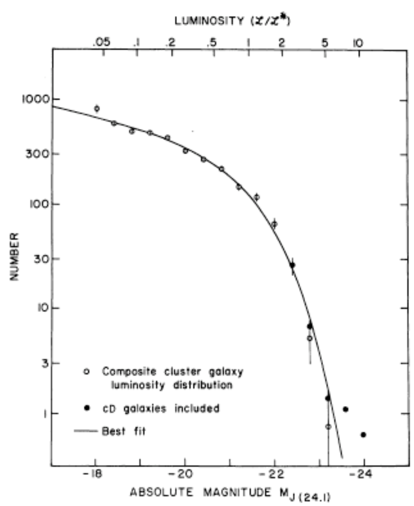
Galaxy Luminosity Function

- Count the number of galaxies as a function of luminosity (or absolute magnitude)
- Useful for:
  - Understanding galaxy formation (distribution by luminosity implies distribution by mass – how many galaxies of a given type and mass were formed)
  - Galaxy evolution models – either must reproduce observed LFs (hierarchal formation models) or assume them (and work backwards in time). Can also measure evolution in LFs vs. redshift!
  - Galaxy Properties

Galaxy Luminosity Function

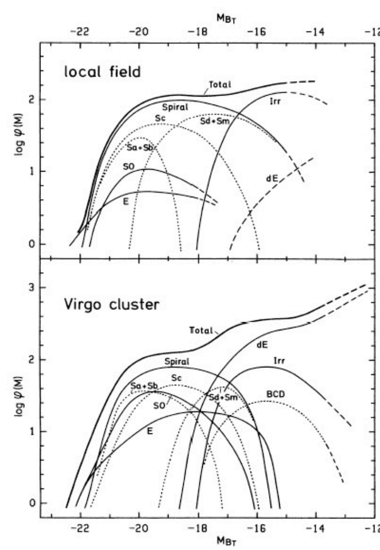
- Schechter (1976) found that
  - $\Phi(L)dL = \Phi^*(L/L^*)^{\alpha} \exp\{-L/L^*\}d(L/L^*)$
  - $\Phi(L)dL$ = # density of galaxies with luminosities between L and L+dL
  - Where L^* is a characteristic luminosity cutoff, α is the power-law slope at the faint end, Φ^* is the normalization (# galaxies/Mpc^3)
- Usually measured in magnitude:
  - $\Phi(M)dM = (0.4\ln10) \times \Phi^* \times 10^{0.4(\alpha+1)(M^*-M)} \times \exp\{-10^{0.4(M^*-M)}\}dM$

Schechter Function



Schechter (1976)

Schechter Function by environment

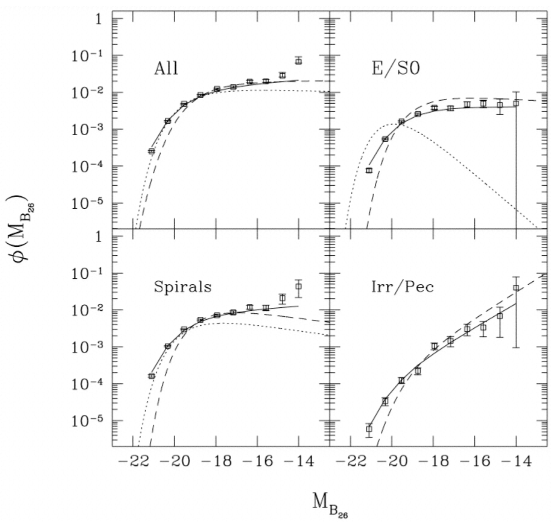


Bingelli (1988)

Field – dominated by Spirals, faint end dIrr

Clusters – many more E/S0 galaxies, faint end dE, more dwarfs than in field

Schechter Function by galaxy type



Marzke (1998)

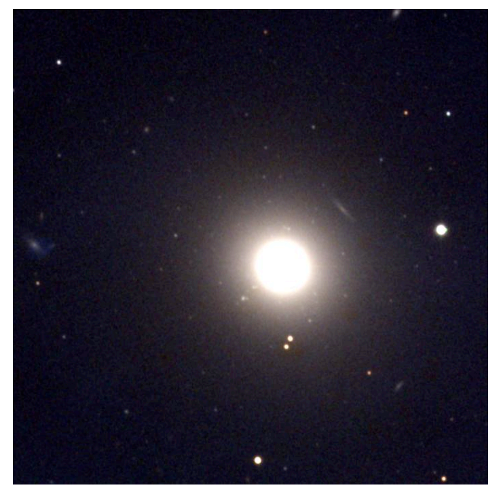
Integrating the Luminosity Function

- If we integrate the Schechter function, we get the total number of galaxies (per Mpc^3), we find:
  - $N = \int_0^\infty \Phi(L)dL = \Phi^* L^* \Gamma(\alpha+1)$
  - Where Γ is the gamma function, $\Gamma(j+1)=j!$ when j is an integer
  - If $\alpha<-1$, $\Gamma(\alpha+1)$ is undefined (!), and N is infinite!!
- We can also integrate to find the total luminosity
  - total lum = $\int_0^\infty L\Phi(L)dL = \Phi^* L^* \Gamma(\alpha+2)$, which diverges if $\alpha < -2$
  - so the total amount of light is finite! (Phew!!)

Approximate Schechter values:

- $M^* \sim -20.5$ (in B), depends on H_0
- $L^* \sim 2 \times 10^{10} L_\odot$ (~Milky Way)
- $\alpha \sim -1$ to -1.5
- Normalization is uncertain!
- Beware of comparing these numbers, as M^* and α are correlated. The Schechter function is just a parametric description.

Ellipticals



M89 – E0

Elliptical galaxies:

- Old view – (ellipticals are boring, simple systems)
  - Ellipticals contain no gas & dust
  - Ellipticals are composed of old stars
  - Ellipticals formed in a monolithic collapse, which induced violent relaxation of the stars, stars are in an equilibrium state
- New view
  - Some ellipticals have hot x-ray gas, some have dust
  - Ellipticals do rotate (speed varies)
  - Some contain decoupled (counter-rotating) cores
  - Some have weak stellar disks
  - Ellipticals formed by mergers of two spirals, or hierarchical clustering of smaller galaxies

Elliptical galaxies:

- Separate ellipticals by luminosity:
  - Luminous: L > L*, $M_B < -20$
  - Midsize: L ~0.1 – 1 L*, M_B=-18 to –20
  - Dwarfs: L < 0.1 L*, $M_B > -18$
- Luminous and midsize ellipticals have somewhat different properties, but form a single sequence
- Dwarf E's are significantly different!!

Elliptical galaxies:

- Luminosity profiles (1D):
  - Sersic profile: $I(r) = I(r_e) \exp\{-b(r/r_e)^{1/n} - 1\}$
  - r_e = effective radius which includes half the light (this defines the constant b), and $I(r_e)$ is the surface brightness at r_e
  - Typical elliptical galaxies have n=4, or follow an $r^{1/4}$-law or "de Vaucouleurs' law" proposed in 1948:
    - $I(r) = I(r_e) \exp\{-7.67 (r/r_e)^{1/4} - 1\}$
  - Light in ellipticals more concentrated towards center than for spirals
  - provides good description for surface brightness of mid to bright ellipticals outside the center, but not dE's
  - cD galaxies have an "outer envelope" of extended light
- Ellipticals show 2D symmetry
  - Some have weak ripples, shells, other fine structure (remnants of mergers?)
  - Also boxy and/or disky isophotes

De Vaucouleurs' Law

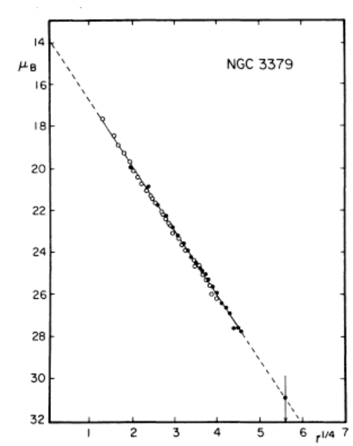


FIG. 2.—Mean E-W luminosity profile of NGC 3379 derived from McDonald photoelectric data. ●, Pe 4 data with 90 cm reflector; ○, Pe 1 data (M + P) with 2 m reflector. Note close agreement with $r^{1/4}$ law.

NGC 3379

De Vaucouleurs' Law

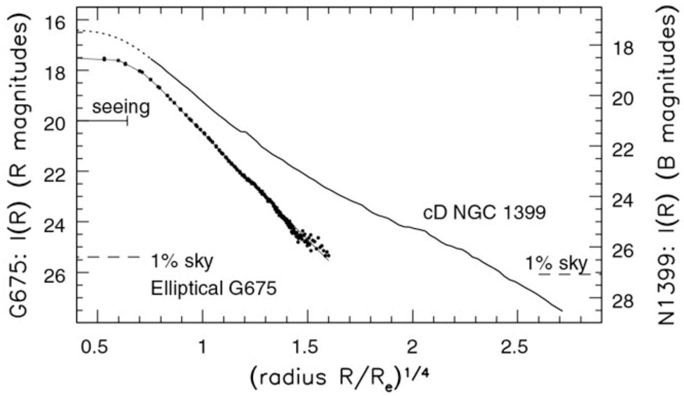


Fig 6.3 (Saglia, Caon) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

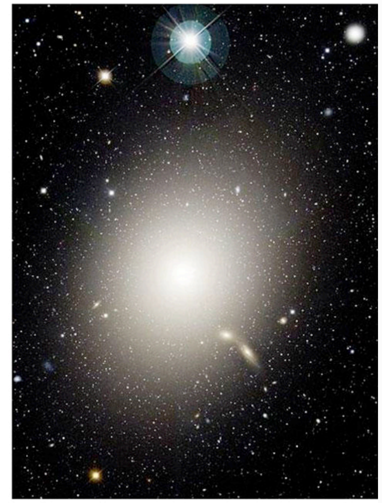


Fig 6.4 (CFHT/J.-C. Cuillandre/Coelum) 'Galaxies in the Universe' Sparke/Gallagher CUP 20

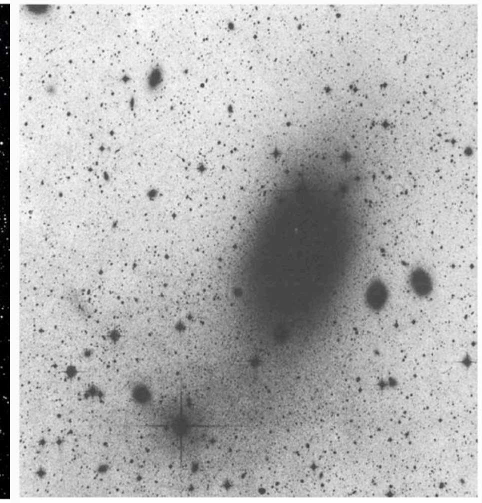


Fig 6.4 (D. Malin) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

M87 -- see starlight out to 70kpc

Surface Brightness Profiles

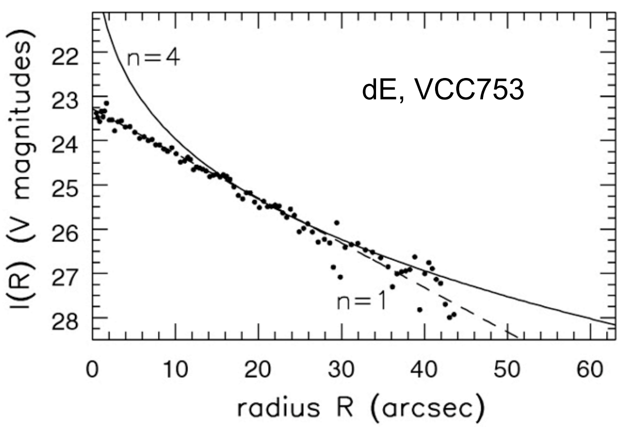
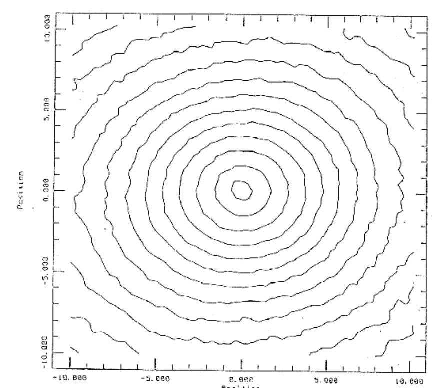


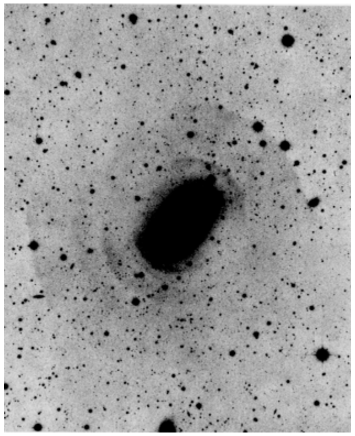
Fig 6.2 (H. Jerjen) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Typical elliptical isophotes



Central regions of the galaxy NGC 4649 out to radii of 10 arcsec.
The distance between the isophotes is 0.2 mag.
see: P. Surma (1988) *Diploma Thesis*

Shells



NGC 3923

Some ellipticals are not so simple …

Cen A

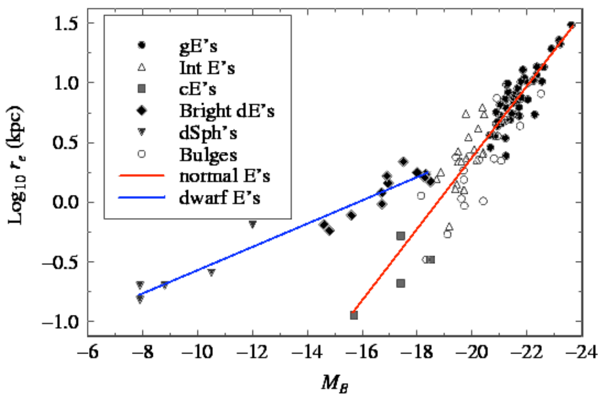
Elliptical galaxies:

- In general, ellipticals --
  - Pressure supported (little rotation), stellar motions are (mostly) random
  - No or very little disk component
  - No or very little star formation
  - No or very little cold (e.g., HI) gas, but contain hot, x-ray gas
  - Almost exclusively found in high density environments (clusters)
  - Populate a fundamental plane in luminosity-surface brightness-central velocity dispersion

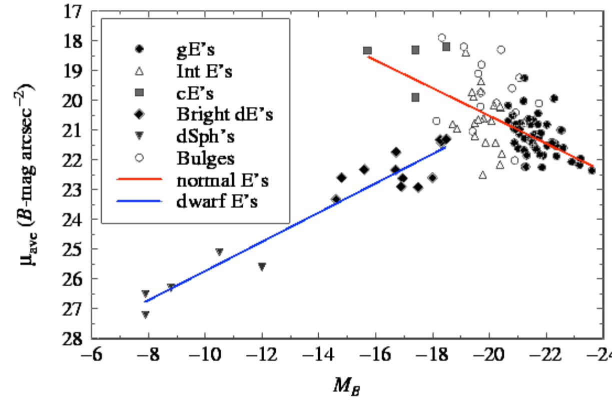
Elliptical galaxies:

- There are other correlations
  - Brighter ellipticals are bigger
  - Brighter ellipticals have lower average surface brightness
  - Can put the above two together to form the Kormendy relation – larger galaxies have lower surface brightnesses -- $\mu_{B,e}$ = 3.02 log r_e + 19.74
  - Brighter ellipticals have lower central surface brightness
  - Brighter ellipticals have larger core radii -- the core radius is the radius where the SB drops to ½ that of the central SB, I(r=0)

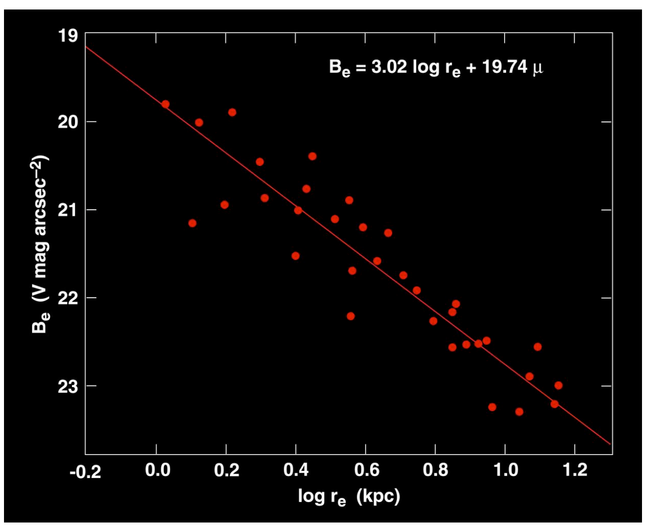
Effective radius vs Absolute magnitude



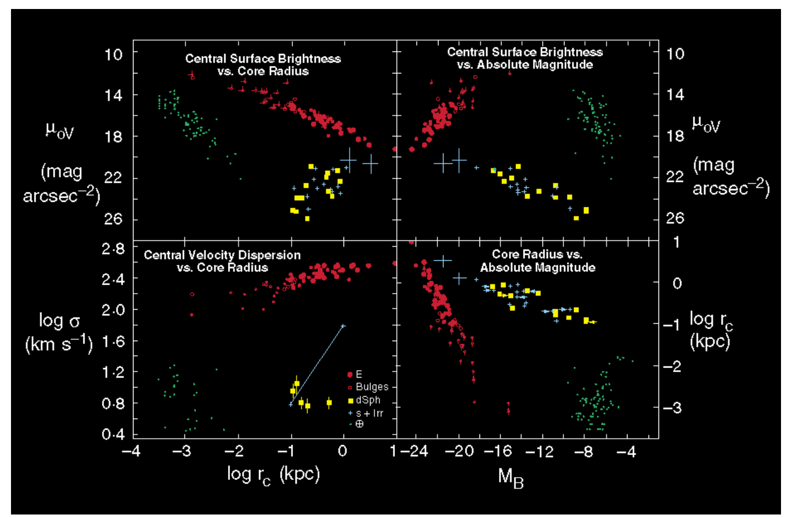
Average surface brightness vs Absolute magnitude



Kormendy relation (1977)



Central surface brightness & core radius relations (Kormendy)



Elliptical galaxies:

- With HST, we can study the nuclei of elliptical galaxies
  - Luminous ellipticals show central cores
  - Mid-sized ellipticals show central cusps, light continues to rise in SB towards center (power-law)

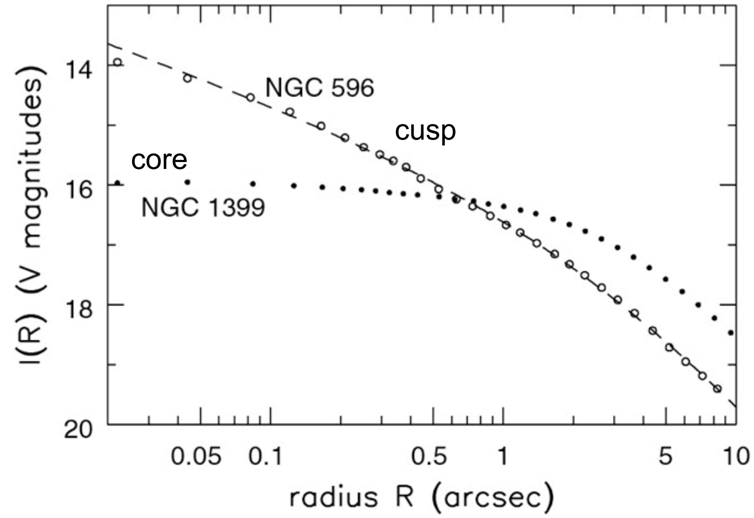


Fig 6.7 (T. Lauer) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Nuclei of Elliptical Galaxies, Faber et al. 1997

1774 FABER *ET AL.*: EARLY-TYPE GALAXIES. IV.

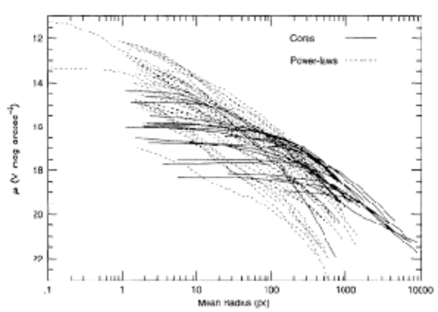
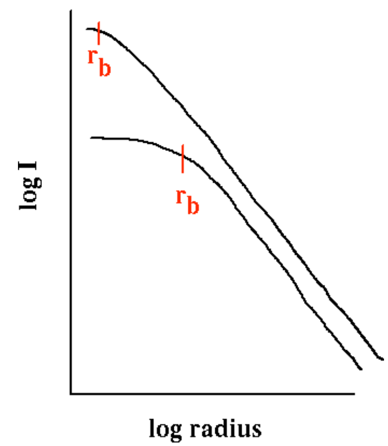


FIG. 1. *V*-band surface-brightness profiles of 55 ellipticals and bulges from *HST*. All were observed in the WFPC1 Planetary Camera through filter F555W and were deconvolved using the Lucy-Richardson algorithm as described in Paper I. Core galaxies (see Sec. 2) are plotted as solid lines, and power-law galaxies are plotted as dashed lines. "Mean radius" is the geometric mean of the semimajor and semiminor axes of the isophotal ellipse.

Definition of Break radius

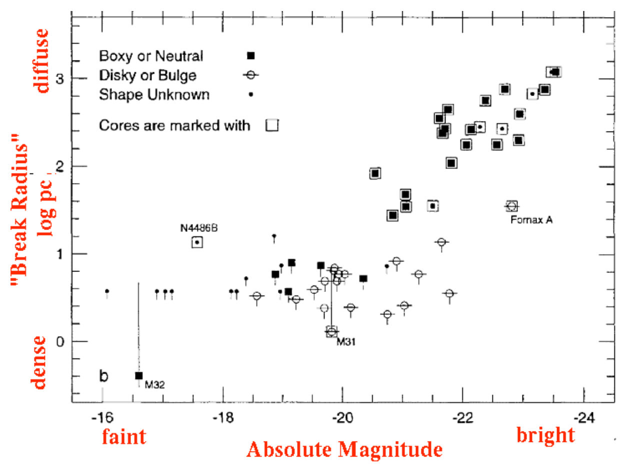


$$I(r) = I_b 2^{(\beta-\gamma)/\alpha} (r_b/r)^{\gamma} [1+(r/r_b)^{\alpha}]^{(\gamma-\beta)/\alpha}$$

r_b = break radius where power-law changes slope and I_b is the surface brightness at the break

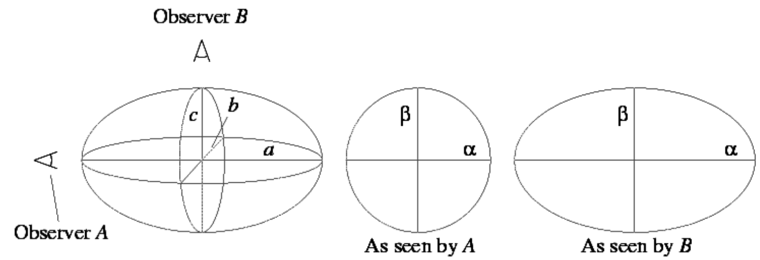
This is a five(!) parameter fit:
β is the outer power-law slope
γ is the inner power law slope
α defines the sharpness of the transition

Break radius vs. Absolute magnitude



Shape of Ellipticals:

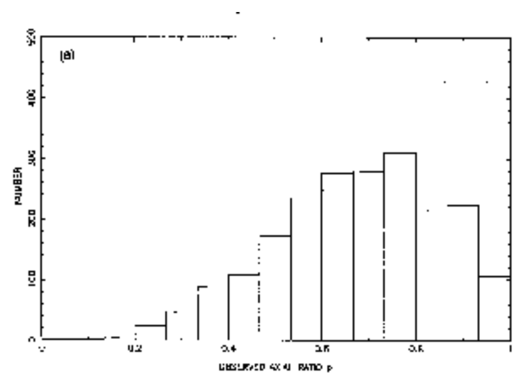
- Ellipticals are defined by En, where n=10ε, and ε=1-b/a is the ellipticity.
- Note this is not intrinsic, it is observer dependent!



Shape of Ellipticals:

- 3-D shapes – are ellipticals predominantly:
  - Oblate: A=B>C (a flying saucer)
  - Prolate: A>B=C (a cigar)
  - Triaxial A>B>C (a football)
  - Note A,B,C are intrinsic axis radii
- Want to derive intrinsic axial ratios from observed
  - Can deproject and average over all possible observing angles to do this
  - Find that galaxies are mildly triaxial:
    - A:B:C ~ 1:0.95:0.65 (with some dispersion ~0.2)
  - Triaxiality is also supported by observations of isophotal twists in some galaxies (would not see these if oblate or prolate)

Observed axial ratio distribution:



a/b

Twisty isophotes:

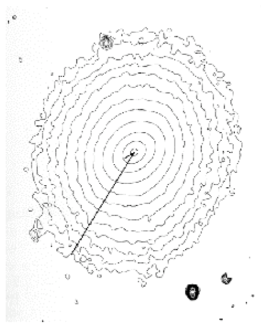


Fig. 4.— Isophotes of the elliptical galaxy NGC 5831 (classified as E3). Notice the isophotal twists from 4 arcseconds to 40 arcseconds (their major-axes are indicated in the plot).

NGC 5831

Shape of Ellipticals – disky/boxy

- Galaxies do not have perfect elliptical isophotes – typical deviations of a few %
- Deviations from ellipses can be classified as disky or boxy
- Measure difference between observed isophote and fitted ellipse as:
  - $\Delta r(t) \approx \Sigma_{k \geq 3}\, a_k \cos(kt) + b_k \cos(kt)$
  - t = angle around ellipse, $\Delta r(t)$ is distance between fitted ellipse and observed isophote
  - a_3 and b_3 describe "egg-shaped" ellipses, generally small, b4 is also usually small
  - $a_4 > 0$, isophote is disky (pushed out)
  - $a_4 < 0$ isophote is boxy (peanut shaped)

Disky and boxy elliptical isophotes

FIGURE 3. — Distribution of the ellipticity classes for all observed elliptical galaxies.

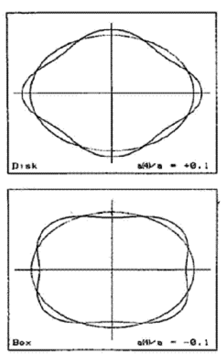


FIGURE 5. — Schematic drawing illustrating isophotes with $a(4)/a = +0.1$ and $a(4)/a = -0.1$.

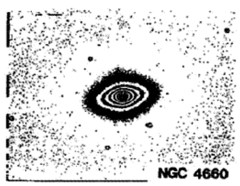


FIGURE 6. — R-image of NGC 4660, an elliptical galaxy with a disk-component in the isophotes ($a(4)/a \sim +0.03$).

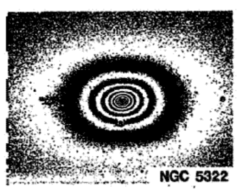


FIGURE 7. — R-image of NGC 5322, an elliptical galaxy with box-shaped isophotes ($a(4)/a \sim -0.01$).

Examples for boxy and disky isophotes from Bender et al. (1988)

Shape of Ellipticals – disky/boxy

- Disky/boxy correlates with other galaxy parameters:
  - Boxy galaxies more likely to show isophotal twists (and hence be triaxial)
  - Boxy galaxies tend to be more luminous
  - Boxy galaxies have strong radio and x-ray emission
  - Boxy galaxies are slow rotators
  - In contrast – disky galaxies are midsized ellipticals, oblate, faster rotators, less luminous x-ray gas