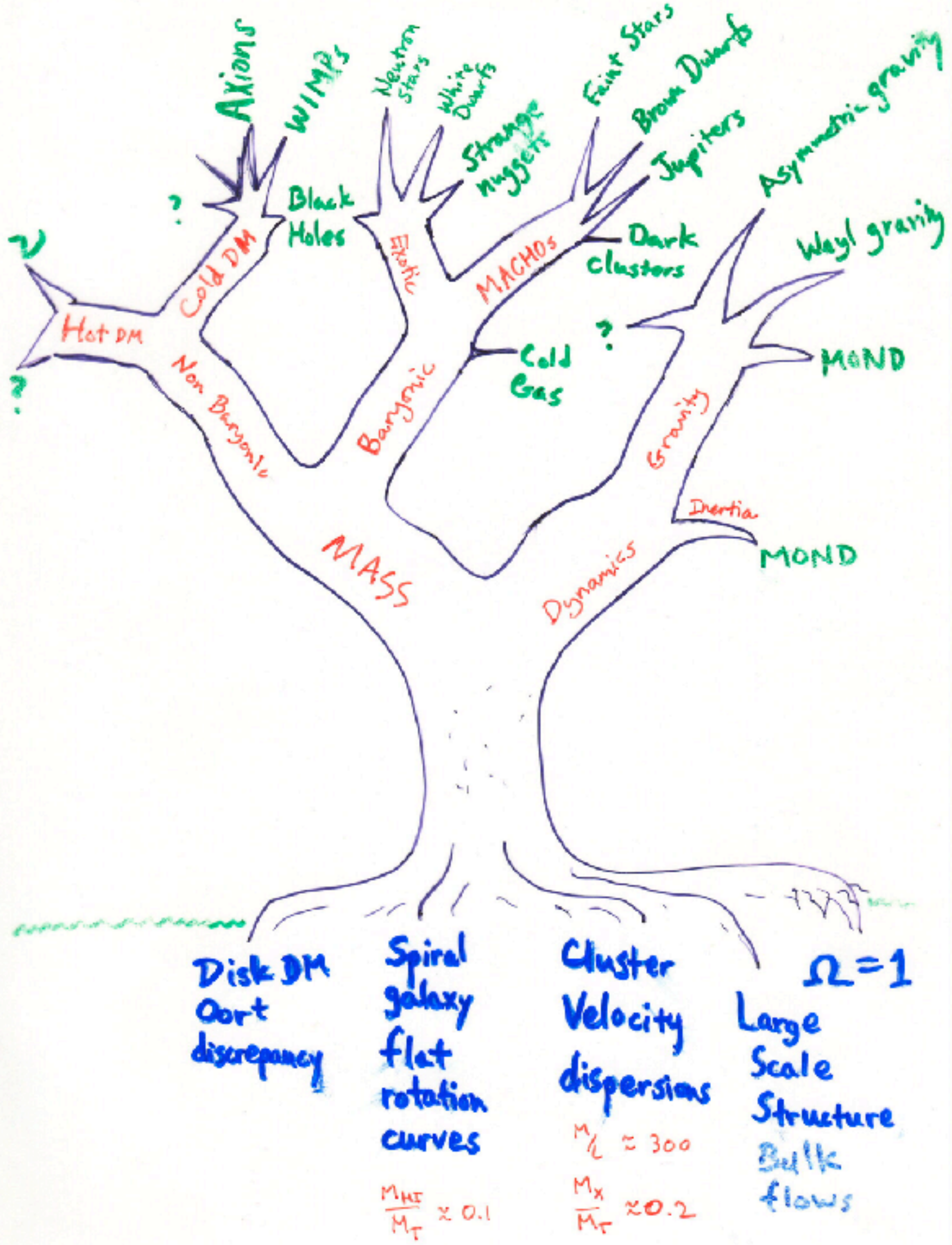
DARK MATTER

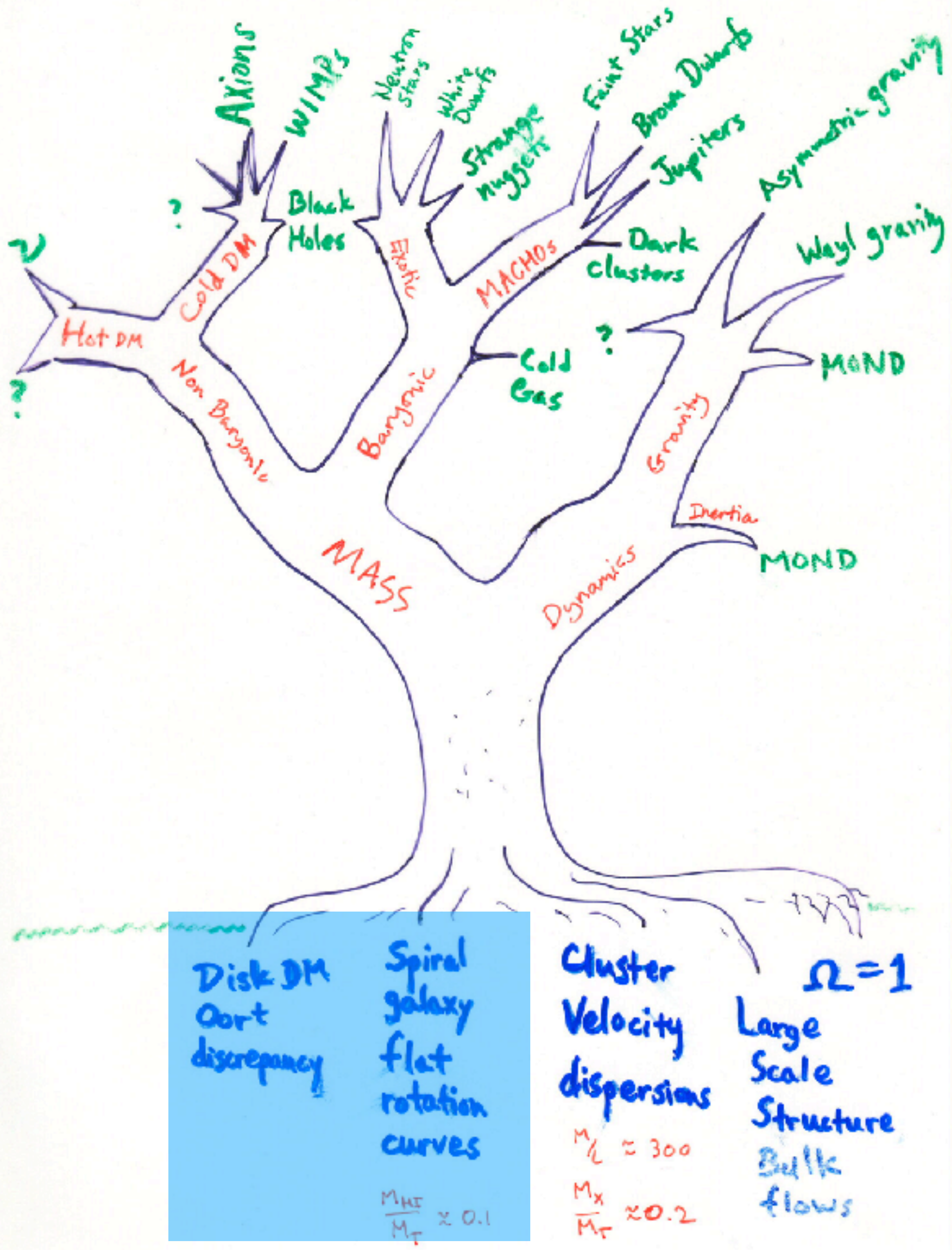
ASTR 333/433
SPRING 2016
T R 4:00-5:15PM
SEARS 552

TODAY

THE BAR INSTABILITY
GALAXY STRUCTURE
STELLAR POPULATIONS

Homework 1
posted on course web page
DUE 8 February





Disk Stability

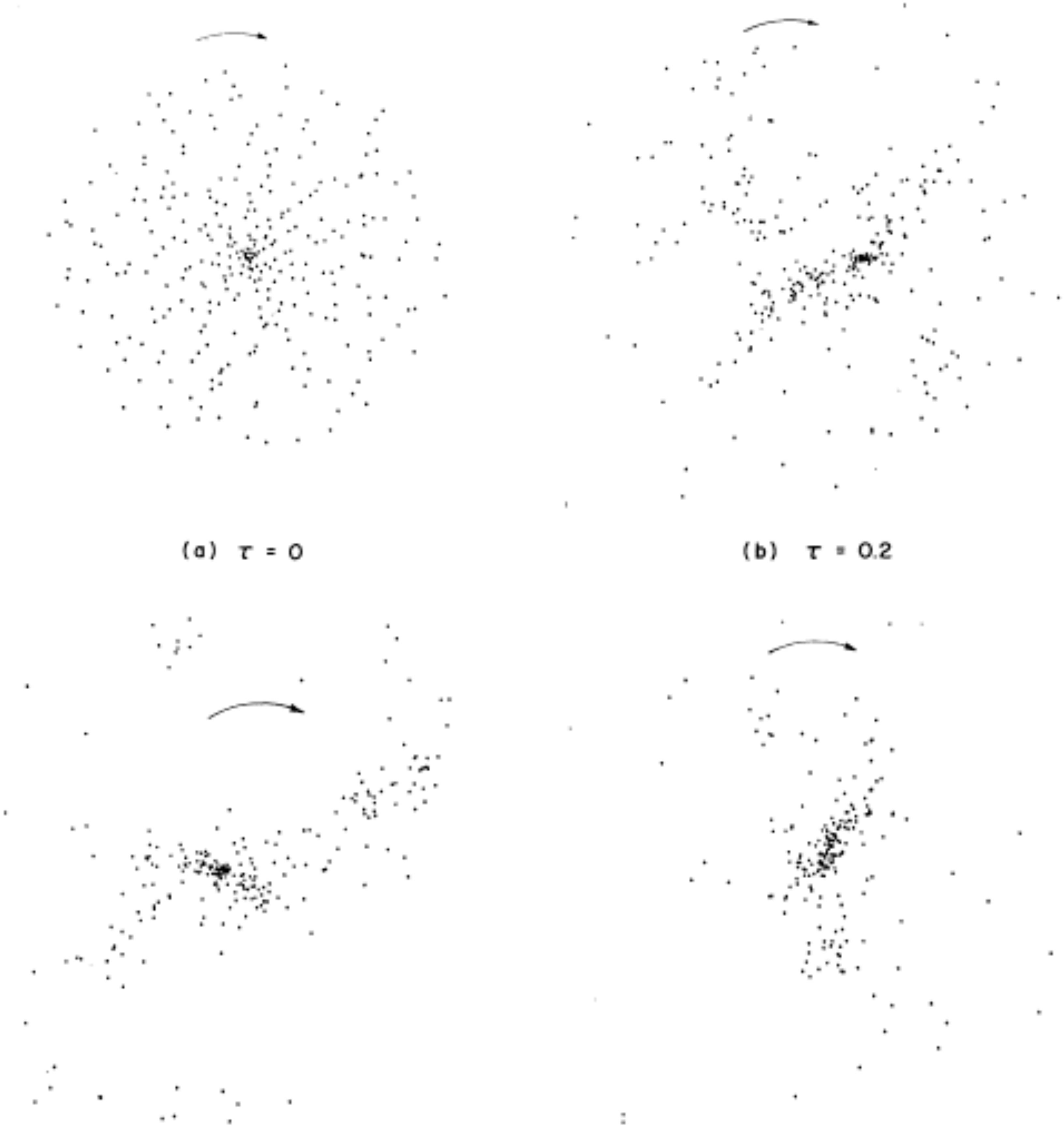
the Ostriker & Peebles
bar instability (etc.)

NGC 1300: a barred spiral galaxy

Exposing the Milky Way's "X"


FROM NASA/JPL-CALTECH/D.LANG

Observation – Simulation = "X" Leftovers



(a) $\tau = 0$

(b) $\tau = 0.2$

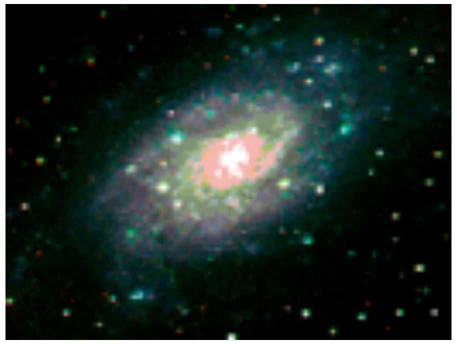
(c) $\tau = 0.6$

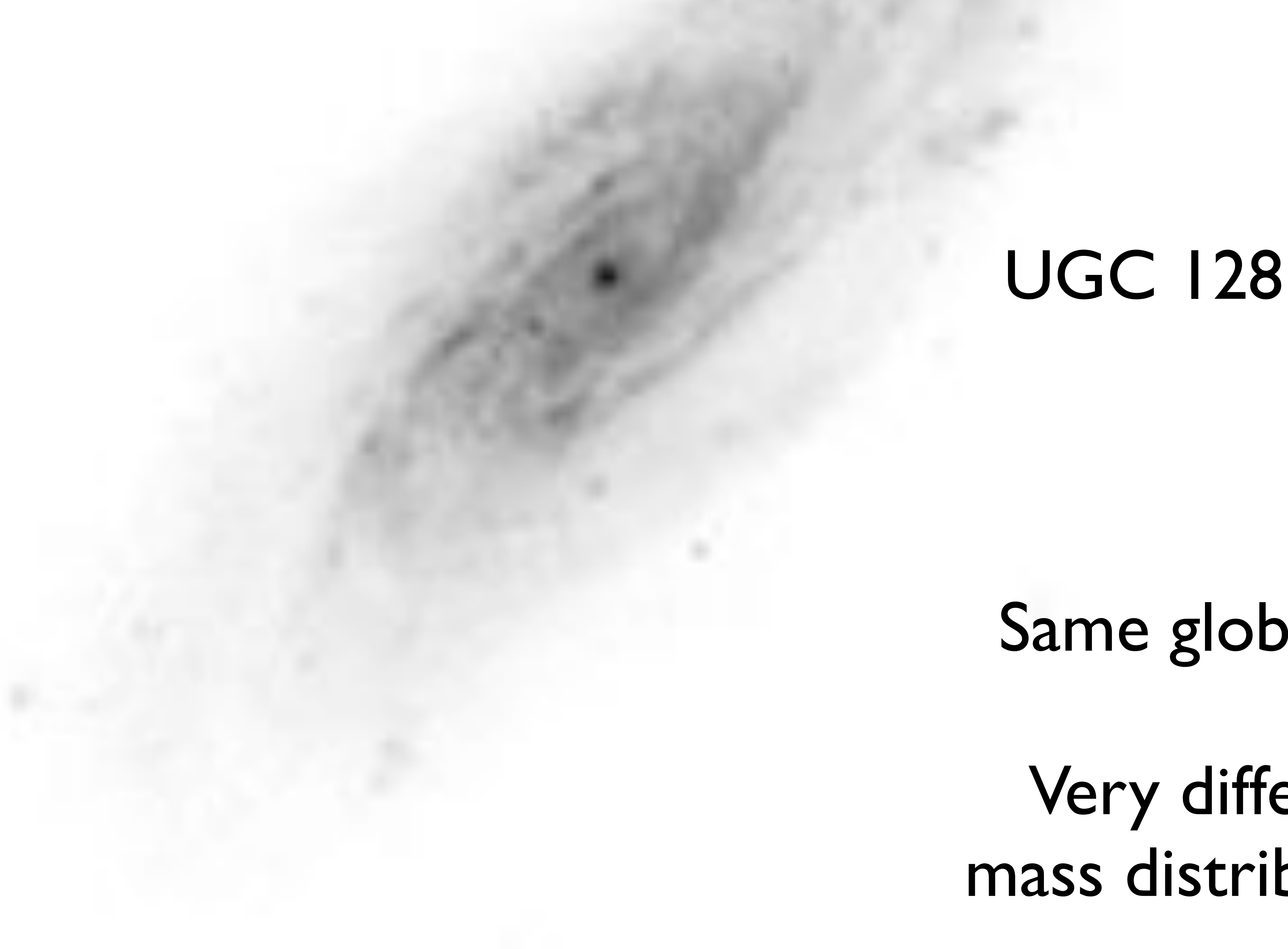
(d) $\tau = 0.94$

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

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

NGC 2403



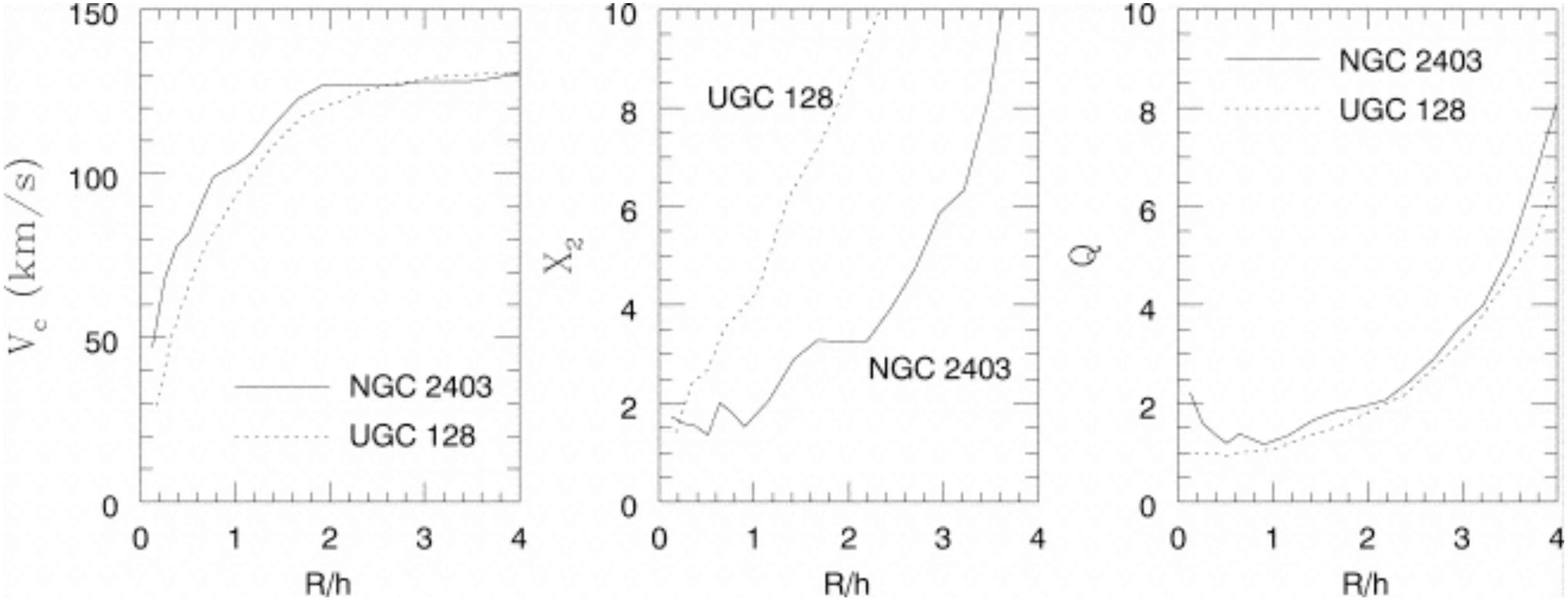


UGC 128

Same global L,V

Very different
mass distributions

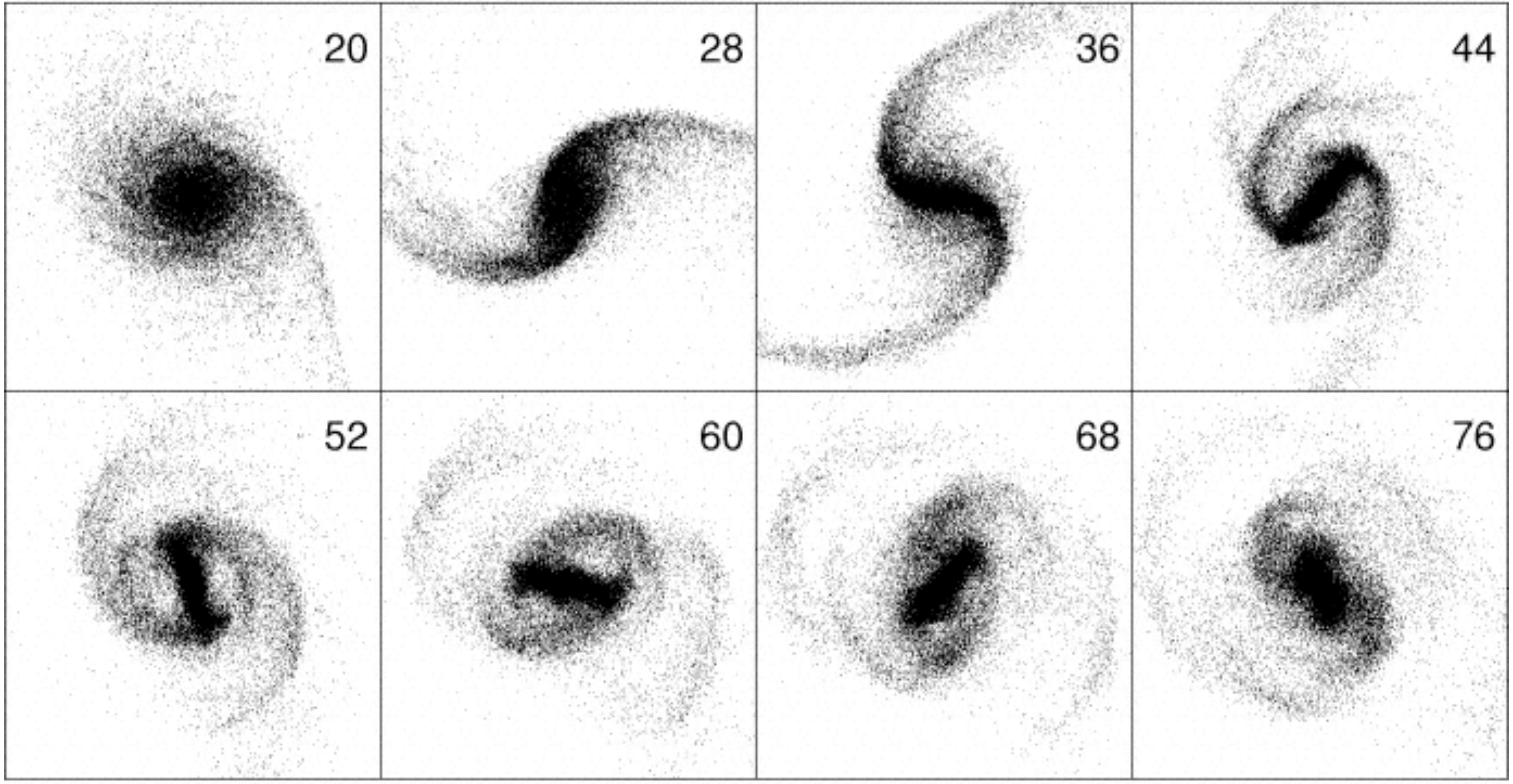
NGC 2403: high surface brightness
UGC 128: low surface brightness



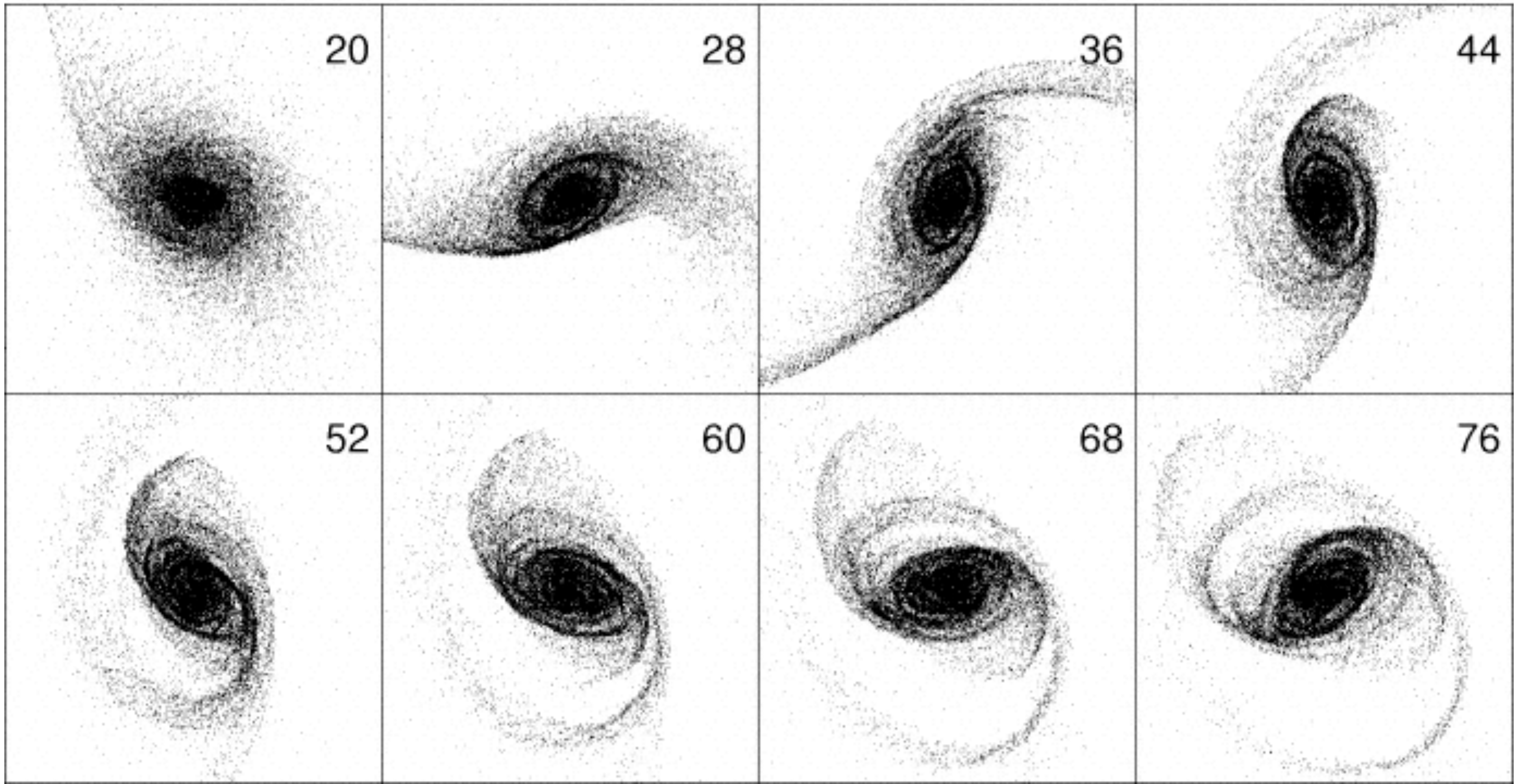
Same rotation curve when radius normalized by scale length

LSB looks more fragile but should be more stable against bar formation because of low surface density

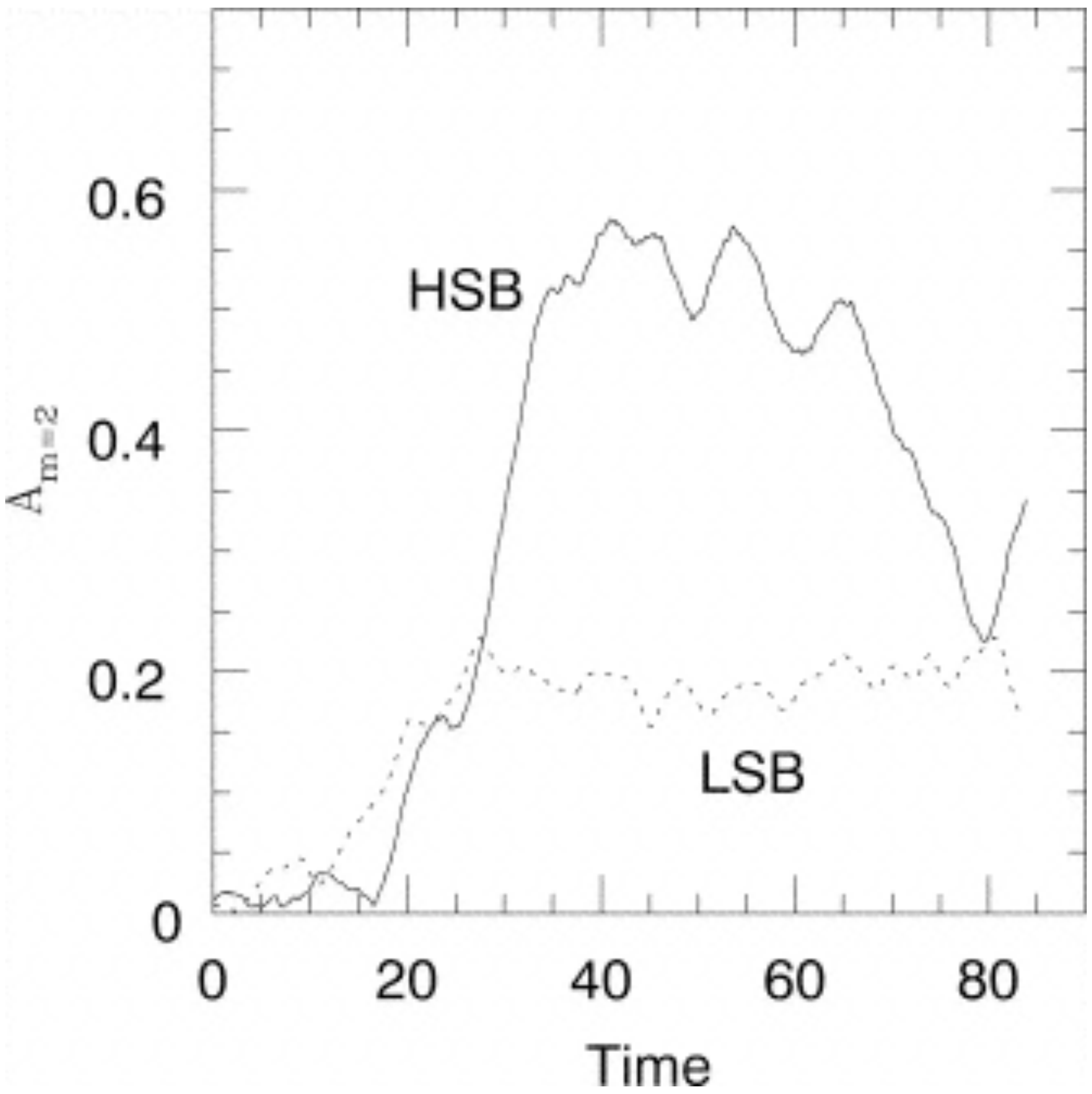
High surface density



Low surface density



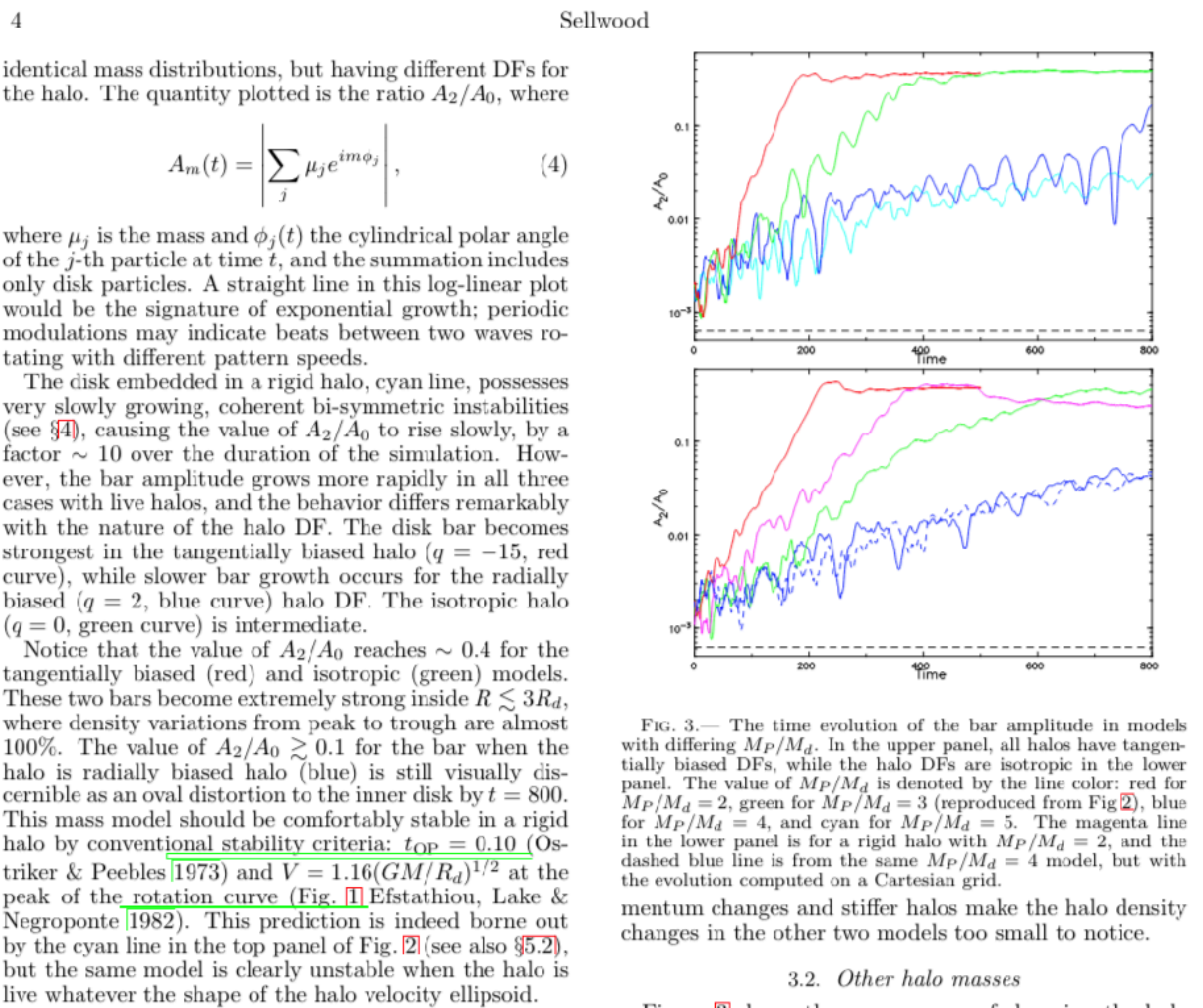
Amplitude of Bar



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

Sellwood (2016) finds that “live” halos *encourage* bar growth

“Live” means dynamically responsive DM particles, not just a fixed background potential



identical mass distributions, but having different DFs for the halo. The quantity plotted is the ratio A_2/A_0, where

$$A_m(t) = \left| \sum_j \mu_j e^{im\phi_j} \right|, \qquad (4)$$

where μ_j is the mass and $\phi_j(t)$ the cylindrical polar angle of the j-th particle at time t, and the summation includes only disk particles. A straight line in this log-linear plot would be the signature of exponential growth; periodic modulations may indicate beats between two waves rotating with different pattern speeds.

The disk embedded in a rigid halo, cyan line, possesses very slowly growing, coherent bi-symmetric instabilities (see §4), causing the value of A_2/A_0 to rise slowly, by a factor $\sim$ 10 over the duration of the simulation. However, the bar amplitude grows more rapidly in all three cases with live halos, and the behavior differs remarkably with the nature of the halo DF. The disk bar becomes strongest in the tangentially biased halo ($q = -15$, red curve), while slower bar growth occurs for the radially biased ($q = 2$, blue curve) halo DF. The isotropic halo ($q = 0$, green curve) is intermediate.

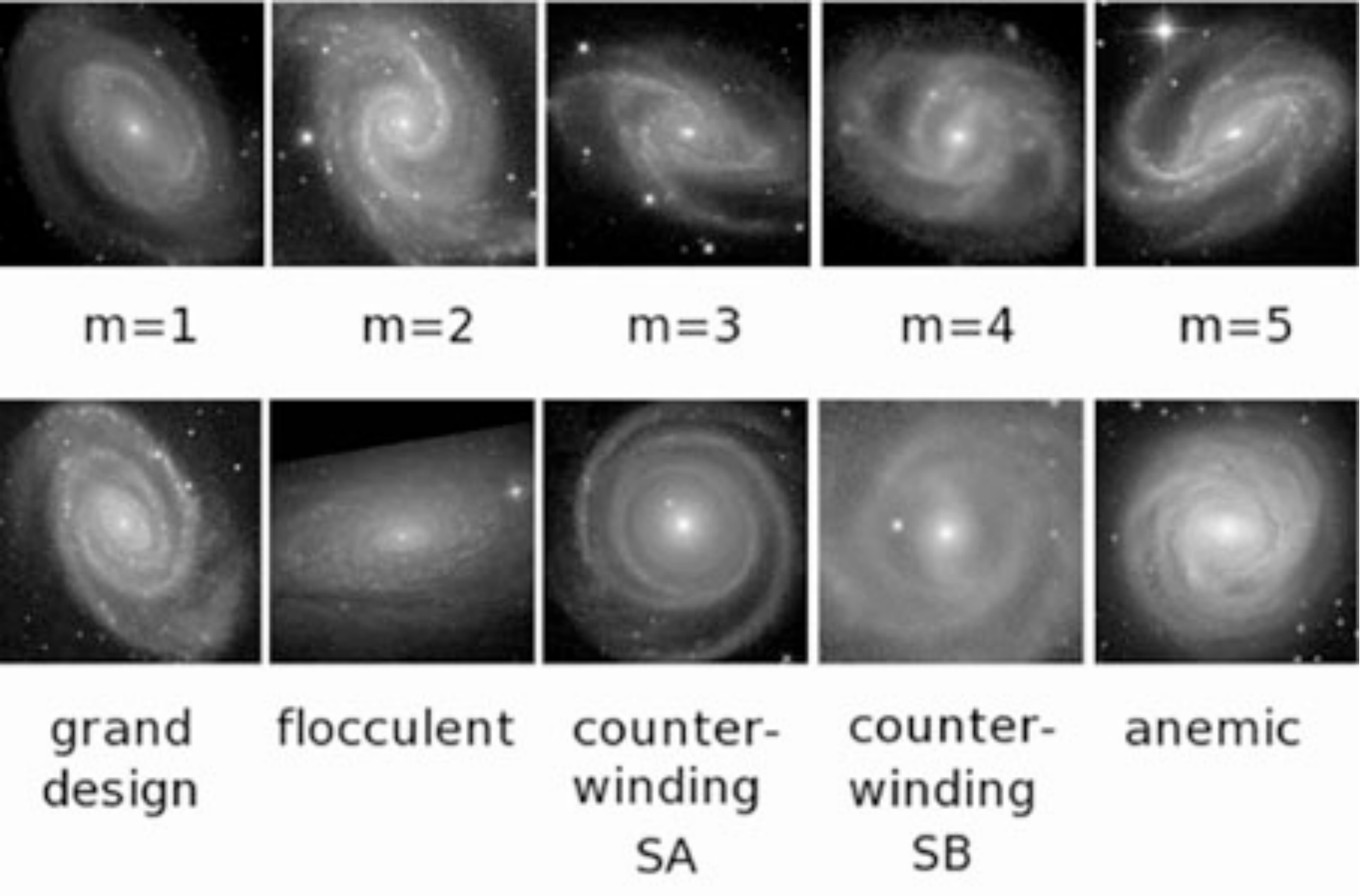
Notice that the value of A_2/A_0 reaches ~ 0.4 for the tangentially biased (red) and isotropic (green) models. These two bars become extremely strong inside $R \lesssim 3R_d$, where density variations from peak to trough are almost 100%. The value of $A_2/A_0 \gtrsim 0.1$ for the bar when the halo is radially biased halo (blue) is still visually discernible as an oval distortion to the inner disk by $t = 800$. This mass model should be comfortably stable in a rigid halo by conventional stability criteria: $t_{OP} = 0.10$ (Ostriker & Peebles 1973) and $V = 1.16(GM/R_d)^{1/2}$ at the peak of the rotation curve (Fig. 1 Efstathiou, Lake & Negroponte 1982). This prediction is indeed borne out by the cyan line in the top panel of Fig. 2 (see also §5.2), but the same model is clearly unstable when the halo is live whatever the shape of the halo velocity ellipsoid.

FIG. 3.— The time evolution of the bar amplitude in models with differing M_P/M_d. In the upper panel, all halos have tangentially biased DFs, while the halo DFs are isotropic in the lower panel. The value of M_P/M_d is denoted by the line color: red for $M_P/M_d = 2$, green for $M_P/M_d = 3$ (reproduced from Fig 2), blue for $M_P/M_d = 4$, and cyan for $M_P/M_d = 5$. The magenta line in the lower panel is for a rigid halo with $M_P/M_d = 2$, and the dashed blue line is from the same $M_P/M_d = 4$ model, but with the evolution computed on a Cartesian grid.

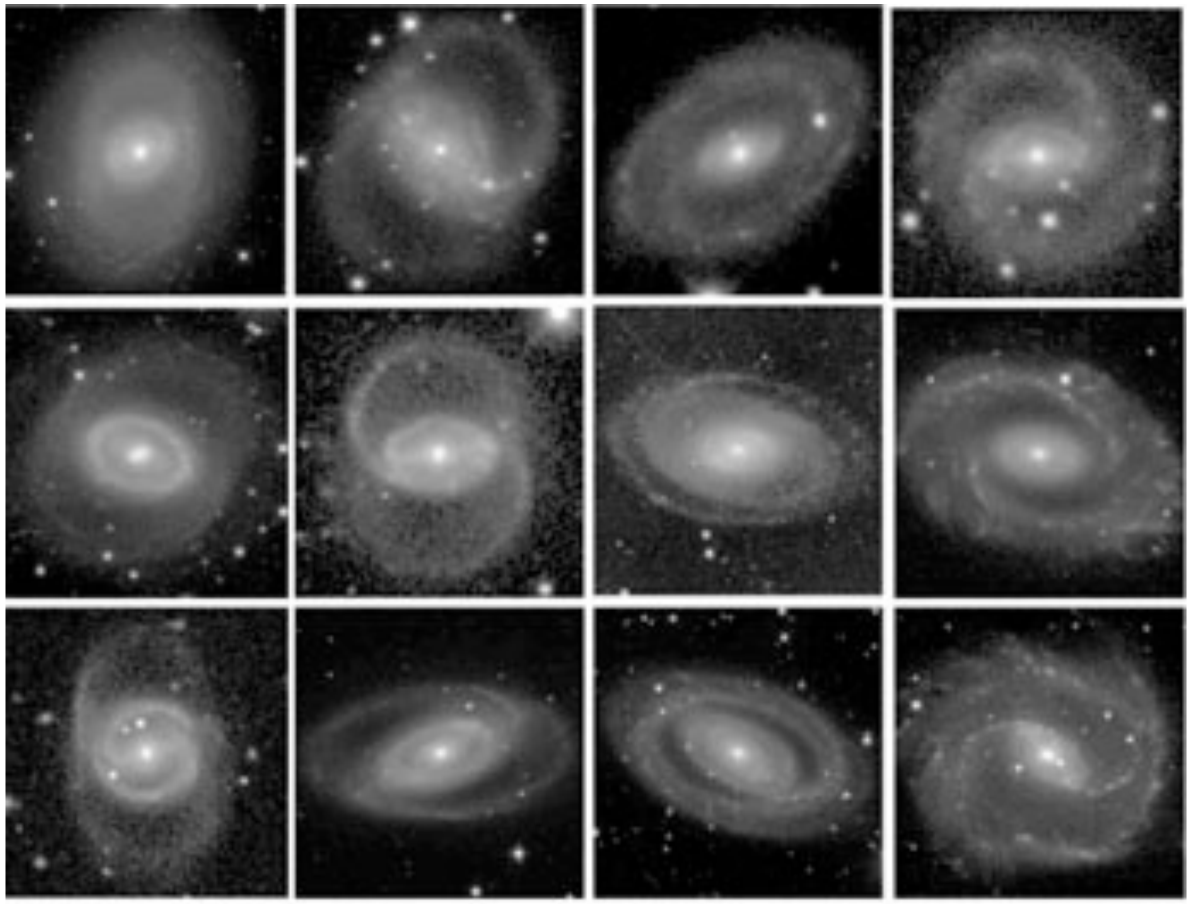
mentum changes and stiffer halos make the halo density changes in the other two models too small to notice.

3.2. *Other halo masses*

Spiral arm type & multiplicity



rings



Disk self-gravity drives bars and also spiral structure. Need a dark matter halo to suppress the rate of growth of these modes (but see Sellwood 2016 on live halos). But need some disk self-gravity to drive the observed features -

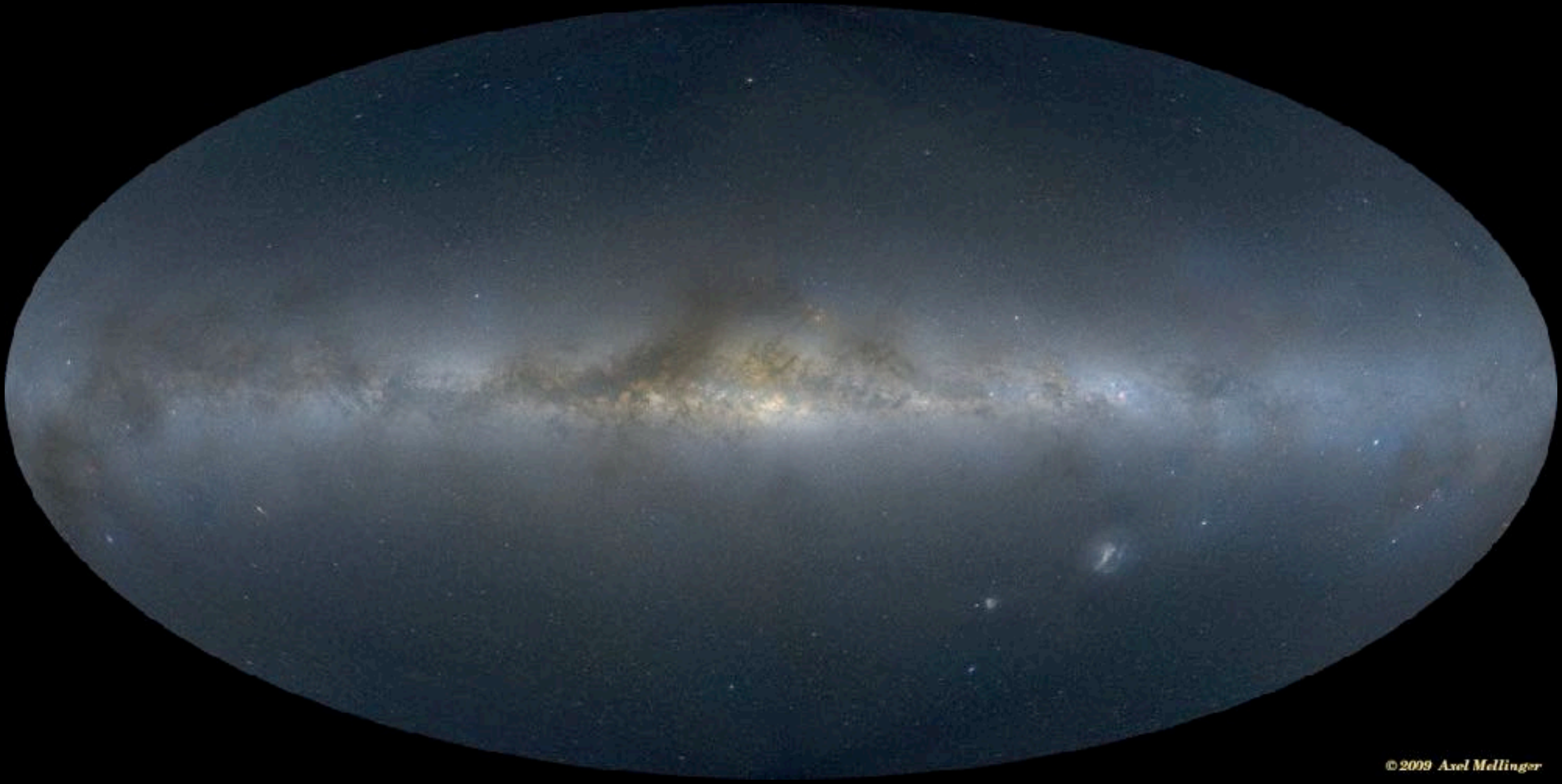
Athanassoula et al. (1987, A&A, 179, 23) find the disk mass has to be within a factor of 2 of maximum disk.

Fuchs (2003, Ap&SS, 284, 719) finds LSB disks need to be heavier than expected by stellar population models in order to drive the observed structure.

Tracers of the Potential Φ

- Photometric
  - – Mass you can see
    - Stars (stellar populations, young & old)
    - Gas (Atomic HI & Molecular H_2/CO)
- Kinematic
  - – Velocities you can trace (Doppler effect)
    - HI
    - Hα
    - Absorption lines (especially from stars)

The Milky Way (all sky projection)



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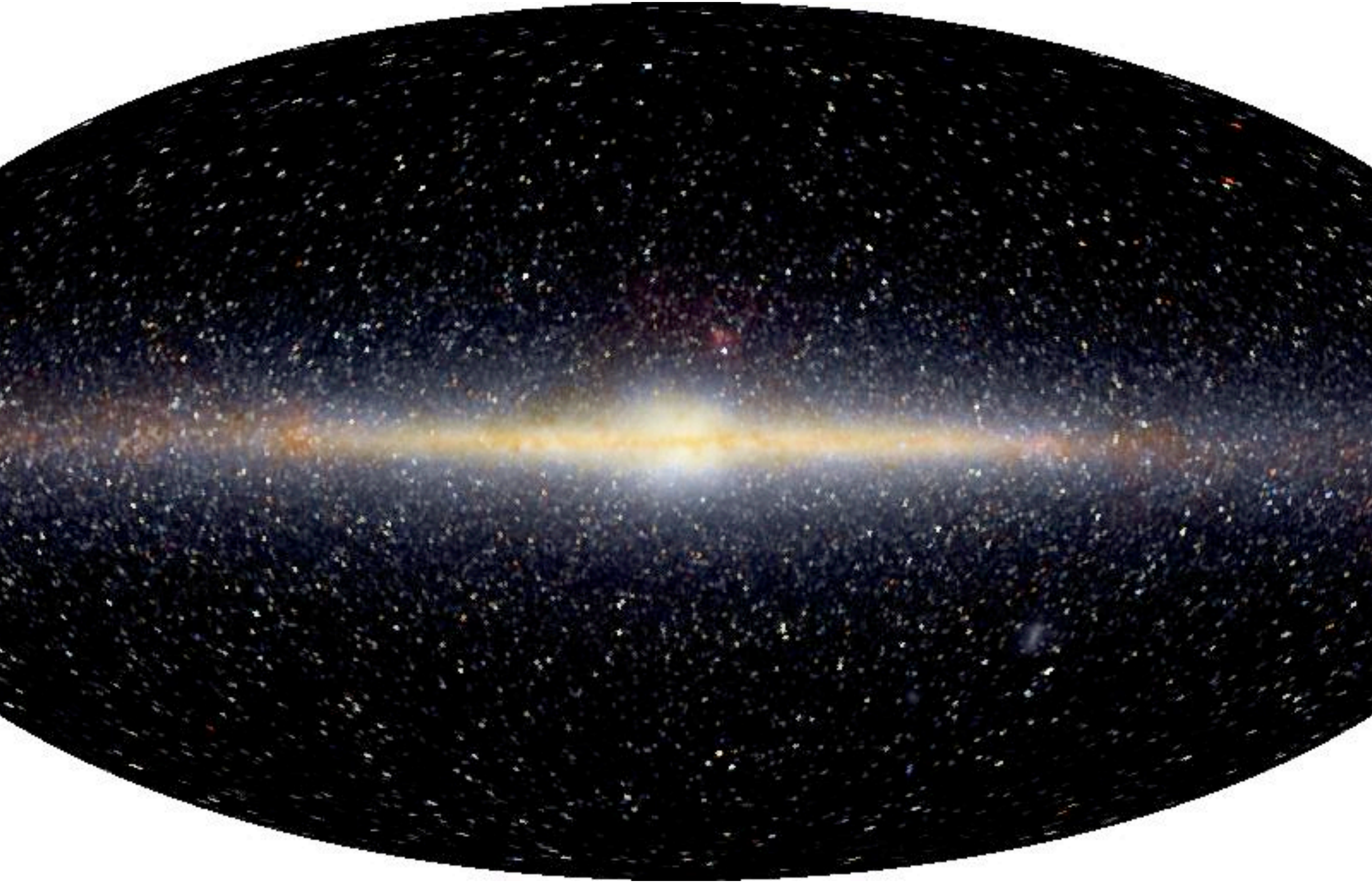
Milky Way in the near-infrared

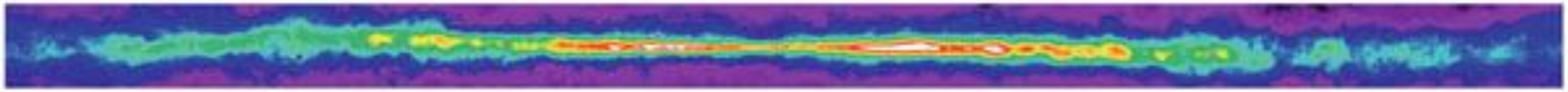


“Galaxies are made of stars” - D. Silva (1990) private communication

- **Stars**
  - Majority of baryonic mass in elliptical and early type spiral galaxies
- **Gas**
  - *Atomic HI*
    - Majority of baryonic mass in Irregular and some late type spiral galaxies
  - *Molecular* H_2
    - traced by CO
  - *Ionized* H^+
    - traced by Hα Little mass at small radii.
- **Dust**
  - little mass, but does get in the way.

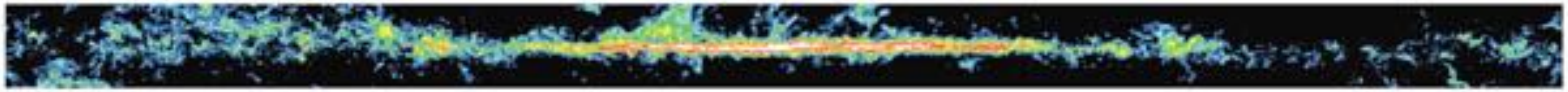
Multi-wavelength Milky Way

radio (21 cm)
HI gas



a 21-cm radio emission from atomic hydrogen gas.

radio (CO)
molecular gas



b Radio emission from carbon monoxide reveals molecular clouds.

far-IR
dust

c Infrared (60–100 μm) emission from interstellar dust.

near-IR
stars

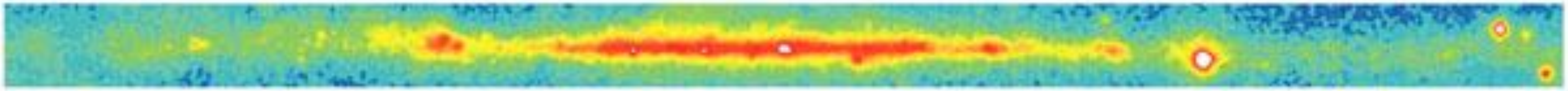
d Infrared (1–4 μm) emission from stars that penetrates most interstellar material.

Optical
stars & dust

e Visible light emitted by stars is scattered and absorbed by dust.

X-ray
hot gas

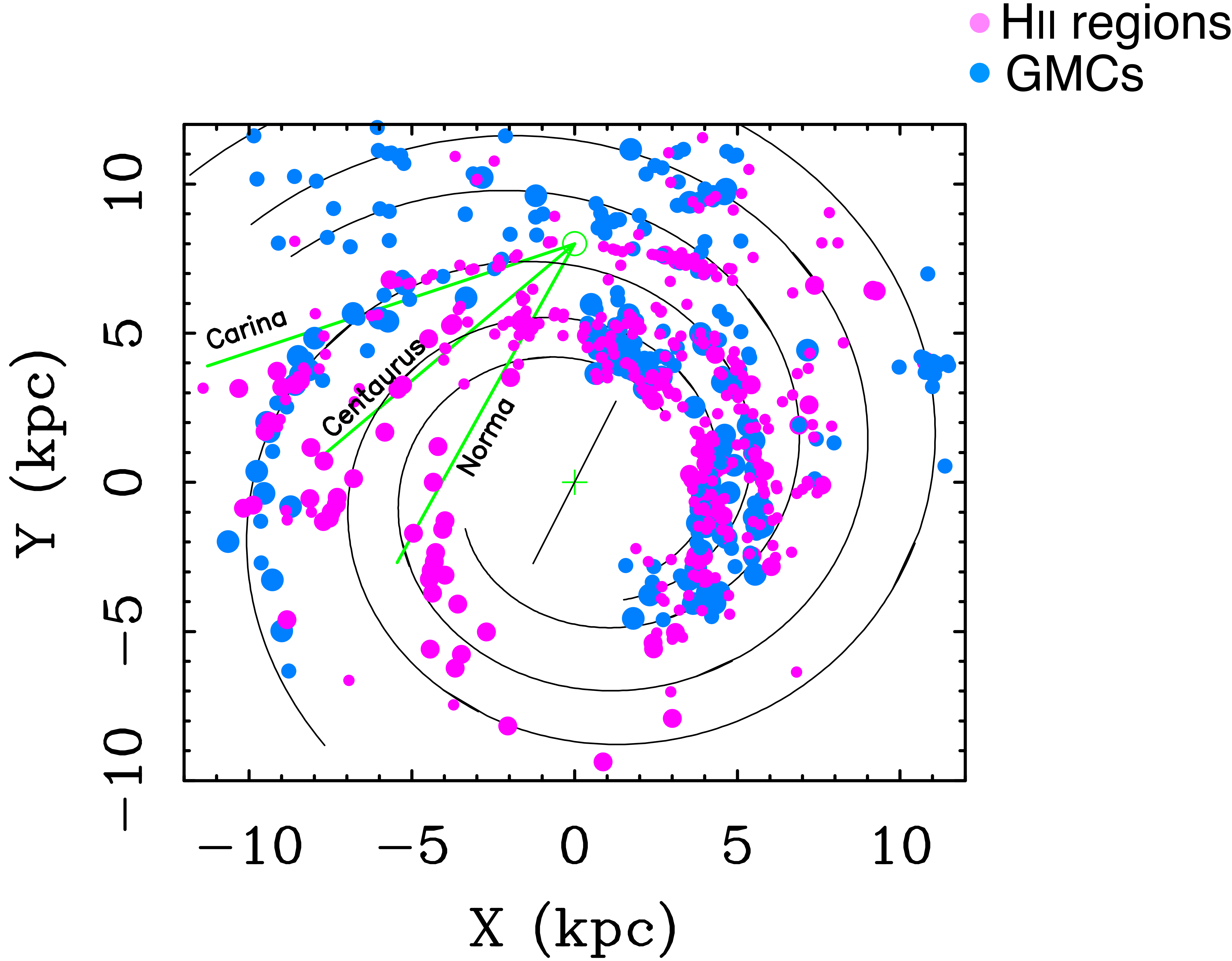
f X-ray emission from hot gas bubbles (diffuse blobs) and X-ray binaries (pointlike sources).



g Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

Face-on Milky Way

(artist’s conception)



HII regions
GMCs
Carina
Centaurus
Norma
Y (kpc)
X (kpc)
10
5
0
−5
−10
−10
−5
0
5
10

Milky Way model illustrating baryonic mass components