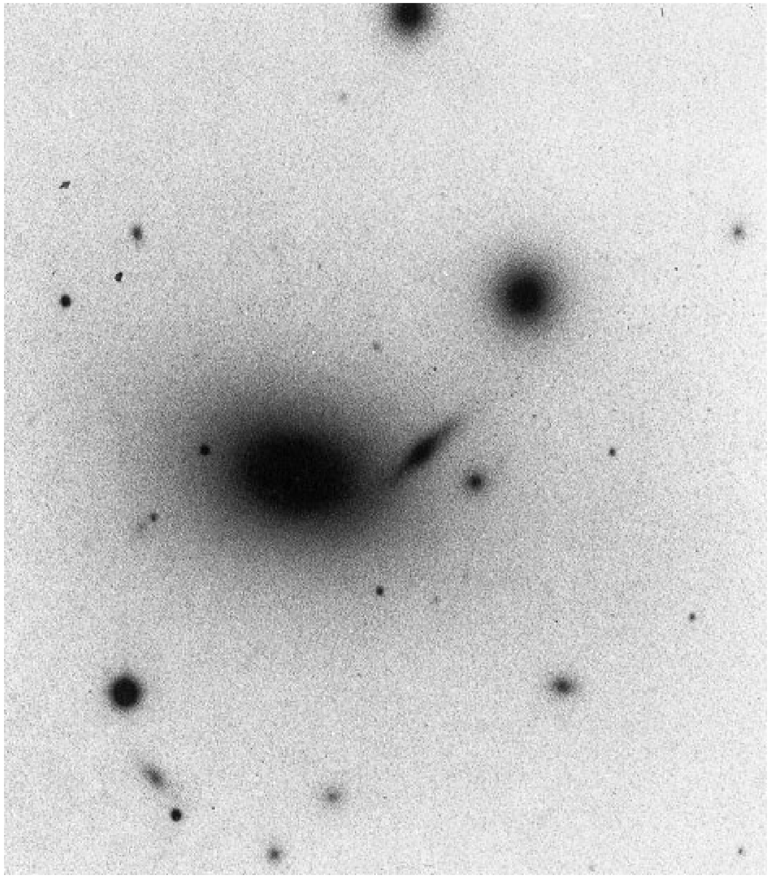
Elliptical Galaxies

NGC 4552 (E0)



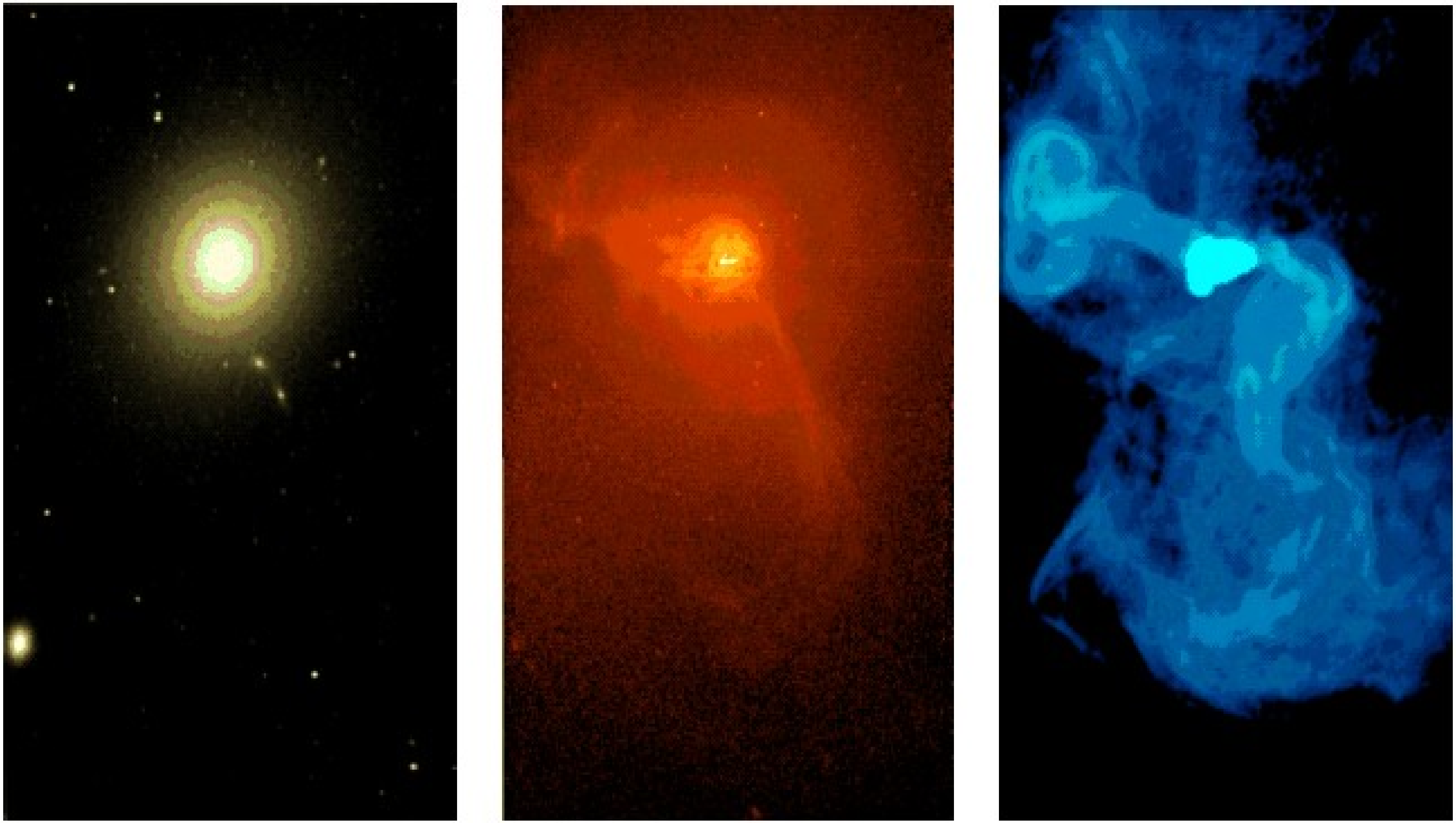
NGC 4889 (E4)

Ellipticals cont.

- Traditional view
  - Ellipticals are simple and dull systems
    - Little or no gas or dusk
    - Old stars
    - Form in a single collapse much like the GC simulation (violent relaxation)
    - Currently in equilibrium

Ellipticals cont.

- Modern view
  - Ellipticals can be complex systems
    - X-ray gas and dust lanes
    - Some have young stars
      - Often in a dynamically distinct disk
    - Some ellipticals have significant rotation
    - Formation is a more complex process, merger of two spirals? Hierarchical accretion of smaller ellipticals? Both?



M87 in the optical X-ray and radio and at the same scale.

Ellipticals cont.

- We can roughly segregate E's by luminosity
  - Luminous: $L > L_*$, $M_B < -20$, $L \approx 2x10^{10} L_\odot$,
  - Mid-sized: $L \sim (0.1\text{-}1.0) L_*$, $M_B < -18$ to -20, $L \approx 3x10^{9} L_\odot$,
  - Dwarf: $L < 0.1 L_*$, $M_B > -18$, $L < 3x10^{9} L_\odot$,
- Unlike disk galaxies once you have measured the luminosity of an elliptical you can predict the other properties very accurately!

Ellipticals cont.

- 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" (de Vaucouleurs1948)
    - $I(r) = I(r_e) \exp\{-7.67\,(r/r_e)^{1/4}-1\}$

Ellipticals cont.

- The de Vaucouleurs' law
  - provides good description for surface brightness of mid to bright ellipticals outside the center
  - 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

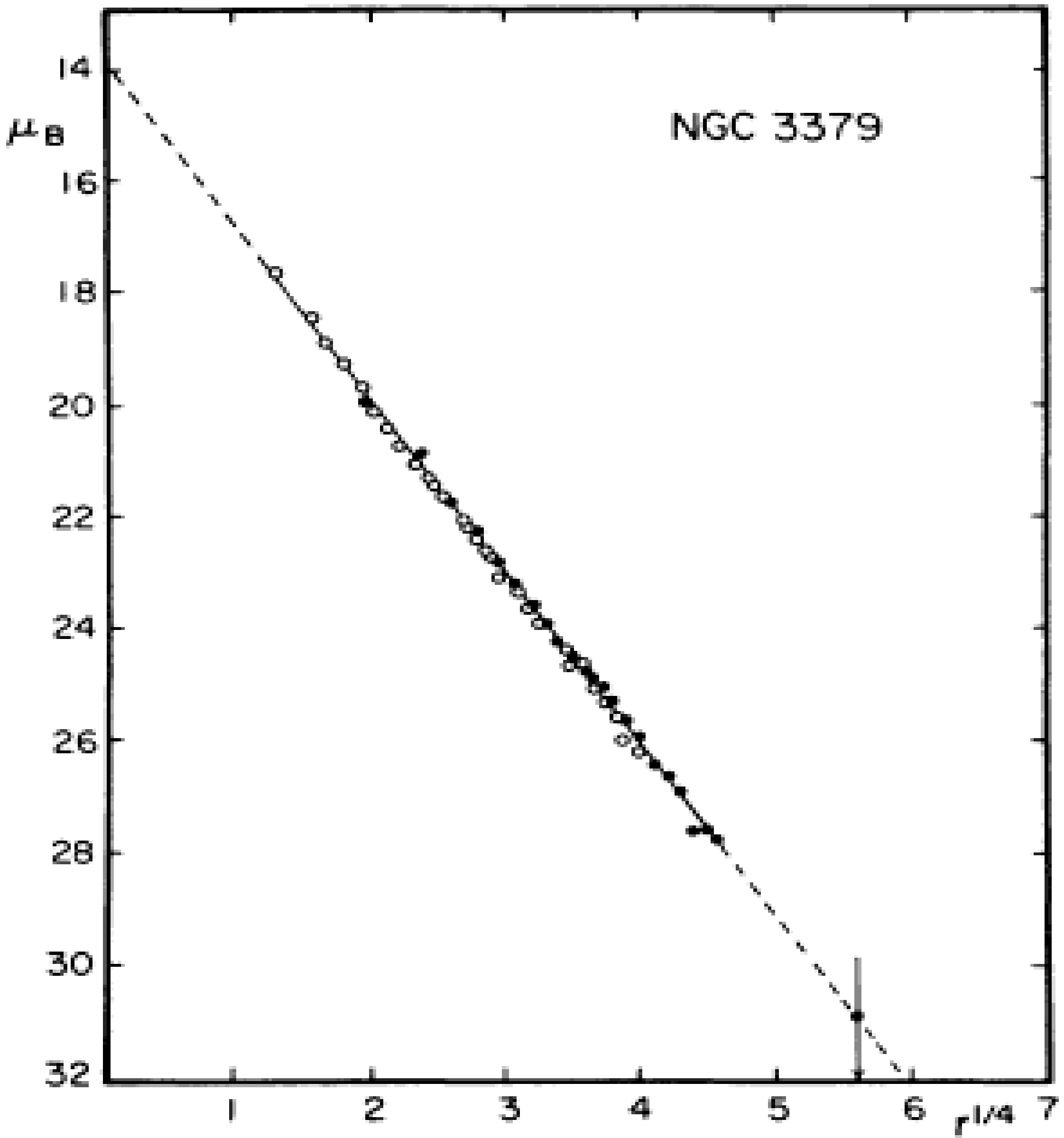
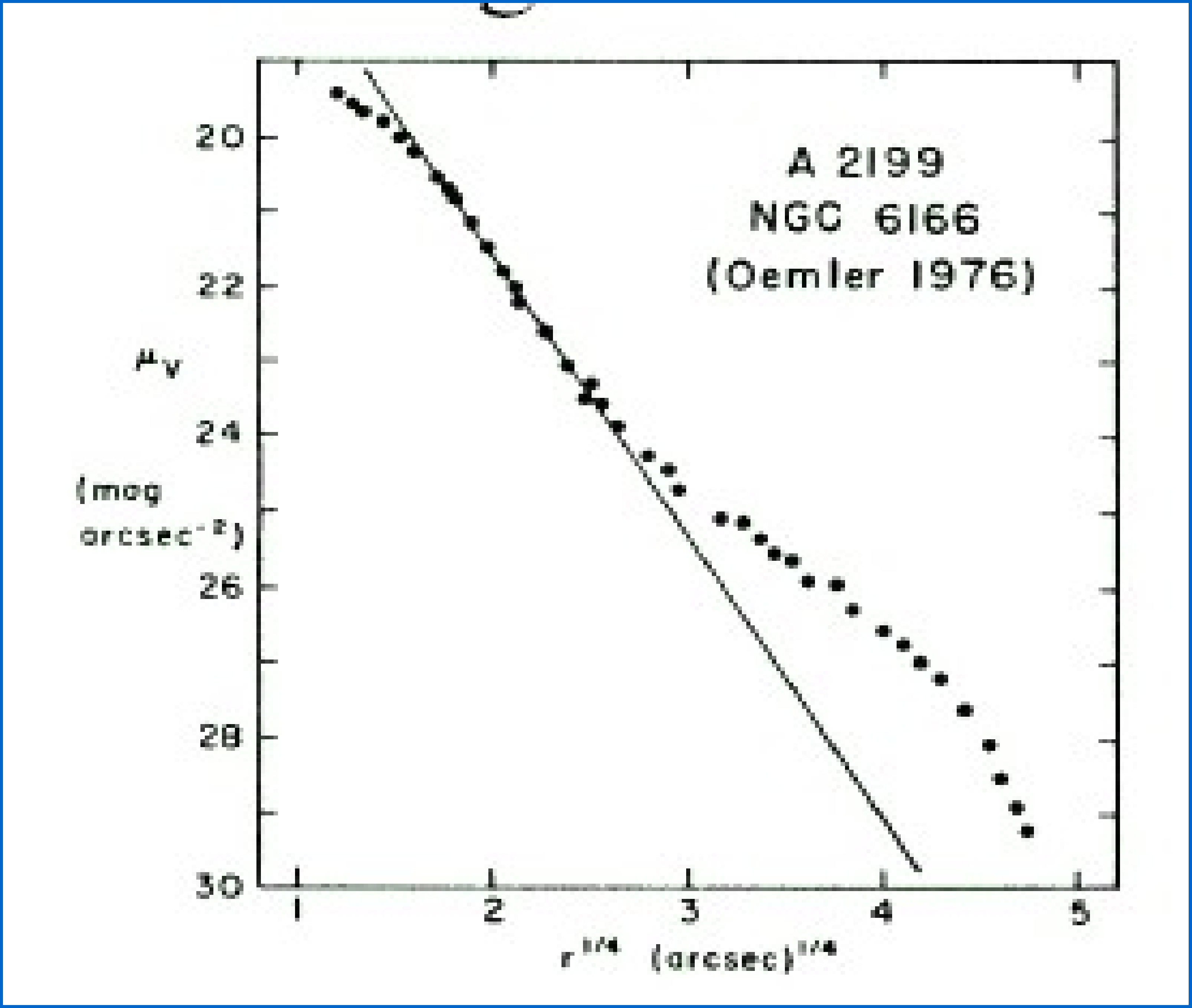


FIG. 2.—Mean E-W luminosity profile of NGC 3379 derived from McDonald photoelectric data. ●, Pe 4 data with 90 cm reflector; ○, Pe 1 data (M + P) with 2 m reflector. Note close agreement with $r^{1/4}$ law.


A 2199
NGC 6166
(Oemler 1976)
μ_V
(mag arcsec^{-2})
20
22
24
26
28
30
1
2
3
4
5
$r^{1/4}$ (arcsec)$^{1/4}$

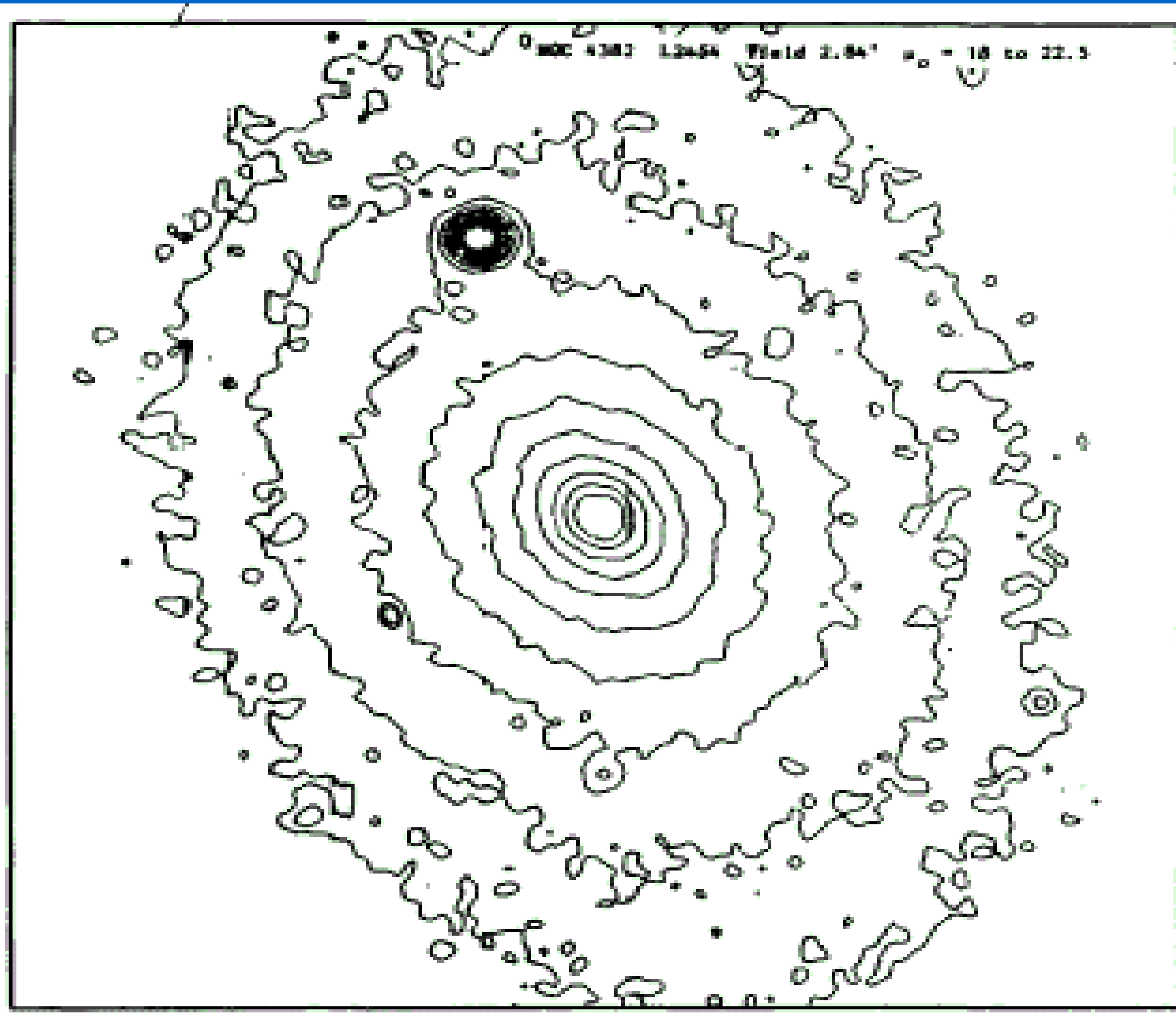


FIGURE 5.5.

Michard 1985

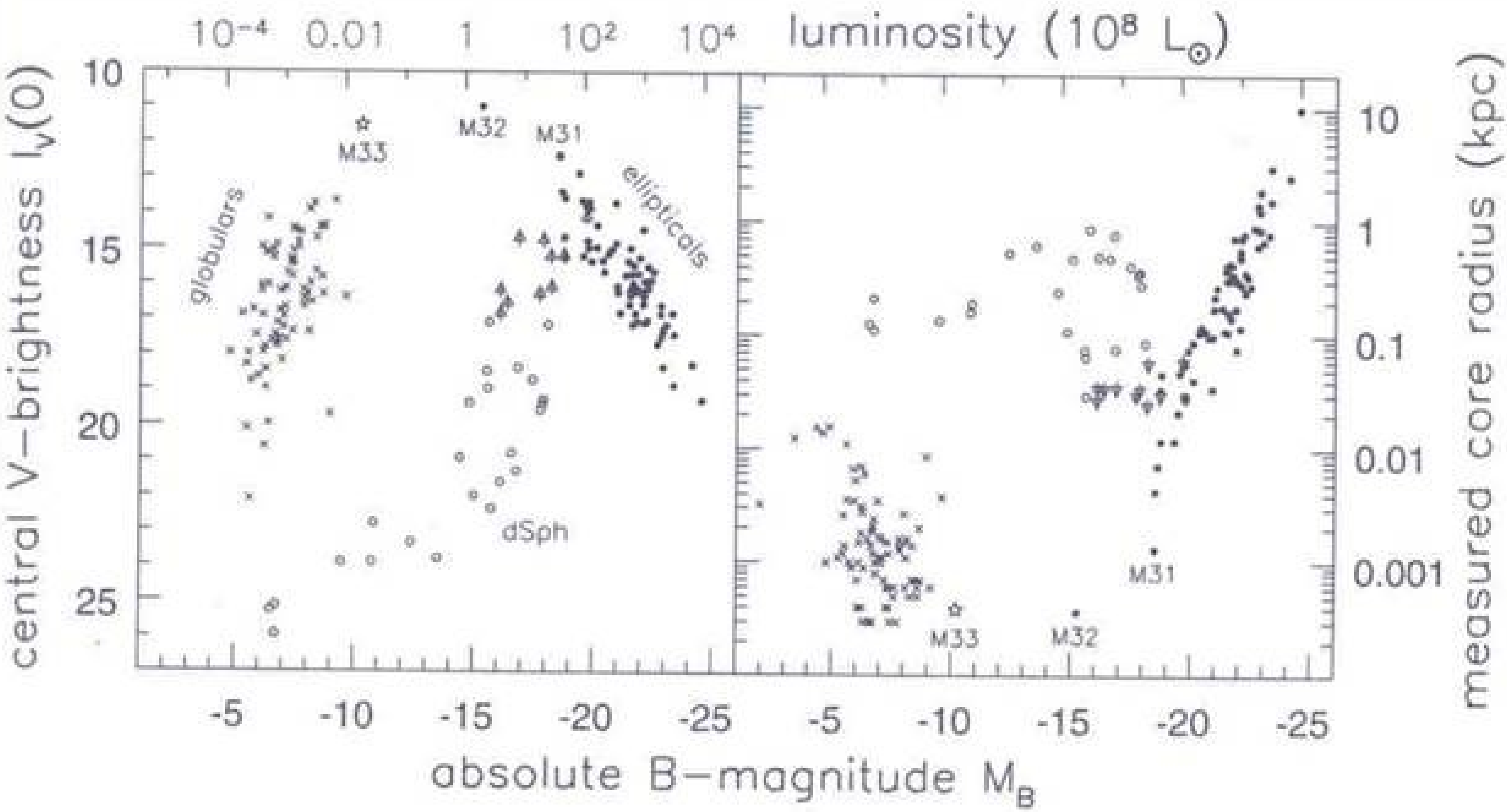
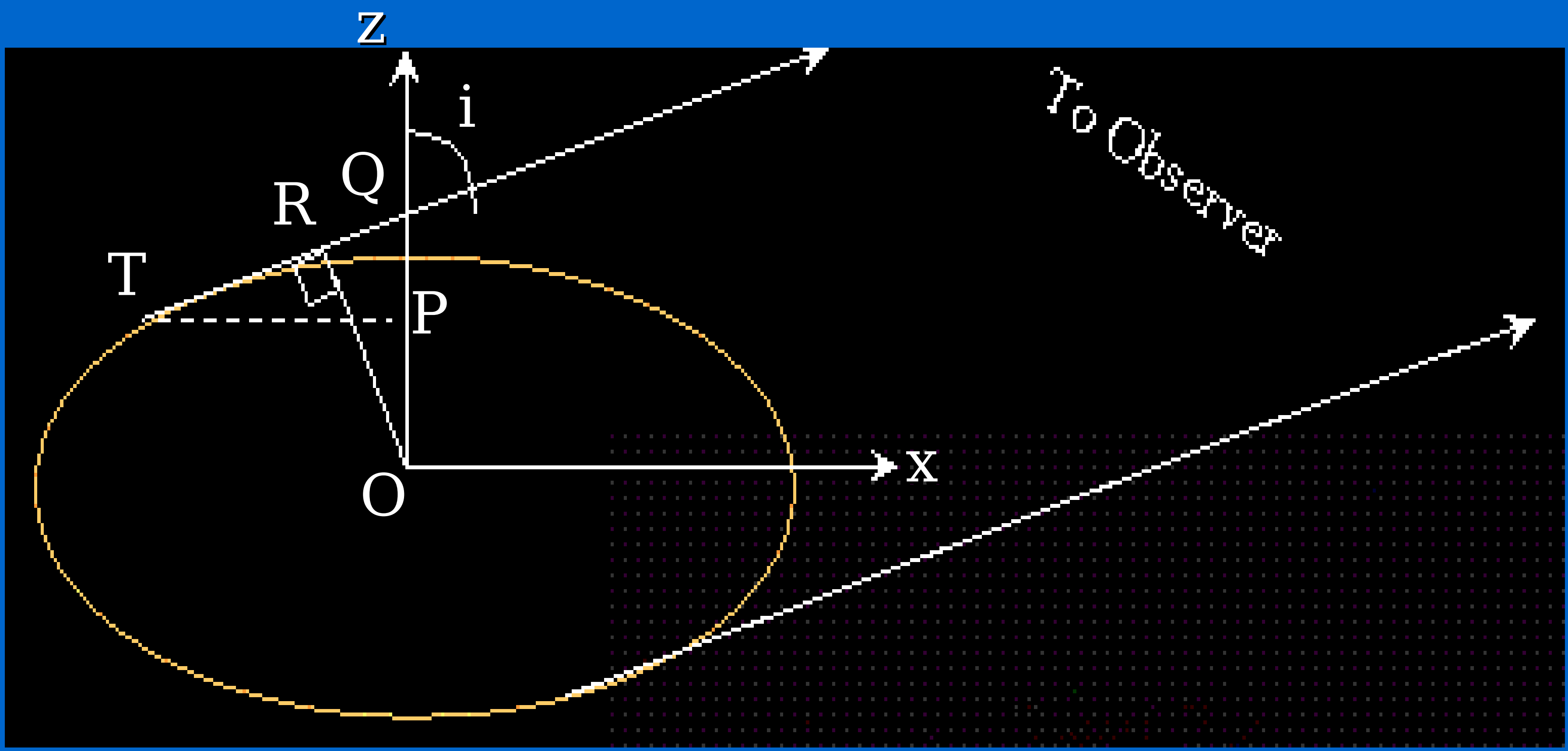


Figure 6.6 Central surface brightness $I_V(0)$ in mag arcsec^{-2} in the V band, and core radius r_c, measured from the ground, plotted against B-band luminosity M_B. Filled circles are elliptical galaxies and bulges of spirals (including the Andromeda galaxy M31); open circles are dwarf spheroidals; crosses are globular clusters; the star is the nucleus of Sc galaxy M33. Arrows show ellipticals in the Virgo cluster; here, seeing may cause us to measure too low a central brightness, and too large a core – J. Kormendy.



If elliptical galaxies are oblate spheriods then

$$\rho(\boldsymbol{x}) = \rho(m^2) \; where \; m^2 = \frac{x^2 + y^2}{A^2} + \frac{z^2}{B^2} \quad \text{with } A \geq B > 0$$

So an observer looking along the z axis would see an E0 (round) galaxy, when viewed at an angle you would see an elliptical shape with apparent axis ratio q = b/a. Looking at the tangent point to the elliptical surface (T) the coordinates of this point are

$$\tan i = \frac{dx}{dz} = -\left(\frac{z}{x}\right)\left(\frac{A^2}{B^2}\right)$$

The elliptical image of this surface has a semi-major axis of a = mA and the semi-minor axis b is OR and this is also OQ sin(i). So from the equations above we can write

$$OQ = OP + PQ = z + (-x)\cot(i) = \frac{B^2 m^2}{z};$$

If q is the ratio of the minor to the major axis then

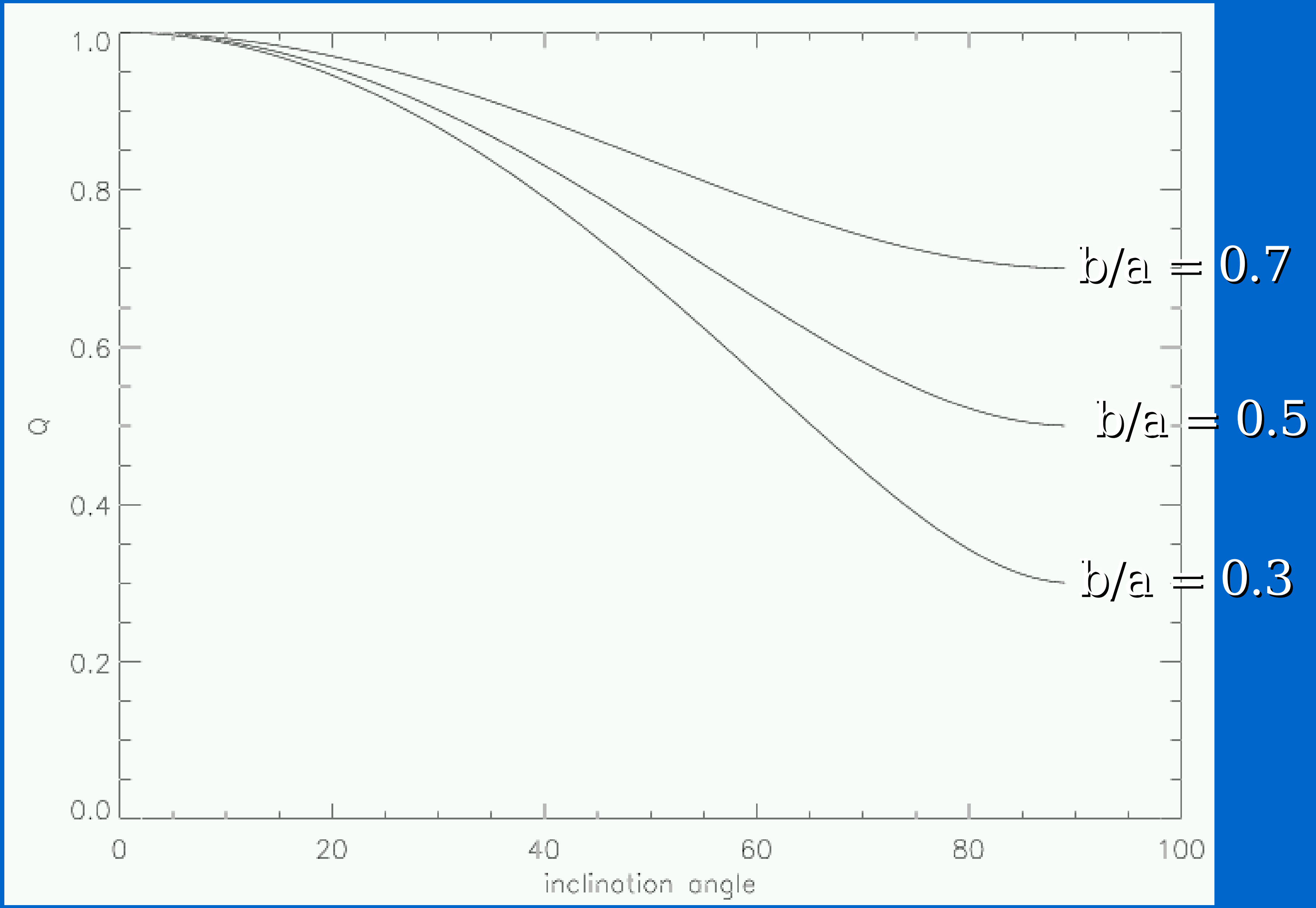
$$q_{obl}=\frac{b}{a}=OQ\ \frac{\sin(i)}{mA}=\frac{B^2 m}{zA}\sin(i)=[\frac{B^2}{A^2}+\cot^2(i)]^{1/2}\sin(i)$$

Using our definition of m for the last step. Finally we can rewrite this as

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

For an oblate spheroid we can do all this again and get

$$q_{prol}^2=(b/a)^2=[(B/A)^2\sin^2(i)+\cos^2(i)]^{-1}$$


1.0
0.8
0.6
0.4
0.2
0.0
Q
0
20
40
60
80
100
inclination angle
b/a = 0.7
b/a = 0.5
b/a = 0.3

Distribution of B/A

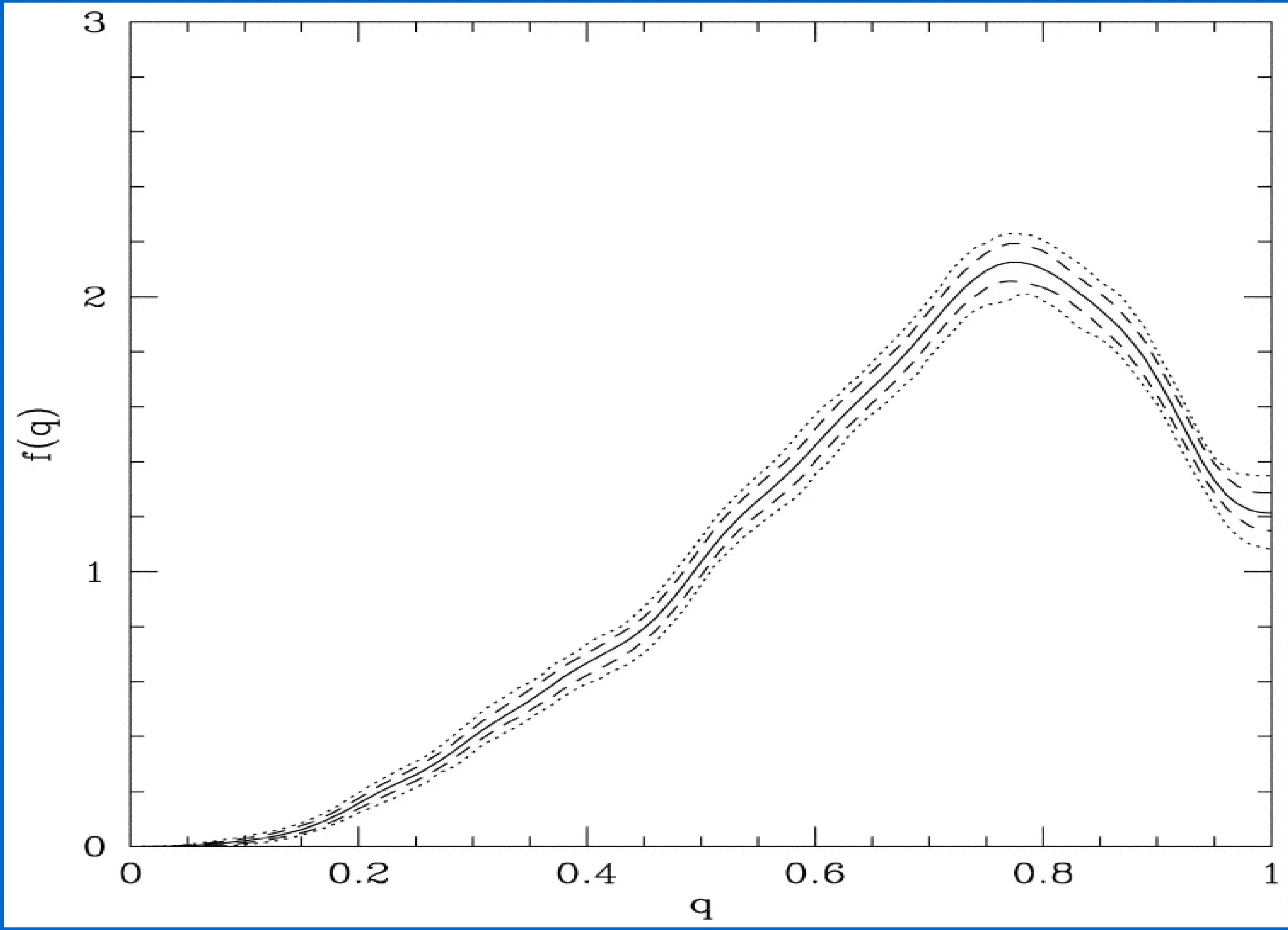
Looking from a random direction what fraction of galaxies do we see between i and i+Δi? It's just sin(i) Δi
So if all galaxies have an axial ratio of B/A then the fraction with apparent ratios between q and q + Δq is

$$f_{obl}(q)\Delta q = \frac{\sin(i)\Delta q}{dq/di} = \frac{q\Delta q}{\sqrt{1-(B/A)^2}\sqrt{q^2-(B/A)^2}}$$

For very flattened systems, B<<A the distribution is almost uniform

Distribution of B/A cont.

- The disks of spiral and S0 galaxies the apparent shapes with $q \approx 0.2$ are found with equal probability.
  - So we conclude that in general their disks have $B/A \leq 0.2$
  - We see very few spirals with $q \leq 0.1$ which means that very few spirals have $B/A \approx 0.1$
- No ellipticals flatter than E7 ($q = 0.3$)
  - Dynamically unstable?



Axial ratios for galaxies fit with de Vaucouleurs profiles (Khairul Alam & Ryden 2002).

Distribution of B/A cont.

- Small E's are more elongated that more luminous E's
- Mid-sized E's have q≈0.75
- Luminous E's have q≈0.85
  - No selection of oblate spheroids can give the observed distribution
  - These galaxies must be triaxial

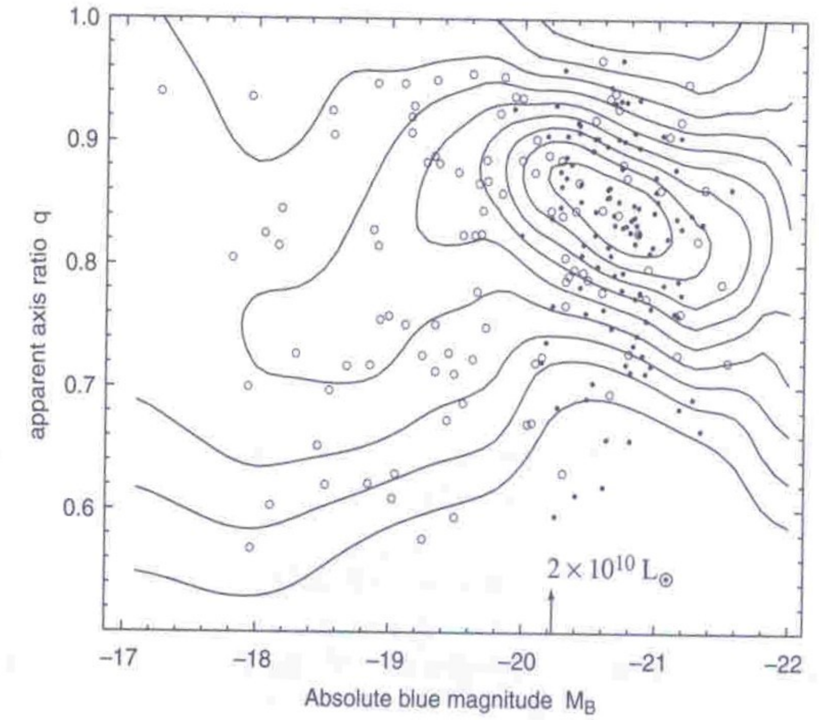
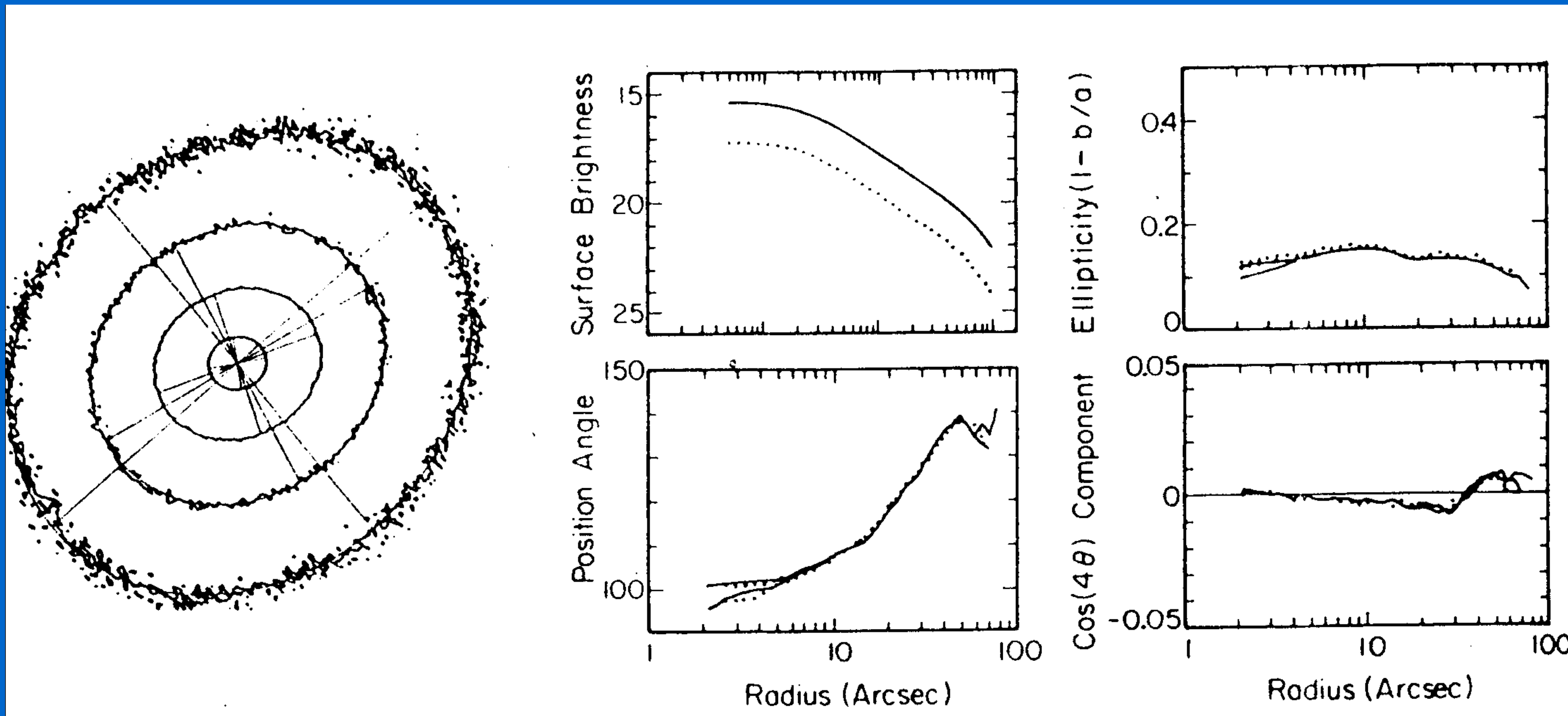


Figure 6.9 Observed axis ratio q and blue absolute magnitude M_B for elliptical galaxies from two different samples, represented by filled and open circles. Bright galaxies (on the right) on average appear rounder. Contours show probability density; the top contour level is 4.5 times higher than at the lowest, with others equally spaced – B. Tremblay & D. Merritt, AJ 111, 2243; 1996.

Isophotal Shapes

- While elliptical galaxy isophotes are close to ellipses small deviations do occur
- We see
  - Twisting isophotes
  - Disky isophotes
  - Boxy isophotes



igure 1: Surface brightness distribution of the elliptical galaxy NGC 1549 taken

X-ray Halos cont.

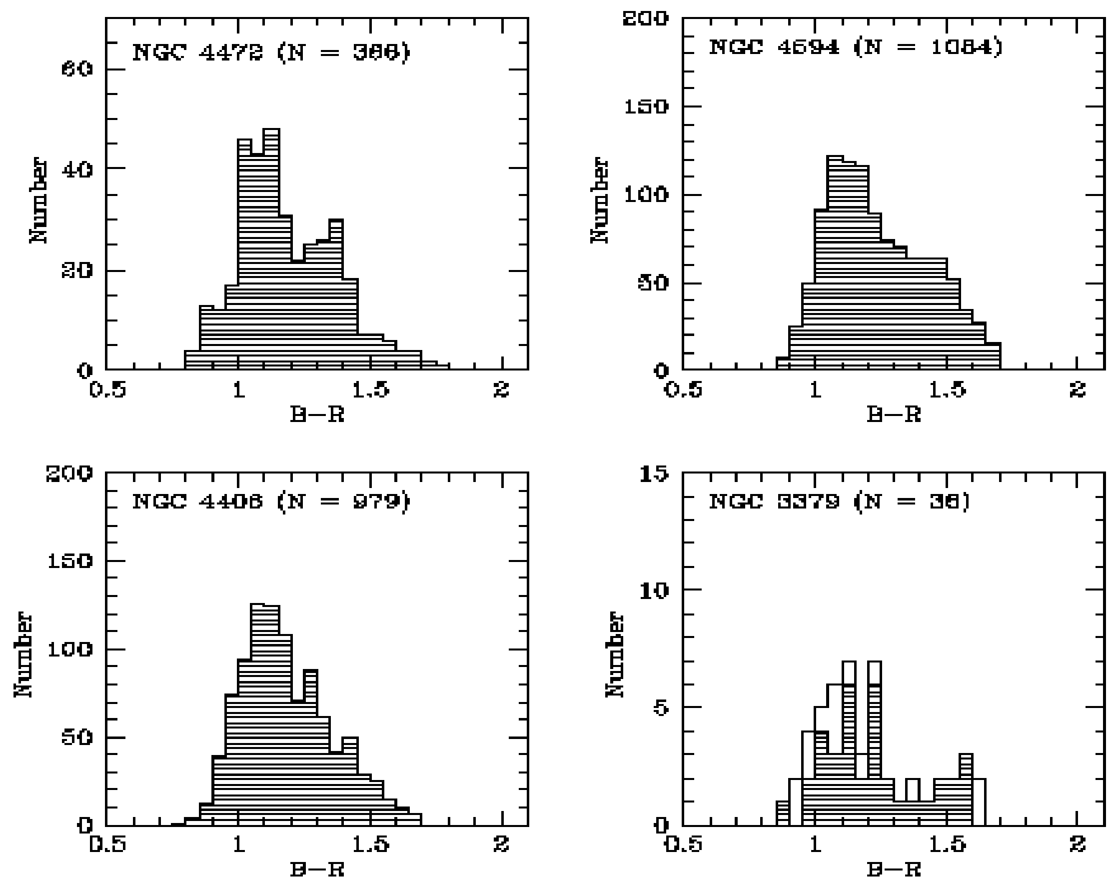
- Where does the hot gas come from
  - We know that it is metal rich (Z~0.5 solar)
  - Stellar winds from red giants and red supergiants
    - Random velocities ≥ 350 km/s and we know that $(1/2)m\sigma^2 \sim 3/2\ kT$
    - So when the stellar winds collide it heats the gas to $> 10^6$ K
- The mass of hot gas can be from $10^8 - 10^{11}\ M_\odot$

Globular Clusters in Ellipticals

- Ellipticals are surrounded by a halo of globular clusters (~ 2x the number of a spiral with similar luminosity)
- Colors of globular clusters show a bimodal distribution in ellipticals
- This is probably due to metallicity, so there is a population of metal poor and a population of metal rich GCs

E2

S0's



E3

E5

Fig. 9.— $B-R$ distributions for the early-type galaxy sample, including NGC 4473 from Paper I. For NGC 3379, the 36-object sample used to estimate the blue/red GC proportions is shown as a shaded histogram and the 50-object sample used as input to KMM is plotted with a solid line.

Rhode & Zeph (2004)
What does this mean?

Globular Clusters in Ellipticals cont.

- This could be caused by the
  - Merger of two galaxies – metal poor clusters are old, metal rich clusters formed during merger process
  - Hierarchical formation – Metal poor GC's are form at an early time and the metal rich population builds up during accretion of gas rich spirals