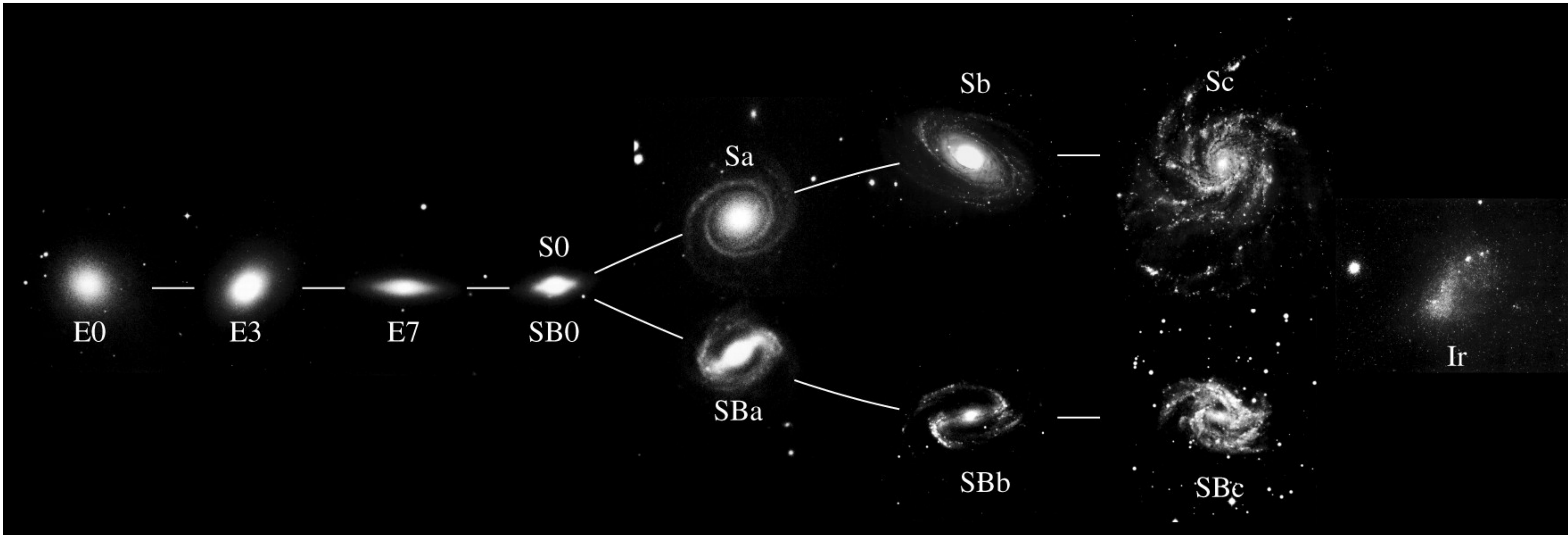
GALAXIES

I. Morphologies and classification
2. Successes of Hubble scheme
3. Problems with Hubble scheme
4. Galaxies in other wavelengths

5. Properties of spirals and Irregulars.

Hubble “tuning-fork” diagram.

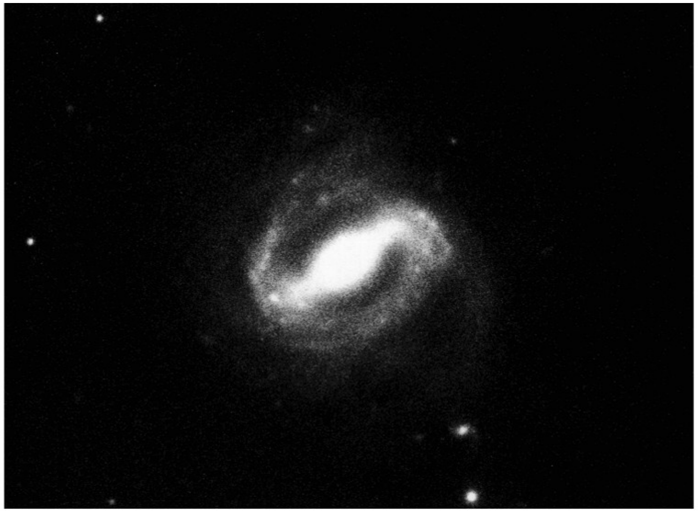


Hubble – Sandage classification
Types: **E0, E1, ..., E7, S0,   Sa,   Sb,   Sc   IrI, IrII**
SB0, Sba, Sbb, Sbc IrI, IrII
Early Types <----------------------> Late Types

Basis for Spiral subtypes:

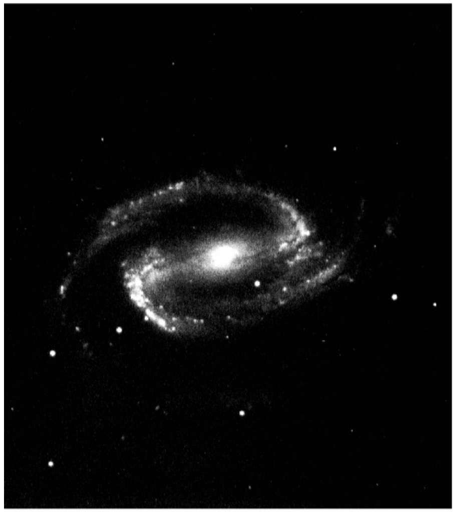
1) relative size/brightness of bulge compared to disk
2) Resolution of arms into clumps of star formation
3) Tightness of winding – spiral pitch angle.

Sample barred spirals.



(a)

NGC 175 SBab(s) I-II



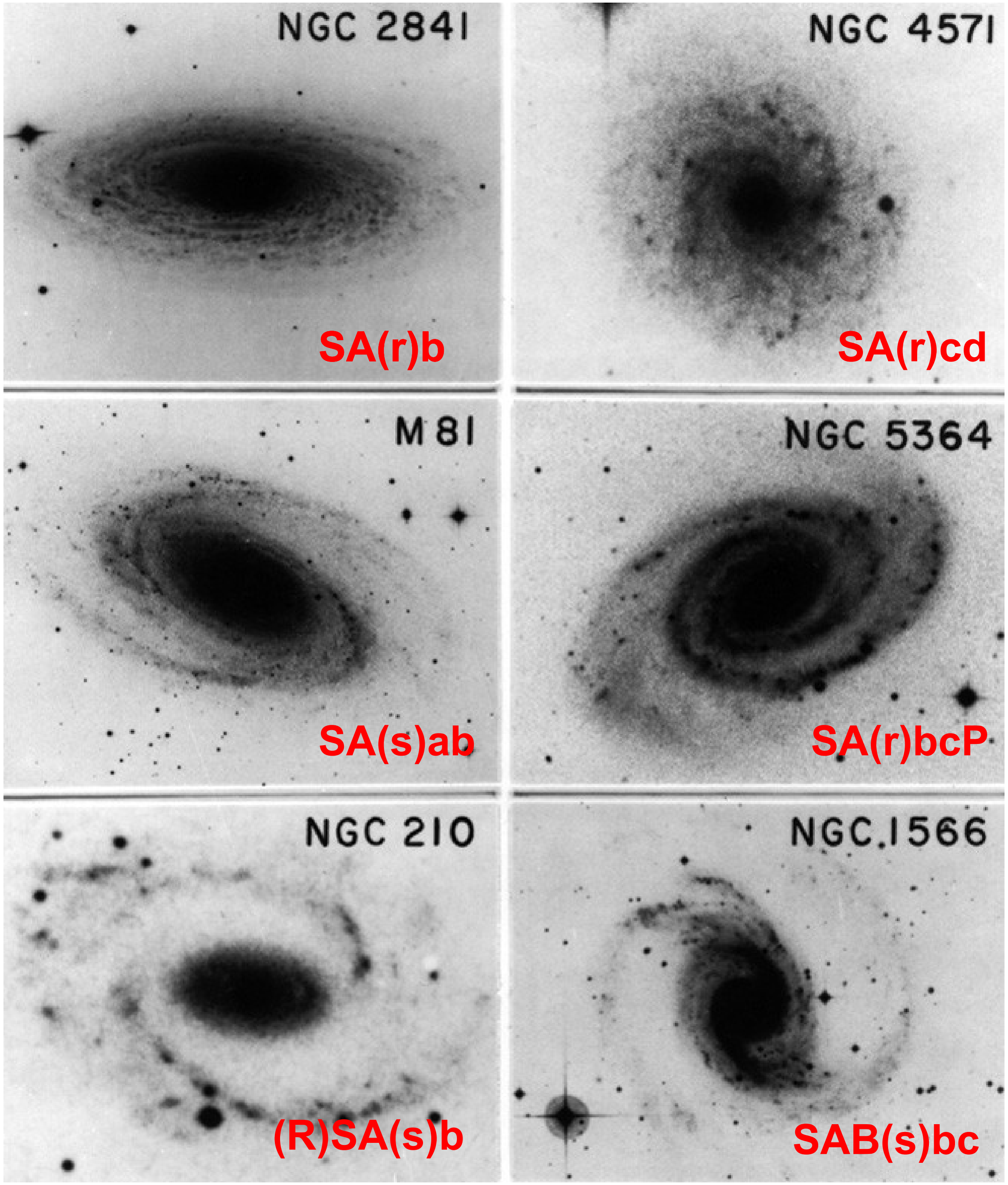
(b)

(c)

NGC 1300 (SBb(s) I)

NGC 2525 (SBc(s)II)

Hubble originally had subtypes and prototypes such as ....



Flocculent spirals, non-global arms.

Global arm pattern, 2-arm Spirals. (Grand design.)

Oval galaxies. Arms imbedded in Low-SB disk on left, and high-SB disk on right.

Successes of the Hubble classification scheme.

The 3 criteria for spiral types correlate with each other.
E.g., big bulge galaxies tend to have smoother, more tightly wound arms.

The types correlate with other properties (see Tables 25.1 and 25.2):

Absolute magnitudes – greater for Sa's than Ir's
Masses – greater for Sa's than Ir's
Diameters – same range for Sa, Sb, and Sc, but smaller for Sd's, Ir's.
M/L – greater for Sa's than Ir's.
Vmax – greater for Sa's than Ir's.
B-V – greater for Sa's then Ir's.
Mgas/Mtot – less for Sa's than Ir's.
M_H2/M_HI – greater for Sa's then Ir's.

Metallicity increases with absolute magnitude.

Problems with (Hubble) classification of galaxies

"Bandwidth bias"

- **Original scheme based on photographic emulsions and the eye which were sensitive to the visible part of the spectrum.**
- **UV and (especially) IR can give a very different view**
- **(see slides ahead for galaxies in other wavelengths)**

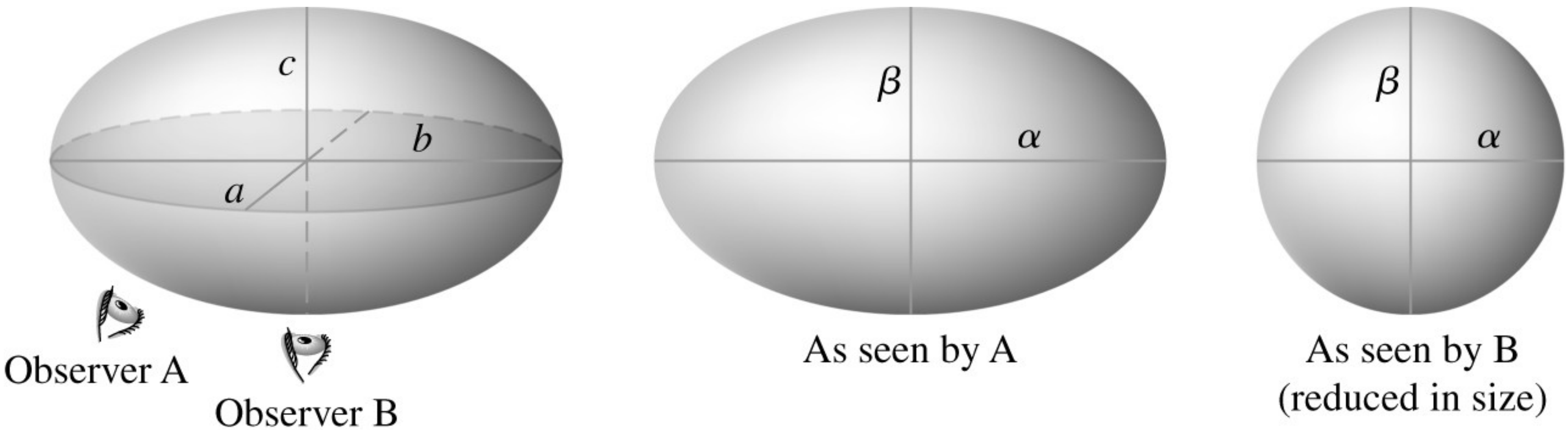
Perspective

- **Arm winding and "clumpiness" of arms difficult to tell for edge-on spirals**
- **Ellipiticity depends on orientation.**
- **True shapes of ellipticals include oblate spheroids, prolate spheroids, and triaxial ellipsoids. (See slides ahead.)**
- **Face-on views of S0's and Sa's can be difficult to distinguish from E's. (An analysis of**

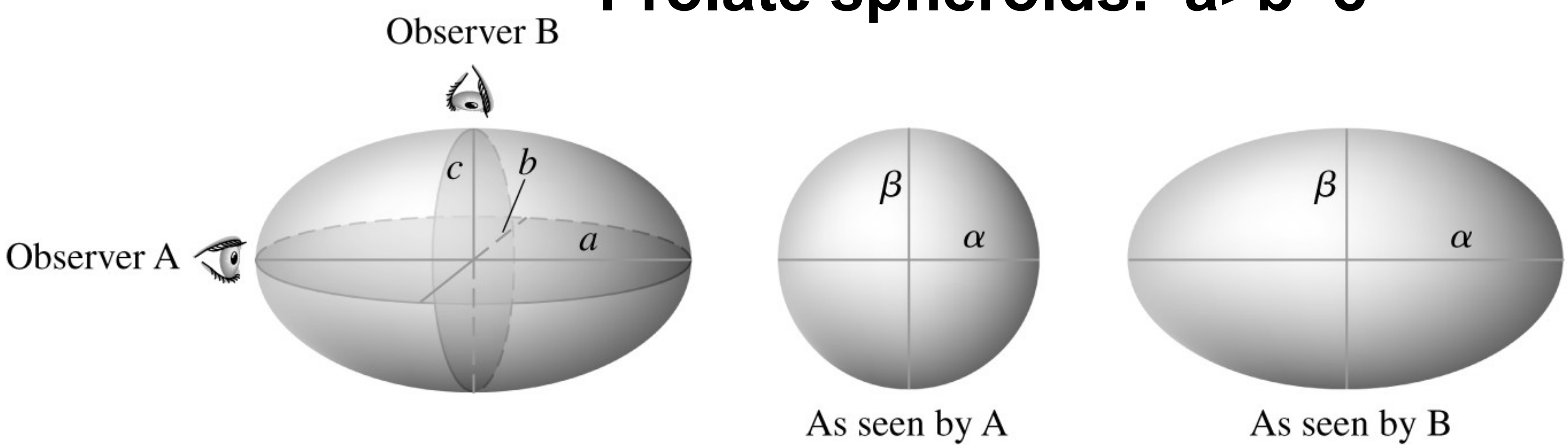
Resolution

- **HST reveals structures not resolved from ground. Esp. dust in early-types.**
- **Far away galaxies are harder to classify**
- **Quasars turned out to be the centers of galaxies**
- **AGN (Active Galactic Nuclei) like quasars and Seyferts can add to the light of the bulge and make the type seem earlier.**

Oblate spheroids.   a=b>c

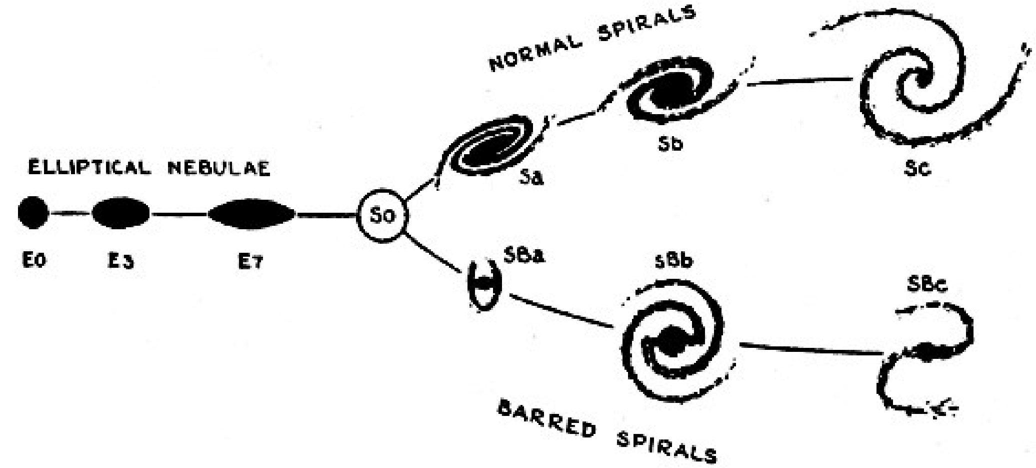


Prolate spheroids. a>b=c



(Not shown: Triaxial. a>b>c)

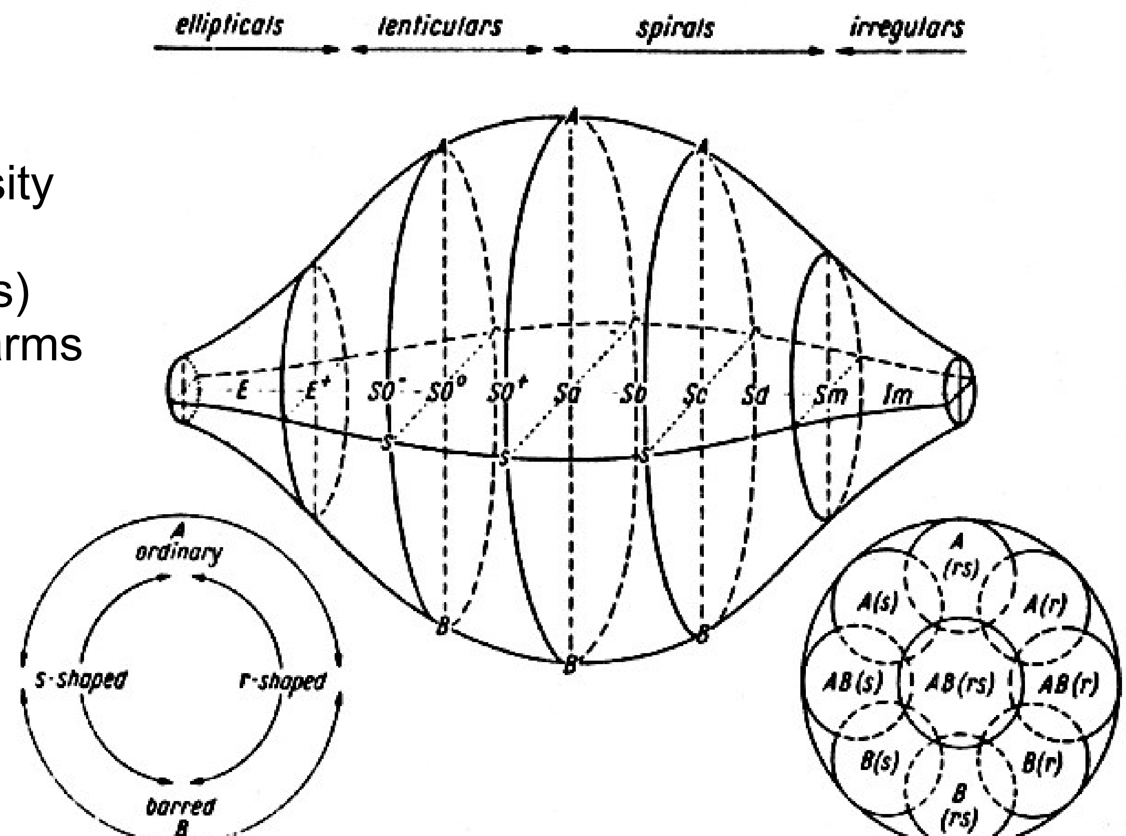
Modifications of Hubble's Classification scheme.



De Vaucouleur's modifications

1) Luminosity classes for galaxies.
   I = well defined arms, luminous
   V = poorly defined arms, low-luminosity

2) r,rs,s,R designations (usually for SB's)
   r = inner ring (usually inside of main arms and just outside of bar)
   s = inner spiral
   R = outer ring (outside of main arms)



Galaxies in other wavelengths.

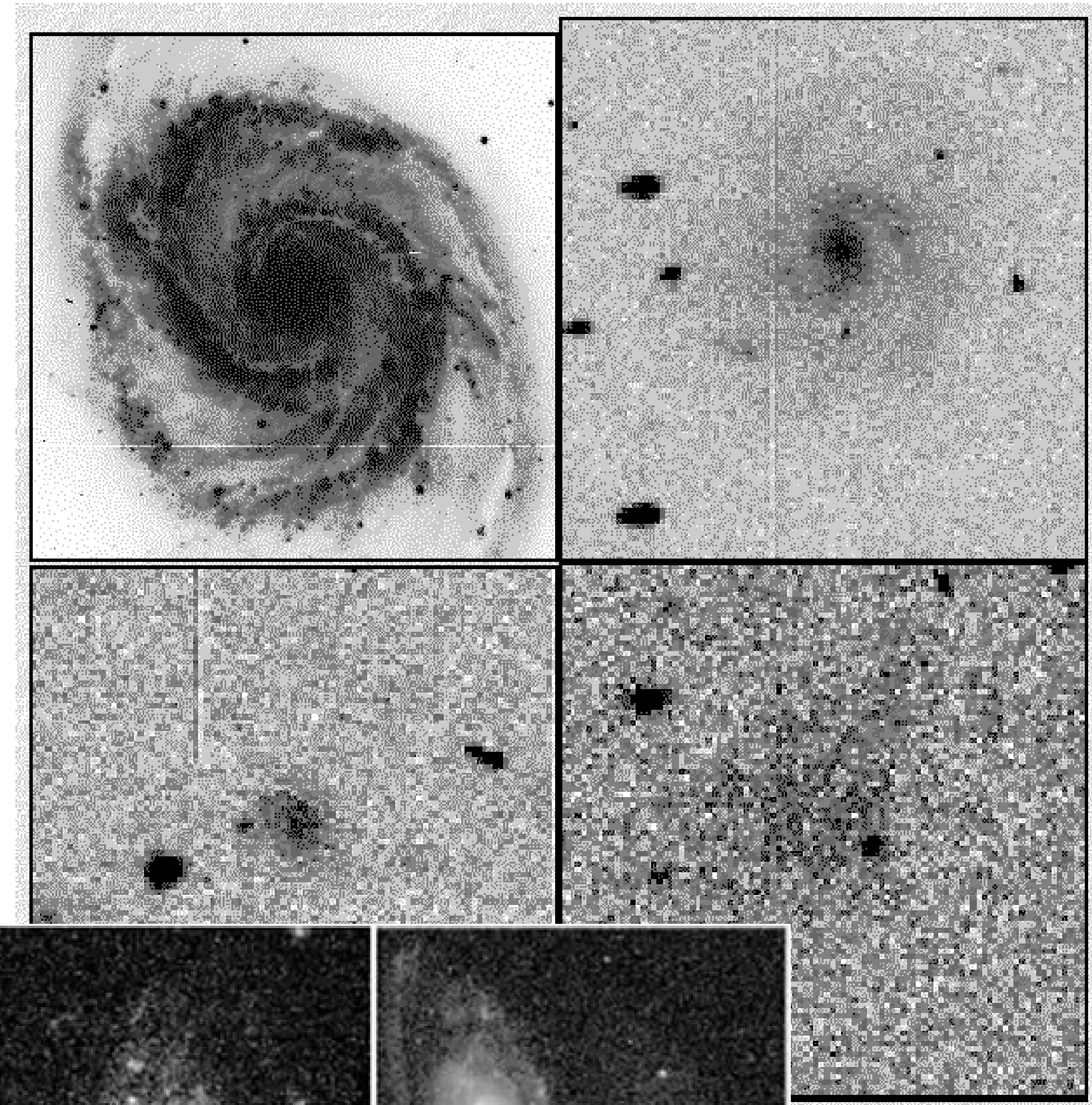
"ULIRGs" = Ultra-luminous Infrared Galaxies.

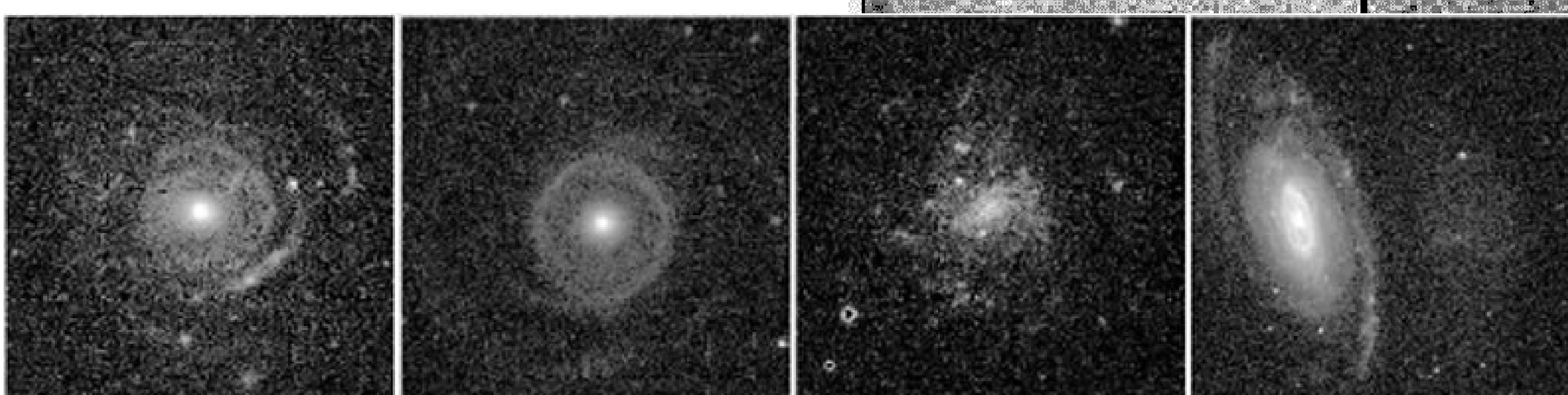
Usually mergers. Extra IR presumably comes from enhanced star formation caused by the merger, and extra dust heating caused by the merger.

Ultraluminous Infrared Galaxies **HST** • WFPC2
NASA and K. Borne (Raytheon ITSS and NASA Goddard Space Flight Center), H. Bushouse (STScI), L. Colina (Instituto de Fisica de Cantabria, Spain) and R. Lucas (STScI)

Galaxies in other wavelengths.

“LSBs” = Low Surface Brightness Galaxies

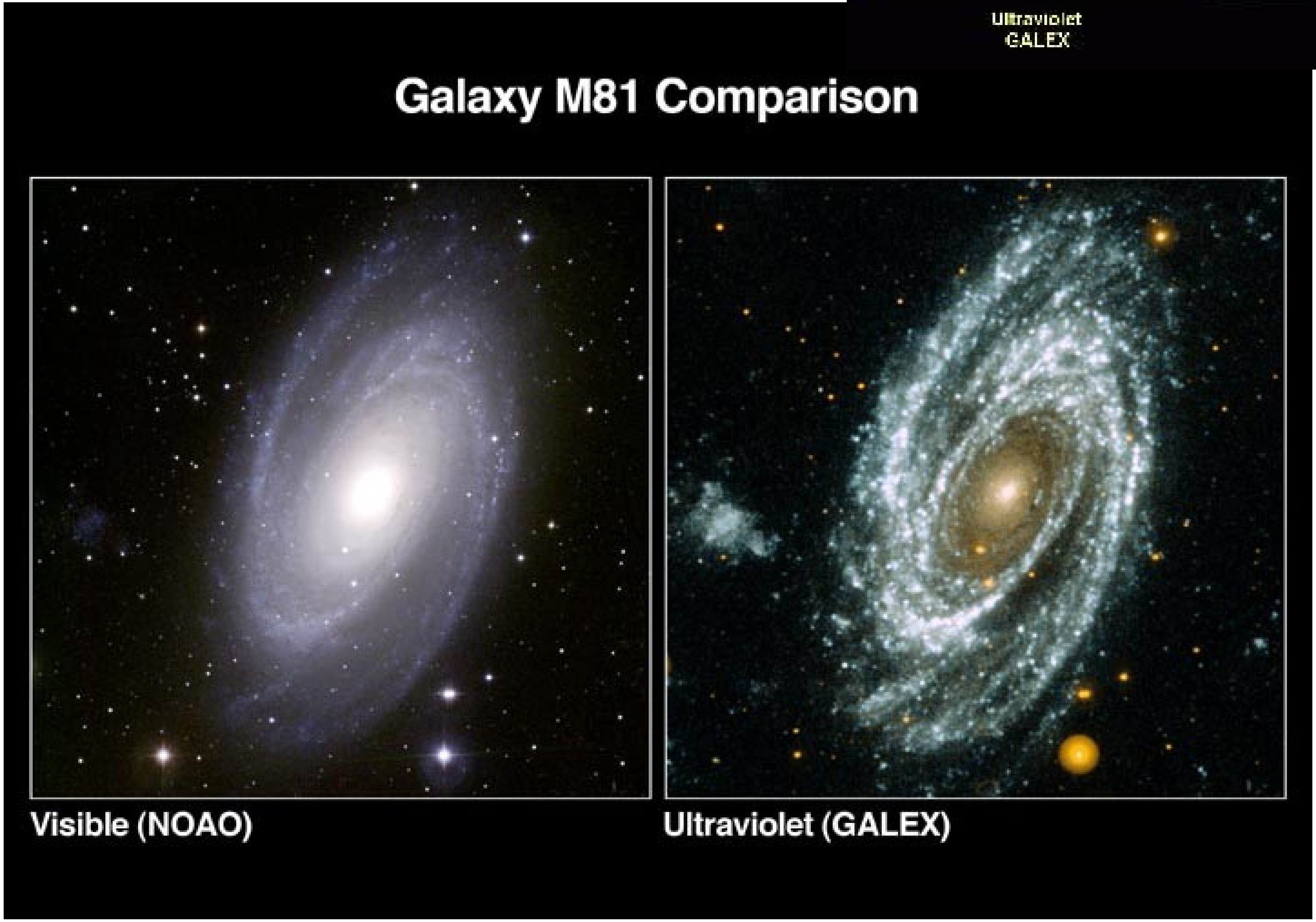




Malin 2 | UGC 6614 | UGC 1230 | NGC 7531 + SGC 2311.8-4353

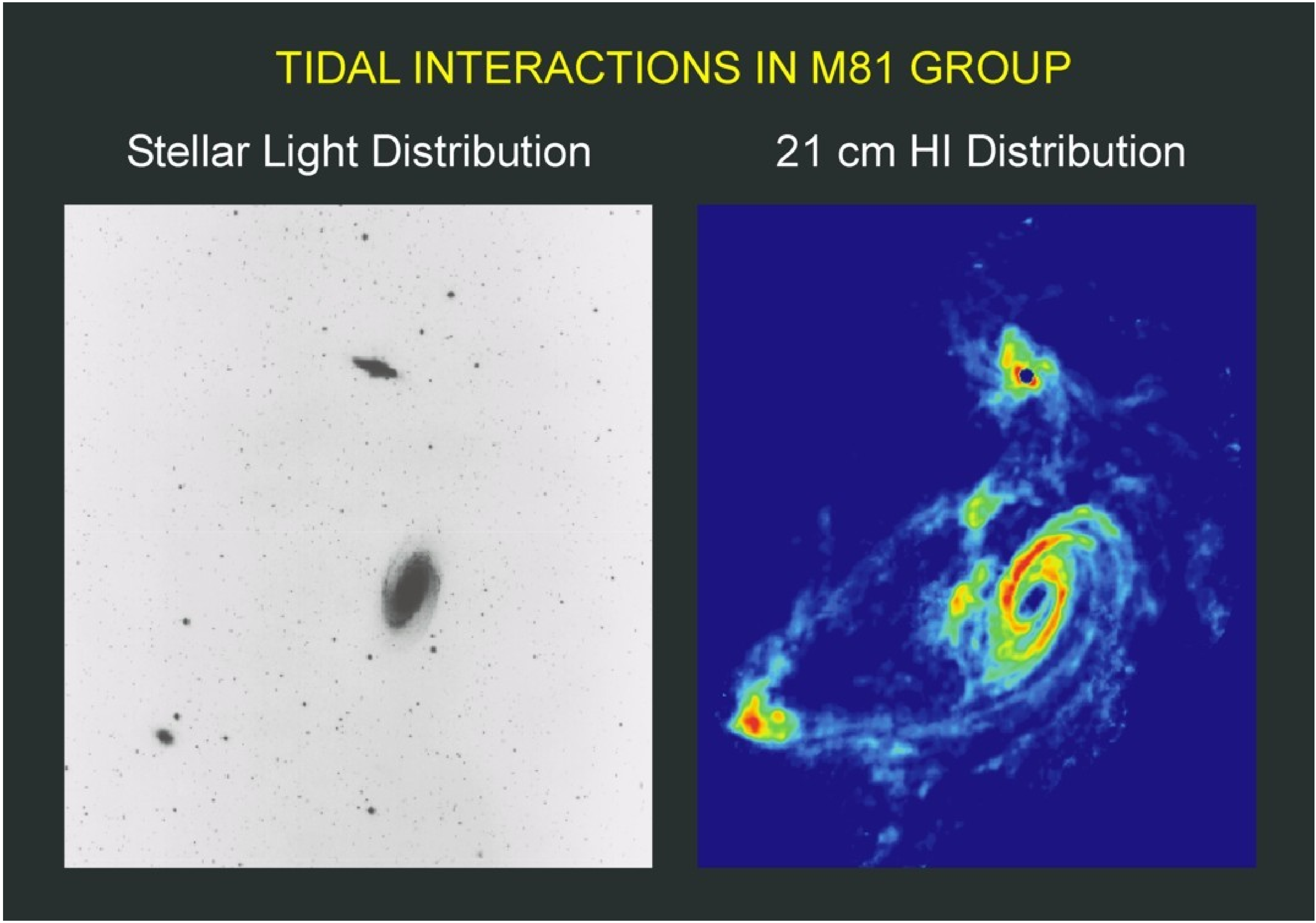
Galaxies in other wavelengths.

Ultraviolet. - More distinct, thin arms. More distant arms.



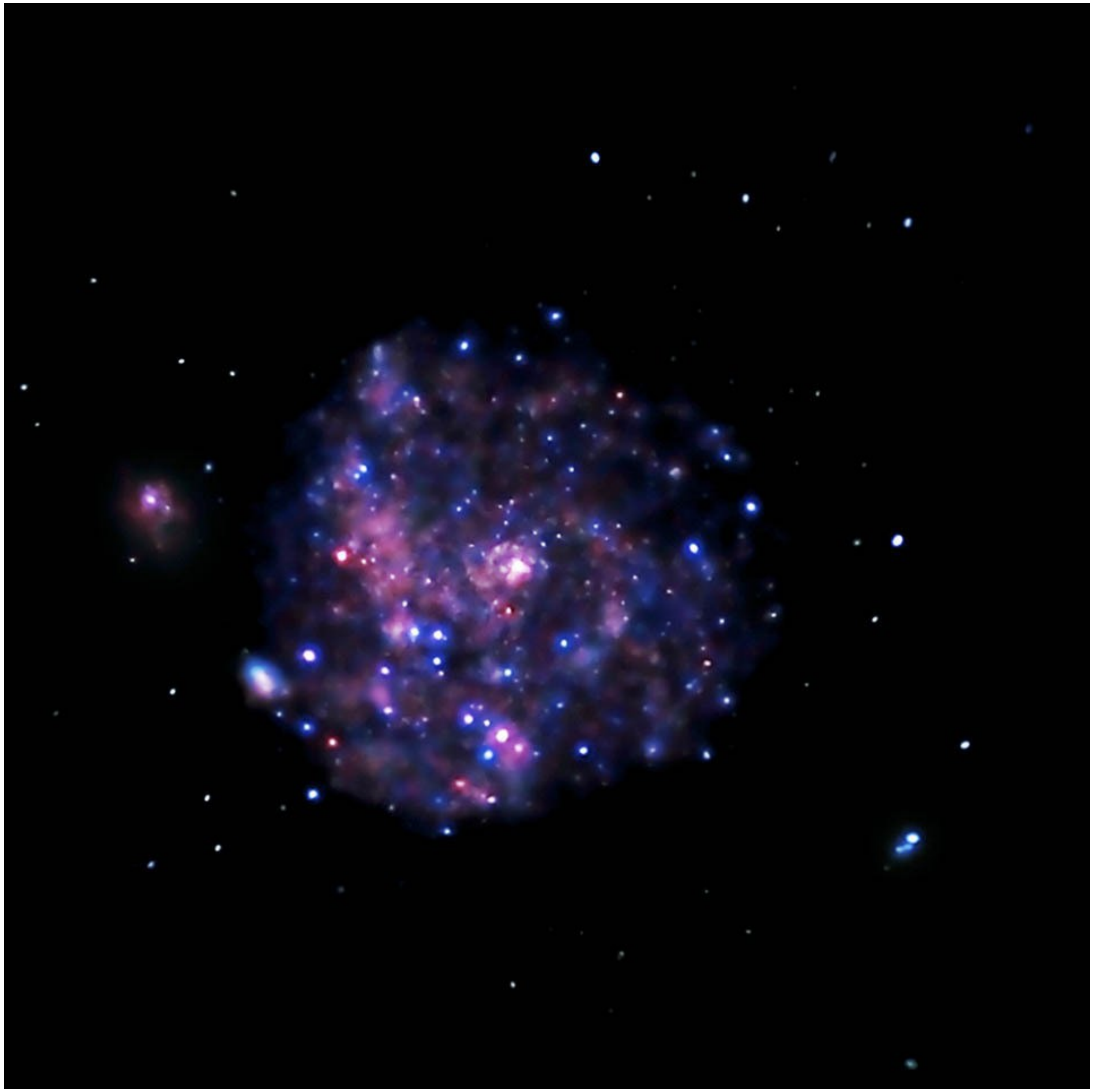
Galaxies in other wavelengths.

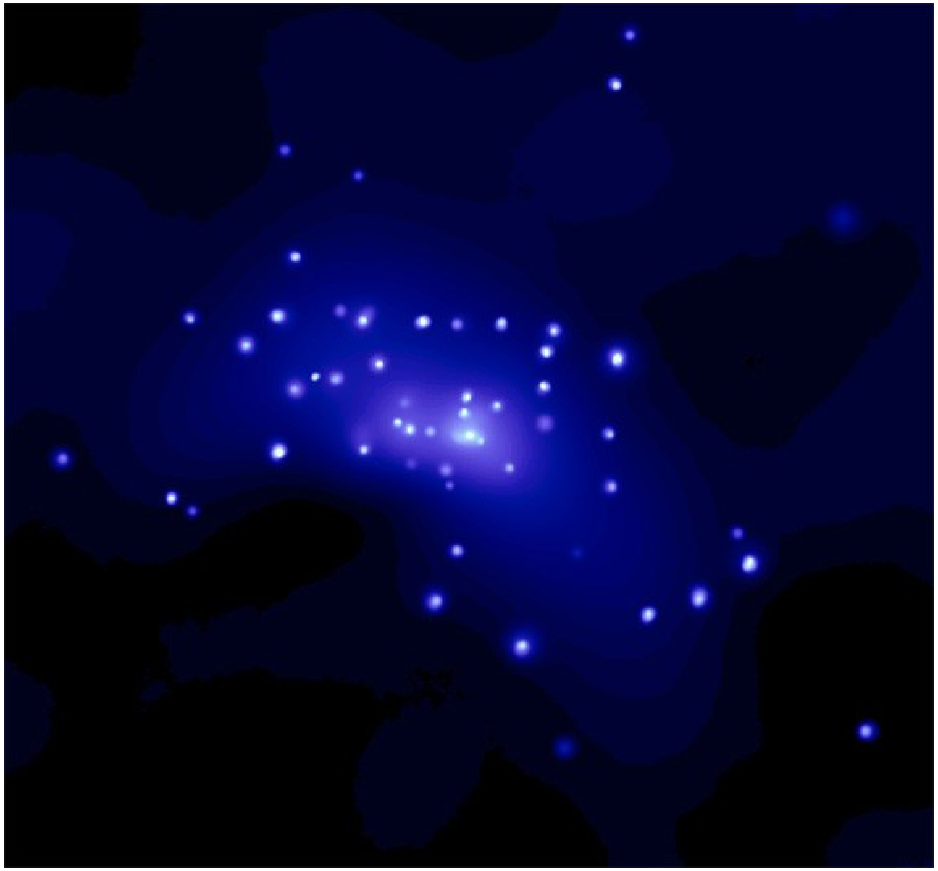
Radio – 21 cm spin-flip transition reveals HI gas.



Galaxies in other wavelengths.

X-ray.
Chandra image of
M101 (Sc I).
Red – soft
Blue - hard.





NGC 4697 (E6). Point sources are BH and neutron stars in binary systems (LMXB's and HMXB's). Diffuse emission from hot gas.

Properties of Spirals and Irregulars

Surface brightness (SB) profiles

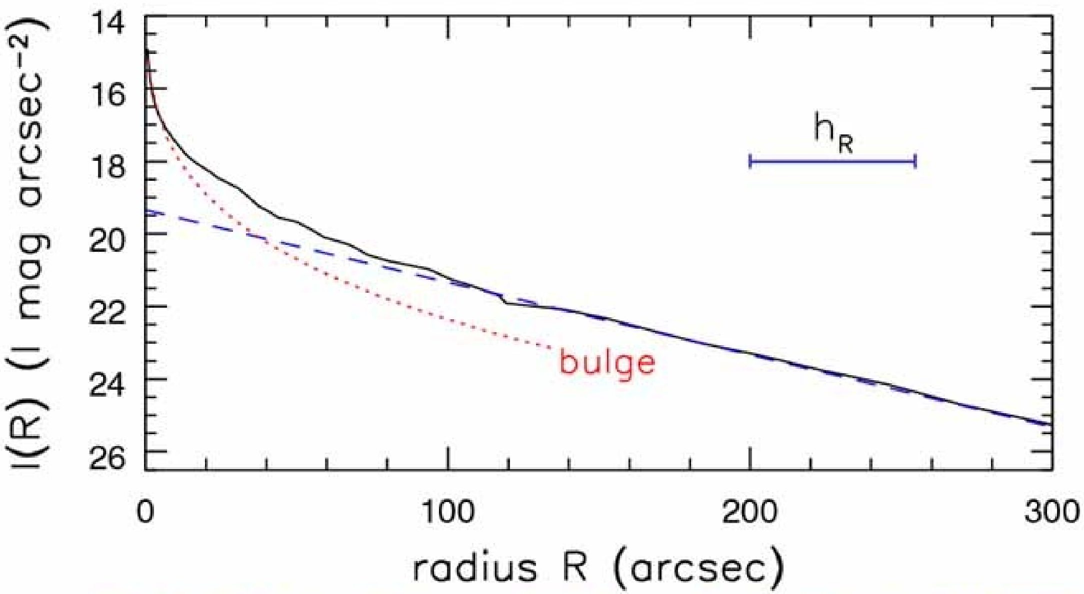
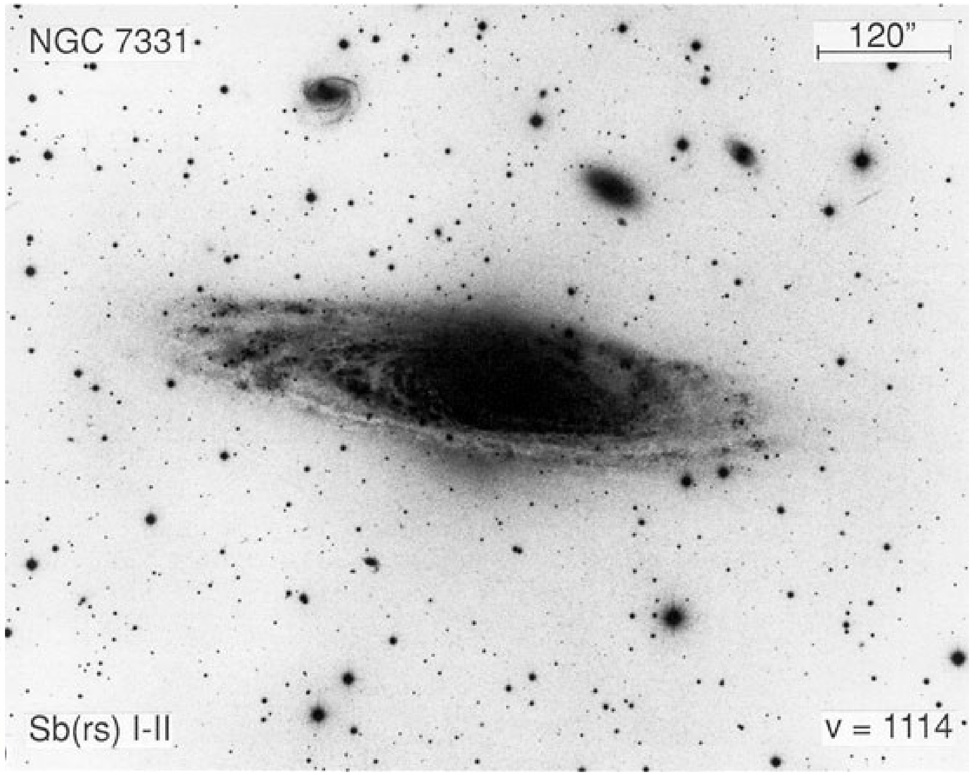


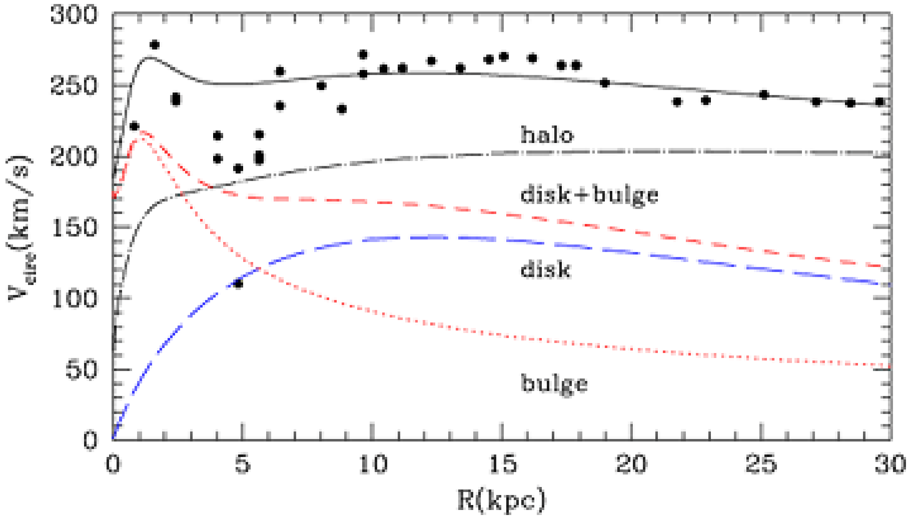
Fig 5.4 (R. Peletier) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007



- **SB profile for spirals is dominated by the bulge at small radii and by the disk at large radii.**
- **The bulges follow a de Vaucouleur's $r^{1/4}$ profile (or more generally, a Sersic $r^{1/n}$ profile).**
- **The disk follows an exponential profile with scale length h_R.**

Properties of Spirals and Irregulars

Rotation curves



M31's rotation curve. (Klypin et al.)

With a mass model for the different components of a galaxy, one can show the "components" of the rotation curve.

- **The peak of the rotation curve (usually taken at large r) is Vmax.**
- **Vmax correlates with the luminosity (L or M_B) of the galaxy; this is the <u>Tully-Fischer</u> relation.**

Properties of Spirals and Irregulars

Rotation curves

Figure 25.8 (right) from Carroll and Ostlie nicely Shows how Vmax correlates with absolute magnitude.
A different Tully-Fisher relation can be fit for Sa, Sb, and Sc galaxies:

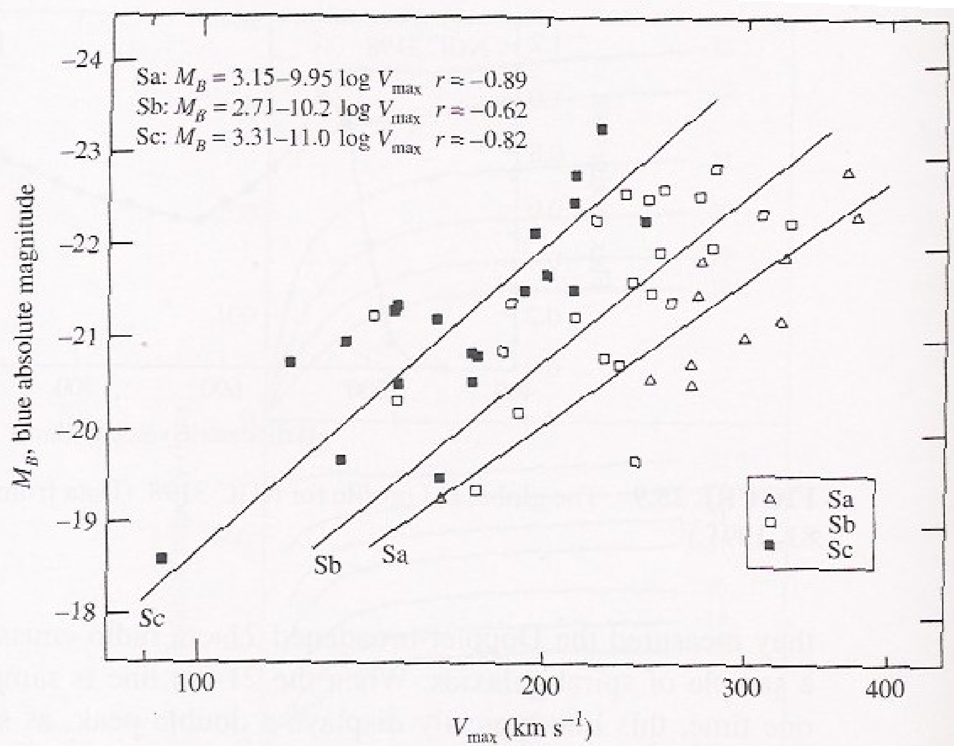
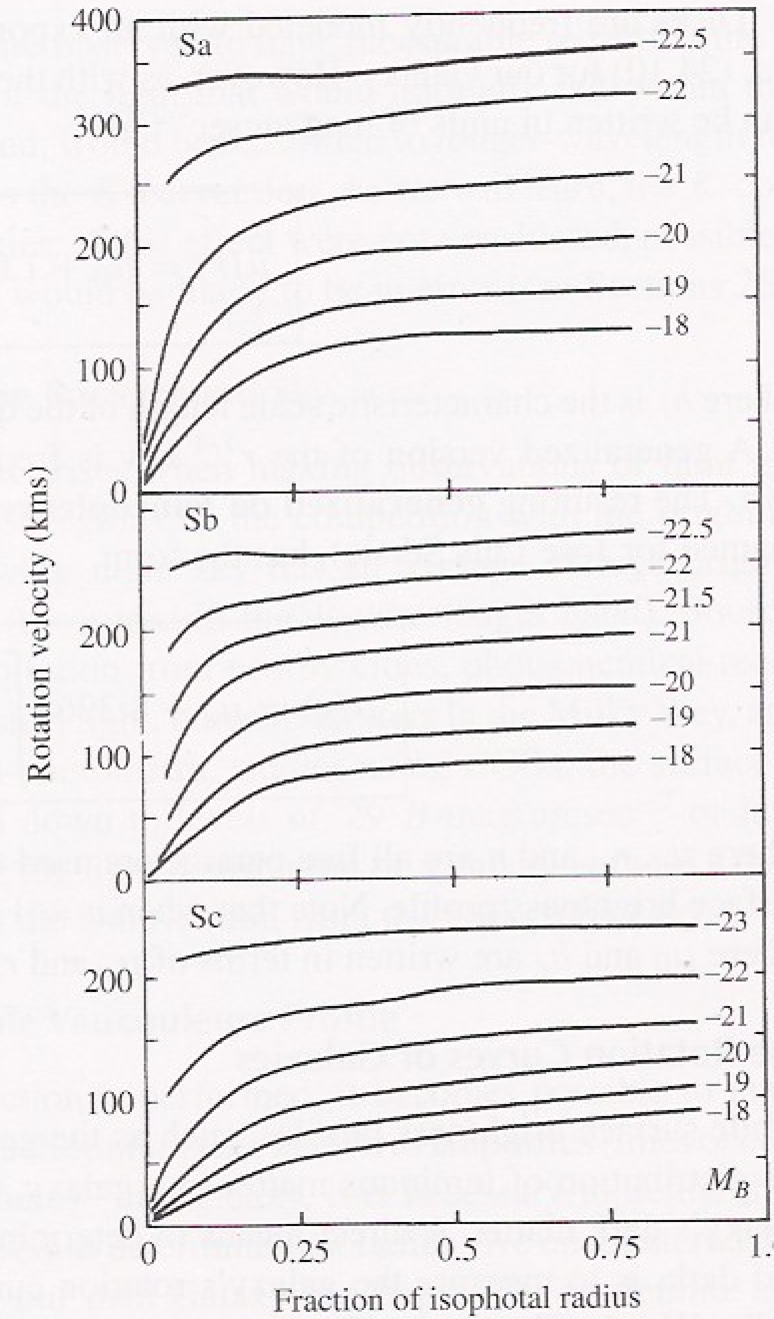


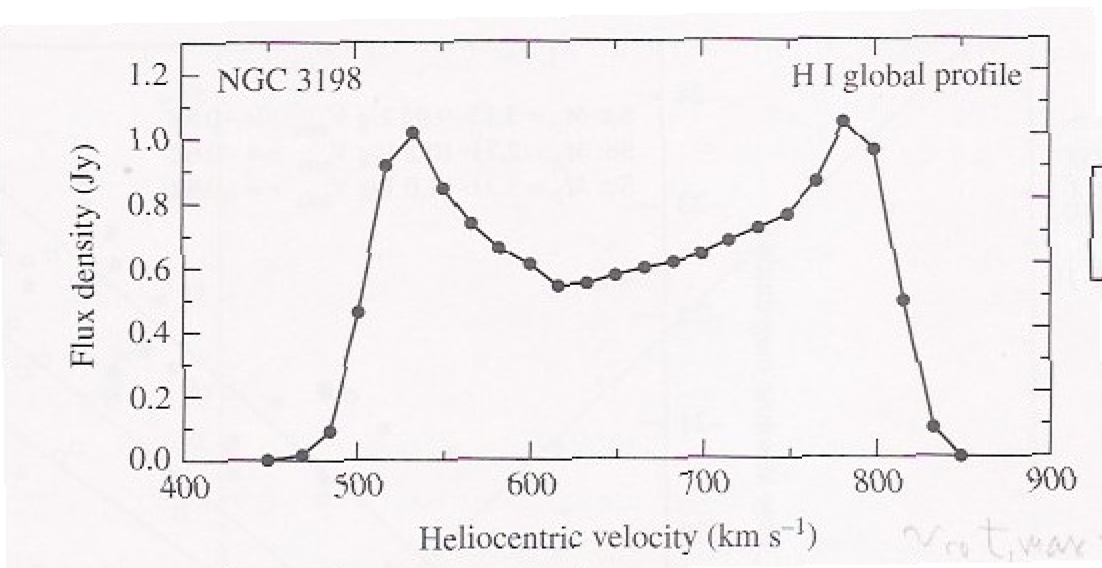
FIGURE 25.10 The Tully–Fisher relation for early spiral galaxies. (Figure adapted from Rubin et al., *Ap. J.*, *289*, 81, 1985.)



Properties of Spirals and Irregulars

Rotation curves

The Tully-fisher relationship takes many forms: optical (previous slide), IR, and HI being the most Common.
With HI, the width of the 21cm line is used. The emission from the entire galaxy is fit inside the aperture (beam). That way the approaching and receding parts each contribute a peak to the double-peaked line.



$$M_H^i = -9.50(\log_{10} W_R^i - 2.50) - 21.67 \pm 0.08.$$

The IR Tully-Fisher relation (above) relates the H-band absolute magnitude to the (inclination corrected) width of an emission line in the H-band.

Properties of Spirals and Irregulars

Spiral Arm structure

Some Facts:

•Arms are defined (traced) by dust lanes and star formation (blue stars and clusters).
•The density of stars and gas is a little higher in the arms, but not as much as the surface brightness would suggest – the population of older stars is almost uniform between the arms, young, bright stars trace the arms.
•For barred spirals, the two arms start at the ends of the bars.
•Most common structure is the two-armed spiral with trailing arms. (NGC 4622 has two trailing arms and one leading arm.)
•The cause of spiral arms is not well understood.

Some theories:

Differential rotation and material arms. Problem: the “winding problem”, spirals should be more tightly wound because many rotations have occurred since most galaxies formed.

Interactions with neighbors. M51 is a possible example.

Lin-Shu Density Wave theory. The arms are a density wave. When gas passes through the wave (usually catching up to it from behind) it compresses and forms new stars. The spiral pattern moves at the pattern speed. At the co-rotation radius, the star speed equals the pattern speed. Problem: what starts and sustains the wave?

For barred spirals, the bar could trigger the wave.

Properties of Ellipticals and Lenticulars

Rotation curves

The Tully-fisher relationship takes many
forms: optical (previous slide), IR, and HI being the most
Common.
With HI, the width of the 21cm line is used. The emission from the
entire galaxy is fit inside the aperture (beam). That way the
approaching and receding parts each contribute a peak to the
double-peaked line.