More on Galaxy Classification

Trends within the Hubble Sequence

- E0 --> S0 --> Sb
  - Decreasing bulge to disk ratio
  - Decreasing stellar age
  - Increasing gas content
  - Increasing star formation rate

Problems

- Constructed to classify massive galaxies
- Spiral parameters not well defined in the sequence
- Bars are yes/no, observations show that bars for a continuum of strengths
- Works best for isolated systems, in clusters classifications can be difficult

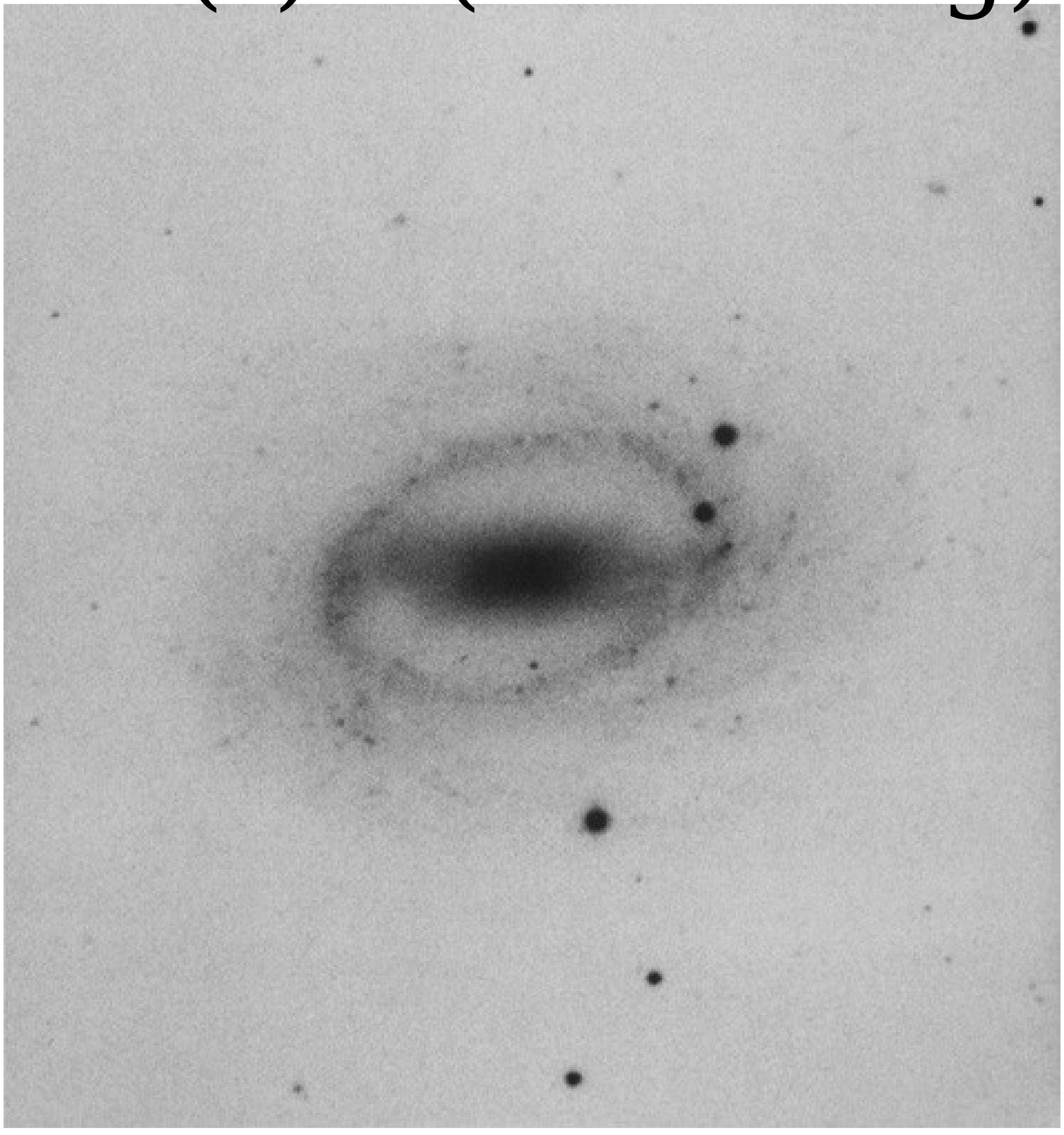
de Vaucouleurs' revision

- Mixed types
  - Sab , Scd, S0/a, E/S0 for intermediate types
  - S no bar, SB strong bar, SAB intermediate bar
- Inner rings
  - Arms in ring (r)
  - Arms out of ring (s)
  - And (rs)

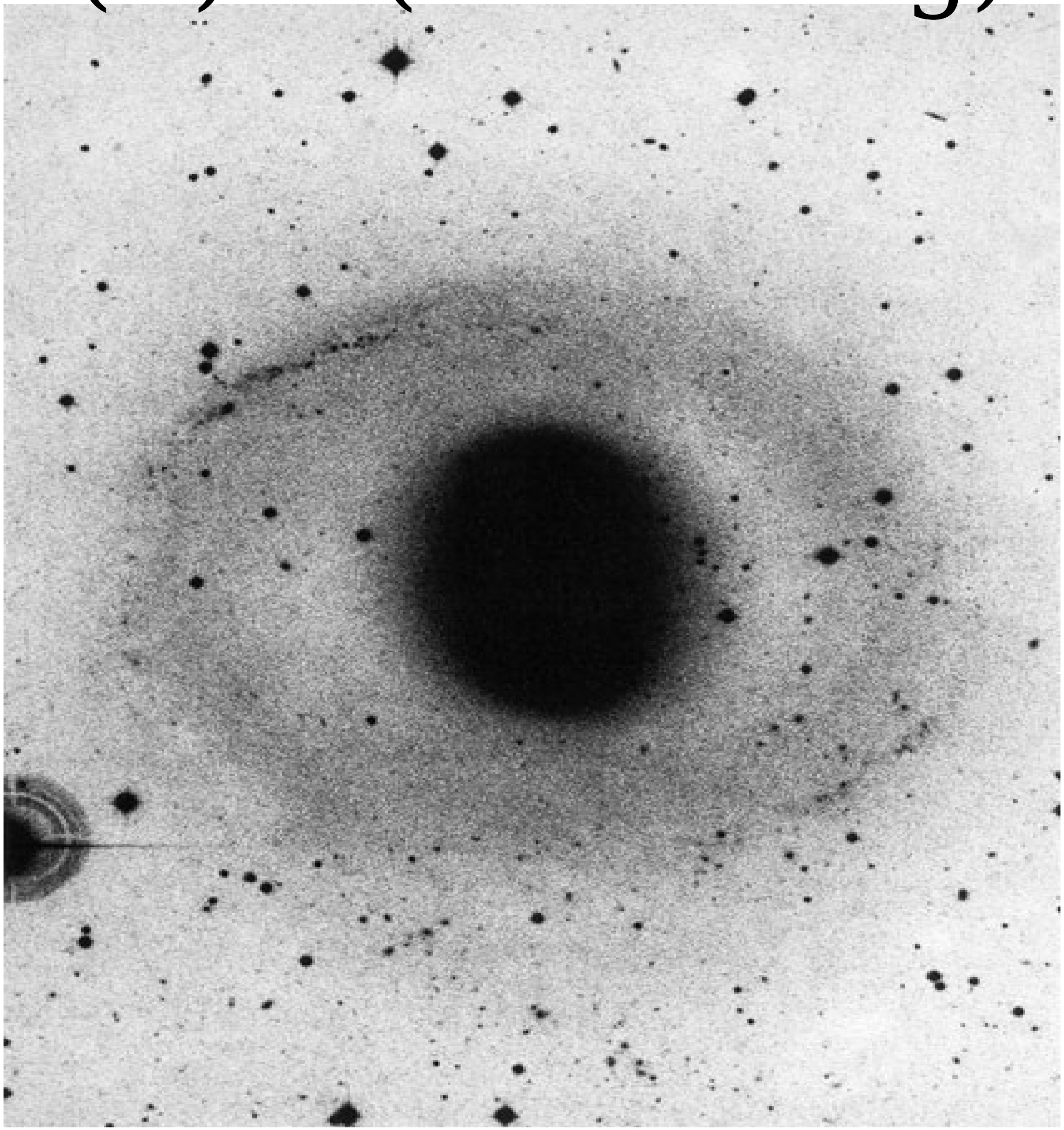
de Vaucouleurs' revision cont.

- Outer ring (R)S
- Extend the Spiral/Irr type
  - Sm (LMC type spiral)
  - Sd (very small bulge)
  - Sdm (intermediate between Sd and Im)
  - Im (Irr class)
  - Sm (Magallanic type spirals)
    - LMC is SB(s)m

IC 5240 example of a SB(r)ab(inner ring)



NGC 1543 example of a (R)SB(Outer ring)

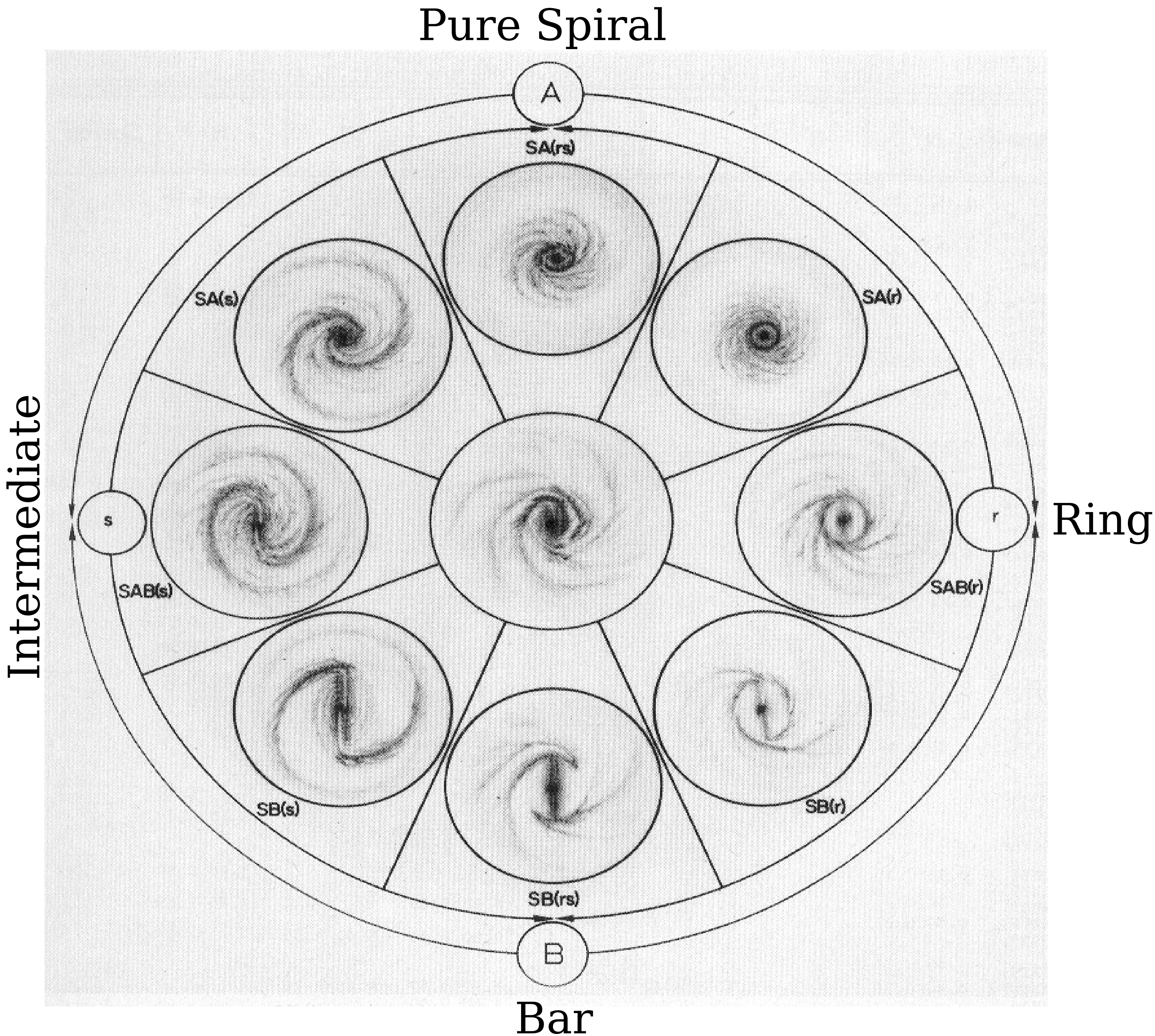


NGC 6783 example of a (R)SB(r)

De Vaucouleurs also introduced the T type

E0 --> S0 --> Sa --> Sb --> Sc --> Im
-5 -1 1 3 5 10

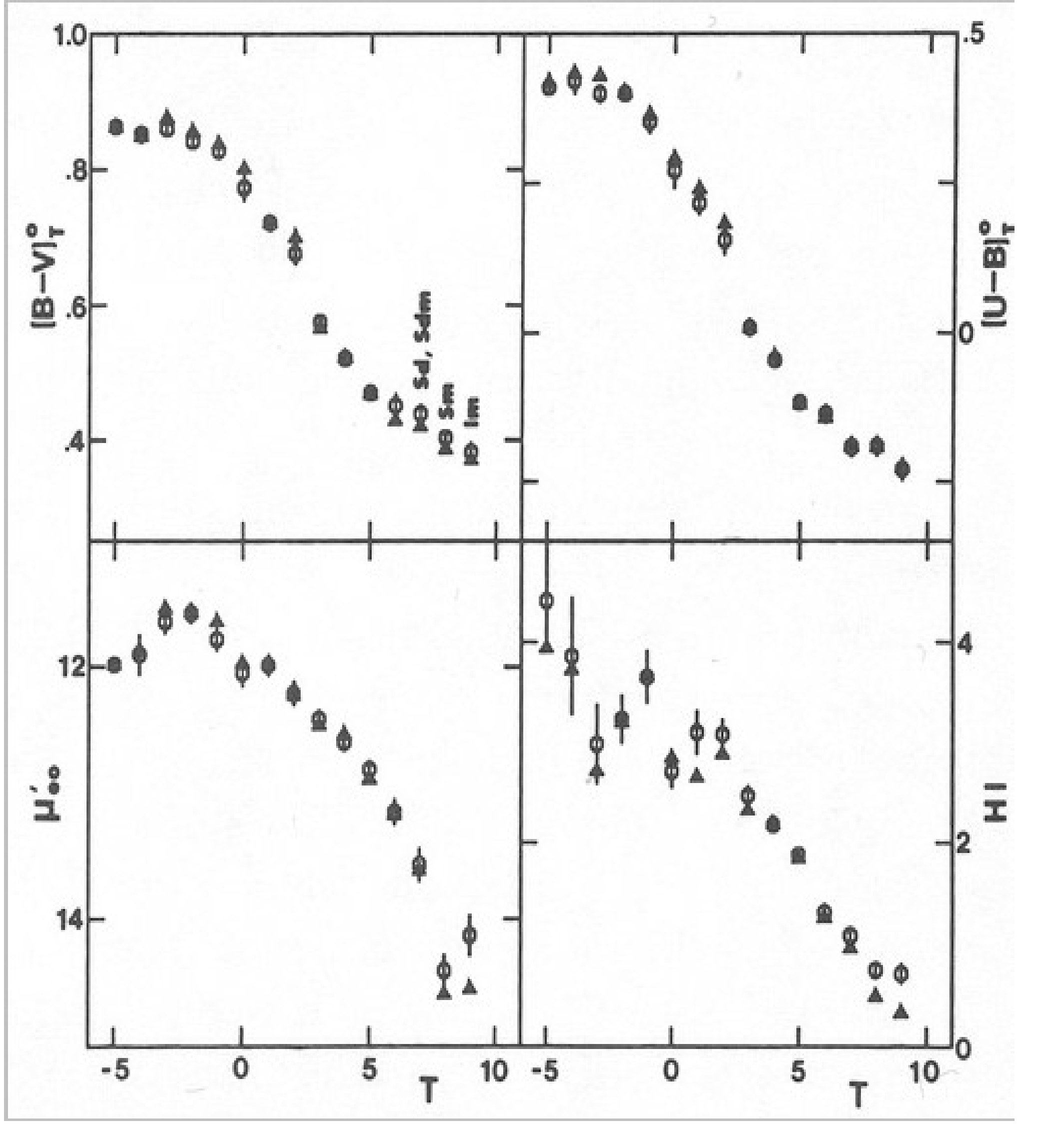
so that computers could be used with his catalogs (RC1 1964, RC2 1974, RC3 1991)



Pure Spiral
A
SA(rs)
SA(s)
SA(r)
Intermediate
s
r
Ring
SAB(s)
SAB(r)
SB(s)
SB(r)
SB(rs)
B
Bar

Advantages of the new system

- Classes are more continuous
- Can classify up to 97% of all galaxies without special bins
- Describes features that are clues to the dynamics
- In wide use



Limitations of the new system

- E -> Im is not a linear sequence of 1 parameter
- Terms are not universally applicable
  - What do ring or bars mean for ellipticals?
- Visual system
  - Not based of a physical parameter (mass, luminosity etc)
- Parameters are not always independent
  - Rings and bars

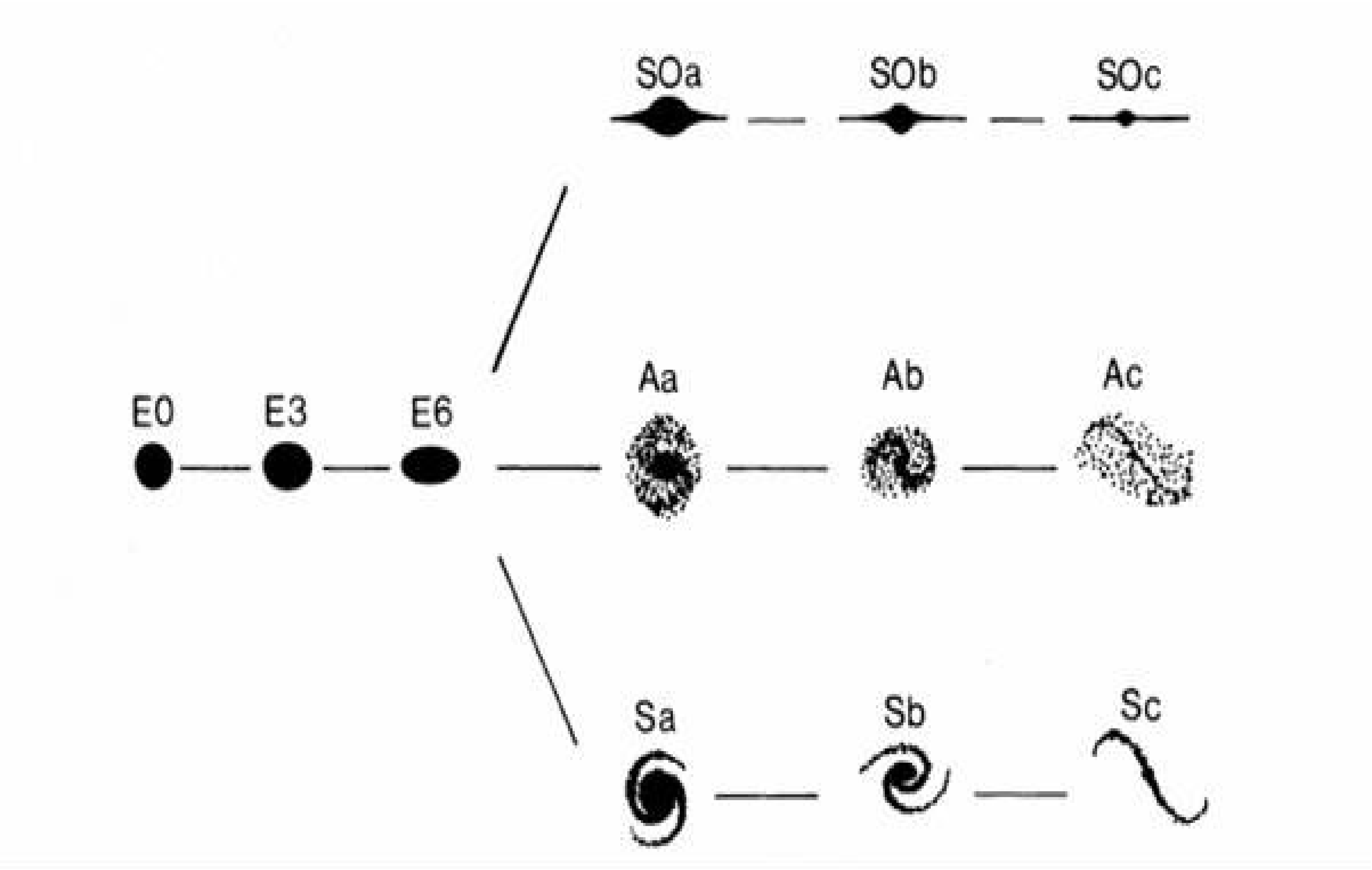
Modifications

- DDO system (Van den Bergh 1960)
  - Added luminosity as a parameter
    - Star formation, gas content, spiral arm “development”
  - Mostly added subclasses to spirals
    - Sc I – well developed arms
    - Sc III – short stubby arms
    - Sc IV – faint spiral structure (LMC)

Modifications cont.

- DDO system (Van den Bergh 1976)
  - Added Anemic as a class
    - Lower gas content than galaxies with similar luminosity
    - Lower star formation rates
    - Spiral arms less well developed

DDO classification of Galaxies

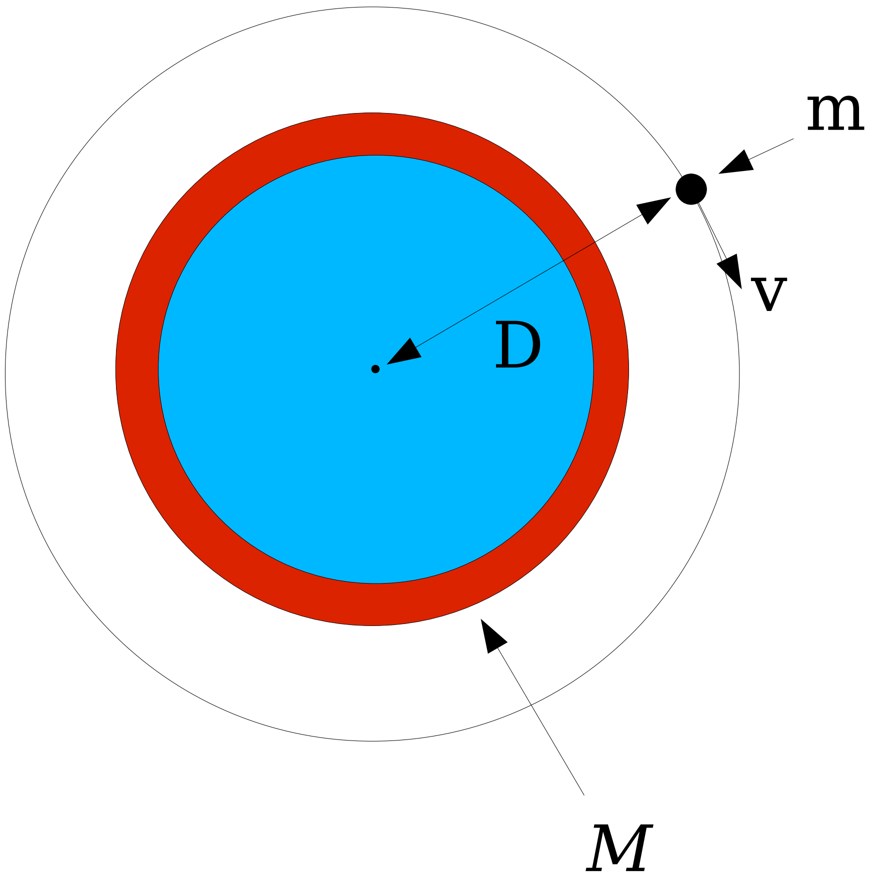


Problems with the DDO system

- Complicated
- Anemic is not necessarily an intrinsic parameter
  - Ram pressure stripping
  - Merger activity

As a result it is not as commonly used as the de Vaucouleurs system

Tidal Stripping



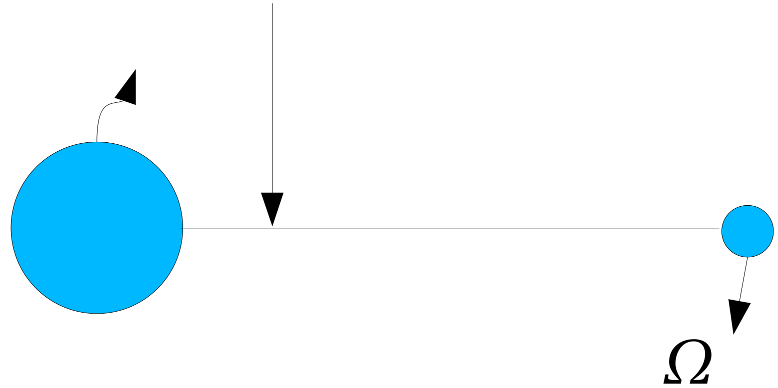
If the mass m is close enough to the particles in M then the particles closest to M are at risk of being removed or stripped from the larger body.

Tidal Stripping cont.

If we select a frame of reference that rotates at the same rate as the satellite m (Ω=v/(2π**D**)). This is so that we have a stationary problem.

Lets also look at this in Center of Mass coordinates.

$$x_{CM} = \frac{D\,M}{M+m}$$



We can write the effective potential in the form

$$\Phi_{eff}(x) = -\frac{G\,M}{|D-x|} - \frac{Gm}{|x|} - \frac{\Omega^2}{2}\left(x - \frac{DM}{M+m}\right)^2$$

Normal gravitational force and angular momentum

This potential will have 3 maxima and we can find these by

$$\frac{\partial \Phi_{eff}}{\partial x} = -\frac{G\,M}{(D-x)^2} \pm \frac{Gm}{x^2} - \Omega^2\left(x - \frac{DM}{M+m}\right) = 0$$

But remember for a circular orbit

$$V^2 = \frac{GM}{r} \quad \text{and the acceleration is} \quad a = \frac{V^2}{r} = \frac{GM}{r^2}$$

Since Ω=v/(2π**r**) then $$a = \frac{V^2}{r} = \Omega^2 r$$

But since we are in the CM coordinate system

$$a = \Omega^2 r = \Omega^2 \frac{DM}{(M+m)} = \frac{GM}{D^2}$$

Solving this for Ω^2

$$\Omega^2 = \frac{G(M+m)}{D^3}$$

Substituting this for Ω^2 below

$$\frac{\partial \Phi_{eff}}{\partial x} = -\frac{GM}{(D-x)^2} \pm \frac{Gm}{x^2} - \Omega^2 (x - \frac{DM}{M+m}) = 0$$

We get

$$-\frac{GM}{(D-x)^2} \pm \frac{Gm}{x^2} - \frac{G(M+m)}{D^3} (x - \frac{DM}{M+m}) = 0$$

If m<<M then x <<D we can rewrite our equation as

$$\frac{G\,M}{D\,(1-\frac{x}{D})^2} \pm \frac{Gm}{x^2} - \frac{GM}{D^2} + \frac{M+m}{D^3} = 0$$

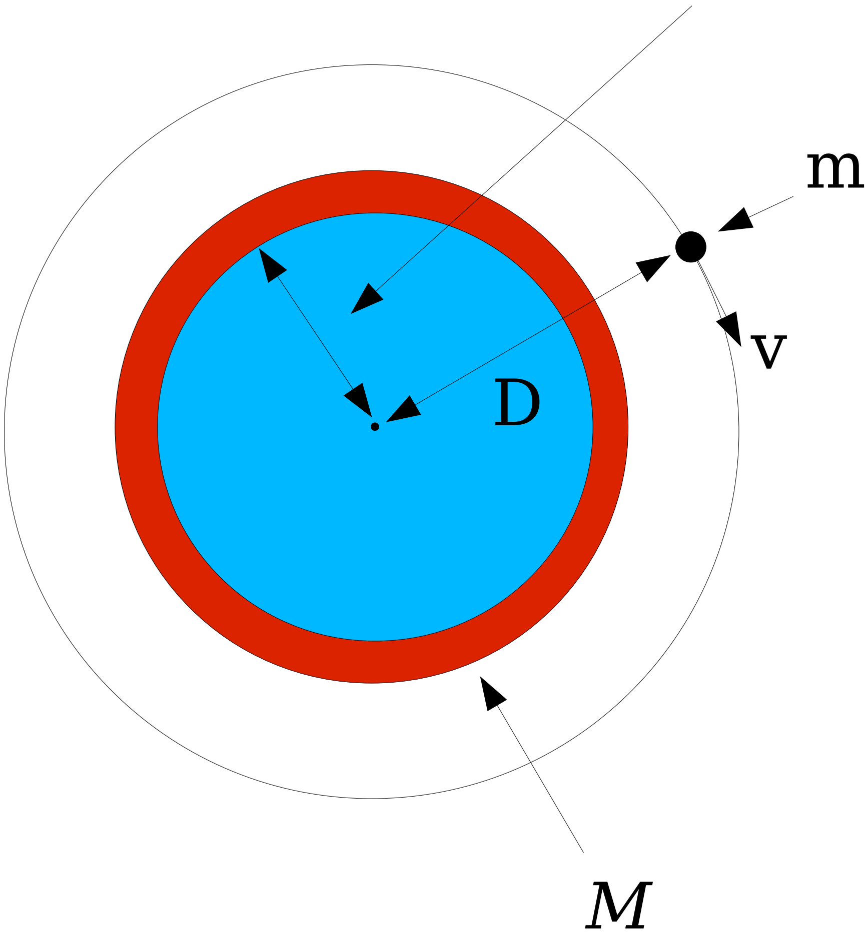
Expanding $(1 + x/D)^{-2}$ in a Taylor series

$$\frac{G\,M}{D^2}\,(1+\frac{2x}{D}+\ldots) \mp \frac{Gm}{x^2} - \frac{GM}{D^2} + \frac{M+m}{D^3} = 0$$

Solving for x we get

$$x = \pm D\,[\frac{m}{M\,(3+m/M\,)}]^{\frac{1}{3}} \approx \pm(\frac{m}{3M})^{\frac{1}{3}} D$$

x is called the Jacobi limit or the Roche limit and is written as r_J



- This provides a crude estimate of the true tidal radius
  - In general the system will not have a circular orbit
  - We derived this for point masses and most systems are extended
  - If done in 3-d (so we get a surface) this is not a spherical surface
  - If $r_J > x$ a particle will not necessarily escape. Numerical studies show that there are some stable orbits up to $r = 2r_J$.

Cartisian Coordinates

$$\nabla^2 \psi(x, y, z) = \frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial \psi^2}{\partial z^2}$$

Polar Coordinates

$$\nabla^2 \psi(\rho, \phi, z) = \frac{\partial^2 \psi}{\partial \rho^2} + \frac{1}{\rho} \frac{\partial \psi}{\partial \rho} + \frac{1}{\rho^2} \frac{\partial^2 \psi}{\partial \phi^2} + \frac{\partial^2 \psi}{\partial z^2}$$

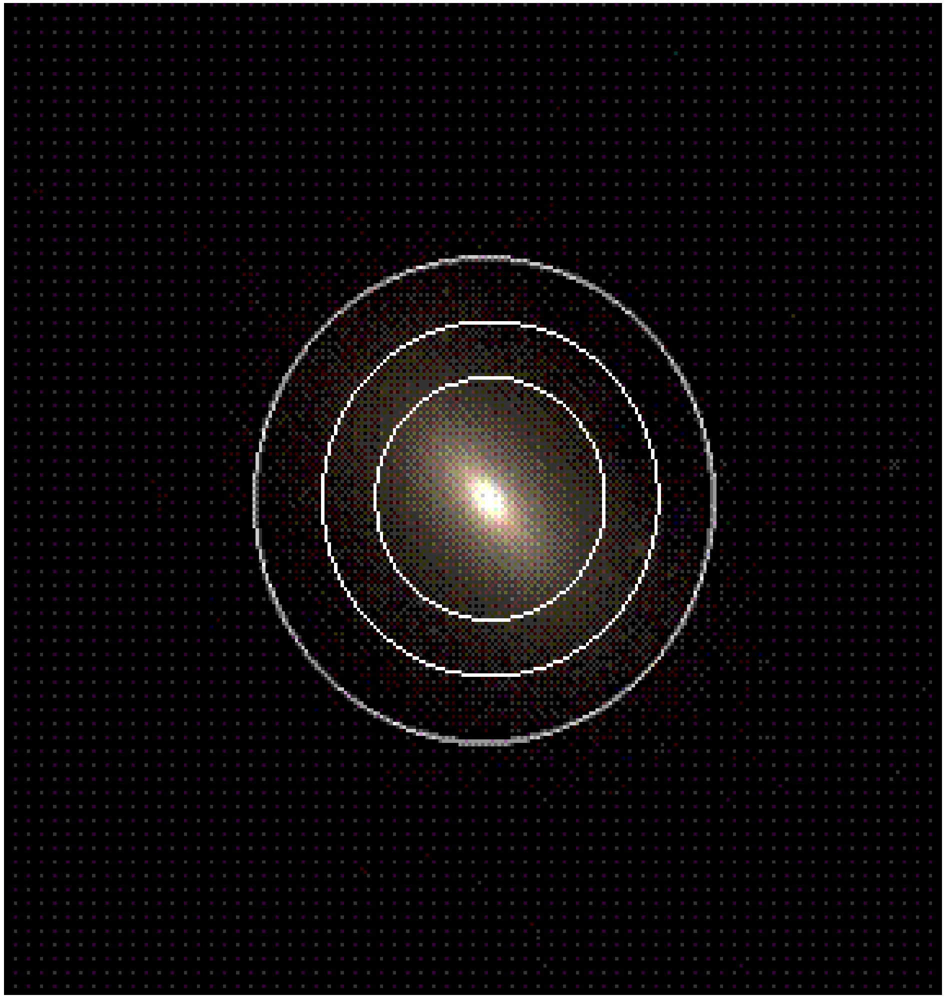
Spherical Coordinates

$$\nabla^2 \psi(r, \theta, \phi) = \frac{1}{r^2} \frac{\partial}{\partial r}\left(r^2 \frac{\partial \psi}{\partial r}\right) + \frac{1}{r^2 \sin\theta} \frac{\partial}{\partial \theta}\left(\sin\theta \frac{\partial \psi}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta} \frac{\partial^2 \psi}{\partial \phi^2}$$

Dust and Gas in External Galaxies

Galaxy Photometry

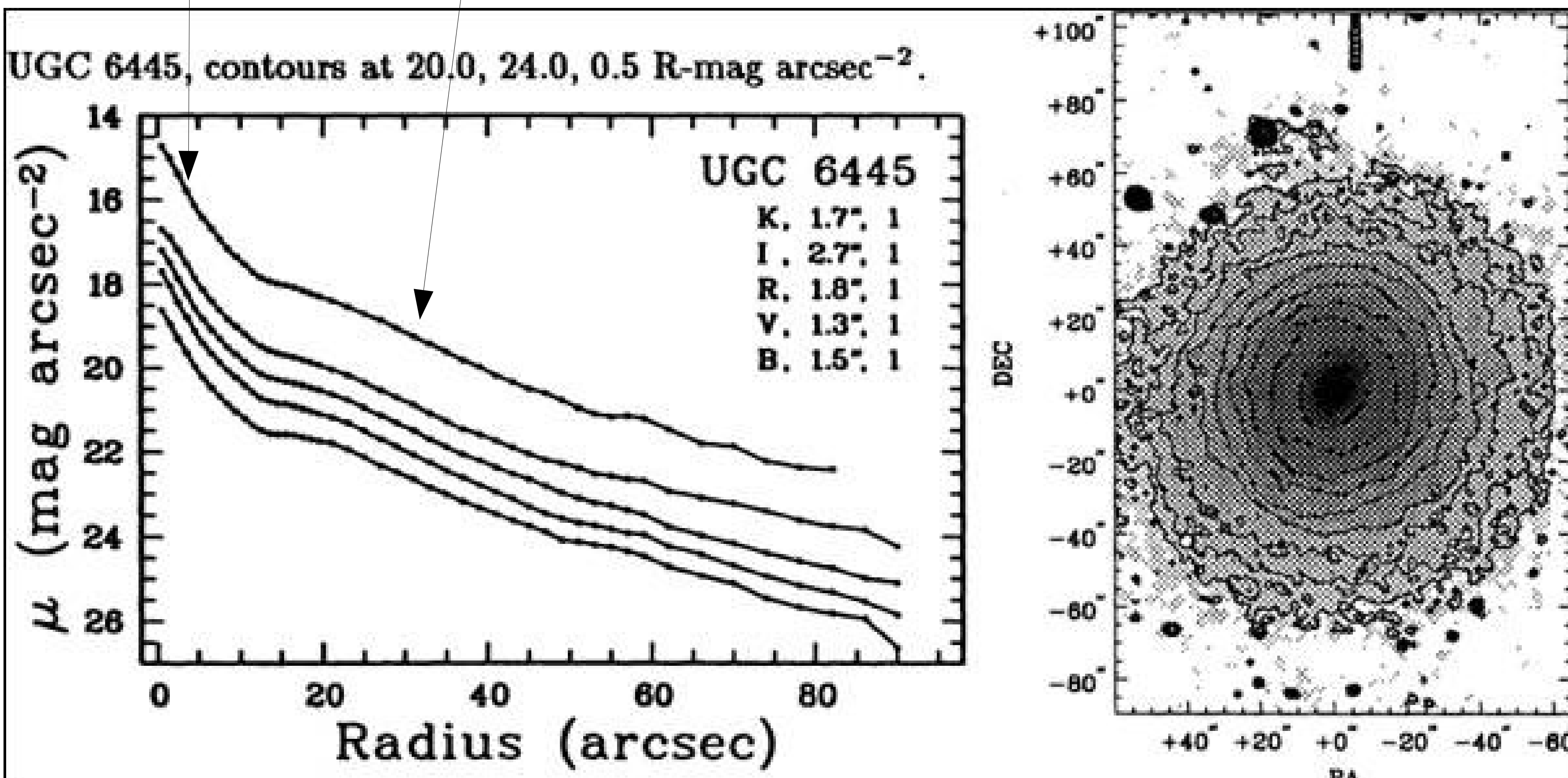
- Surface Photometry is often used to measure stellar distribution
- Measured in concentric radii (mag/sq arcsec)
- Use a fit function to measure SB
- Compare different anulii e.g. Concentration index, assymetry



Spiral galaxy profiles

Two components

Bulge Disk



Elliptical galaxy profiles

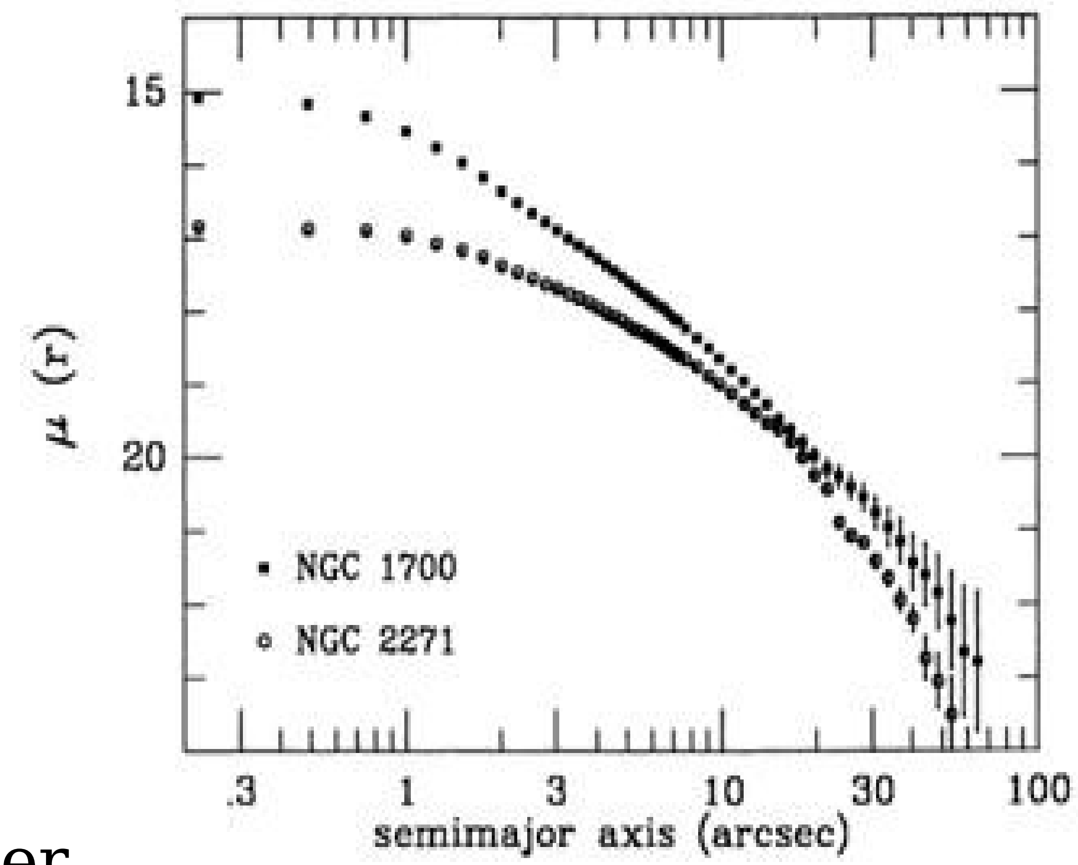
Often well fit with an exponential profile

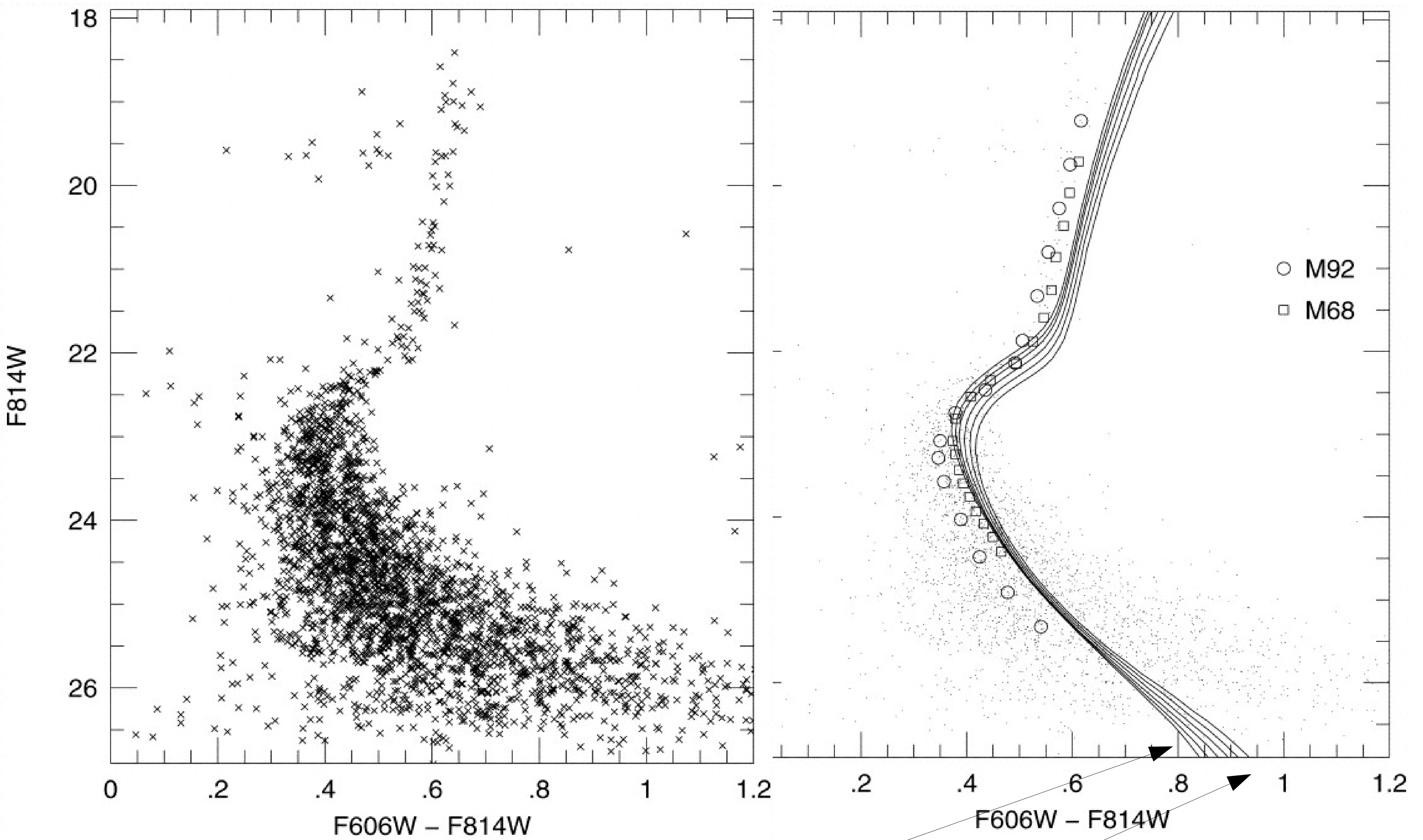
$$I(r) = I(r_e)\exp\left[-b\left(\frac{r}{r_e}\right)^{\frac{1}{n}} - 1\right]$$

If n = 4 this is a de Vaucouleur's law for general n Sersic's law.

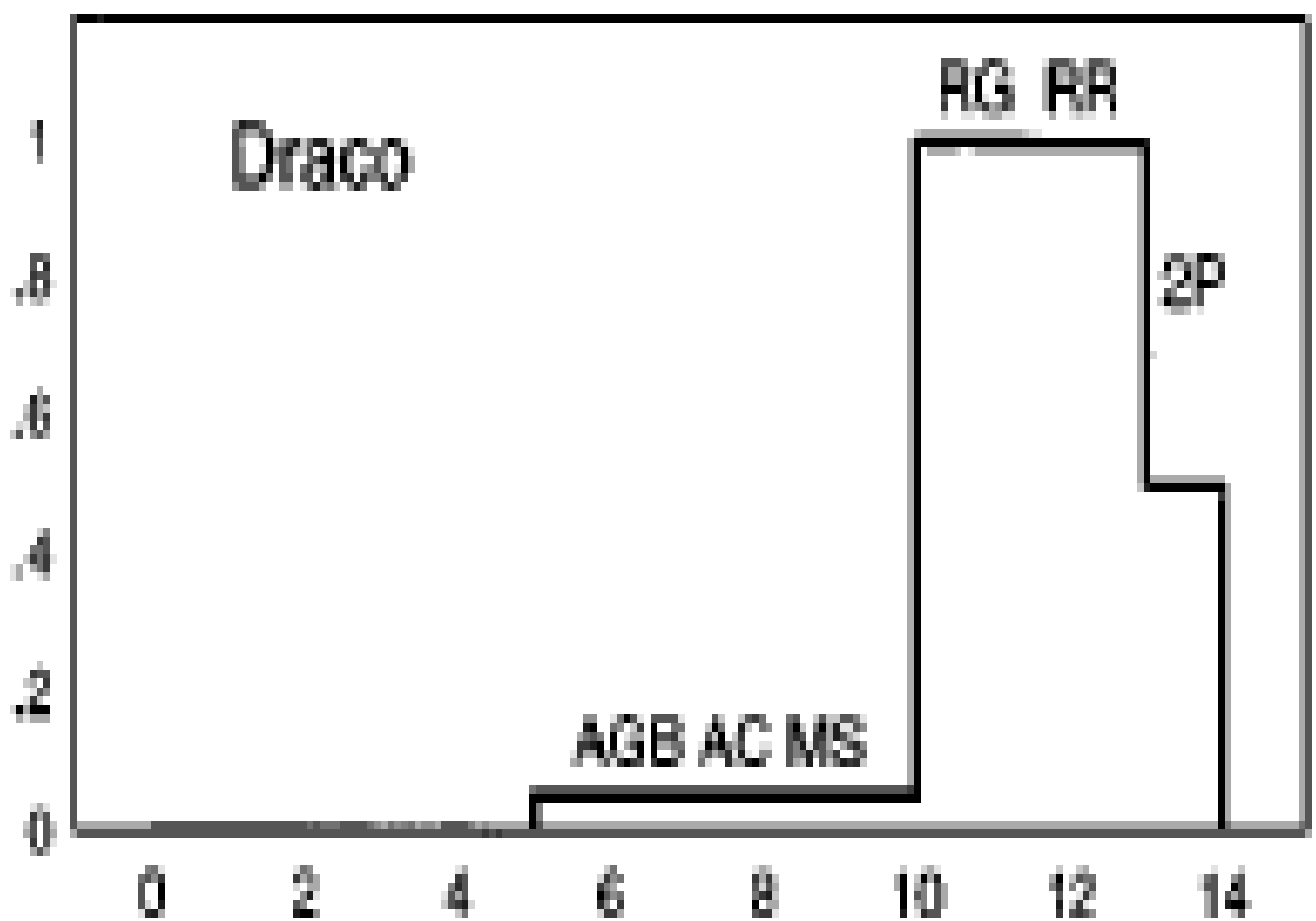
Often flattens in the center

Fit spiral bulges as well





Measured and color magnitude diagram for the draco dSph the fit is for an age of 16 Gyr with metalicities 2.2>[Fe/H] >1.2 (Grillmair et al. 1998)



Draco
RG
RR
2P
AGB AC MS
1
.8
.6
.4
.2
0
0
2
4
6
8
10
12
14