AST 1420

Galactic Structure and Dynamics

Q&A

Gaia EDR3 today!

- Exciting day for Galactic Dynamics and Galactic Astrophysics: Gaia EDR3 was released at 6am today
- (currently downloading to our servers…)
- Exciting new results on the dynamics of the LMC and the acceleration of the solar system
- Hack week happening this week, see Ted Mackereth's email —> everybody welcome to hack at any level! Important thing is to have fun!
    - Pitch/intro session at 1:30 today, see slack#general for info

Bars and spiral structure

Dynamical structure of bars

- For a weak bar, we have approximately (m=2)

$$R_1(t) = C_1 \cos(\kappa_0 t + \alpha) - \left[\frac{\mathrm{d}\Phi_\mathrm{b}}{\mathrm{d}R} + \frac{2\Omega\Phi_\mathrm{b}}{R(\Omega - \Omega_\mathrm{b})}\right]_{R_0} \frac{\cos\left[m(\Omega_0 - \Omega_\mathrm{b})t\right]}{\Delta},$$

$$C_2 \equiv -\frac{1}{\Delta}\left[\frac{\mathrm{d}\Phi_\mathrm{b}}{\mathrm{d}R} + \frac{2\Omega\Phi_\mathrm{b}}{R(\Omega - \Omega_\mathrm{b})}\right]_{R_0}$$

- Parent of closed orbit is the loop with C_1=0
- Orbits that make up the bar must be elongated along the bar: $(\Omega_0-\Omega)t = \phi_0$
  - bar is along ϕ_0 =0 here —> $C_2 > 0$

Dynamical structure of bars

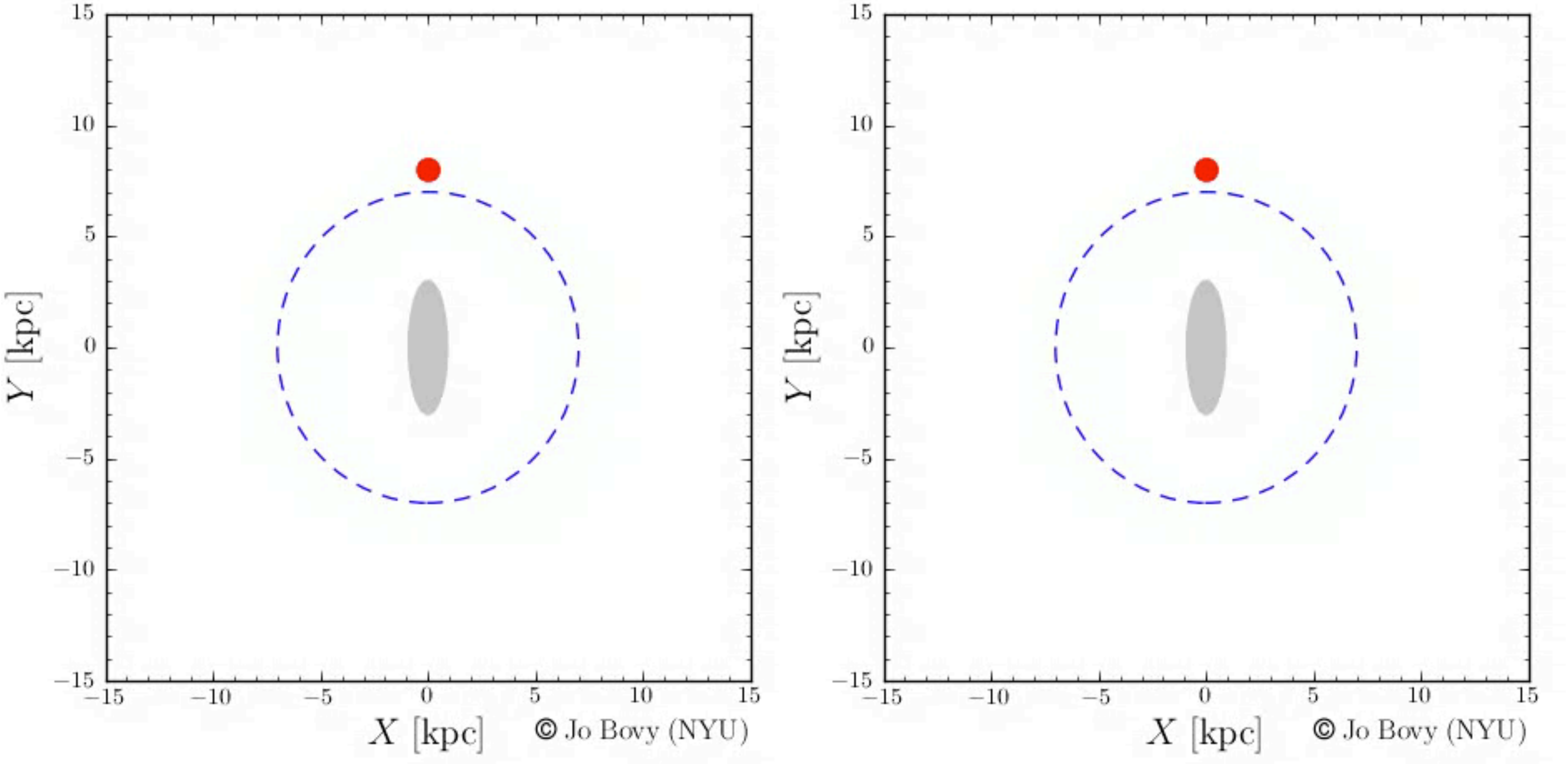
$$C_2 \equiv -\frac{1}{\Delta}\left[\frac{\mathrm{d}\Phi_\mathrm{b}}{\mathrm{d}R} + \frac{2\Omega\Phi_\mathrm{b}}{R(\Omega-\Omega_\mathrm{b})}\right]_{R_0}$$

- $C_2 > 0$ at $R < R_{CR}$:
  - $\Omega > \Omega_b$ —> $2\Omega/(\Omega-\Omega_b) > 2$
  - Second term dominates and $\phi_b < 0$, so we need $\Delta > 0$ or

$$\Delta \equiv \kappa_0^2 - m^2(\Omega_0 - \Omega_\mathrm{b})^2.$$

  - $\Omega_b > \Omega - \varkappa/2$
- $C_2 > 0$ at $R > R_{CR}$:
  - Similar argument requires $\Delta > 0$ or
  - $\Omega_b < \Omega - \varkappa/2$
- Therefore, a self-consistent bar can only exist:
  - Between the inner Lindblad resonance and corotation
  - Outside of the outer Lindblad resonance —> cannot happen
- This explains why bars end at corotation

Outer Lindblad resonance



Spiral structure in disk galaxies

- Spiral structure is ubiquitous in disk galaxies; defining feature of the *spiral nebulae*

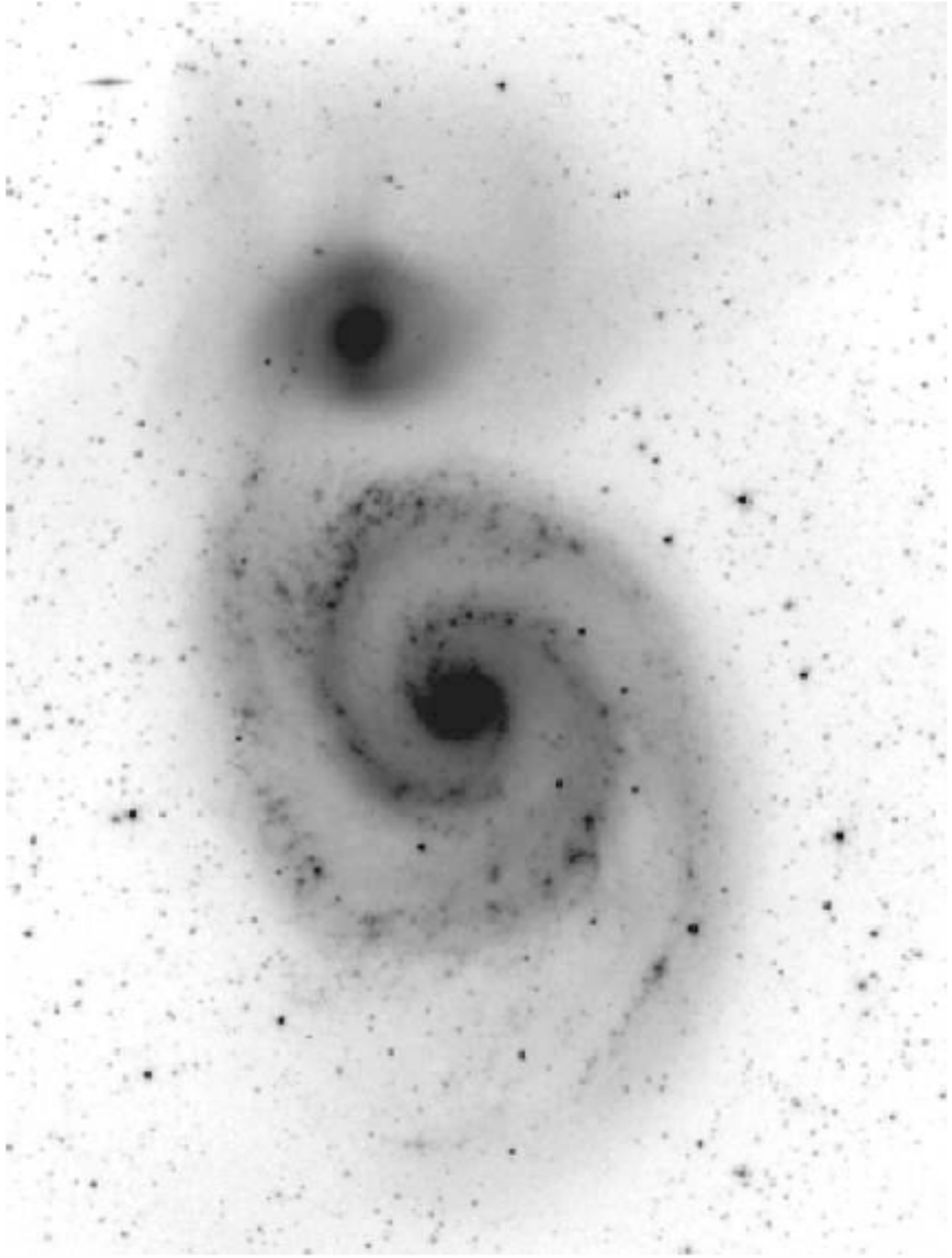
- Galaxies form disks because gas can radiate energy, but cannot rid itself of its angular momentum —> minimum E state at fixed L is disk

- Could evolve to lower E state by contracting radially, but that would violate conservation of angular momentum

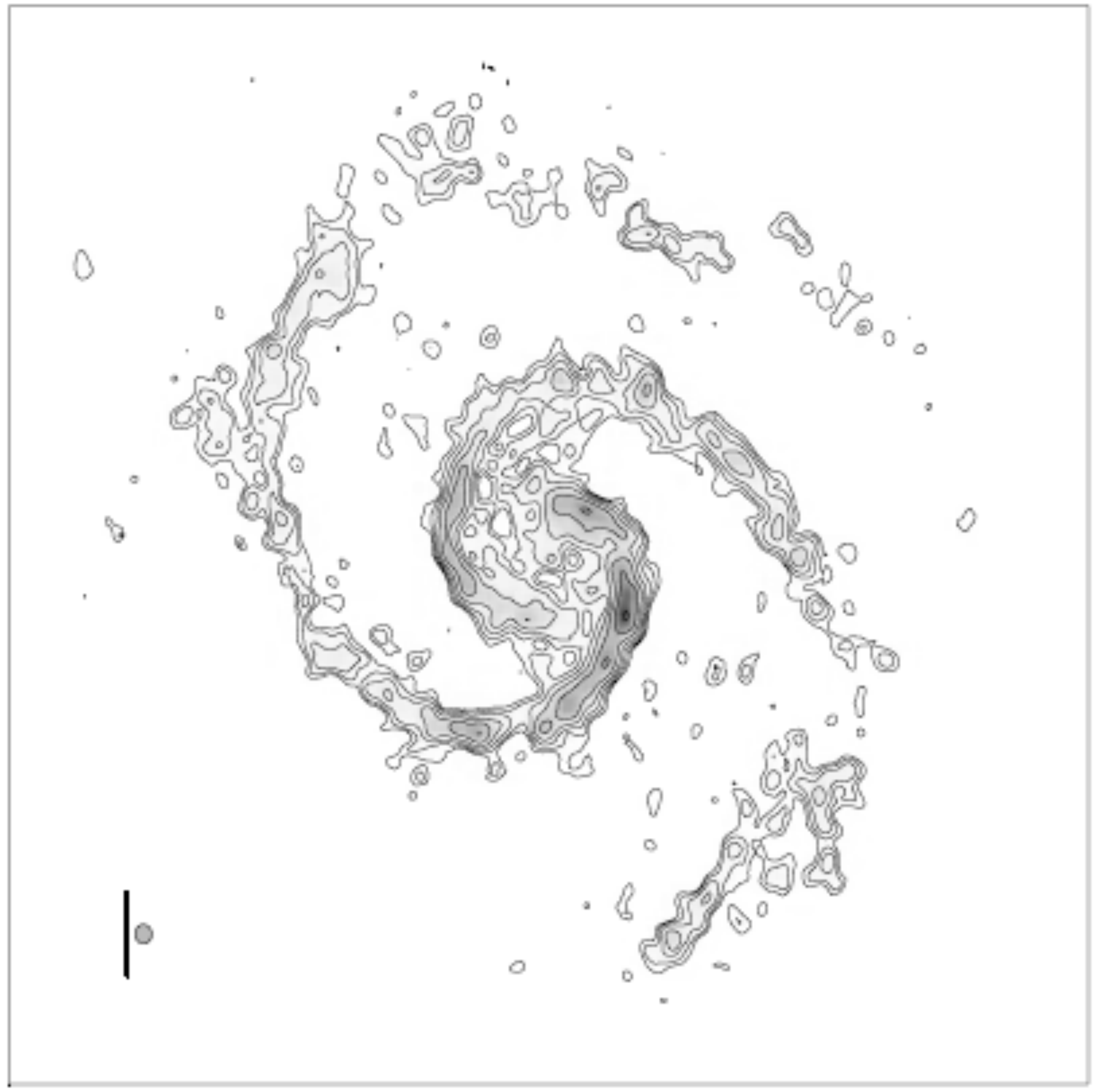
- Solution: send small amount of mass to infinity, rest can then fall to the center

- Require non-axisymmetry to allow this type of transport —> spirals and bars

Spirals show up in basically *all* gaseous and stellar components



NIR



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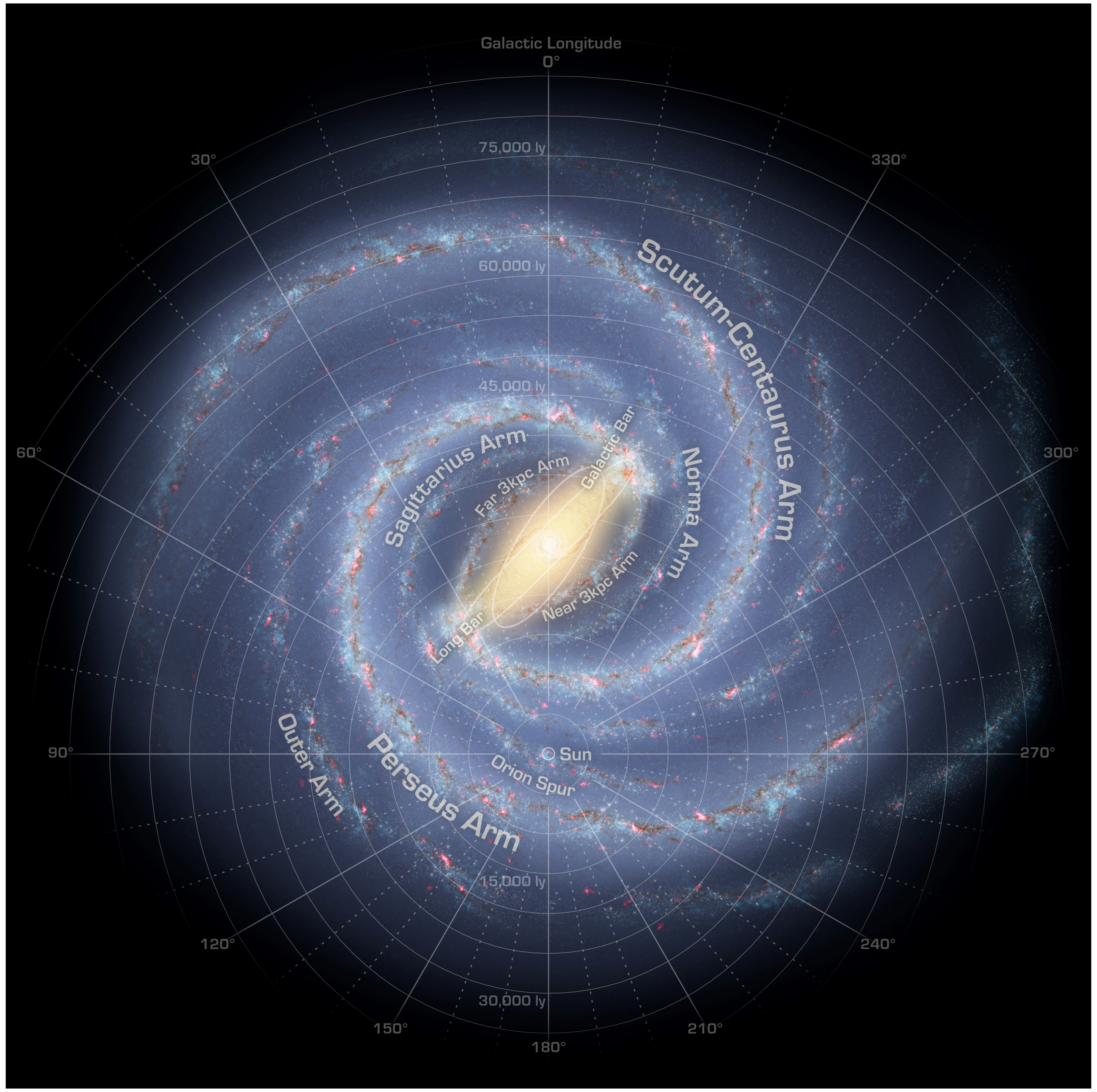
Do spirals always start from the bar's end?

- Often, but not always
- Hard to determine, because ends of the bar aren't *that* well defined, so it often looks as if the spirals start at the end of the bar
- Four-armed spirals can't all start at the end!
- Connection between bar and spiral structure is not well understood!
- Because bars only exist in disk galaxies, and all disk galaxies have some spiral structure, there are essentially no barred galaxies without spiral structure



Effect of mergers

- Mergers between galaxies affect the bar and spiral structure in multiple ways:
  - Major merger can destroy disk galaxy —> destroys bar and spiral structure
  - Lesser merger can perturb system significantly enough to completely reshape the spiral structure and the bar
  - Mergers are also an important source of perturbations that give rise to spirals structure in the first place

Dynamical friction

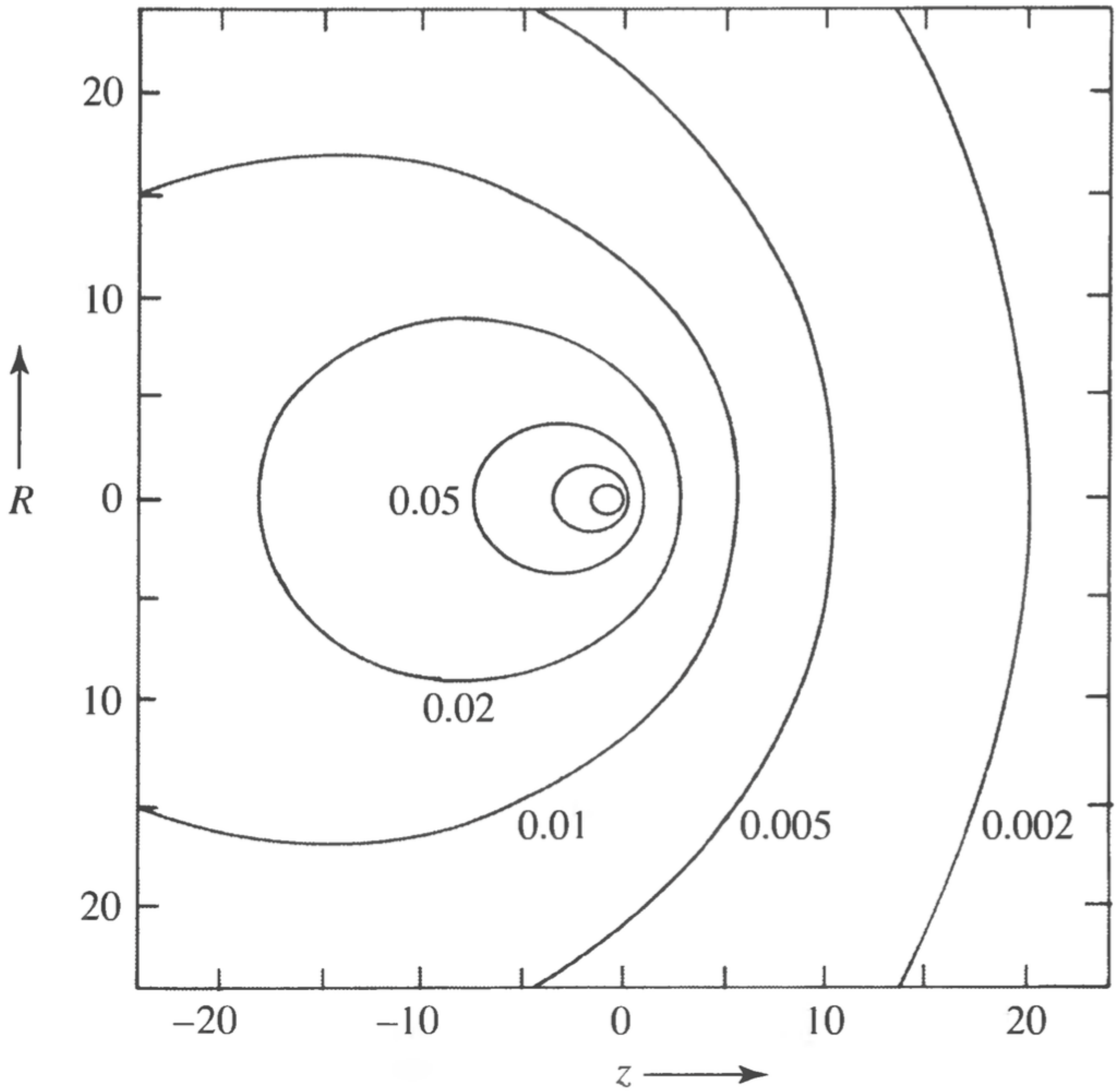
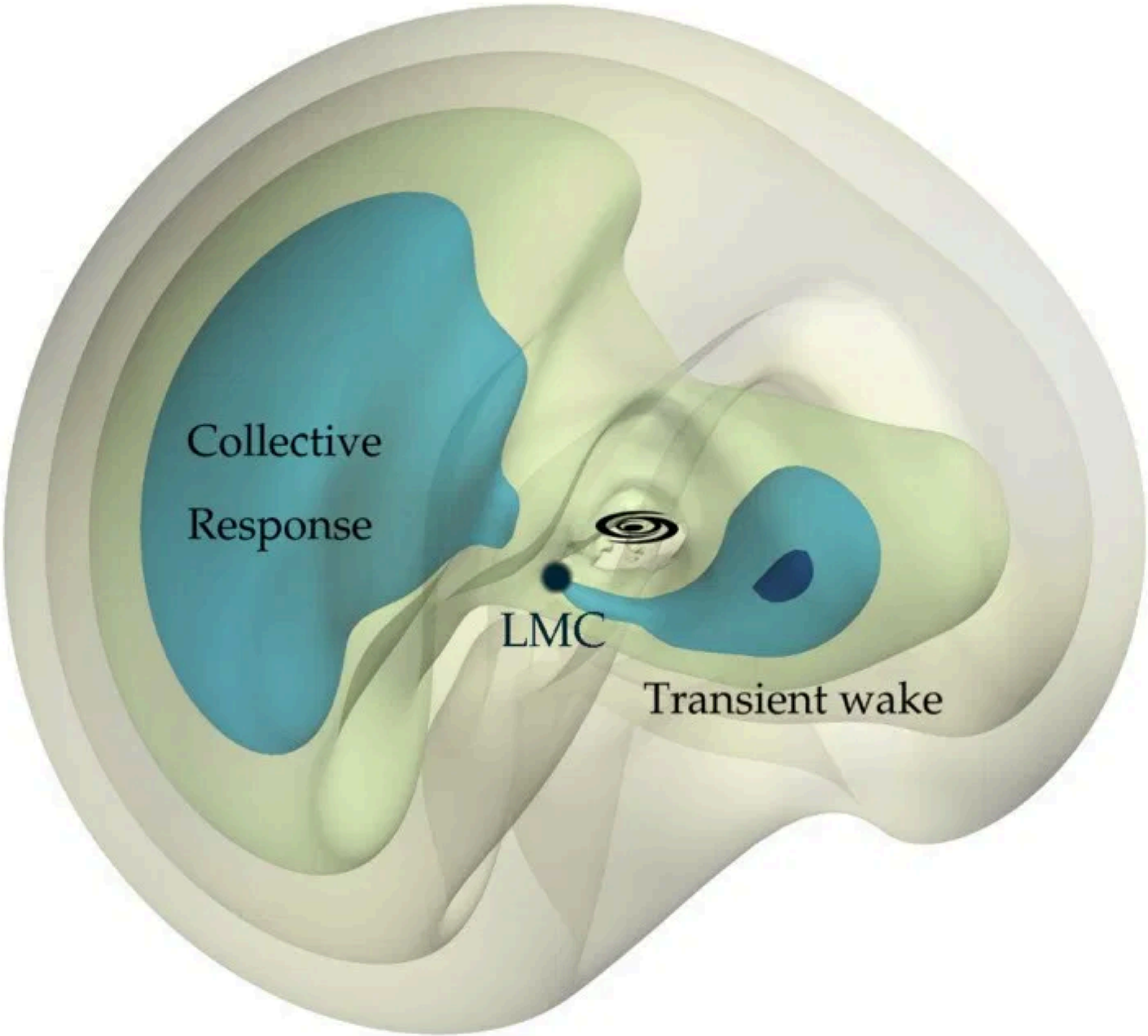


FIGURE 26.5 The fractional enhancement in the density of stars caused by the motion of a mass *M* in the positive *z* direction. (Figure adapted from Mulder, *Astron. Astrophys.*, *117*, 9, 1983.)

(from Carroll & Ostlie)



Garavito-Camargo et al. (2020)

Can this be measured?

- Yes! Should give rise to systematic motions of stellar-halos stars and some groups are claiming to see this effect (e.g., Petersen & Penarrubia 2020)

Dynamical friction

Clarifications and discussion

- Dynamical friction acts anywhere when a massive body moves through a see of smaller bodies:
    - Satellites in galaxy halos
    - Black holes in galaxies or star clusters
    - …
    - This leads to massive objects sinking to the center everywhere
- Disturbing of orbits in the ‘sea’ heats the sea a bit, total energy is conserved so sea needs to go to higher energies to make up for the energy loss of the massive object

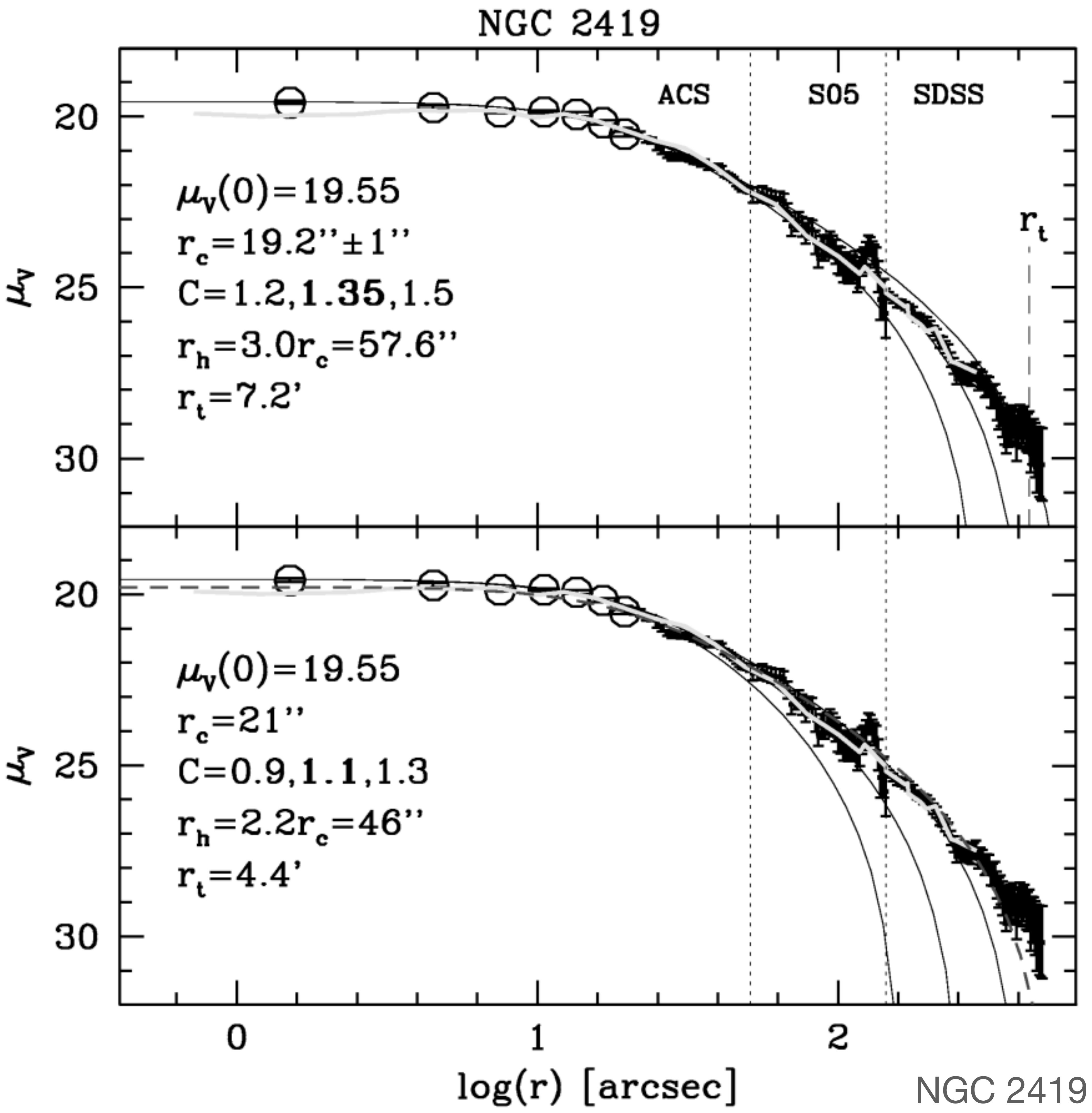
$$t_{\rm fric} = \frac{1.17}{\ln\Lambda}\frac{\mathcal{M}(r)}{M} t_{\rm cross},$$

- t_fric that we computed is the time for an object to sink to r=0
- We can model dynamical friction as a diffusion process for the massive object: total effect is the combination of *many* encounters, each which perturbs the massive object’s motion only very weakly and not in a fully coherent way —> diffusion description holds

Tides

Tidal stripping

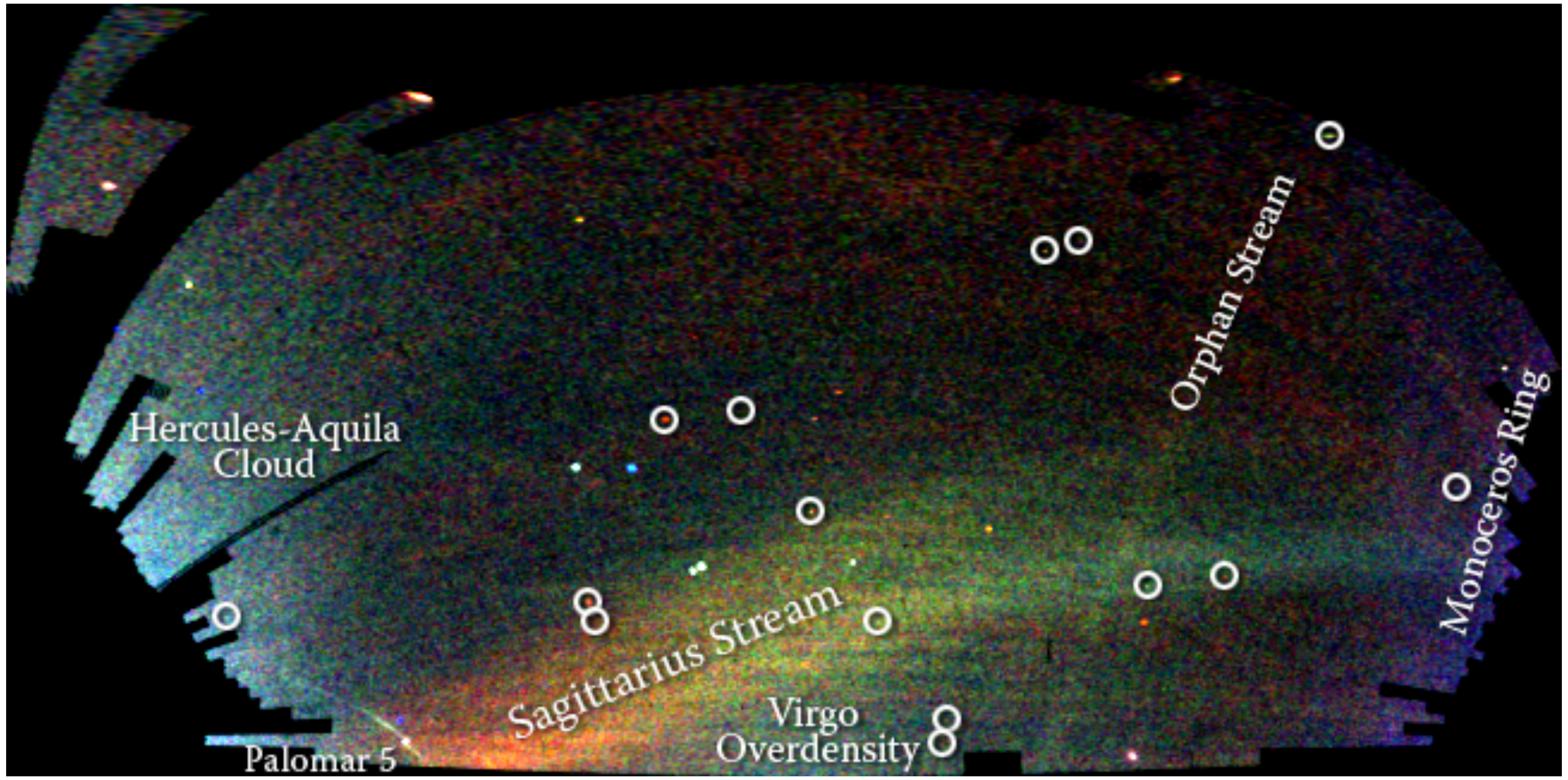
- Observing the tidal cut-off:
  - Difficult for satellite galaxies, because their tidal radii are quite large (due to their DM content) and their stars typically live at the center
  - Observed for globular clusters, which are well described by a model that has a tidal truncation
- Massive end: tidal stripping or merger?
  - Difficult to say, because continuous move towards more and more tidal stripping that is at some best described as a merger
  - Major and large minor mergers lead to distortions that look like tidal tails
  - Major merger: mass ratio smaller than 3
  - Mergers with mass ratios > 10 will look more like tidal stripping at least at first (LMC, Sgr in the MW)



NGC 2419
(Bellazzini 2007)

Stars stripped from merging satellites

- Stars stripped from satellites eventually just become part of the smooth halo through phase mixing
- These are just regular stars, so they don't experience dynamical friction once they've been stripped
- Numbers in the end are quite small: Sgr contributes a significant fraction of the stellar halo (tens of %), all other systems are much less
- But we do think we know that most of the stars in the stellar halo were brought in through tidal stripping and mergers (long ago)



Belokurov et al. (2006)