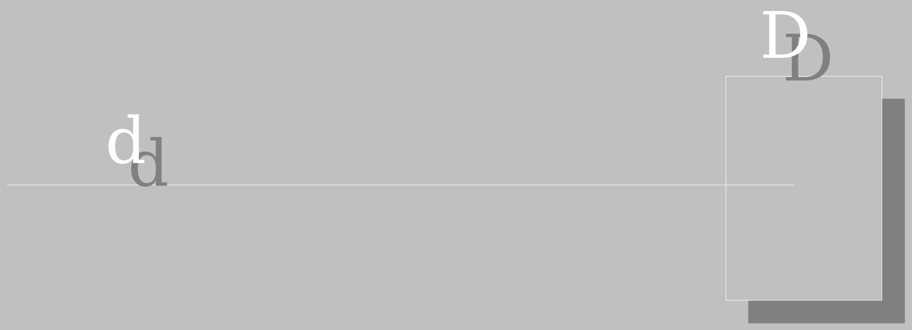
Measuring Galaxy Luminosities

Galaxy luminosities are much harder to measure than stellar luminosities because they are extended objects and have no well defined edges

We define the surface brightness of a galaxy to as the amount of light per square arcsecond on the sky.



If we have a square patch with side length D, in a galaxy at a distance d from us we see that this subtends an angle $\alpha = D/d$ on the sky.

If we look at the luminosity of all the stars in this small patch L, then the total flux we see is

$$F = \frac{L}{4\,\pi\,d^2}$$

And we can define surface brightess as

$$I \equiv \frac{F}{\alpha^2} = \frac{\frac{L}{4\,\pi\,d^2}}{\frac{D^2}{d^2}} = \frac{L}{4\,\pi\,D^2}$$

The units for surface brightness is mag arcsec^{-2}. So if a galaxy has a surface brightness of 20 mag arcsec^{-2} then we receive as many photons from one square arcsecond of the galaxy that we would observing a 20th magnitude star.

Typical surface brightness values for galaxies are about 18 mag arcsec^{-2} in the center.

To find the total brightness of a galaxy we need to integrate the light coming from all parts of the system. Since galaxies do not have sharp edges we typically measure the brightness out to some brightness called the limiting isophote.

Measurements are typically integrated out to some limiting isophote and is called the isophotal magnitude. A typical limit is 25 mag arcsec^{-2}. This is usually measured in the B band ($\lambda_{\mathrm{Central}}$ = 4400Å.)

Properties of Bulges

Bulges are some of the densest stellar systems. They can be flattened, ellipsoidal or bar-like. The surface brightness of a bulge is often approximated by the Sersic law:

$$I(R) = I(0)\ \exp\{-(R/R_0)^{1/n}\}$$

Recall that n=1 corresponds to an exponential decline, and n=4 is the de Vaucouleurs law.

About half of all disk galaxies contain a central bar-like structure. The long to short axis ratio can be as large as 5:1.

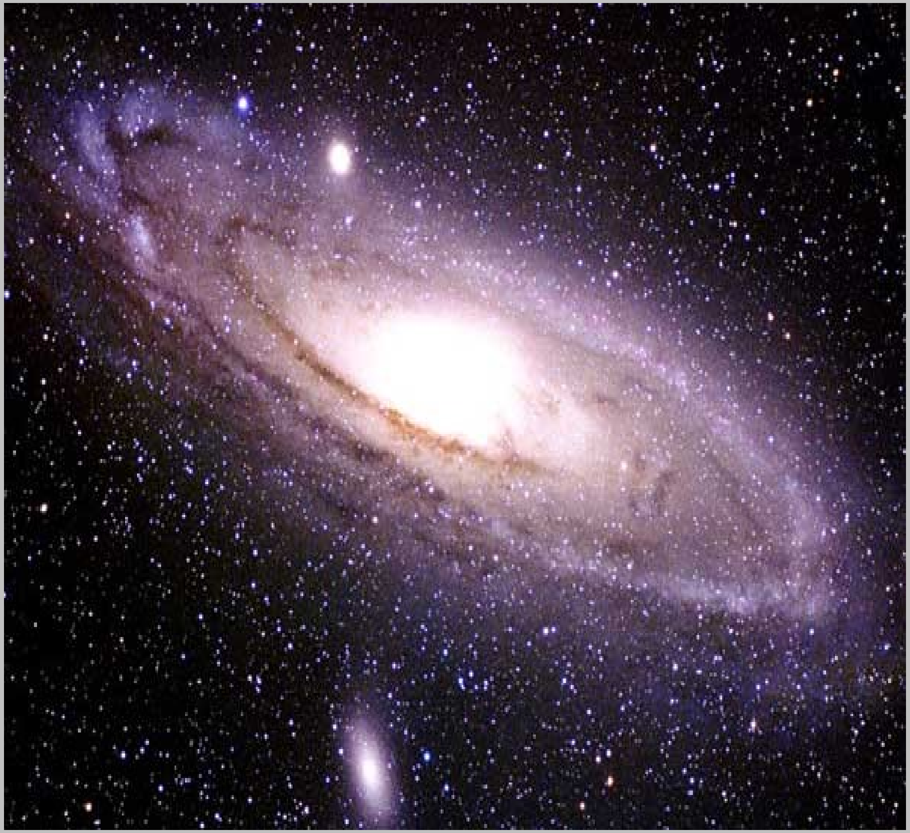
When viewed edge-on, the presence of a bar can be noticed from the boxy shape of the halo. In some cases the isophotes are squashed, and the bulge/bar has a peanut-like shape.

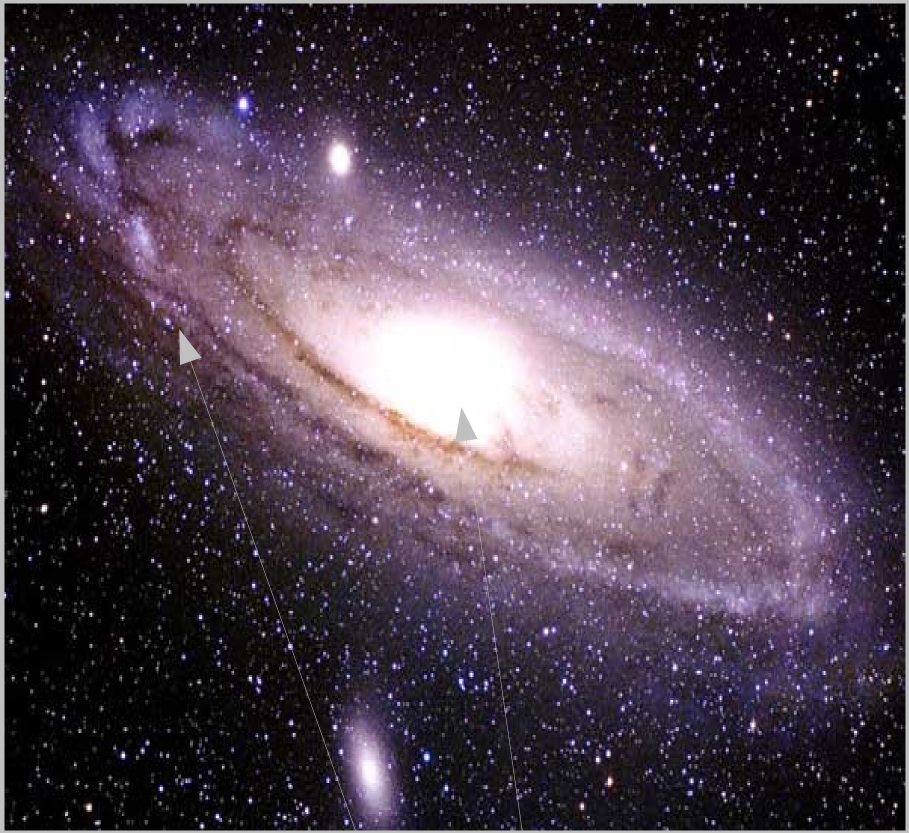
Colors of Disk Galaxies

M31 is the closest spiral galaxy (besides the MW)

At r< 6 kpc the bulge dominates the light and the color is similar to an E galaxy

Further out the young stars contribute more and more to the light





Population I & II

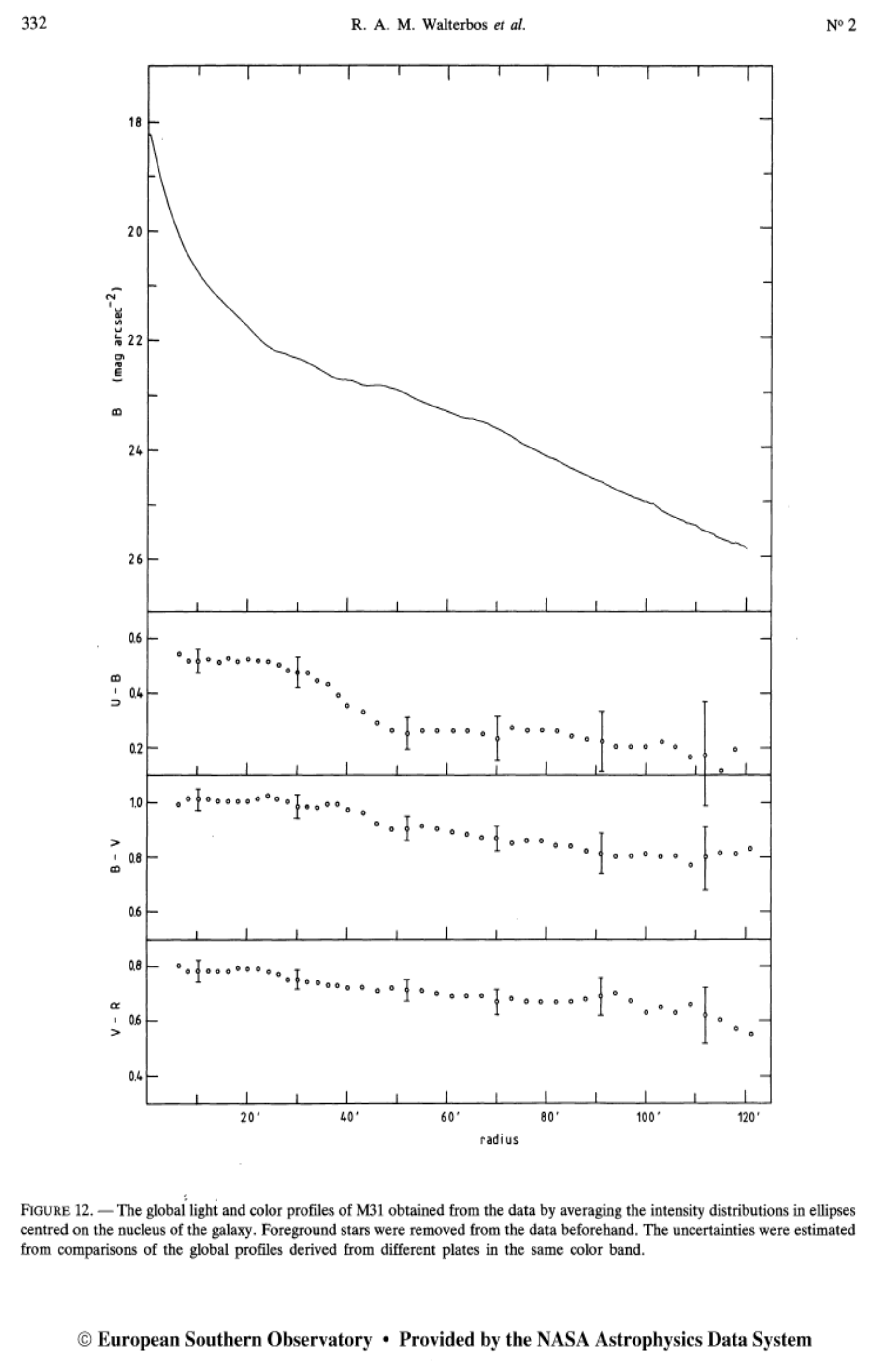


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FIGURE 12. — The global light and color profiles of M31 obtained from the data by averaging the intensity distributions in ellipses centred on the nucleus of the galaxy. Foreground stars were removed from the data beforehand. The uncertainties were estimated from comparisons of the global profiles derived from different plates in the same color band.

Stellar Populations I & II

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC05-01

- Population I
  - Young
  - Metal rich
  - Found in galaxy disks
- Population II
  - Old
  - Metal poor
  - Found in Globular clusters, Spiral bulges and Ellipticals

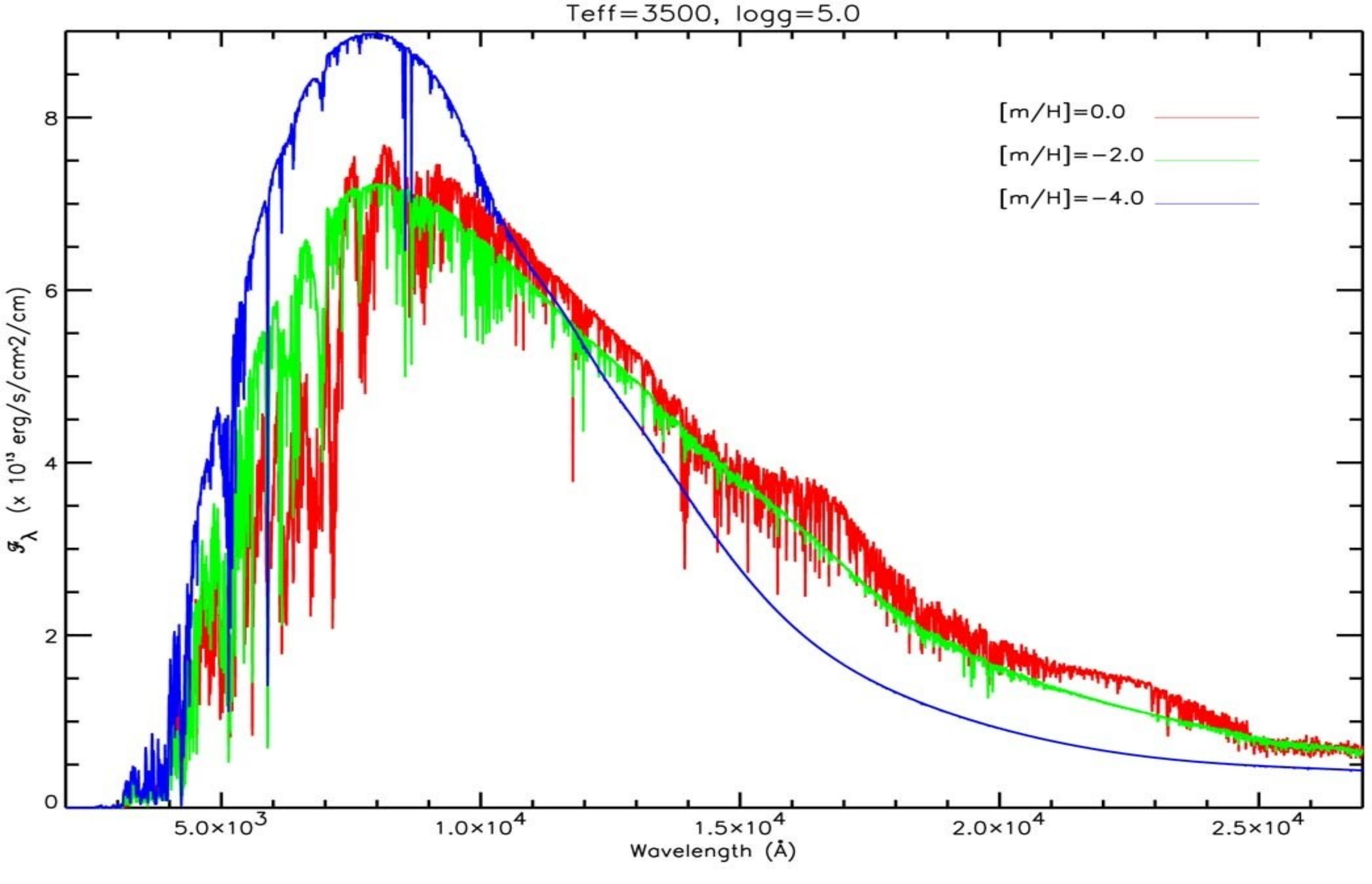
But remember there are several effects that can complicate the picture

1) Metallicity – metal poor stars are bluer than metal rich stars

2) Age – younger stars are generally bluer

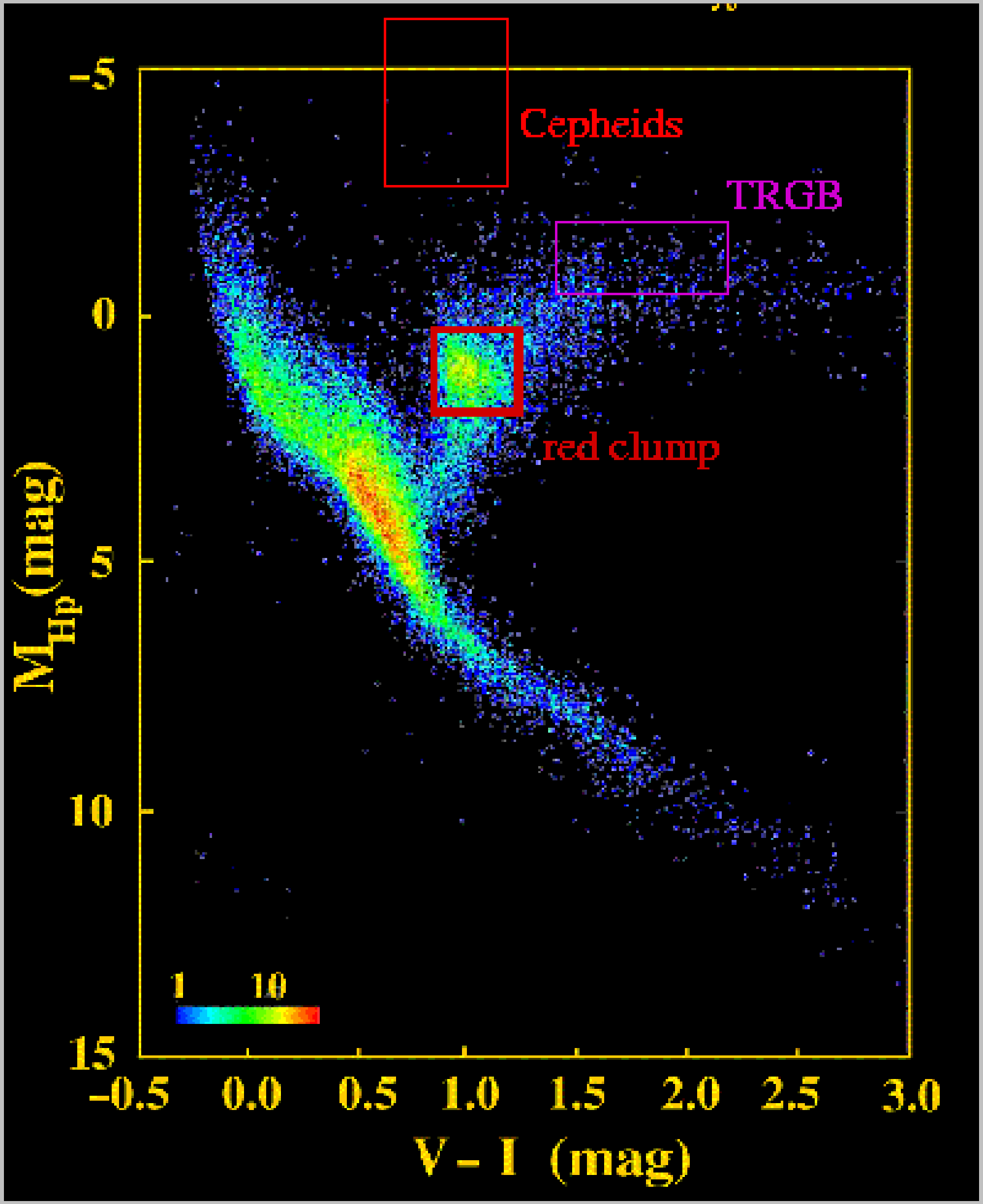
3) Dust – makes stars appear redder

Low metallicity stars are blue

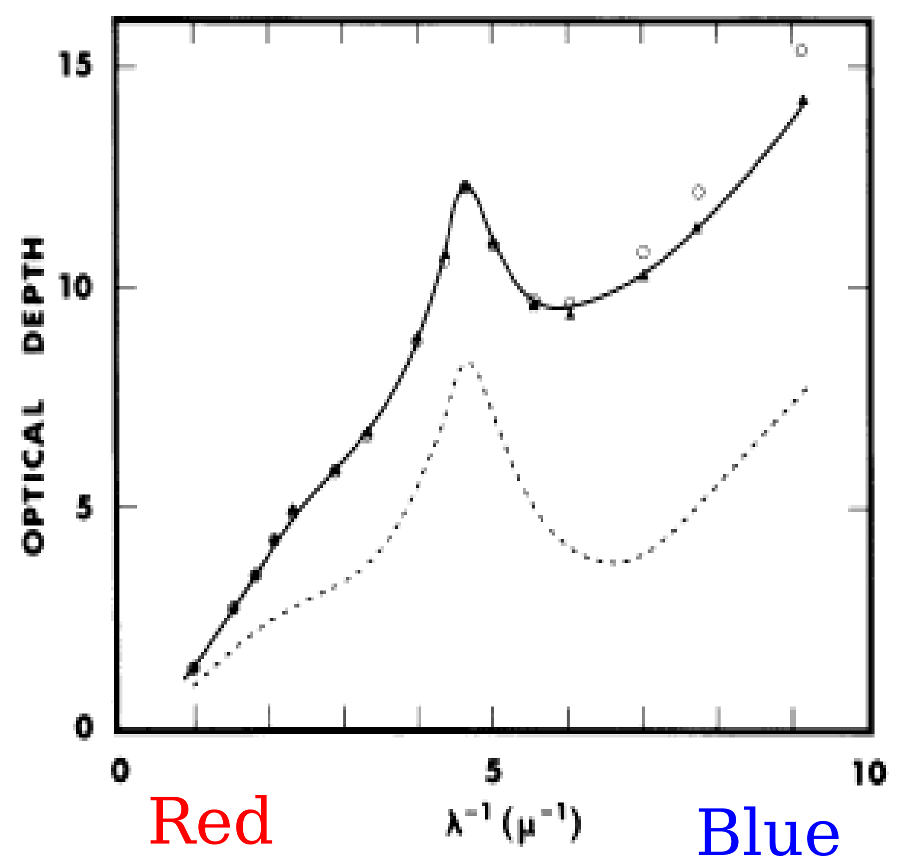


Jao et al. 2008 ApJ 136, 804

Older Stars are redder



Interstellar extinction



Mathis, Rumpl, and Nordsieck (1977)

Spirals are Complex

- As we've seen spirals are complex systems
  - Wide range of morphologies
  - Many fine scale details
    - HII regions
    - Structure in the arms
    - bulge/disk ratio
  - Wide range of stellar populations
    - Young
    - Old
    - Intermediate

- Wide range of stellar dynamics
  - “Cold” disk stars – young rotationally supported
  - “Warm” thick disk stars – moderate age rotationally supported with a significant z component
  - “Hot” halo stars – supported by velocity dispersion, includes the bulge stars
- Has a substantial ISM
  - H_2 (molecular gas)
  - HI (atomic gas)
  - HII (ionized Hydrogen)

Spiral Building Blocks

Basic Components

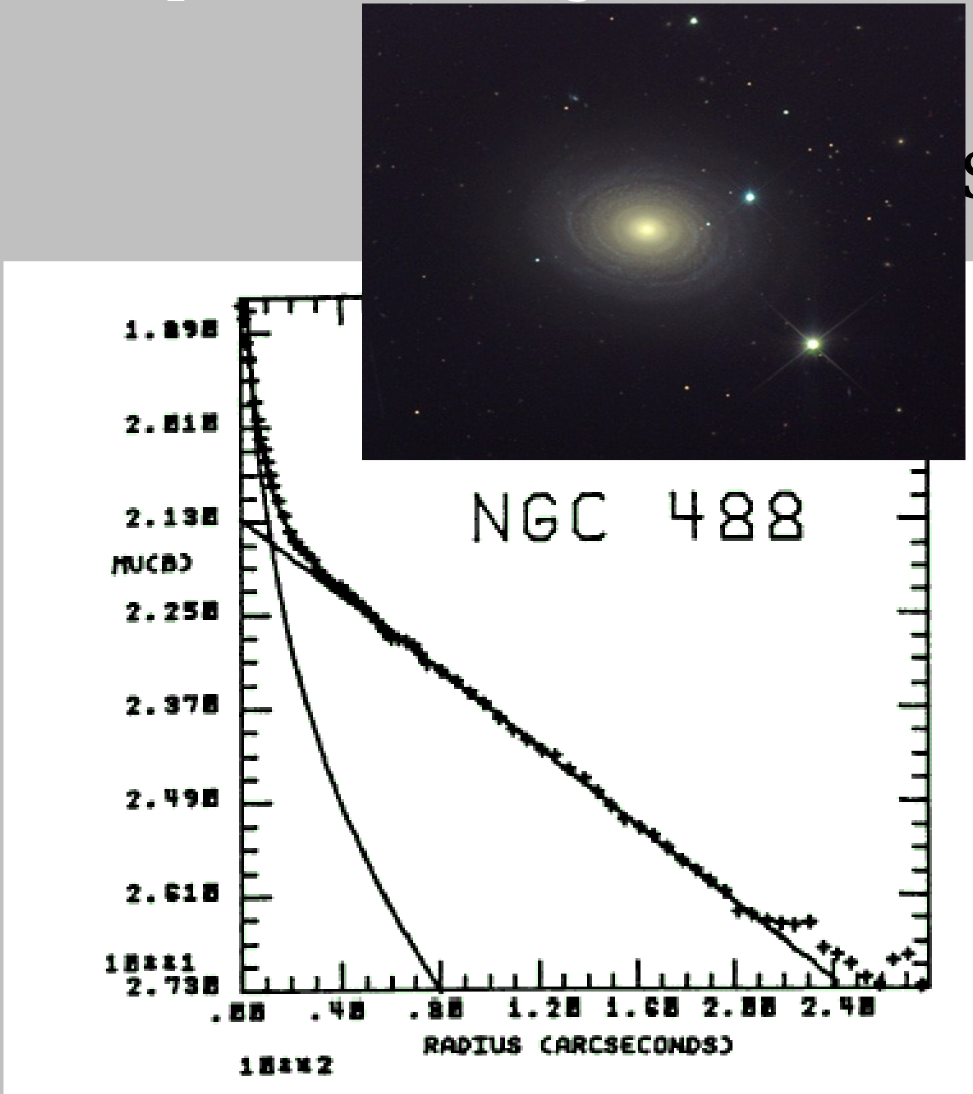
- Disk, metal rich stars, ISM is metal rich, stars have orbits that are nearly circular, small random velocities in the z direction, spiral patterns
- Bulge, old metal poor stars, high densities, and motions are mosty random, like ellipticals
- Bars, seen in also 50% of all spirals, long lived features
- Nucleus, very high stellar densities, often has a supermassive black hole
- Halo, very diffuse, low density, metal poor old stars, GC's, Hot (10^6 K) gas
- Dark Matter, most of the mass, composition ?

Average profile

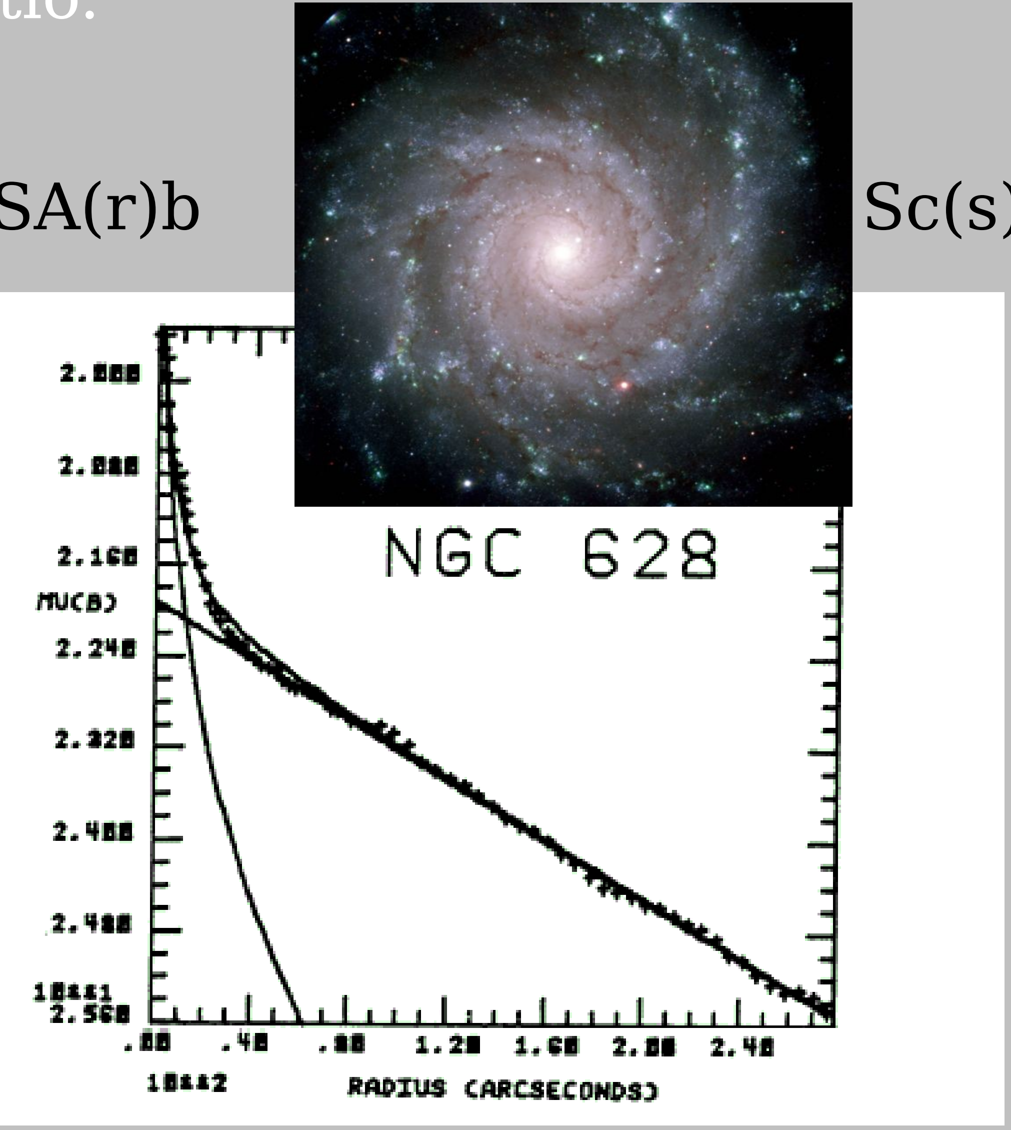
- Luminosity
  - Disk follows an exponential model
    $I(r)=I(0)e^{-r/rd}$
  - The disk scale length (r_d) is typically 2-6 kpc
  - Disk fades dramatically after 4-5 r_d
  - Bulge follows $r^{1/4}$ law (like many Ellipticals)

Decomposition of spiral profiles

We can fit the 1-D profiles with a bulge + disk model and compute the bulge to disk ratio.

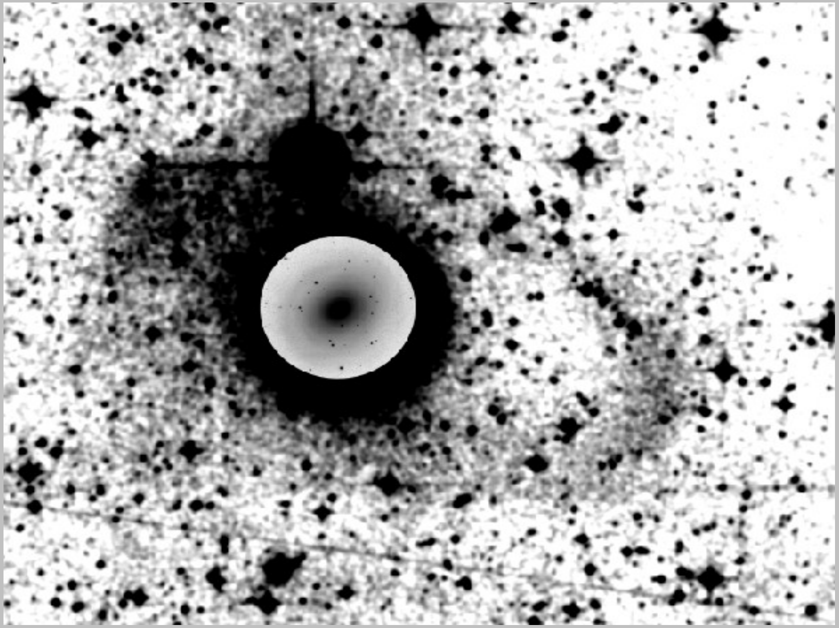


SA(r)b



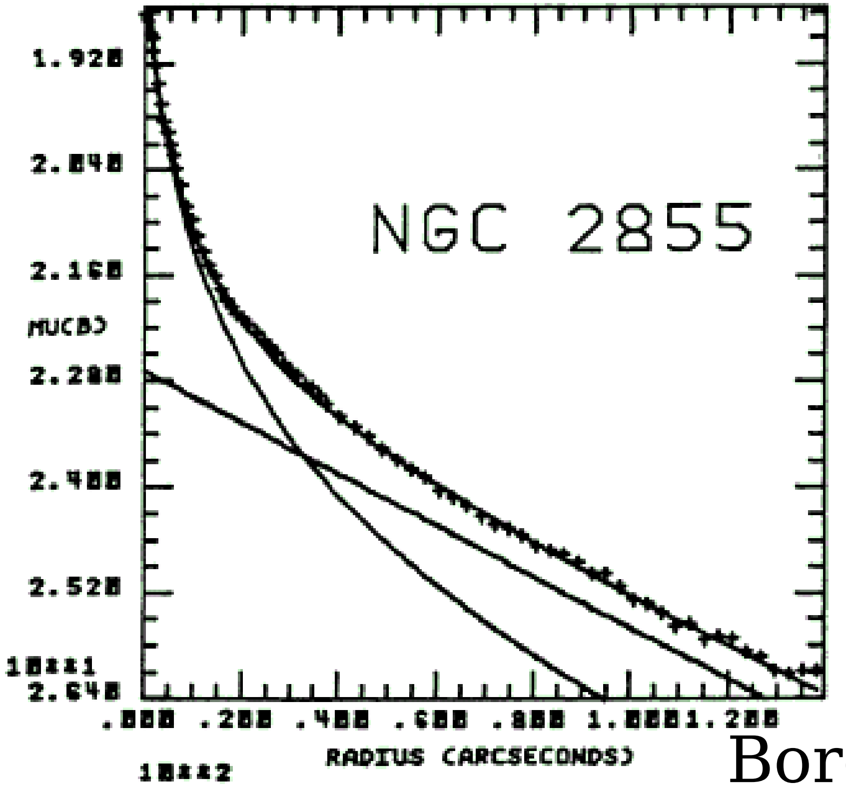
Sc(s)I

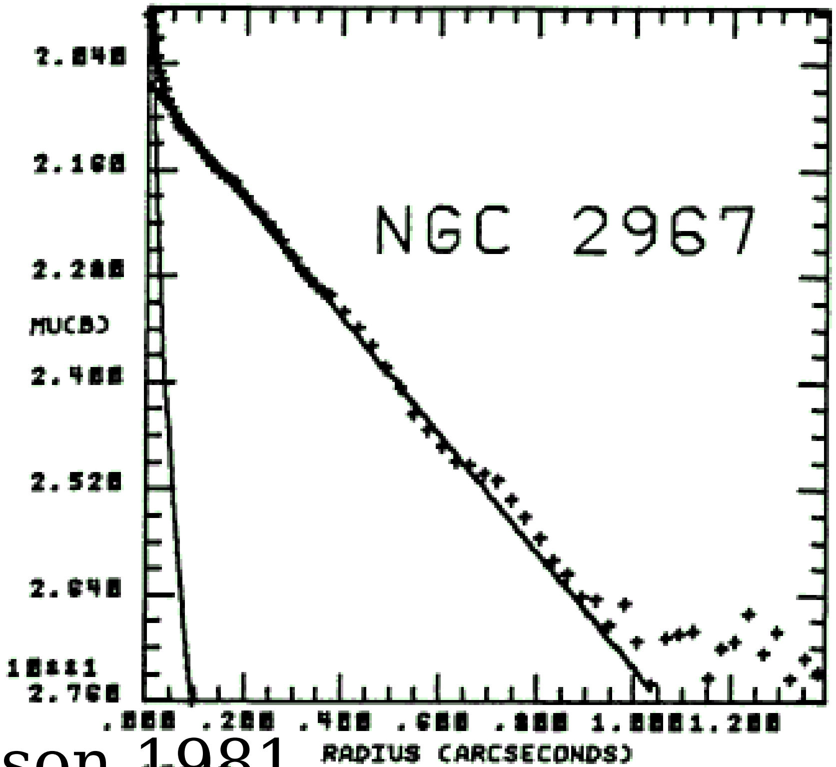
Boroson 1981



(R)SA(rs)0/a

SA(s)c





Boroson 1981

Freeman's Law

Freeman's law states that the central surface brightnes of a spiral galaxy is about 21.7 mag arcsec^2.

Yoshizawa and Wakamatsu (1975)
(24 galaxies) 21.28+/- 0.71
Schweiezer (1976) (6 galaxies)
21.67+/- 0.35

Disney (1976) showed that this is an observational effect and led to the search for LSB galaxies.

But Boroson (1981) showed that there is a fairly large range of central SB.

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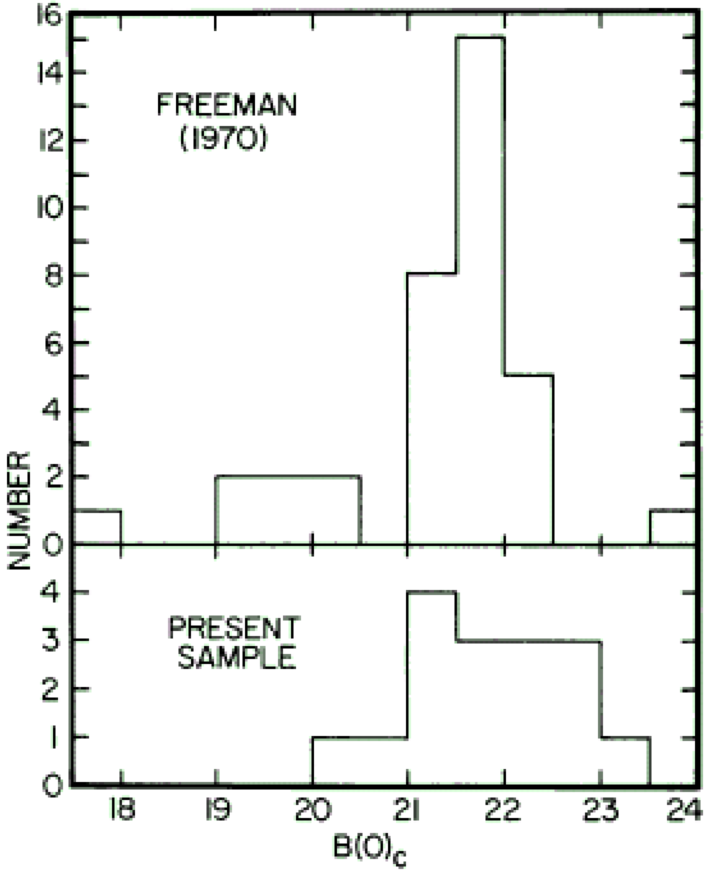
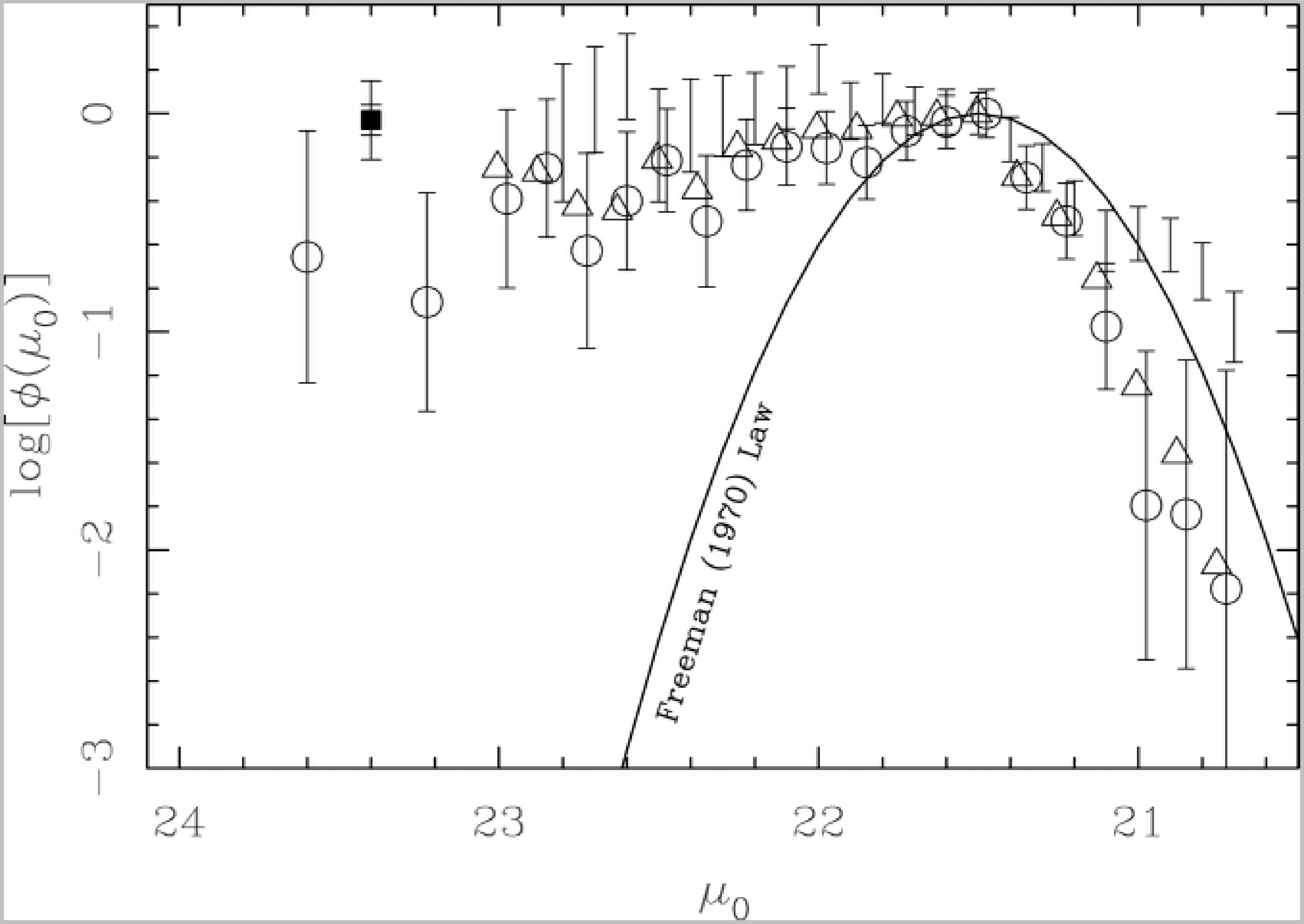


FIG. 7.—The distribution of disk central surface brightness in this study (*lower panel*) and in the study of Freeman (1970) (*upper panel*).

We now know that there are many LSB galaxies.



Simien & de Vaucouleurs (1986) showed that the B/D decreases with T type

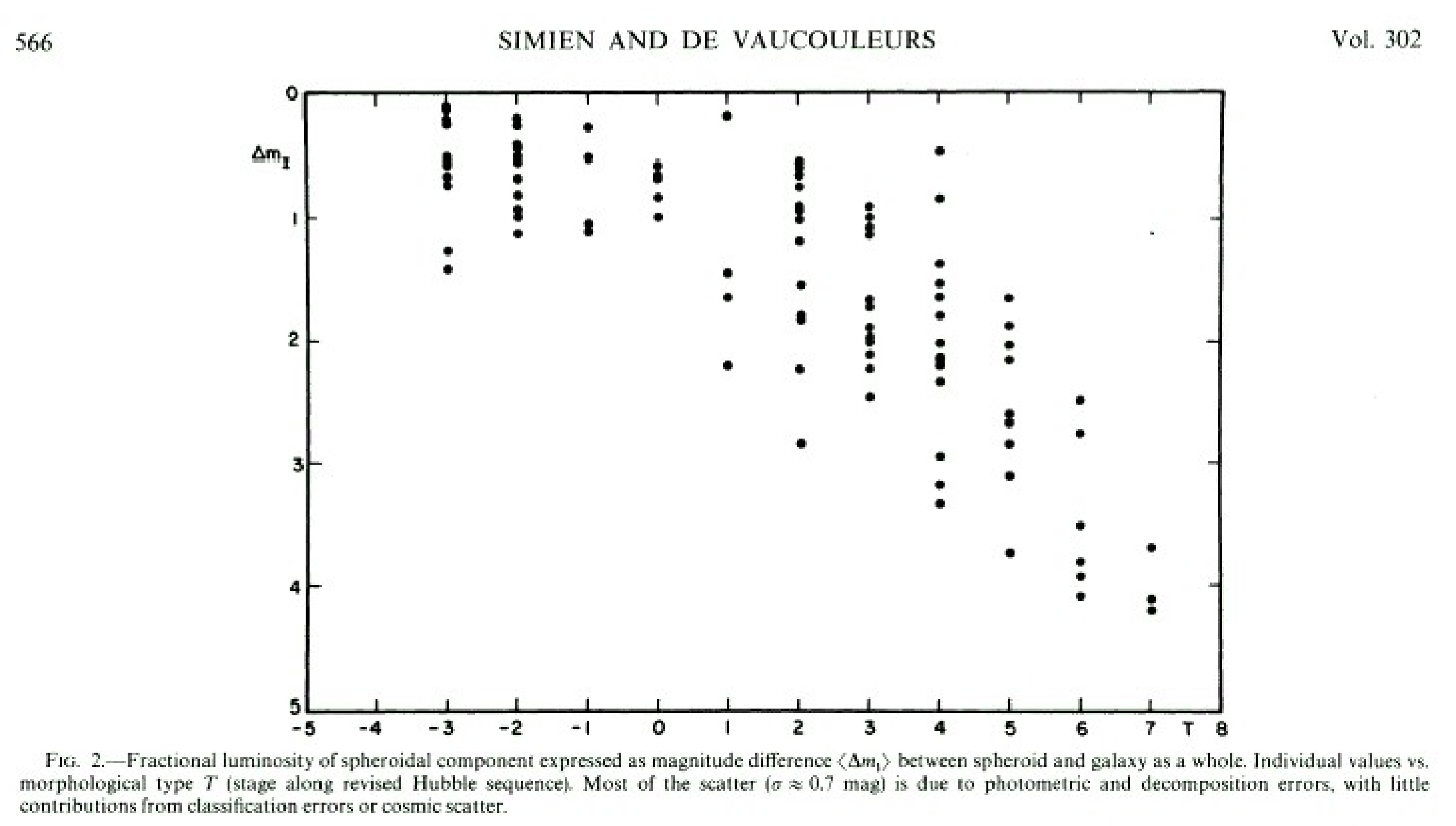


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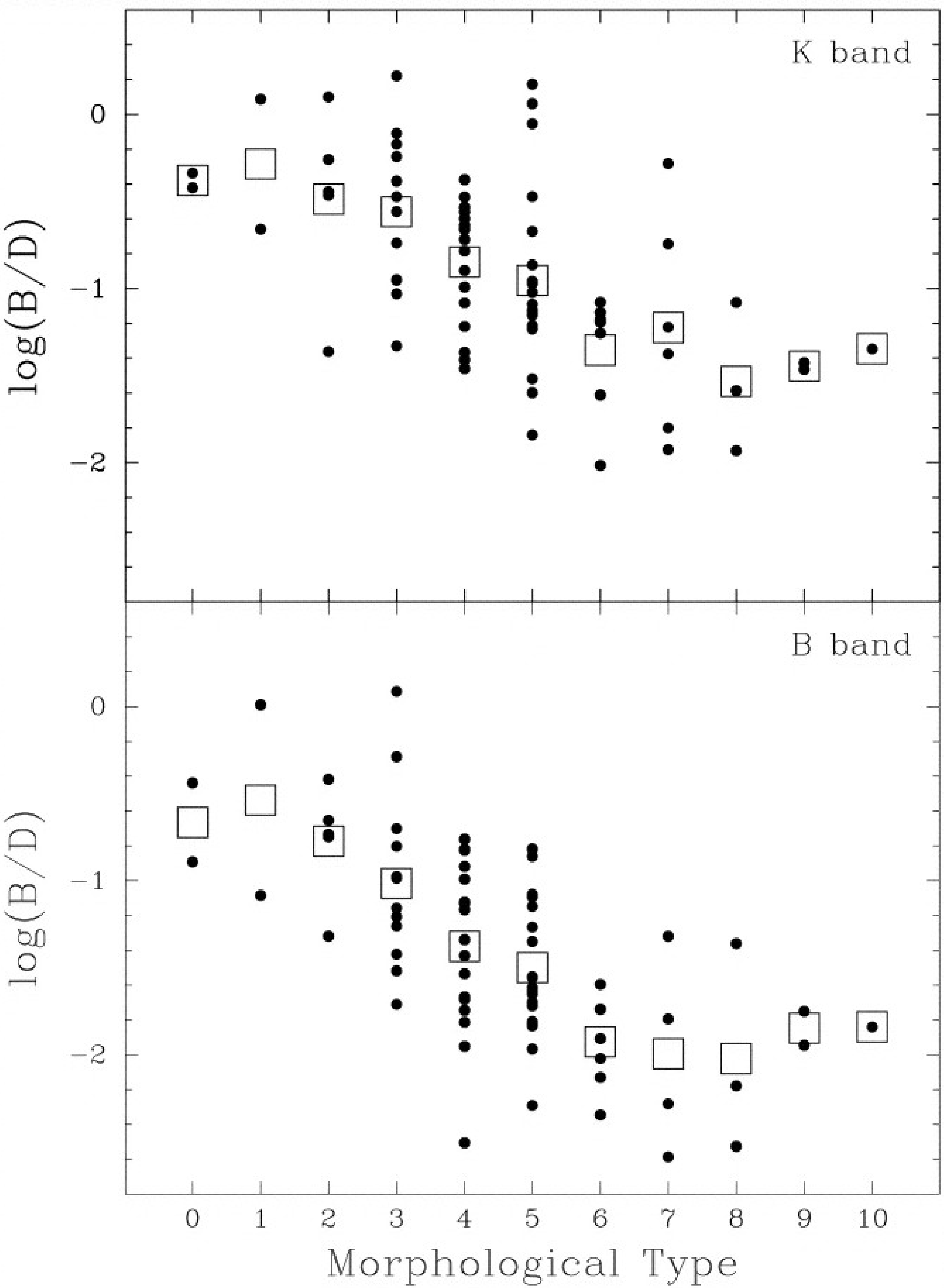
FIG. 2.—Fractional luminosity of spheroidal component expressed as magnitude difference $\langle \Delta m_I \rangle$ between spheroid and galaxy as a whole. Individual values vs. morphological type *T* (stage along revised Hubble sequence). Most of the scatter ($\sigma \approx 0.7$ mag) is due to photometric and decomposition errors, with little contributions from classification errors or cosmic scatter.

Modern data show this same trend and that T types > 7 this flattens (Graham 2001)



Inclination Effects

When we integrate the SB profile to derive the total magnitude we need to correct for effects of inclination

- We need to correct for
  - Dust
    - Internal (MW) and in the galaxy
    - Inclination (i=0 face on, i=90 edge on)
- We get total correct magnitude B_T^0
- Assuming a thin disk cos i = b/a, a = major axis and b = minor axis radius

The effects of dust attenuation is clearly most severe for highly inclined systems as Pierini et al. (2004) show.

Giovanelli et al (1994) show that the internal absorbtion can be model by $A_v = 1.12(+/-0.05) \log(a/b)$

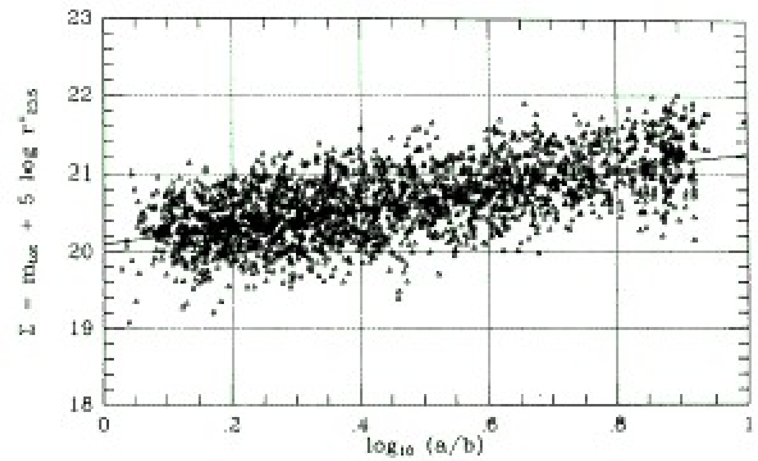
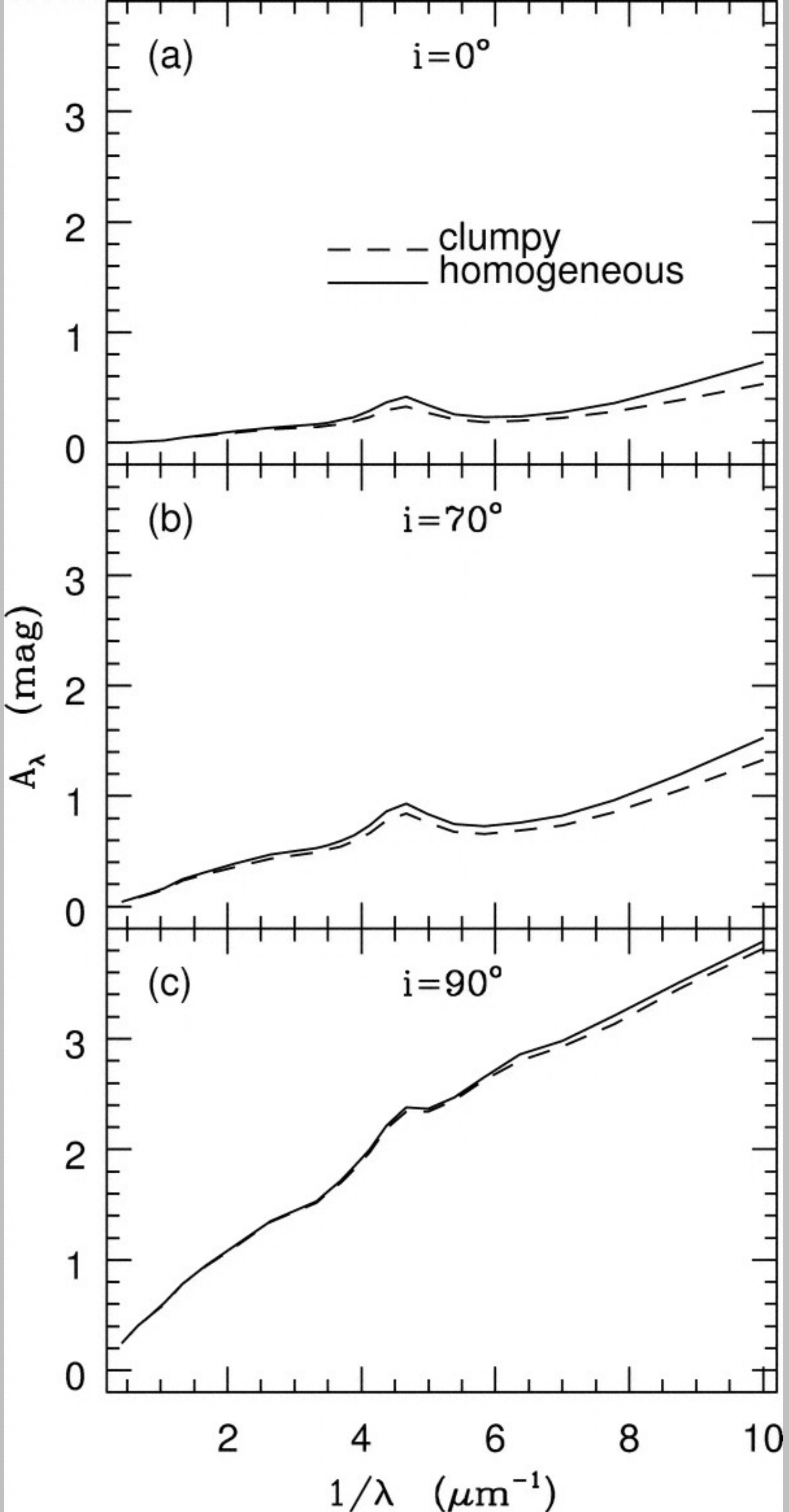


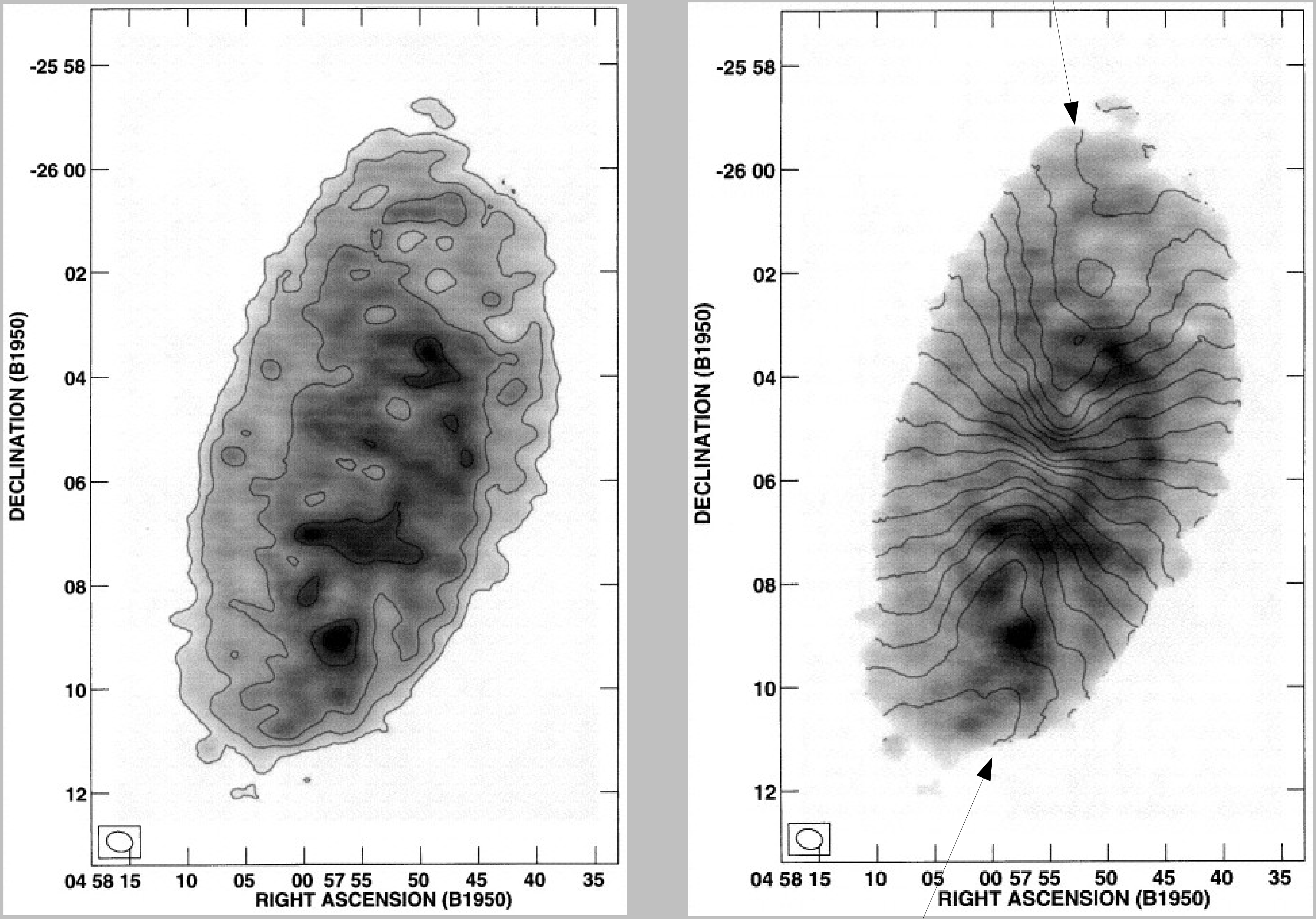
FIG. 17. Surface magnitude—obtained from the total magnitude m_{tot}—averaged over a circular aperture of radius $r^{o}_{23.5}$ vs log of the axial ratio. The filled circles are local averages and the solid line is a linear fit to the averaged values, with parameters given in Eq. (28). This relationship is obtained for galaxies in the expanded sample of 2272 objects.



Gas in Spirals

- Spirals have large HI disks
  - This gas is optically thin
    - This means that we see all the gas and can measure the amount directly from the line intensity
  - HI gas is much more extended than the optical light, $r > 2.5\ R_{25}$
  - Gives a unique tracer for the velocity in spiral galaxies

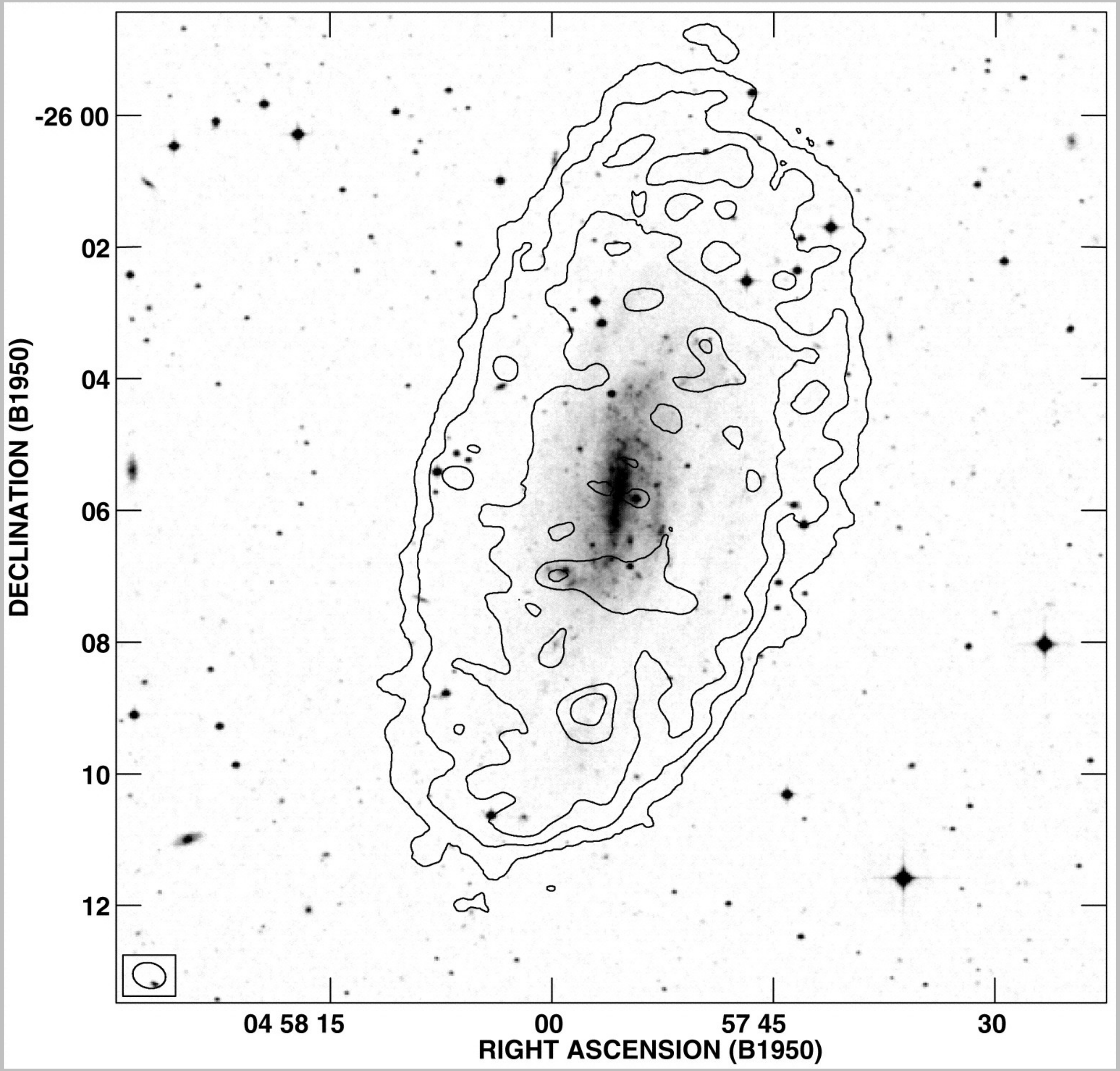
NGC 1744 Pisano et al. 1998

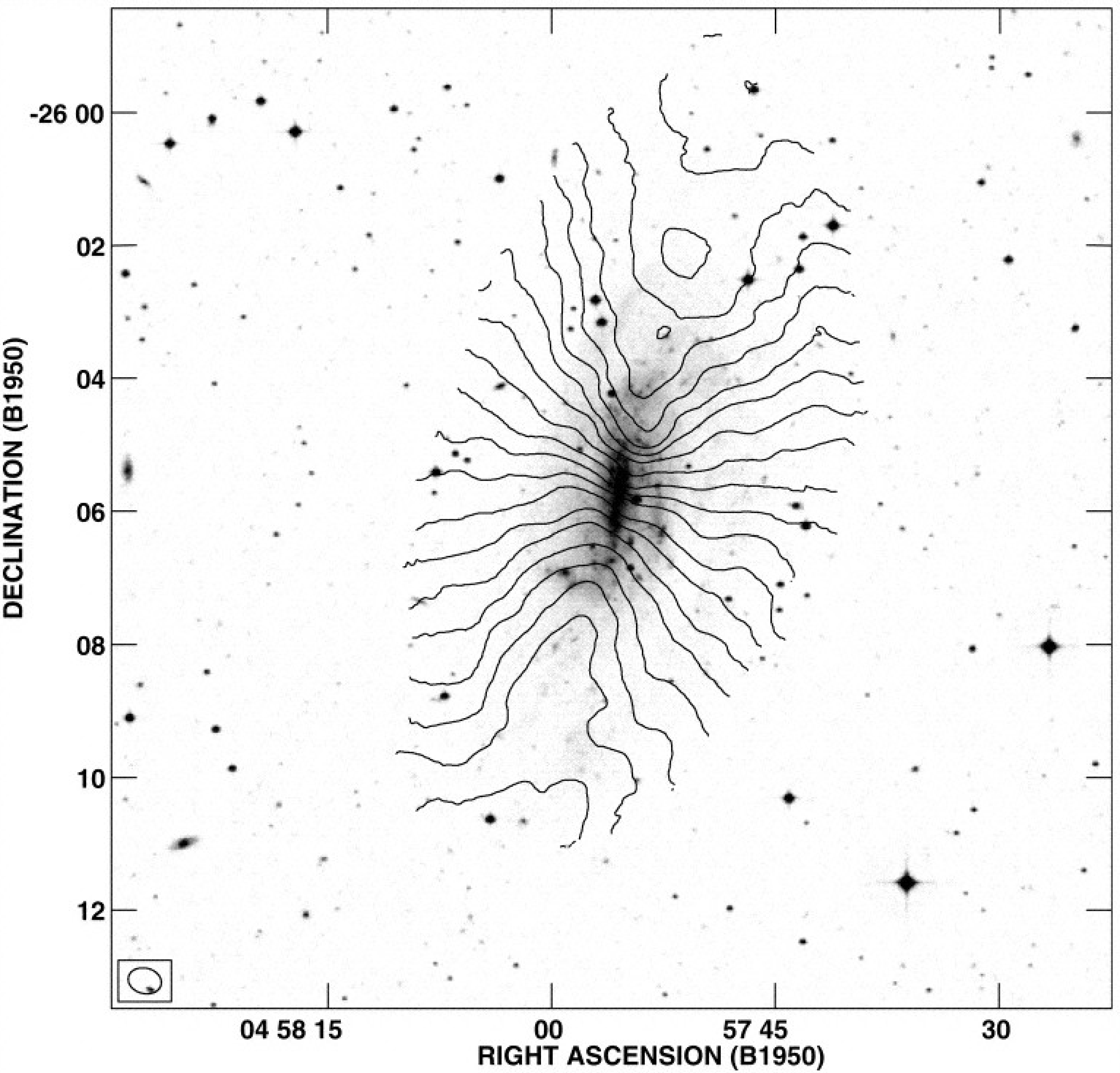


620 km/s

830 km/s

NGC 1744 in HI (the contours) and in the B band.




-26 00
02
04
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12
DECLINATION (B1950)
04 58 15
00
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30
RIGHT ASCENSION (B1950)

M81 optical

HI gas