Galactic Interactions & Elliptical galaxies

Transformation of cluster galaxies
Structure, Dynamics, &
the Formation of Elliptical Galaxies,
The fundamental plane

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Disk heating from minor mergers

In the case of minor mergers (mass ratio $q \gg 1$), the more massive progenitor will only be mildly perturbed.

A satellite of mass M_s orbiting within a halo of mass $M_h \gg M_s$ that hosts a central disk galaxy of mass M_d will experience a drag force due to dynamical friction, losing orbital energy as it spirals towards the center of the halo. This energy is transferred to the halo and disk, heating both of them up.

Assuming that the initial disk has a density

$$\rho_d(R,z) = \rho_0 e^{-R/R_d} \operatorname{sech}^2\left(\frac{z}{2z_d}\right)$$

we find that the disk will thicken by

$$\frac{\Delta z_d}{z_d}(R) = \frac{2}{9}\frac{\lambda}{\sqrt{2}} \ln\left(\frac{\sqrt{2}}{\lambda}\right)\frac{R_d}{z_d}\frac{M_s}{M_d}e^{R/R_d}$$

Cluster galaxy transformations

The characteristics of cluster galaxies (redder, less gas-rich, lower sSFR) are so different from those in the field that it is thought that some process exists to transform galaxies when they enter or become a part of the denser environment.

The cluster environment is likely to affect cluster galaxies via

- Tidal interactions with other members and/or the cluster potential
- Dynamical friction
- Interactions with the hot intracluster medium (ICM)

Galaxy harassment

All galaxy interactions within a cluster can be considered high-speed encounters, since the galaxy velocity is approximately equal to the galaxy velocity dispersion in the cluster, which is much smaller than the internal galaxy velocity dispersion.

Colliding galaxies within a cluster are thus impulsively heated, resulting in it being less bound and more vulnerable to further disruptions form galactic encounters or tidal interactions with the cluster potential.

The cumulative effect of multiple high-speed impulsive encounters is known as galaxy harassment.

Ram-pressure stripping

As galaxies move through the ICM, their gas components experience a ram pressure. If this ram pressure is sufficiently strong, it can strip the gas from the galaxy.

Ram-pressure stripping will occur when

$$\rho_{\rm ICM} > \frac{2\pi G \Sigma_* \Sigma_{\rm ISM}}{V^2}$$

The potential for new star formation is greatly reduced once gas is removed due to ram-pressure stripping.

Strangulation

If a galaxy only had the gas in the ISM available for star formation, it would run through its gas in only a few Gyr. For star formation to last as long as observations indicate, galaxies are thought to be surrounded by reservoirs of gas comprised of

- Gas falling onto the system for the first time
- Gas that has been shock-heated and is cooling
- Gas that has been expelled from the ISM by feedback processes

Both ram pressure and tides can easily strip this gas reservoir from a galaxy, resulting in strangulation. Strangulation therefore results in a slow decline of star formation as the galaxy slowly runs out of fuel.

Three classes of elliptical galaxies

In general, elliptical galaxies are smooth, roundish stellar systems that are gas- and dust-poor.

Bright ($M_B \lesssim -20.5$) have little rotation, boxy isophotes, and relatively shallow central surface brightness profiles.

Intermediate luminosity ($-20.5 \lesssim M_B \lesssim -18$) are supported by rotation, have disky isophotes, and have steep central surface brightness profiles

Faint ($M_B \gtrsim -18$) (dwarf ellipticals and spheroidals) have no rotation and exponential surface brightness profiles.

Elliptical galaxy observables

To study a galaxy's properties, we need to understand how the observables (line-of-sight projections of 3D quantities) are related to the physical quantities.

Let $\rho(\vec{x})$ be the 3D distribution of stellar mass in a system, and $\nu(\vec{x})$ be the 3D distribution of light in a system; the two are related by $\Upsilon(\vec{x})$, the stellar mass-to-light ratio.

If Υ is a constant, then the normalized surface brightness is

$$I(x,y) = \frac{\Sigma(x,y)}{\Upsilon} = \frac{1}{\Upsilon}\int \rho(\vec{x})\, dz$$

and the normalized distribution of the velocity along the line of sight is

$$\mathcal{L}(x,y,v_z) = \frac{1}{\Sigma(x,y)} \iiint f(\vec{x},\vec{v})\, dv_x\, dv_y\, dz$$

where $f(\vec{x},\vec{v})$ is the phase-space distribution function.

Isophotal twists

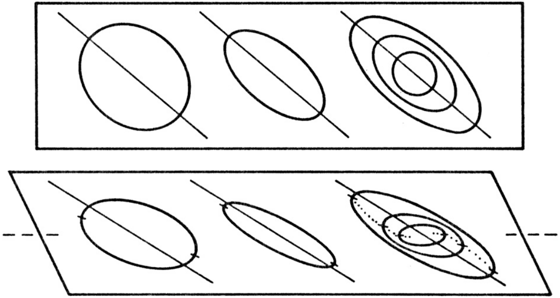
Some ellipticals reveal isophotal twists, with the direction of the major axis of the isophote changing with isophotal level.

Most of these ellipticals have boxy isophotes.

The simplest explanation is that these elliptical galaxies are triaxial, and have their intrinsic axis ratios change with radius.

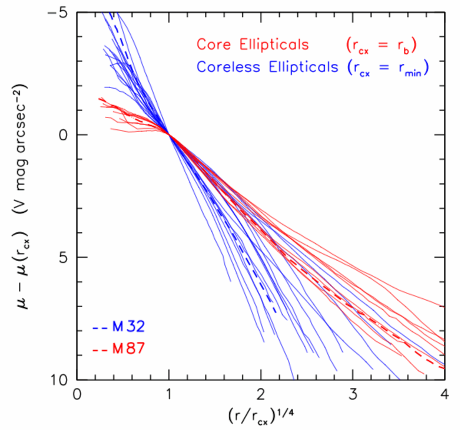
In projection, these systems will reveal isophote twist.

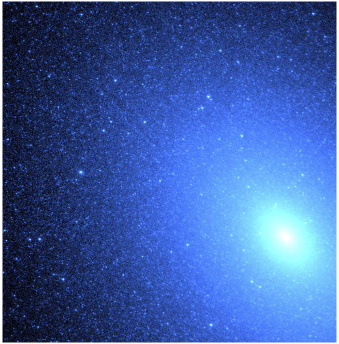
The presence of isophotal twists in bright, boxy ellipticals is evidence that these systems are triaxial.

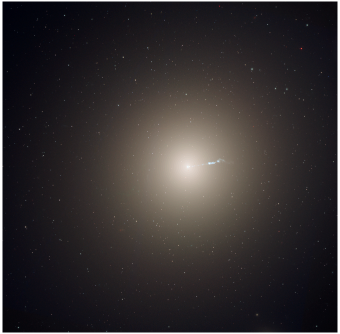


The nuclei of elliptical galaxies

The central regions of disky elliptical galaxies have steep cusps, while boxy ellipticals have more shallow cores.







Elliptical galaxy kinematics

An elliptical galaxy's spectrum is a convolution of the template spectrum, which is the luminosity-weighted spectrum of all the various stars along the line of sight, and a broadening function, which is a combination of the instrumental broadening function and the line of sight velocity distribution (LOSVD).

A typical functional form for the LOSVD is a simple Gaussian

$$\mathcal{L}(v) = \frac{1}{\sqrt{2\pi}\sigma} e^{-w^2/2} \qquad w = \frac{v - V}{\sigma}$$

However, the LOSVD is generally not Gaussian, and it has become standard practice to adopt a Gauss-Hermite series

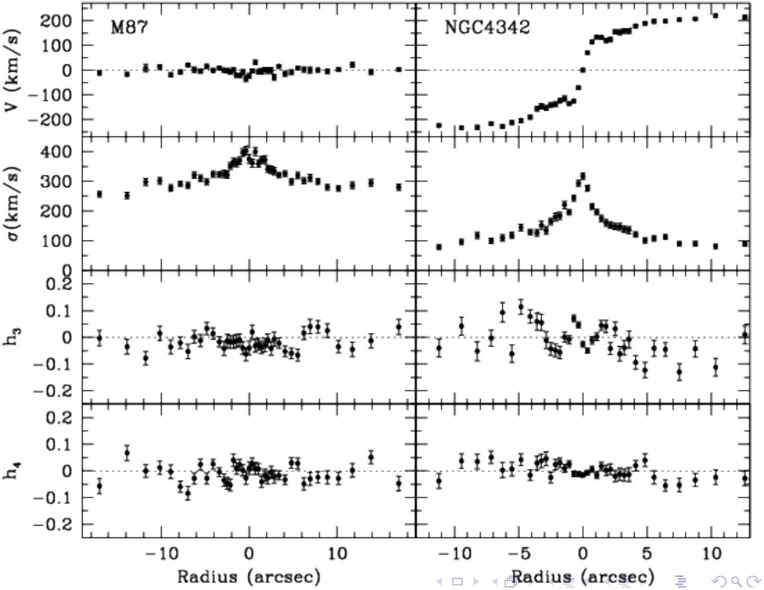
$$\mathcal{L}(v) = \frac{1}{\sqrt{2\pi}\sigma} e^{-w^2/2} \left[1 + \sum_{j=3}^{N} h_j H_j(w) \right]$$

The series is typically truncated at $N = 4$, so the LOSVD is described by four parameters: V, σ, h_3, and h_4.

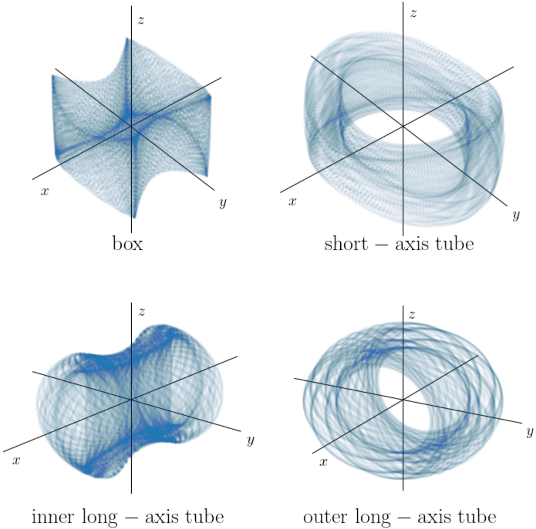
Elliptical galaxy kinematics

Disky ellipticals typically reveal strong rotation along the major axis, consistent with them being “oblate rotators” (oblate in shape, flattening due to rotation).

Boxy ellipticals reveal very little rotation, and occasionally rotate along the minor axis. The latter is clearly a sign that boxy ellipticals are triaxial.



Orbital families in triaxial potentials



Dark halos around ellipticals

It is much more difficult to probe the mass distribution of elliptical galaxies at large radii than in disk galaxies, since there is no organized rotation and the surface brightness profile drops off so quickly.

Combined with the shape of the velocity profiles beyond the second moments (via the Gauss-Hermite moments), the shape of the velocity dispersion as a function of radius depends on M/L.

X-ray mapping shows that $\sim 100 M_\odot/L_\odot$ at ~ 100 kpc.