Part V

Elliptical Galaxies

Elliptical Galaxies: General Characteristics

- Elliptical galaxies contain stars but have little gas in the cold ISM.
- Most elliptical galaxies have had little recent star-formation – spectra dominated by populations of older stars.
- Some exceptions and some gas will be returned to the ISM from stars as they evolve.
- Large ellipticals often have large halos of hot (X-ray emitting) gas, extending well beyond the galaxy.
- The absence of dust obscuration makes some observations simpler.
- However, the absence of gas makes it difficult to study their dynamics since HI observations cannot be used.
- Many elliptical galaxies have relatively simple morphologies (E0–E7).
- However they can be far more complex than their morphology suggests – boxy/disky/shell galaxies/ kinematically decoupled cores (KDCs) etc.
- Huge range of elliptical galaxies: giant ellipticals located at the centre of clusters (e.g. M87) to dwarf ellipticals (e.g. M32).
- Many elliptical galaxies are found in groups and clusters of galaxies.

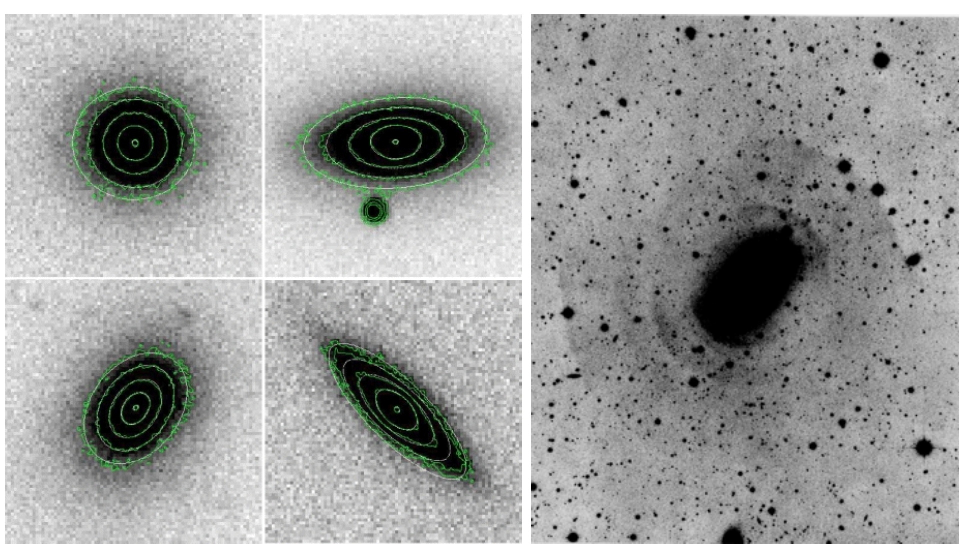

Figure 5.1: Left panels: a sample of surface brightness profiles taken from the SDSS. The bottom two galaxies show "boxy" (left) and disky (right) surface brightness profiles. Right panel: a deep optical image of the E4 elliptical galaxy NGC 3923 showing a series of shells, which are probably tracers of past interactions/mergers.

- M87 has $\sim 10^4$ globular clusters (~ 200 for the Milky Way) and a mass of $3 \times 10^{12} M_\odot$ within $r < 30$ kpc.
- Most (all) big ellipticals contain a massive black hole, and sometimes show spectacular jets. The M87 black hole has a mass of $3 \times 10^9 M_\odot$.
- Formation: either early "monolithic collapse", or via merger processes – the merger of two gas-rich spirals leads to the formation of an elliptical.

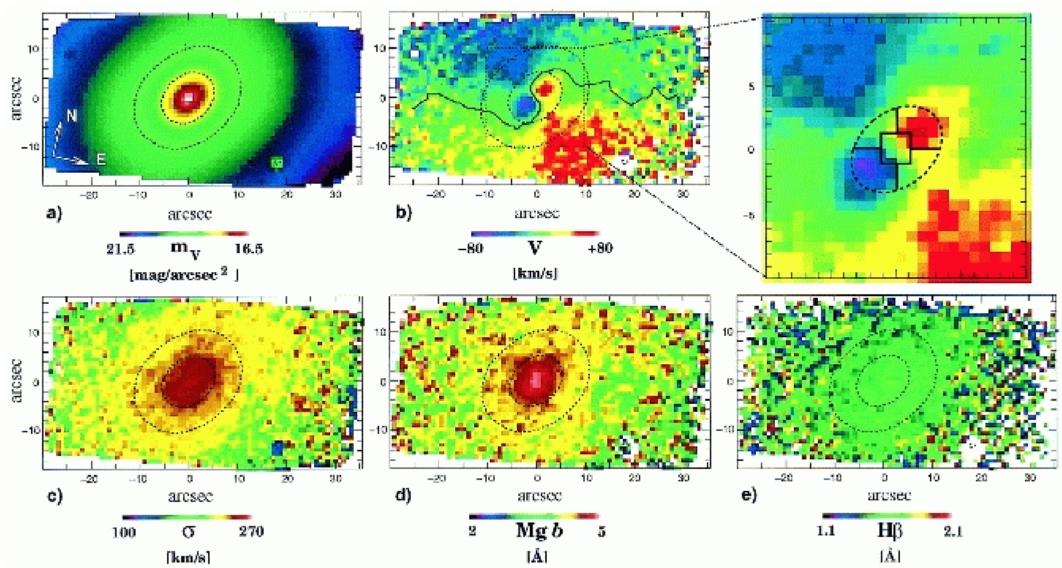

Figure 5.2: The surface brightness and stellar velocity images of the E3 elliptical galaxy NGC 4365. The top row shows the surface brightness and then the stellar velocity, which shows that the rotation of the stars for the bulk of the galaxy is different to that of the core, where the rotation axis is perpendicular to that of the rest of the galaxy. This is a kinematically decoupled core (KDC) and is probably the result of a merger event.

Surface Brightness Profiles

The surface brightness profiles of elliptical galaxies (and bulges of spirals) follows the same basic relation:

$$I(R) = I_e \, 10^{-3.33[(R/R_e)^{1/4}-1]} = I_e \, e^{-7.67[(R/R_e)^{1/4}-1]}. \tag{5.1}$$

This is the *de Vaucouleurs $R^{1/4}$ law.*

The length scale R_e – effective radius, and the numerical value 3.33 (or 7.67) means that if the galaxy were circularly symmetric, then half the total light of the galaxy lies within a radius R_e.

The outer parts of certain giant ellipticals, normally found at the centre of rich clusters of galaxies, show more light than is expected from the de Vaucouleurs profile – these are known as cD galaxies.

The de Vaucouleurs profile can be generalised by replacing the 1/4 with $1/n$, where n is the Sersic index.

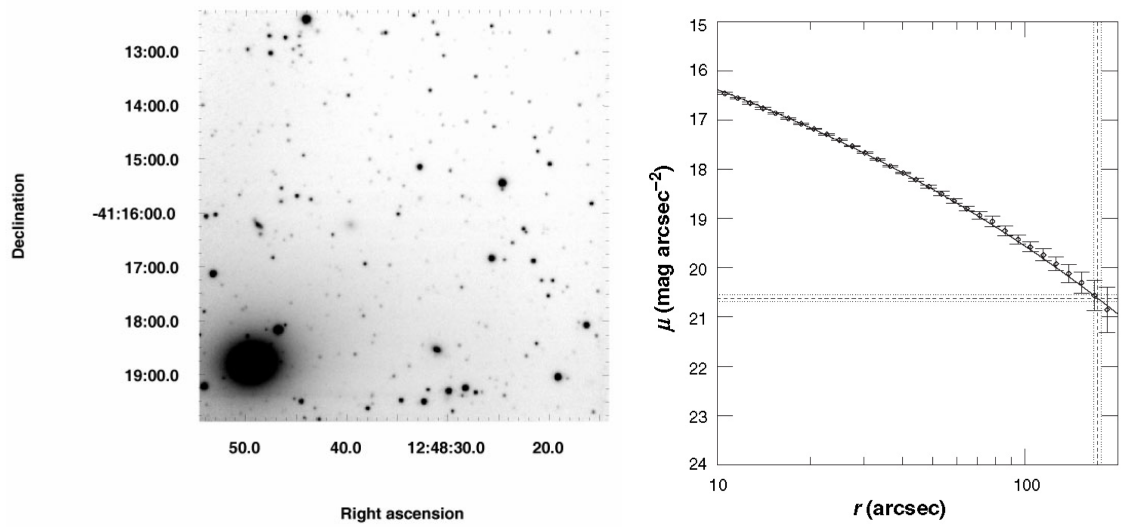

Figure 5.3: The E1 elliptical galaxy NGC 4696 and the surface brightness fit using a de Vaucouleurs profile.

The Faber-Jackson Relation

The luminosity of an elliptical galaxy scales with its average stellar velocity dispersion σ, with

$$L \propto \sigma^4, \tag{5.2}$$

or more precisely

$$\frac{L_V}{2 \times 10^{10} L_\odot} \sim \left(\frac{\sigma}{200 \text{km s}^{-1}} \right)^4, \tag{5.3}$$

This is the Faber-Jackson relationship (Faber+Jackson 1976).

The F-J relation is often used to measure distances to ellipticals.

This was the relation used to find evidence for a 'Great Attractor' in our neighbourhood.

All ellipticals do not obey the F-J relation in the same way – the surface brightness of the elliptical plays a role as well.

The Fundamental Plane of Elliptical Galaxies

If we assume that the velocity dispersion of stars σ and the M/L ratio is constant throughout an elliptical galaxy, we can use the Virial theorem to infer a relation between the global measurable parameters of ellipticals.

From the Virial theorem we have $2T + V = 0$, or, approximately,

$$Mv^2 - \frac{3}{5} \frac{GM^2}{R} = 0. \tag{5.4}$$

This gives a galaxy mass of $M \sim v^2 R/G$.

The *mass surface density* Σ should scale as

$$\Sigma \sim \frac{M}{R^2} \sim \frac{v^2}{GR}, \tag{5.5}$$

whereas the *surface brightness* I is

$$I \sim \frac{L}{R^2} = \frac{L}{M}\frac{M}{R^2} \sim \frac{v^2}{GR}.\frac{1}{M/L}. \tag{5.6}$$

For an elliptical galaxy with little rotation, the v is the stellar velocity dispersion σ.

Replacing the radius R by the characteristic half-light radius R_e, we have

$$R_e \sim \sigma^2 I^{-1}. \tag{5.7}$$

The observed result from real ellipticals is (see S&G, Fig. 6.13)

$$R_e \sim \sigma^{1.24} I^{-0.82}. \tag{5.8}$$

This is known as the *Fundamental Plane* relation.

The fact that the theoretical expectation does not match the observed relation probably shows that our assumption of the mass to light M/L ratio being constant throughout the galaxy is probably not correct.

Like the Faber-Jackson relationship (to which it is closely related) – the Fundamental Plane can be used to estimate distances of galaxies.

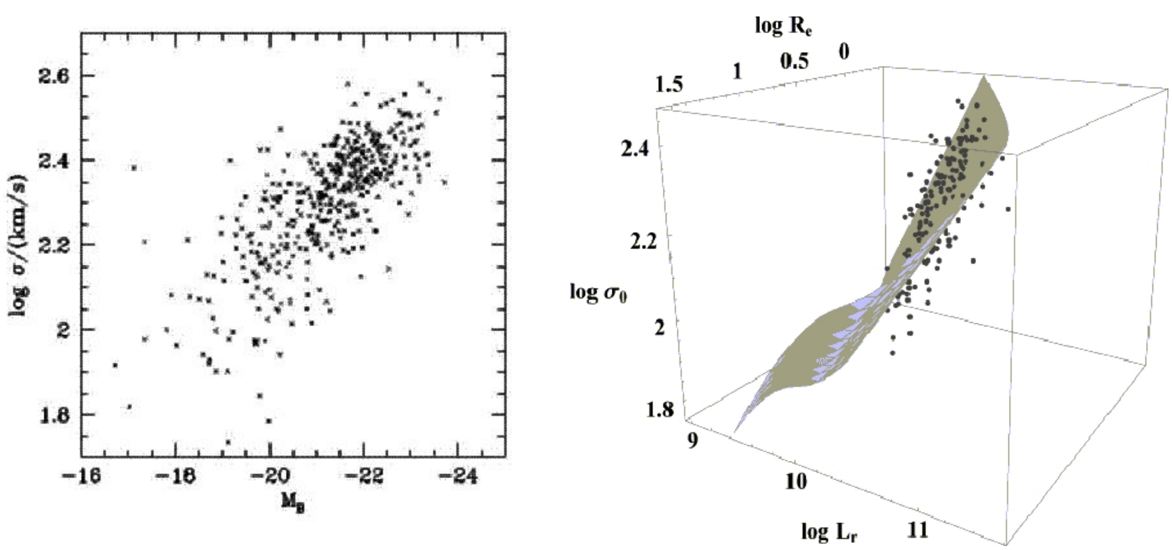

Figure 5.4: Left: the Faber-Jackson relationship for elliptical galaxies. Right: a 3D representation of the Fundamental Plane of elliptical galaxies (though with luminosity instead of surface brightness in this representation).

The $D - \sigma$ Relationship

Another relationship related to the Fundamental Plane is the $D - \sigma$ correlation

$$\frac{D}{\mathrm{kpc}} = 2.05 \left(\frac{\sigma}{100\mathrm{km\ s}^{-1}}\right)^{4/3} \tag{5.9}$$

where D is the diameter within which the mean surface brightness is 20.75 mag arcsec^{-2}

This relationship is more useful for distance determination.

It is easier to measure the amount of light within a diameter D than the total luminosity of a galaxy (Dressler et al. 1987).

Do Elliptical Galaxies Rotate?

The tensor Virial theorem predicts that if the flattened shape of an elliptical galaxy were due to its rotation, then the ratio of its average rotational speed (v) to its velocity dispersion (σ) would be

$$\frac{v}{\sigma} = \sqrt{\frac{\epsilon}{1-\epsilon}}, \tag{5.10}$$

where $\epsilon = 1 - b/a$ is the ellipticity of the galaxy.

Applies to an isotropic rotating oblate spheroid – idealised, but realistic model of an elliptical galaxy.

Therefore, even fairly round galaxies ($b/a \sim 0.7$) should rotate fairly fast.

Observations of ellipticals, however, indicate that luminous elliptical galaxies span a range of values of v/σ, but all these values are far too small to indicate that elliptical galaxies are flattened by rotation (see S&G, Fig. 6.14).

The flattening in these systems is caused by velocity anisotropy of their stars.

Fainter ellipticals (and spiral bulges) have $v/\sigma \sim 1$ – significant role for rotation in determining their shapes.

Probably composite systems, with a fast-rotating stellar disk embedded within a slower-rotating ellipsoidal outer galaxy.

Summary: Higher mass ellipticals tend to be "boxy" - no rotational support.

Lower mass ellipticals tend to be "disky" – rotational support.