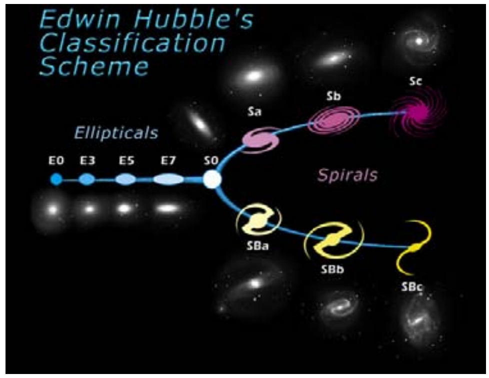
The “Tuning Fork” Diagram



“Early” **“Late”**

Galaxy Properties

From M. Longair “Galaxy Formation”

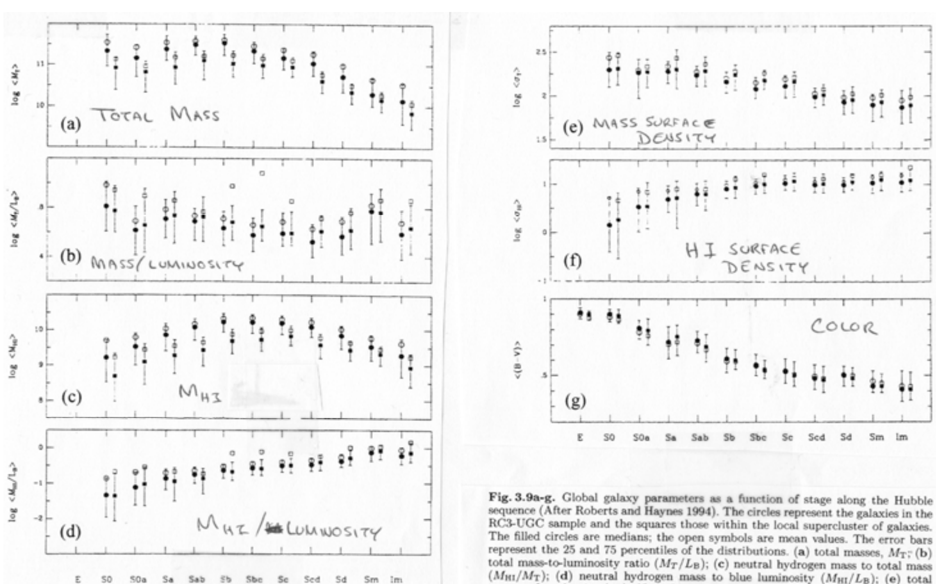


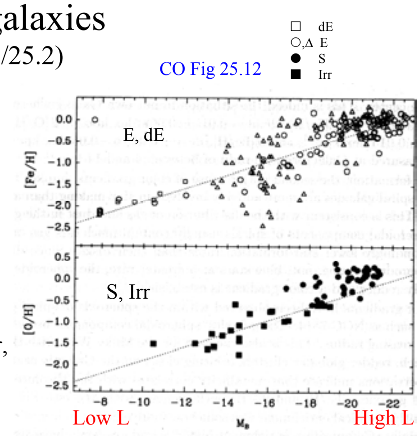
Fig. 3.9a-g. Global galaxy parameters as a function of stage along the Hubble sequence (After Roberts and Haynes 1994). The circles represent the galaxies in the RC3-UGC sample and the squares those within the local supercluster of galaxies. The filled circles are medians; the open symbols are mean values. The error bars represent the 25 and 75 percentiles of the distributions. **(a)** total masses, M_T; **(b)** total mass-to-luminosity ratio (M_T/L_B); **(c)** neutral hydrogen mass to total mass (M_{HI}/M_T); **(d)** neutral hydrogen mass to blue luminosity (M_{HI}/L_B); **(e)** total mass surface density (σ_T); **(f)** surface mass density of neutral hydrogen (σ_{HI}); **(g)** integrated $(B - V)$ colour.

Trends in spiral galaxies

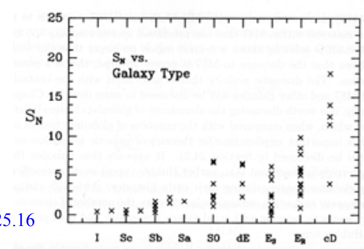
(see CO Tables 25.1/25.2)

- Mass/Light ratios
  - Sa ➔ Sc : M/L_B = 6.2 ➔2.6
    but Longair's plot ➔ constant
  - Sc's dominated by younger, hotter, more massive stars.
- Colors
  - Sa ➔ Sc : B-V = 0.75 ➔0.52 (Red ➔ Blue)
  - Bluer colors ➔ Sc's dominated by younger, hotter stars.
- M_{gas}/M_{total}
  - Sa ➔ Sd: M_{gas}/M_{total} = 0.04 ➔ 0.25
- Molecular/atomic hydrogen
  - Sa ➔ Sd: M_{H2}/M_{HI} = 2.2 ➔ 0.3
- Metallicity
  - Depends on absolute magnitude
- No. of Globular Clusters/Total Luminosity

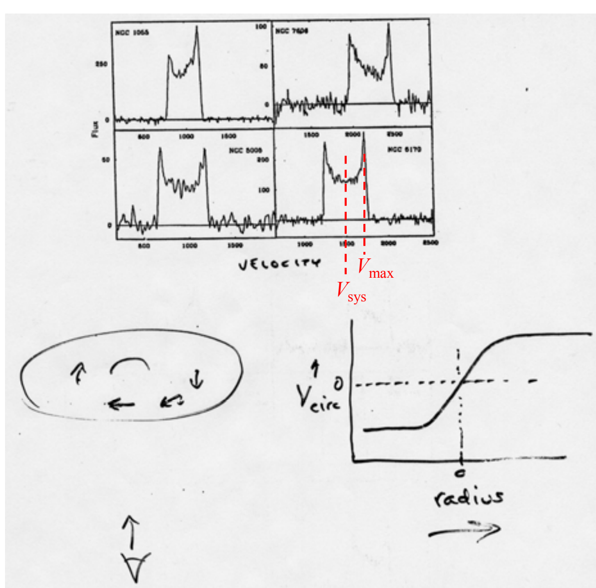
CO Fig 25.12



CO Fig 25.16

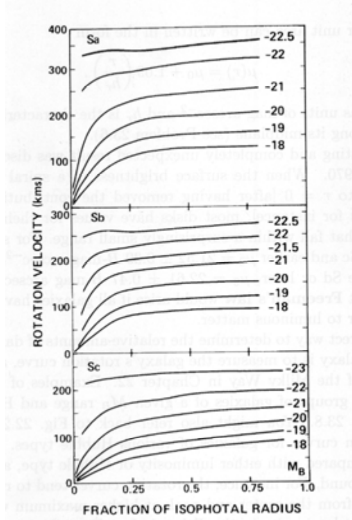


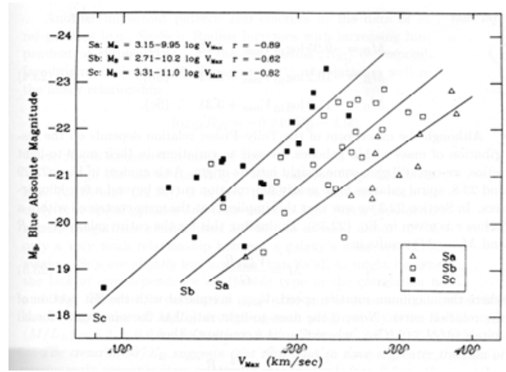
H I Spectra of Spiral Galaxies



Tully-Fisher Relation

Rotation Curves





- Maximum rotation velocity-Luminosity relation [FIG 25.10]
  - **Tully-Fisher** relation
    - $M_B = -9.95 \log_{10} V_{Max} + 3.15$ (Sa)
    - $M_B = -10.2 \log_{10} V_{Max} + 2.71$ (Sb)
    - $M_B = -11.0 \log_{10} V_{Max} + 3.31$ (Sc)

Semi-derivation of Tully-Fisher Relation:

$M_B = -9.95 \log_{10} V_{max} + 3.15$ (Sa)
$M_B = -10.2 \log_{10} V_{max} + 2.71$ (Sb)
$M_B = -11.0 \log_{10} V_{max} + 3.31$ (Sc)

- Mass interior to outermost *R* where rotation curve can be measured:

$$Mass = \frac{V_{max}^2 R}{G}$$

- Assume $L = Mass / const.$
- "Freeman Law" (observed fact ---maybe):

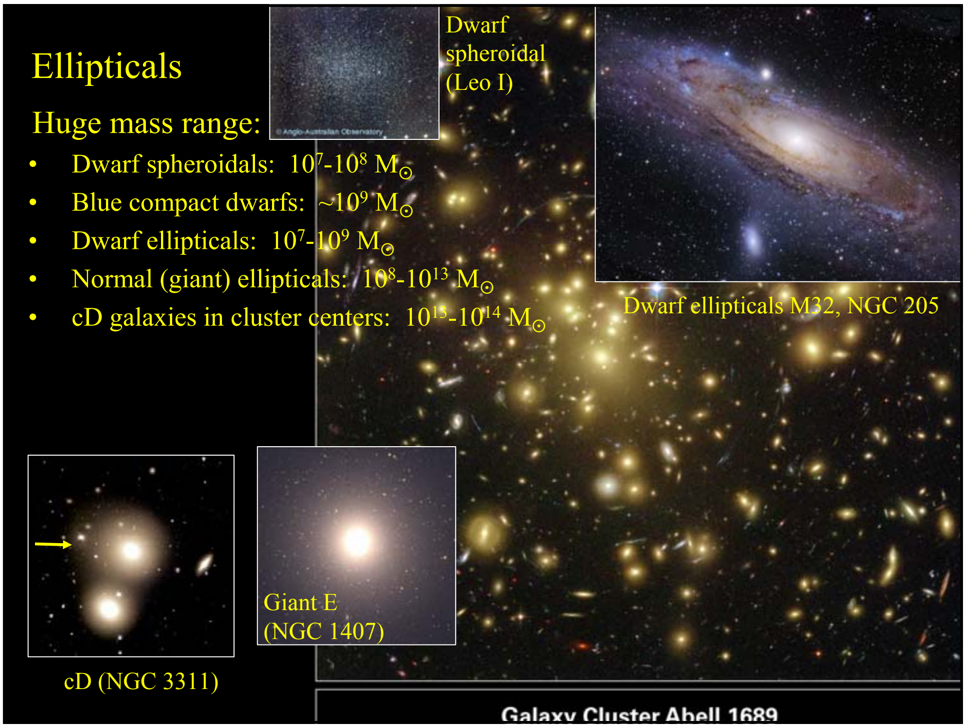
$$Surf.Bright. = \frac{L}{4\pi R^2} = const.$$

$$L = const \times V_{max}^4$$

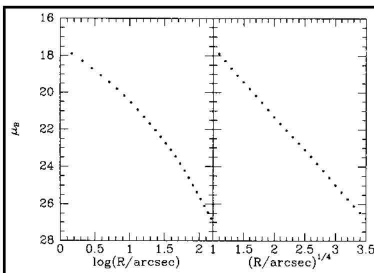
Important as a DISTANCE calibrator!

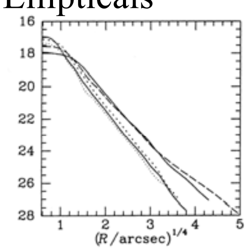
- Convert to Absolute B-band magnitudes:

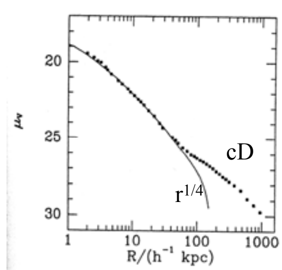
$$M_B = M_{sun} - 2.5 \log_{10}\left(\frac{L}{L_{sun}}\right) = -10 \log_{10} V_{max} + const.$$



Ellipticals







Best

- $R^{1/4}$ law usually fits radial surface brightness distribution

$$I(R) = I_e 10^{-3.33\left[\left(\frac{R}{R_e}\right)^{1/4} - 1\right]}$$

Good

- Also Hubble's law

$$I(R) = \frac{I_o}{\left(1 + \frac{R}{R_o}\right)^2}$$

Better

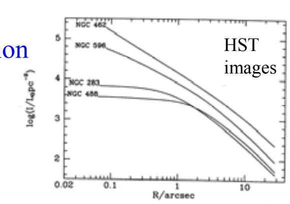
- Modified Hubble's law

$$I(R) = \frac{I_o}{1 + \left(R/R_o\right)^2}$$

Diverges, but at least is projection of simple 3D distribution:

$$I(R) = \frac{I_o}{\left[1 + \left(R/R_o\right)^2\right]^{3/2}}$$

- + others



HST images

The Virial Theorem [CO 2.4]

- For gravitationally bound systems *in equilibrium*
  - Total energy = ½ time-averaged potential energy.

    E = total energy
    U = potential energy.
    K = kinetic energy.

    $E = K + U$

- Can show from Newton's 3 laws + law of gravity:
  - $\frac{1}{2}(d^2I/dt^2) - 2K = U$ where $I = \Sigma m_i r_i^2$ = moment of inertia.
  - Time average $\langle d^2I/dt^2 \rangle = 0$, or at least ~ 0.
  - Virial theorem ➔ $-2\langle K \rangle = \langle U \rangle$

    $\langle K \rangle = -\frac{1}{2}\langle U \rangle$

    $\langle E \rangle = \langle K \rangle + \langle U \rangle$ ➔

    $\langle E \rangle = \frac{1}{2}\langle U \rangle$

Mass determinations from absorption line widths

- Virial Theorem

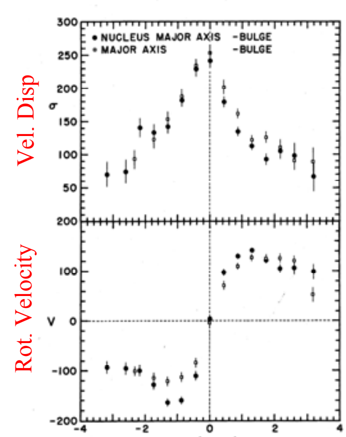
  $2K = -U$

  $\langle v^2 \rangle = 3 \langle v_r^2 \rangle$

  ➔ $\sigma^2_r = GM/(5R)$

  $$U = -\frac{3}{5}\frac{GM^2}{R}$$

- See pp. 959-962, + Sect. 2.4
- Applied to nuclei of spirals ➔ presence of massive black holes
- Also often applied to
  - E galaxies
  - Galaxy clusters



Nuclear bulge of M31

Mass determinations from absorption line widths

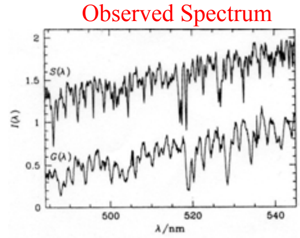
- Virial Theorem
  - 2K = -U
  - <v2> = 3 <vr2>
  - ➔ σ2r = GM/(5R)
- See pp. 959-962, + Sect. 2.4

$$U = -\frac{3}{5}\frac{GM^2}{R}$$

- Applied to nuclei of spirals ➔ presence of massive black holes

- Also often applied to
  - E galaxies
  - Galaxy clusters

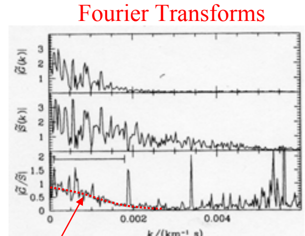
Observed Spectrum



K star

E galaxy = K star convolved with Gaussian velocity distribution of stars.

Fourier Transforms



Star

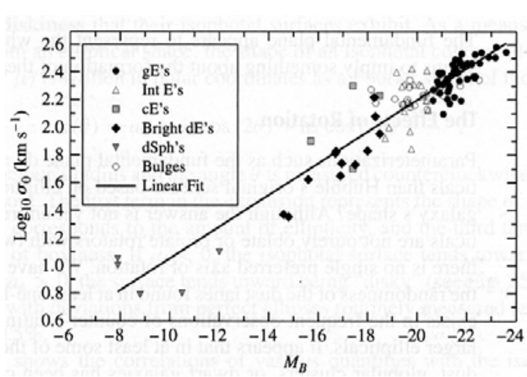
Galaxy

Ratio

Gaussian fit:

- Convolution turns into multiplication in F.T. space.
- F.T. of a Gaussian is a Gaussian.

Faber-Jackson relation: $L_e \sim \sigma_0^4$



(Absolute magnitude)

Homework Assignment 5
Due Monday Oct. 1

- CO 2nd edition problems 25.13, 25.14, 25.16
  - Same as 1st edition problems 23.11, 23.12, 23.14

- There may be one addition derivation-type problem having to do with the stellar velocities found in E galaxies. It depends on whether I cover that in class with enough lead time.

Do CO problem 25.20 (= problem 23.18 in 1st edition)