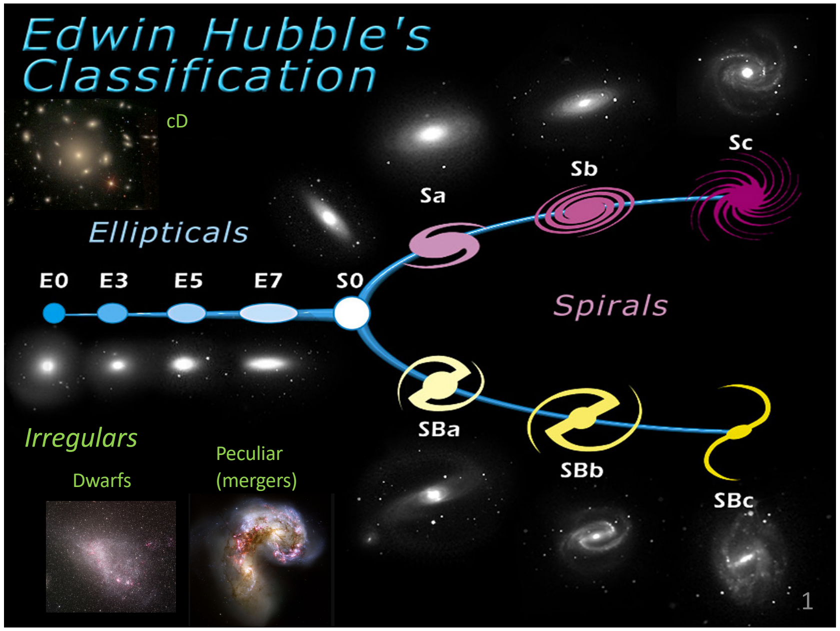
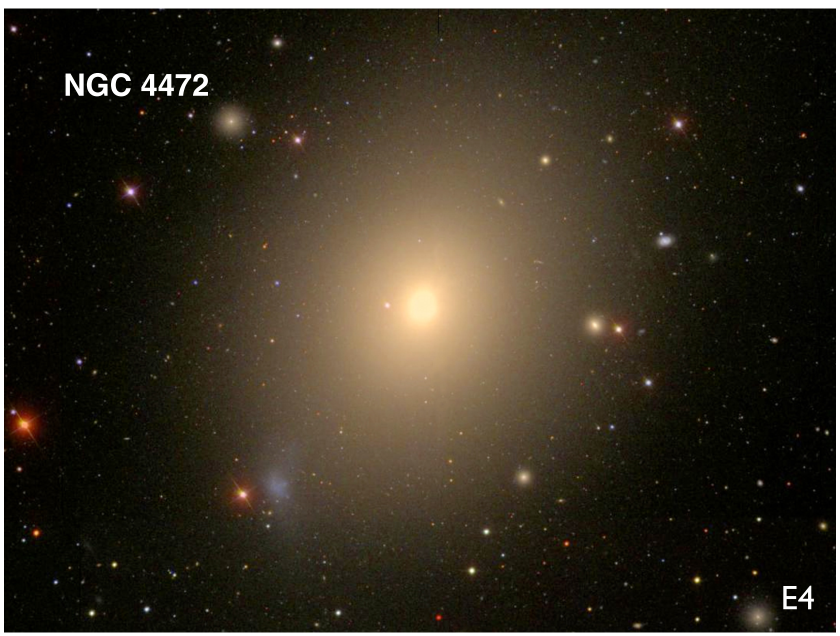

Edwin Hubble's Classification
cD
Ellipticals
E0
E3
E5
E7
S0
Sa
Sb
Sc
Spirals
SBa
SBb
SBc
Irregulars
Dwarfs
Peculiar (mergers)
1

1


M87
E1

2


NGC 4472
E4

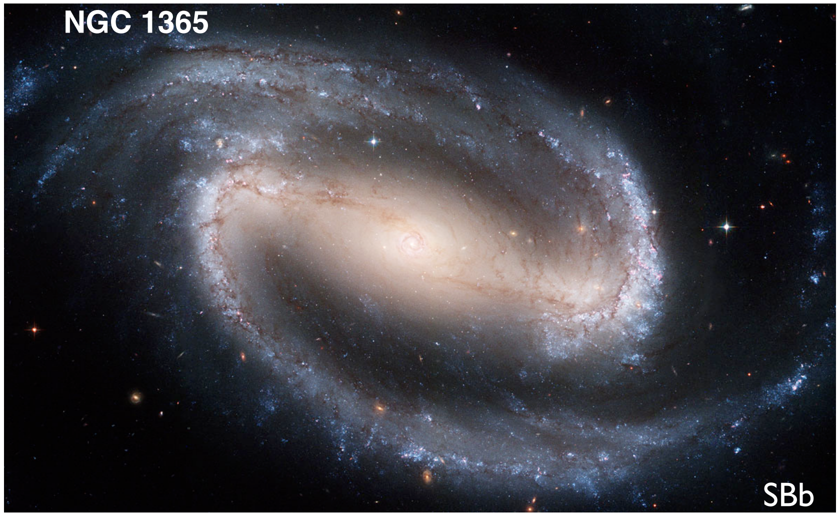
3


M51
Sc

4

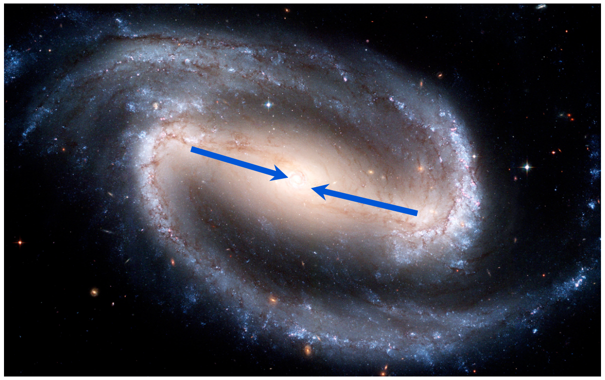
5

About 1/3 of nearby spiral galaxies are barred



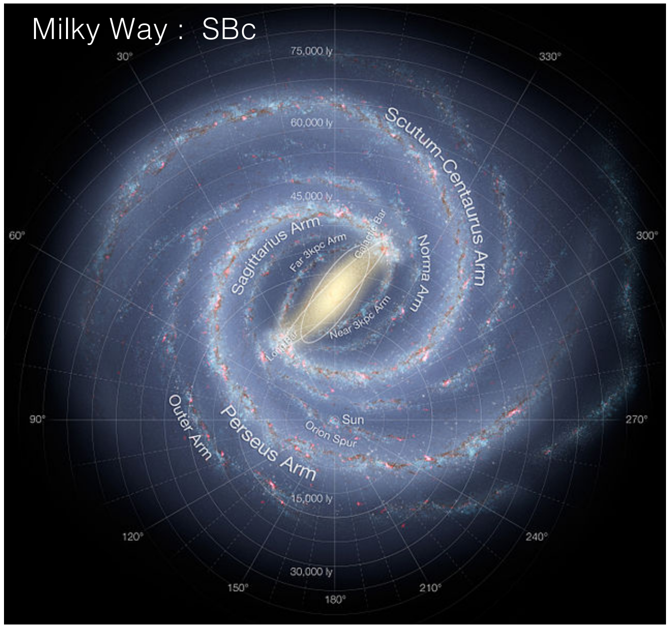
6

Bars contain both stars and gas. (Note the dust lanes.) The non-circular motions cause the gas to experience torques and lose angular momentum - this allows it to flow in.

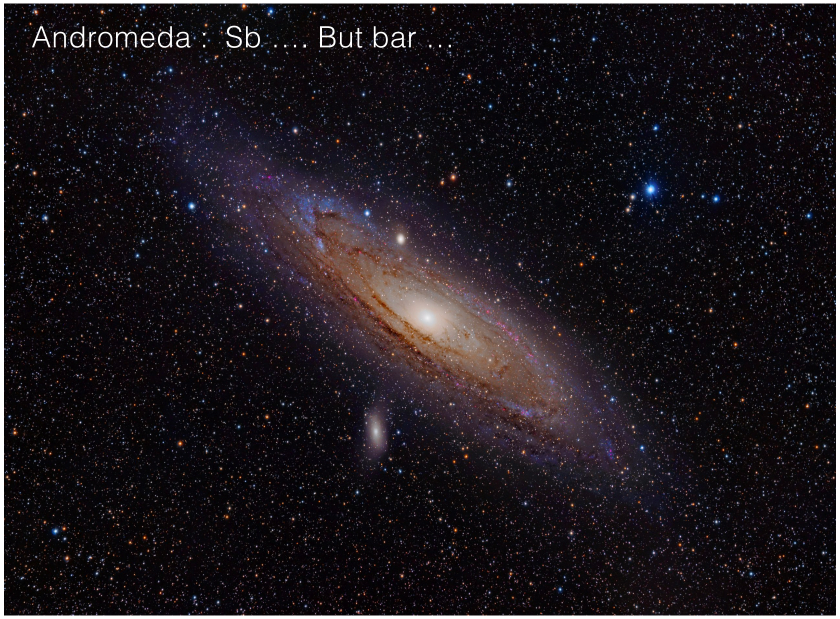


Bars may be an important way of providing fuel to the nuclear regions of galaxies (resulting in central starbursts and black hole accretion).

7



8



9

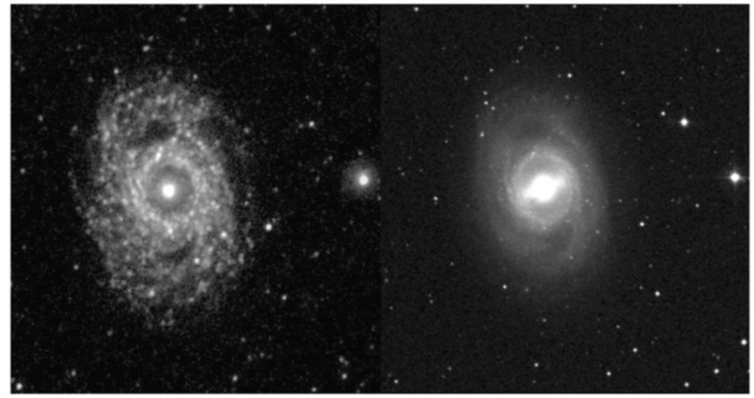
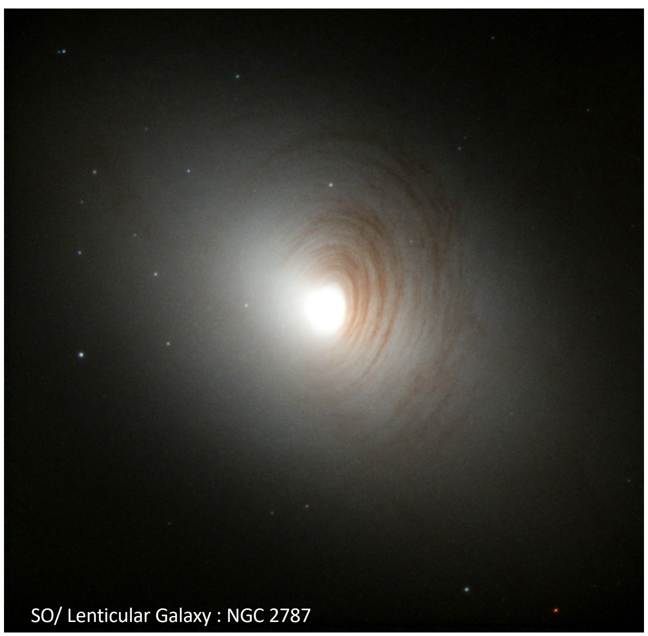


Fig 5.10 (Galex) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

SBb barred spiral galaxy NGC 3351 (M95). The left image combined UV light at 1530 Angstrom and 2300 Angstrom. We do not see the bar, since it lacks young blue stars; starforming knots give the spiral arms a fragmented appearance. Right: in visible light we see a strong central bar, surrounded by a ring and smooth spiral arms.

10

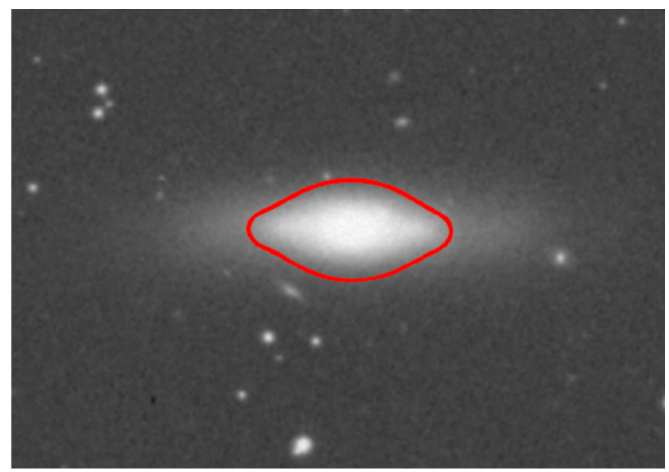
10



SO/ Lenticular Galaxy : NGC 2787

11

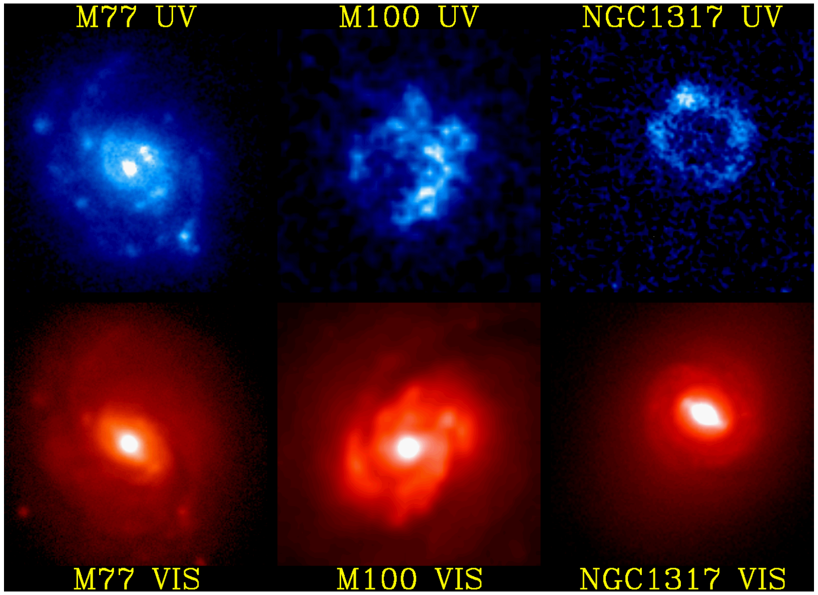
11



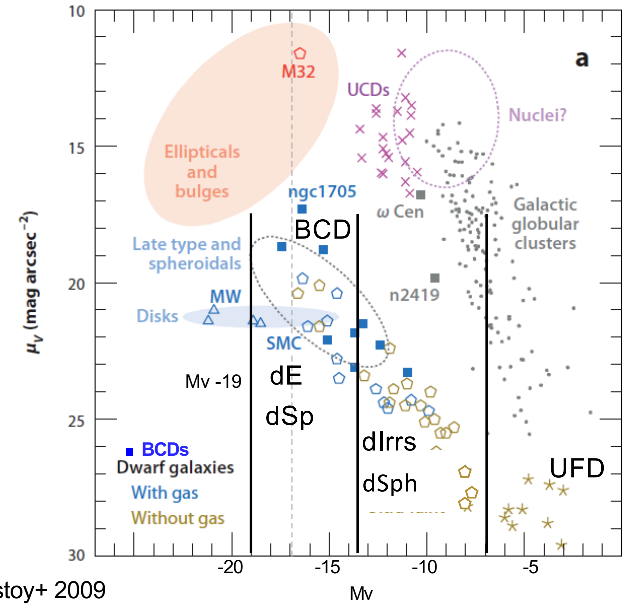
SO, lenticular galaxy: NGC 2549 (Courtesy of Sloan Digital Sky Survey)

12

12

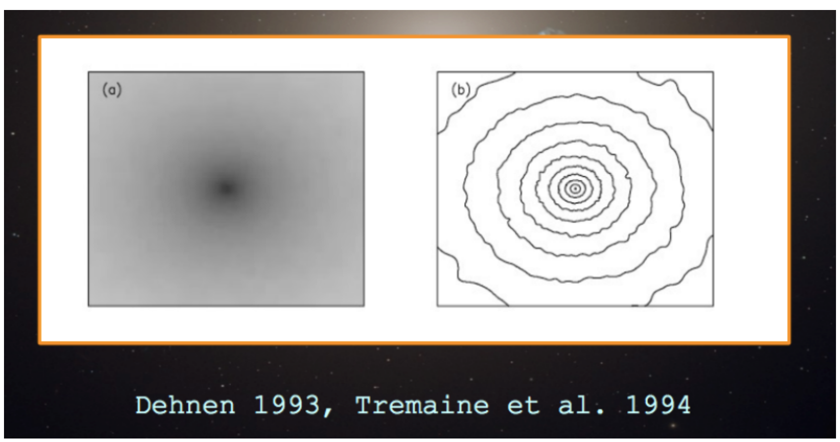


Astro Observatory and the Ultraviolet Imaging Telescope



Tolstoy+ 2009

Contours connecting the same surface brightness levels are called **isophotes**. Usually they are measured in a given band.



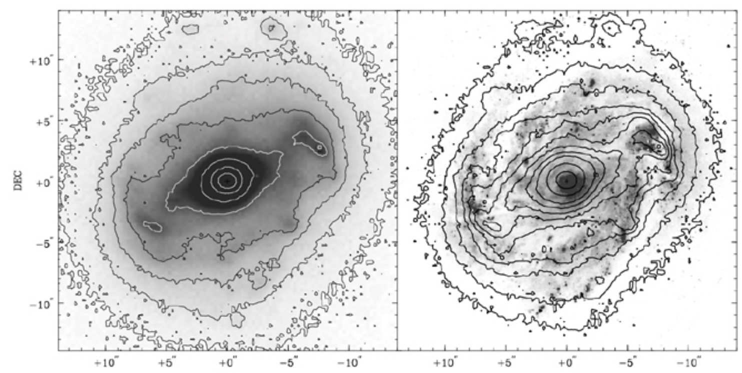
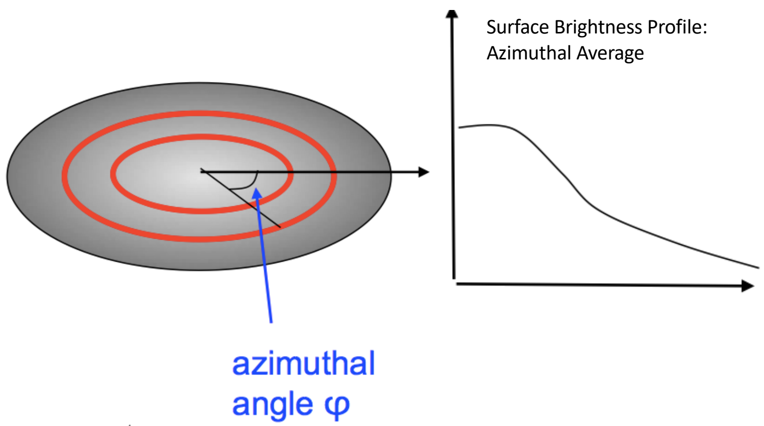
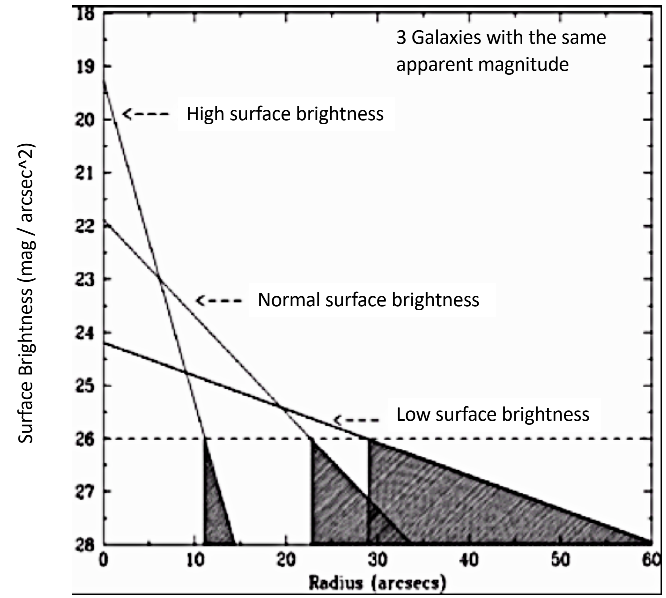
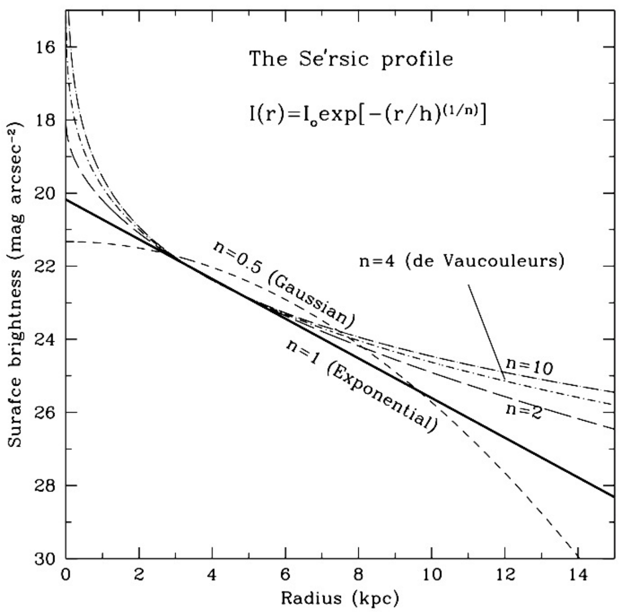


Fig 5.9 (J. Knapen) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

A negative image of inner parts of Sbc galaxy M100 (NGC 4321): 26”=2 kpc. Left: K-band image and iosphotes at 2.2 micron, showing a central bar. Right: Halpha (visible light) emission from gas around young massive stars, with K-band isophotes superimposed. The bar is hidden by dust!







Io is the central intensity.

h is the scalength (radius at which intensity drops by e−1)

n = Sersic index (shape parameter)

Total Luminosity

$$I(r) = I_o \exp(-(\mathrm{r}/\mathrm{h_r})^{1/\mathrm{n}})$$

$$L = \int_0^{2\pi} \int_0^{\infty} I(r) r dr = 2\pi I_o \int_0^{\infty} r\exp[-(r/h_r)^{1/n}] dr$$

$$L = \pi I_o h_r^2 2n(2n-1)! = \pi \mathbf{I_o h_r^2 (2n)}!$$

$$m = \mu_o - 5\log(h_r) - 2.5\log[(2n)!\pi]$$

Ellipticals

A standard profile for ellipticals is referred to as the De Vaucouleurs (1948) Profile. This occurs if n = 4. Often referred to as the $r^{1/4}$ law – centrally peaked, and more light at larger radii vs. n=1 profile.
n = 4:

$$m = \mu_o - 5log(h_r) - 12.7 \tag{10}$$

Note: in reality there are marked deviations from this profile exhibited by real ellipticals.
Example: Consider an elliptical whose surface brightness is well fit by a sersic index of n=4 and central surface brightness of μ_o = 15 mag/arcsec^2. If the apparent magnitude for such a profile is m = 19.7 mags. What is the scale length?
Answer:

$$m = \mu_o - 5\log_{10}h_r - 12.7 \qquad h_r = 10^{0.2[\mu_o - m - 12.7]} = 3.3 \times 10^{-4}\mathrm{arcsec} \tag{11}$$

This is too small to measure! So one often redefines the profile in terms of the half-light radius, also known as the effective radius $R_e = 3459h_r$. In this example, R_e = 1.15 arcsec, which is measurable.

$$I(r) = I_o\mathrm{exp}(-7.67(\mathrm{r/R_e})^{1/4}) \tag{12}$$

where the surface brightness at R=Re is given by

$$I_e = I_o\mathrm{exp}(-7.67) = I_o 10^{-3.33} \tag{13}$$

Ellipticals are really bright in the central regions! So Ie is often easier to use. So we can rewrite the total luminosity as follows :

$$\boxed{L = 7.2\pi I_e R_e^2} \tag{14}$$

and more generally:

$$\boxed{I(r) = I_e\mathrm{exp}(-7.67[(\mathrm{r/R_e})^{1/\mathrm{n}} - 1])} \tag{15}$$

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Spirals

$$I(r,z) = I_o\mathrm{exp}[-\mathrm{r/h_r}]\mathrm{exp}[-|\mathrm{z}|/\mathrm{h_z}]$$

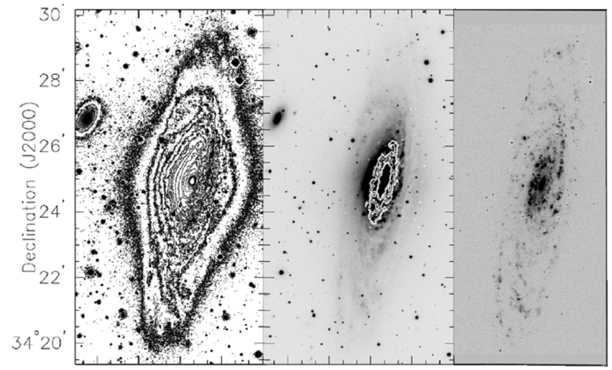

Fig 5.3 (Ferguson, Thornley) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Sb spiral galaxy NGC 7331. Left, isophotes in the R band. Center: negative image in the R band, with contours of CO emission overlaid. Right: negative image in Halpha, showing HII regions in the spiral arms

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Surface Brightness Profile of Spiral Galaxy NGC 7331

Disk+ Bulge $I(r) = I_o\mathrm{exp}(-r/h_r) + I_e\mathrm{exp}(-7.67(r/R_e)^{1/4} - 1))$

$$L = 2\pi I_o h_r^2 + 7.2\pi R_e^2 I_e$$

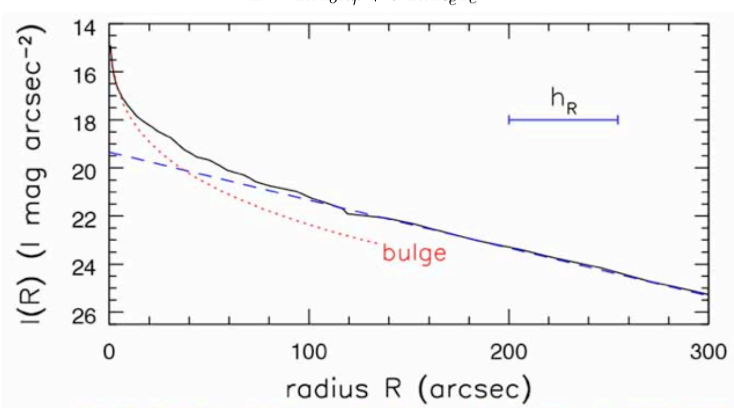

Fig 5.4 (R. Peletier) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

The solid line shows surface brightness in the I band., near 8000 Angstrom. The dashed line is an exponential with scale length h_r = 55" (3.6 kpc); the dotted line represents additional light, attributed to a bulge.

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The Edge of the Disk

Many galaxies have an apparent "edge" to their stellar disk where the surface brightness falls dramatically. R_{max} ~ 10-30 kpc = 3-5 h_R

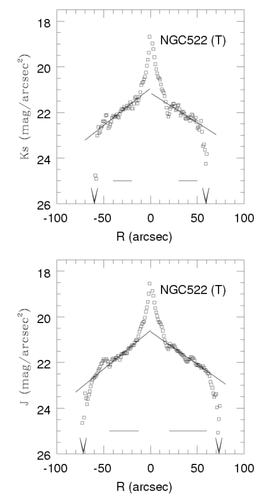

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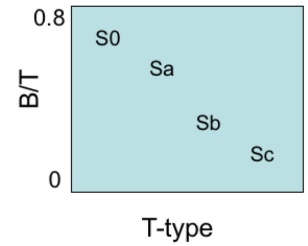
Fig 5.5 (WIYN) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

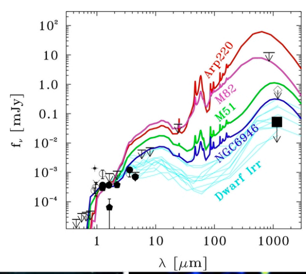
A V-band image of Sa galaxy M104, the 'Sombrero'; this is a luminous galaxy with Lv ~ 8x10^10 Lsun, about 10 Mpc away. Note the large bulge .

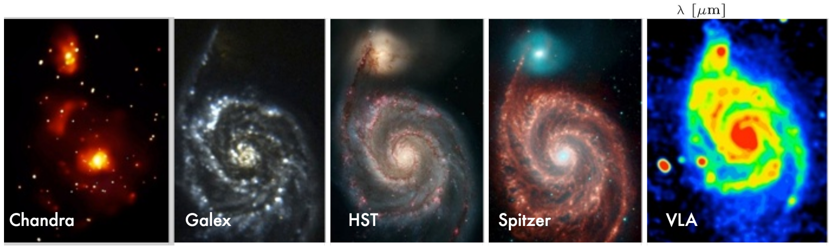
<u>Bulge fraction:</u> in spirals, determine the ratio of bulge to disk or total luminosity – follows Hubble type

$$B/T = \frac{R_e^2 I_e}{R_e^2 I_e + 0.28\, h_R^2\, I_o}$$



Spectral Energy Distribution - SED





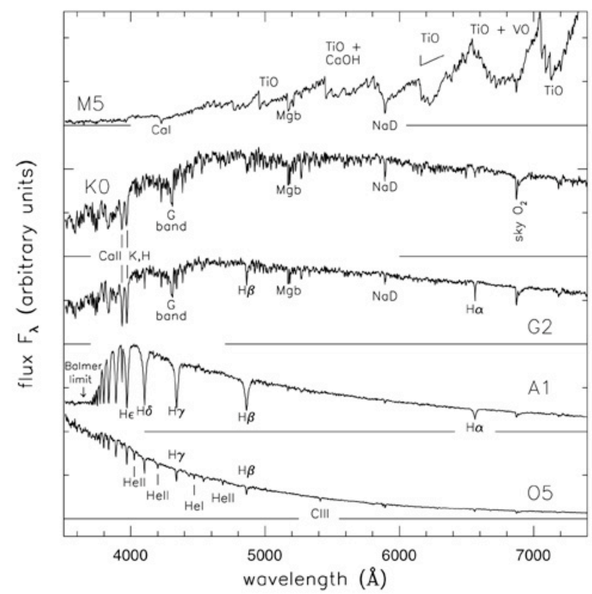


Fig 1.1 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Spectra of galaxies from ultraviolet to near-infrared wavelengths; incompletely removed emission lines from the night sky are marked. From bottom to top:

1) a red S0 galaxy;

2) a bluer Sb galaxy;

3)an Sc spectrum showing blue and near UV light from hot young stars and gas emission lines;

4) a blue starburst galaxy, that has made many of its stars in the past 100 Myr.

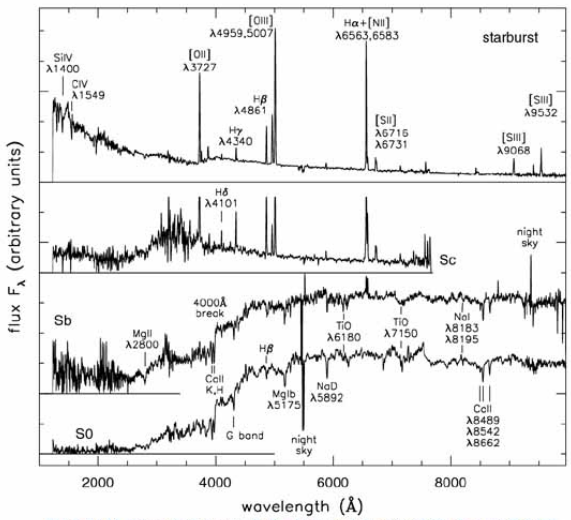


Fig 5.24 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

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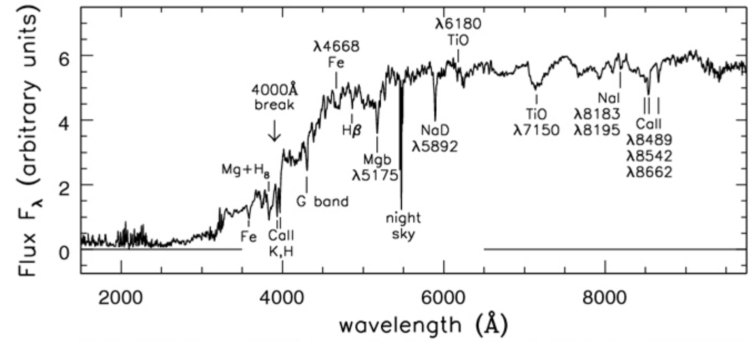
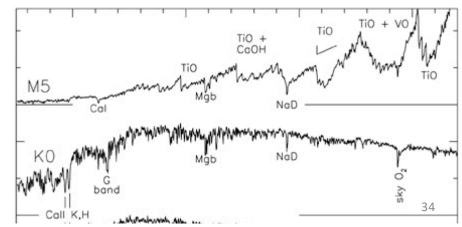


Fig 6.17 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

The spectrum of an elliptical galaxy. Dominated by K and M stars (see right)



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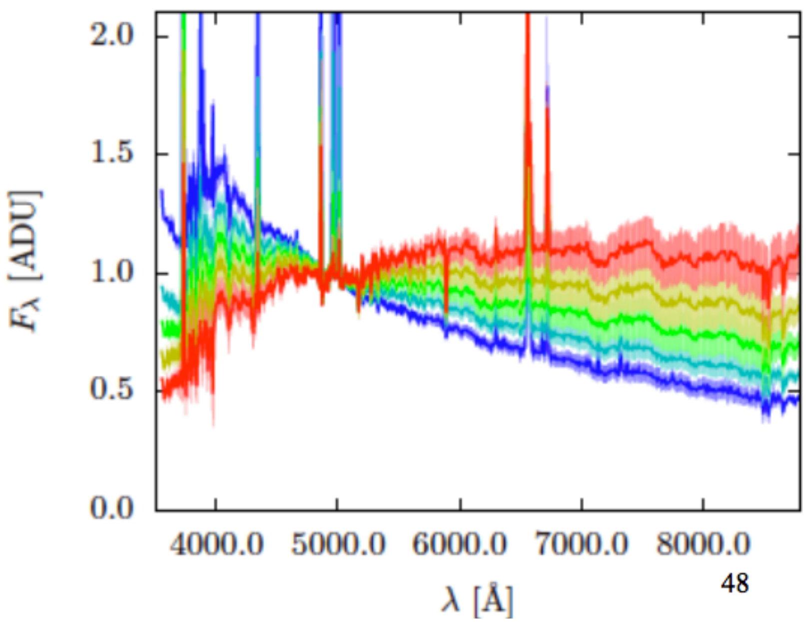

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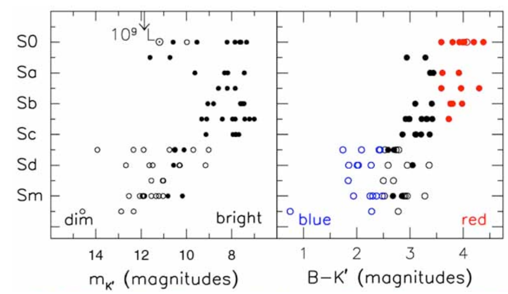
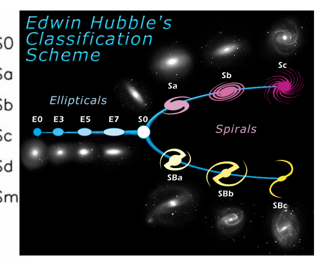
Correlations with Hubble type



Ursa Major group (all at the same distance)



- Galaxy brightness and color both depend of the Hubble type.
- Earlier types are usually brighter (also more massive) and redder.

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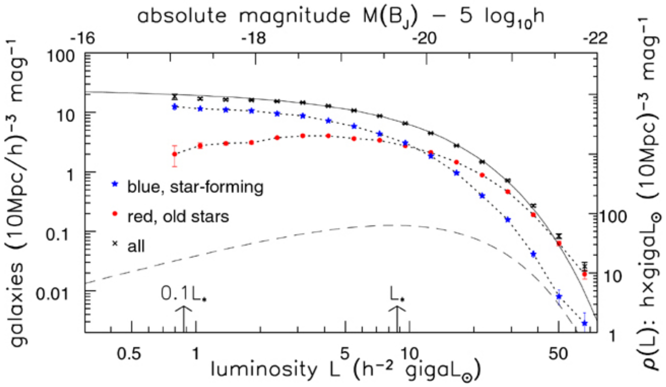
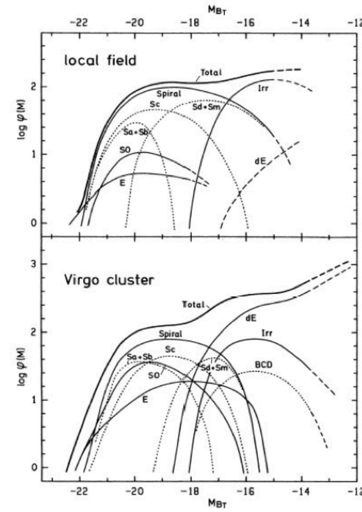


Fig 1.16 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

The Number of galaxies per 10 Mpc cube between absolute magnitude M(Bj) and M(Bj) + 1 (crosses). Dotted lines show number of blue (stars) and red(filled dots) galaxies making up this total; vertical bars indicate errors. The solid line shows the luminosity function; the dashed line gives the light in each interval of absolute magnitude. The blue bandpass Bj is matched to the photographic plates used to select the galaxies.

The galaxy luminosity function varies with galaxy type and environment



Bingelli (1988)

Field – dominated by Spirals, faint end dIrr

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