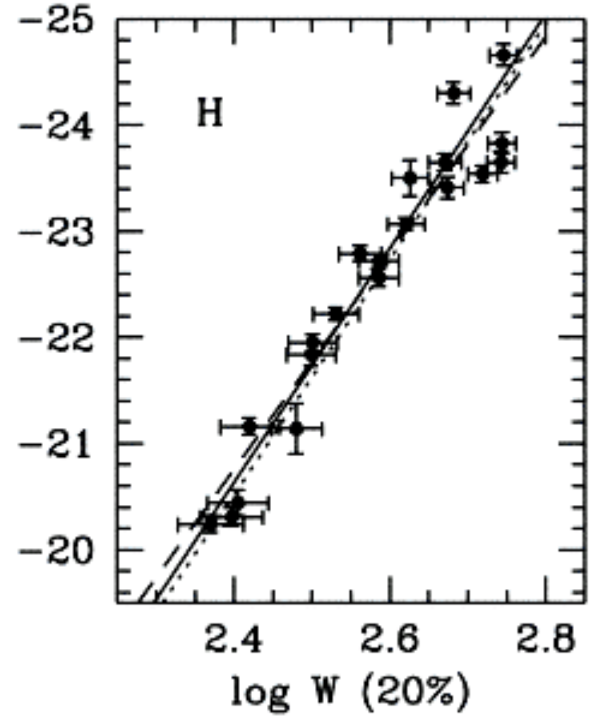
Slope= 3.2
Scatter=0.25 mag

Red



Slope= 3.5
Scatter=0.25 mag

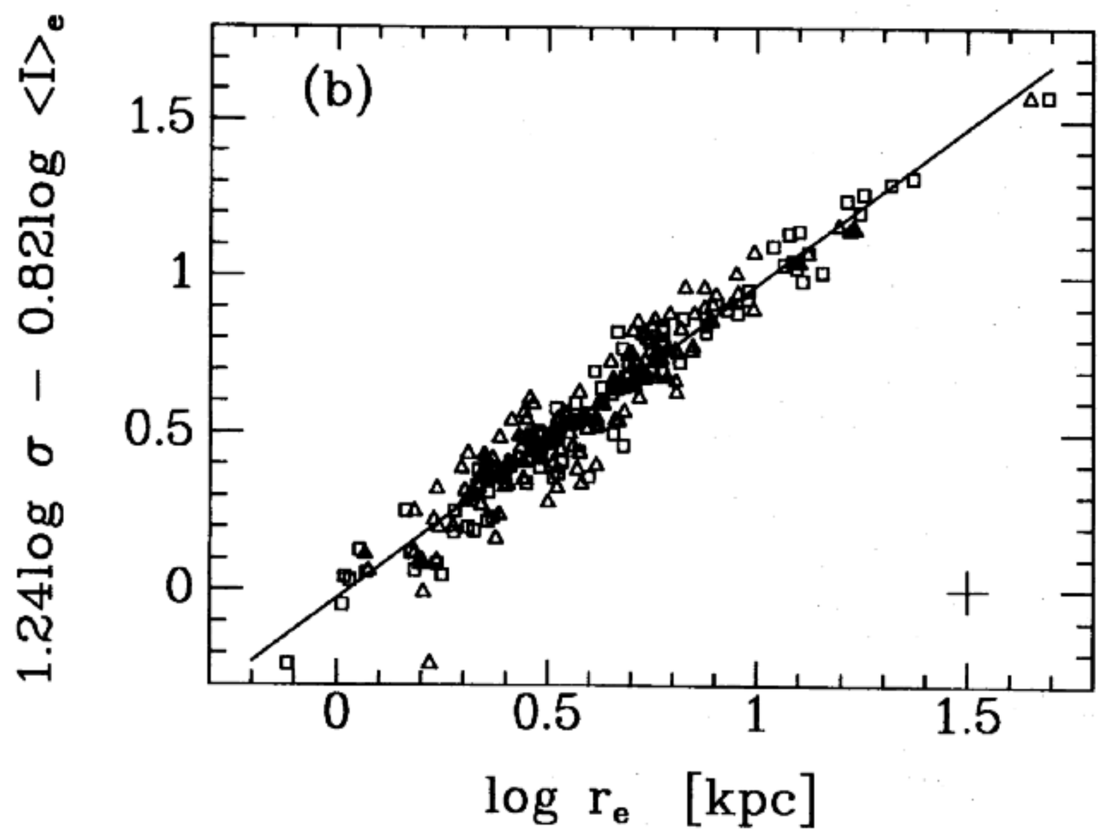
Infrared



Slope= 4.4
Scatter=0.19 mag

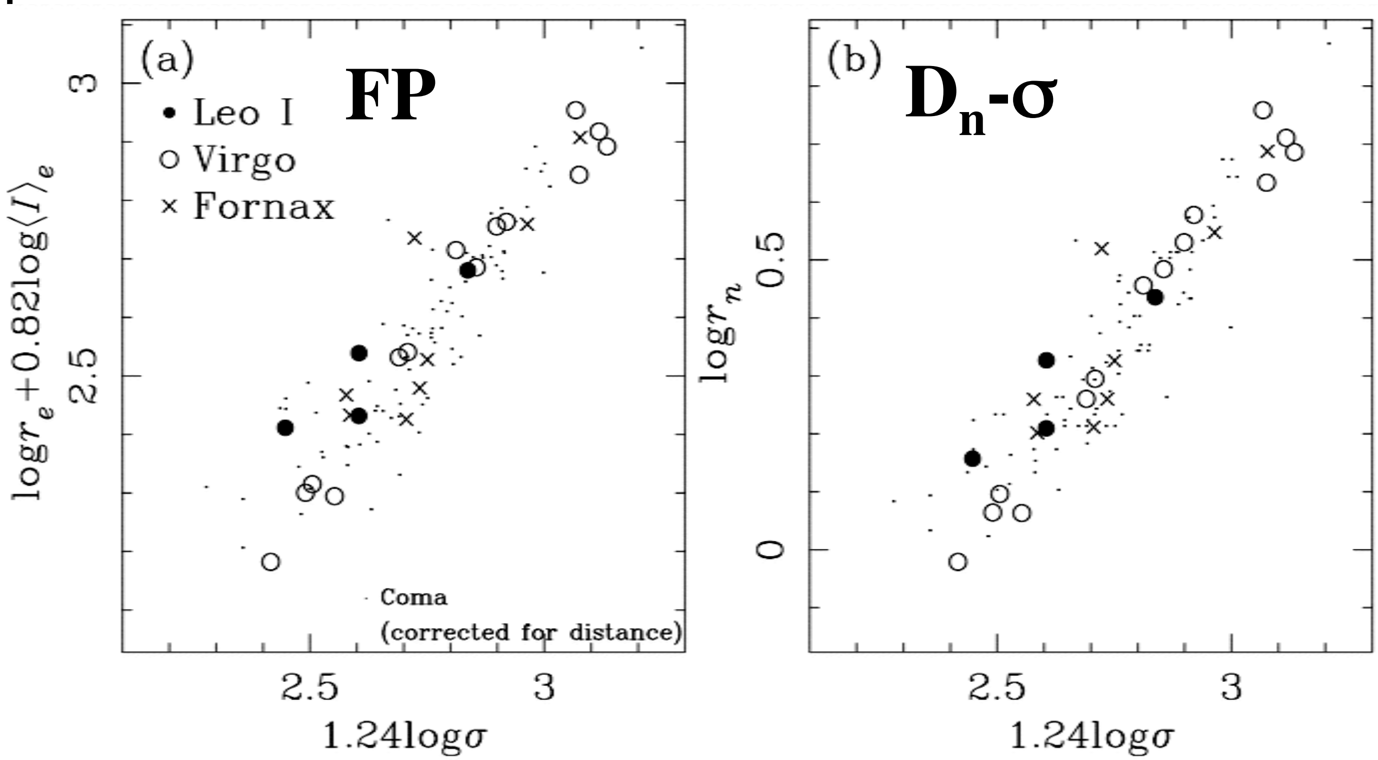
Fundamental Plane Relations

- A set of bivariate scaling relations for elliptical galaxies, including relations between distance dependent quantities such as radius or luminosity, and a combination of two distance-independent ones, such as velocity dispersion or surface brightness
- Scatter ~ 10%, but it could be lower?
- Usually calibrated using surface brightness fluctuations distances



The D_n-σ Relation

- A projection of the Fundamental Plane, where a combination of radius and surface brightness is combined into a *modified isophotal diamater* called D_n which is the angular diameter that encloses a mean surface brightness in the *B* band of $\langle\mu_B\rangle = 20.75$ mag/arcsec^2
- D_n is a *standard yardstick*, and can be used to measure relative distances to ellipticals
- Also calibrated using SBF




Next:
Supernova
Standard
Candles