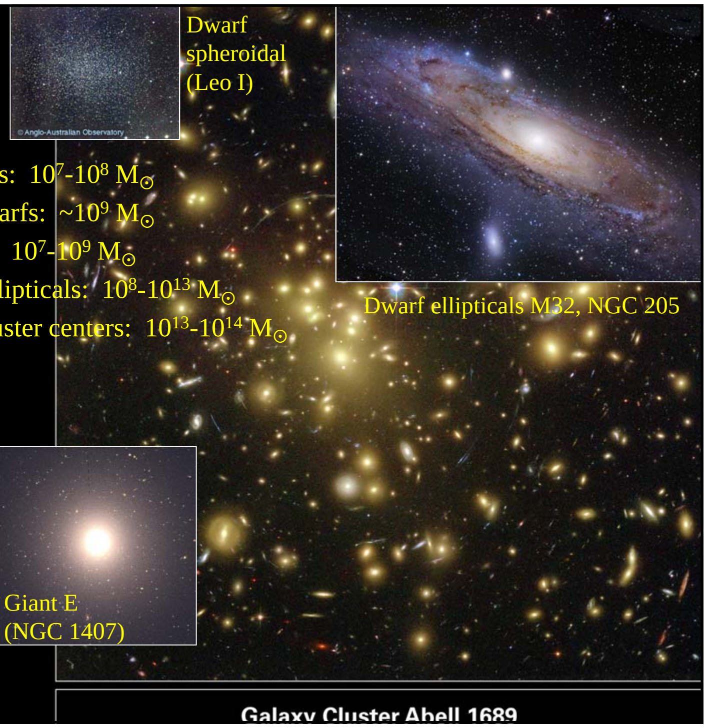
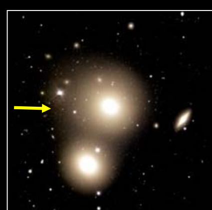
Ellipticals

Huge mass range:

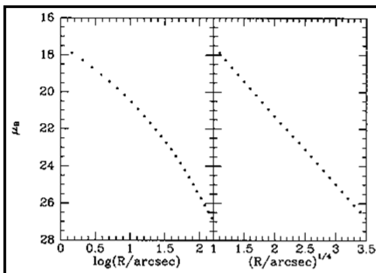
- Dwarf spheroidals: 10^7-10^8 $M_\odot$
- Blue compact dwarfs: ~10^9 $M_\odot$
- Dwarf ellipticals: 10^7-10^9 $M_\odot$
- Normal (giant) ellipticals: 10^8-10^{13} $M_\odot$
- cD galaxies in cluster centers: 10^{13}-10^{14} $M_\odot$

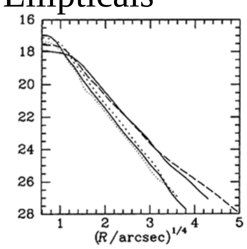


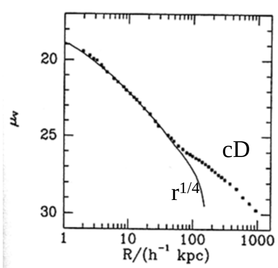


cD (NGC 3311)

Ellipticals

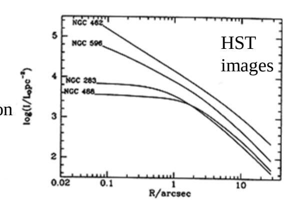






Good

- 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:

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

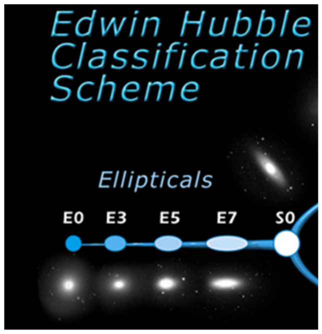
Best

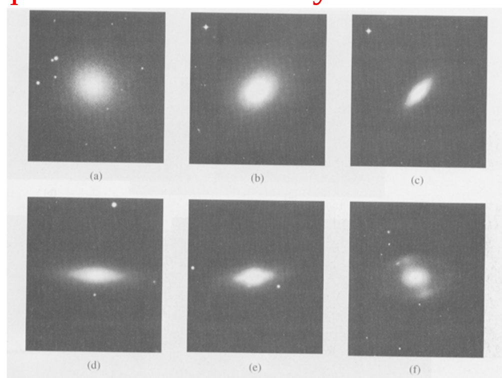
- deVaucouleurs' $R^{1/4}$ law usually fits radial surface brightness distribution

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

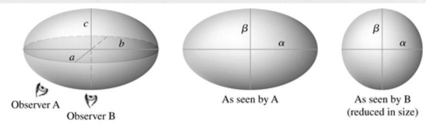
- \+ others

True shapes requires statistical analysis

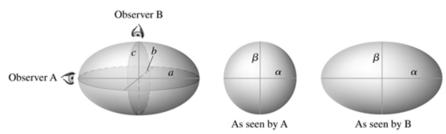




- *Oblate* = pancakes



- *Prolate* = footballs



[CO figs 25.2, 25.3]

True shapes requires statistical analysis

CO pgs. 988-989

- Lower luminosity ➔ rotationally supported
  - $(V_{rot} / \sigma) \sim \sqrt{\varepsilon/(1-\varepsilon)}$ ← Ellipticity = 1 – *b*/*a*
- Higher L ➔ pressure supported
  - $(V_{rot} / \sigma) << 1$

Curve expected for galaxies that are flattened by rotation (i.e. have isotropic random velocity dispersions)

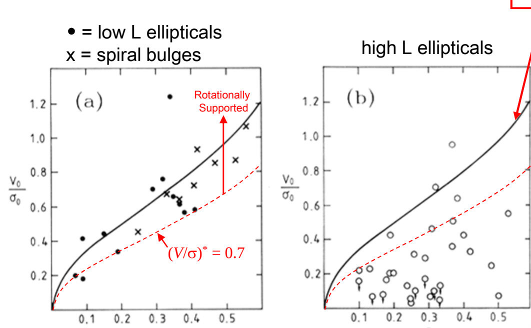
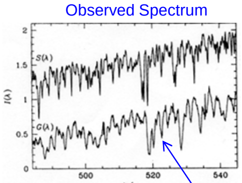


Figure 4-6. (a) The positions in the $(v/\sigma, \epsilon)$ plane of elliptical galaxies (dots), and of spheroids (crosses), that have luminosities smaller than $L = 2.5 \times 10^{10}\,L_\odot$. (b) The same as (a) but for elliptical galaxies brighter than $L = 2.5 \times 10^{10}\,L_\odot$. (After Davies et al. 1983.)

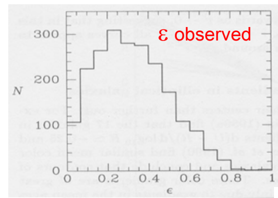
From Binney & Tremaine, *Galactic Dynamics*

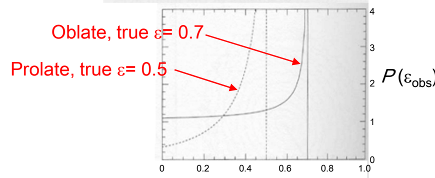


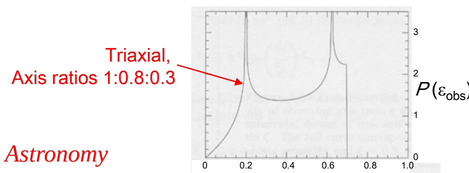
E galaxy = K star convolved with Gaussian velocity distribution of stars.

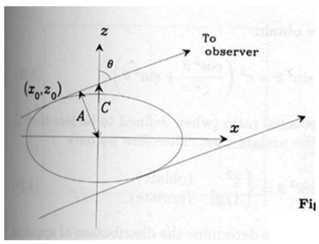
Statistics of $\varepsilon = (1- b/a)$

- Oblate, prolate spheroids can't fit the observed distribution.
  - Summing over wide range of true values of ε would fill in the dip at ε_{obs} = 0.
- Triaxial spheroids can fit.
  - Nearly oblate triaxial spheroids seem best.









From Binney & Merrifield, *Galactic Astronomy*

Other evidence for triaxial systems

- Isophotal twists
- Kinematics (star motions)

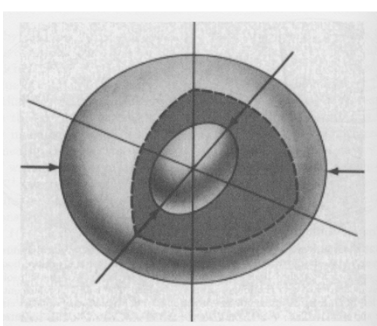
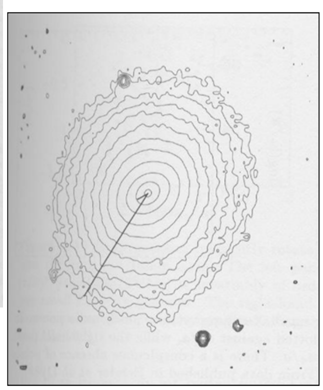


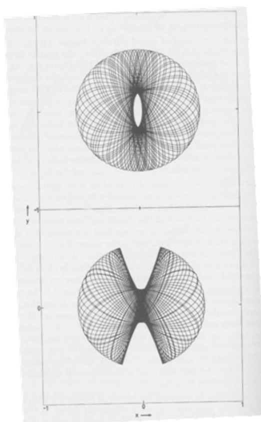
Figure 4.24 Isophotal twist as a consequence of triaxiality. Two concentric, coaxial ellipsoids are shown. The dashed lines mark the intersections of the ellipsoids with the coordinate planes, while the solid lines show their outlines to the observer. The arrows mark the directions of their apparent principal axes.

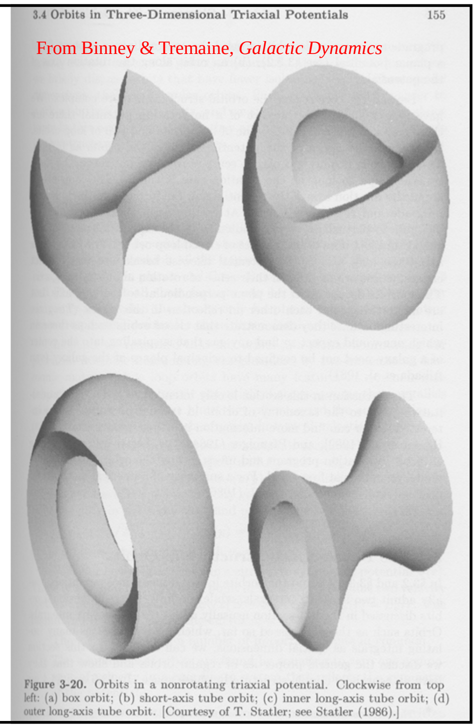


From Binney & Merrifield, *Galactic Astronomy*

Orbits in E galaxies

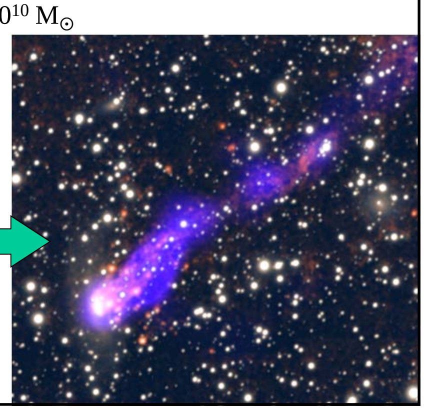
- Some families of non-closed orbits in a mildly triaxial potential.





E galaxies are transparent, but 40% still have some dust lanes

- Even if complete star formation at t=0, stars must subsequently have lost gas.
- Detected by:
  - X-rays (Brehmsstrahlung): 10^8-10^{10} $M_\odot$
  - H I emission lines: 10^7-10^9 $M_\odot$
  - H II emission lines: 10^4-10^5 $M_\odot$
- But gas can be lost by
  - Supernova-driven winds
  - Ram pressure stripping



The Virial Theorem [CO 2.4]

- For gravitationally bound systems *in equilibrium*
  - Time-averaged kinetic 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

Sorry… I had left out the ½ when I showed this slide in class.

- Virial Theorem

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

  $K = \frac{1}{2} M\langle v^2\rangle = 3/2\, M\langle\sigma_r^2\rangle$

  ➔ $M_{virial} = \frac{5R\sigma_r^2}{G}$

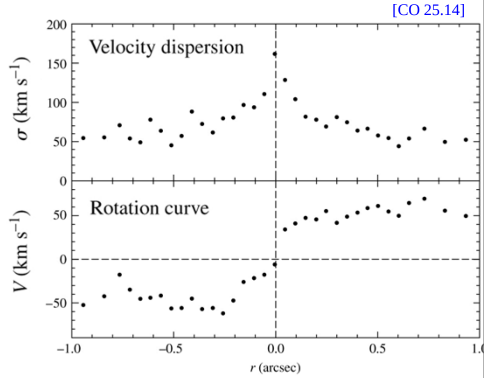
- See pp. 959-962, + Sect. 2.4

- Applied to nuclei of spirals

  ➔ presence of massive black holes

- Also often applied to
  - E galaxies
  - Galaxy clusters

[CO 25.14]



M32

Mass determinations from absorption line widths

- Virial Theorem

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

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

  $K = ½ M\langle v^2 \rangle = 3/2\, M \langle \sigma_r^2 \rangle$

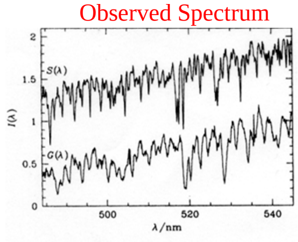
  ➔ $M_{virial} = \frac{5R\sigma_r^2}{G}$

- 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

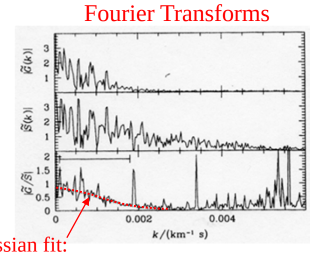
Observed Spectrum



K star

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

Fourier Transforms



Star

Galaxy

Ratio

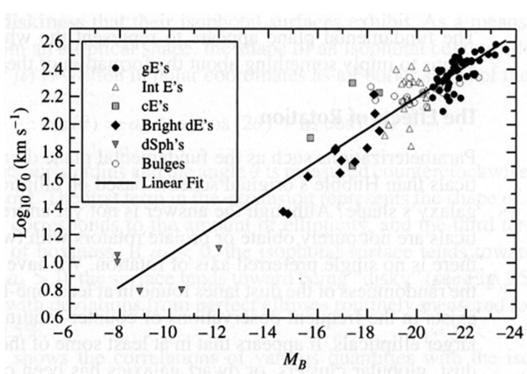
Gaussian fit:
- Convolution turns into multiplication in F.T. space.
- F.T. of a Gaussian is a Gaussian.

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

I_e = surface brightness at R_e

L_e = luminosity *within* R_e

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



(Absolute magnitude)

Mass-Luminosity relationships

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

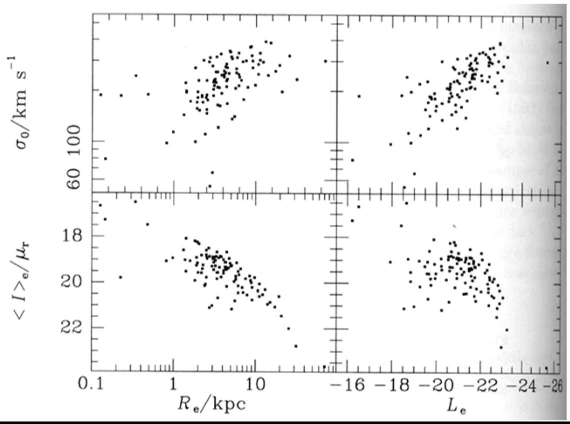
- Faber-Jackson relation: $L_e \sim \sigma_0^4$
- D_n - σ_0 correlation.
  - D_n = diameter within which <I> = 20.75 μ_B (mag/arcsec^2)
- Fundamental plane in log R_e, <I>$_e$, log σ_0 space
  - R_e = scale factor in $R^{1/4}$ law
  - <I>$_e$ = mean surface brightness within R_e *Different from I_e !*
  - *Intro. to Principle Component Analysis*: astro-ph/9905079

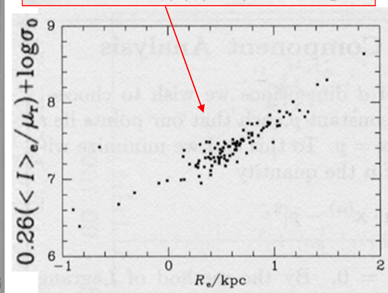
CO give different coefficients???

$r_e \propto \sigma_0^{1.24} I_e^{-0.82}$

$L \propto \sigma_0^{2.65} r_e^{0.65}$

$$\log R_e = 0.36(\langle I\rangle_e/\mu_B) + 1.4 \log \sigma_0$$

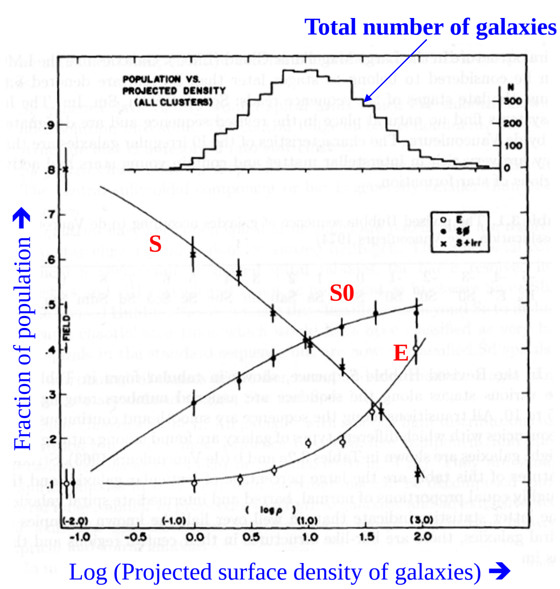




From Binney & Merrifield, *Galactic Astronomy*

Distribution of galaxy types

- Dense regions (cluster centers) predominantly ellipticals.
- Field galaxies predominantly spirals.
- On average, roughly even split between E and S.



Dressler 1980

Schechter Luminosity Function

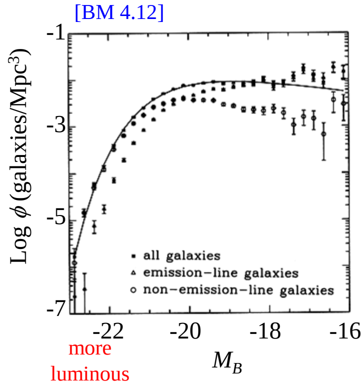
$$\phi(L)dL = L^{\alpha} e^{-L/L^*} dL$$

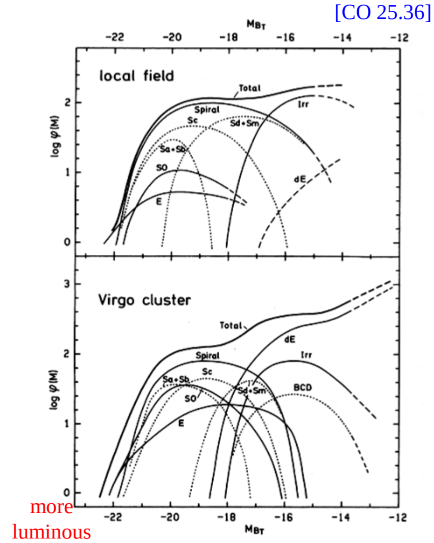
$$\phi(M)dM = 10^{-0.4(\alpha+1)M} e^{-10^{0.4(M^* - M)}} dM$$

[CO 25.36]

- The Milky Way is an L^* galaxy.

[BM 4.12]





Problem 24.15: "Assuming that the highest velocity stars are near the escape speed, estimate the mass of the M.W."

Correct: $v_{esc} = v_{circ}$ + max v_{pec} = 220 + 65 ~ 300 km s^{-1}.

K.E. = Potential Energy ➔ $\frac{mv_{esc}^2}{2} = \frac{GmM}{R_0}$ ➔ $M = \frac{R_0 v_{esc}^2}{2G}$

Wrong: follow example 24.3.1 and calculate mass required to hold star in circular orbit with v = 300 km s^{-1}

$$M = \frac{R_0 v_{esc}^2}{G}$$

Problem 24.36: "Point mass M_0 at center of MW + mass distributed with density $\rho(r) \propto 1/r^2$. (a) Show that $M_r = kr + M_0$."

Correct:

$$M_r = M_0 + \int_0^r \rho(r')\,dvol(r') = M_0 + \int_0^r \frac{C}{r'^2} 4\pi r'^2 dr' = M_0 + C4\pi r$$

↑ Black Hole

Wrong: anything that does not show that you realized that you need to integrate over $\rho(r')\,dvol(r')$