Galaxy Classification Methods

- **Method 1)** Visual Classification - e.g. Hubble Classification
- **Method 2)** Quantifying surface brightness profiles – i.e the concentration of light.
- **Method 3)** Spectral Energy Distribution – focus on current state of SF and BH activitiy,

Edwin Hubble's Classification

Method 1: Visual Classification

cD

Ellipticals

E0 E3 E5 E7 S0

Sa Sb Sc

Spirals

SBa SBb SBc

Irregulars

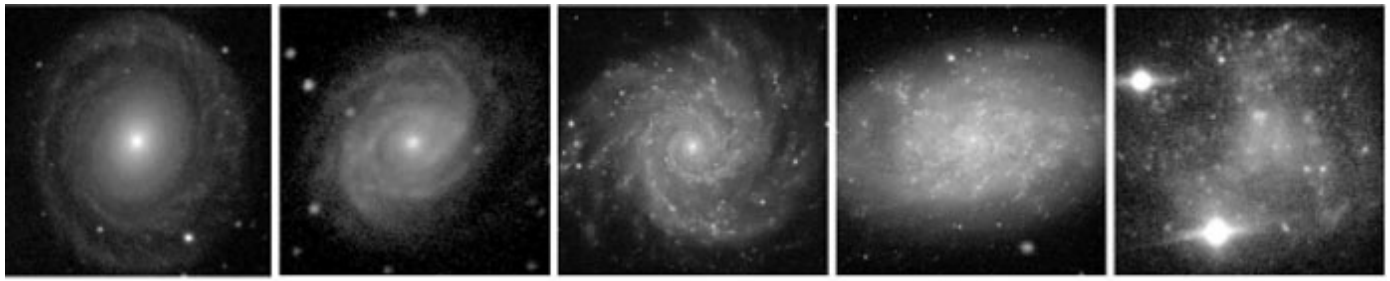
Dwarfs

Peculiar (mergers)

NED: http://ned.ipac.caltech.edu/

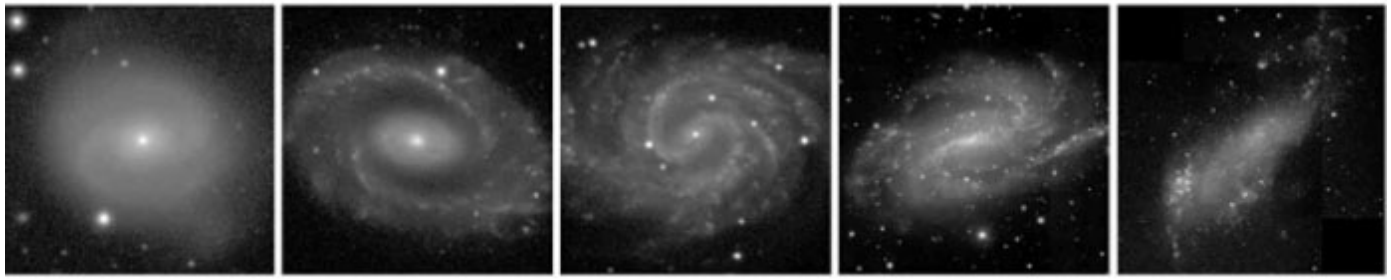
De Vaucouleurs 1963 system

No bar



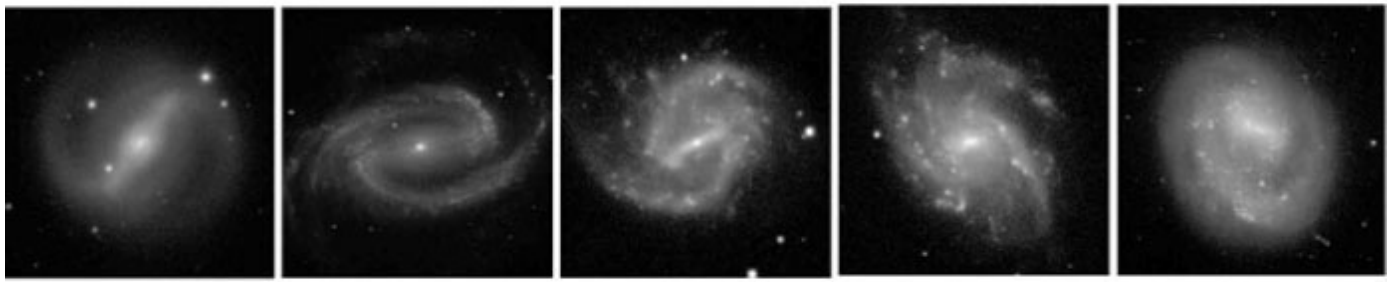
SAa SAb SAc SAd SAm

In between

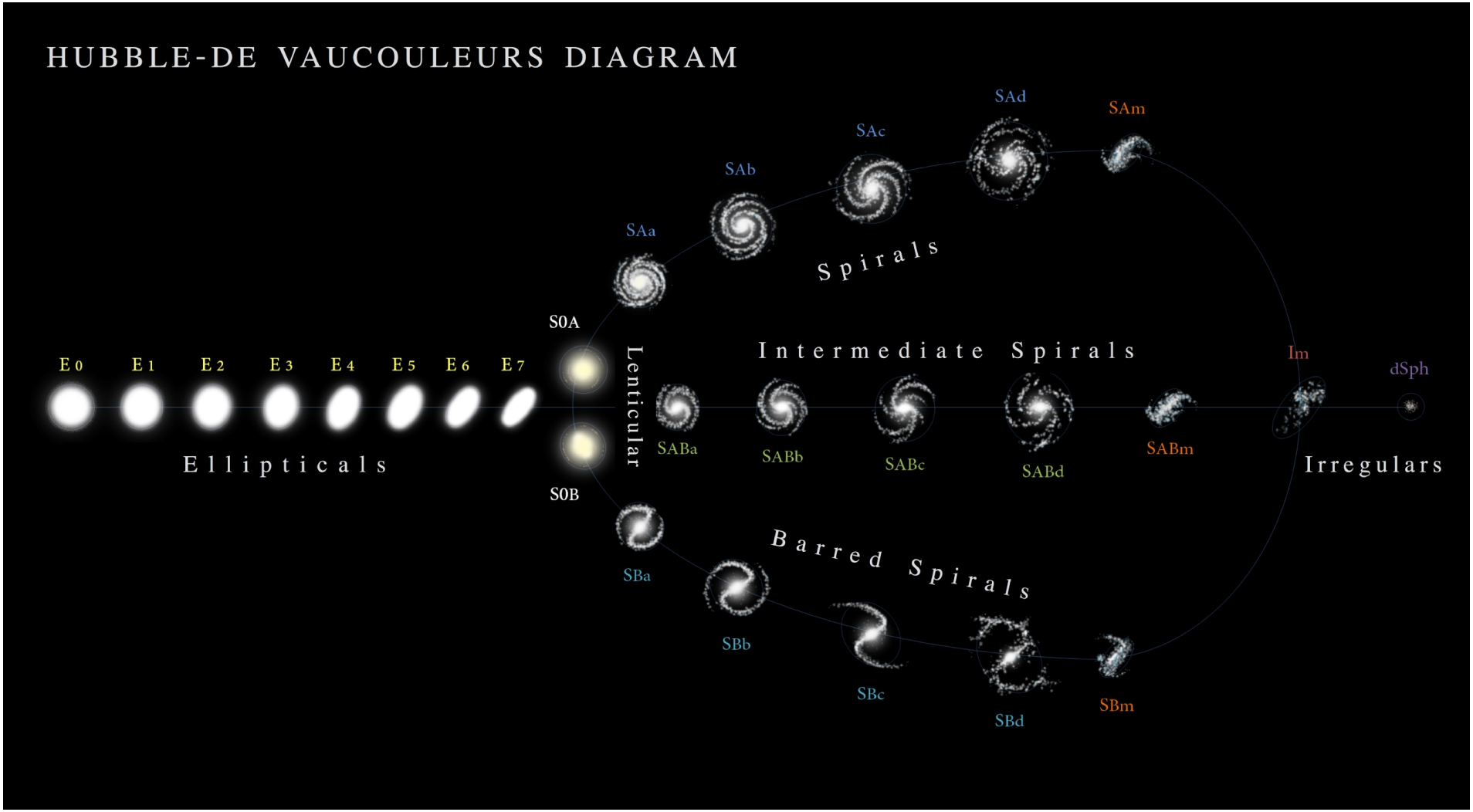


SABa SABb SABc SABd SABm

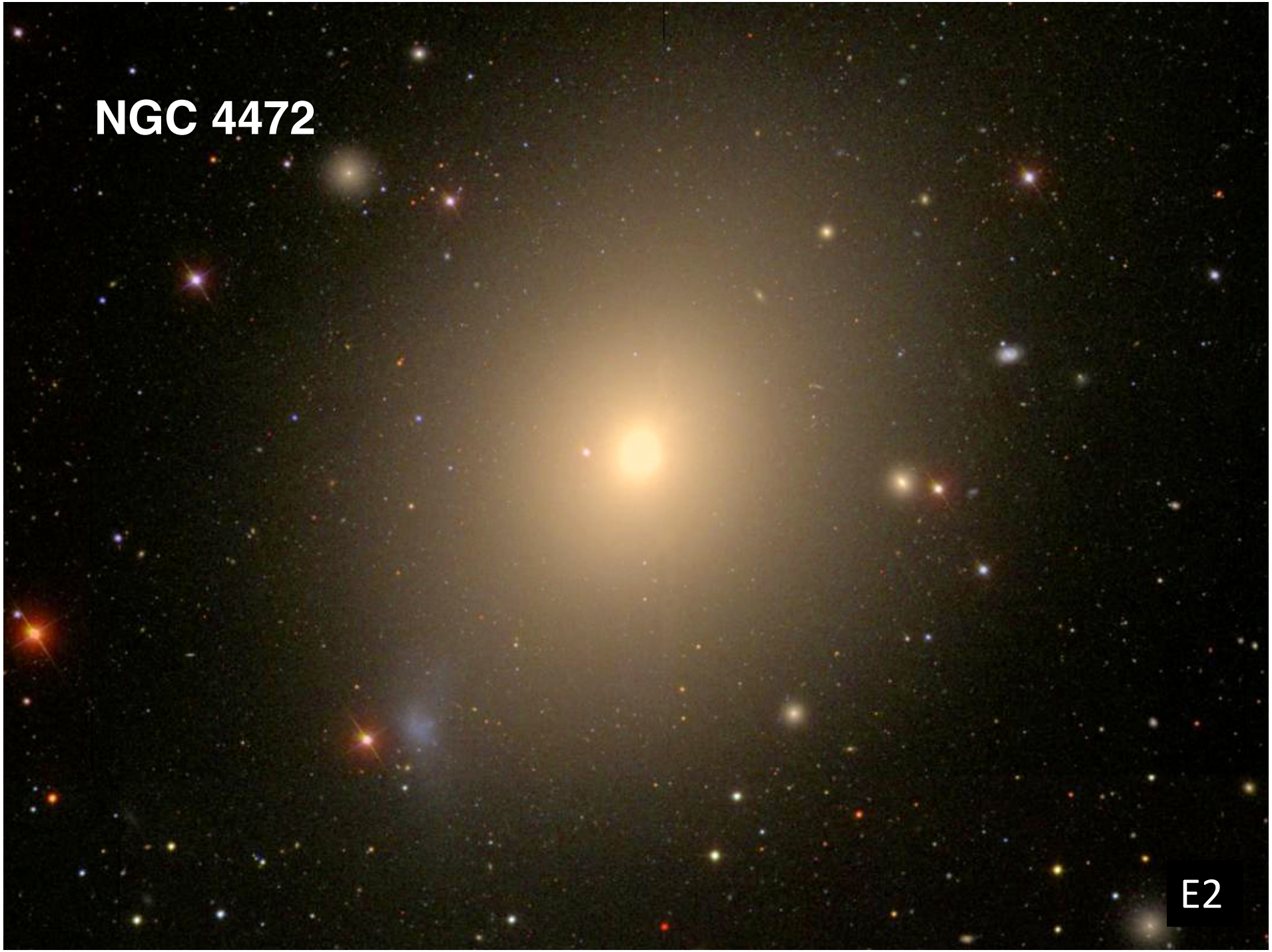
Barred



SBa SBb SBc SBd SBm


HUBBLE-DE VAUCOULEURS DIAGRAM
E0
E1
E2
E3
E4
E5
E6
E7
Ellipticals
S0A
S0B
Lenticular
SAa
SAb
SAc
SAd
SAm
Spirals
Intermediate Spirals
SABa
SABb
SABc
SABd
SABm
Im
dSph
Irregulars
SBa
SBb
SBc
SBd
SBm
Barred Spirals

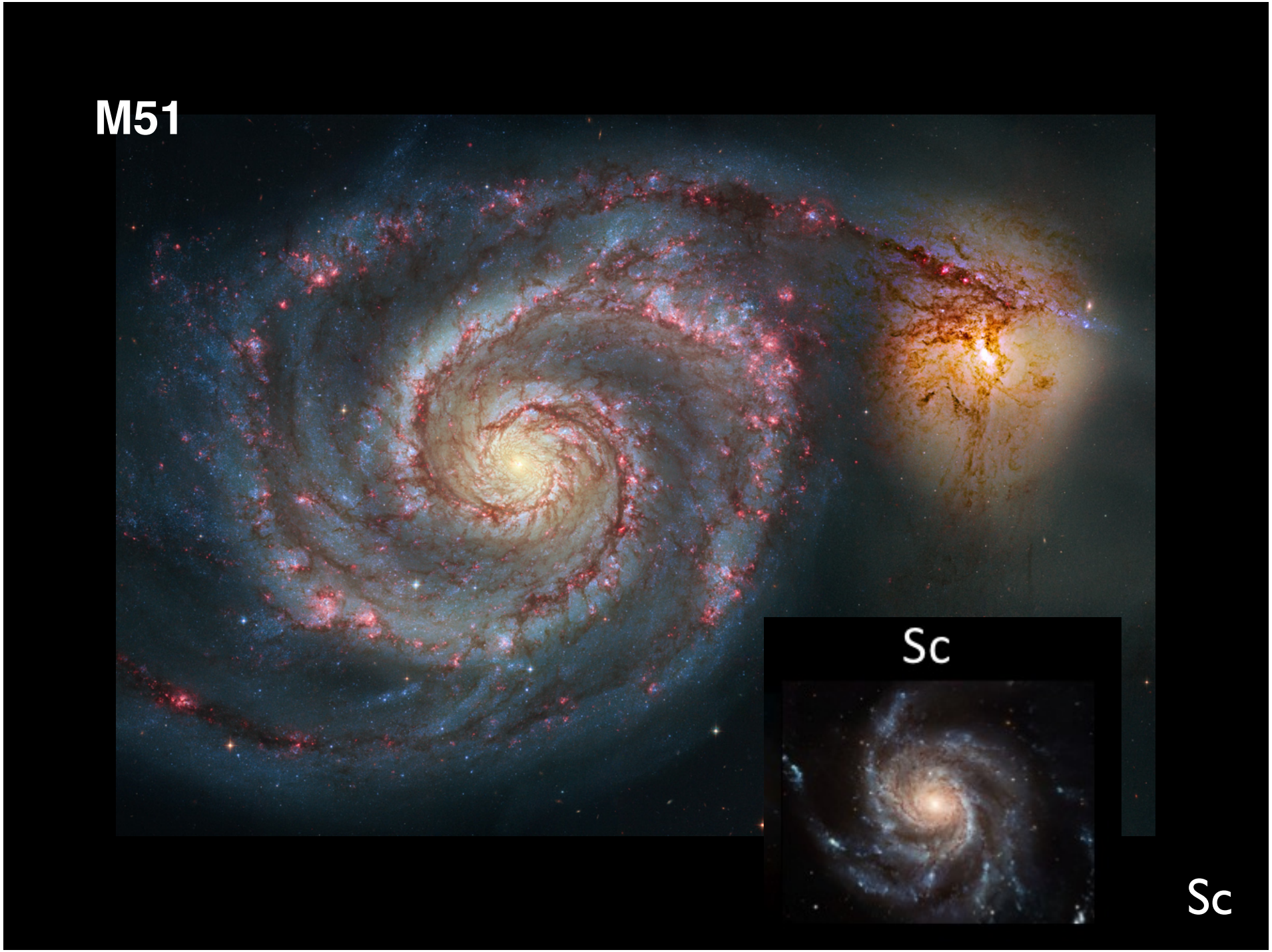

M87
cD
E1

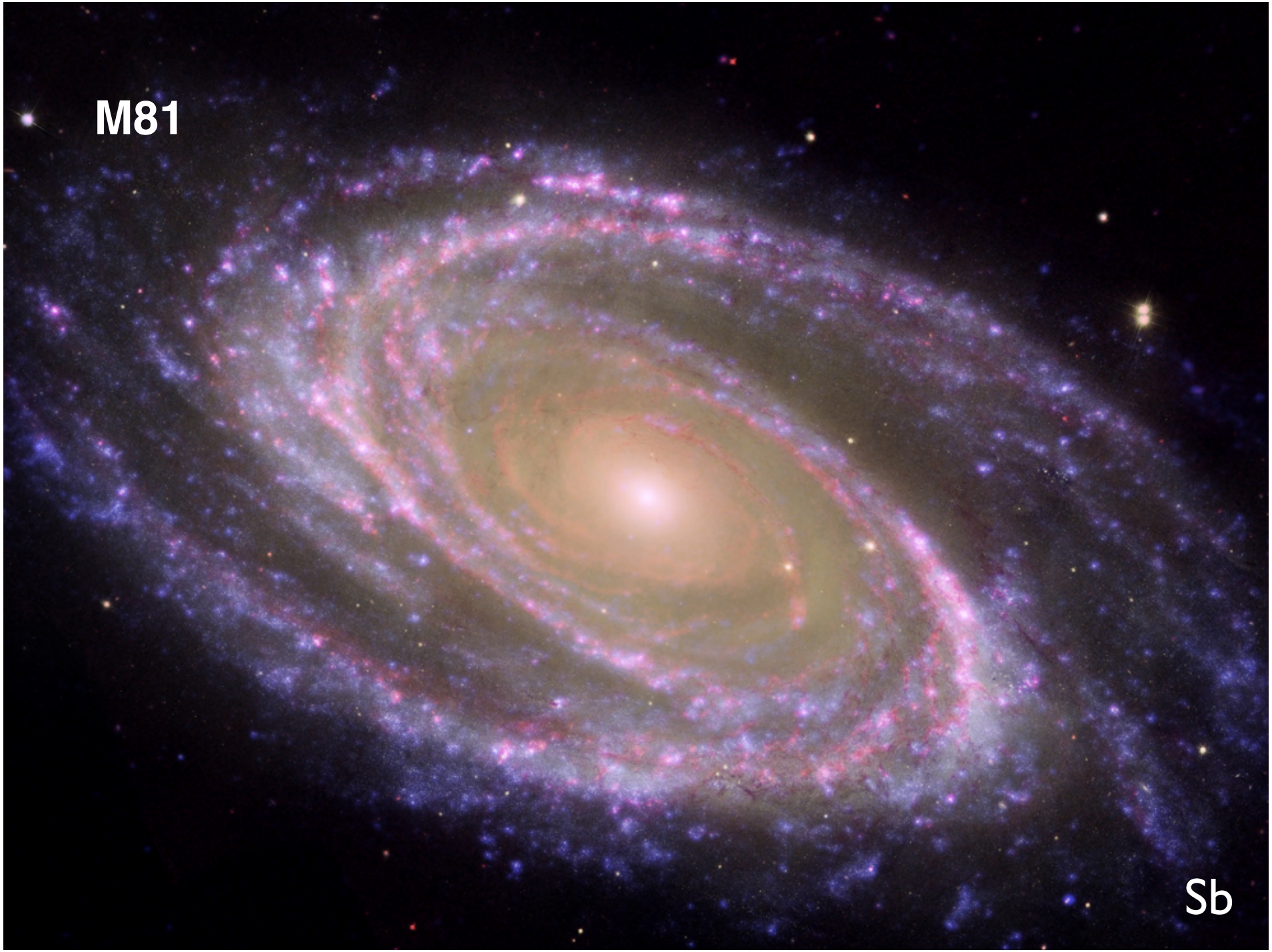

NGC 4472
E2

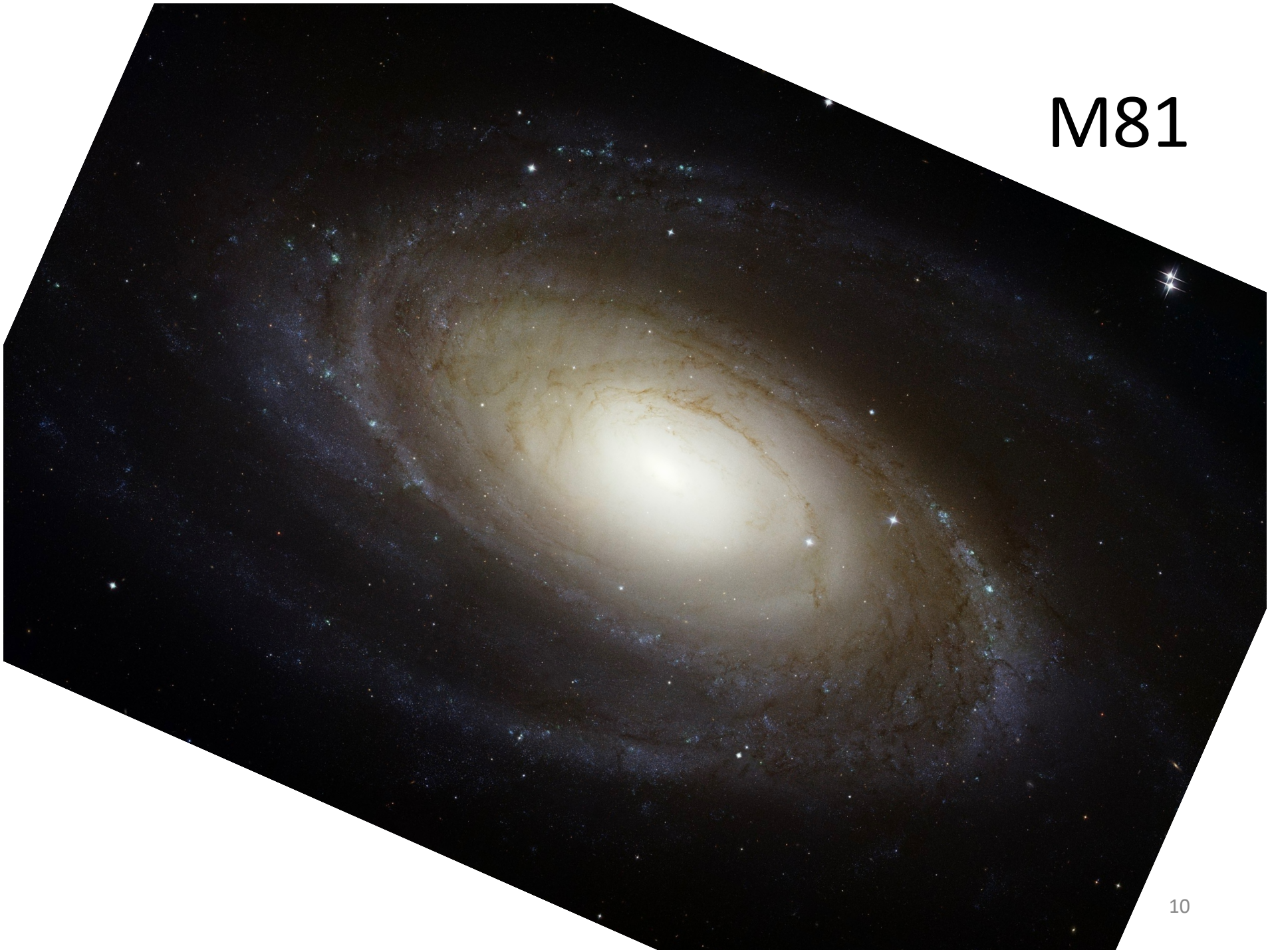
M110

E5

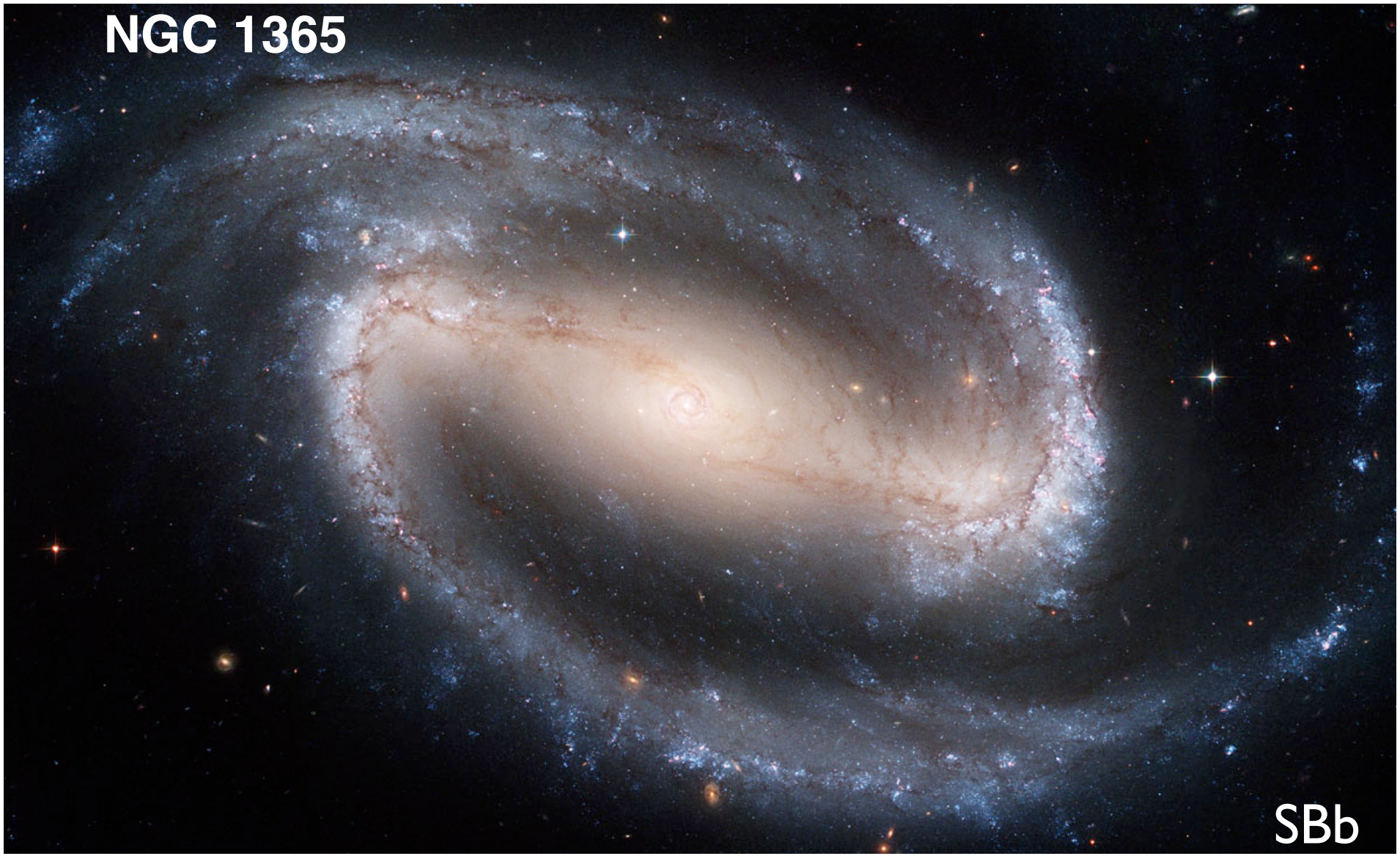
(dE)


M51
Sc
Sc

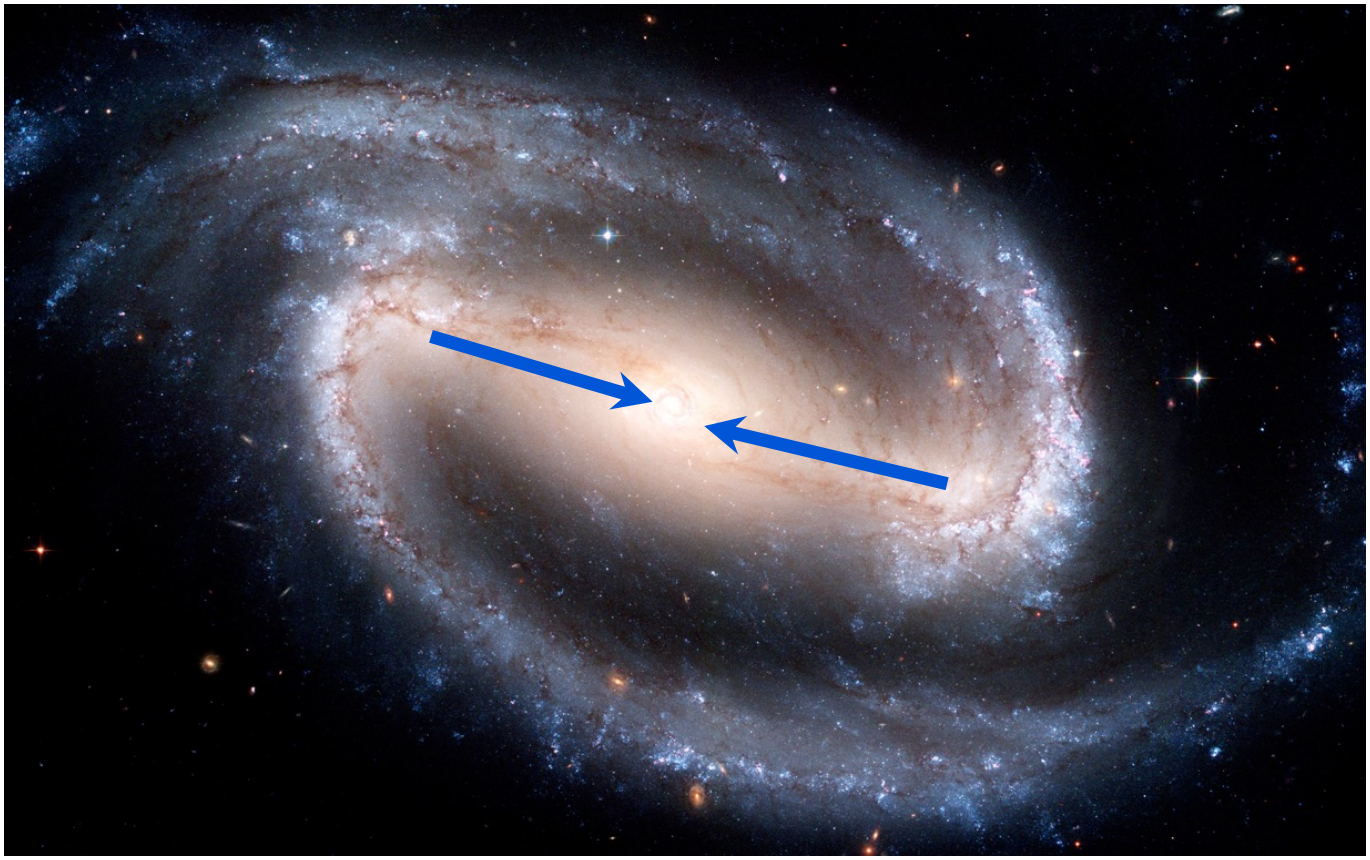

M81
Sb


M81

About 1/3 of nearby spiral galaxies are barred

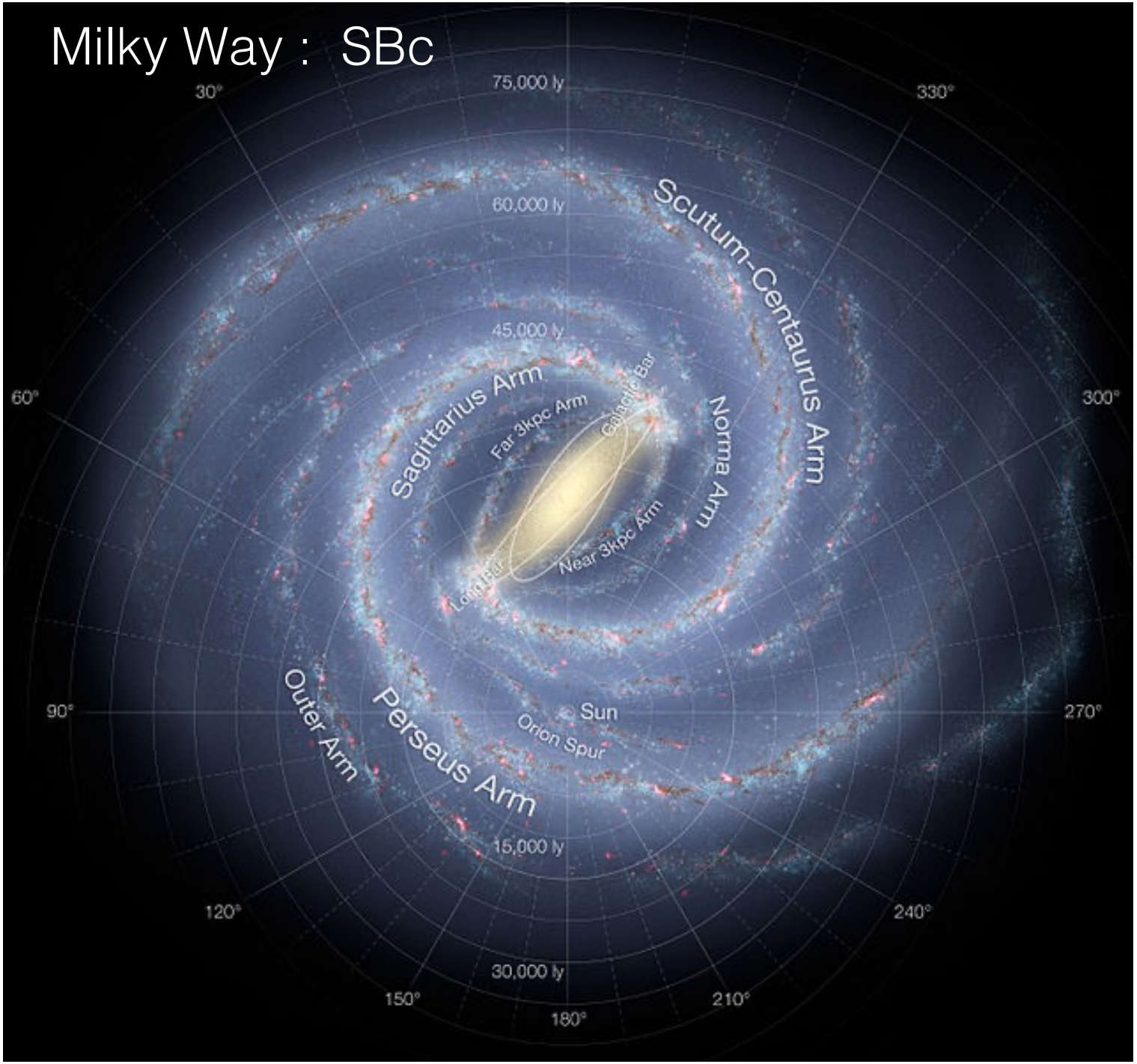


Bars contain both stars and gas. (Note the dust lanes.)
Non-circular motions cause the gas to experience torques and lose angular momentum - this allows gas to flow inwards.



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

Milky Way : SBc




Andromeda : Sb …. But bar …

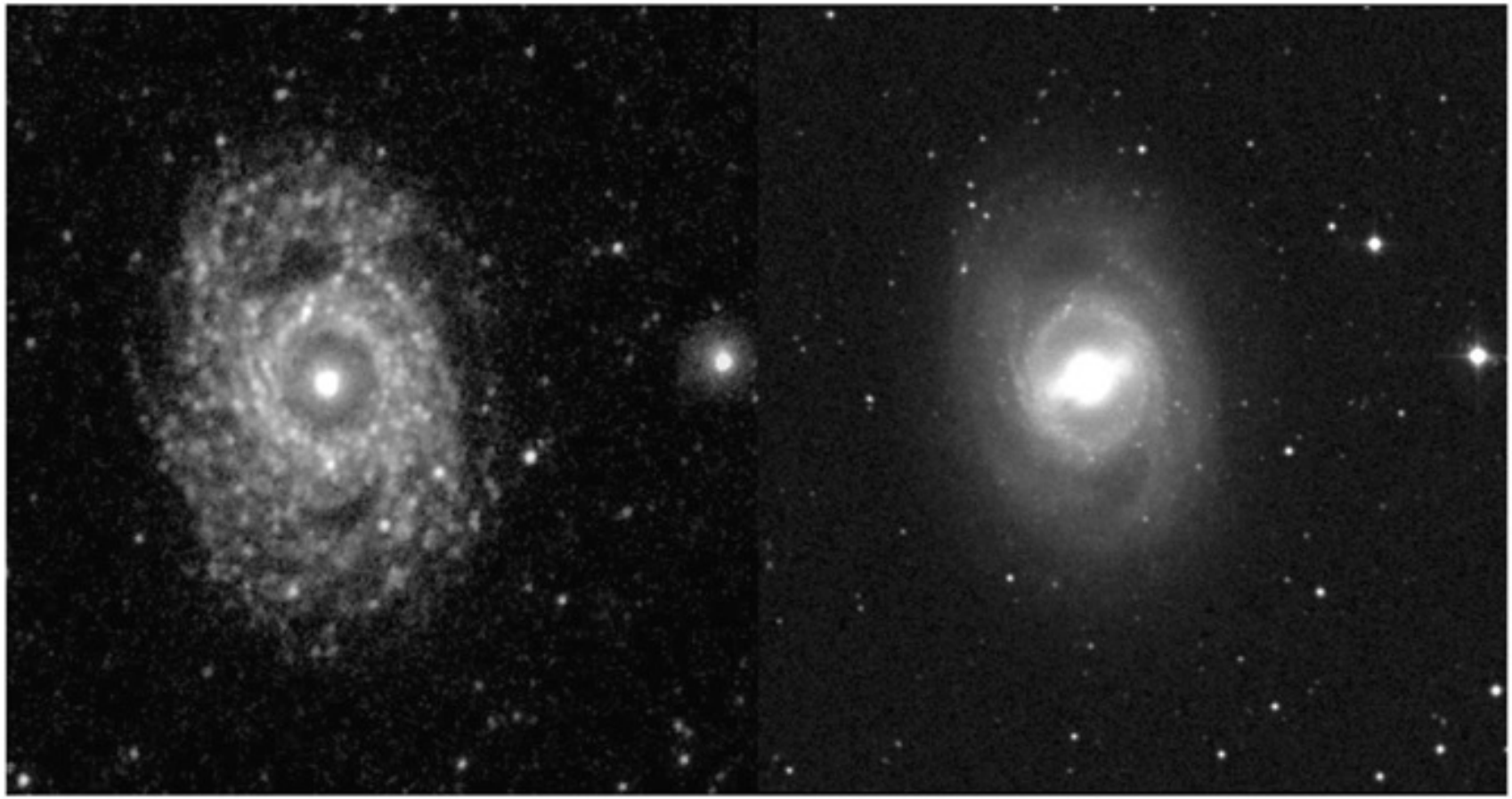
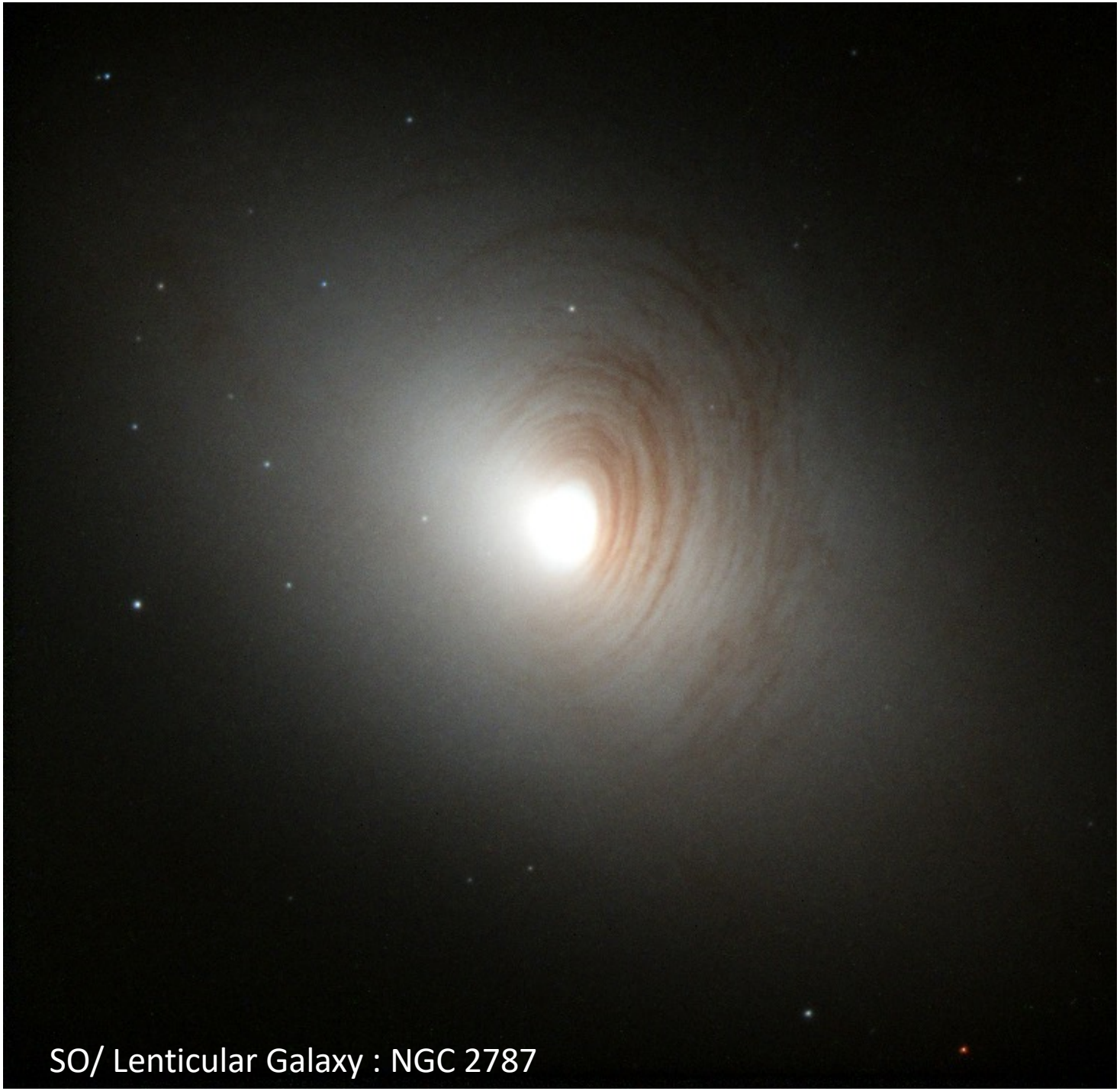
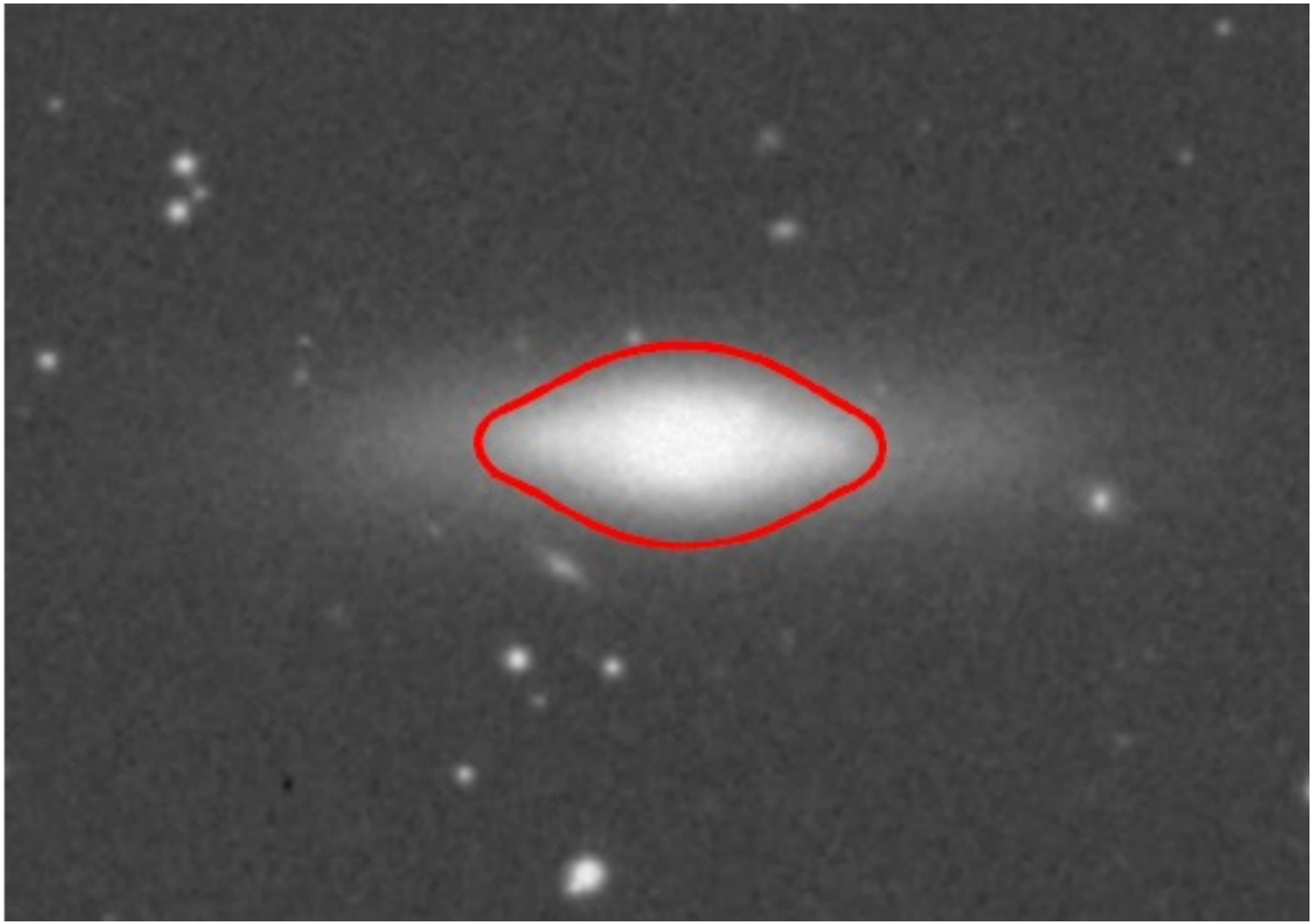


Fig 5.10 (Galex) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

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; star forming 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.

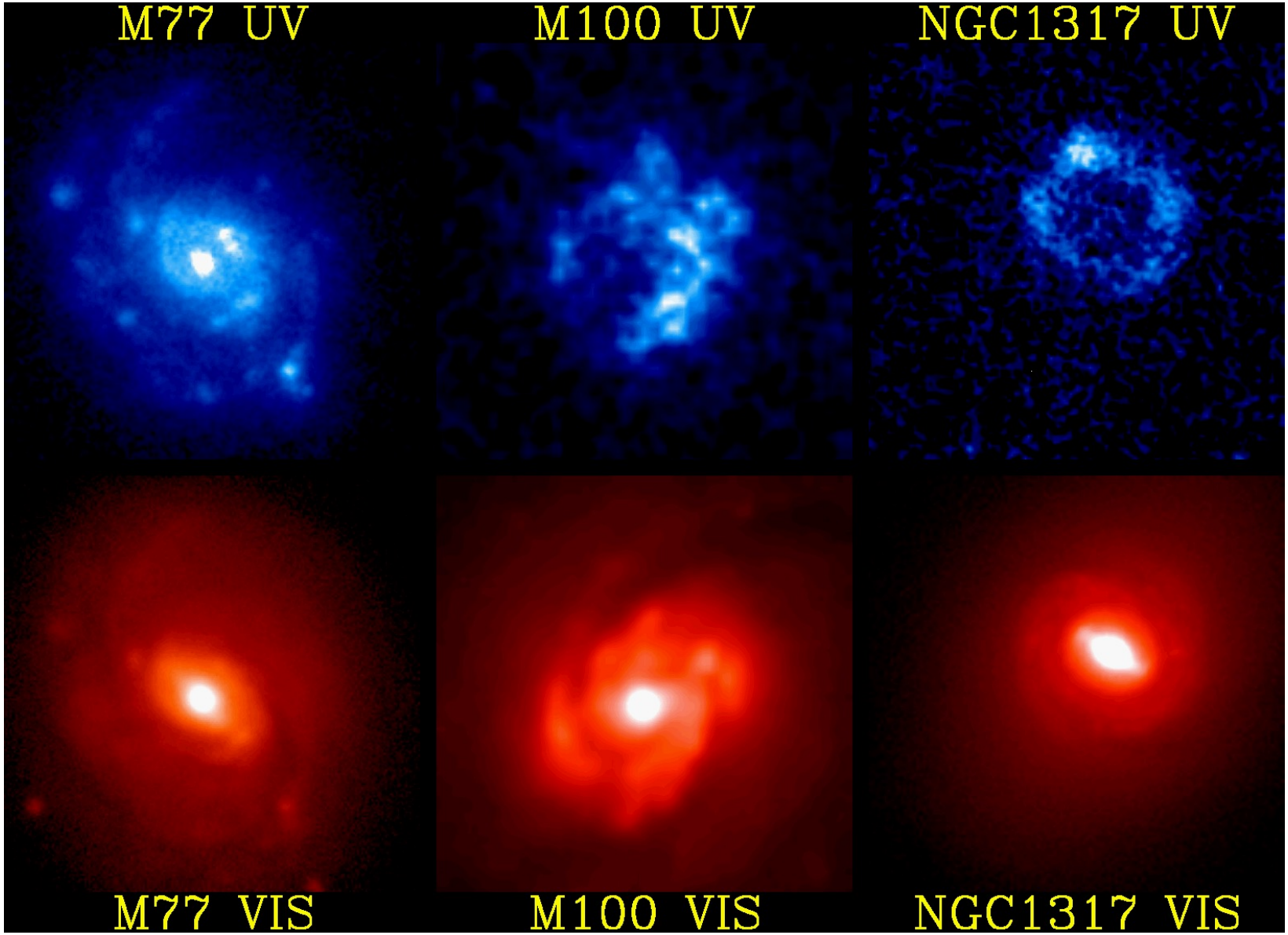


SO/ Lenticular Galaxy : NGC 2787

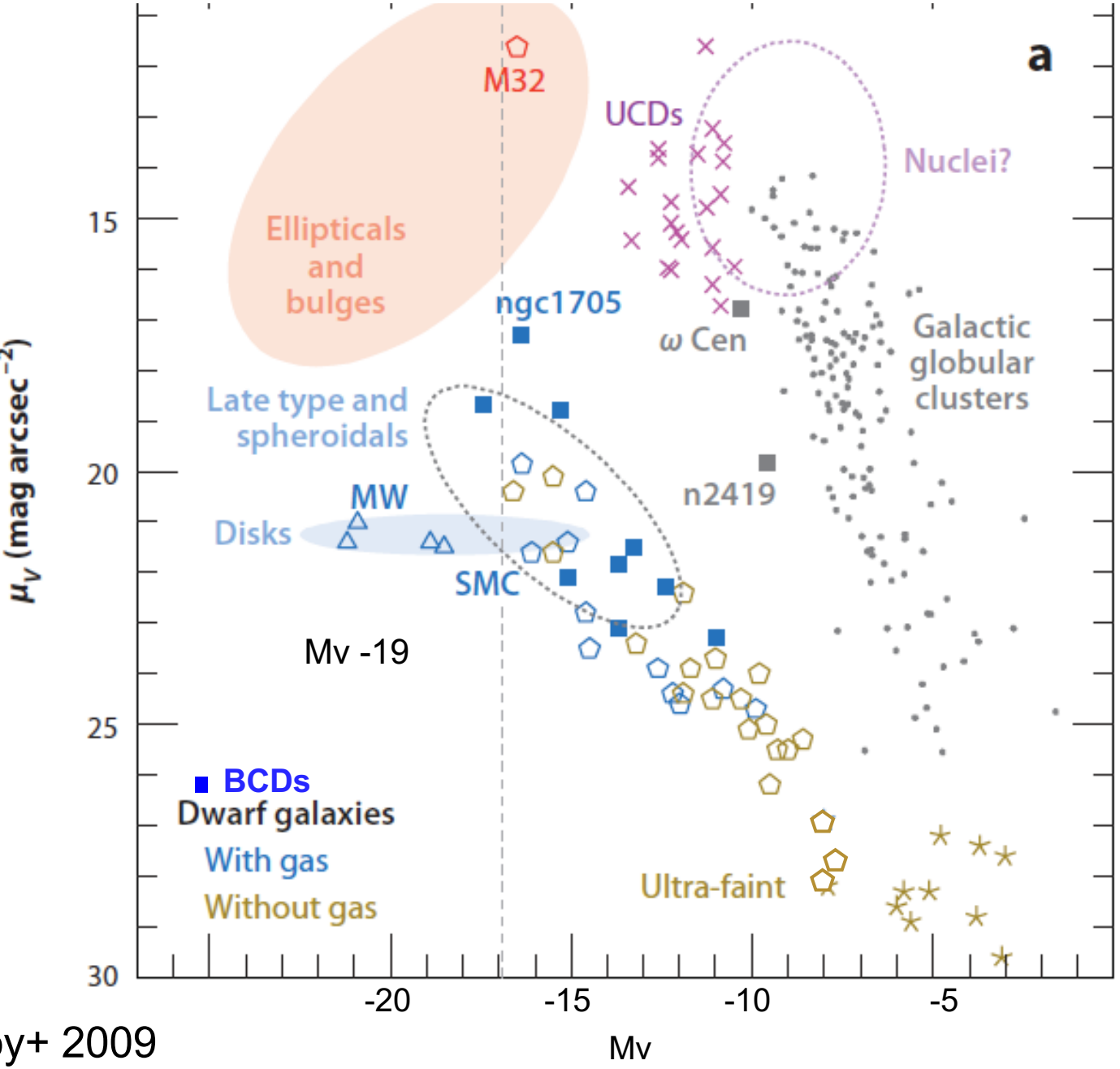


SO, lenticular galaxy: NGC 2549 (Courtesy of Sloan Digital Sky Survey)

Problems with Visual Inspection?

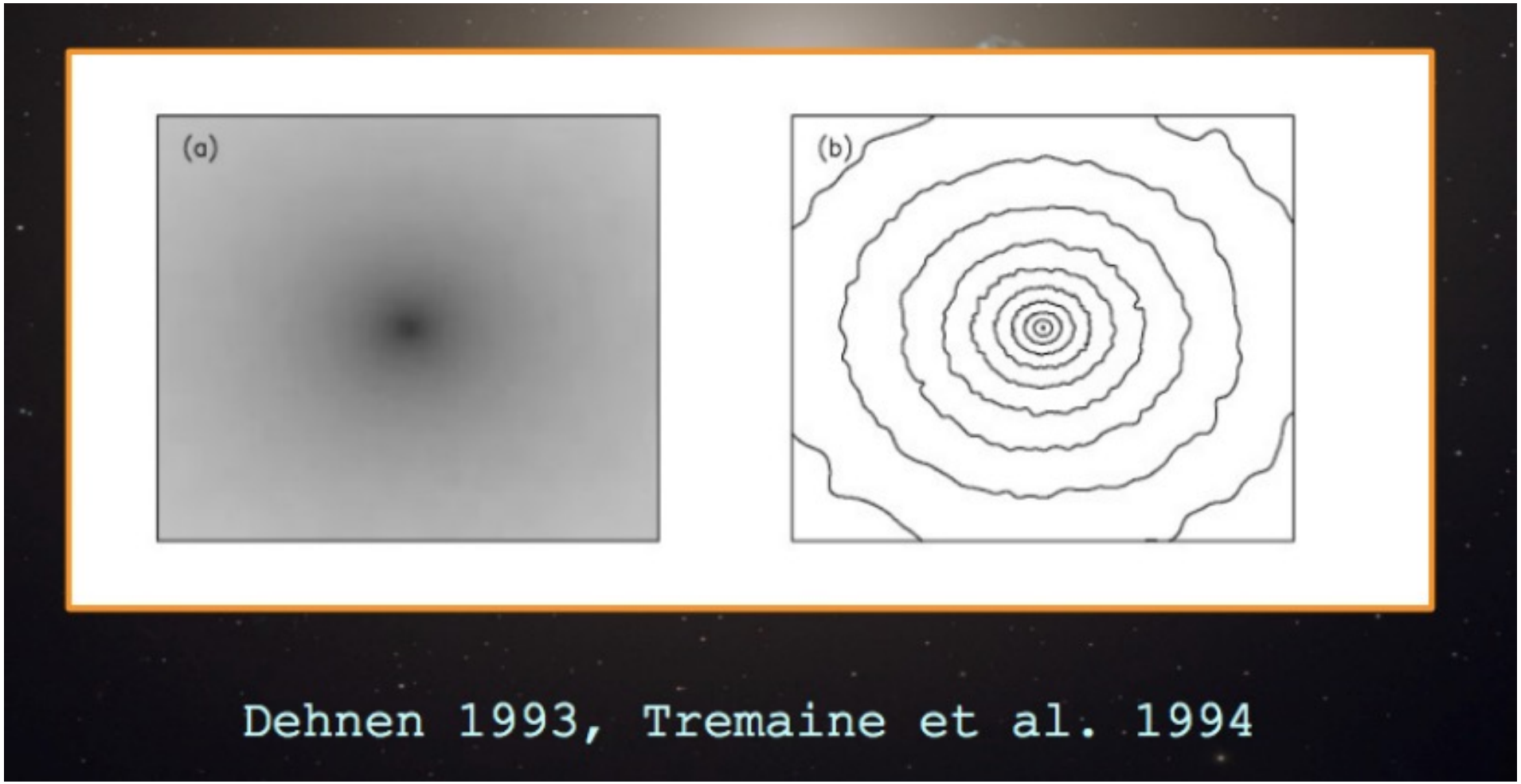


Gal Class. Method 2) Surface Brightness Profiles



Tolstoy+ 2009

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



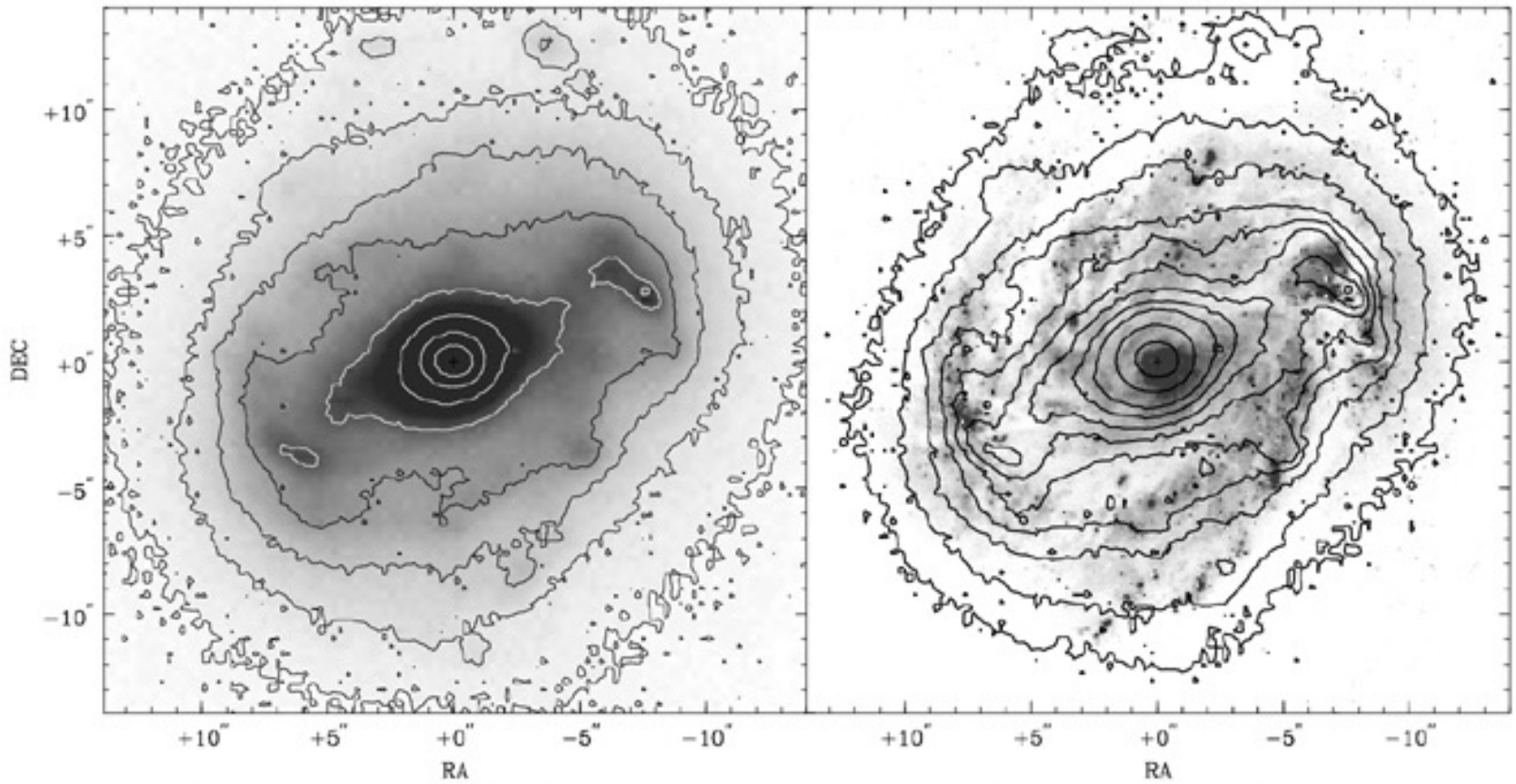
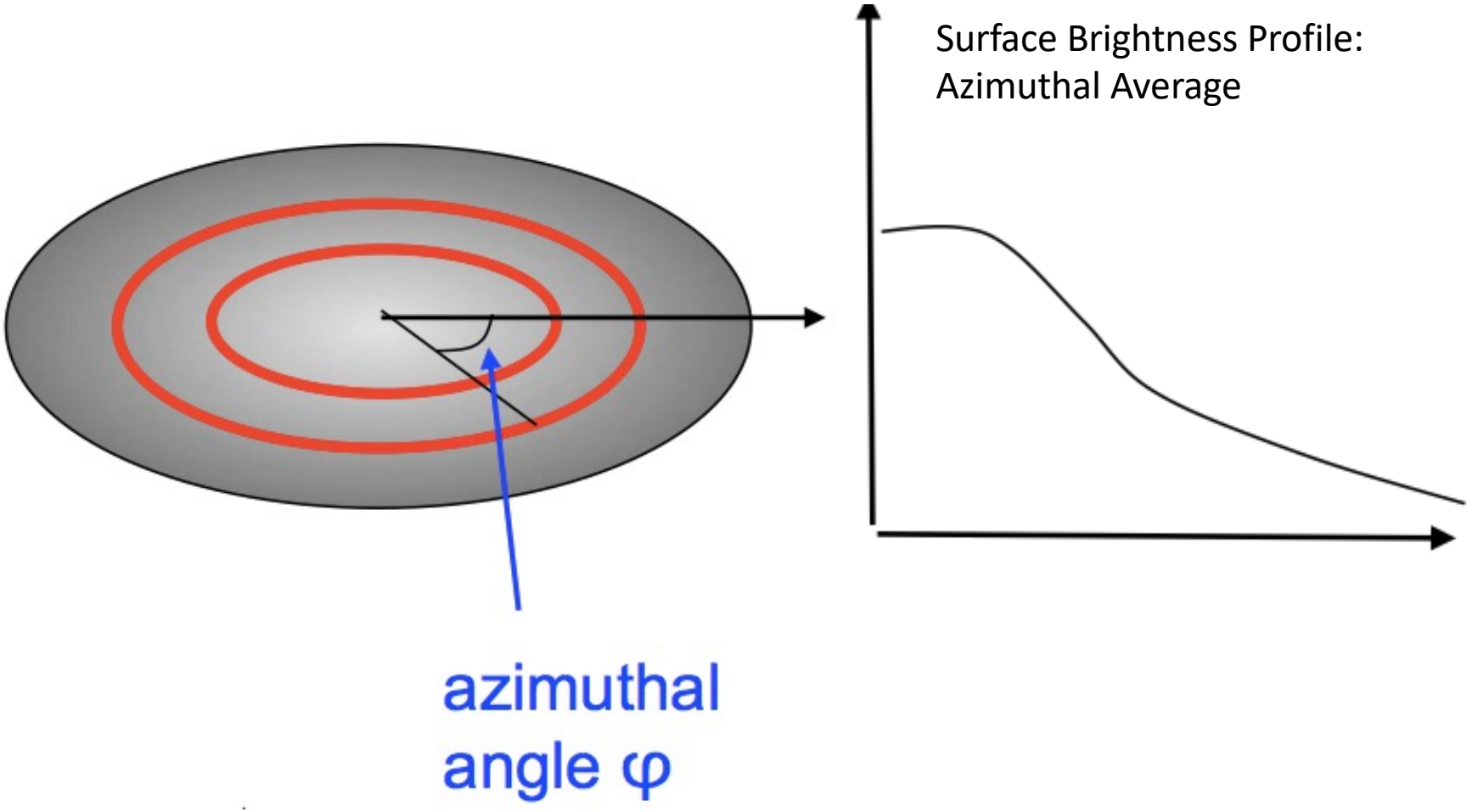
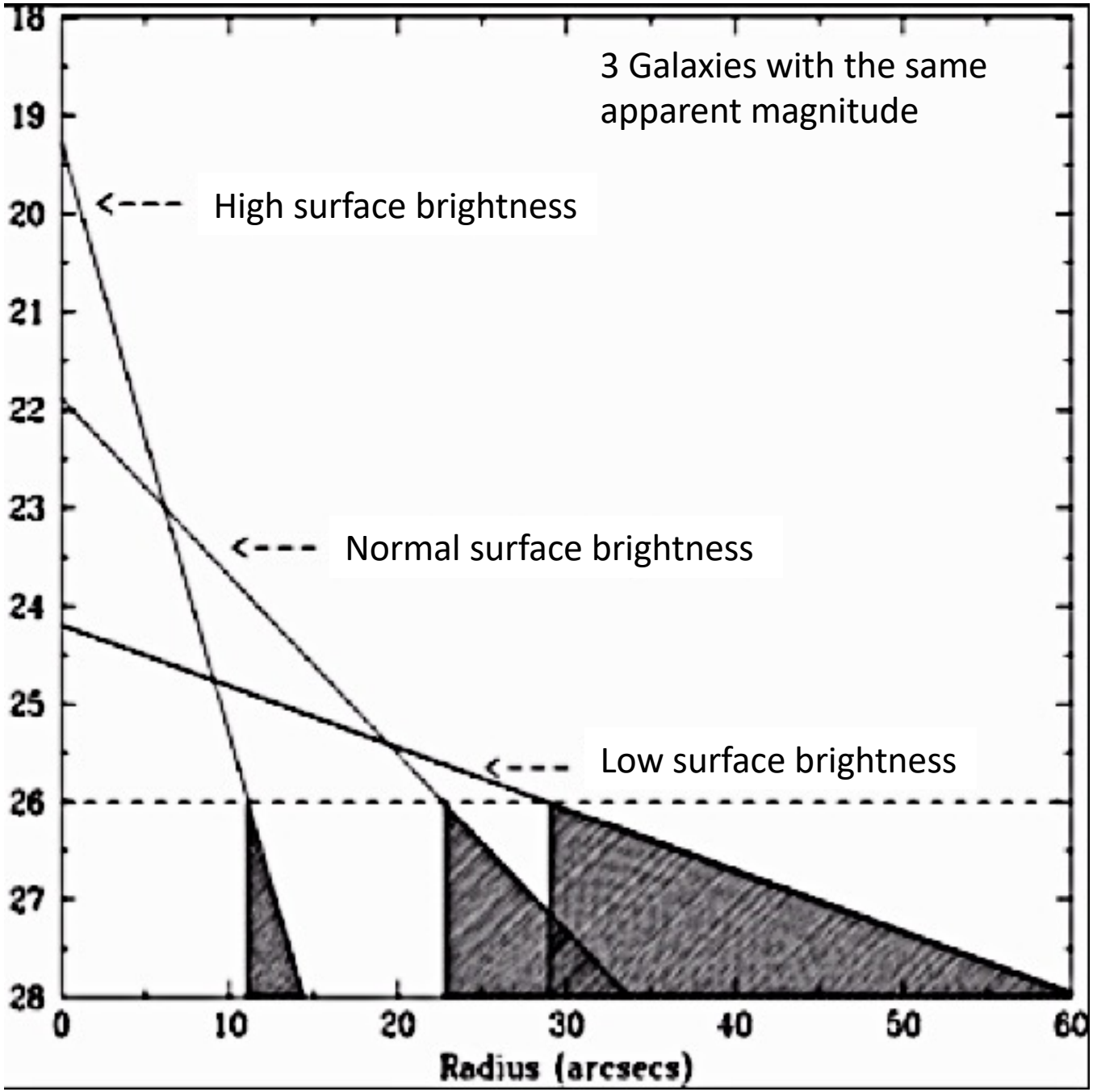
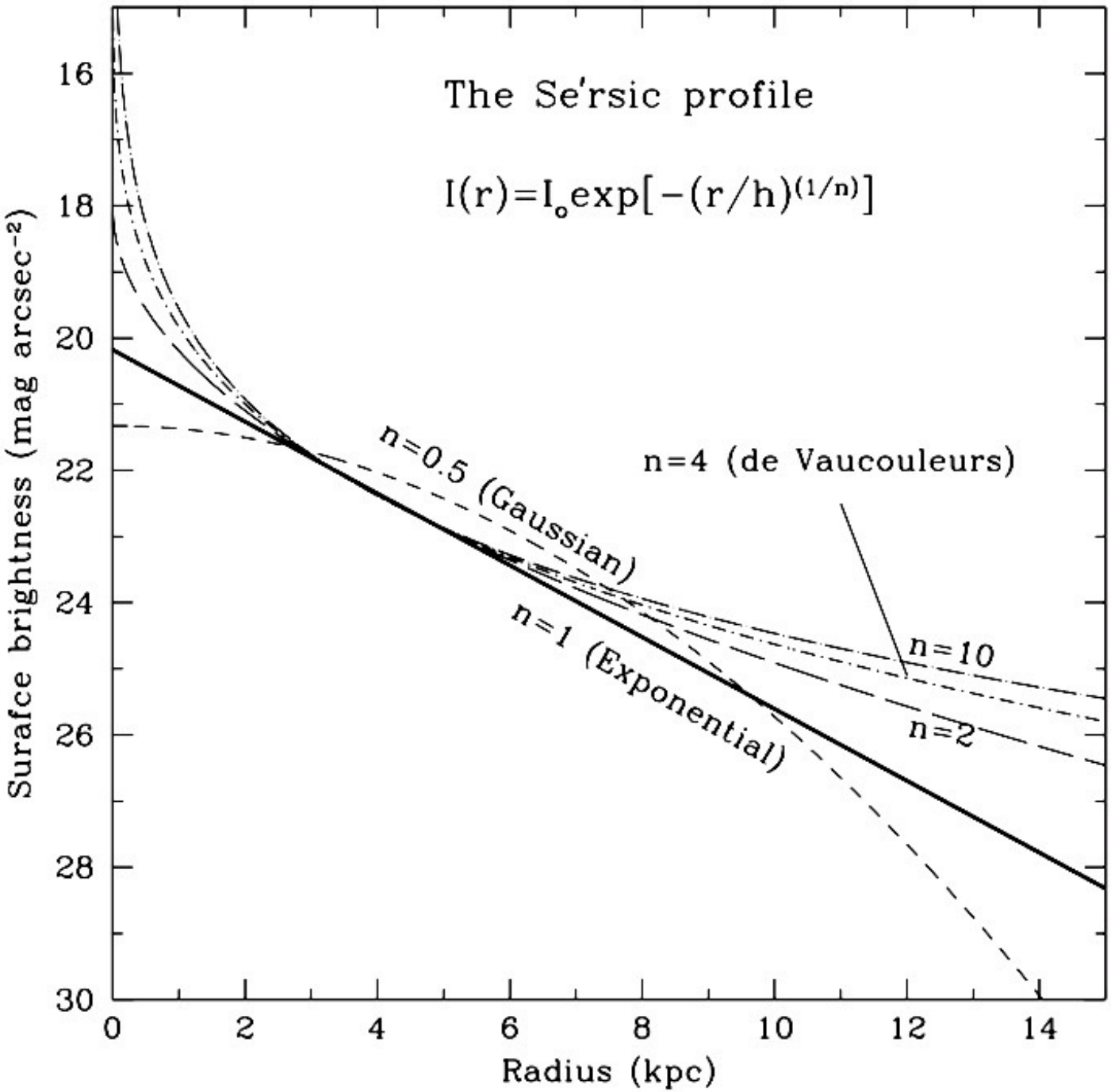


Fig 5.9 (J. Knapen) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

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!


Surface Brightness Profile:
Azimuthal Average
azimuthal
angle φ


3 Galaxies with the same apparent magnitude
High surface brightness
Normal surface brightness
Low surface brightness
Surface Brightness (mag / arcsec^2)
Radius (arcsecs)
18
19
20
21
22
23
24
25
26
27
28
0
10
20
30
40
50
60



Io is the central intensity.

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

n = Sersic index (shape parameter)

Total Luminosity

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

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

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

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

Ellipticals

Typically, n = 4 → De Vaucouleurs Profile

$$m = \mu_o - 5log(h_r) - 12.7$$

Effective Radius (2D radius that contains half the light):

$$R_e = 3459 h_r$$

Surface Brightness in terms of Re instead of h_r

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

Setting r = Re

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

$$L = 7.2\pi I_e R_e^2$$

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

Spirals

Edge on

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

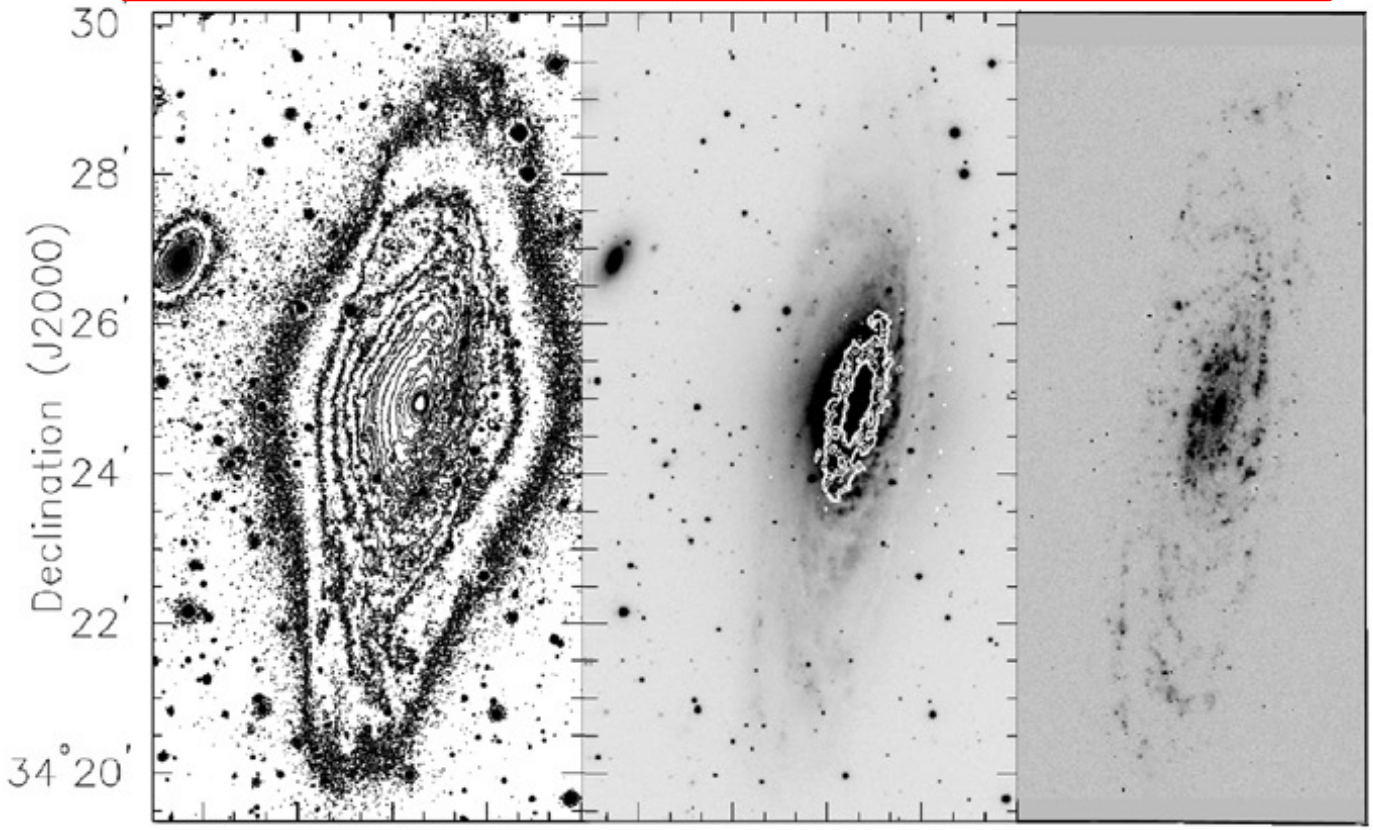


Fig 5.3 (Ferguson, Thornley) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

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

Surface Brightness Profile of Spiral Galaxy NGC 7331

Face On Disk + Bulge

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

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

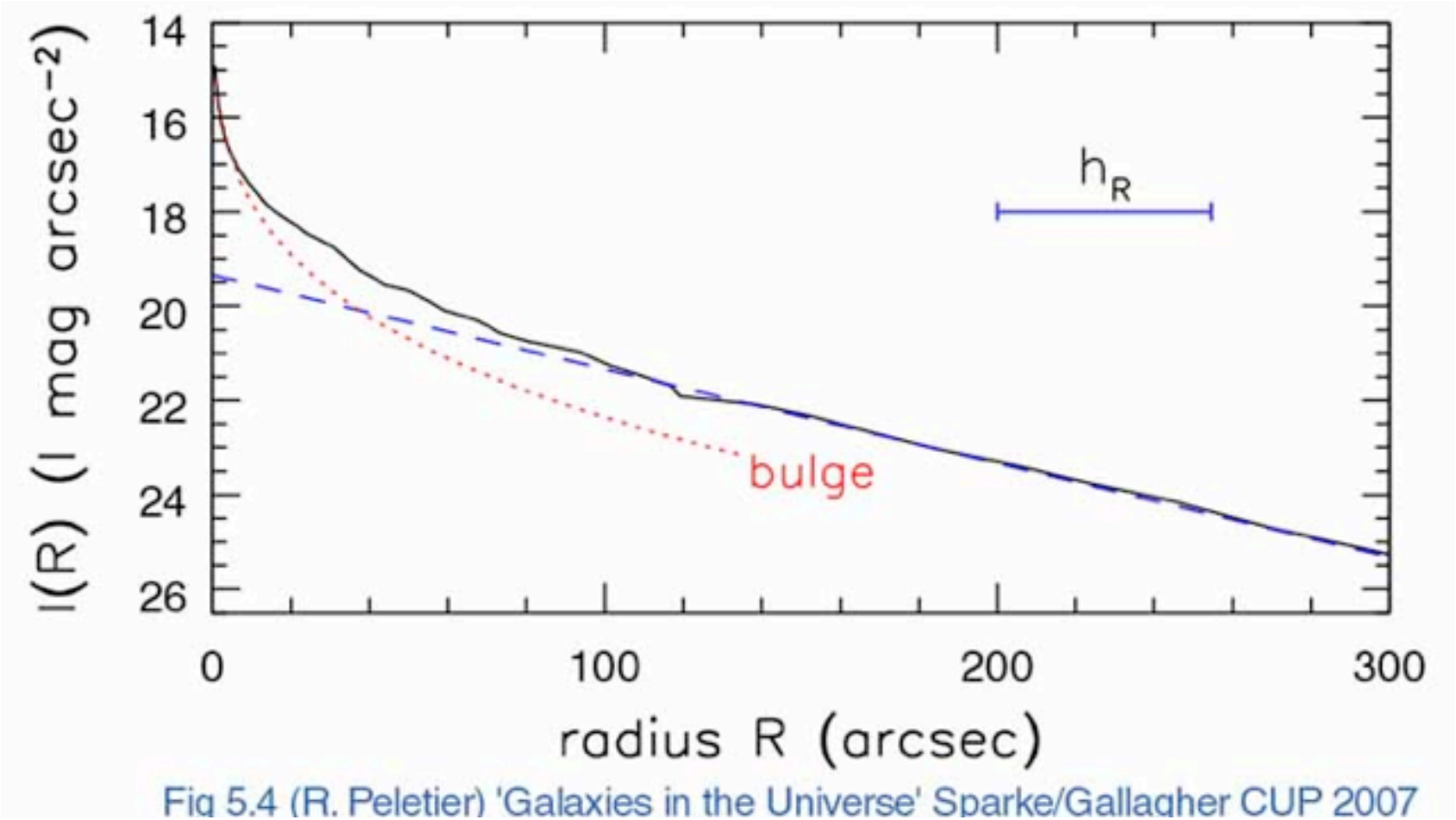
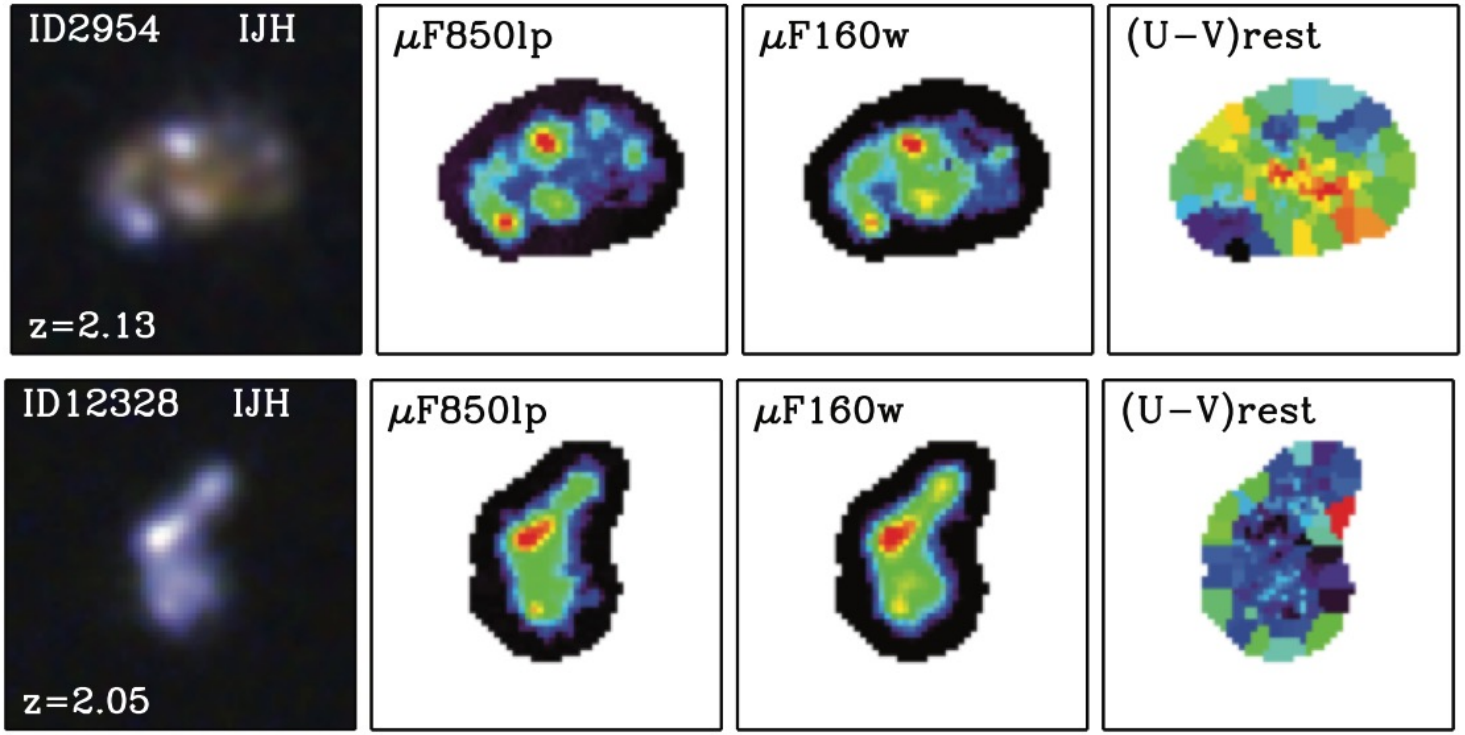


Fig 5.4 (R. Peletier) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

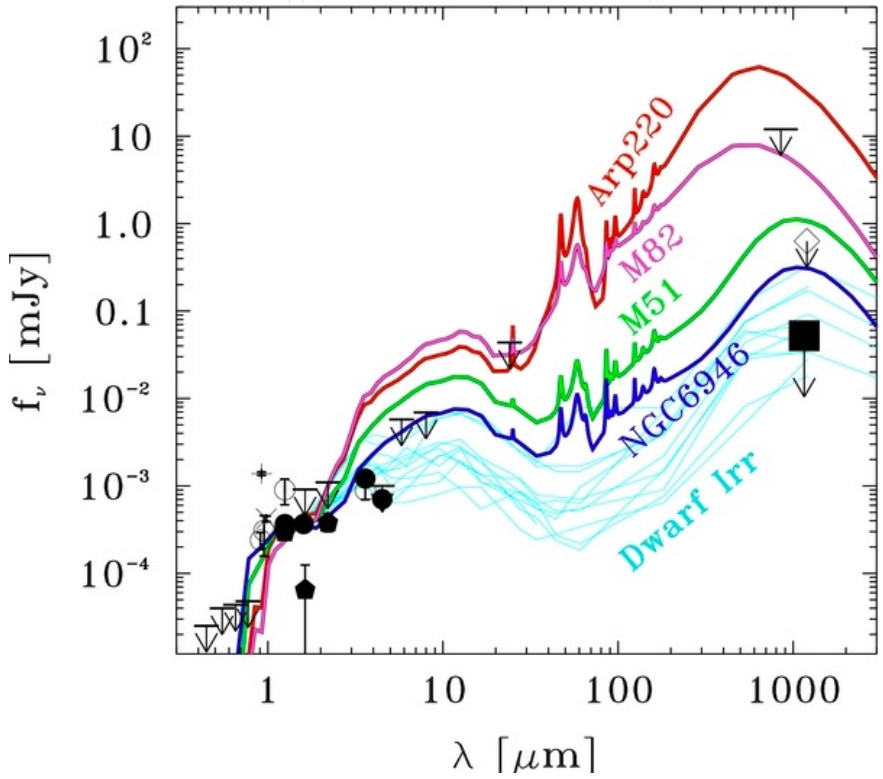
The solid line shows surface brightness in the I band., near 8000 Angstrom. The dashed line is an exponential with scale length h_r = 55" (3.6 kpc); the dotted line represents additional light, attributed to a bulge.

Problems with Surface Brightness Profile Method?



Wuyts + 2013

Gal Class. Method 3. Spectral Energy Distribution - SED



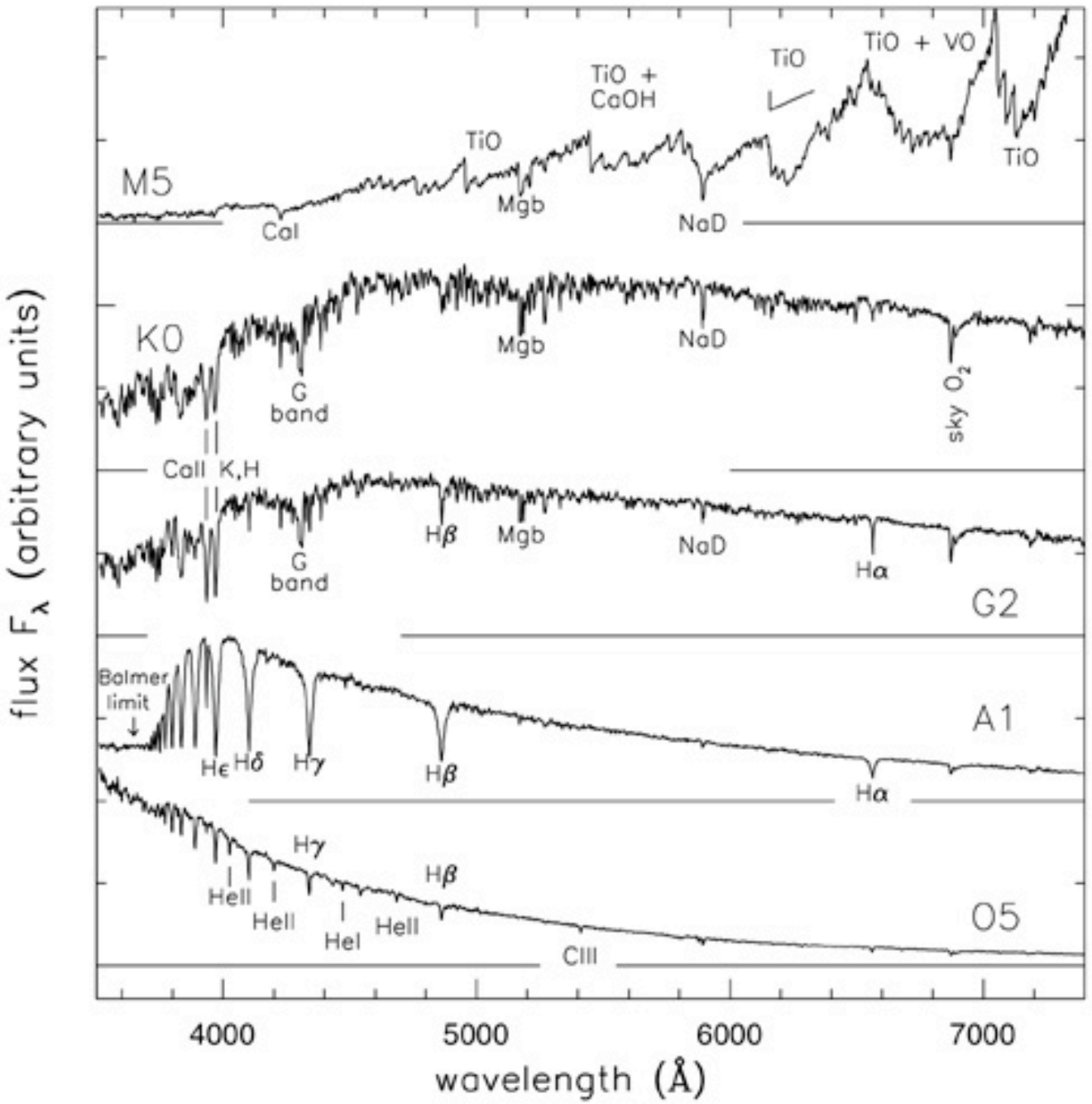


Fig 1.1 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

SED 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.

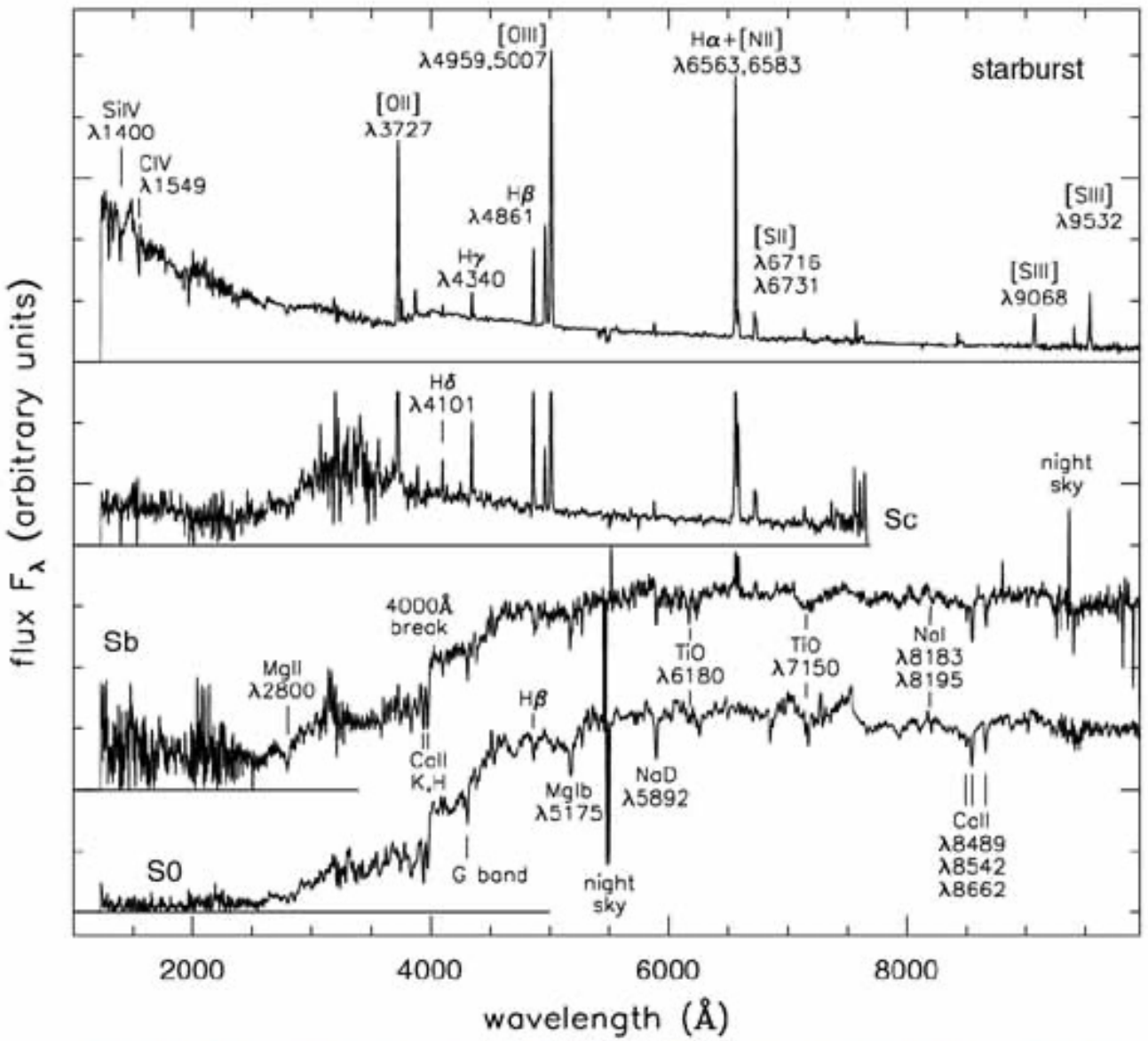


Fig 5.24 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

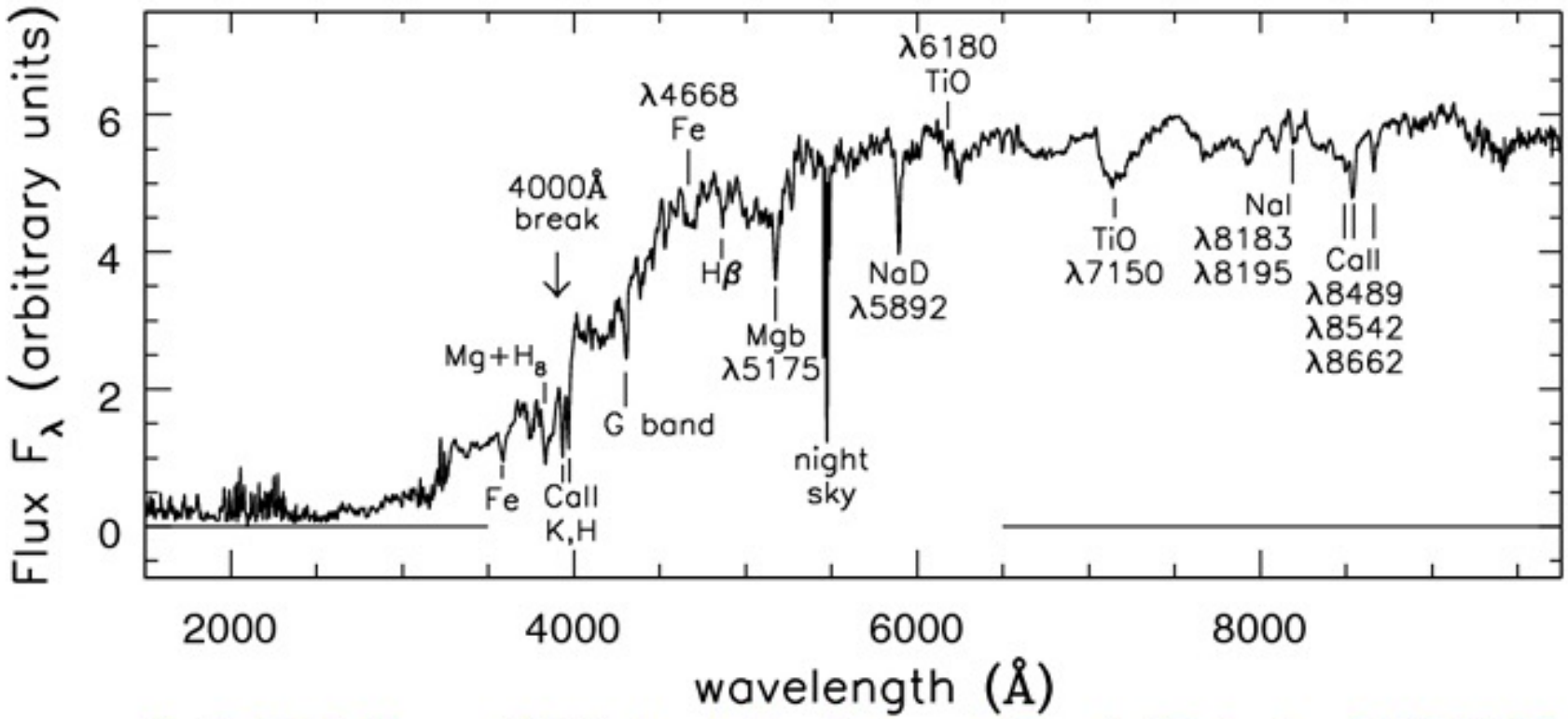
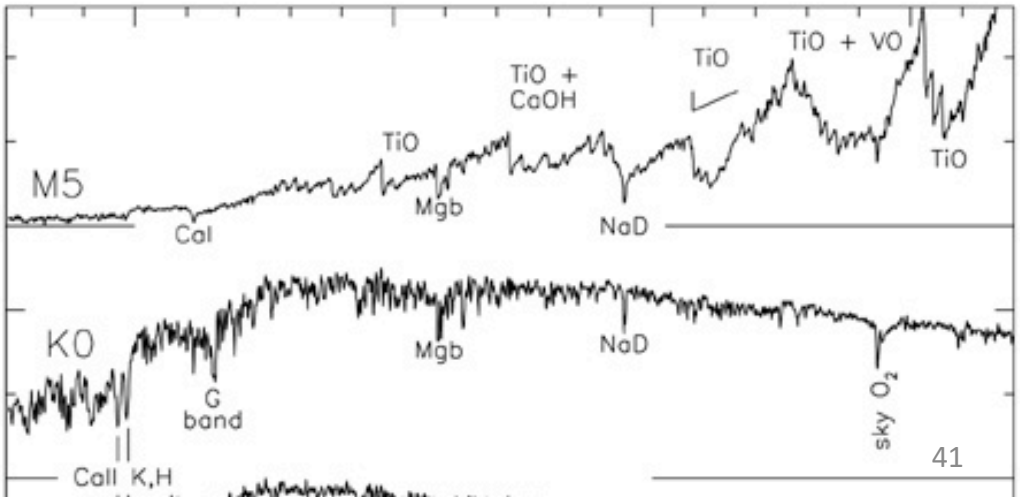
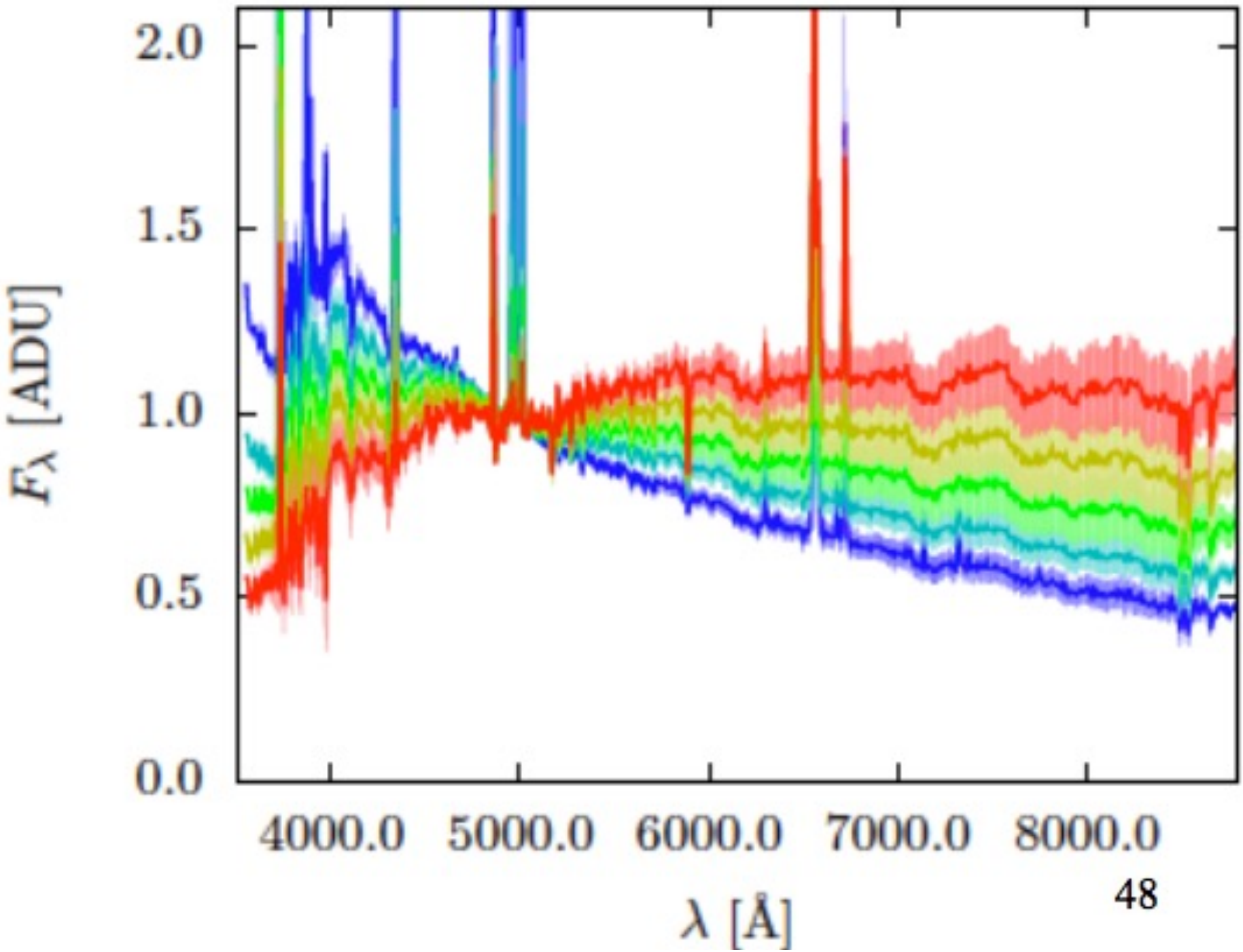


Fig 6.17 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

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




2.0
1.5
1.0
0.5
0.0
F_λ [ADU]
4000.0
5000.0
6000.0
7000.0
8000.0
λ [Å]