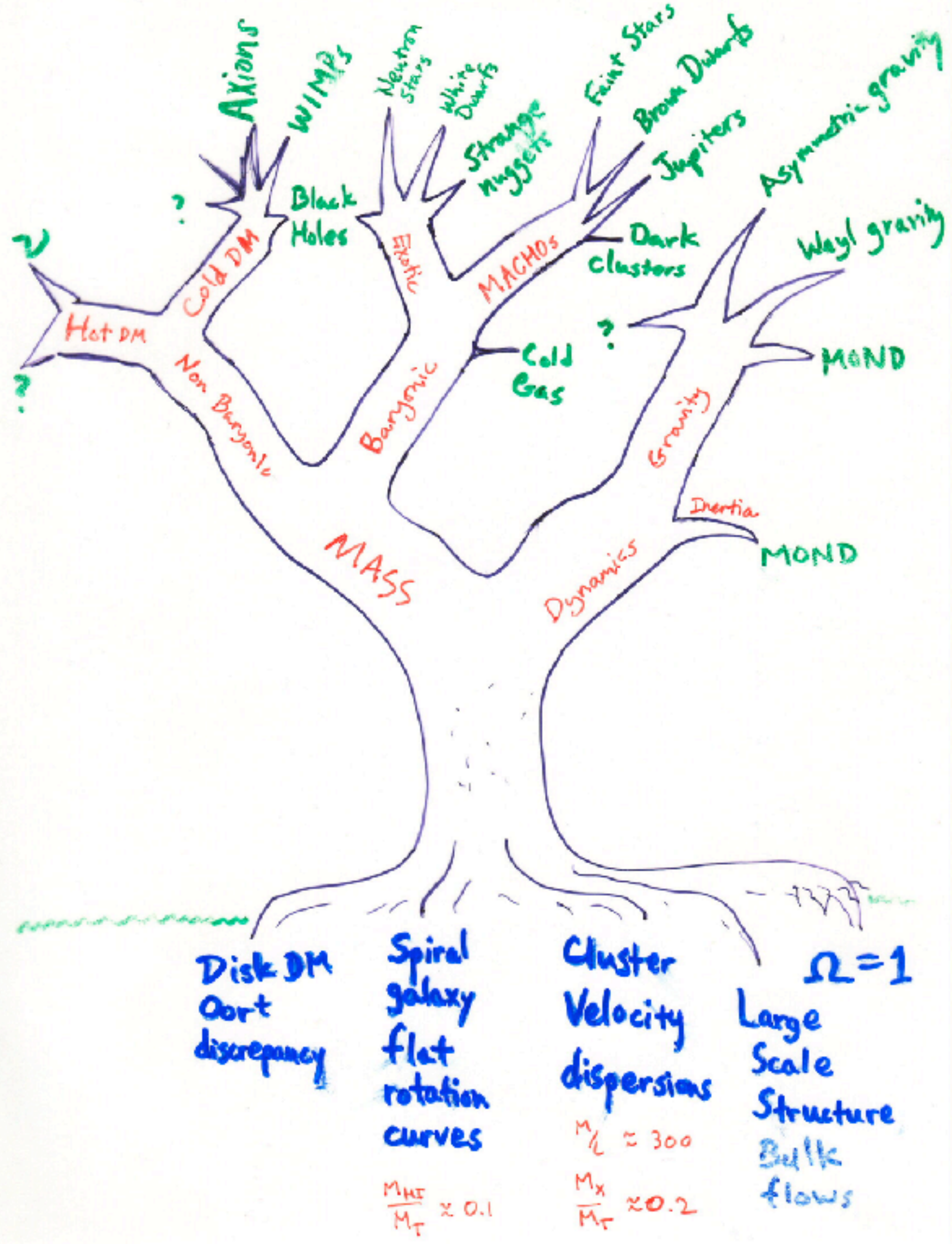
Dark Matter

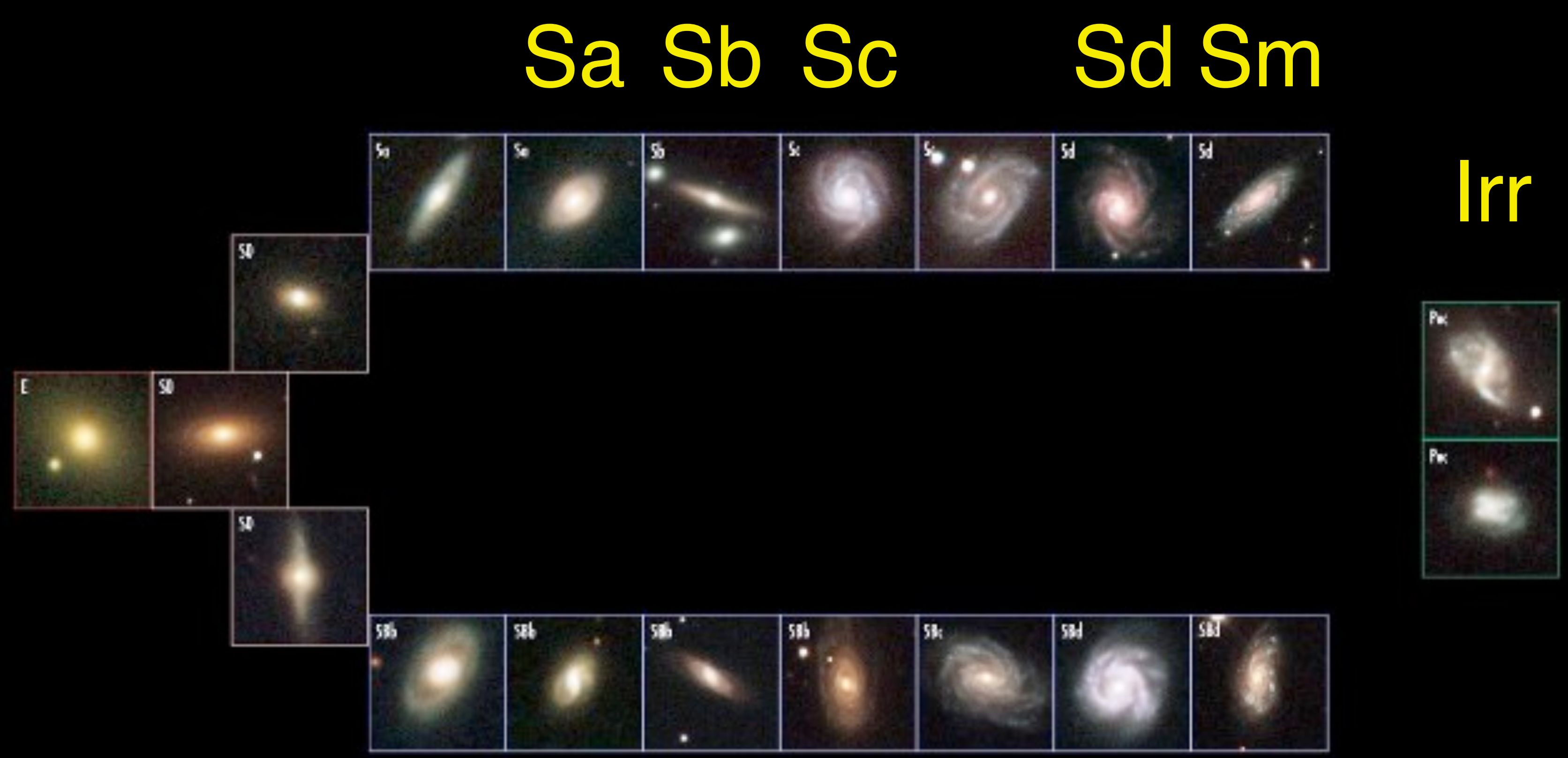
ASTR 333/433
Spring 2016
T R 4:00-5:15pm
Sears 552

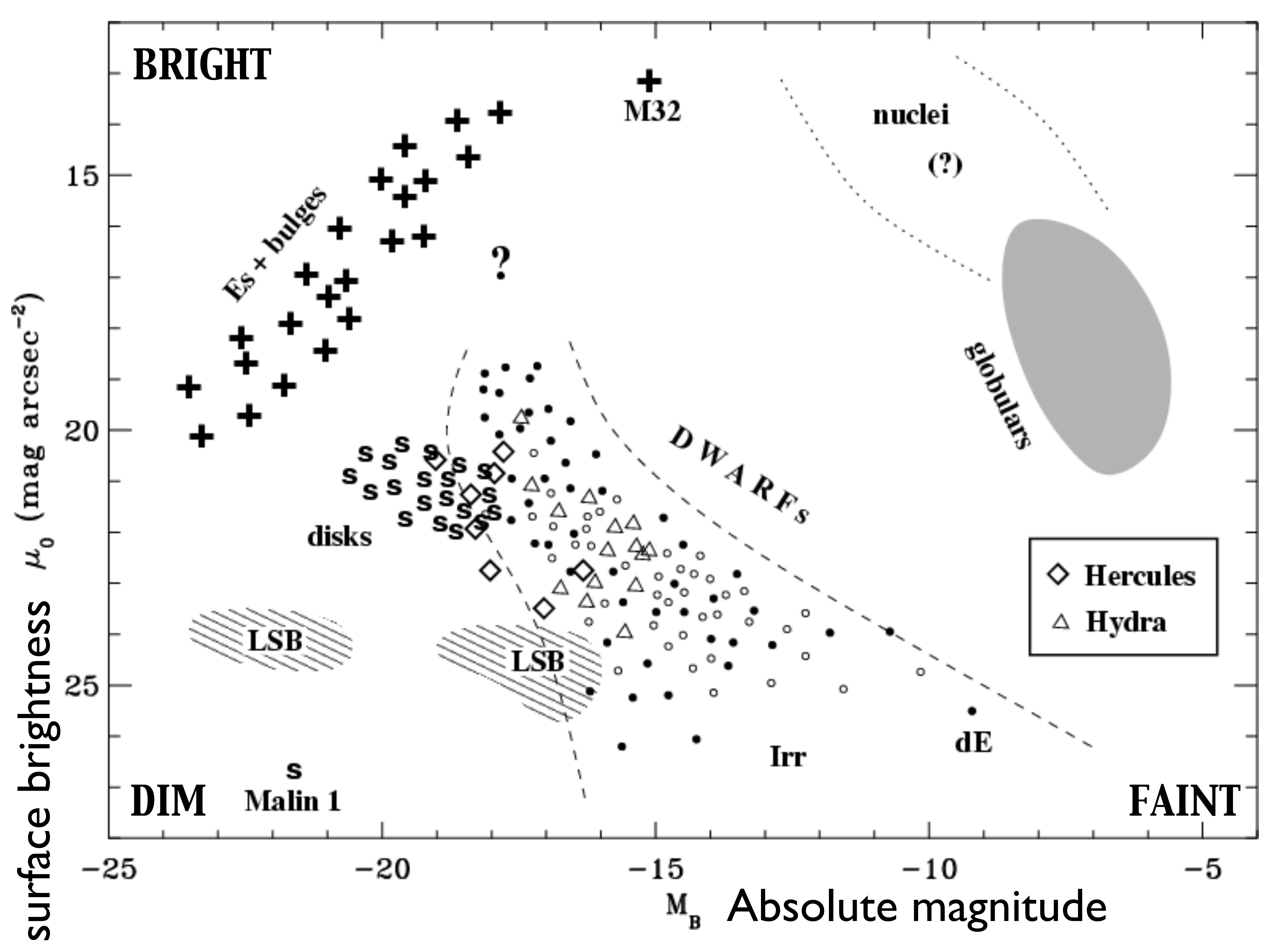
TODAY

Range of Galaxy Properties
The Oort Limit
The Bar Instability

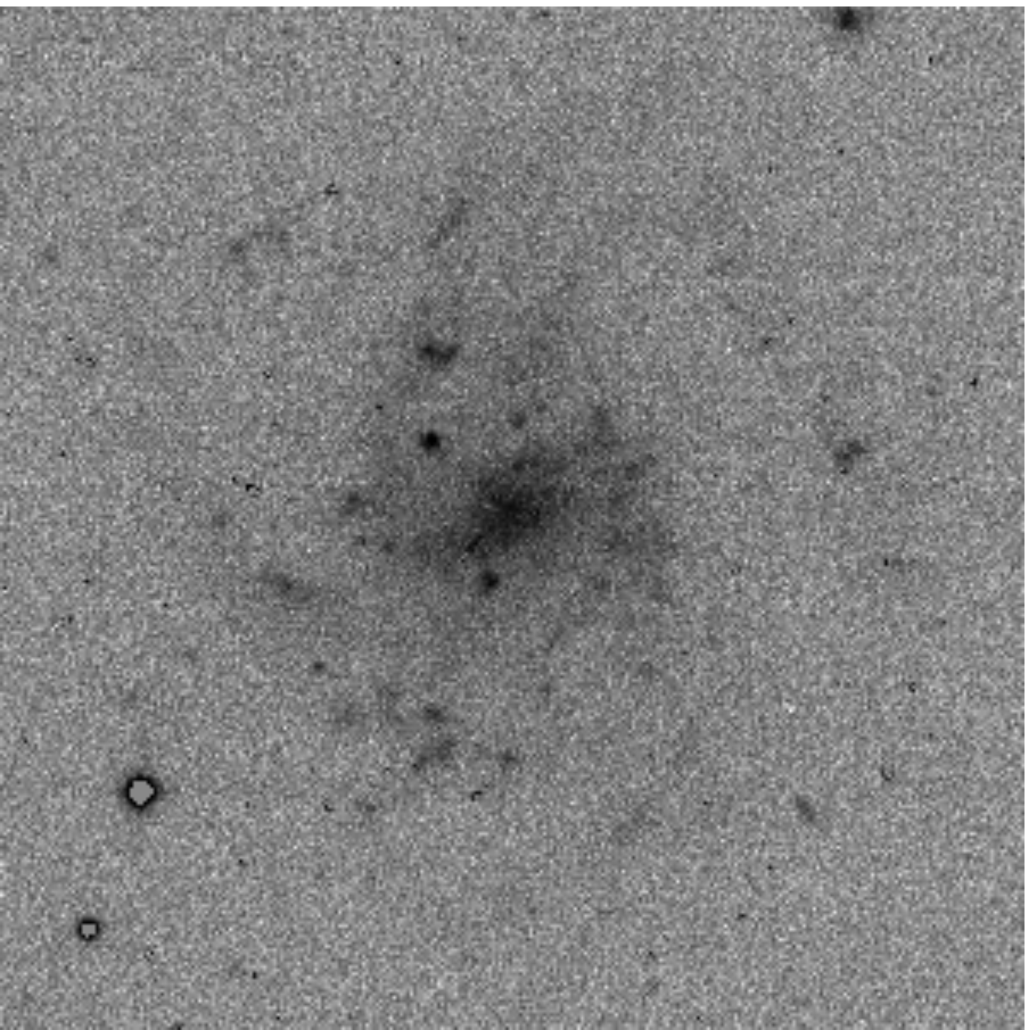


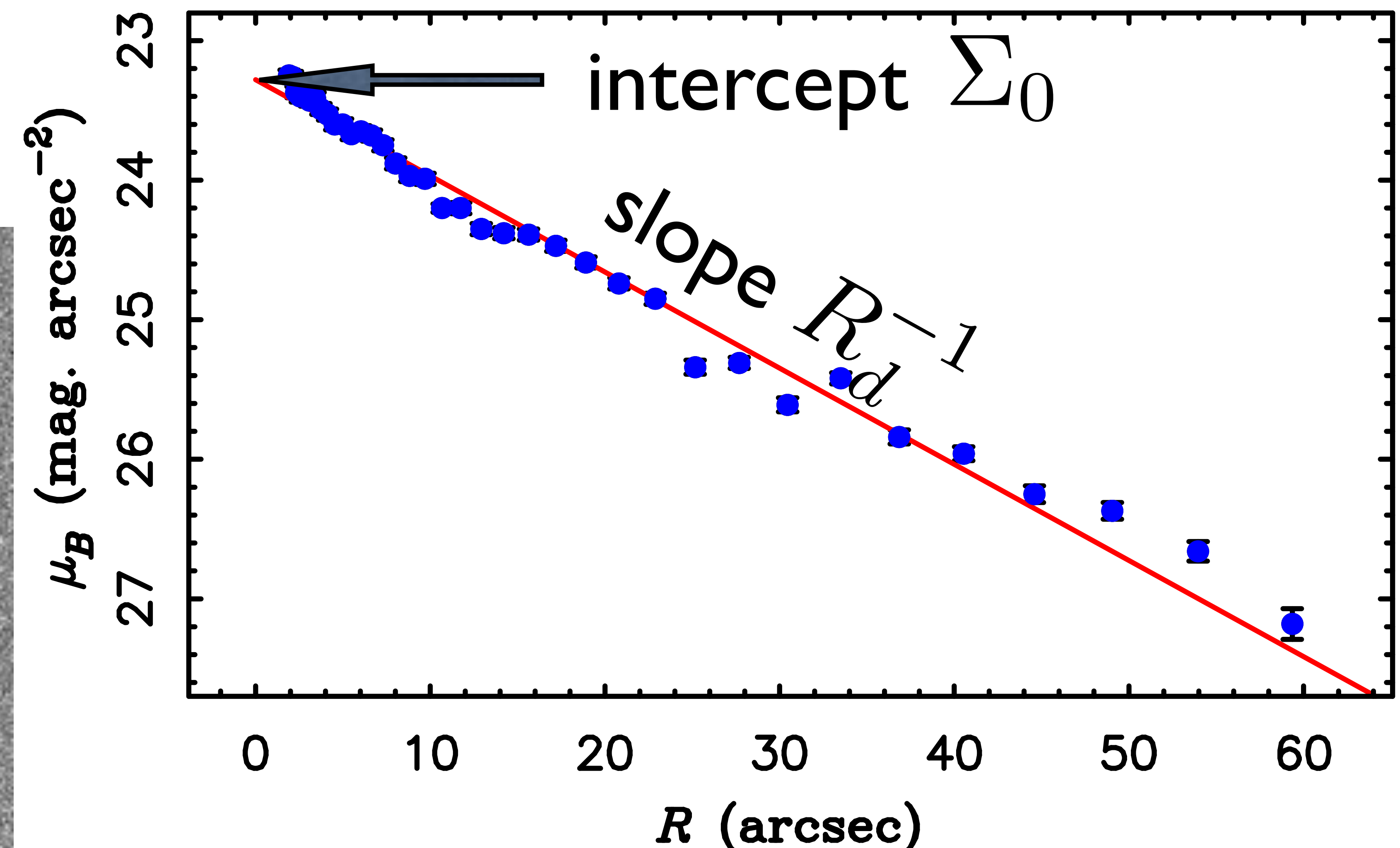
The original Hubble sequence extented to later types





BRIGHT
M32
nuclei
(?)
Es + bulges
?
globulars
DWARFs
disks
Hercules
Hydra
LSB
LSB
Irr
dE
DIM
Malin 1
FAINT
15
20
25
−25
−20
−15
−10
−5
μ_0 (mag arcsec^{-2})
surface brightness
M_B Absolute magnitude

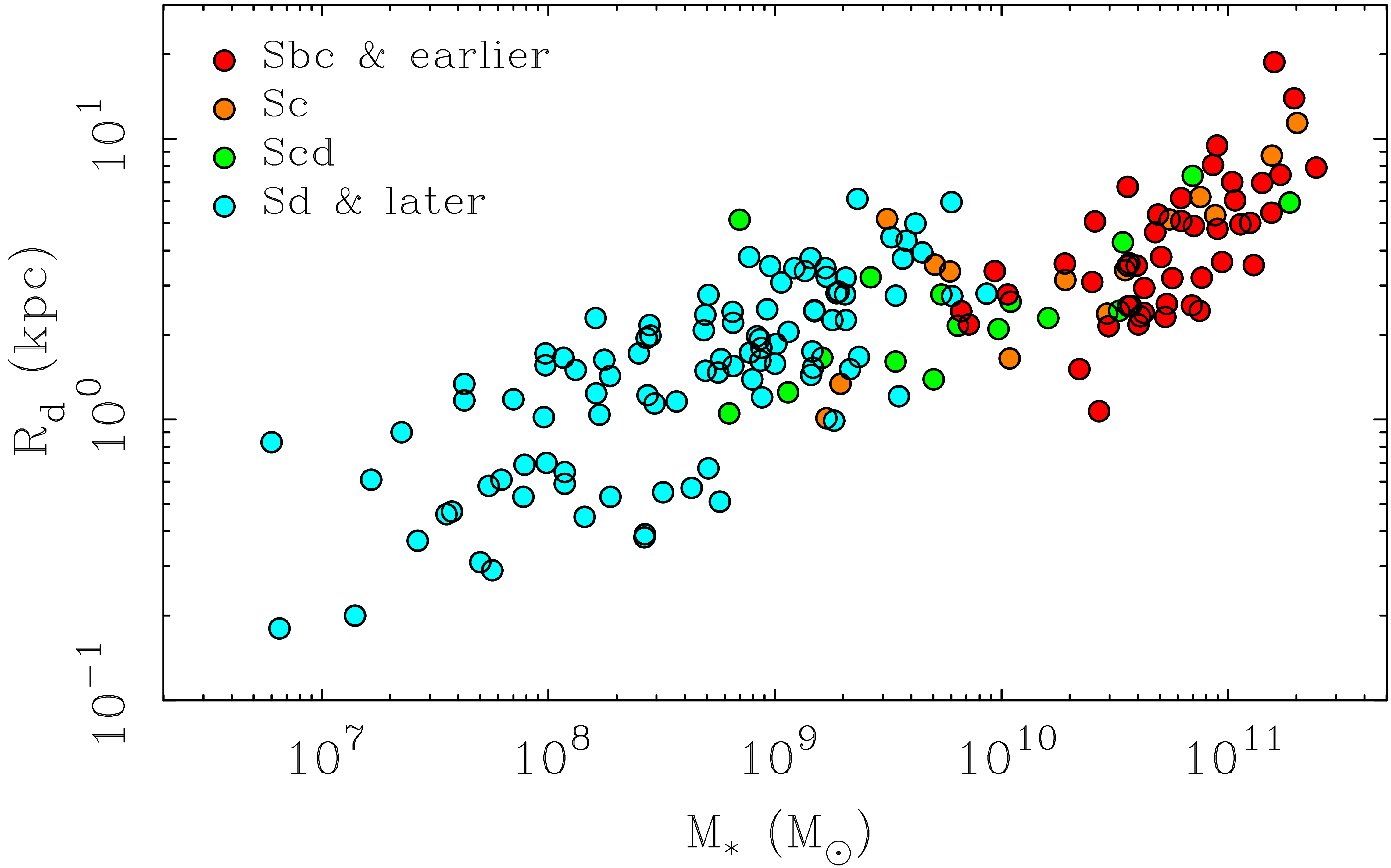


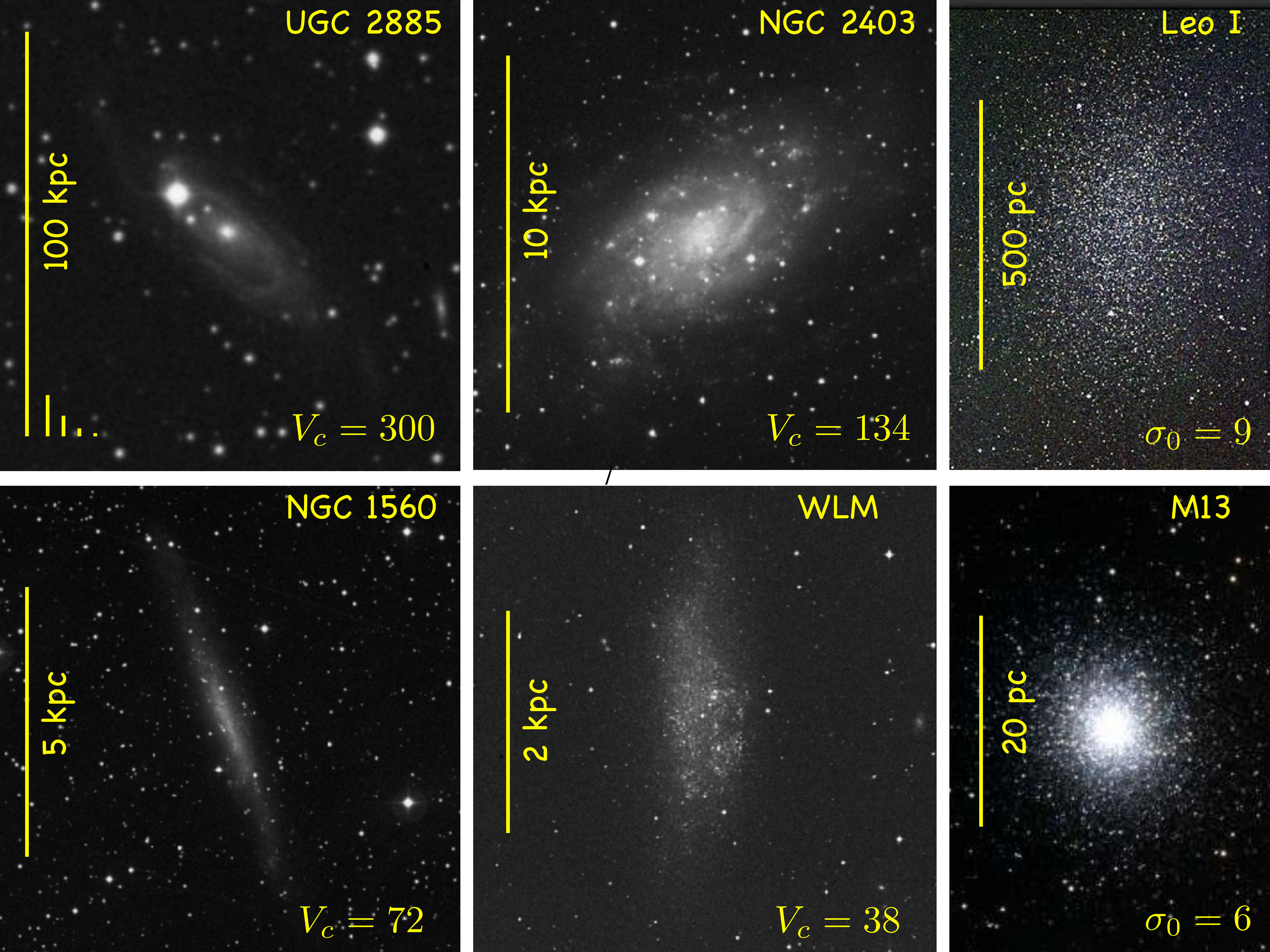


$$\Sigma(R) = \Sigma_0 e^{-R/R_d}$$

Azimuthally averaged light distribution approximately exponential for spiral disks.

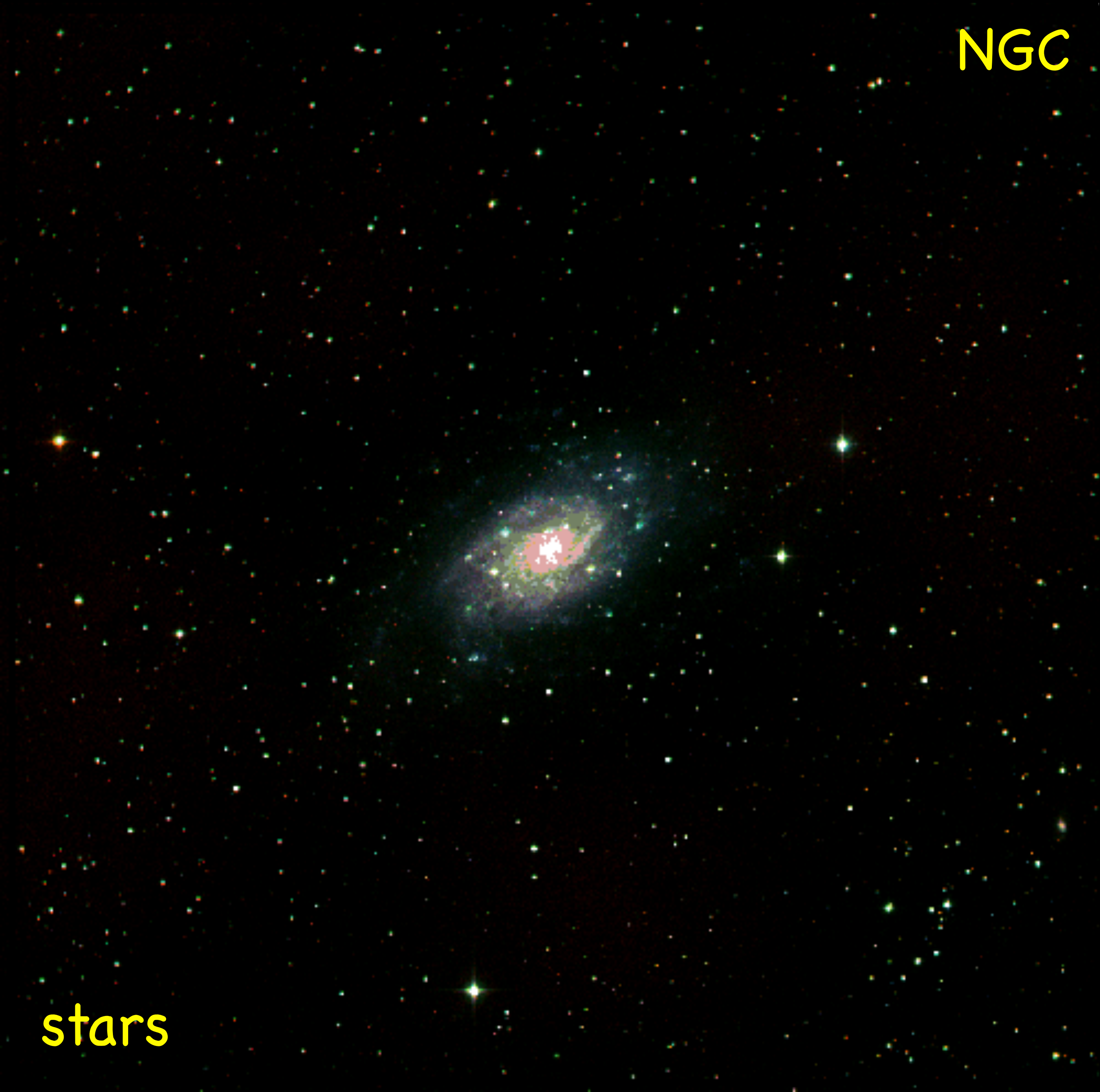
Sizes and masses of rotationally supported galaxies

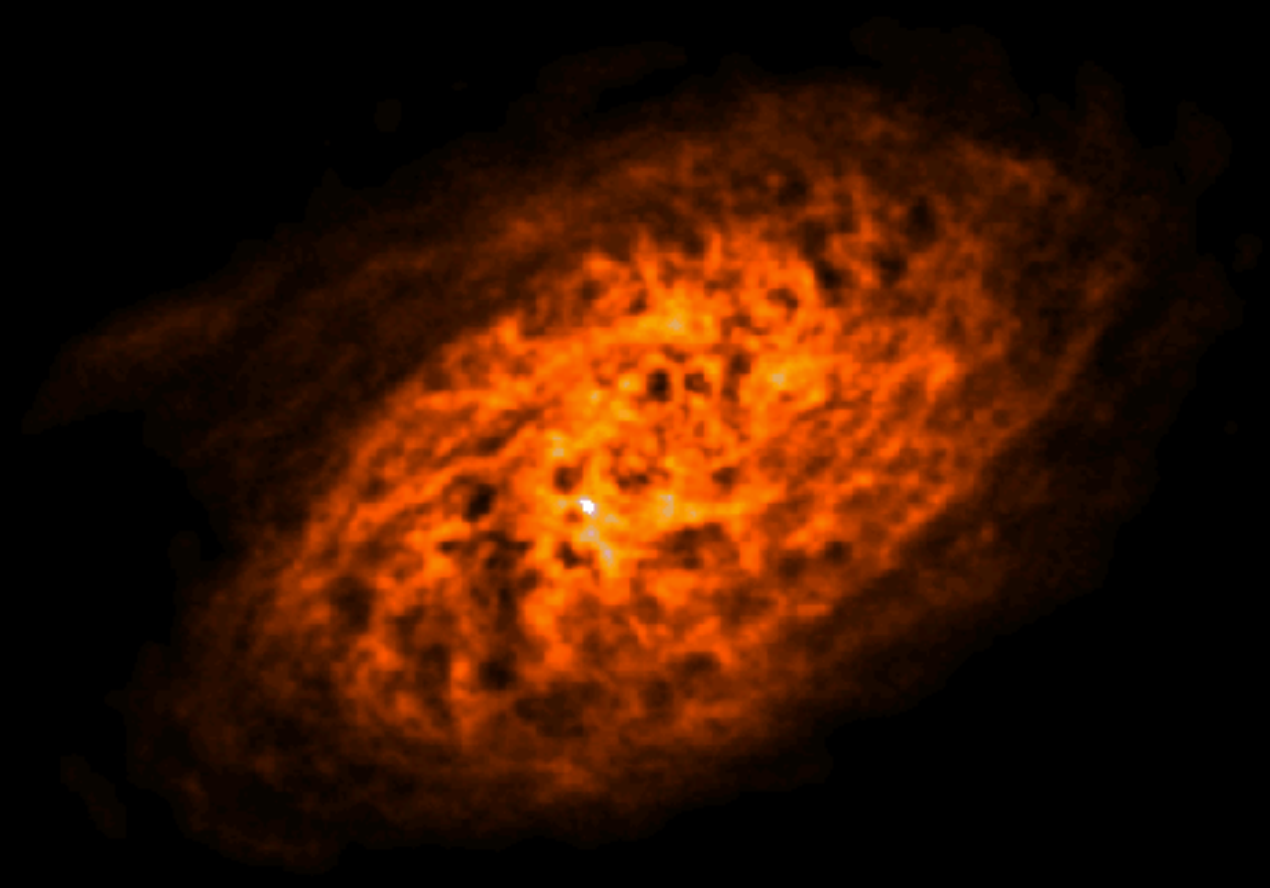



UGC 2885
100 kpc
$V_c = 300$
NGC 2403
10 kpc
$V_c = 134$
Leo I
500 pc
$\sigma_0 = 9$
NGC 1560
5 kpc
$V_c = 72$
WLM
2 kpc
$V_c = 38$
M13
20 pc
$\sigma_0 = 6$

The atomic gas of the ISM is often more extended than the stars

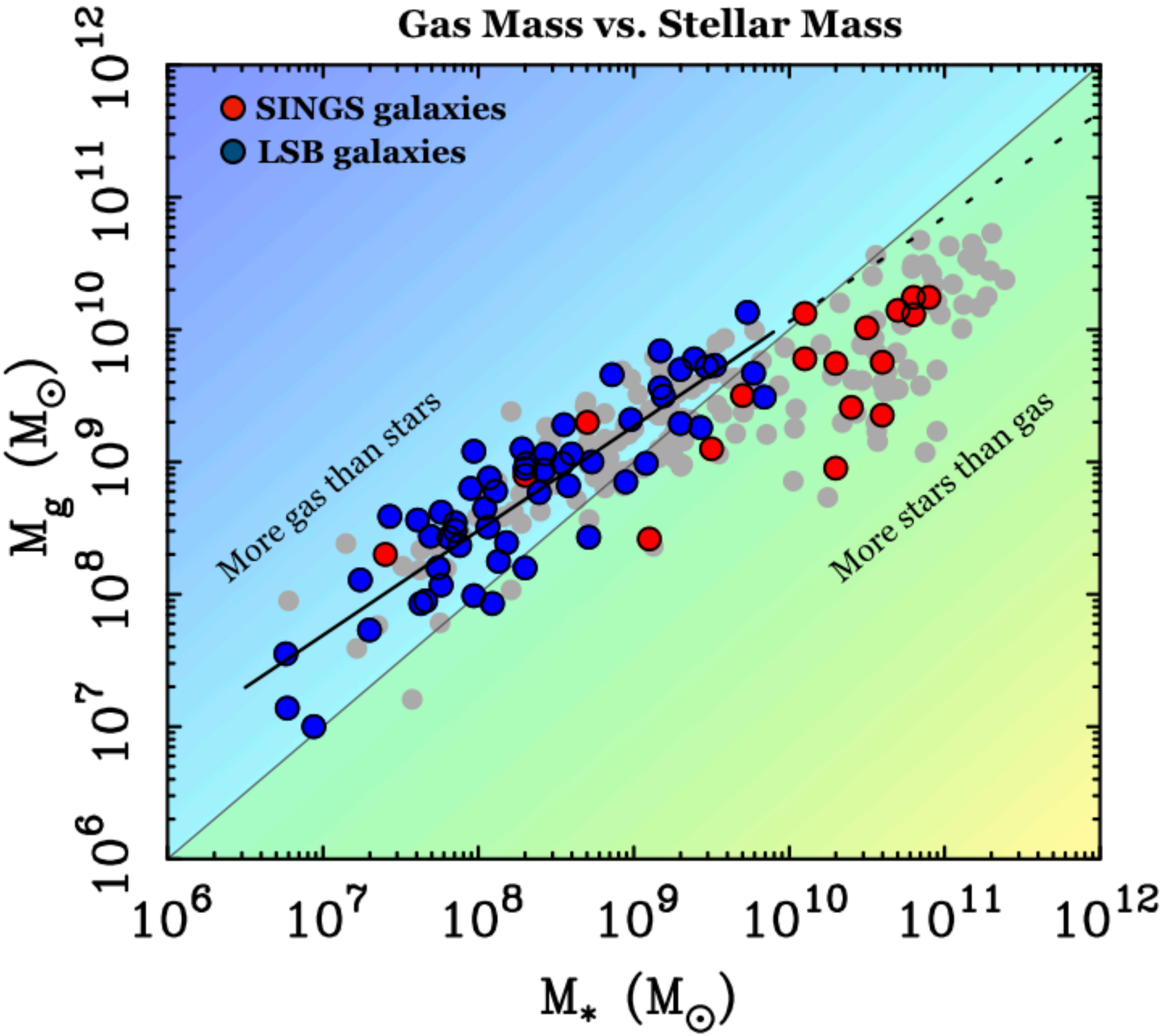
NGC 2403

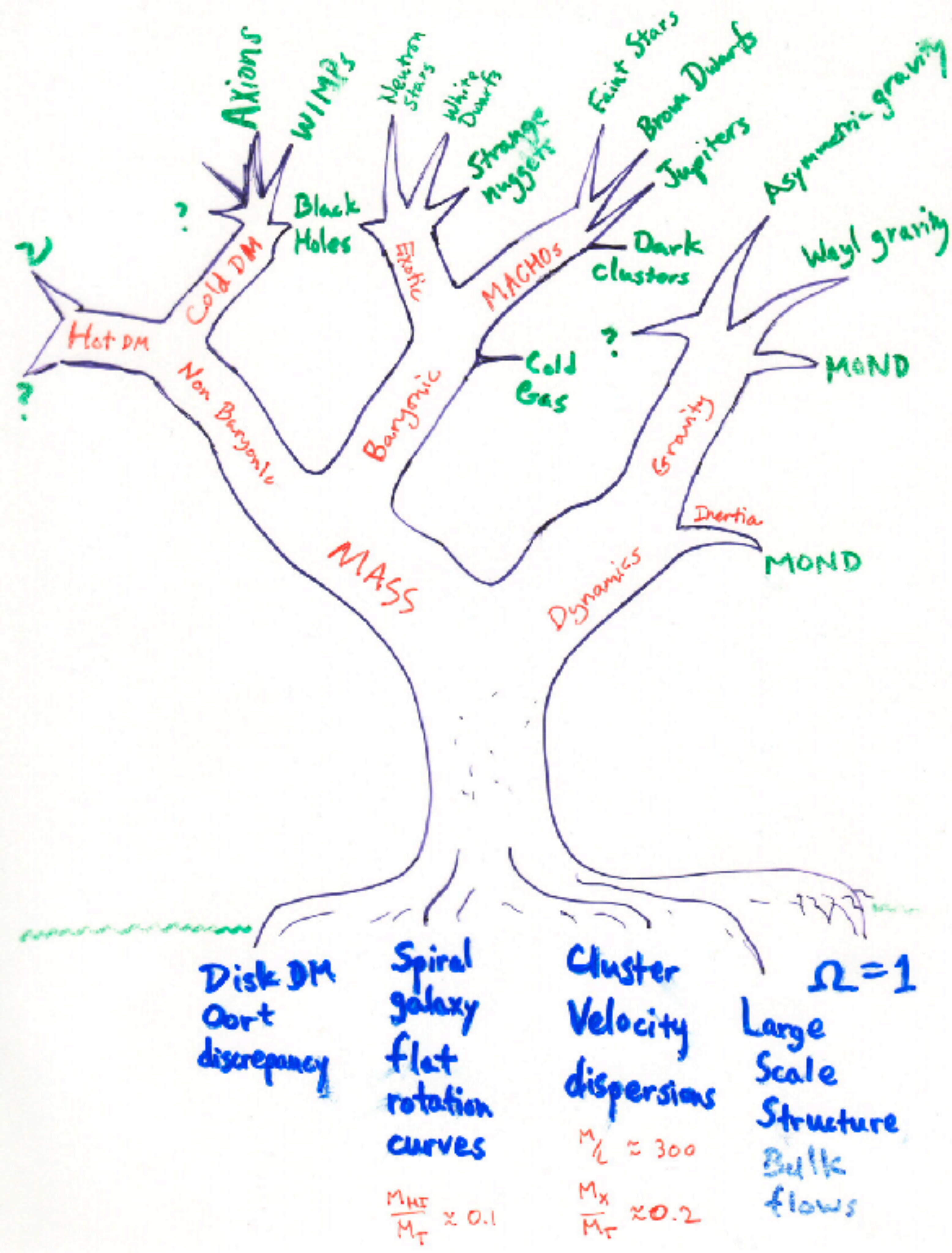




Fraternali, F., Oosterloo, T., Sancisi, R., van Moorsel, G.A. 2001, ApJ, 562, L47

Rotationally supported galaxies (no Ellipticals)





Vertical motion in the Milky Way

the Oort limit

Artist's depiction of face-on Milky Way informed by *Spitzer* GLIMPSE data

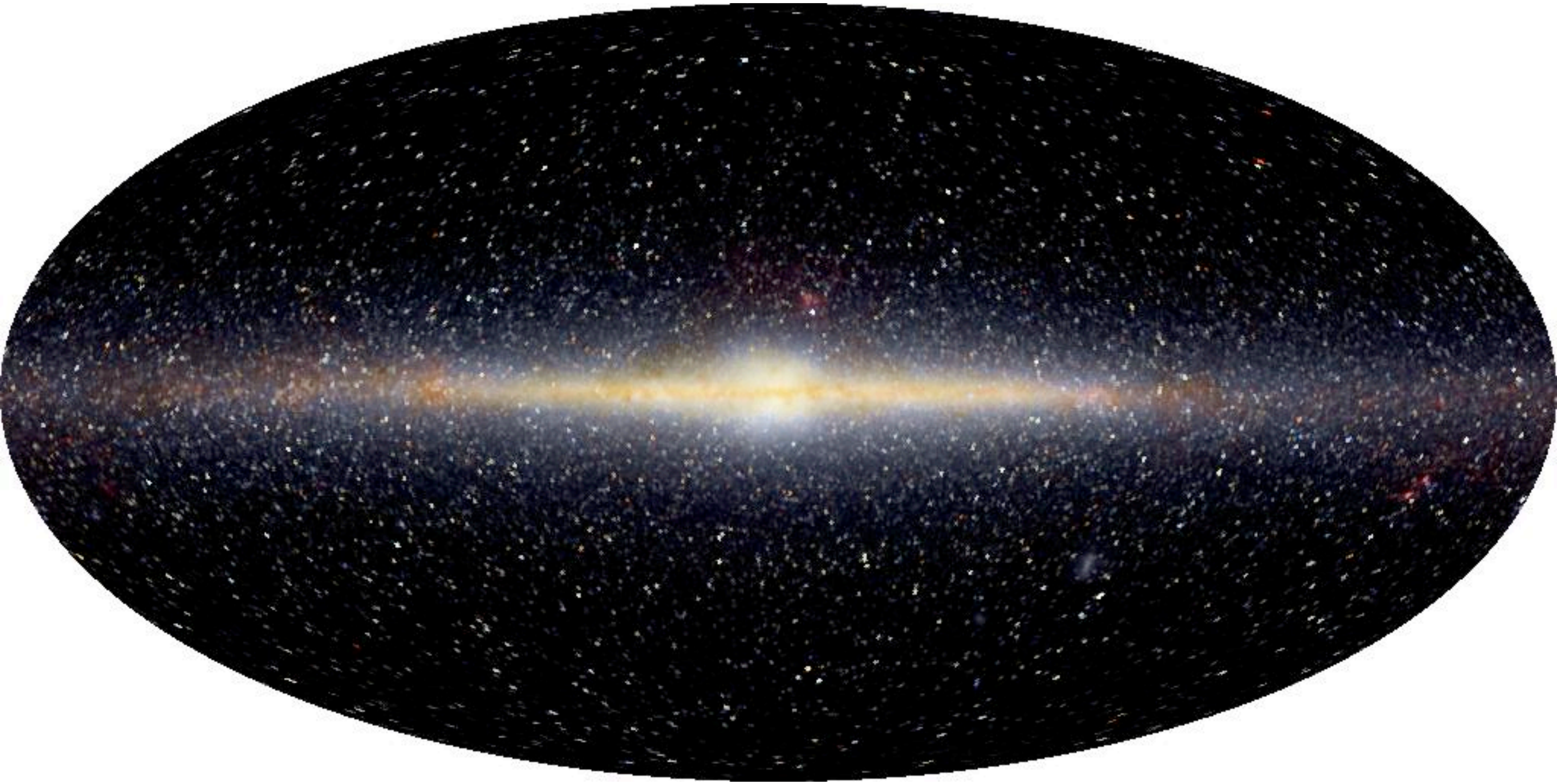
$$M_* \approx 5.5 \times 10^{10}\ \mathrm{M}_\odot$$

$$M_g \approx 1.2 \times 10^{10}\ \mathrm{M}_\odot$$

$$R_d \approx 2.2\ \mathrm{kpc}$$

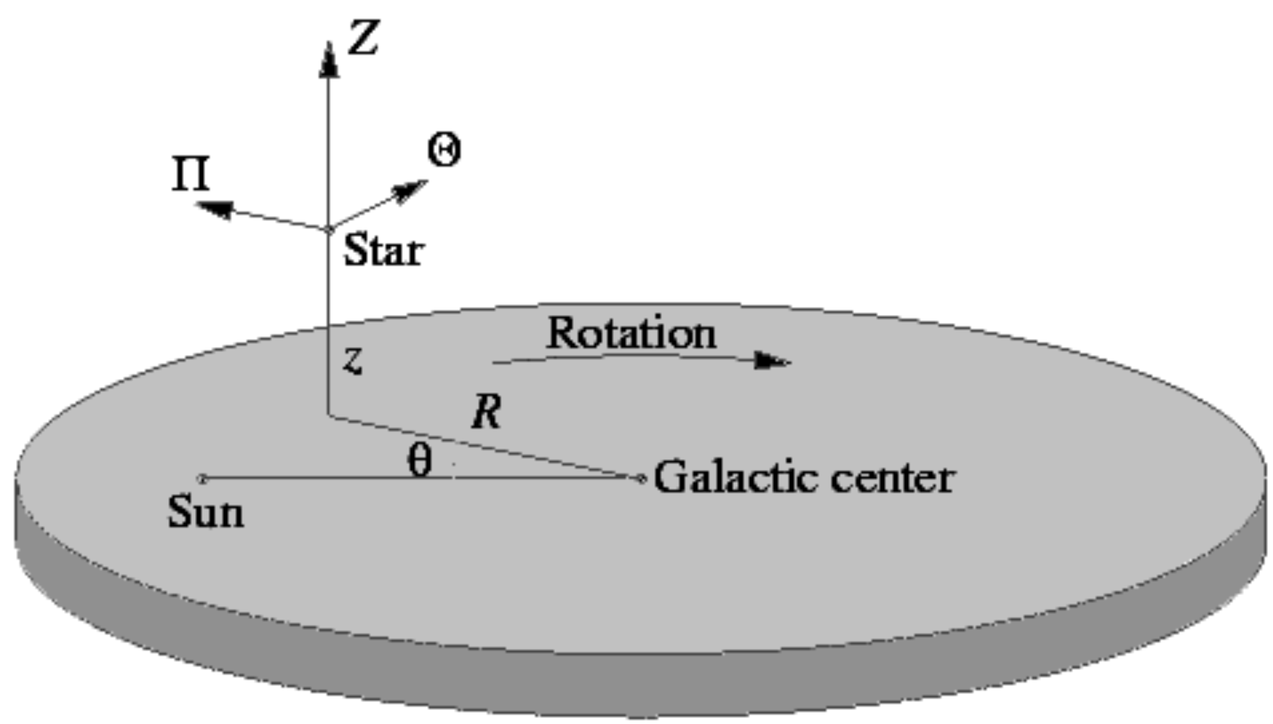
$$V_f \approx 205\ \mathrm{km\,s^{-1}}$$

Milky Way in the near-infrared



Cylindrical coordinates

Let's define a coordinate system:



$$\text{Position}: (R, \theta, z) \quad \text{Velocity}: (\Pi, \Theta, Z)$$

- R = galactocentric distance
- theta = azimuthal coordinate
- z = height above/below the plane

- Pi = velocity in/out from center
- Theta = tangential velocity
- Z = velocity up and down

OR (X,Y,Z) centered on either the sun or the G.C.

Oort limit - imagine the disk as a plane parallel slab

from Sparke & Gallagher

First, think of balancing KE with PE for a small mass m orbiting a big mass M: $\frac{1}{2}mv^2 \sim \frac{GMm}{r}$

So we can solve for the big mass M: $v^2 \sim \frac{2GM}{r}$

Now, instead of a big mass M, think of a circular patch of radius r and surface density Sigma (in M_{sun}/pc^2). It has a total mass: $M \sim \Sigma_0 \pi r^2$

So plug that in and get $v^2 \sim 2\pi G \Sigma_0 r$

Or, now thinking about a group of stars: $\sigma_z^2 \sim 2\pi G \Sigma_0 z_0$

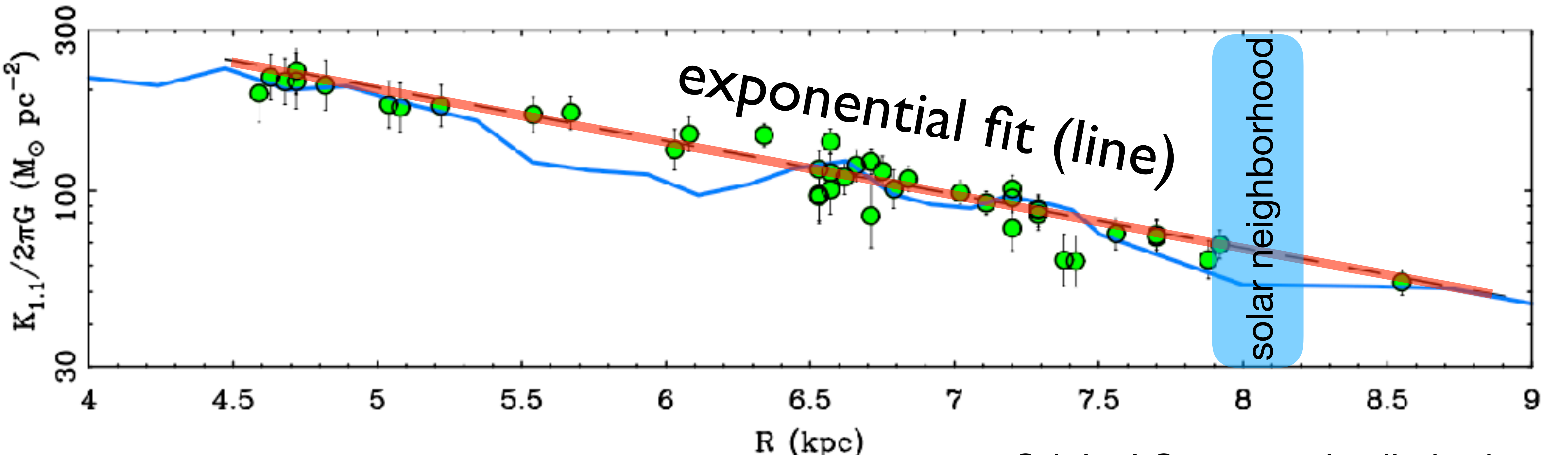
So if we measure velocity dispersions and scale heights for groups of stars, we can measure the mass density of the Galaxy's disk. This was first done in the early 1960s by Jan Oort and is called the **Oort limit**. A recent (and more sophisticated) analysis gives ~ 70 M_{sun}/pc^2.

Now let's just add up all the mass we see:

Stars	25 M_{sun}/pc^2
Stellar remnants (mostly WDs)	20 M_{sun}/pc^2
Gas (HI+H2)	5 M_{sun}/pc^2
Total	50 M_{sun}/pc^2

Are we happy with these sums?

$$K_Z = 2\pi\Sigma + \frac{Z}{R}\frac{\partial V^2}{\partial R}$$



Original Oort exercise limited to the solar neighborhood. Can now expand to other radii.

$$\Sigma(R) = \Sigma_\odot e^{-\frac{(R-R_\odot)}{R_d}}$$

$$\Sigma_\odot = 38\ \mathrm{M}_\odot\ \mathrm{pc}^{-2}$$ (stars only)

$$R_d = 2.15\ \mathrm{kpc}$$ Bovy & Rix (2013)