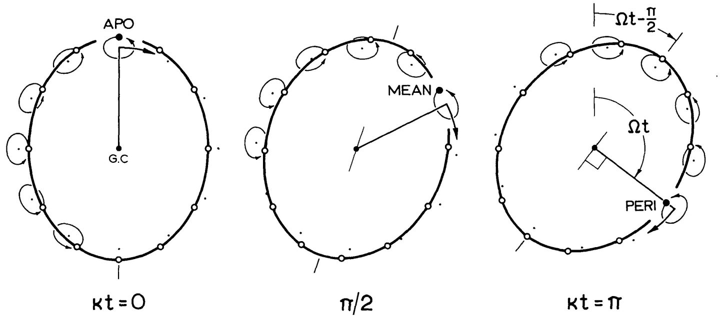
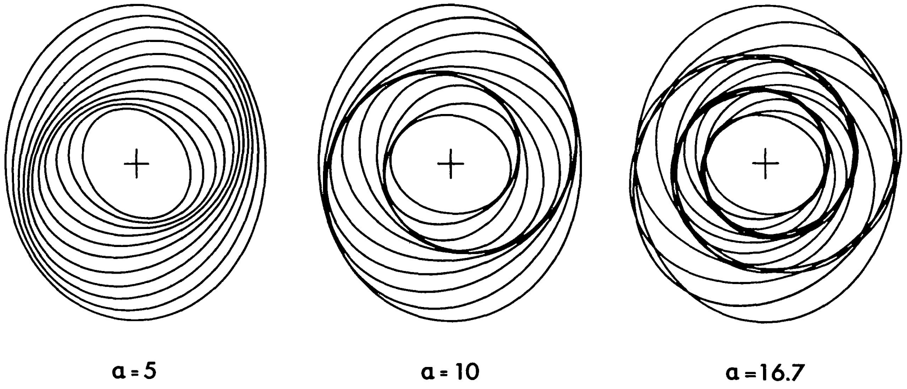
Epicyclic Orbits



(Toomre, 1977, Fig. 2)

Epicyclic motion produces a spiral pattern (see figure, Sparke & Gallagher, and Toomre 1977), with pattern speed

$$\Omega_\mathrm{p} = \Omega - \kappa/2 \tag{4.47}$$



(Toomre, 1977, Fig. 3)

With this different types of spirals can be formed: Density wave theory

Hubble Heritage Team, ESA, NASA

SSRO-South (R.Gilbert,D.Goldman,J.Harvey,D.Verschatse) - PROMPT (D.Reichart)

Observations, III

About half of all disk galaxies show a central linear bar!

Shape can be box-like or as extreme as 1 : 5 in ratio of short to long axis.

Edge-on view of disk galaxies tells us that bars are as thin as the disks themselves.

In contrast to spiral arms, bars occur in gas-rich and gas-poor systems.

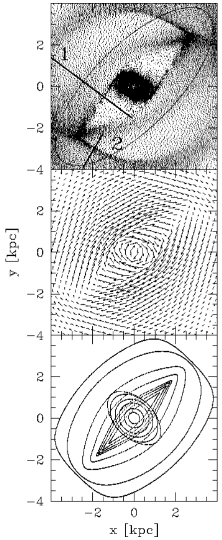
Bars are not density waves!

It is not well understood why some galaxies are barred, while others are not.

Spiral arms usually start from the ends of bars

⇒ Bars are rotating with the same pattern speed as spiral arms.

Numerical Calculation



Numerical calculation of particle distribution and velocity field of test particles in bars possible.

Particle orbits close on themselves in corotating frame.

Velocity gradients along the orbits cause shocks

⇒ Gas and dust are compressed

⇒ Dust lanes along the bar major axis

⇒ Energy dissipation leads to angular momentum transport

⇒ Gas inflow toward galaxy center

Englmaier & Gerhard (1997)

Bulges

Bulges are among the densest stellar systems.

Surface brightness approximated by Sérsic's formula (empirical!):

$$I(R) = I(0)\exp\left[-(R/R_0)^{1/n}\right] \quad . \tag{4.48}$$

For $n = 1$, exponential decrease; for $n = 4$, de Vaucouleurs formula (developed for elliptical galaxies).

$R \to 0$: $I \to \infty$.

Observed values reach thousands of stars per cubic parsec.

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Seigar M., Carollo C.M., Stiavelli M., et al., 2002, AJ 123, 184

Shu F.H., 1991, The Physics of Astrophysics, Vol. I. Radiation, University Science Books, Mill Valley, CA

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Photometry, I

Bulges of disk galaxies are similar to elliptical galaxies in many respects.

NGC 5846 and NGC 5850 – `http://www.krneki.ws`

Surface brightness: modified Sérsic's formula:

$$\log\left(\frac{I(R)}{I(R_\mathrm{e})}\right) = b\left[\left(\frac{R}{R_\mathrm{e}}\right)^{1/n} - 1\right] \tag{4.49}$$

where R_e: effective radius, i.e., radius containing in half of the total luminosity.

Photometry, II

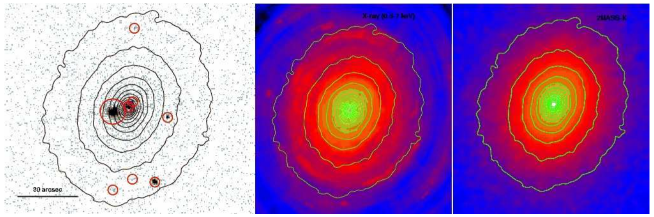
Three classes of elliptical galaxies:

- Luminous giant ellipticals: $L > 2 \times 10^{10} L_\odot$
- Midsized ellipticals: $3 \times 10^9 L_\odot < L < 2 \times 10^{10} L_\odot$
- Dwarf ellipticals: $L < 3 \times 10^9 L_\odot$.

Hubble type: En, where $n = 10(1-b/a)$ (a: major axis of isophotes, b: minor axis; $(1-b/a) = \epsilon$).

E0 galaxies: circular; E5 galaxies: axial ratio 1 : 2.

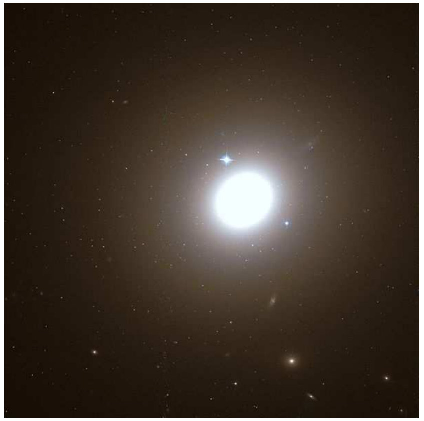
The Hubble type of an elliptical galaxy depends on our viewing direction! Characteristic parameters are largely determined by luminosity.



Near-IR isophotes vs. diffuse X-ray emission of M 32 (Revnivtsev et al., 2007).

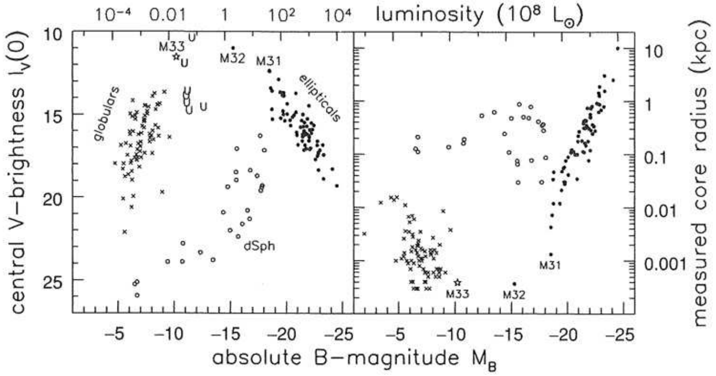
Photometry, III

The most luminous of all galaxies are the cD galaxies, the central galaxies of groups or clusters. $R^{1/4}$–law fulfilled out to $\sim\ 20 R_\mathrm{e}$. Beyond that, excess surface brightness from cluster stars or *shredded* debris of cannibalized dwarf galaxies.



HST image of NGC 1399 in Fornax cluster

Photometry, IV



Sparke & Gallagher Fig 6.6

Central brightness and core radius are tightly linked to the luminosity for luminous and midsized ellipticals (and disk bulges):

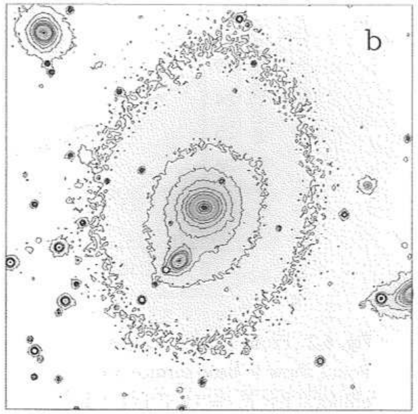
The more luminous the galaxy, the lower its central surface brightness and the larger its core. Opposite trend for dwarf ellipticals.

Photometry, V

A couple of complications:

- Luminosity/Central-Brightness correlation and Luminosity/Core-Radius correlation observationally similar to color-magnitude diagram relations for stars, but much harder to understand (in stars, the mass determines both luminosity and temperature; in galaxies, the processes in galaxy formation are most likely dominating)
- Surface brightness measurements are hampered by seeing and angular resolution. cD galaxies tend to have cores with approximately constant surface brightness but less-bright ellipticals have often central *cusps* (surface brightness keeps rising). ⇒ Core-radius measurements are uncertain.
- The isophotes of some (luminous) elliptical galaxies *twist* from the inner to the outer isophotes. ⇒ Evidence for *triaxiality*.

Photometry, VI



Sparke & Gallagher Fig.6.1b

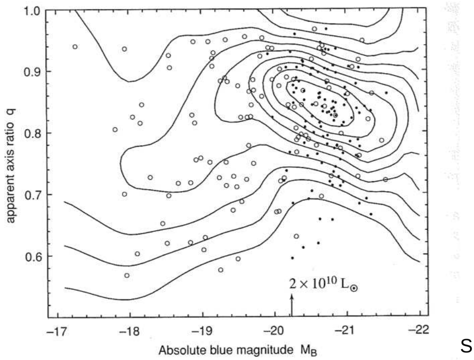
Twisted isophotes of a giant elliptical galaxy: the long axis of the inner isophotes is roughly horizontal, while the outer ones are near-vertical.

The 3D Shapes of Elliptical Galaxies

The appearance (Hubble type) of an elliptical galaxy depends on the direction from which it is observed. A near-circular does not guarantee that the ellipsoid has a true spherical three-dimensional structure.

⇒ Distribution of apparent shapes has to be studied.

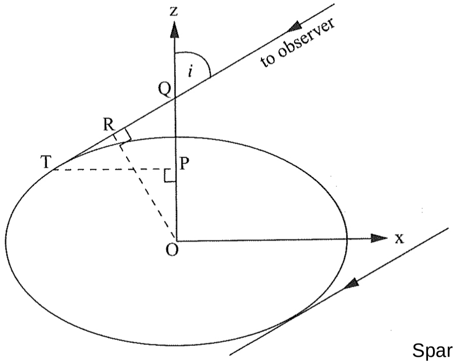
First clues: There are no ellipticals in the sky more flattened than E7 ($b \sim 0.3a$) and bright ellipticals on average appear rounder.



Sparke & Gallagher Fig.6.9

The 3D Shapes of Elliptical Galaxies

Try to understand apparent shapes with oblate spheroids:



Sparke & Gallagher Fig.6.9

Stellar density $\rho(\mathbf{x})$ is

$$\rho(\mathbf{x}) = \rho(m^2), \text{ where } \quad m^2 = \frac{x^2 + y^2}{A^2} + \frac{z^2}{B^2} \tag{4.50}$$

with $A > B > 0$ (the true major and minor axes of the oblate spheroid).

The 3D Shapes of Elliptical Galaxies

Eq. 4.50 describes and ellipse for constant m^2, i.e., for constant stellar density, i.e., for isophotes.

⇒ the oblate spheroid appears elliptical under all viewing angles.

Following Sparke & Gallagher (Sect. 6.8), it can be shown easily that the observed axial ratio q_{obl} is given by

$$q_{\mathrm{obl}}^2 = (b/a)^2 = (B/A)^2 \sin^2 i + \cos^2 i \quad . \tag{4.51}$$

(For prolate galaxies, there is a fully analogous statement.)

A spheroidal galaxy never appears more flattened than its true axial ratio A/B.

Revnivtsev M., Churazov E., Sazonov S., et al., 2007, A&A 473, 783