DARK MATTER

ASTR 333/433

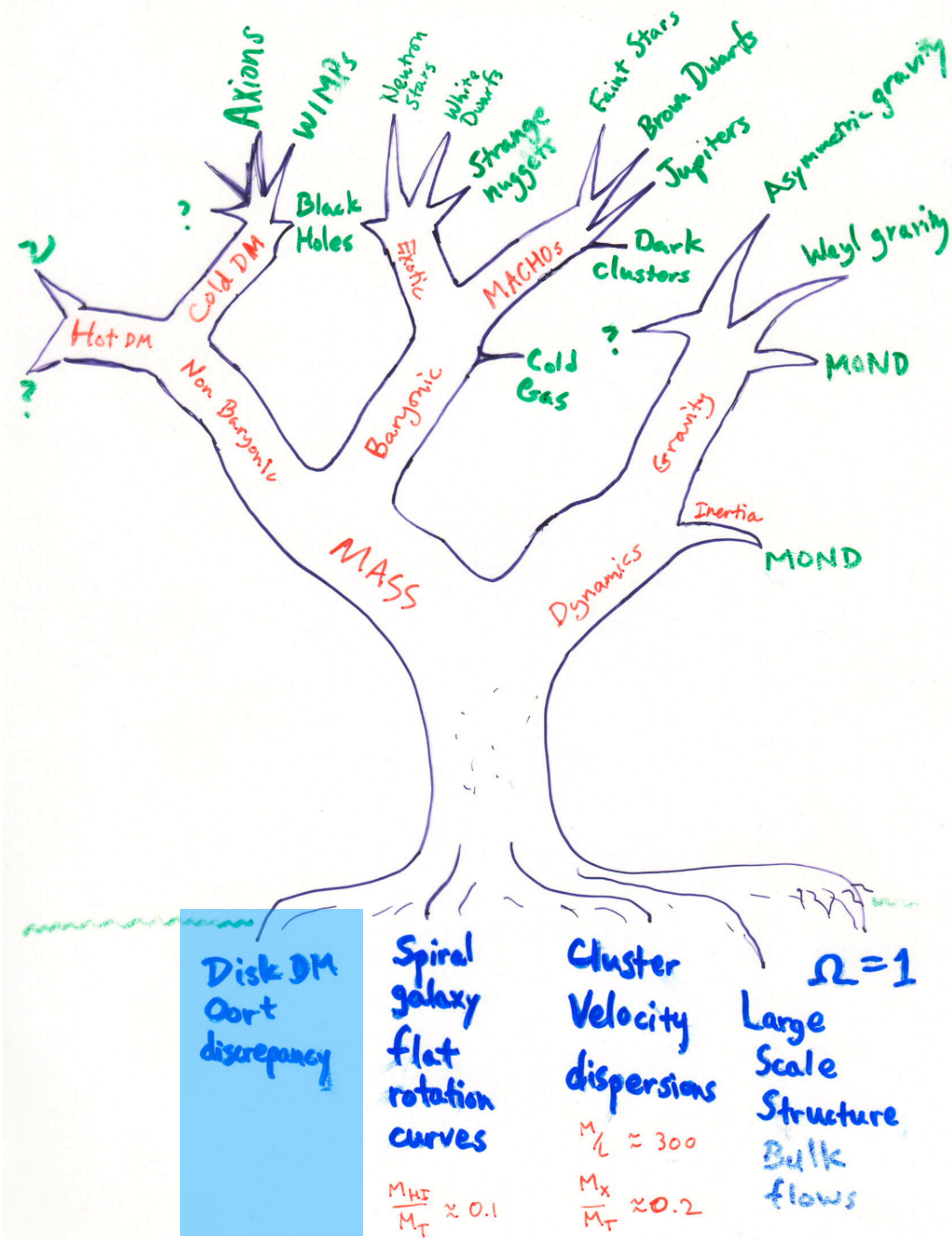
<u>TODAY</u>

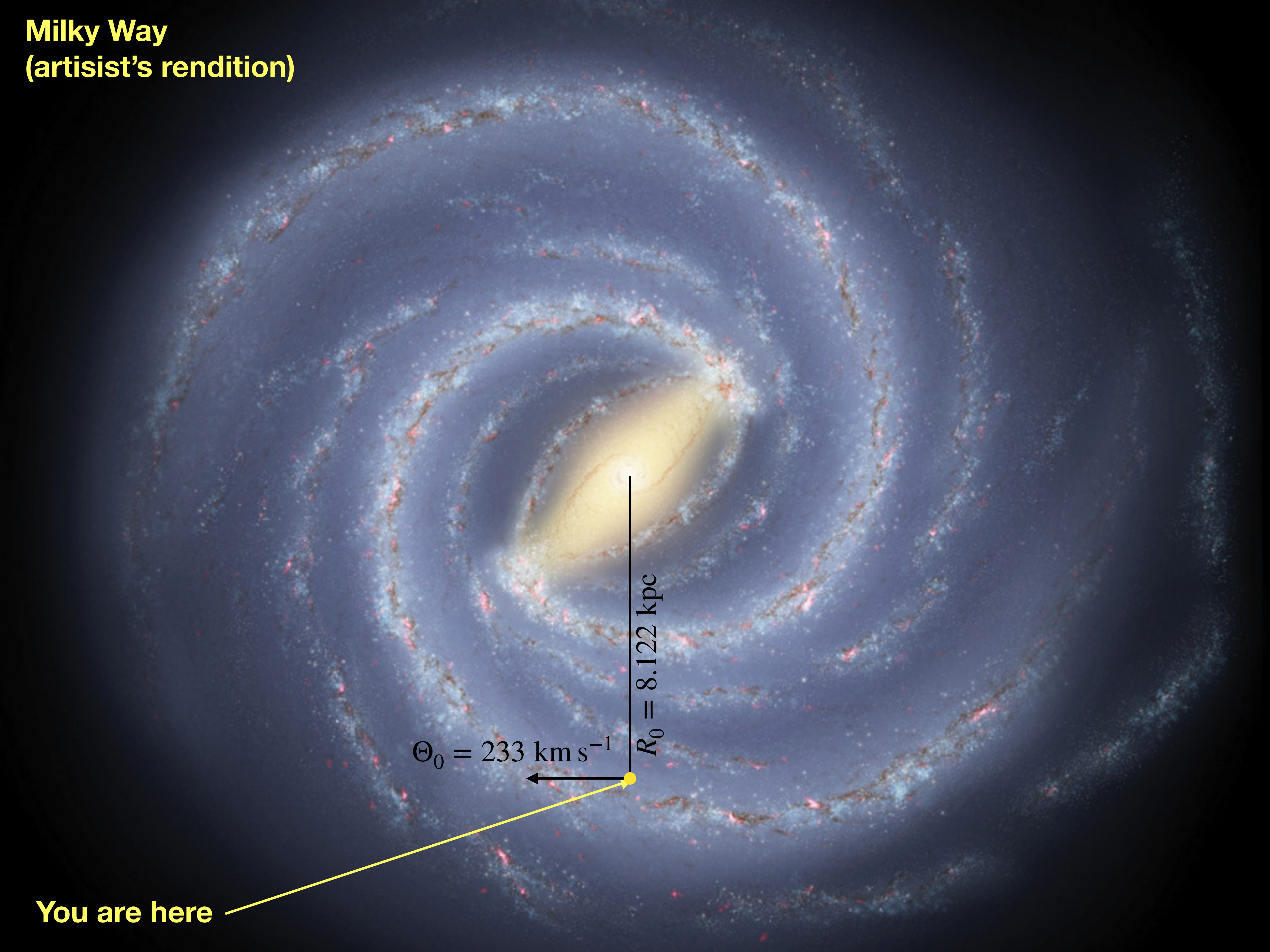
Vertical motion in the Milky Way

the Oort limit

The Bar Instability

Ostriker & Peebles; Sellwood




Milky Way
(artisist’s rendition)
$R_0 = 8.122$ kpc
$\Theta_0 = 233$ km s^{-1}
You are here

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: $\sigma_z^2 \sim 2\pi G \Sigma_0 z_0$

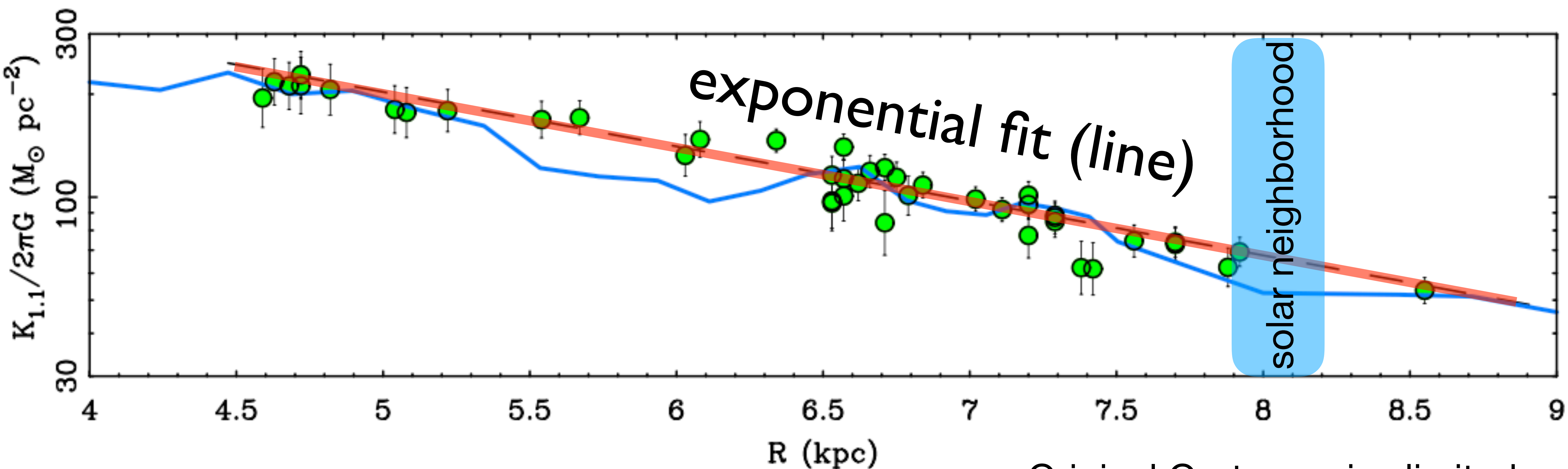
So if we measure velocity dispersions and scale heights for groups of stars, we can measure the mass density of the Galaxy's disk. This was first done in the early 1960s by Jan Oort and is called the **Oort limit**. A recent (and more sophisticated) analysis gives ~ 70 M_{sun}/pc^2.

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?

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



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

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

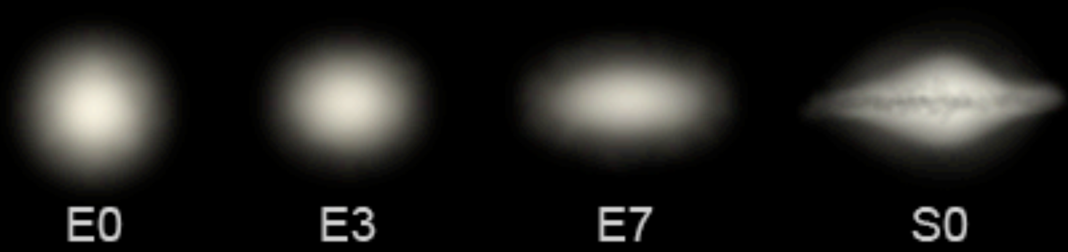
$$\Sigma_\odot = 38\ \mathrm{M_\odot\ pc^{-2}}$$ (stars only)

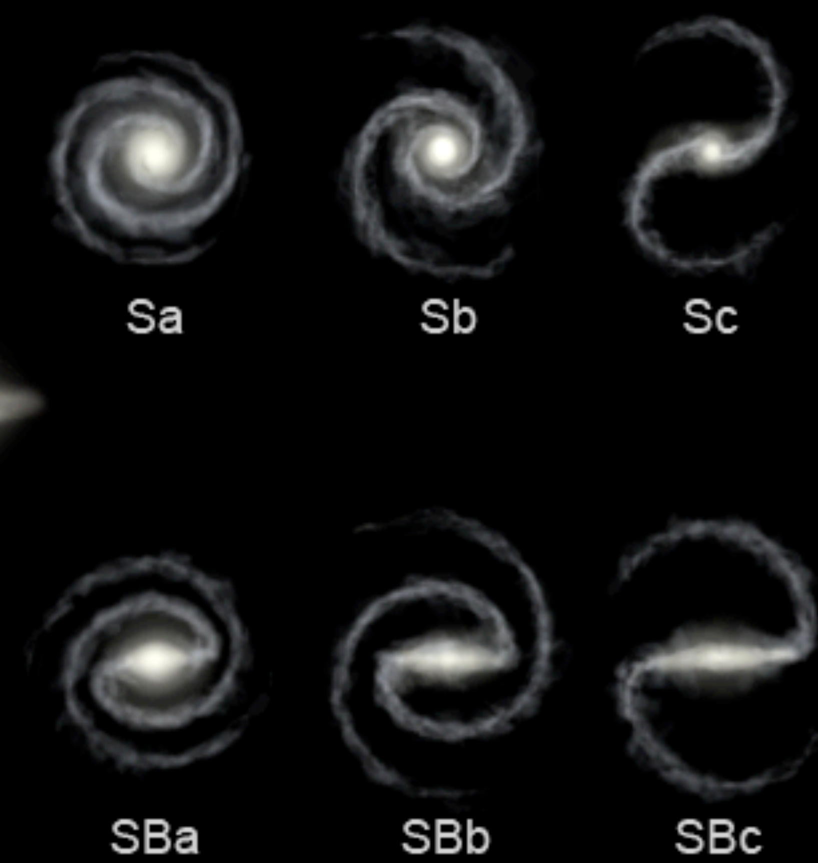
$$R_d = 2.15\ \mathrm{kpc}$$ Bovy & Rix (2013)

Galaxy Morphology
The Hubble Tuning-fork sequence

increasing disk →

← increasing bulge





regular spirals

barred spirals

Ellipticals
(and bulges)
3D ellipsoids
pressure support
V/σ small

Spirals
2D disks
rotational support
V/σ large

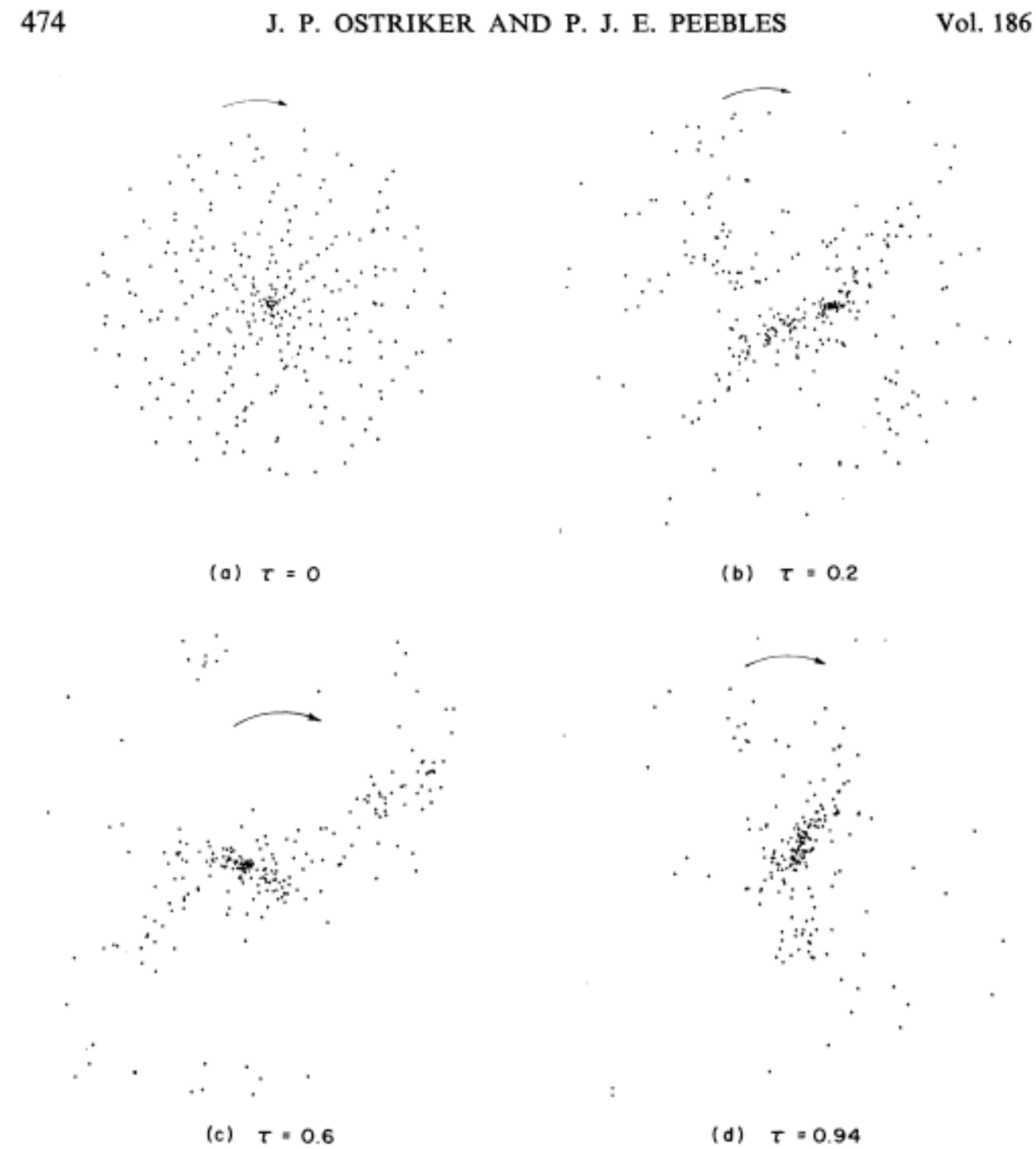
NGC 628: a spiral galaxy

NGC 1300: a barred spiral galaxy

The Bar Instability

Spiral disks unstable to the development of m=2 bar modes.

Left to themselves, spiral disks fall apart in just a few dynamical times (< 1 Gyr for the Milky Way).



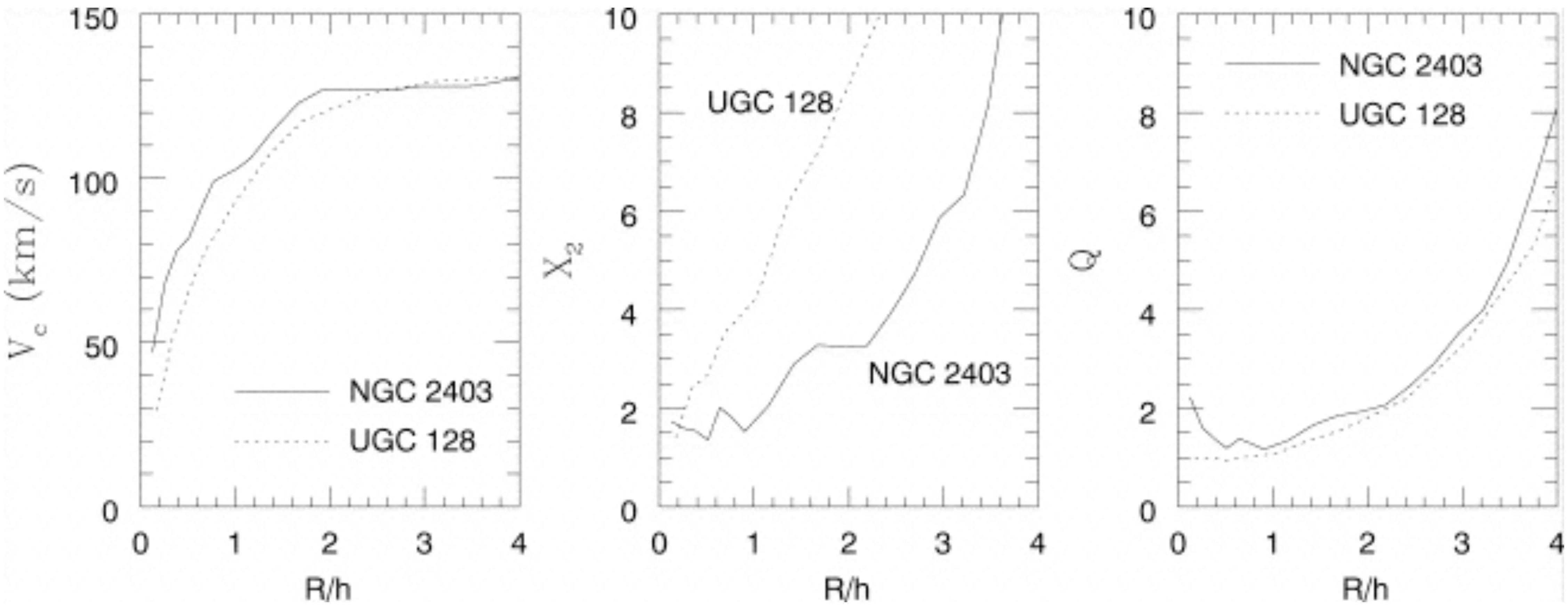
Ostriker & Peebles (1973)

Sellwood (2016)

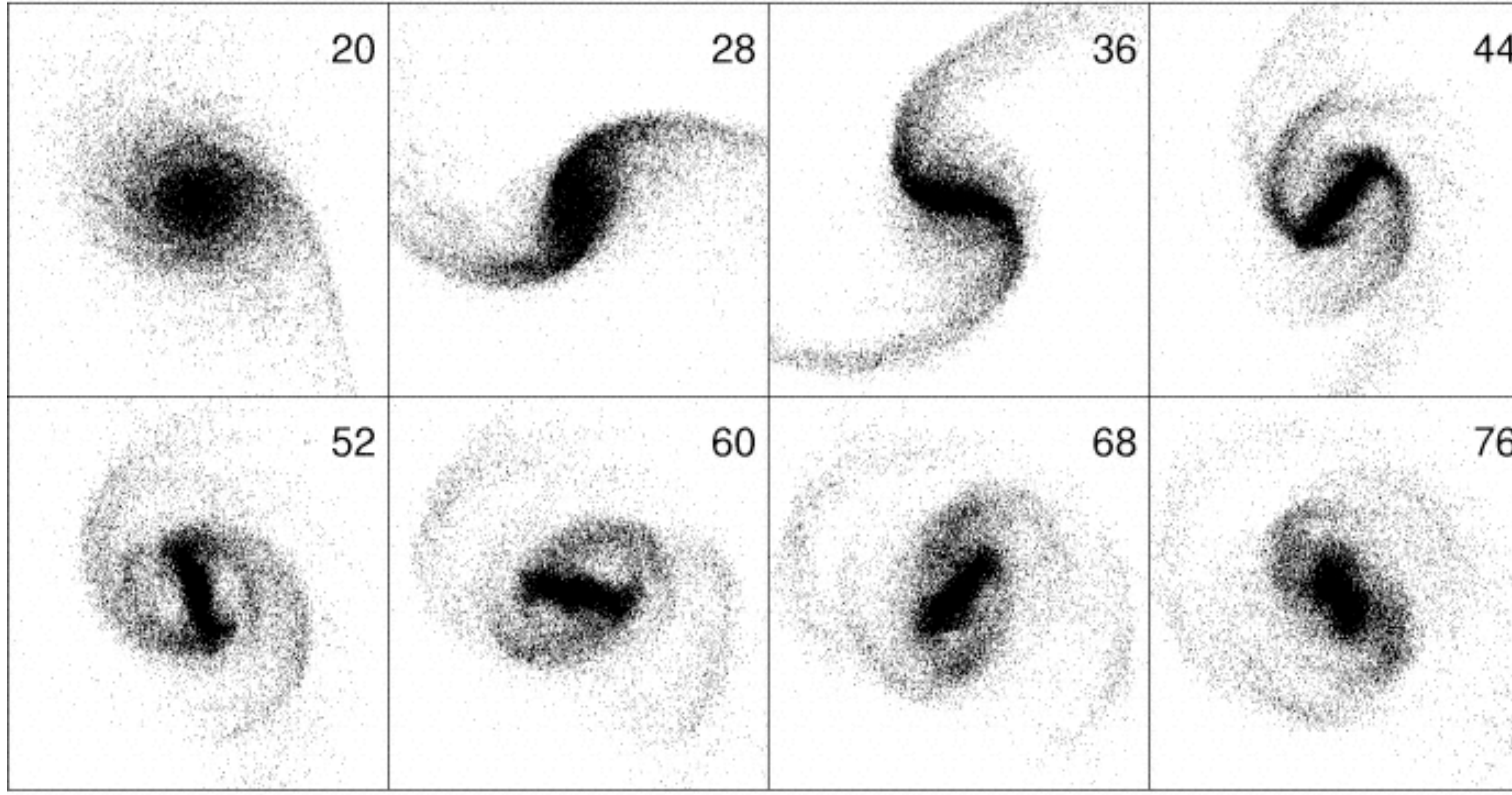
http://burro.astr.cwru.edu/Academics/Astr222/Galaxies/Spiral/nohalo.mpg

http://burro.astr.cwru.edu/Academics/Astr222/Galaxies/Spiral/halo.mpg

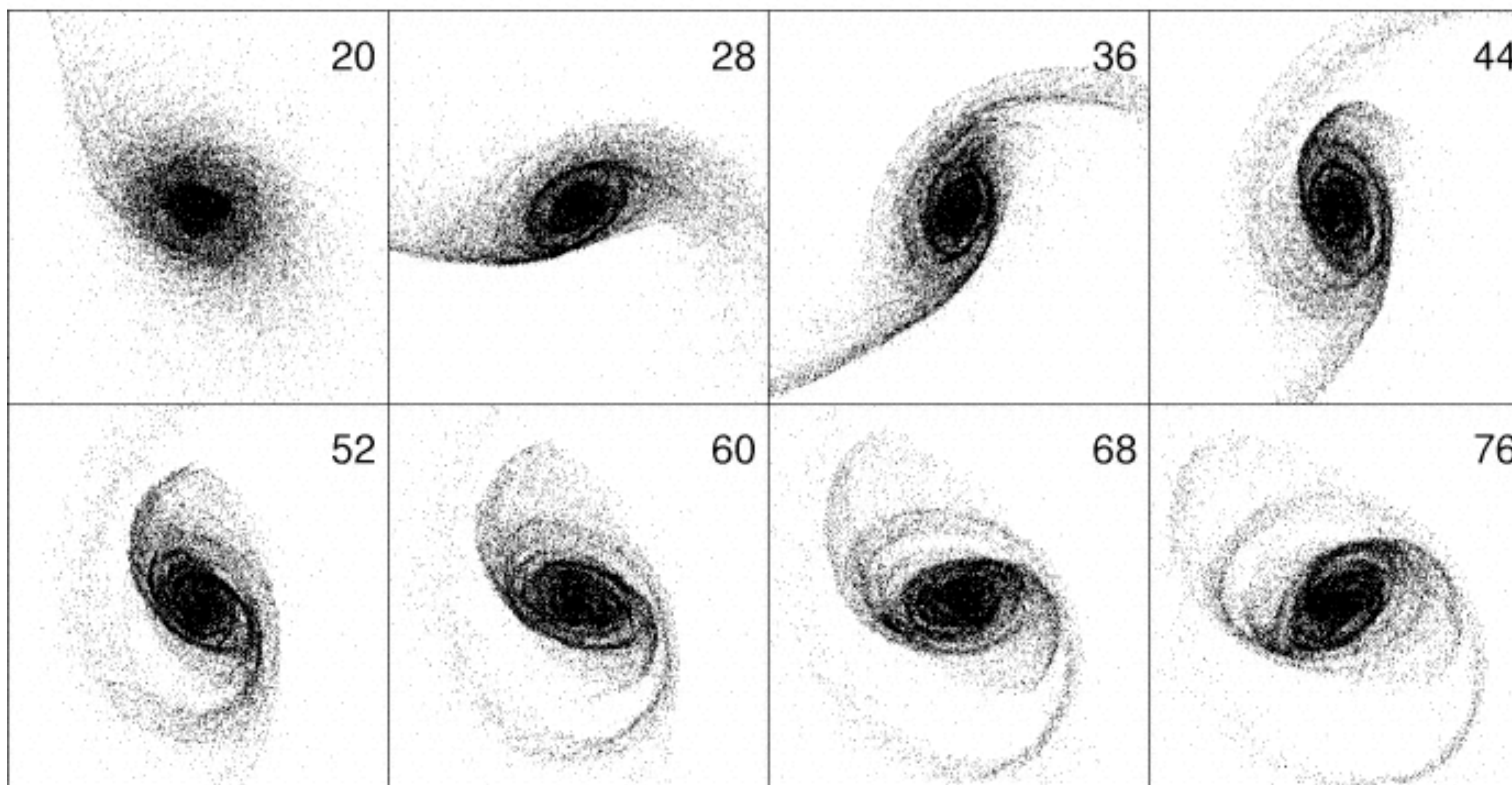
NGC 2403: high surface brightness
UGC 128: low surface brightness



High surface density



Low surface density

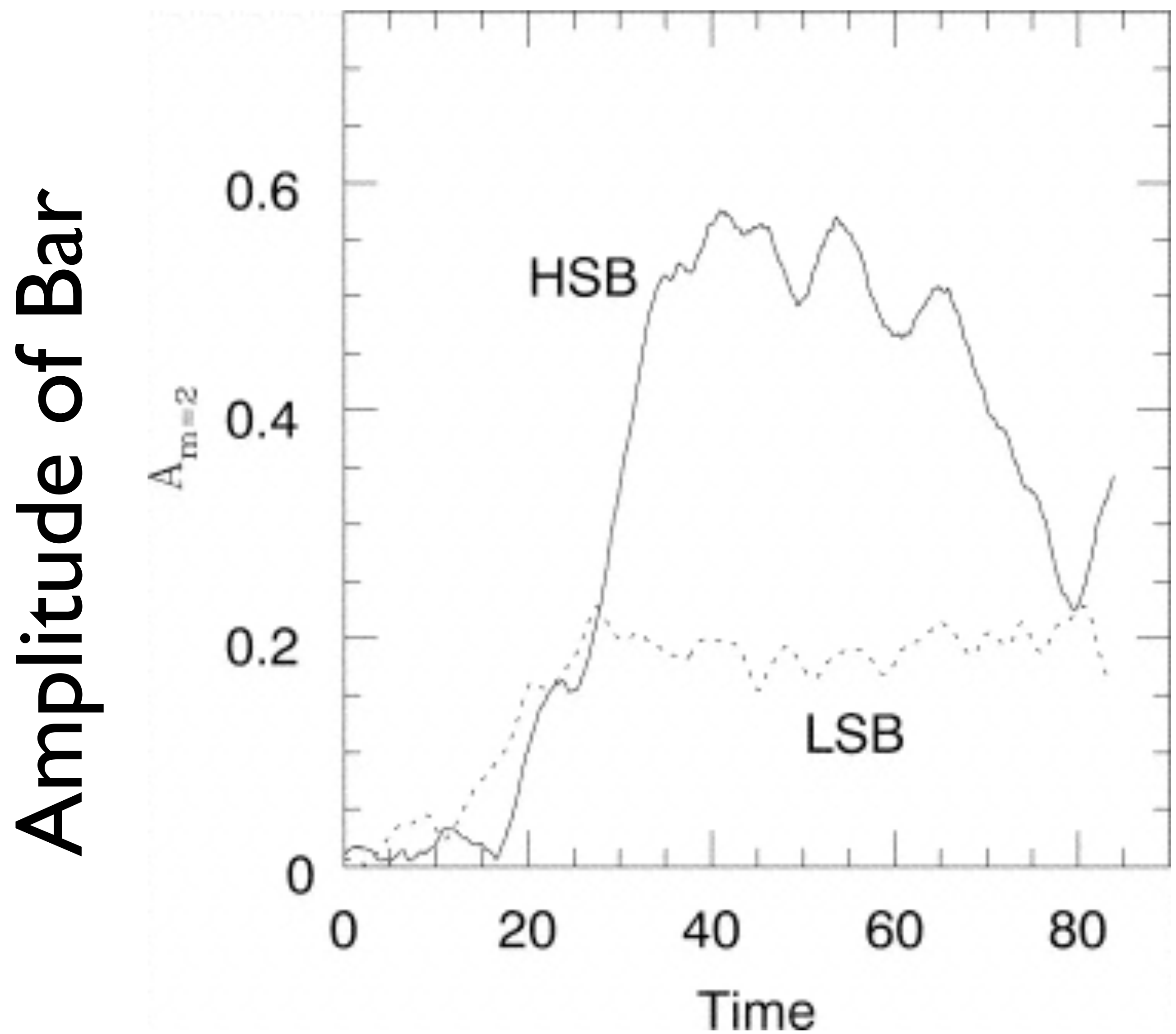


$$A_m = \frac{1}{N}\sum_{j=1}^{N} e^{i[m\theta_j + p\ln(R_j)]}$$

A bar is an m=2 mode

A two-armed spiral is an m=2 mode with a pitch angle p > 0.

A four armed-spiral has m=4, etc.



https://www.youtube.com/watch?v=gSwiXwP56js

http://www.youtube.com/watch?v=byI9yhITDsM

Sellwood (2016)

Time evolution of the bar amplitude in models with differing $\frac{M_{halo}}{M_{disk}}$