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:*

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

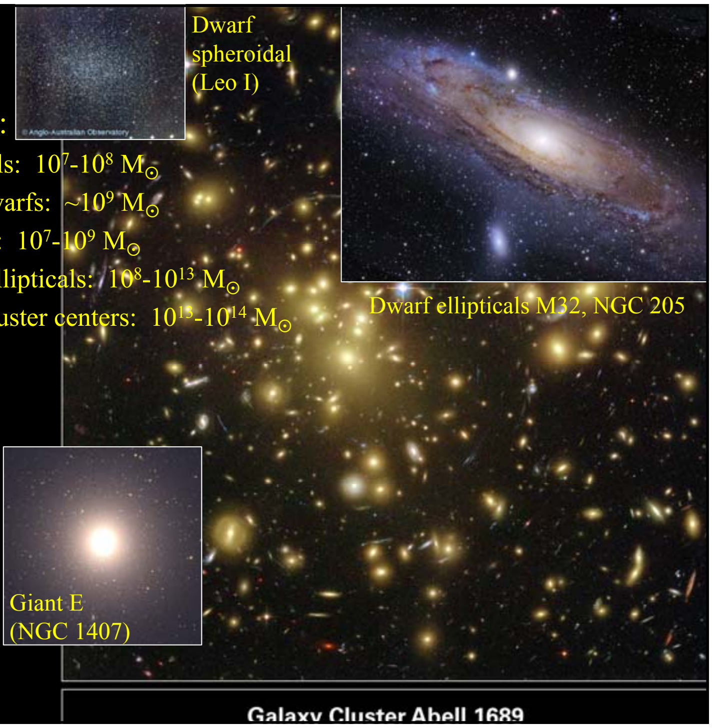
*Wrong:* anything that does not show that you realized that you need to integrate over $\rho(r')\,dvol(r')$

---

# 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: $10^{13}$-$10^{14}$ $M_\odot$

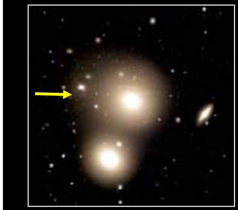


Dwarf spheroidal (Leo I)

Dwarf ellipticals M32, NGC 205

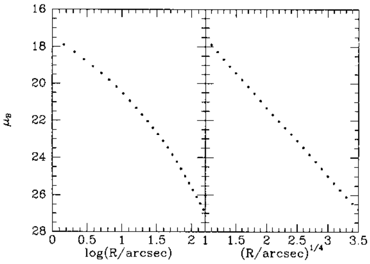
Giant E (NGC 1407)

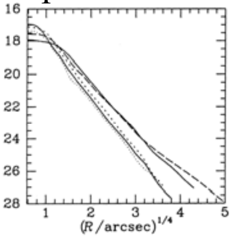
Galaxy Cluster Abell 1689

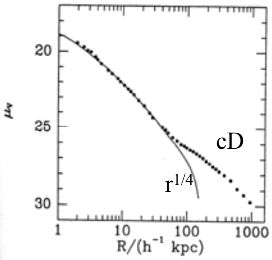


cD (NGC 3311)

# Ellipticals







***Good***

- Hubble's law $$I(R) = \frac{I_o}{\left(1+\frac{R}{R_o}\right)^2}$$

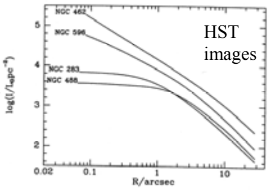
***Better***

- 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***

- 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

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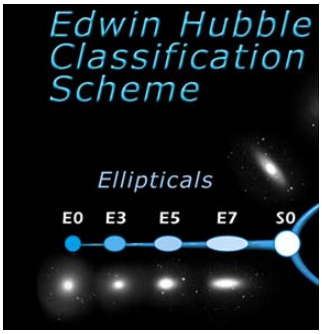
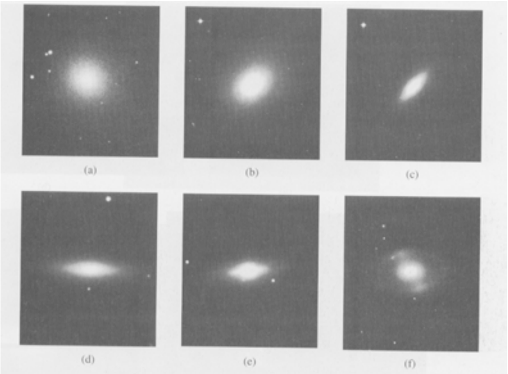
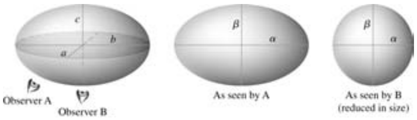
# True shapes requires statistical analysis

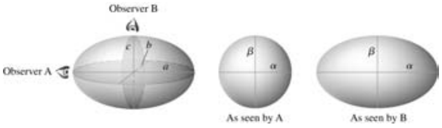




- *Oblate* = pancakes



- *Prolate* = footballs



# True shapes requires statistical analysis

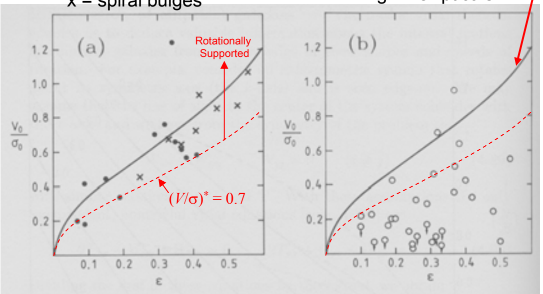
- Lower luminosity ➔ rotationally supported
  - $(V_{rot} / \sigma) \sim \sqrt{\varepsilon/(1-\varepsilon)}$
- Higher L ➔ pressure supported
  - $(V_{rot} / \sigma) << 1$

CO pgs. 988-989

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

• = low L ellipticals
x = spiral bulges

high L ellipticals

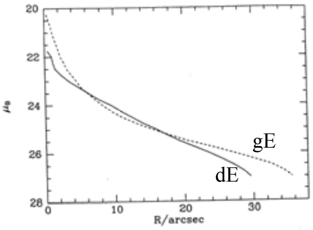


Rotationally Supported

$(V/\sigma)^* = 0.7$

**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*



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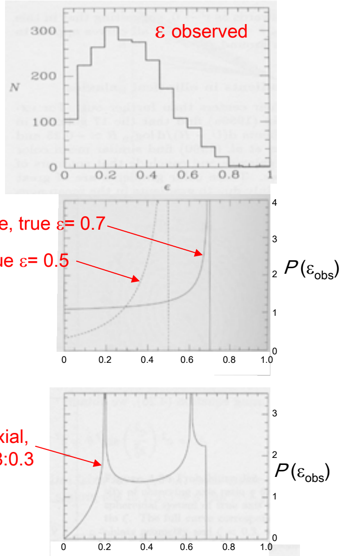
# Statistics of $\varepsilon = (1 - b/a)$

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

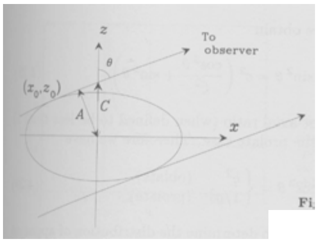


ε observed

Oblate, true ε= 0.7

Prolate, true ε= 0.5

Triaxial,
Axis ratios 1:0.8:0.3



From Binney & Merrifield, *Galactic Astronomy*

# Other evidence for triaxial systems

- Isophotal twists
- Kinematics (star motions)

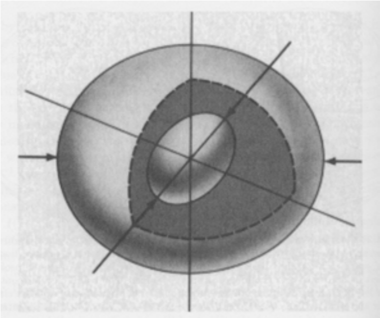
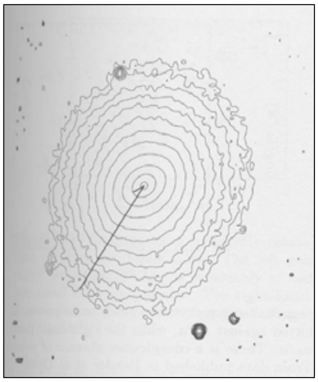


**Figure 4.24** Isophotal twist as a consequence of triaxiality. Two concentric, coaxial ellipsoids are shown. The dashed lines mark the intersections of the ellipsoids with the coordinate planes, while the solid lines show their outlines to the observer. The arrows mark the directions of their apparent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



From Binney & Merrifield, *Galactic Astronomy*

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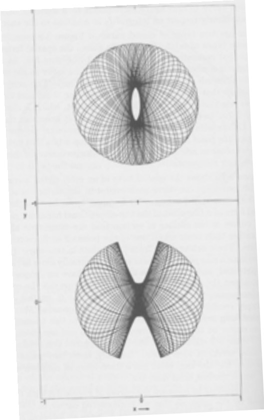
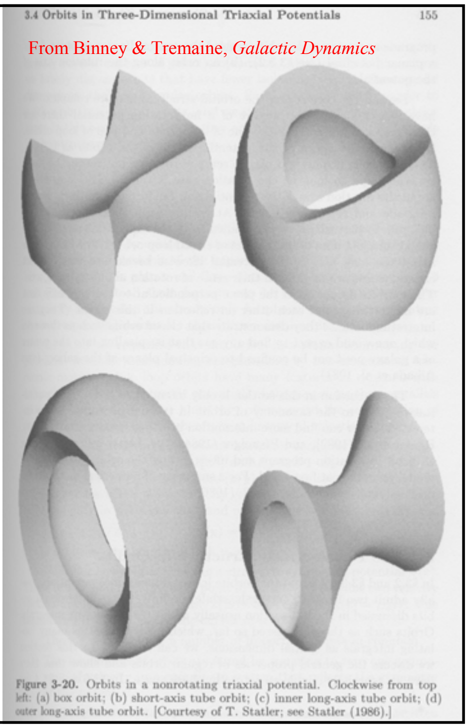
# Orbits in E galaxies

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



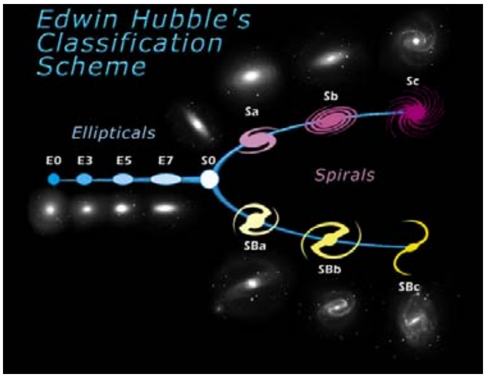


3.4 Orbits in Three-Dimensional Triaxial Potentials 155

From Binney & Tremaine, *Galactic Dynamics*

**Figure 3-20.** Orbits in a nonrotating triaxial potential. Clockwise from top left: (a) box orbit; (b) short-axis tube orbit; (c) inner long-axis tube orbit; (d) outer long-axis tube orbit. [Courtesy of T. Statler; see Statler (1986).]

# The "Tuning Fork" Diagram



**"Early"** **"Late"**

# 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