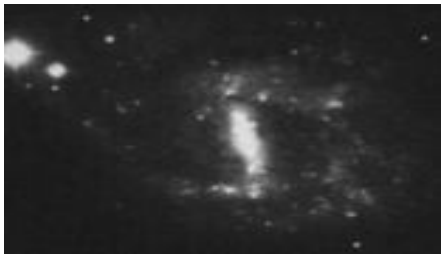
Galaxy Morphology

- a description of the structure of galaxies



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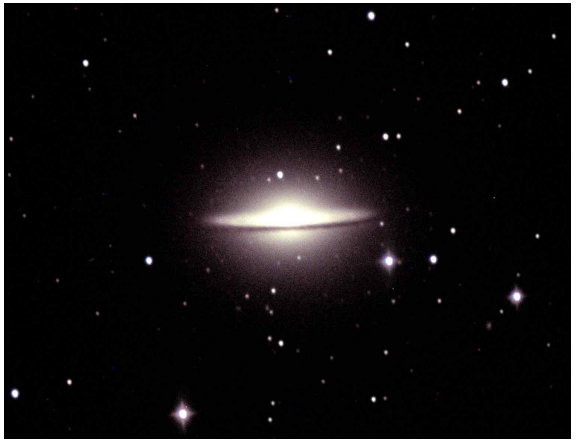

Galaxy Morphology

- a description of the structure of galaxies

Clearly astronomical bodies are not uniform density spheres.

Need a classification scheme to describe shapes – assume that the shapes are telling us about structure and genuine physical differences.

Requirements for scheme:

1. Set of criteria: e.g. amount of spirality, central concentration - will depend on galaxy sample available

2. Homogeneous data: all images in same rest wavelength and to same depth i.e. magnitude limit

3. Criteria should reflect physically important properties if possible

4. Classification should be unique – order in which criteria are applied should be clear to avoid ambiguity

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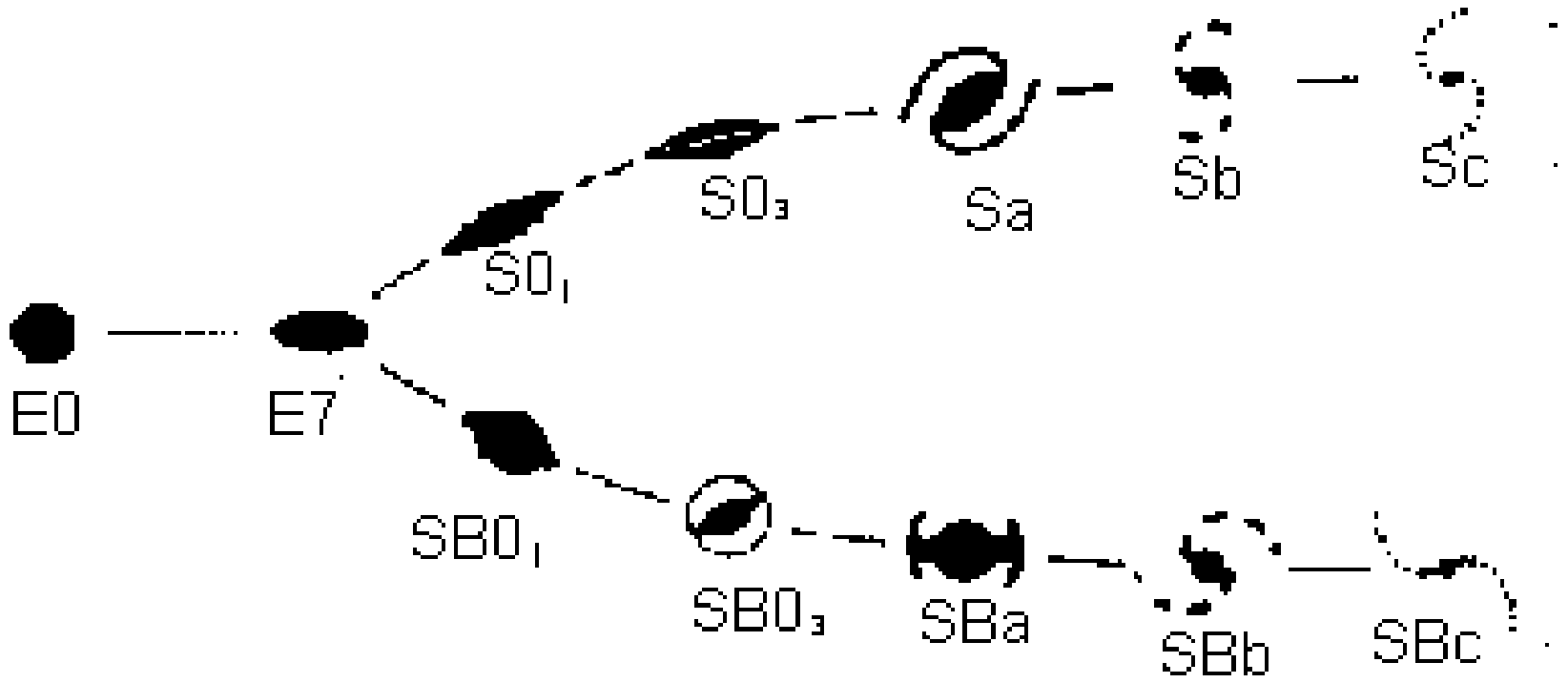
Most common classification scheme is basically that proposed by Hubble (ApJ, 64, 321, 1926) and described in detail in Sandage's introduction to "The Hubble Atlas of Galaxies" (1961)

In summary:



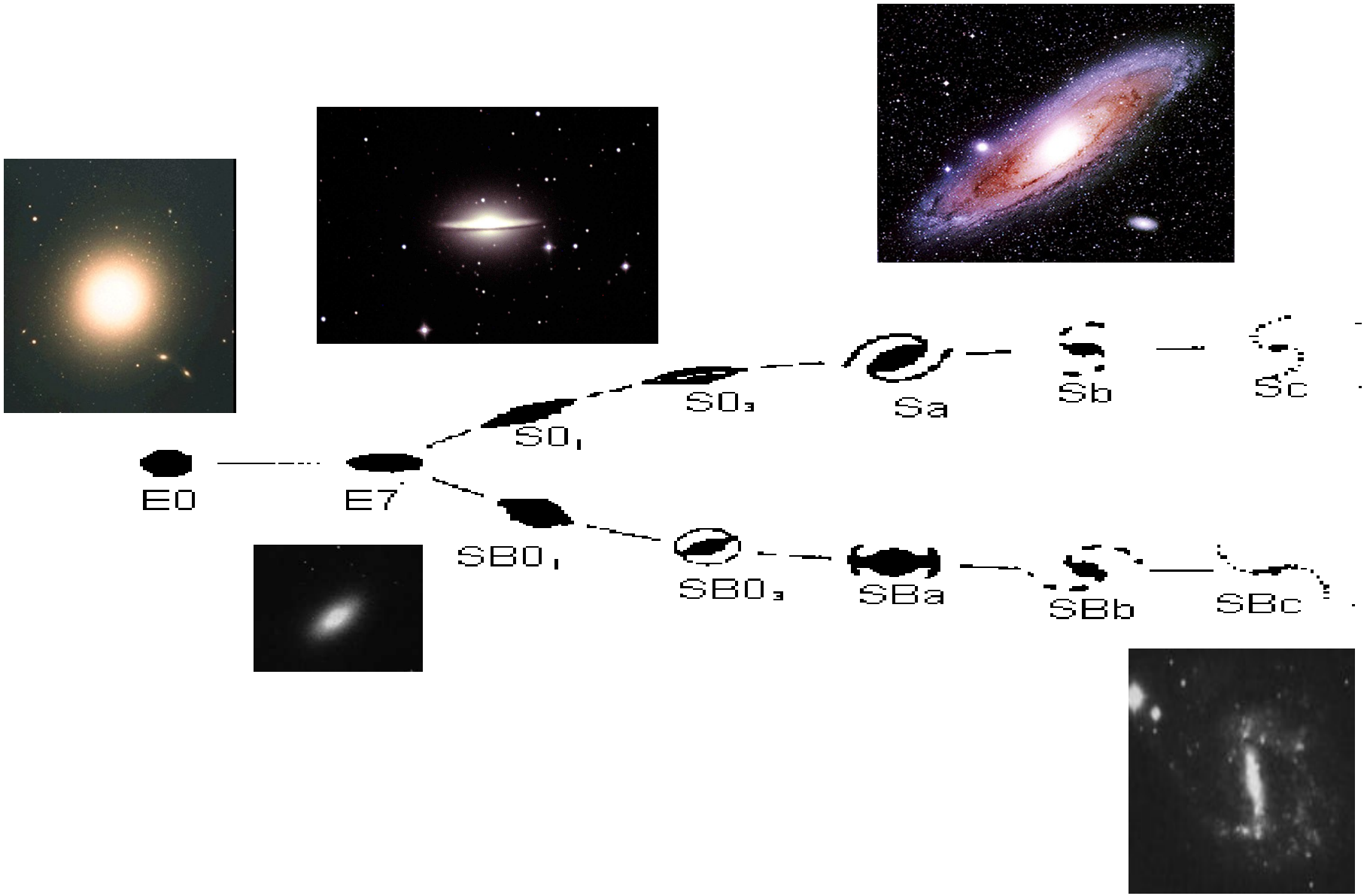
Ellipticals -- Lenticulars < spirals

barred spirals

No spiral arms (Lenticular)

tight arms

loose arms


E0
E7
S0₁
S0₂
Sa
Sb
Sc
SB0₁
SB0₂
SBa
SBb
SBc

Originally thought to be an evolutionary sequence
E (early) -> S0 -> Sabc (late)

(with Irregulars as a separate “hard basket”)

No longer thought of this way, but the terminology remains .....

Most galaxies classified until recently by human assessment of an image.

What is error in doing this? Naim et al (1995) found that RMS scatter in Hubble type is ~1.8, i.e. most people put galaxies into, at worst, neighbouring classes.

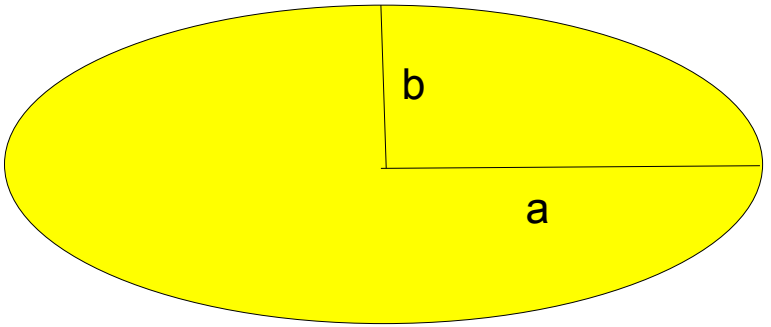
So don't take the exact class too literally

Elliptical Galaxies

Sandage (1961): "*Images have complete rotational symmetry – figures of revolution with two equal principal axes. The third, the axis of rotation, is smaller than the other two.*"

i.e. oblate spheroids, rotating about axis of symmetry

Apparent ellipticity
n=10(a-b)/a
=> En



Observe E0 (round) to E7

M87 (E0)

M59 (E5)

E7

Hubble profile: $\Sigma(R) = \frac{\Sigma_0}{\left(1+\frac{R}{a}\right)^2}$

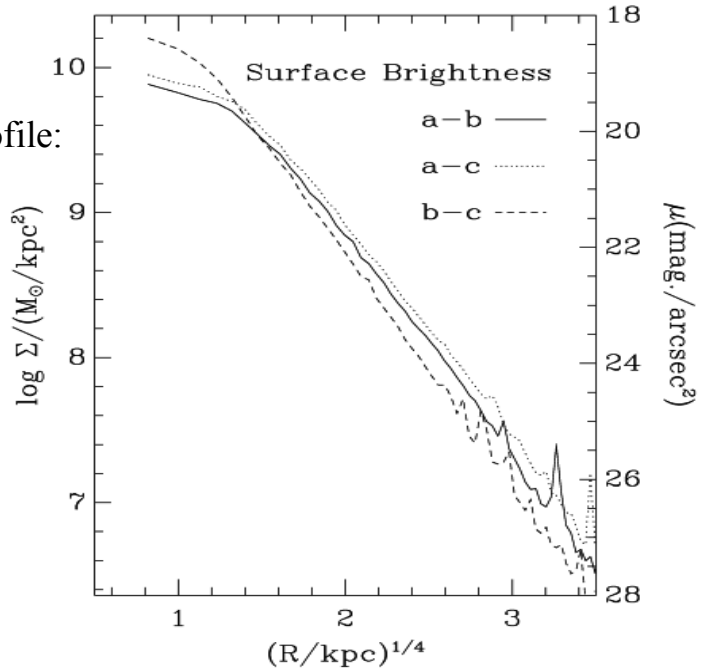
de Vaucouleurs profile: $\Sigma(R) = \Sigma_0 e^{-kR^{\frac{1}{4}}}$, where k is a constant.

Images are smooth – no gas or dust
Images are red - only old stars

So dynamically old, quietly evolving systems

= boring THE END

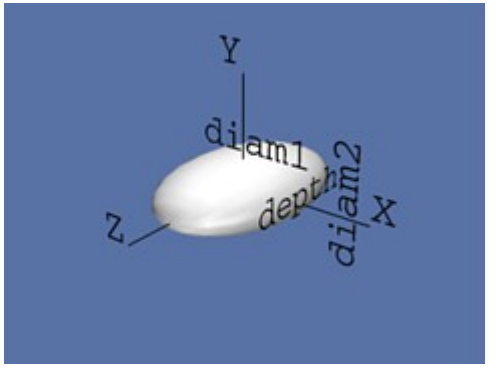
Surface brightness profile:



BUT The picture has now changed -elliptical galaxies are much more interesting than had been believed, and are the subject of current research.

1. Binney (1985): Looking at shapes *and* velocities (e.g. are they rotating about an axis?)

Triaxial ellipsoids: $\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1$



From morphology alone can't tell if elliptical galaxies are

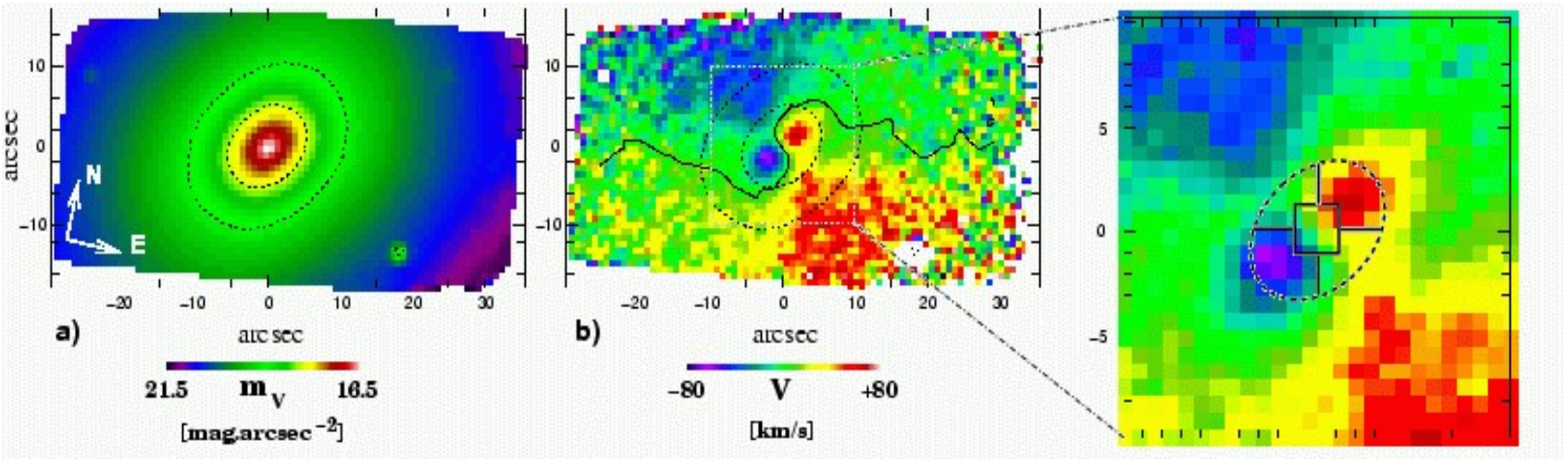
1. spherical $a=b=c$
2. prolate $a>b=c$ (rugby ball)
3. oblate $a=b>c$ (smartie)
4. triaxial $a>b>c$

Binney concluded that ellipticals are generally triaxial.

.. so not symmetric about the rotation axis

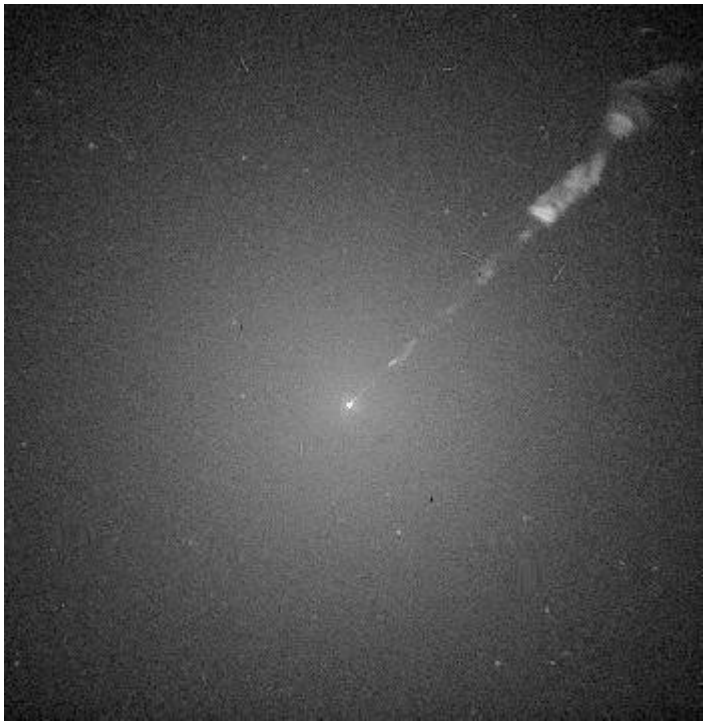
2. Elliptical galaxies are rotating, but giant ellipticals do not owe their flattening to rotation (they rotate too slowly).

3. Some galaxies have kinematically decoupled cores. e.g. NGC4365



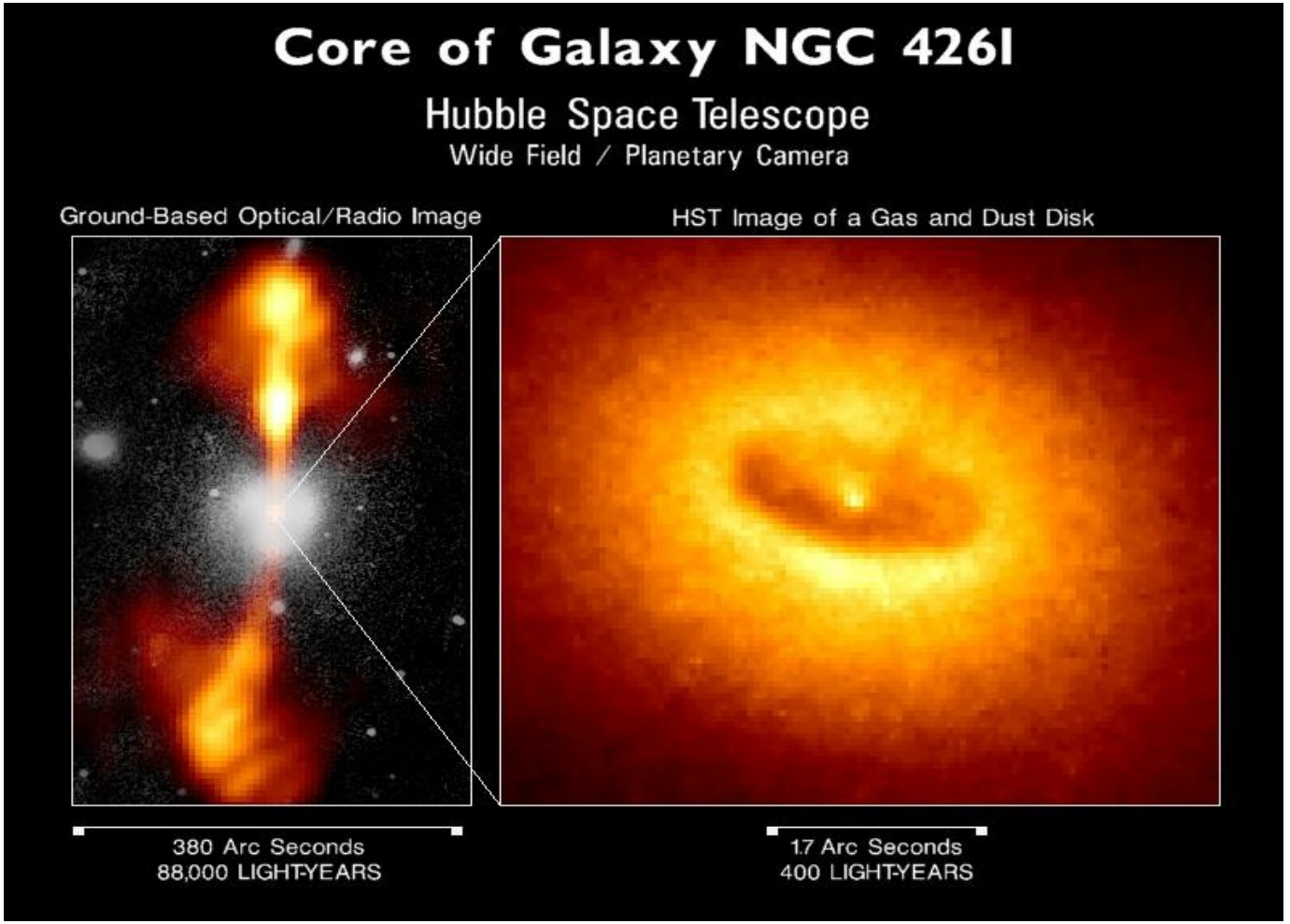
4. Jets. In M87 come from a black hole of mass ~ 3.10^9 solar masses
- will affect internal stellar dynamics.

Processed image of inner region

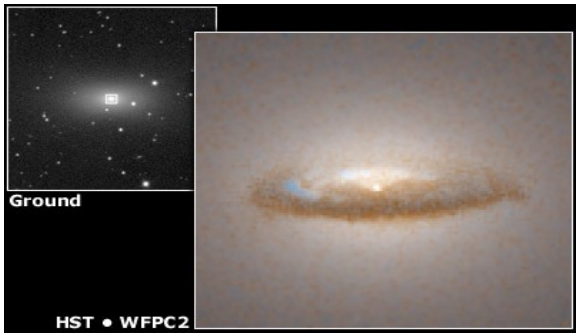


(not to same scale)

5. Dust disks –
e.g. in NGC4261

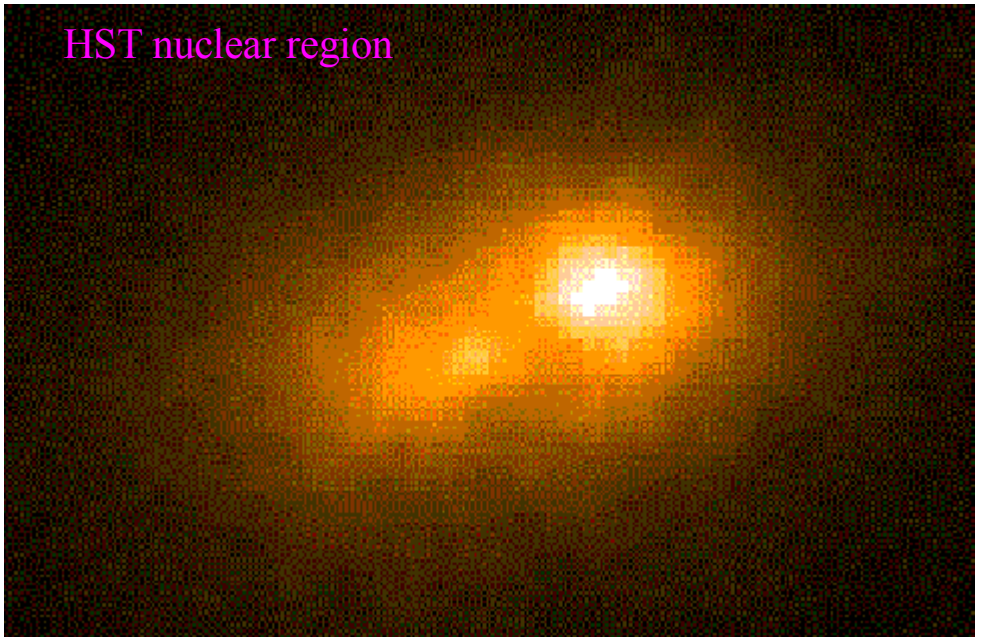


and in NGC 7052



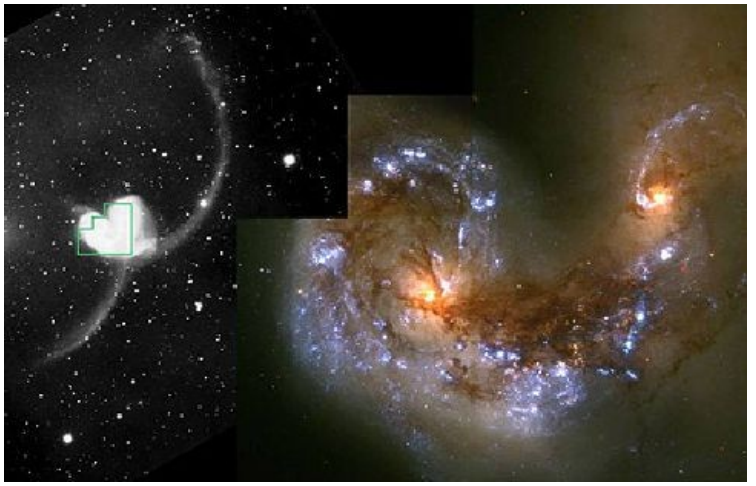
Left: Composite optical (white)/radio view, showing radio jets.
Right: HST image of core, showing a giant disk of gas and dust which fuels a possible black hole.

6. Multiple nuclei (e.g. M31)



Ellipticals seem to form from merging spiral galaxies.

(see http://oposite.stsci.edu/pubinfo/pr/2002/11/vid/v0211d3.mpg for a 3.4Mb MPEG movie of a computer simulation)



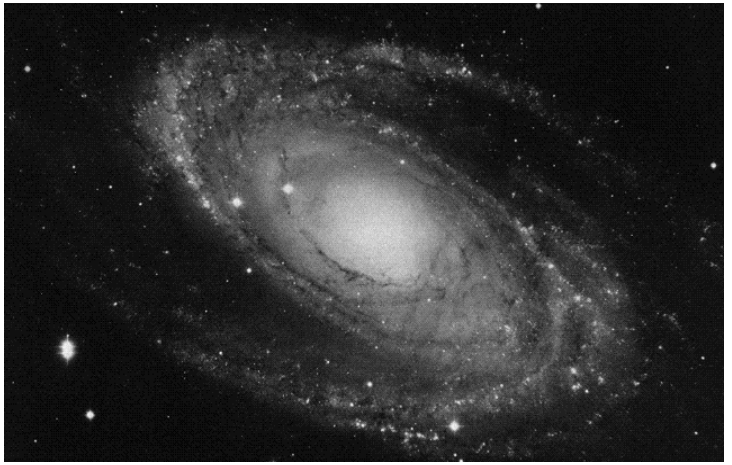
“Normal” Spiral Galaxies

(i.e. about half of the spirals)

Sa

M94

Sb



M81

Sc

M101

Trends a -> c: - openness of spiral arms increases
resolution of arms into clumps increases
size of unresolved nuclear region (bulge) decreases

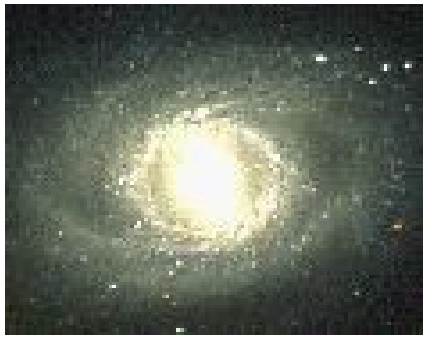
Sa: covers most of sequence
ill-defined arms, smooth and tightly wound
nuclear region can be large or small

Sc: small amorphous central region
spiral pattern dominates in blue light
multiple arms, loosely wound
high degree of resolution of arms into knots

Often fitted with exponential profile $I(R) \alpha \exp(-R/R_d)$

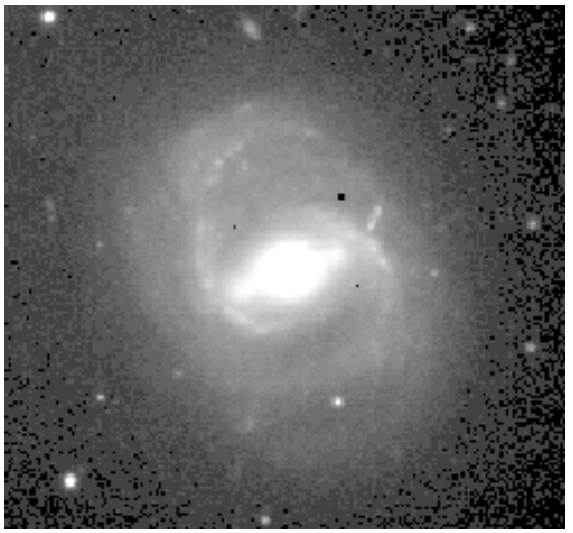
Barred Spirals: as above but with a central bar (about 50% of spirals are barred)

Sba



M95

SBb



M91

SBc

M61

No such classifaction scheme is complete... de Vaucouleurs described the Milky way as SAB(rs)bcII

(AB for weak central bar, (rs) for weak central ring, ...)

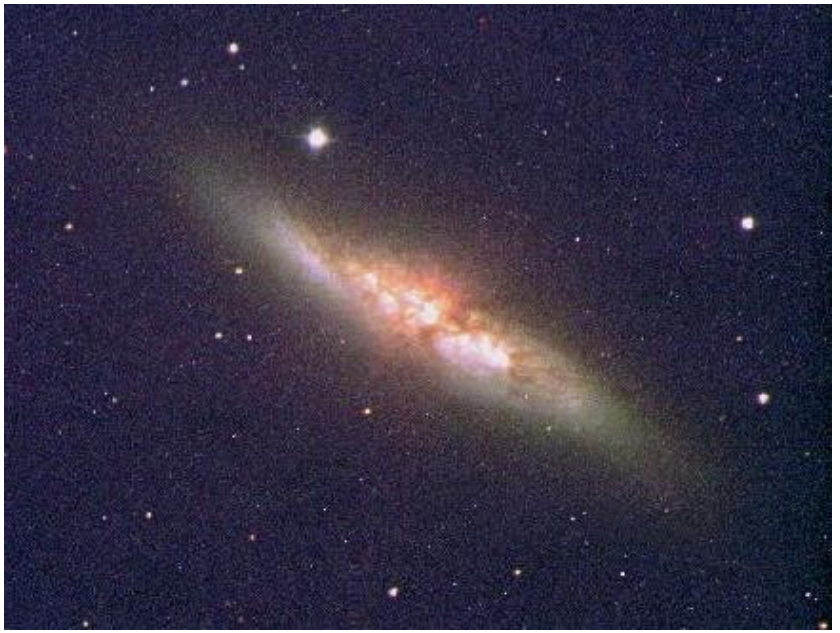
Rings etc. complicate classification
but are important

e.g. NGC2523

Irregular galaxies: Not regular, not symmetric – don't fit in to above classes

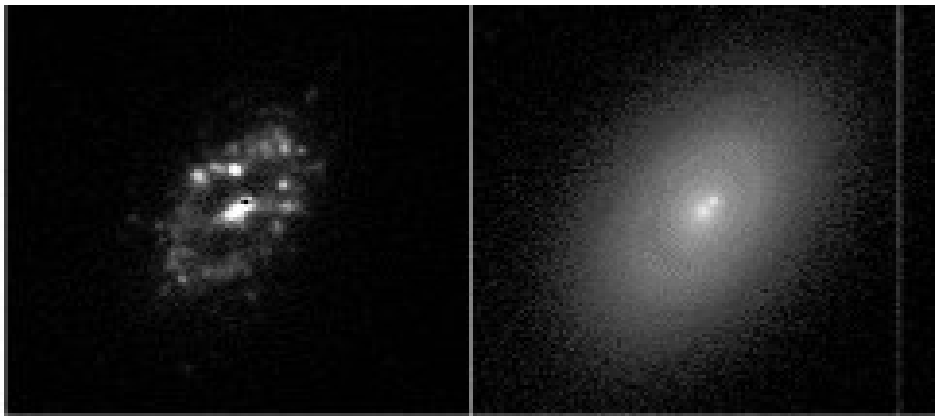
IrrI – lack symmetry or well-defined spiral arms, and are knotty
e.g. LMC

IrrII – smooth, often have dust lanes, and are disturbed by e.g. intense star formation.
Example - M82



S0 or SB0 or Lenticular galaxies

Intermediate between E & S
Disky – i.e. rotate about symmetry axis but no spiral structure
SB0 are barred
Bright nucleus – central 'lens', faint and sometimes extensive envelope
Sometimes with circular dust lanes



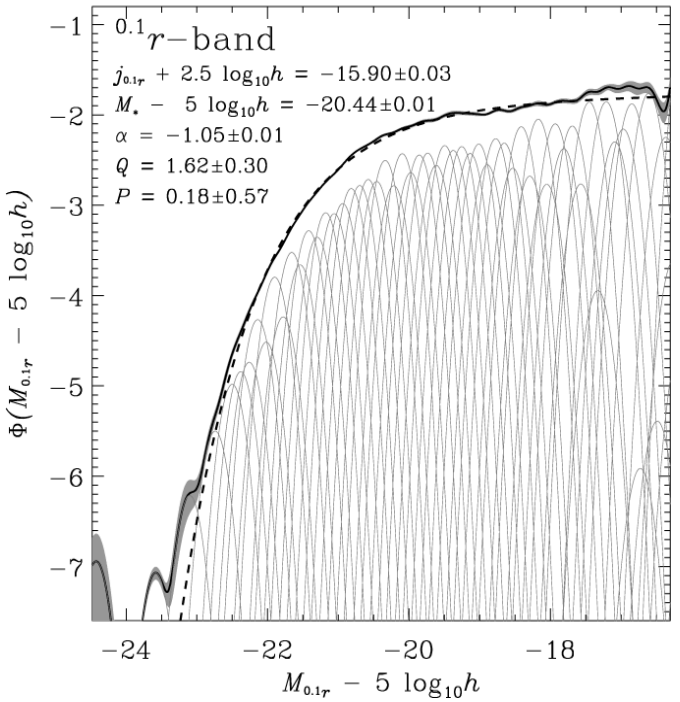
H-alpha (star forming regions) & stellar continuum
NGC4138 S0

NGC936 SB0

Galaxy luminosity function: Φ dM is number density of galaxies in the absolute magnitude range (M, M+dM)

Spirals dominate in the field
Ellipticals dominate in clusters, especially at faint and bright ends.

Blanton et al. (2003) (astro-ph/0210215)



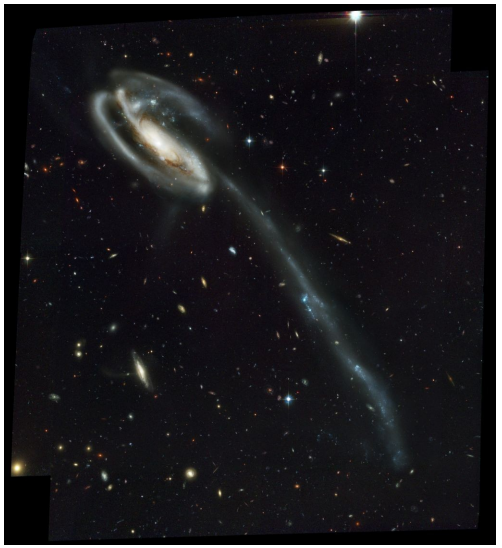
Also expressed as number density per unit luminosity $\Phi(L)dL$, in which case the Schecter form

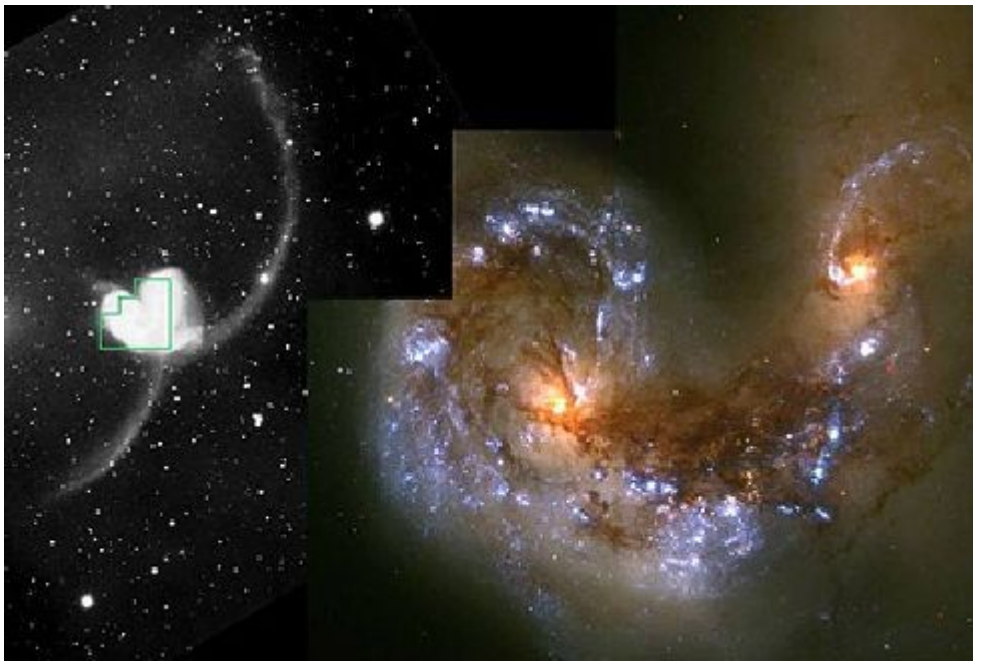
$$\Phi(L) = \left(\frac{\Phi^*}{L^*}\right)\left(\frac{L}{L^*}\right)^{\alpha}\exp\left(-\frac{L}{L^*}\right)$$

is often used.

Galaxy collisions & transformations

Irregular/peculiar galaxy morphology can be due to interactions.





Ellipticals may form from merged spirals.