DARK MATTER

ASTR 333/433

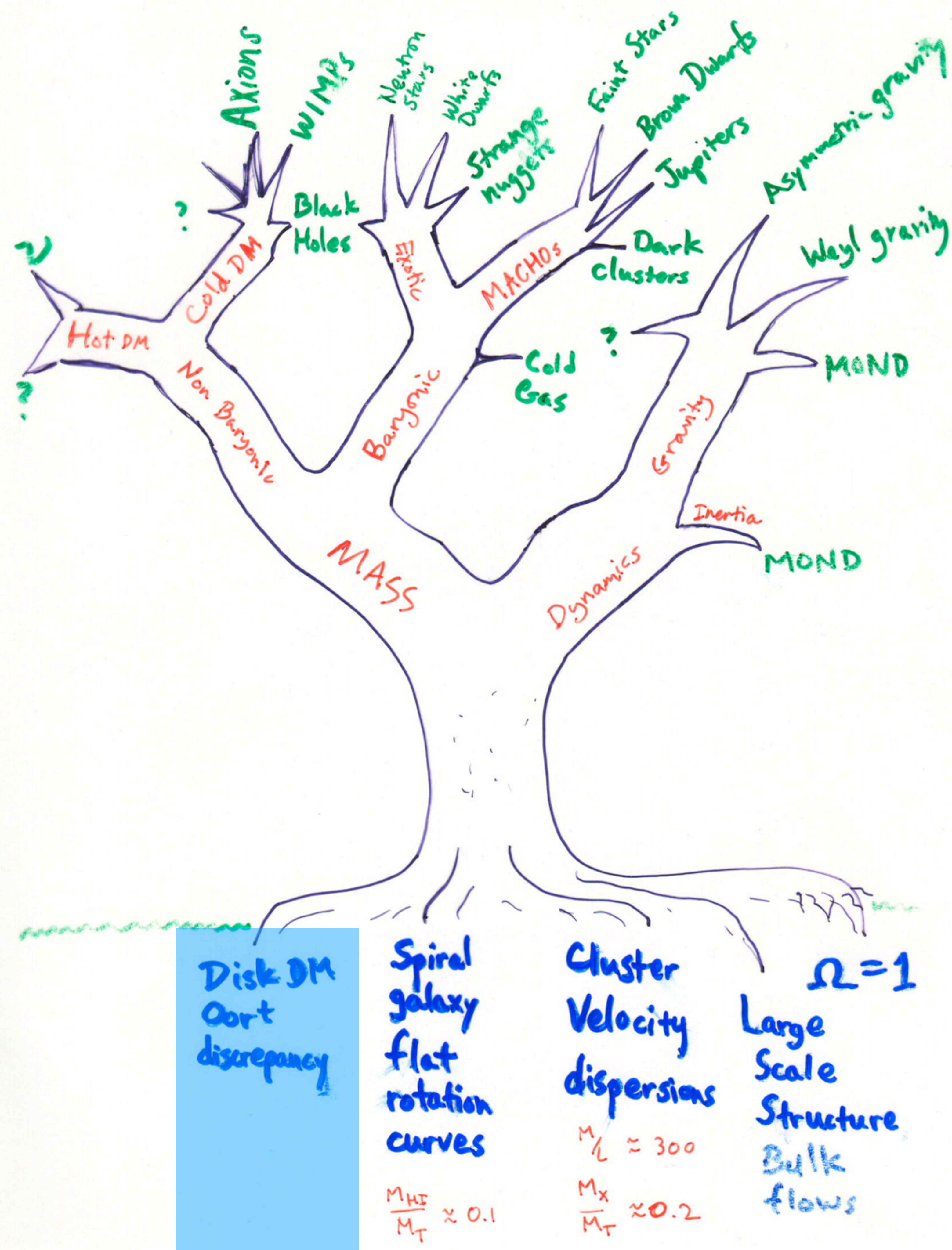
<u>TODAY</u>

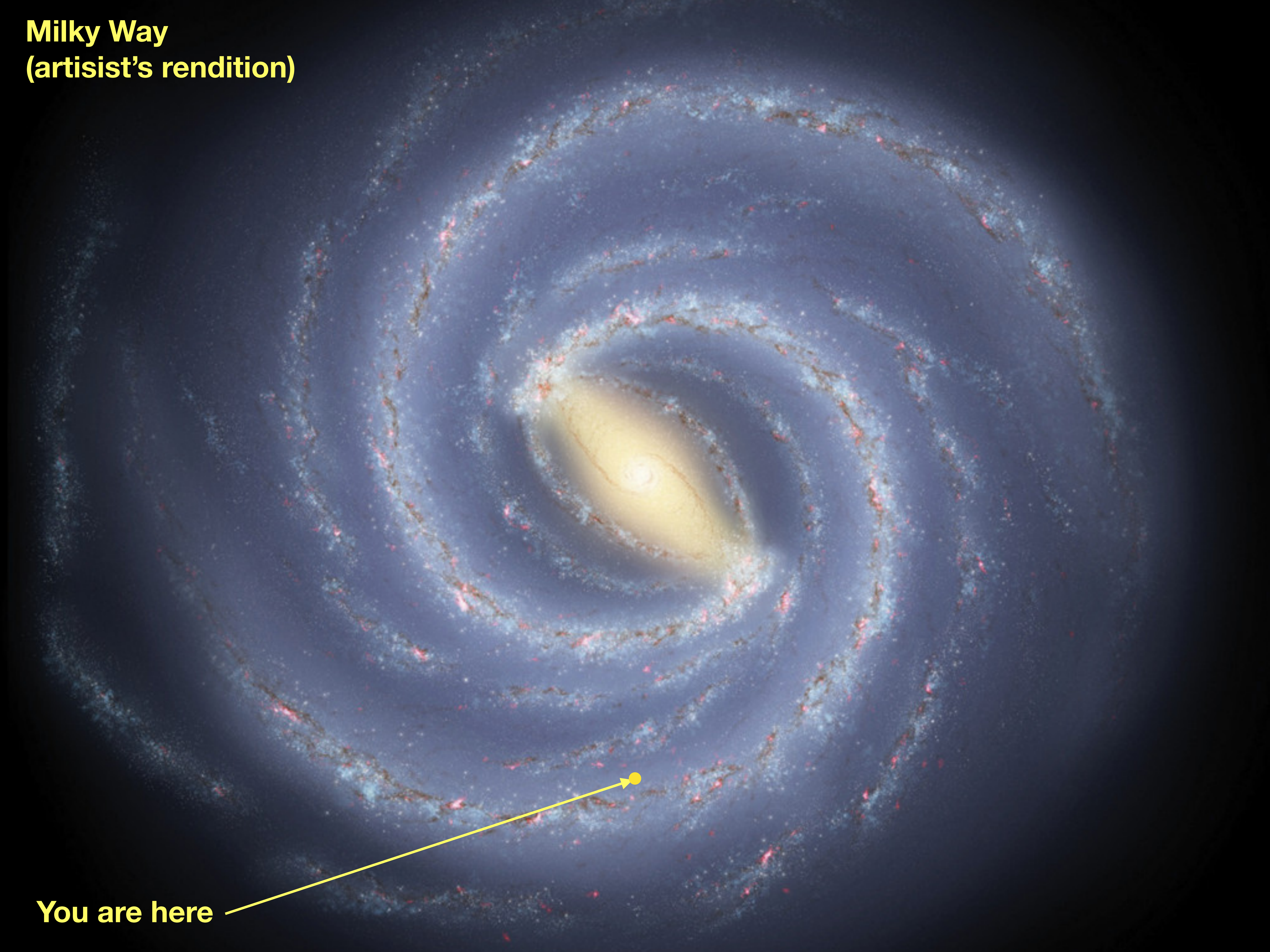
Contents of the Milky Way

the Oort limit

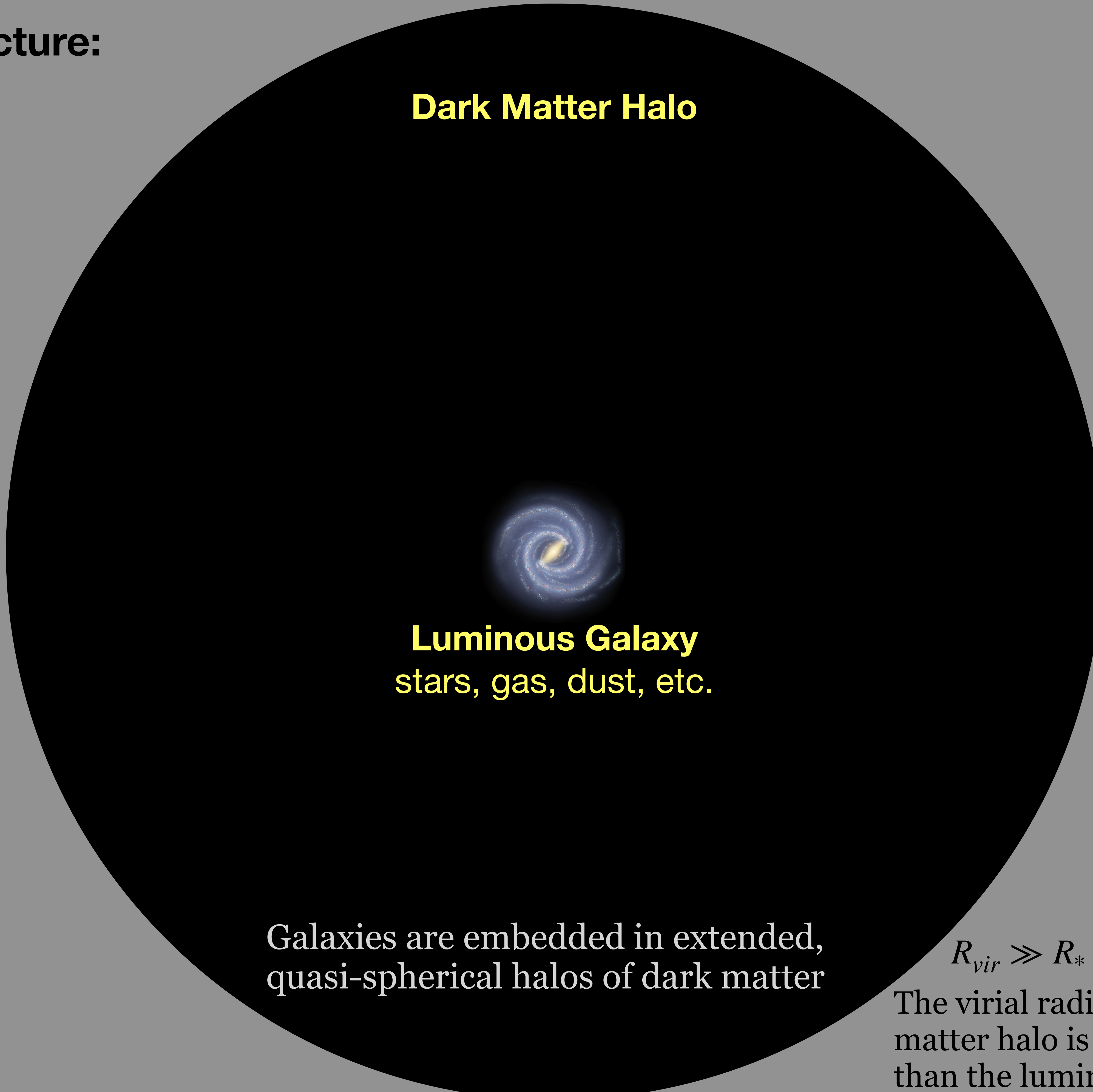
The Bar Instability

Ostriker & Peebles; Sellwood




Milky Way
(artisist’s rendition)
You are here

Basic Picture:



$R_{vir} \gg R_*$

The virial radius of the dark matter halo is much larger than the luminous galaxy

Cylindrical coordinates

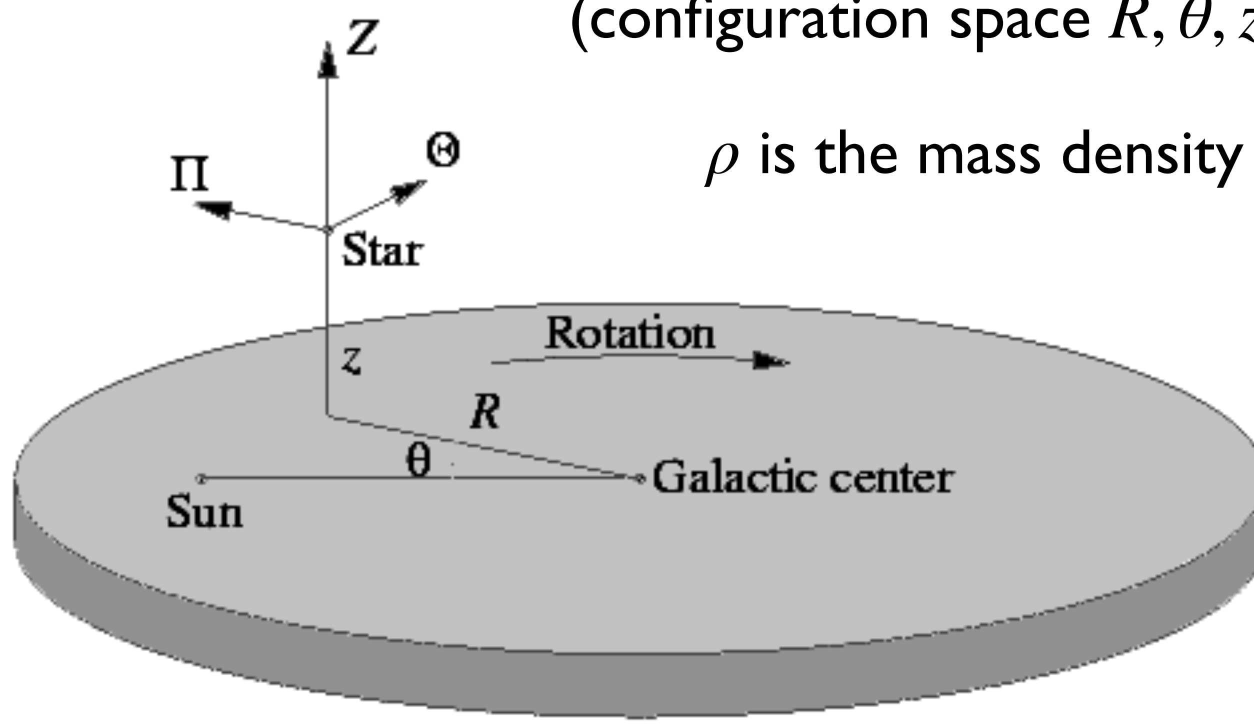
Poisson equation: $\nabla^2\Phi = 4\pi G\rho$

in cylindrical coordinates $\nabla^2\Phi = \frac{1}{R}\frac{\partial}{\partial R}\left(R\frac{\partial\Phi}{\partial R}\right) + \frac{1}{R^2}\frac{\partial^2\Phi}{\partial\theta^2} + \frac{\partial^2\Phi}{\partial z^2}$

Let's define a coordinate system:
Galactocentric cylindrical coordinates

We wish to extract the gravitational potential Φ from observations of the 6D phase space of stars (configuration space R, θ, z; momentum Π, Θ, Z)

ρ is the mass density (including dark matter)



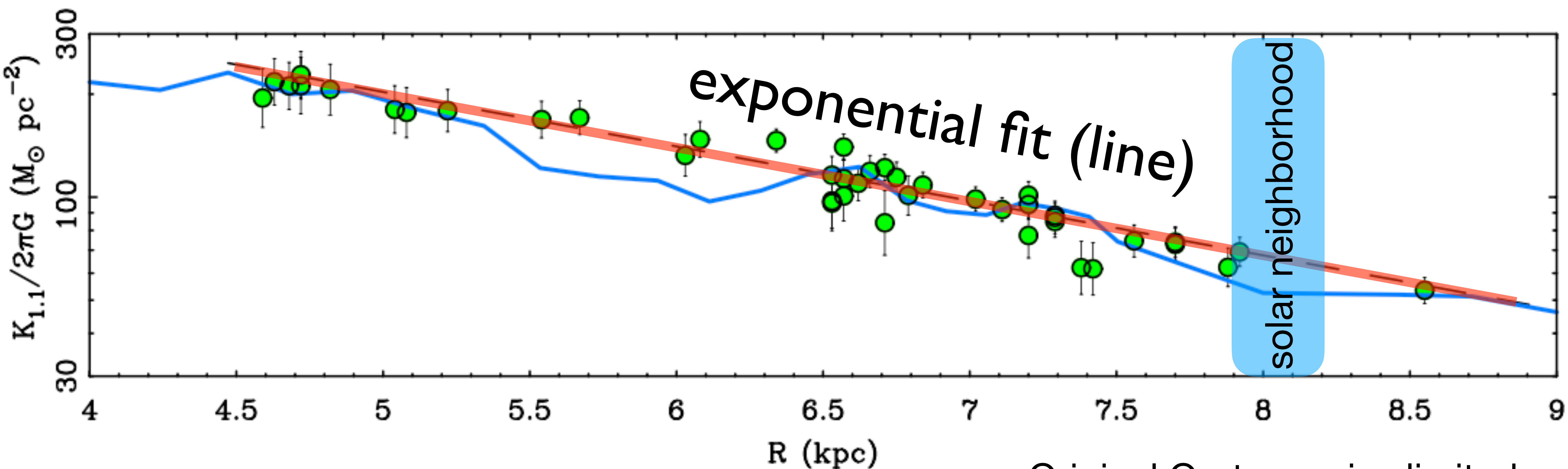
$$\text{Position} : (R, \theta, z) \quad \text{Velocity} : (\Pi, \Theta, Z)$$

- 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 Cartesian (X,Y,Z; U,V,W) centered on either the sun or the Galactic Center.

Assuming axial symmetry and that $\Phi(R, z)$ is separable, the vertical force is $$K_Z = 2\pi G\Sigma + \frac{Z}{R}\frac{\partial V^2}{\partial R}$$



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

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

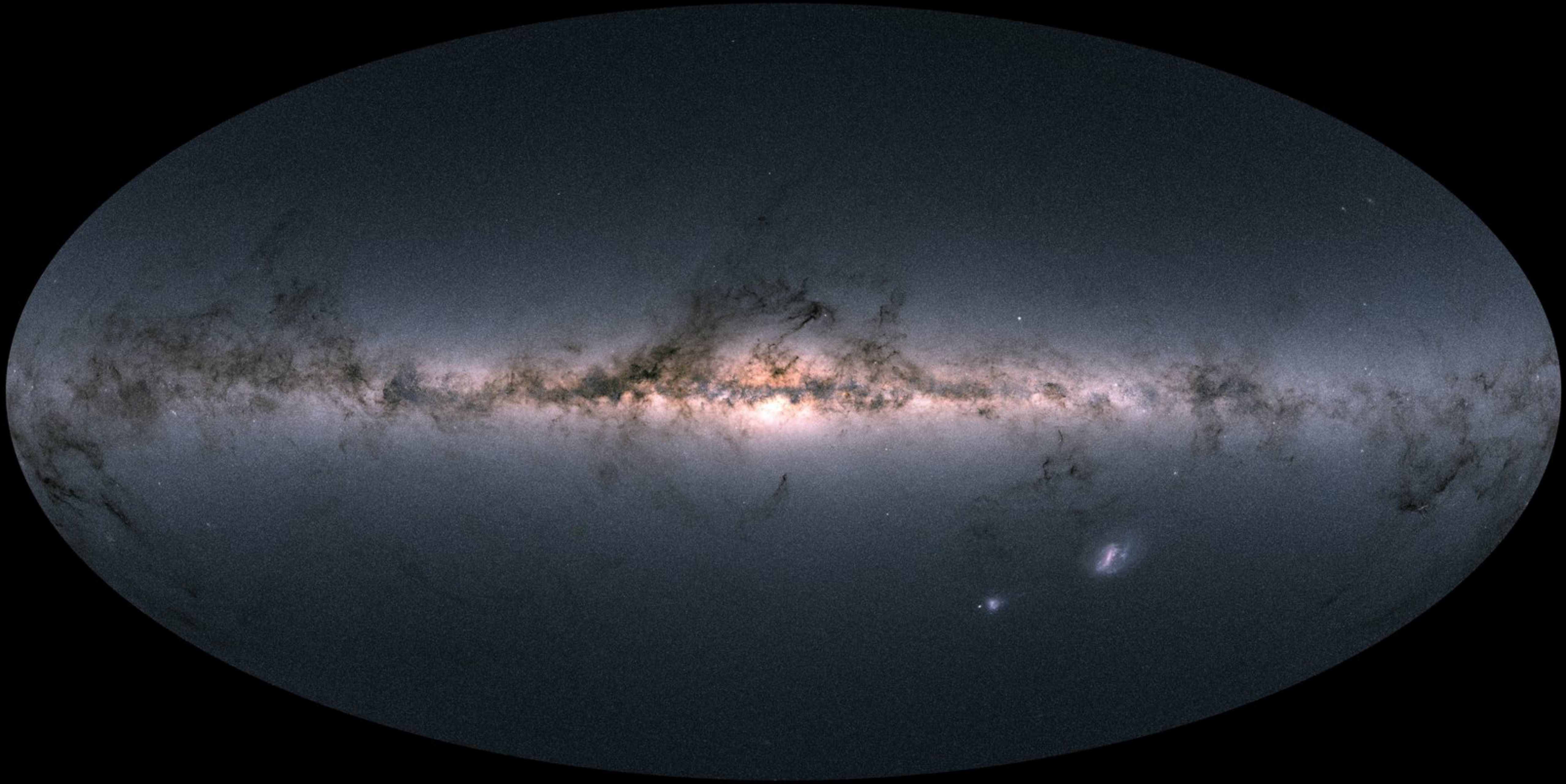
$$\Sigma_\odot = 38\ \mathrm{M}_\odot\,\mathrm{pc}^{-2}$$ (stars only)

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

Continues to improve with surveys like Gaia and APOGEE, e.g.,

Price-Whelan et al. (2021, ApJ, 910, 17)
Eilers et al. (2019, ApJ, 871, 120)
McGaugh (2019, ApJ, 885, 87)

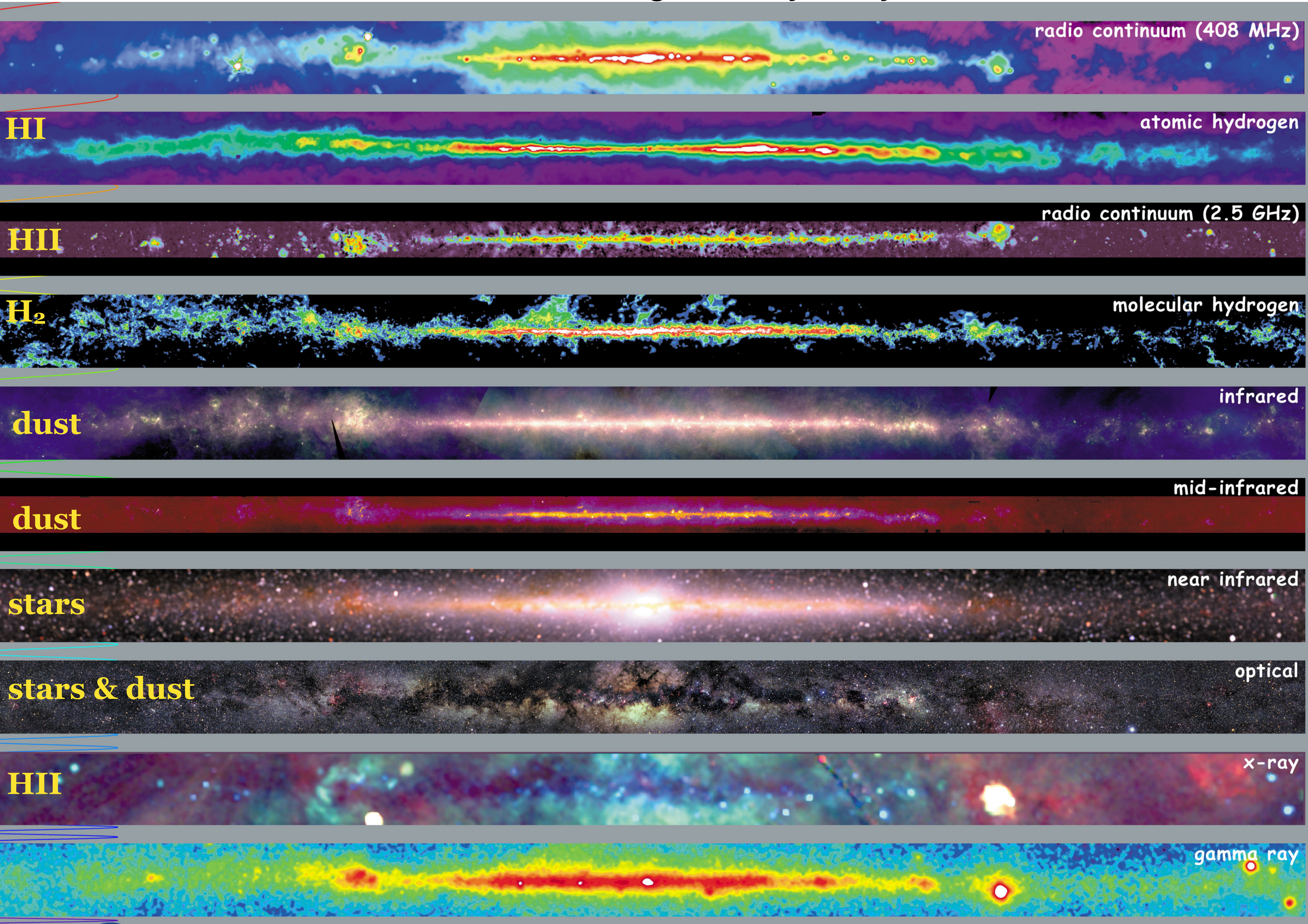
Milky Way in the optical (Gaia data)



Baryonic Content of Galaxies

- **Stars**
  - Majority of baryonic mass in bright galaxies
- **Gas**
  - *Atomic gas* - H I
    - traced by 21 cm line Majority of baryonic mass in faint galaxies
  - *Molecular gas* - H_2
    - traced by CO Mass usually a distant third to stars and atomic gas
  - *Ionized gas* - H II
    - traced by Hα Large volume but little mass where stars are; there might be a lot out to the virial radius.
- **Dust**
  - little mass, but it does get in the way.

Multi-wavelength Milky Way

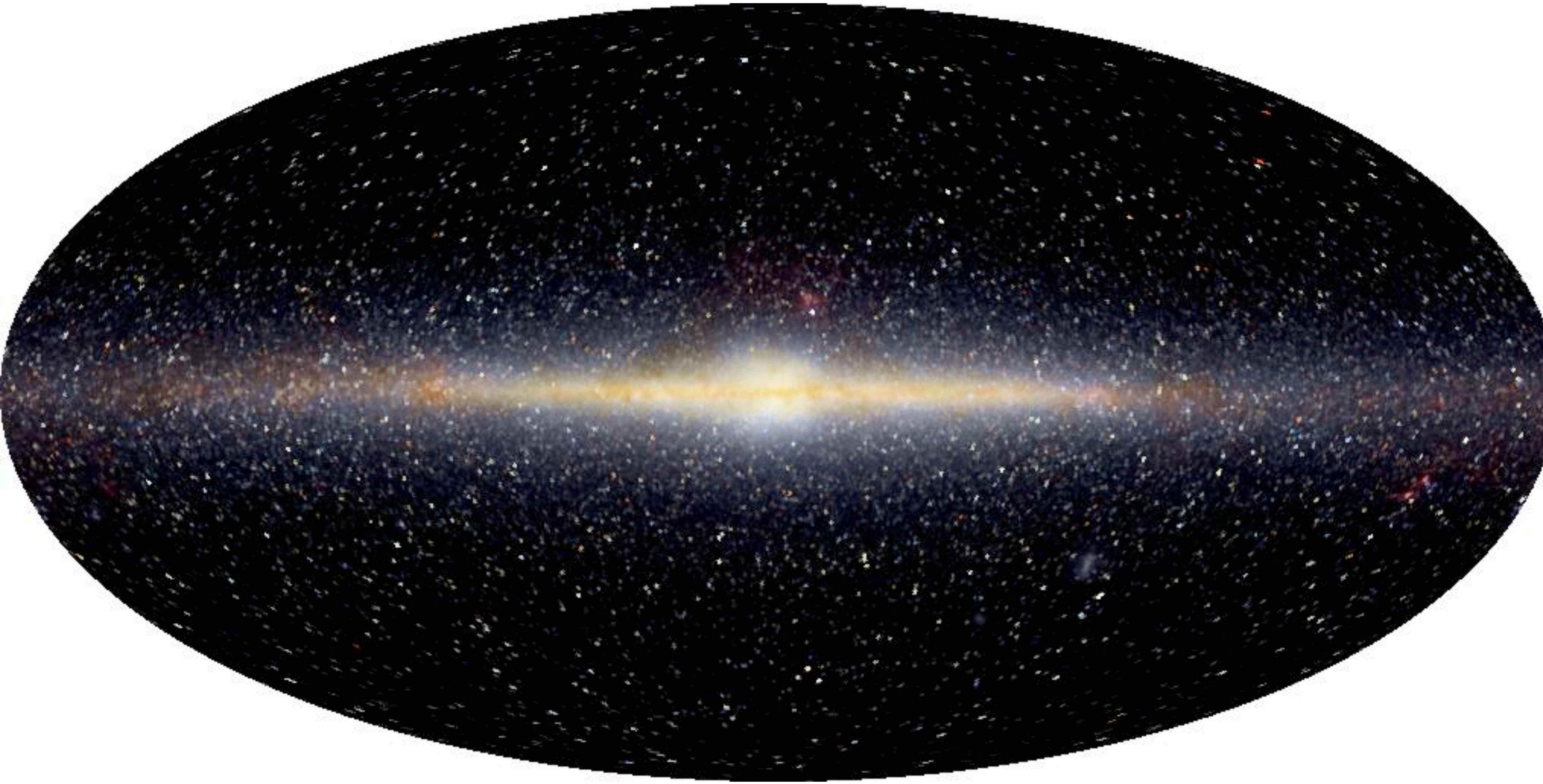


Disk Stability

NGC 628: a spiral galaxy

NGC 1300: a barred spiral galaxy

The Milky Way is a barred spiral



Peanut-shaped bulge is the signature of a bar seen edge-on.
Our viewing angle is 20 - 30^{o} from the major axis of the bar.

The Bar Instability

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

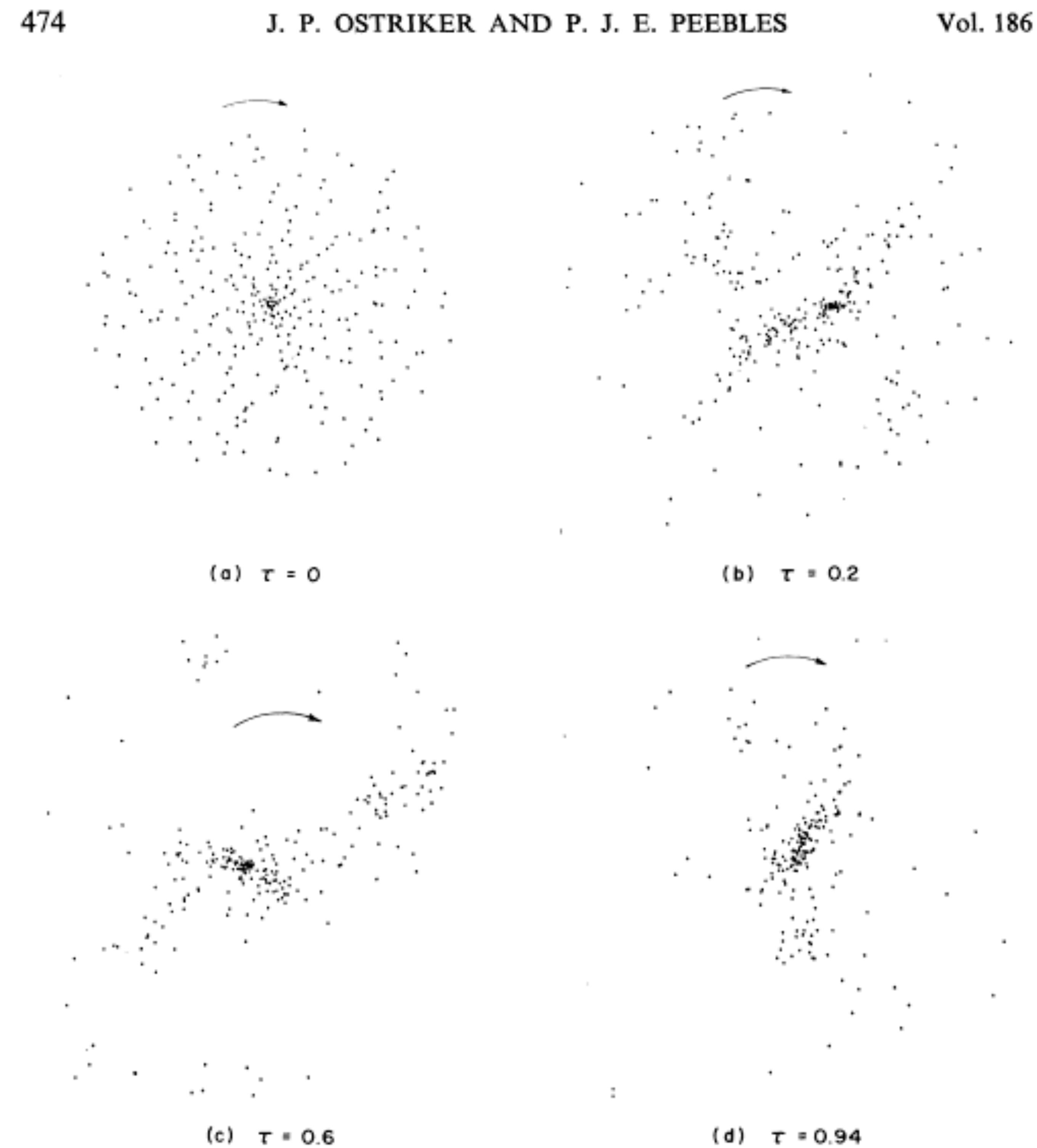
Left to themselves, spiral disks fall apart in just a few dynamical times (< 1 Gyr for the Milky Way).

Cold disks are unstable if left to themselves, So Ostriker & Peebles suggested embedding them in dark matter halos.

By “cold” we mean that ordered rotation exceeds random motions: $V \gg \sigma$.

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

Sellwood (2016)

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