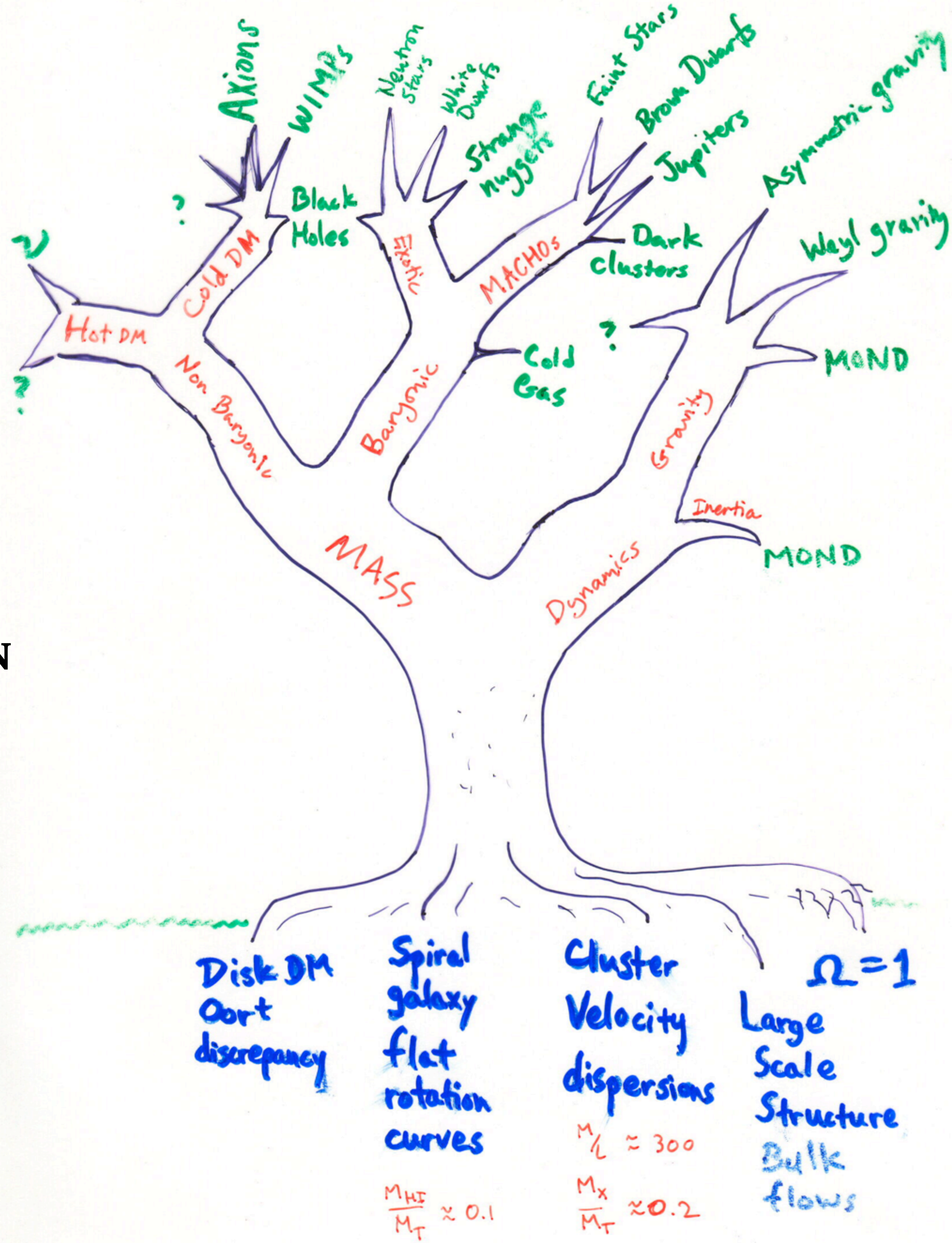
Dark Matter

ASTR 333/433

TODAY

Hierarchical Galaxy Formation
Adiabatic Contraction
Feedback

Homework due
Midterm 3/19



Orbital Anisotropy

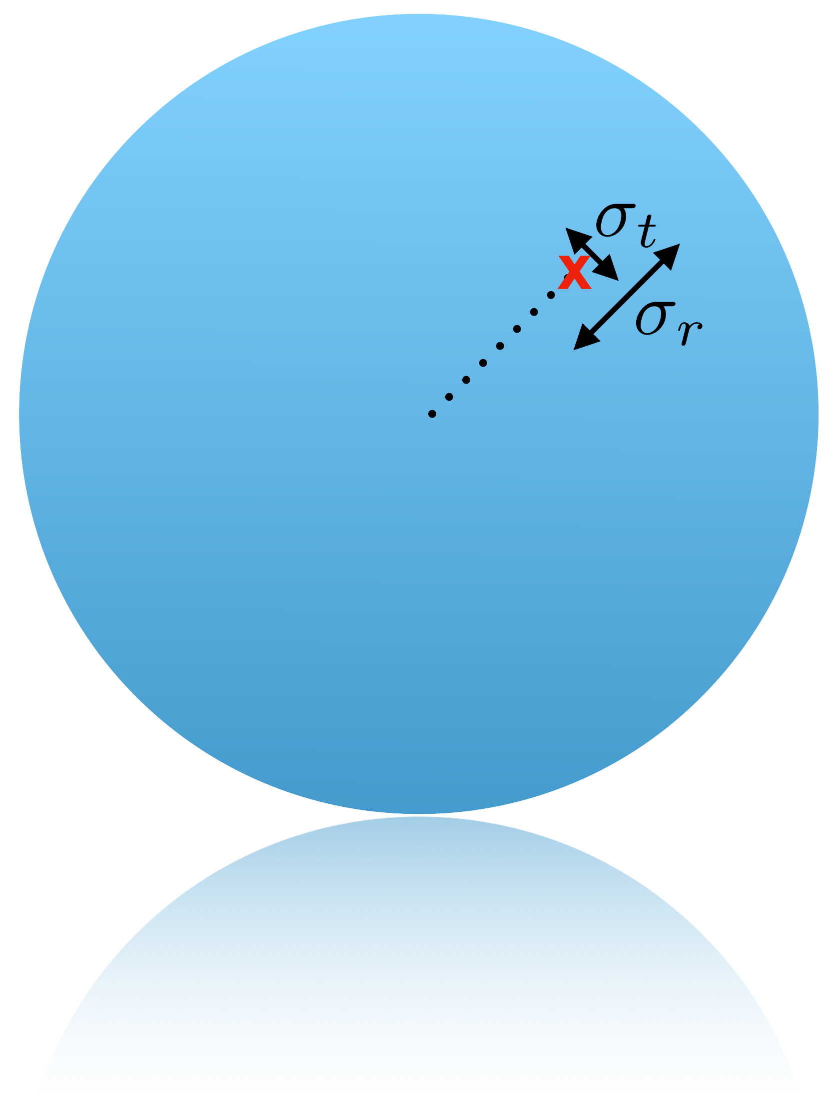
The anisotropy parameter measures how radial or circular orbits are

$$\beta = 1 - \frac{\sigma_t^2}{\sigma_r^2}$$

σ_t^2 ← tangential velocity dispersion

σ_r^2 ← radial velocity dispersion

$$GM(r) = r\sigma_r^2 \left(-\frac{\partial \ln \nu_*}{\partial r} - \frac{\partial \ln \sigma_r^2}{\partial r} - 2\beta \right)$$



PHASE SPACE IS CONSERVED

Combines conservation of mass, angular momentum, and energy. Can mix in empty space (spread things out), but cannot compress.

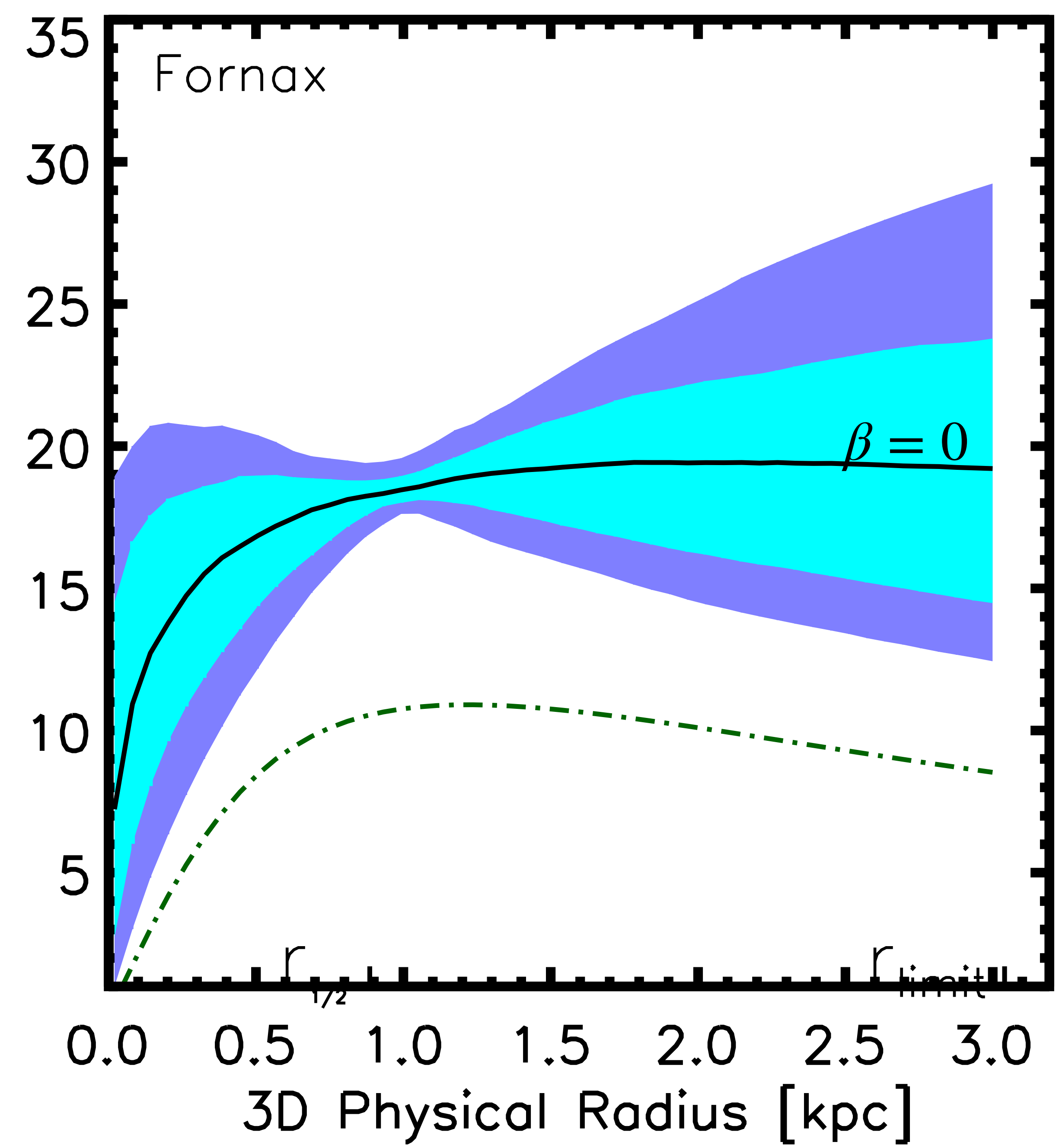
Fornax

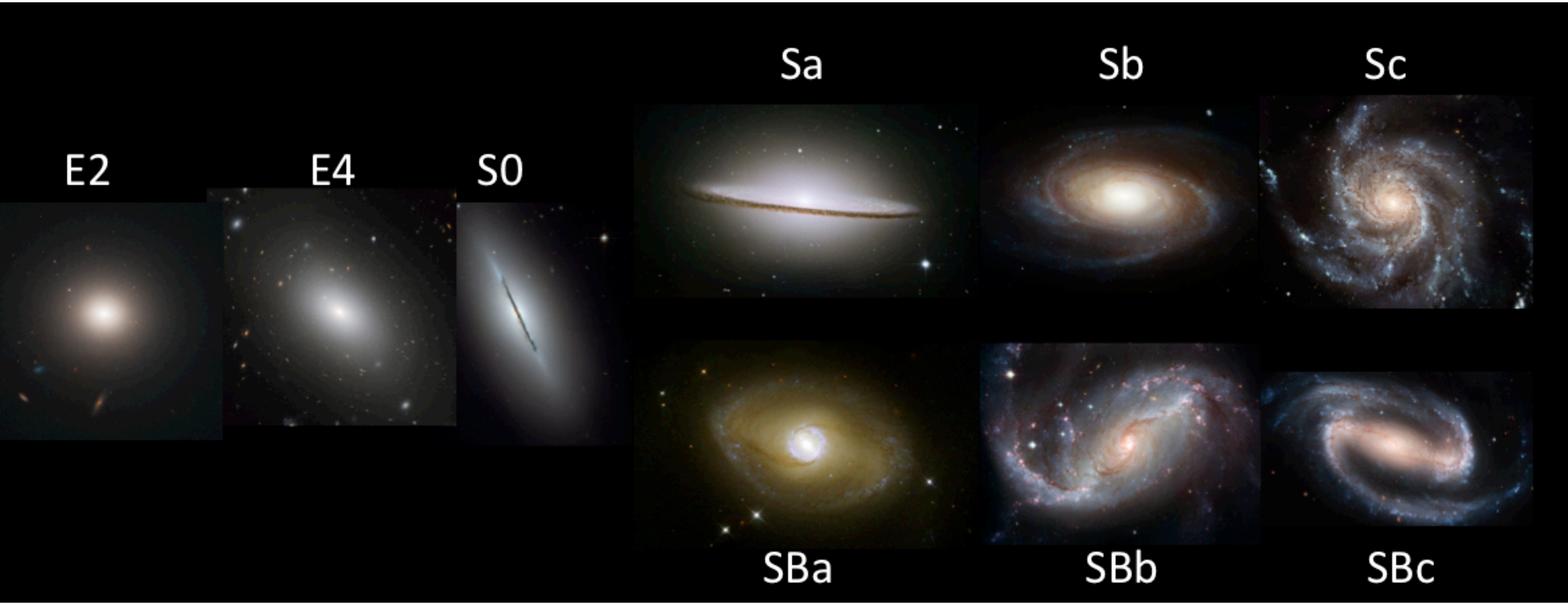
dwarf spheroidal (dSph)
satellite of the Milky Way

$$GM(r) = r\sigma_r^2 \left(-\frac{\partial \ln \nu_*}{\partial r} - \frac{\partial \ln \sigma_r^2}{\partial r} - 2\beta \right)$$

Mass-anisotropy degeneracy

$M(r)$ degenerate with $\beta(r)$





Hierarchical galaxy formation

“bottom up” formation from sequence of mergers

(big galaxies are built by piling up small galaxies - happens with cold dark matter)

Searle-Zinn (1978) fragments:

“…halo [globular] clusters originated within transient protogalactic fragments that gradually lost gas while undergoing chemical evolution and continued to fall into the Galaxy after the collapse of its central regions had been completed.”

Hierarchical galaxy formation (*not* monolithic)

Small objects conglomerate to make big ones

Gas dissipates and cools to form thin disks.

Stars cannot cool: if hot coming in, stay hot.

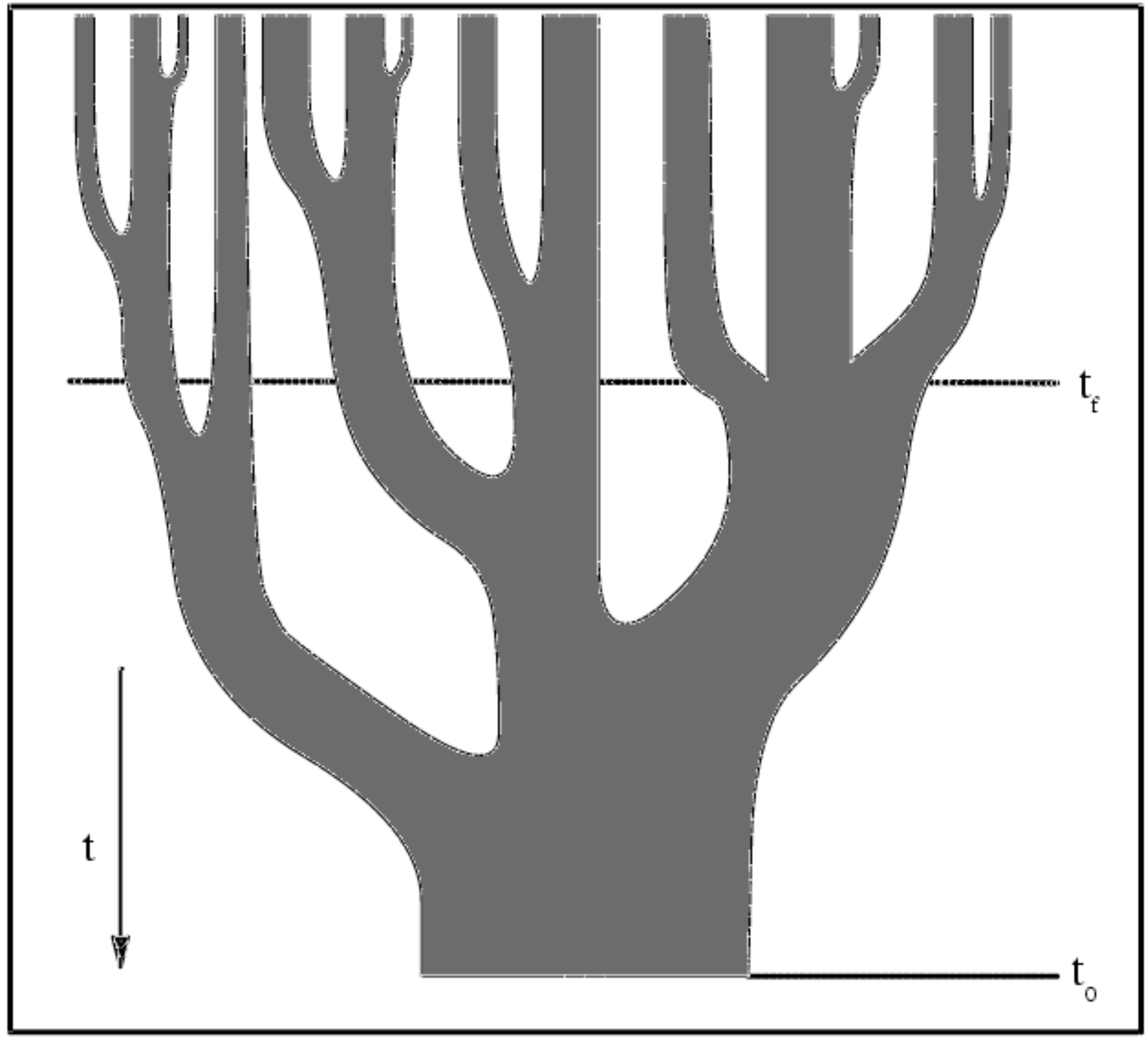


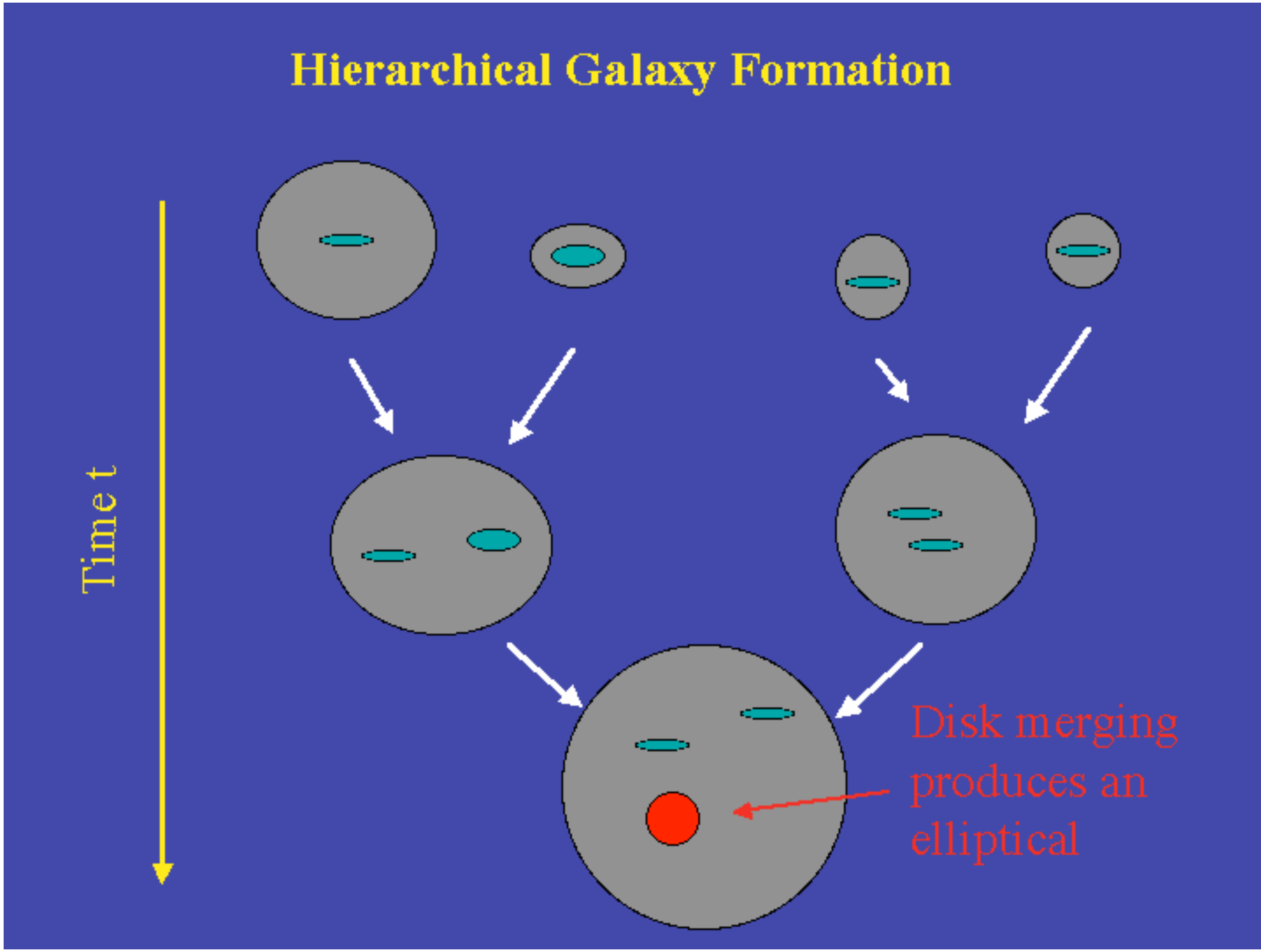
Figure 6. A schematic representation of a "merger tree" depicting the growth of a halo as the result of a series of mergers. Time increases from top to bottom in this figure and the widths of the branches of the tree represent the masses of the individual parent halos. Slicing through the tree horizontally gives the distribution of masses in the parent halos at a given time. The present time t_0 and the formation time t_f are marked by horizontal lines, where the formation time is defined as the time at which a parent halo containing in excess of half of the mass of the final halo was first created.

Gray: dark matter halos

Blue: gas rich disks

Red: elliptical merger remnant

sometimes it is imagined that a disk re-forms around an elliptical to form a bulge+disk system like and Sa galaxy



Adiabatic Compression

In a spherical potential, the squared angular momentum of a circular orbit is $L^2 = rGM(r)$, and if this quantity is conserved as a disk with the mass profile Md(r) grows slowly, we have

$$r_i M_i(r_i) = r_f\left[M_d(r_f) + (1 - f_d) M_f(r_f)\right], \qquad (1)$$

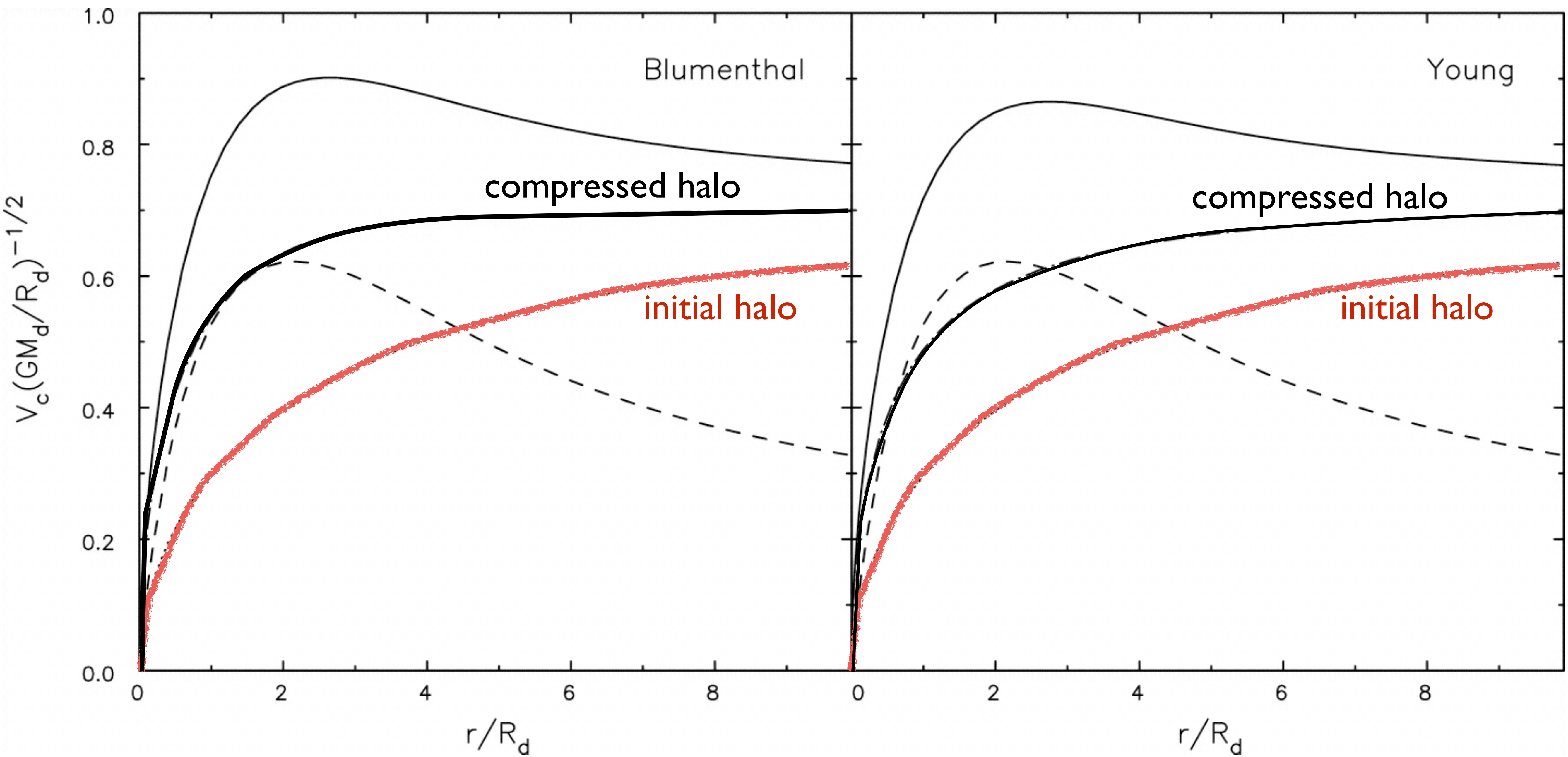
where Mi is the initial total mass (dark plus baryonic) profile, (1 - fd)Mf is the desired final dark matter mass profile, and rf is the final radius of the mass shell initially at radius ri. The quantity fd is the fraction of the initial total mass, assumed to be independent of radius, that condenses to form the disk. We can substitute for Mf(rf) by making use of the assumption

$$M_i(r_i) = M_f(r_f), \qquad (2)$$

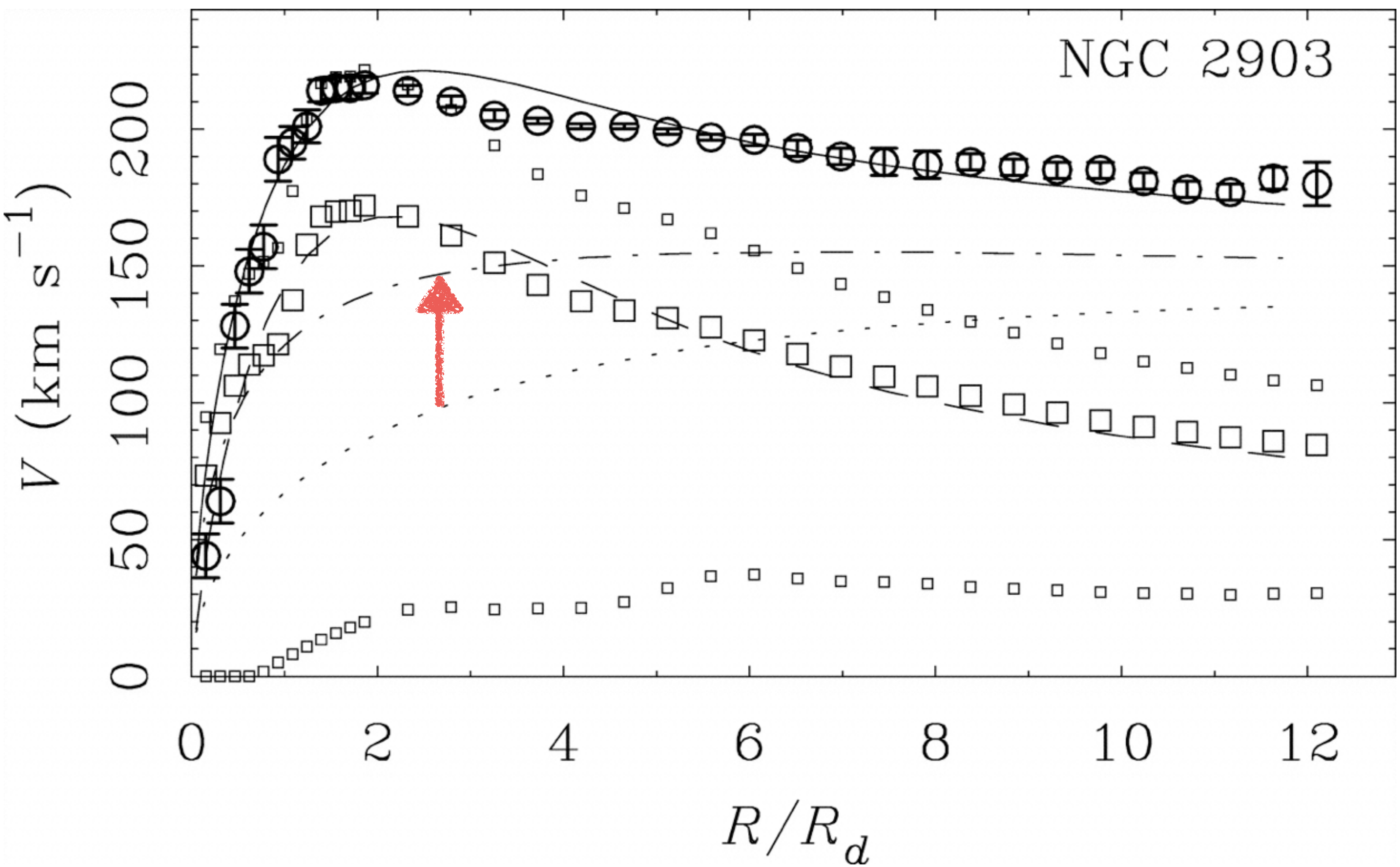
which is sometimes stated as "shells of matter do not cross." We can then find ri for any desired rf, and through equation (2), we can obtain the mass profile of the compressed dark matter halo. For convenience, we denote this the Blumenthal algorithm.

The Blumenthal algorithm only conserves angular momentum. Young's algorithm conserves the adiabats of the orbit, but is harder to implement (Sellwood & McGaugh 2005).

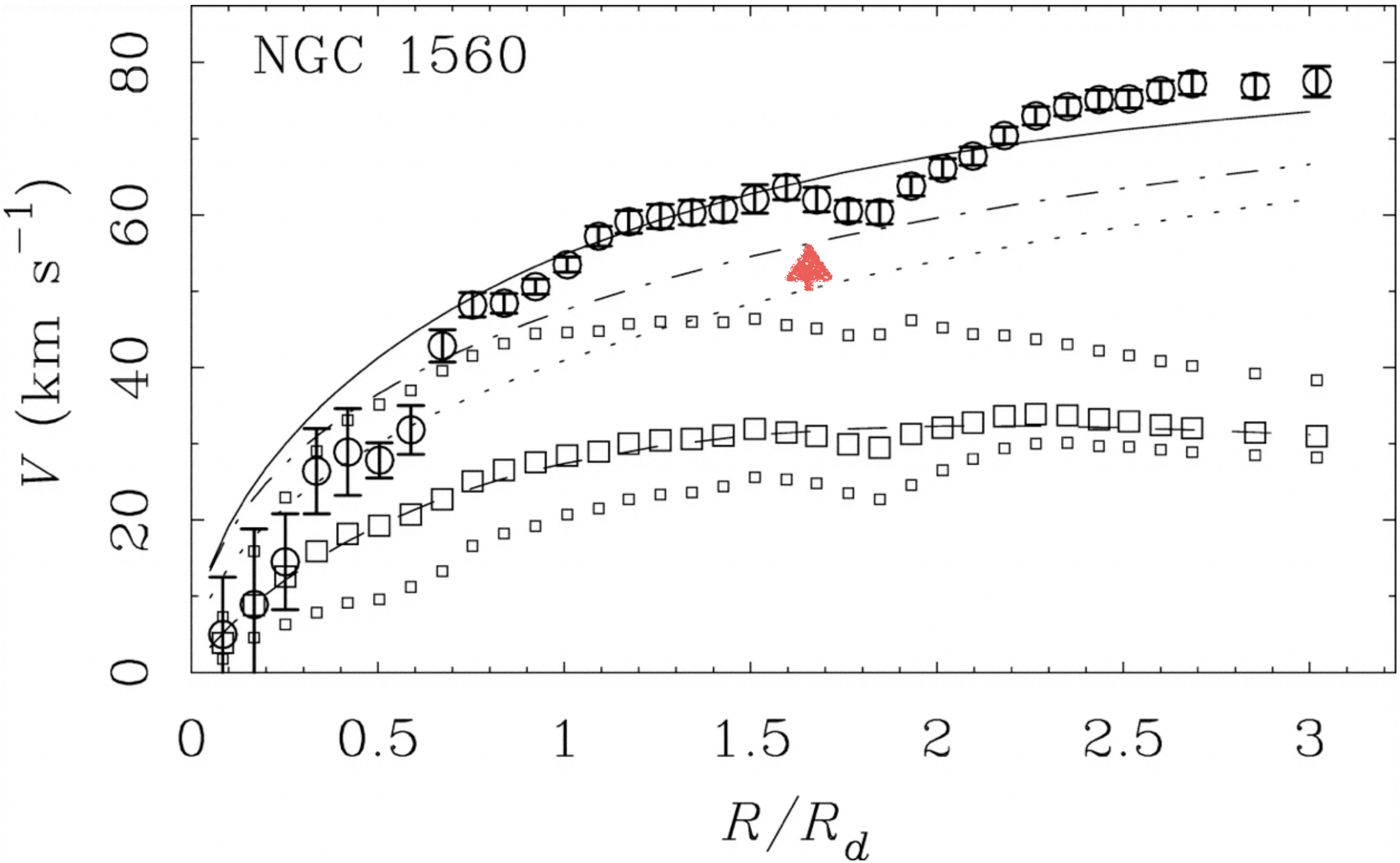
Adiabatic compression



The Blumenthal algorithm over-compresses. Young's algorithm allows for more nearly maximal disks.

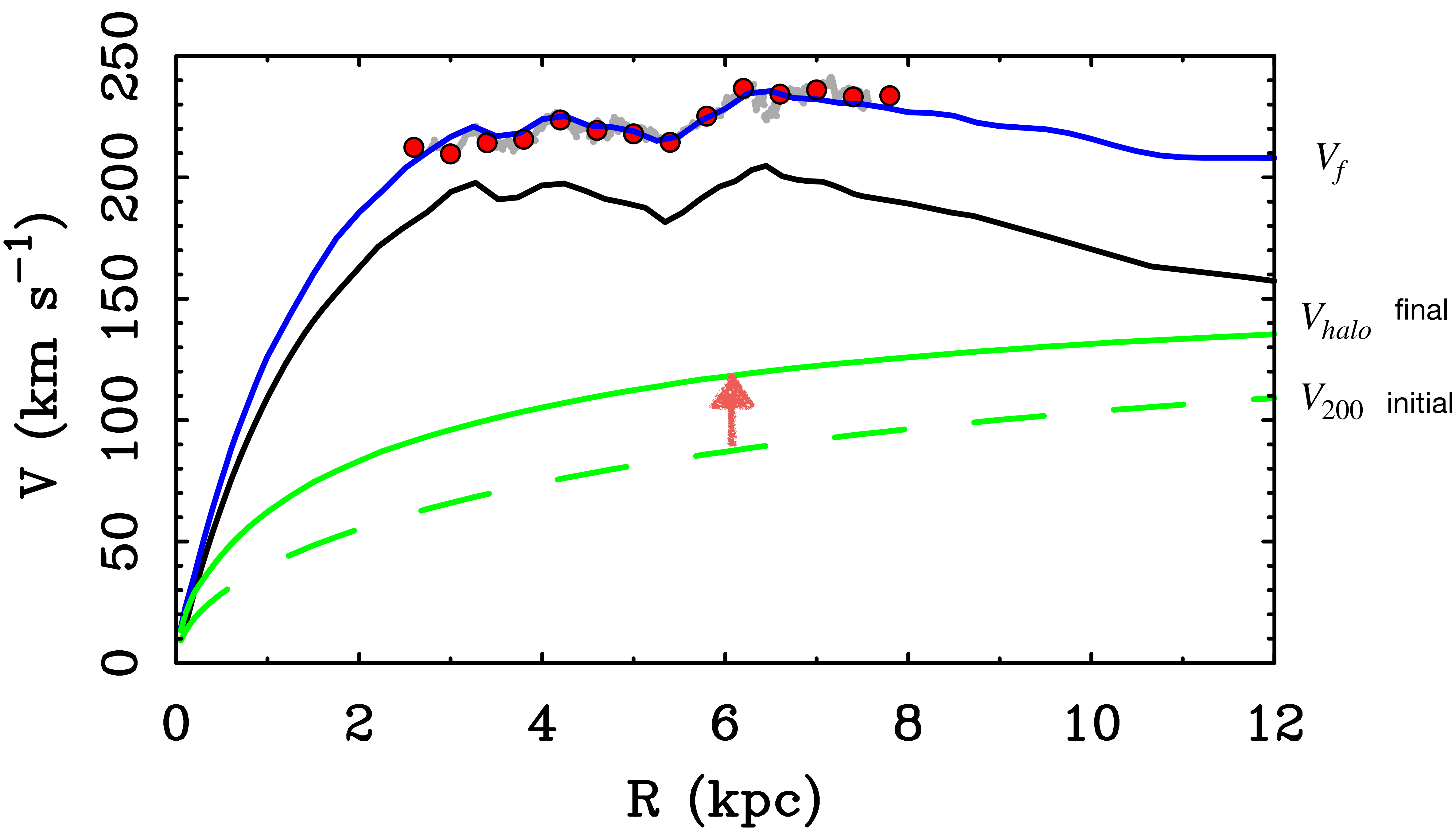


High surface density disks cause noticeable compression; tend to steepen halo profile



Low surface density disks cause only minor compression; don't affect profile much

Adiabatic compression changes the initial dark matter halo profile:
what we measure is not what the simulators predict



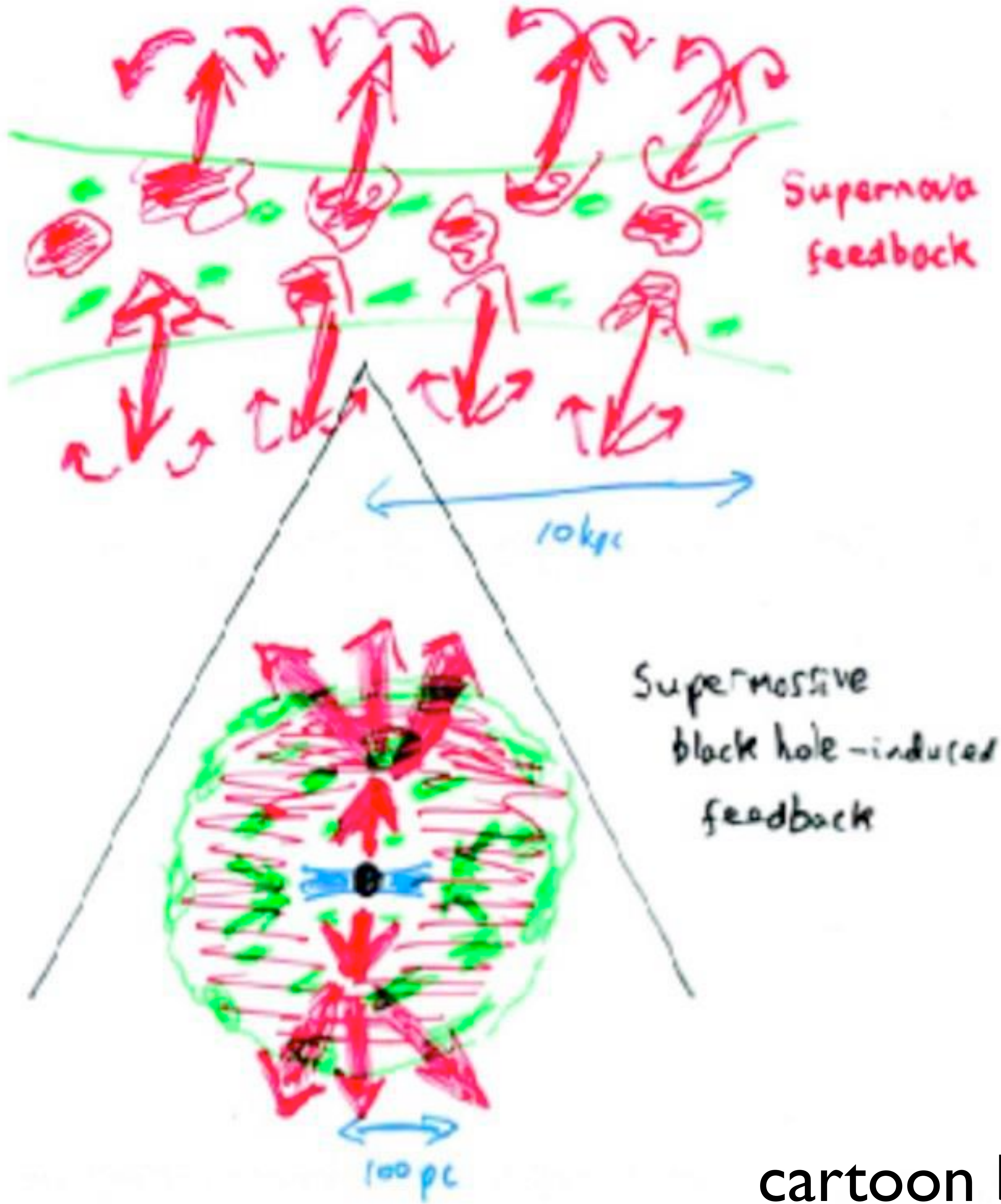
Only works in the Milky Way if the halos is not NFW or there is no bulge/bar:
such a central mass concentration over-compresses the halo,
beyond the maximum limit imposed by the rotation curve.

Generic CDM problem

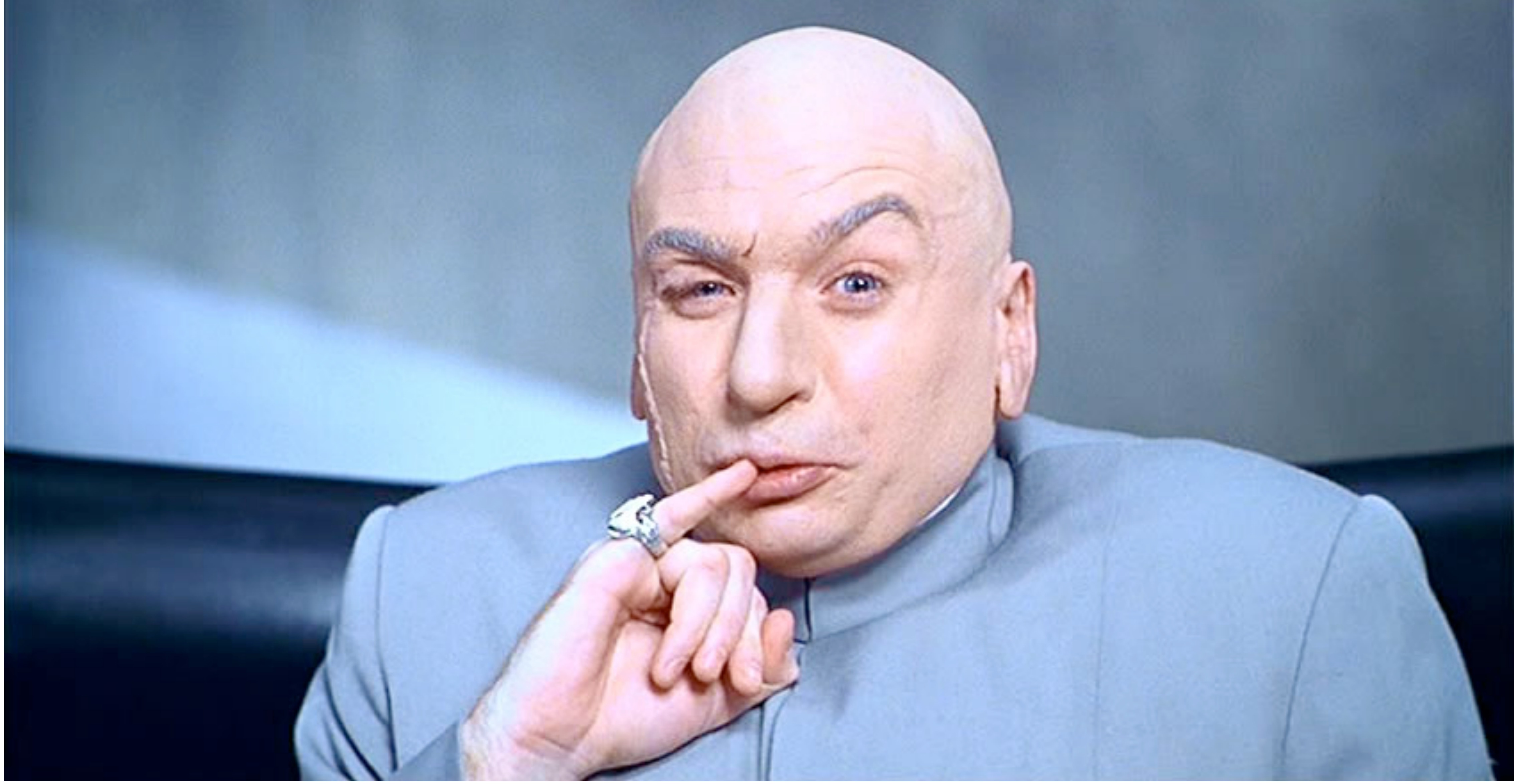
- Too much mass at small radii
  - Cusp-core problem (esp. in dwarfs)
  - Massive bulges & near-maximal disks (bright galaxies)
- Missing Satellites
  - too few satellites around bright galaxies
  - overcooling problem in field

Generic prescription: Feedback

FEEDBACK



cartoon by Joe Silk



Theorist: I have an even better idea. I'm going to place model galaxies in easily escapable dark matter halos by invoking overly elaborate and exotic feedback schemes.
Observer: Wait, aren't you even going to test that? It might not work!
Theorist: No no no, I'm going to leave it alone and not actually witness it happening; I'm just gonna assume it all went to plan. What?