Secular Evolution of Disk Mass profiles

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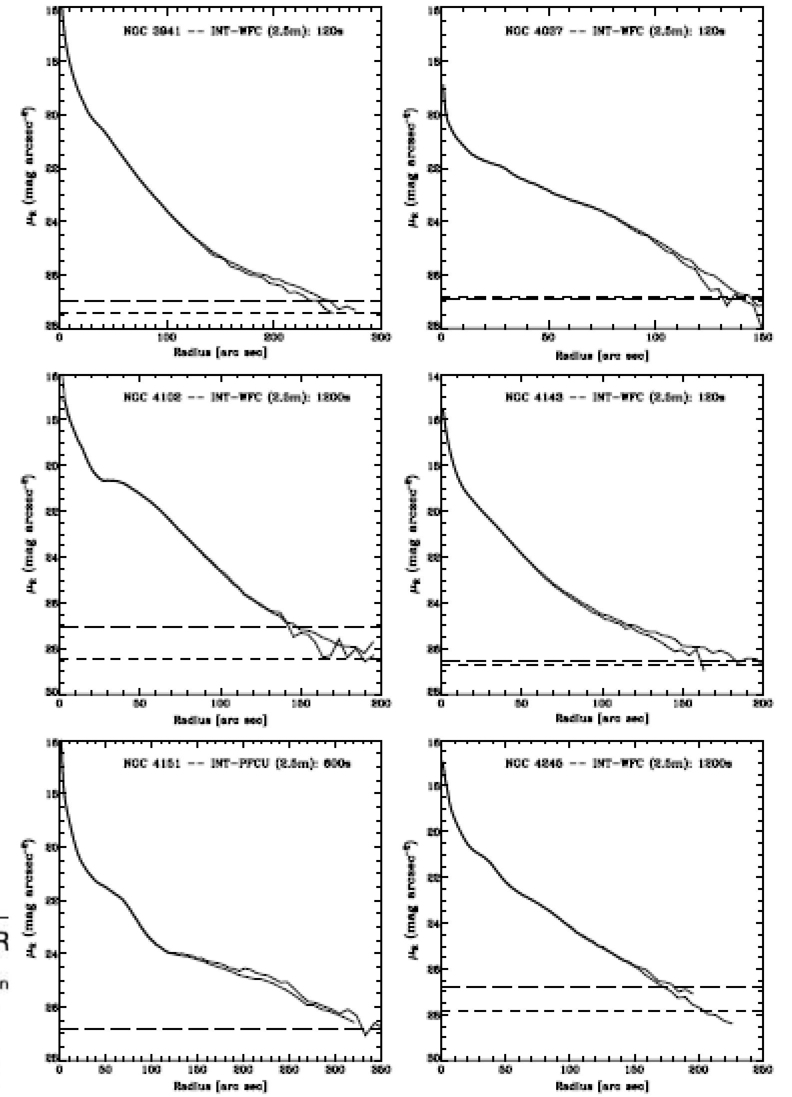
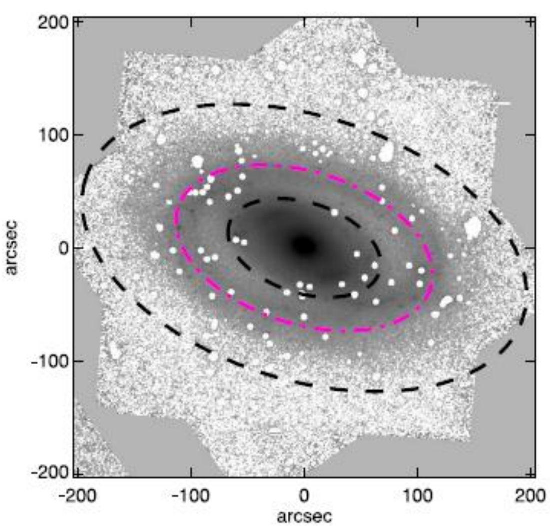
Departures from perfect exponentials

- Aside from type II and type III truncations
- Departures from exponential are equally interesting



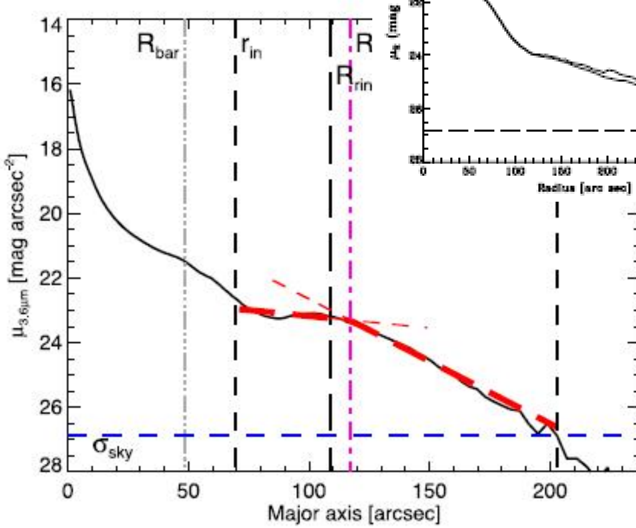


S^{4}G

Type II

NGC7098

Outer ring



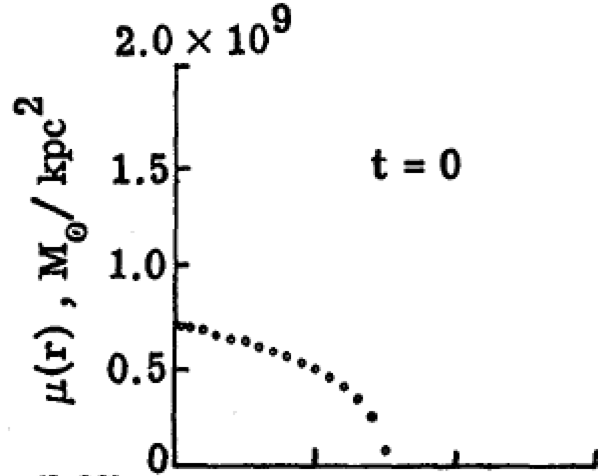
Erwin *et al*.

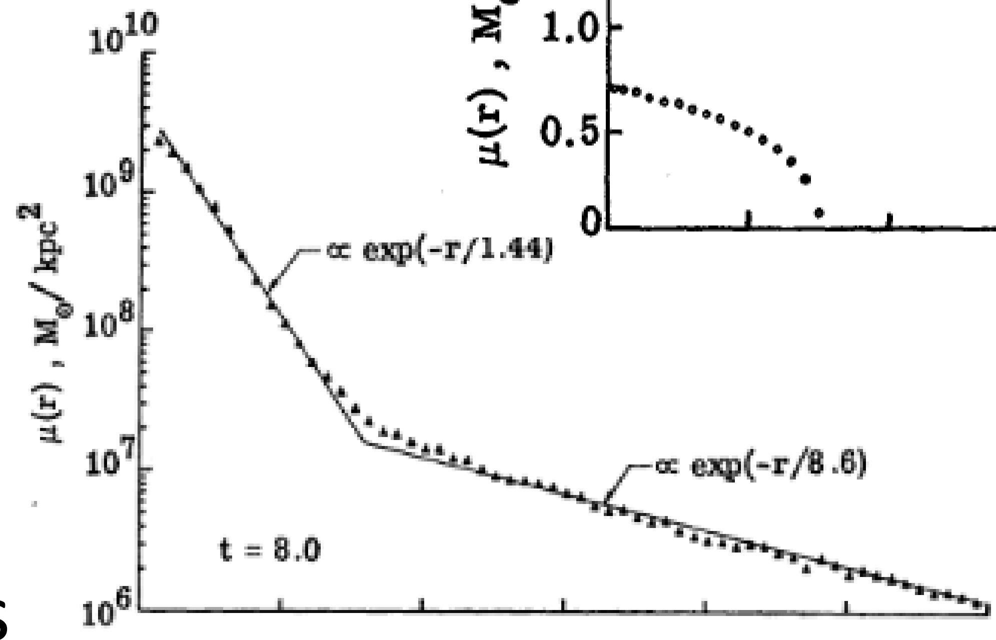
Disk formation

- Most ideas favor "inside out" growth of disks
  - late arriving material has more L_z
- Hierarchical galaxy formation: infalling gas arrives in the disk from
  - a steady drizzle of
  - streams of cold gas
  - lumps from minor mergers
- Just how sensitive is the final disk profile to the detailed distribution of L_z in this material?

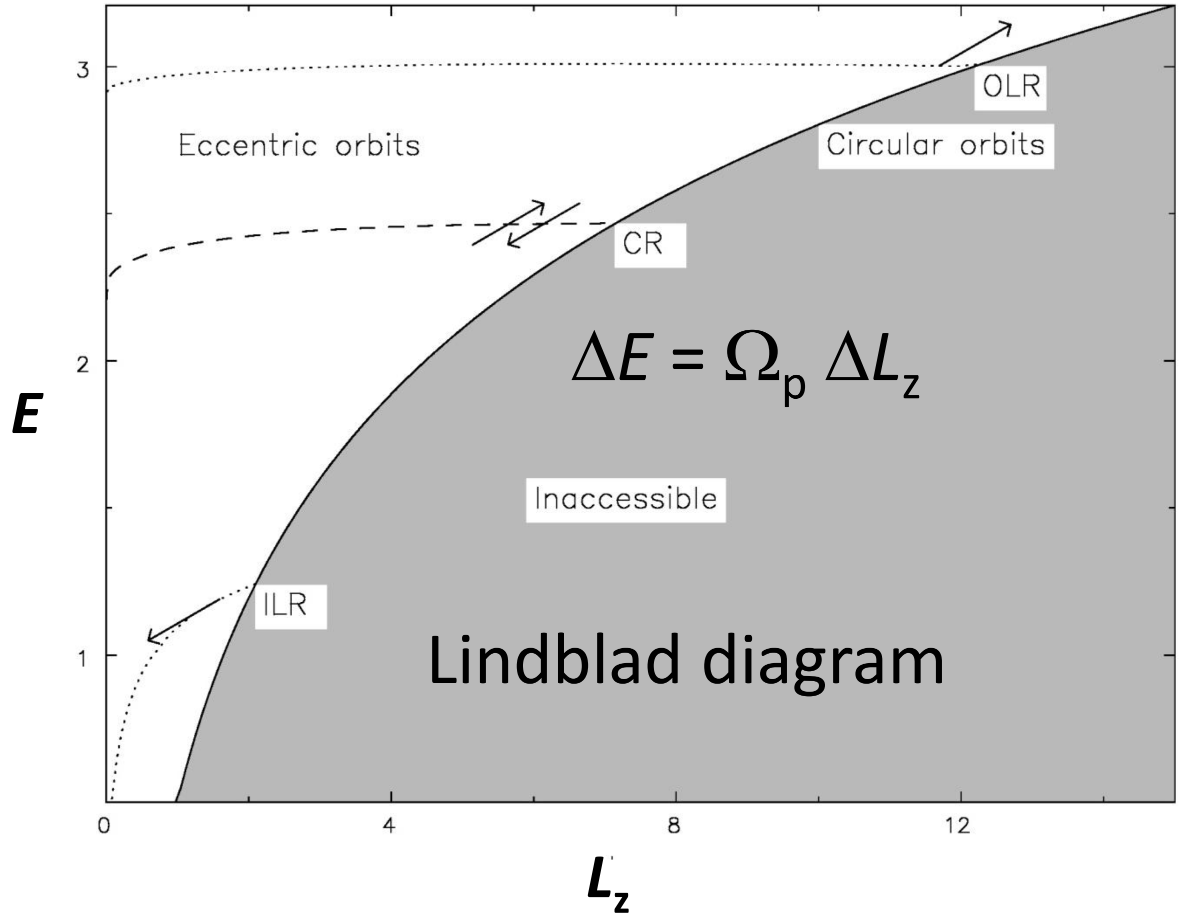
Dynamical instability can create exponential disks

- Bar formation: *e.g*. Hohl (1971), Debattista *et al*. (2006)
  - happens on a short time scale
  - bar persists
  - leaves a hot outer disk
  - not really secular
- Multiple spiral patterns are more promising





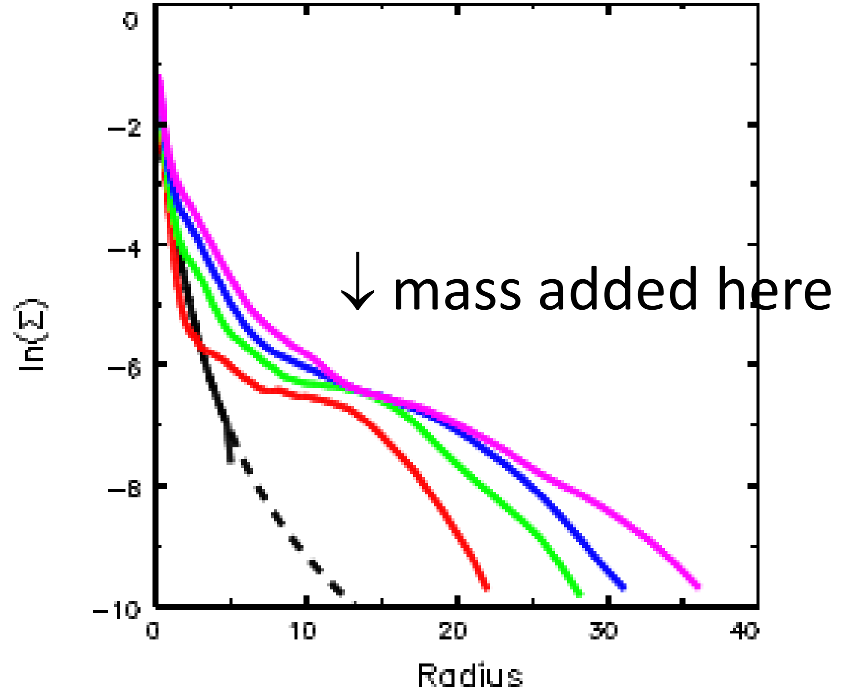
Scattering by rotating perturbations

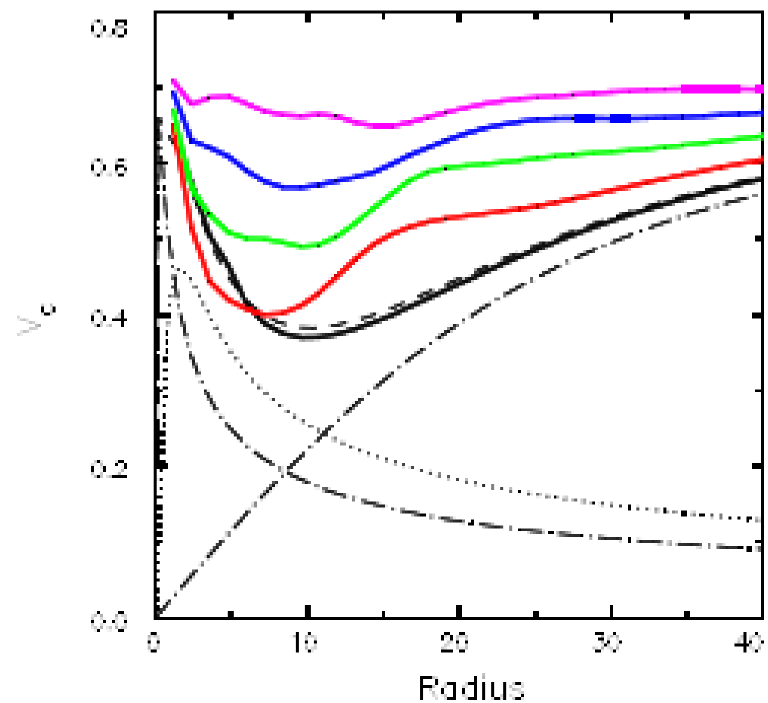


- Angular momentum changes cause heating at Lindblad resonances but not at corotation
- Most disks are dynamically cool, so L_z changes at Lindblad resonances must have been small
- Can L_z changes at corotation change the disk mass profile?

A growing disk

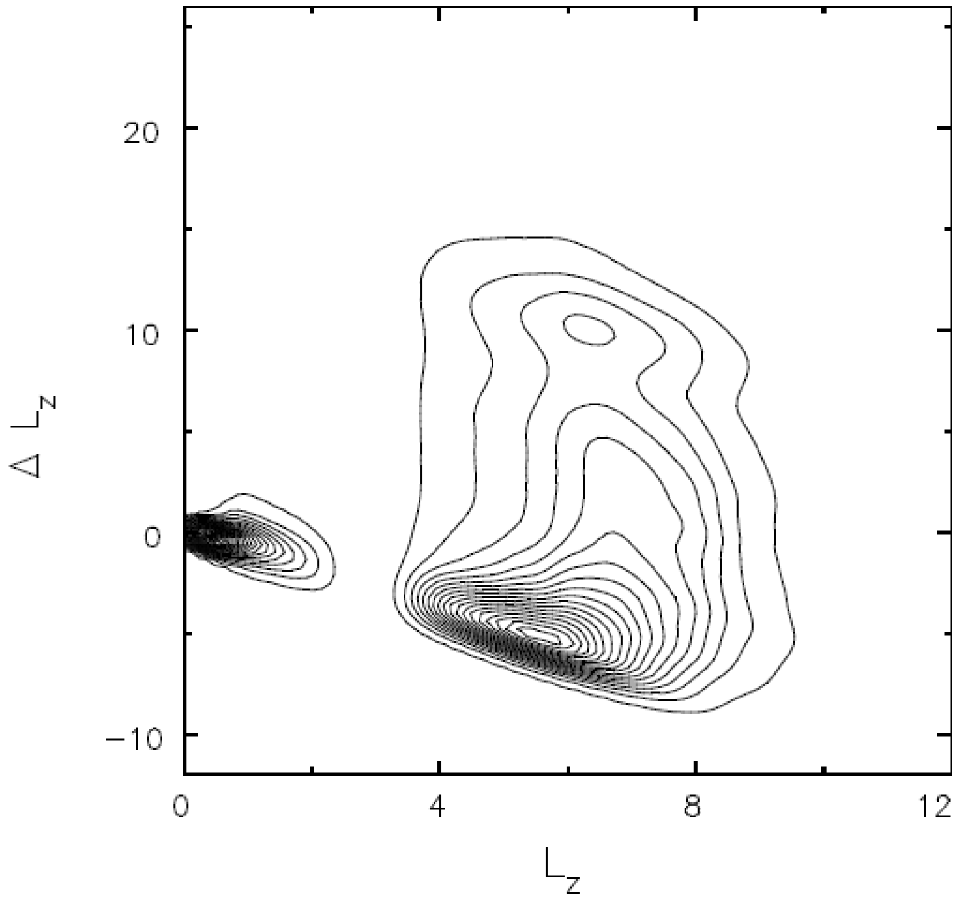
- Artificial simulations
  - rigid bulge & halo to isolate disk dynamics
  - mass added continuously or episodically in a fixed or moving annulus
  - many attempts to make an unrealistic galaxy model
- Strong, open, 2- and 3-arm spirals spread the mass all across the disk over time





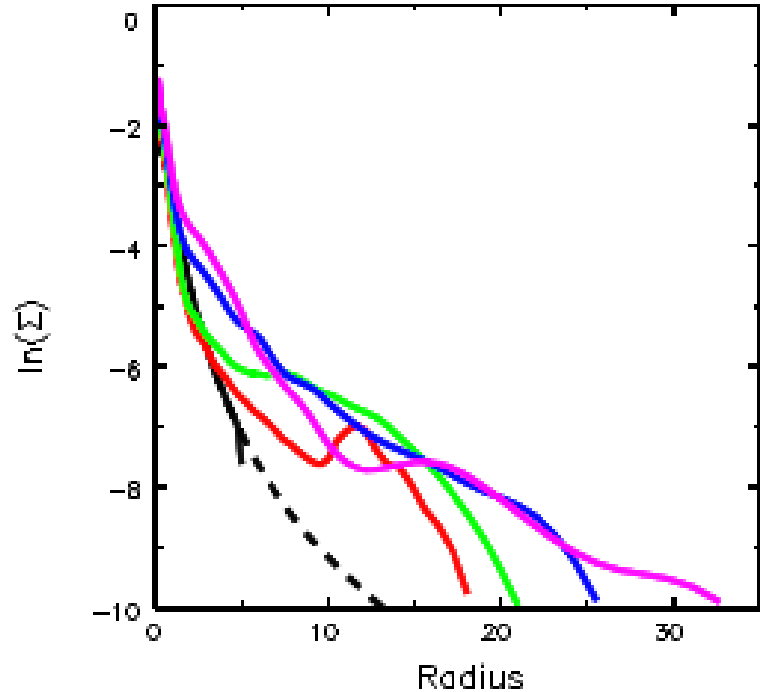
Change of angular momentum

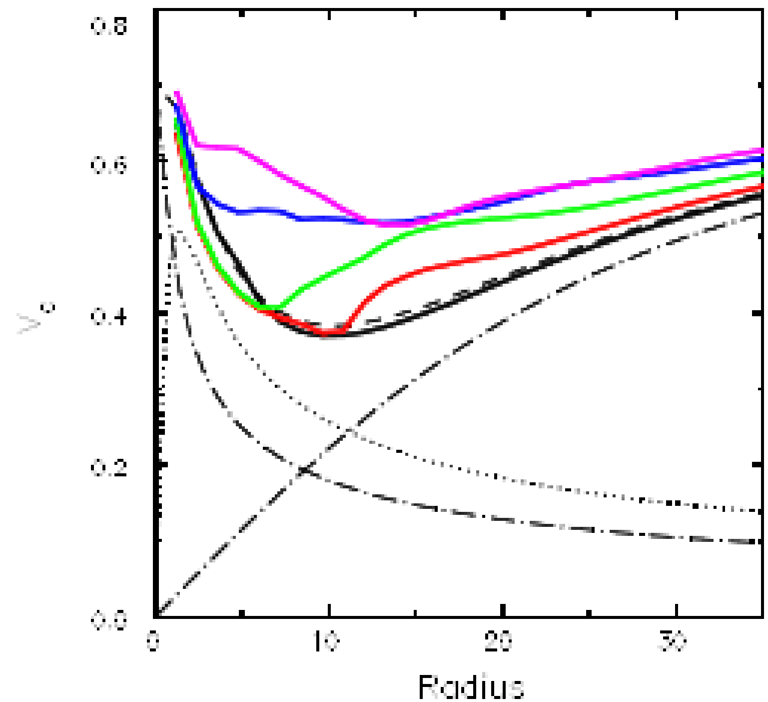
- Initial disk + added particles have separate ranges of initial L_z
- Disk both shrinks and spreads
- Some added particles gain more than twice their initial L_z



"Outside in" growth

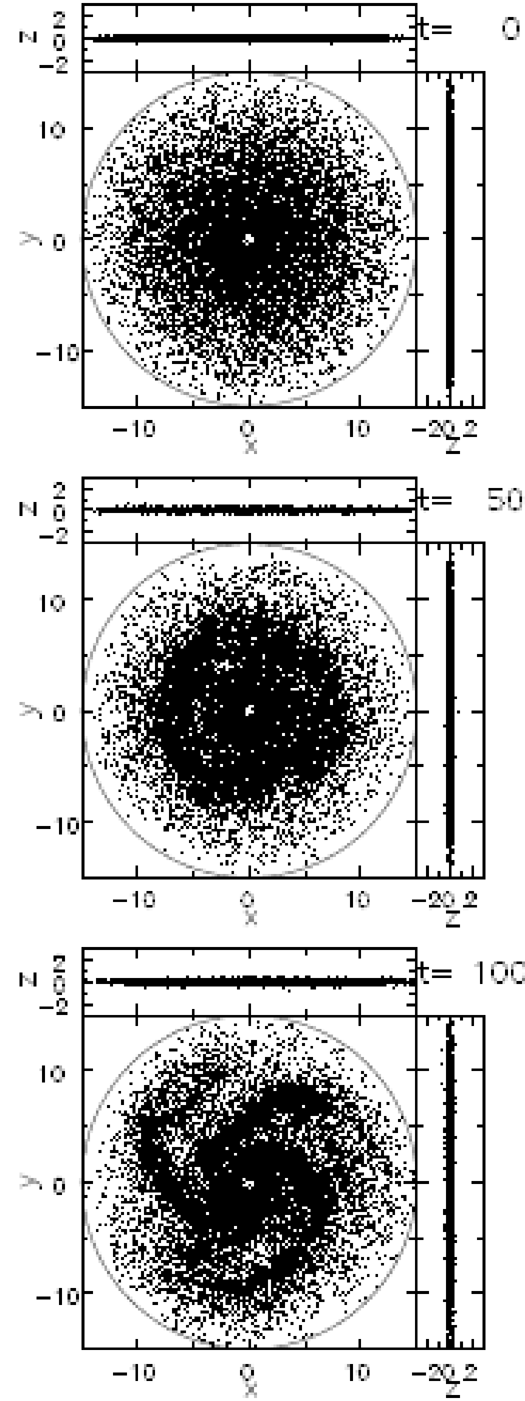
- Radius of added matter moved inwards over time
- Result was pretty nearly the same
  - quasi-exponential disk
  - almost flat rotation curve (blue)
- As with episodic growth, wide or narrow annuli, uniform or Gaussian annuli, *etc*.
- Spirals always spread the mass efficiently



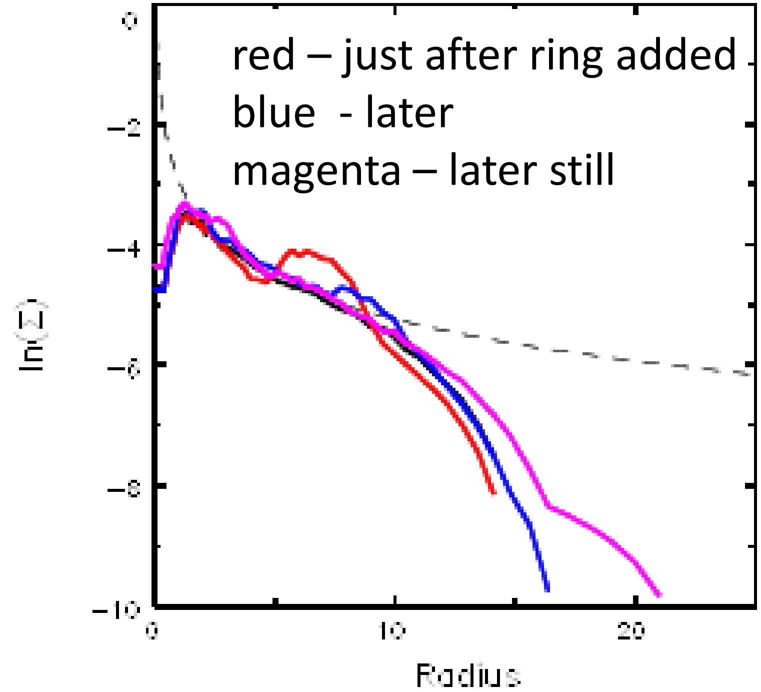


Smoothing mechanism

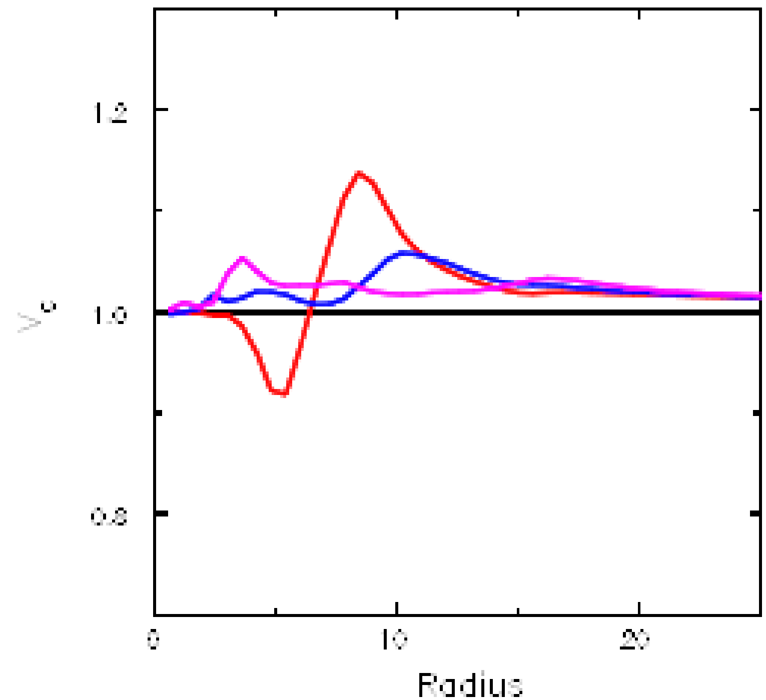
- 1/3 mass Mestel disk (~stable)
- add a ring of mass very quickly then wait to see what happens
- provokes 3-arm spiral pattern
  - swing amplification most effective for *m* = 1/(disk mass fraction) in the Mestel disk



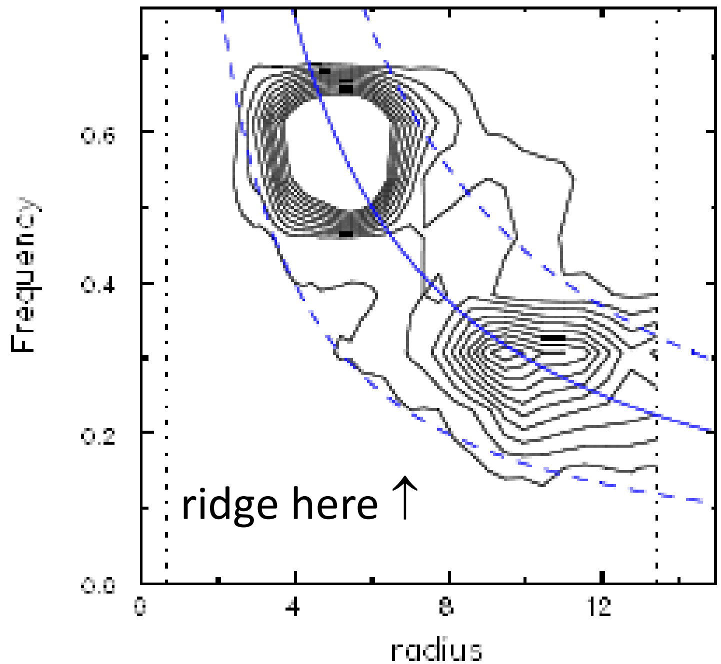
Evolution of density and rotation curve



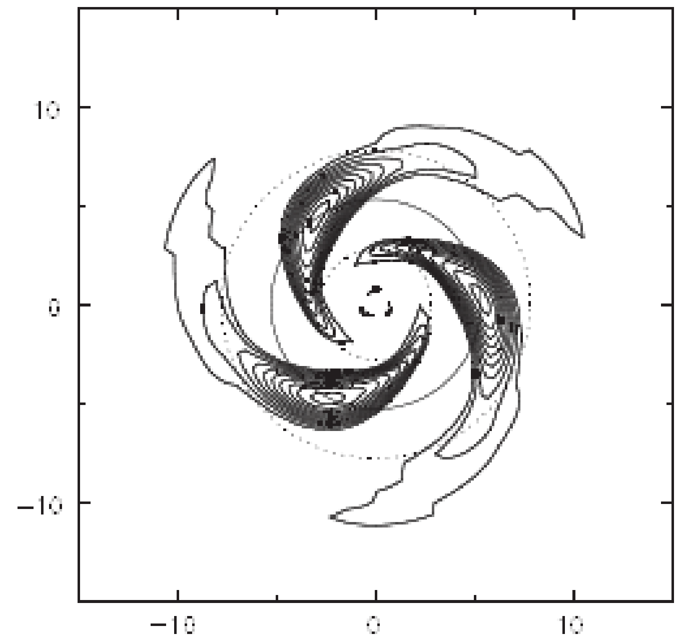
- Feature is erased very effectively
- within ~5 orbits at the ring radius

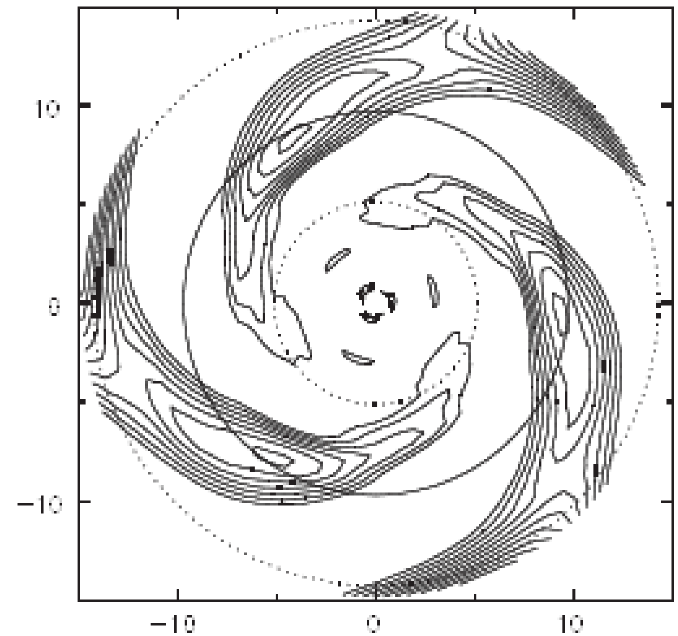


Two m=3 modes were excited

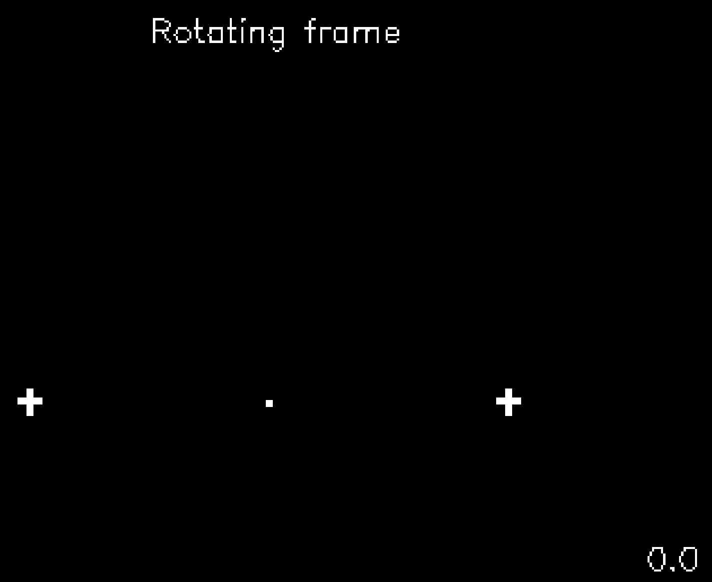


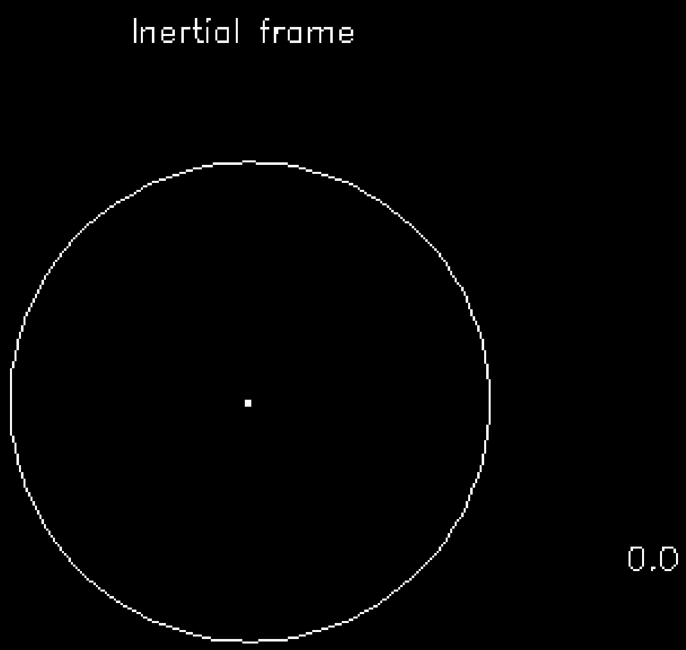
- Rapidly growing modes
- Corotation of each just in/outside the overdensity





Horseshoe in rotating frame

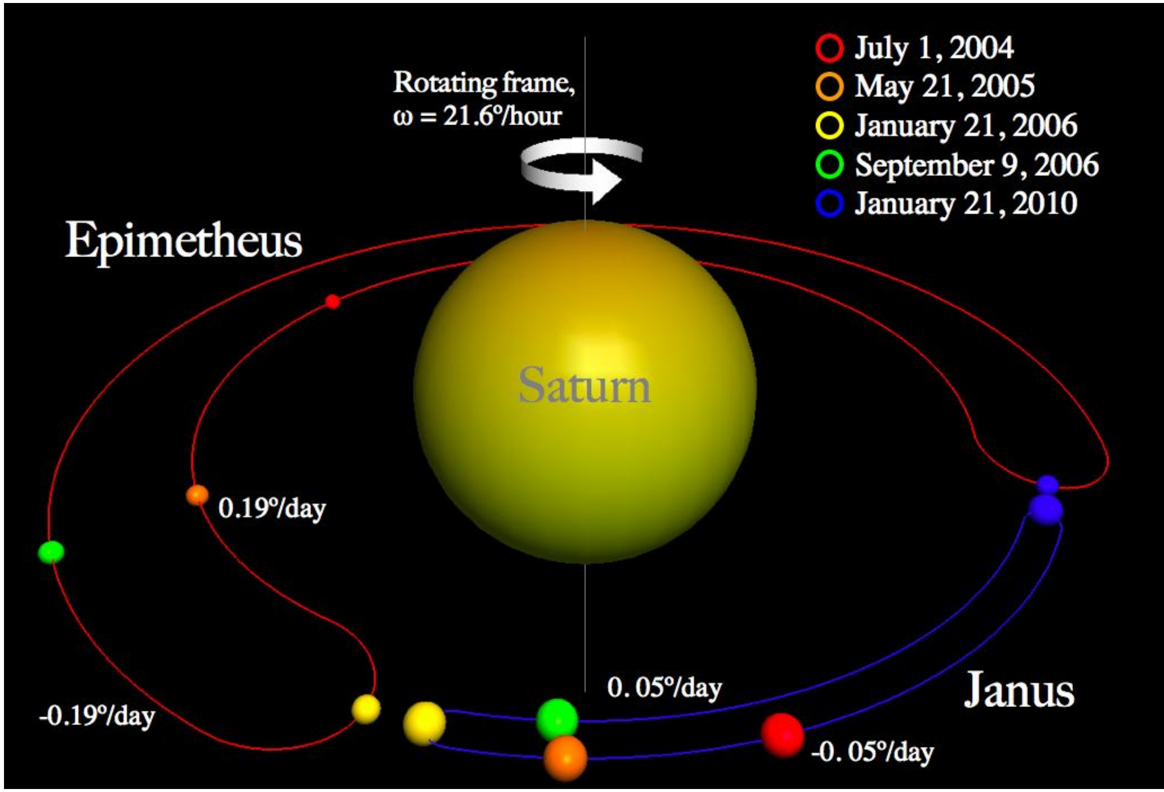




- Crossed corotation because L_z changed
- But no increase in epicyclic motion

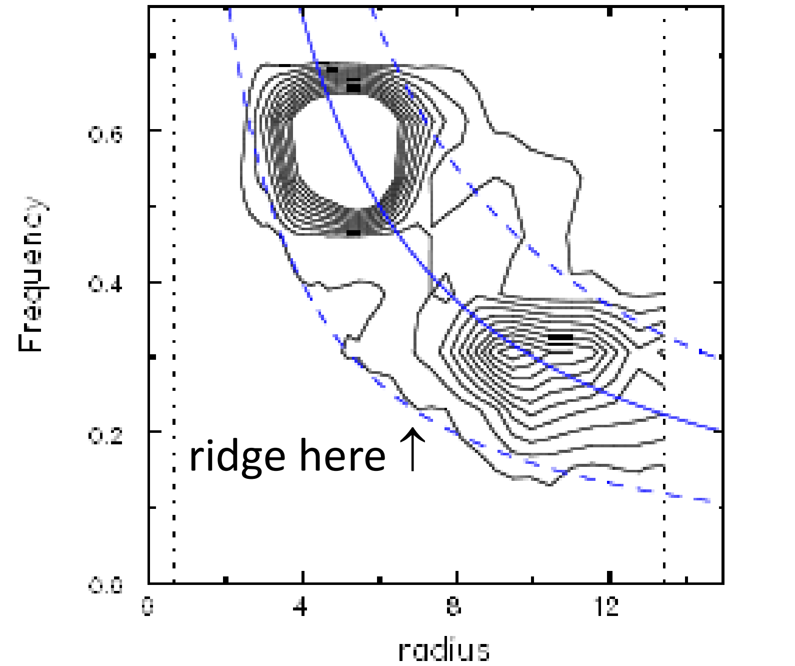
Horseshoe orbits

- Orbits swap sides of corotation
  - reverse direction in the rotating frame only



- Same happens in spirals
  - but their transient nature causes just one change for each star
  - angular momentum can change by ~20% in one step with no increase in random motion

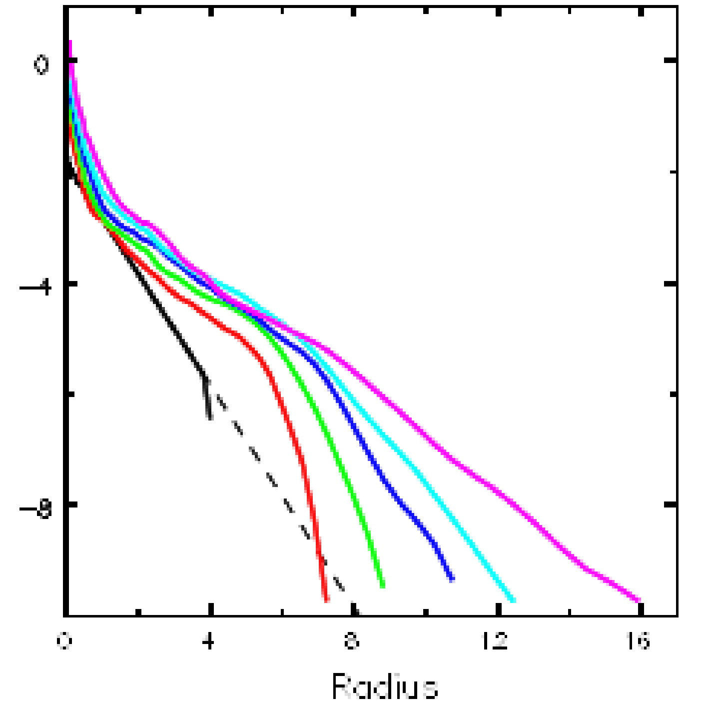
Ridge is erased

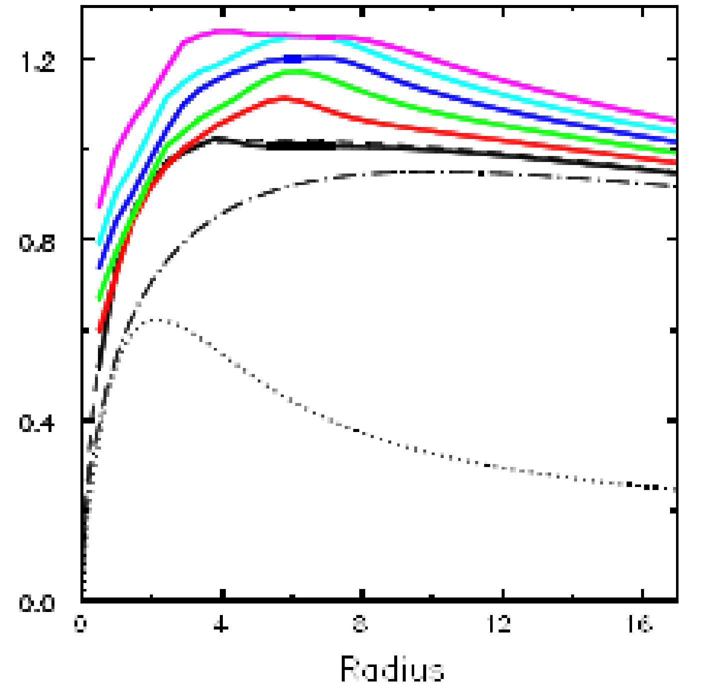


- Roughly equal numbers of stars gain and lose in a disk having a smooth profile
- Little change – they simply swap places
- But with a density ridge, spirals pull much more mass out of the ridge, both inwards and outwards, than they put back into the ridge
- The ridge is flattened
  - – argued by Lovelace & Hohlfeld (1979)!

Sub-maximal disk

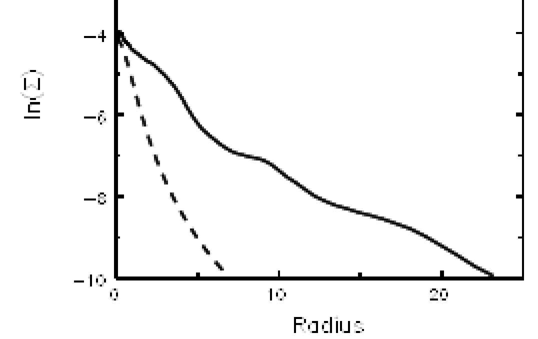
- Similar calculation, but more halo dominated
- Smaller scale, more multi-arm patterns
  - as expected for a sub-maximal disk
- Feature in both density profile and rotation curve erased more slowly

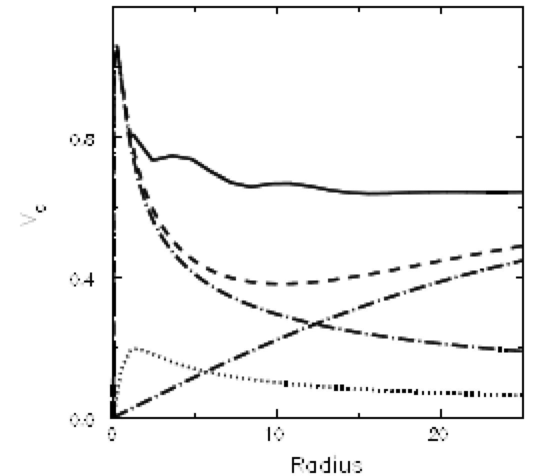


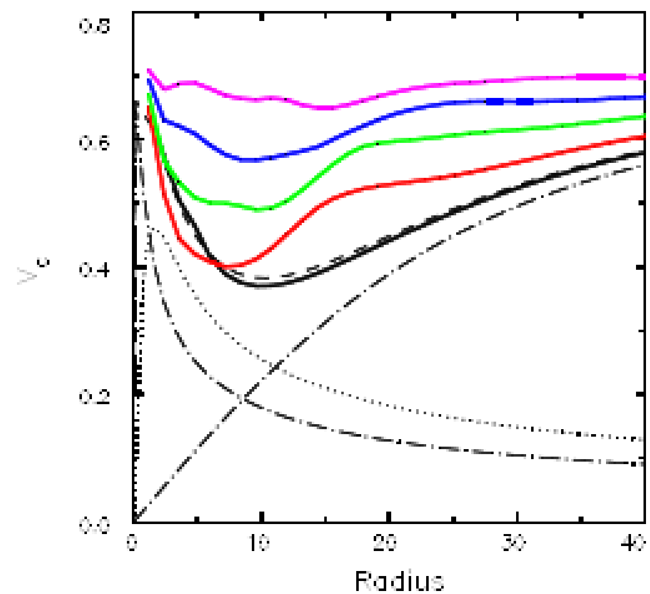


Renzo's rule

- Sancisi (2004) remarked
  - "For any feature in the luminosity profile there is a corresponding feature in the rotation curve and vice versa"
- We see this all the time in our simulations
- Also a "disk-halo conspiracy" (Bahcall & Casertano 1985)



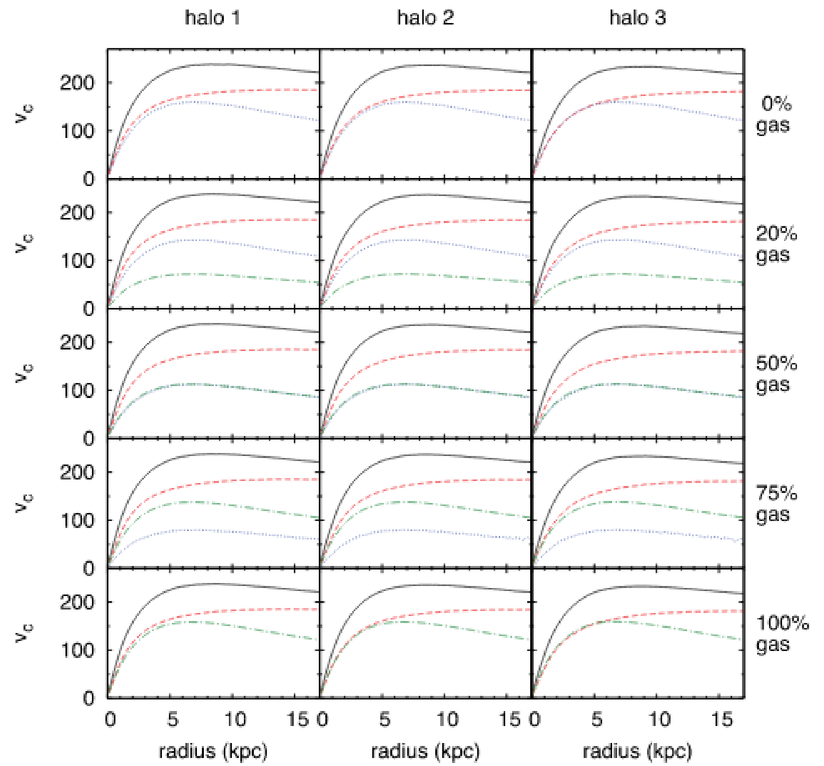


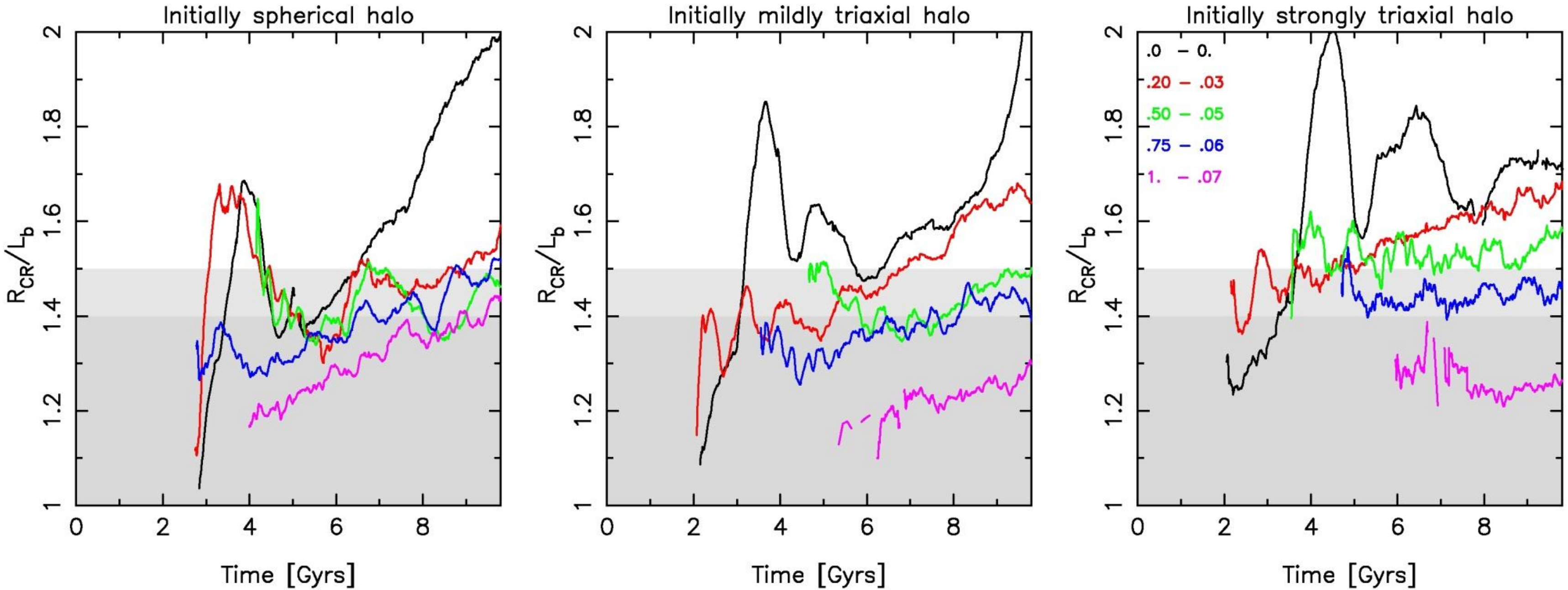


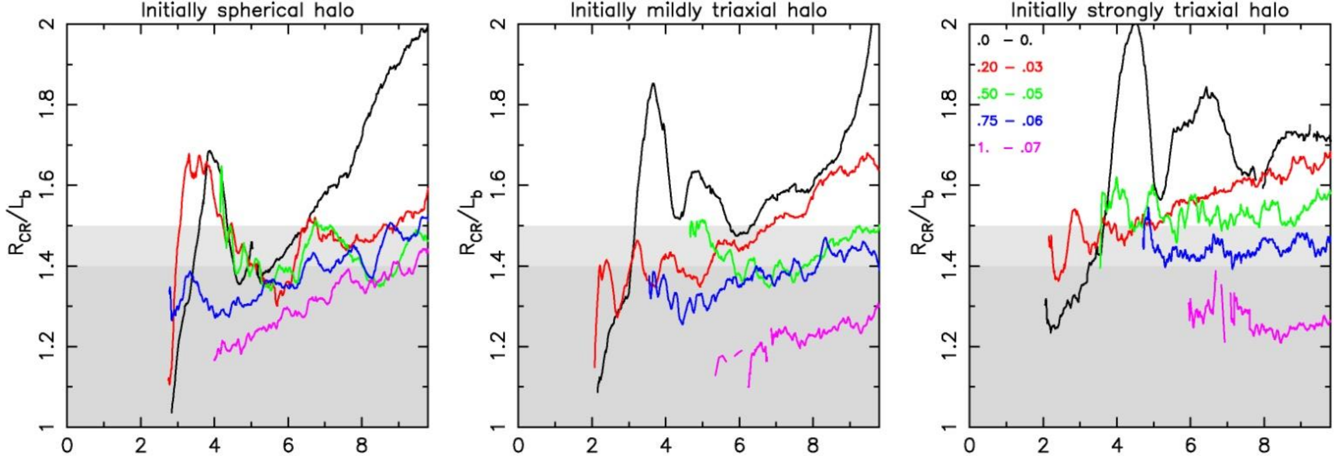
Maximum disks

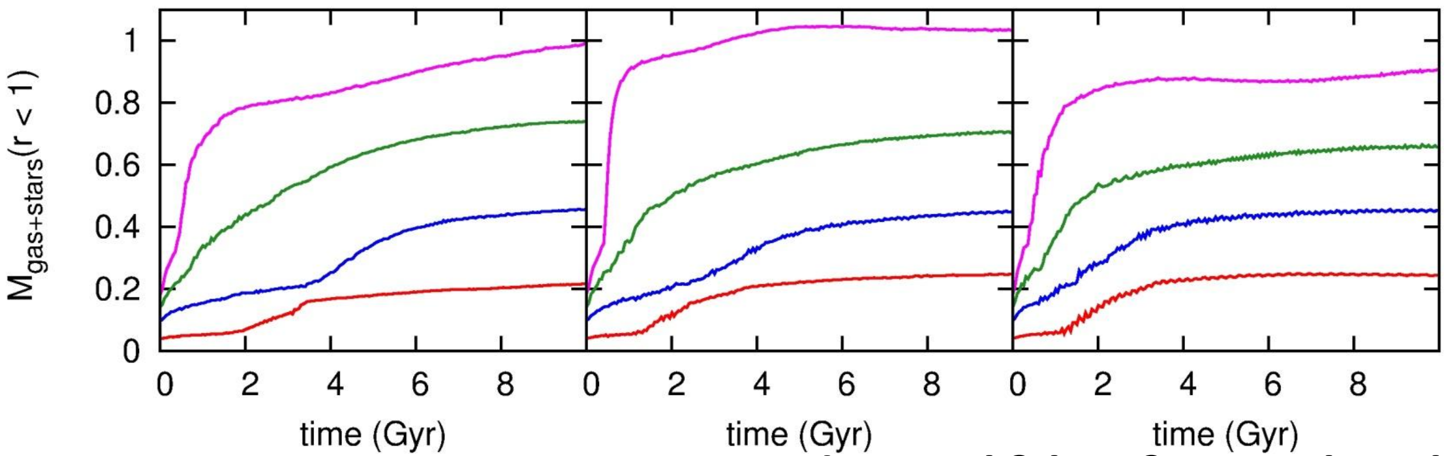
- Many strands of evidence suggest that baryonic matter dominates the central attraction in large, HSB disk galaxies
  - gas flow in bars (e.g. Weiner et al. 2001)
  - spiral arm multiplicity (e.g. JS & Carlberg 1984)
  - dynamical friction against bars (Debattista & JS 2000) if $\mathscr{R} \equiv R_c/a_B < 1.4$ for a strong bar $\rightarrow$ the galaxy has a maximum disk
  - notwithstanding Athanassoula (2014) who wrote: "the $\mathscr{R}$ value cannot constrain the halo density, nor determine whether galactic discs are maximal or submaximal"

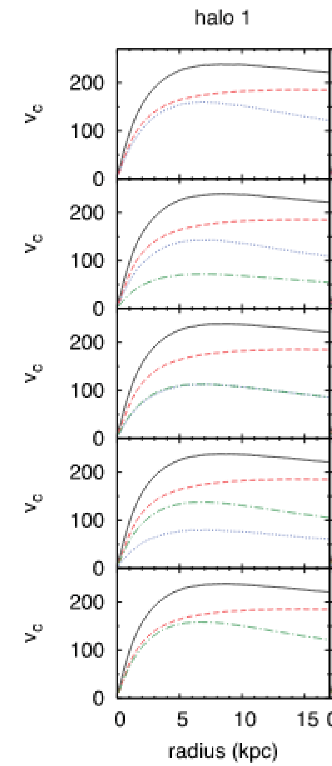
- Her argument was based on the figure below
- All models start with the same submaximal disk











- Gas mass rearranged itself before the bar settled
  - – i.e. gas rich disks quickly became maximal
- $\mathscr{R}$ values in complete agreement with other work
- Remains true that $\mathscr{R} < 1.4$ requires a max disk

Conclusions

- The final surface density profile is insensitive to the detailed distribution of angular momentum of material that makes up the disk
  - high L_z mass on circular orbits can be spread radially by spiral patterns
  - effected by changes at corotation without heating
  - relative change in radius up to $\sim$20%
  - later patterns can spread it farther
- Happens more slowly in sub-maximal disks