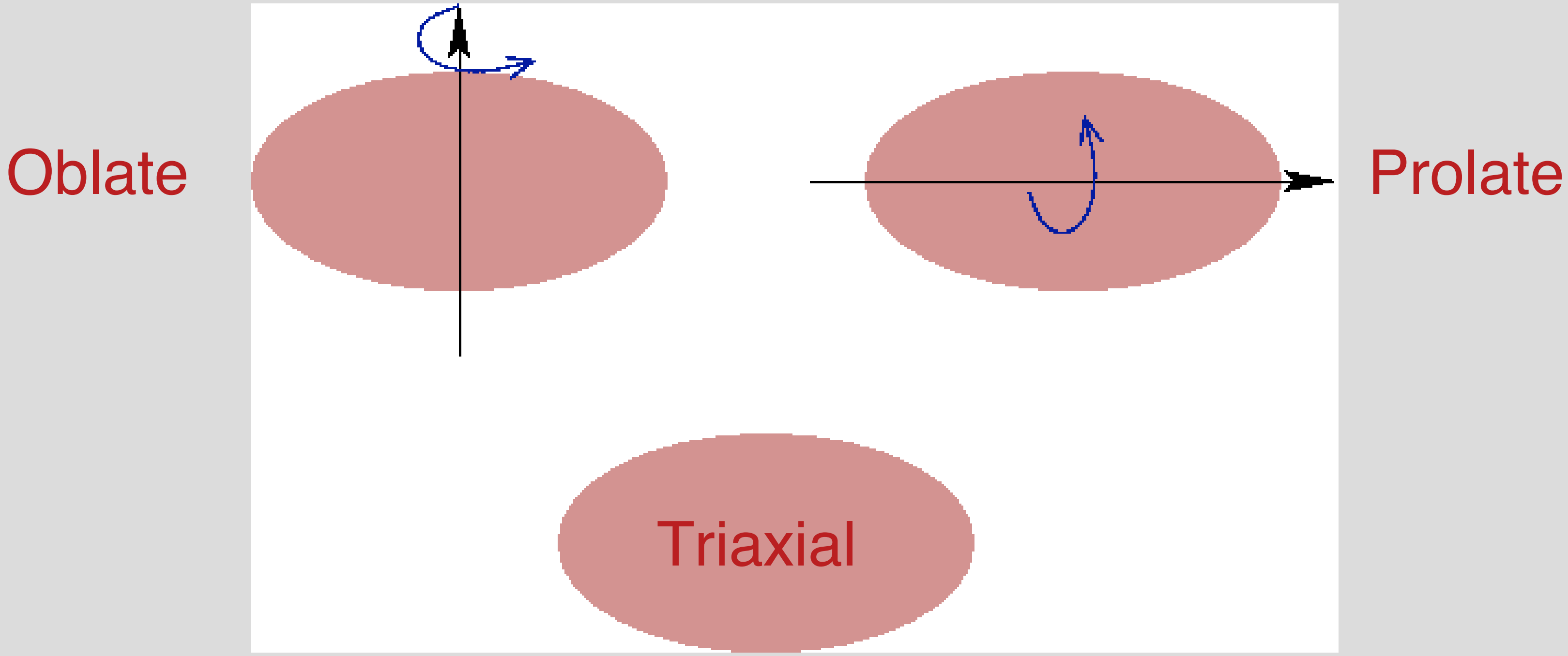
Dynamics of elliptical galaxies

Galaxies that appear elliptical on the sky may be intrinsically oblate, prolate, or triaxial, depending upon their symmetries:



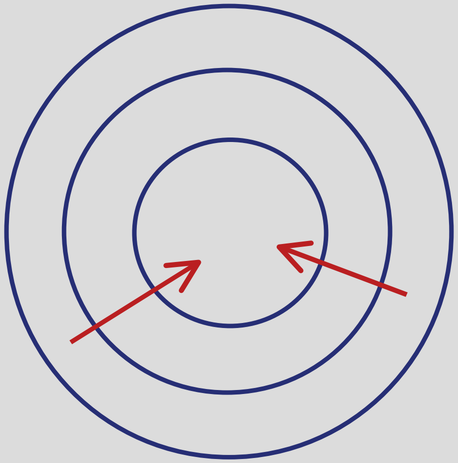
For an individual galaxy, can’t determine from an image what the intrinsic shape of the galaxy is.

Orbits of stars differ substantially in different types.

Orbits in elliptical galaxies

Classification of stellar orbits in elliptical galaxies is much more complicated than for disk galaxies. Most important distinction is between **axisymmetric galaxies** (prolate or oblate) and **triaxial galaxies**.

In an axisymmetric galaxy, there is a plane, perpendicular to the symmetry axis, in which gravitational force is central.



No azimuthal force, so component of angular momentum about symmetry axis (say, z-axis) is conserved

$$L_z = m(\mathbf{r} \times \mathbf{v})_z$$

Only stars with $L_z=0$ can reach center, other stars must avoid the center.

Orbits in elliptical galaxies

Triaxial potential: energy is conserved but not L_z

Simple example is the potential:

$$\Phi(\mathbf{x}) = \frac{1}{2}\left[\omega_x^2 x^2 + \omega_y^2 y^2 + \omega_z^2 z^2\right]$$

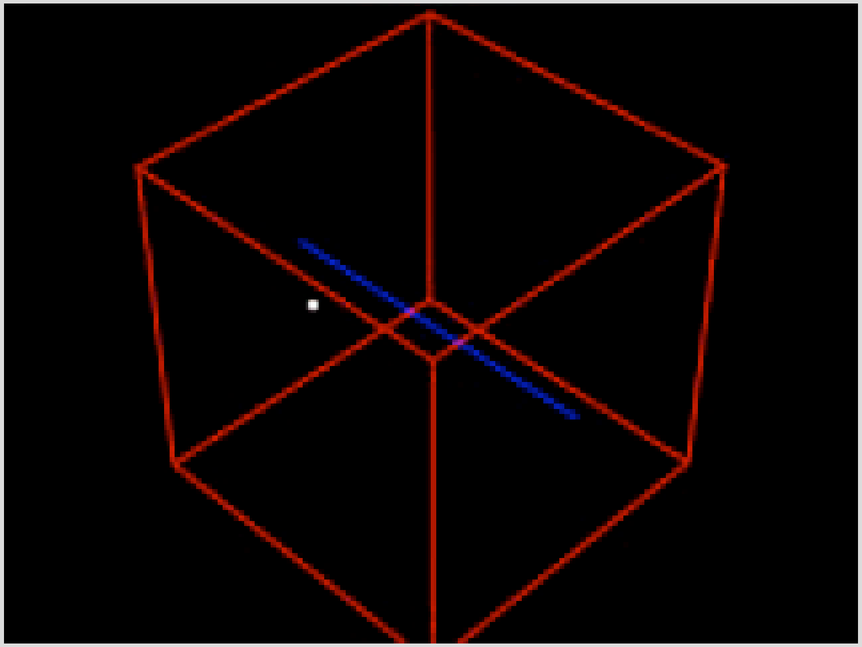
…which is the potential inside a uniform density ellipsoid. ω_x etc are constants. Star in this potential follows harmonic motion in each of the x,y,z directions *independently*.

Unless ω_x, ω_y and ω_z are rational multiples of each other (eg 1:2:7) orbits never close - star completely fills in a rectangular volume of space in the galaxy.

Example of a **box orbit**.

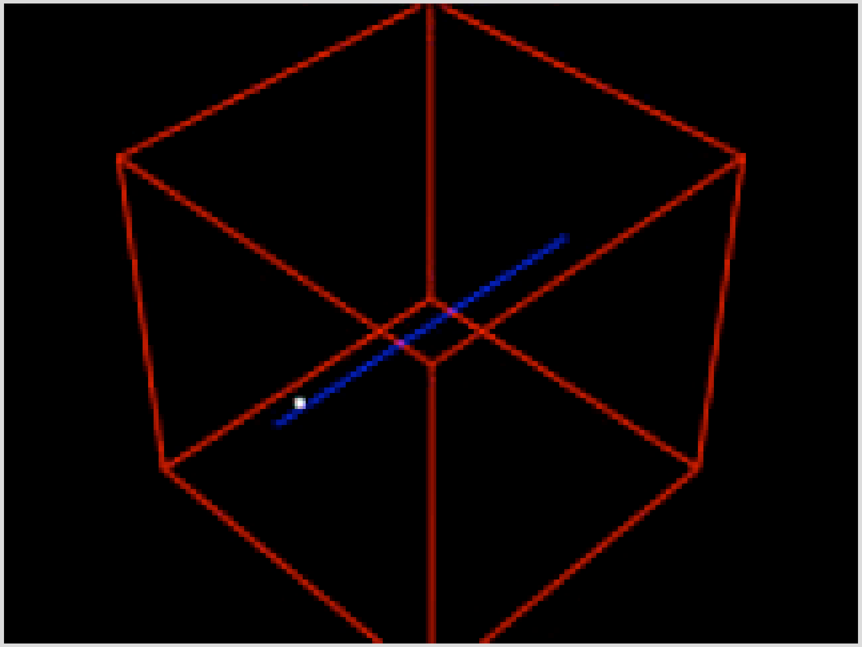
Orbits in elliptical galaxies

Numerical examples of orbits from Josh Barnes



z-tube orbit

Orbit loops around the minor axis - only orbit family in oblate potential



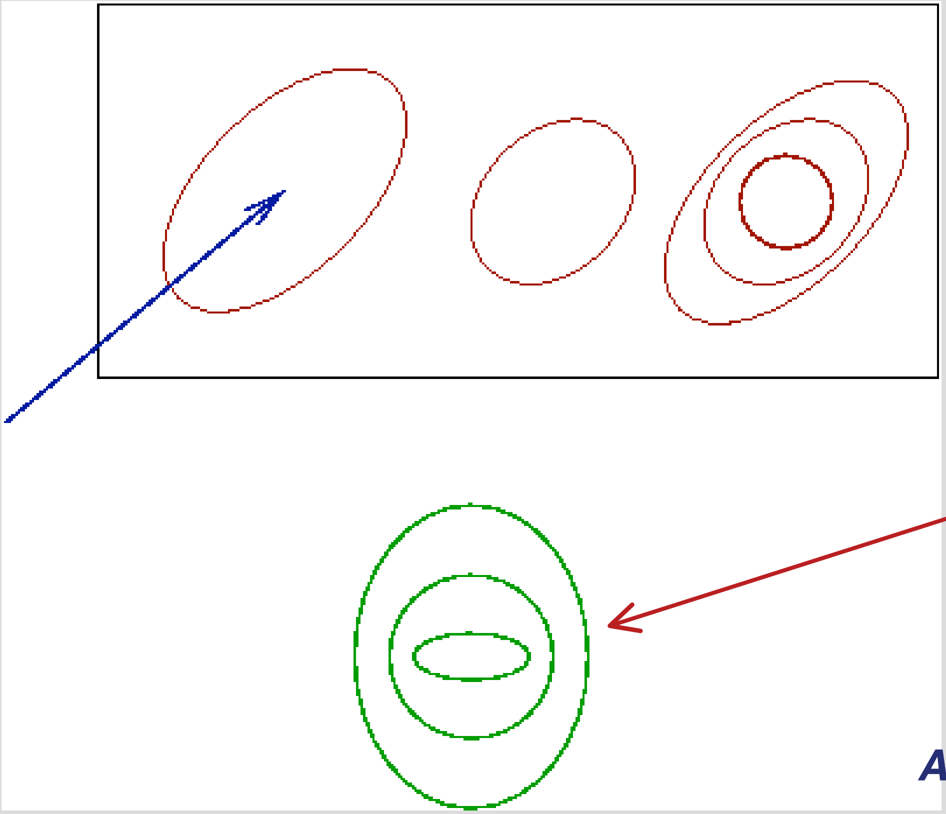
box orbit

Main orbit family in triaxial potentials - note orbit does not avoid the center

Fine structure in elliptical galaxies

Contours of constant surface brightness often depart slightly from true ellipses.

Twists: major axis of the isophotes changes angle going from the center of the galaxy to the edge. This can be interpreted as a projection effect of a triaxial galaxy in which the ellipticity changes with radius:



View ellipses on flat surface from lower left

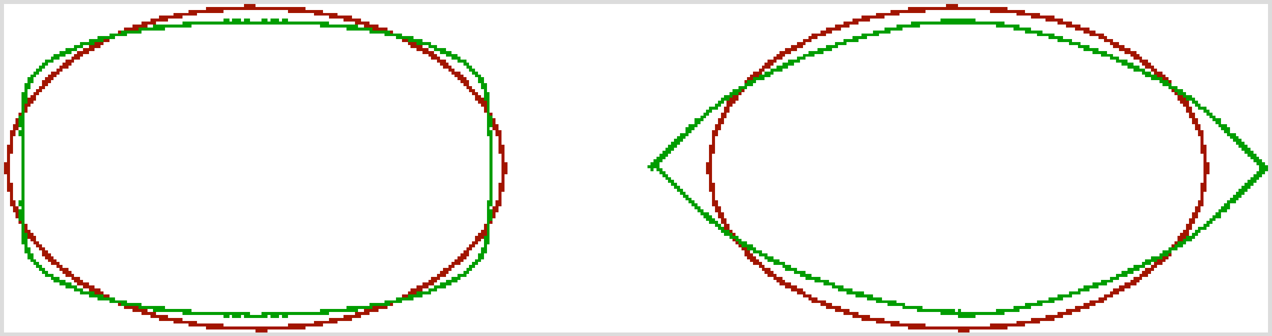
See apparent twist in the isophotes

Fine structure in elliptical galaxies

Surface brightness distribution can also depart slightly from ellipses:

Boxy isophotes

Disky isophotes



Normally subtle distortions

Luminous ellipticals are often boxy, midsized ellipticals disky

Could classify ellipticals based on their degree of boxiness / disky-ness - S0s would then be continuation of a trend to increasing disky-ness.

Faber-Jackson relation

Analog of the Tully-Fisher relation for spiral galaxies. Instead of the peak rotation speed V_{max}, measure the velocity dispersion along the line of sight σ. This is correlated with the total luminosity:

$$L_V = 2 \times 10^{10} \left(\frac{\sigma}{200\ \mathrm{km s^{-1}}} \right)^4 L_{sun}$$

Can be used as a (not very precise) distance indicator.

Fundamental plane

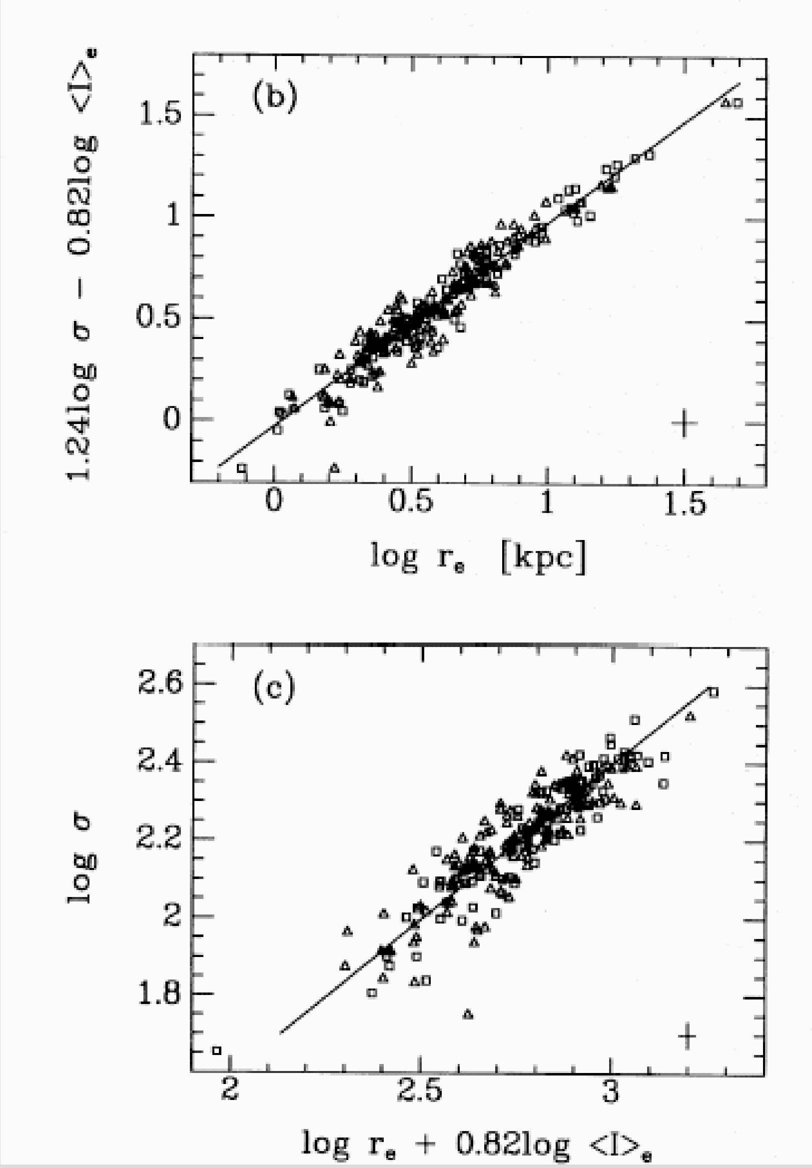
Recall that for an elliptical galaxy we can define an *effective radius* R_e - radius of a circle which contains half of the total light in the galaxy. Measure three apparently independent properties;

- The effective radius R_e
- The central velocity dispersion □
- The surface brightness at the effective radius $I_e=I(R_e)$

Plot these quantities in three dimensions - find that the points all lie close to a single plane!

Called the **fundamental plane**.

Fundamental plane



Jorgensen et al. (1996)

Plots show edge-on views of the fundamental plane for observed elliptical galaxies in a galaxy cluster.

Approximately:

$$R_e \propto \sigma^{1.24} I_e^{-0.82}$$

Measure the quantities on the right hand side, then compare apparent size with R_e to get distance

Origin of the fundamental plane unknown…