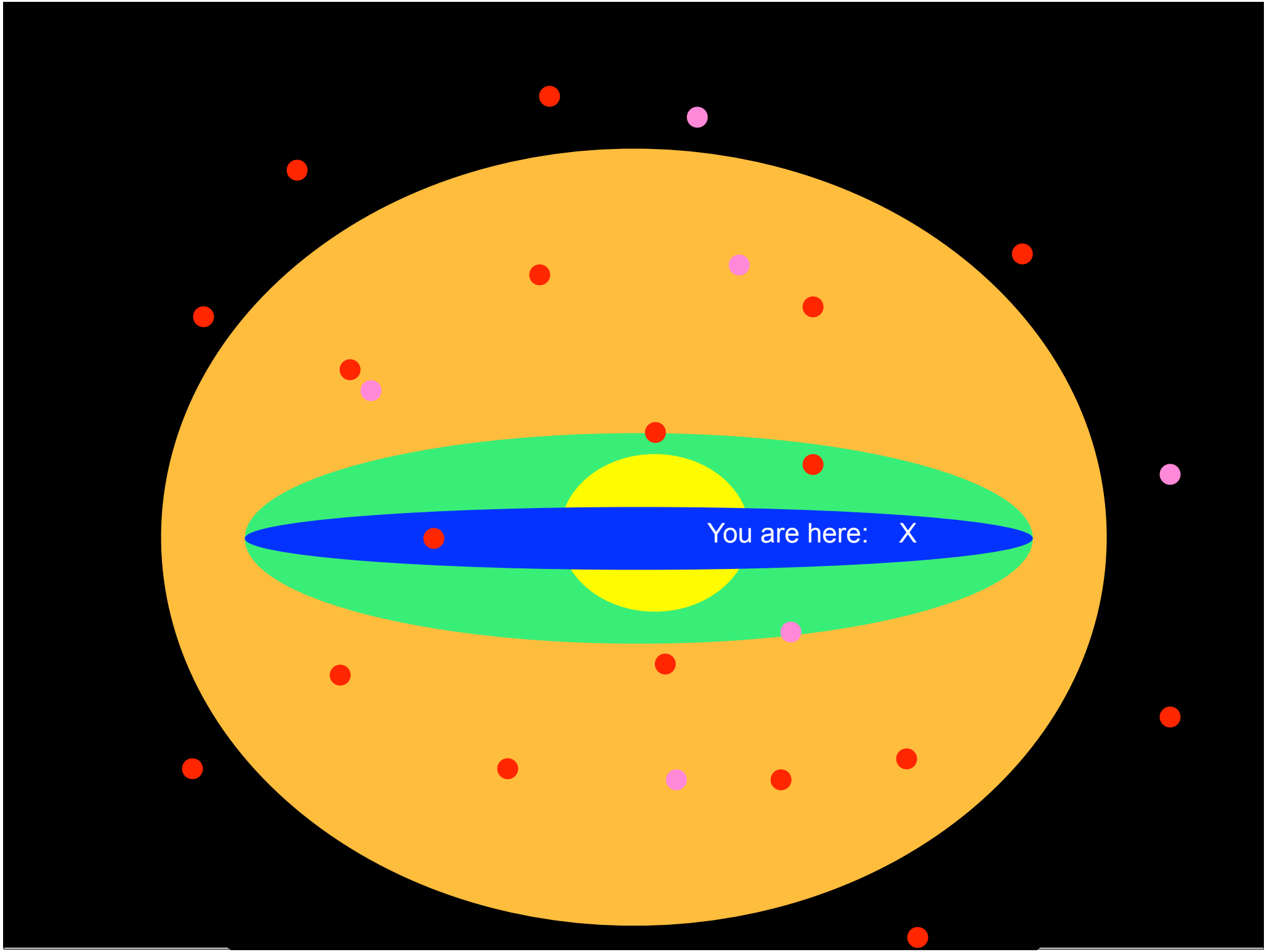

The Joys of Thick Disks
Peter Yoachim
Astro 323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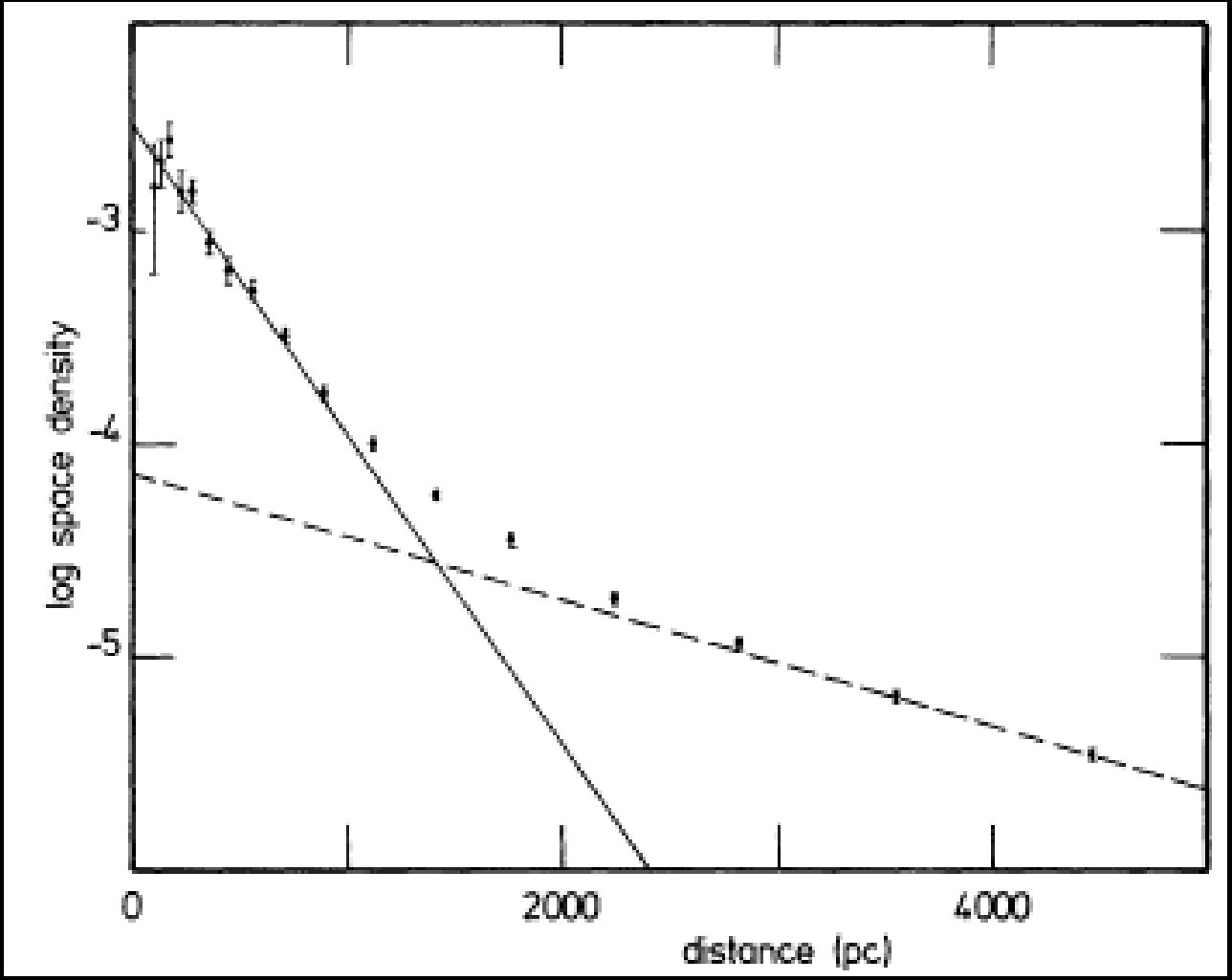
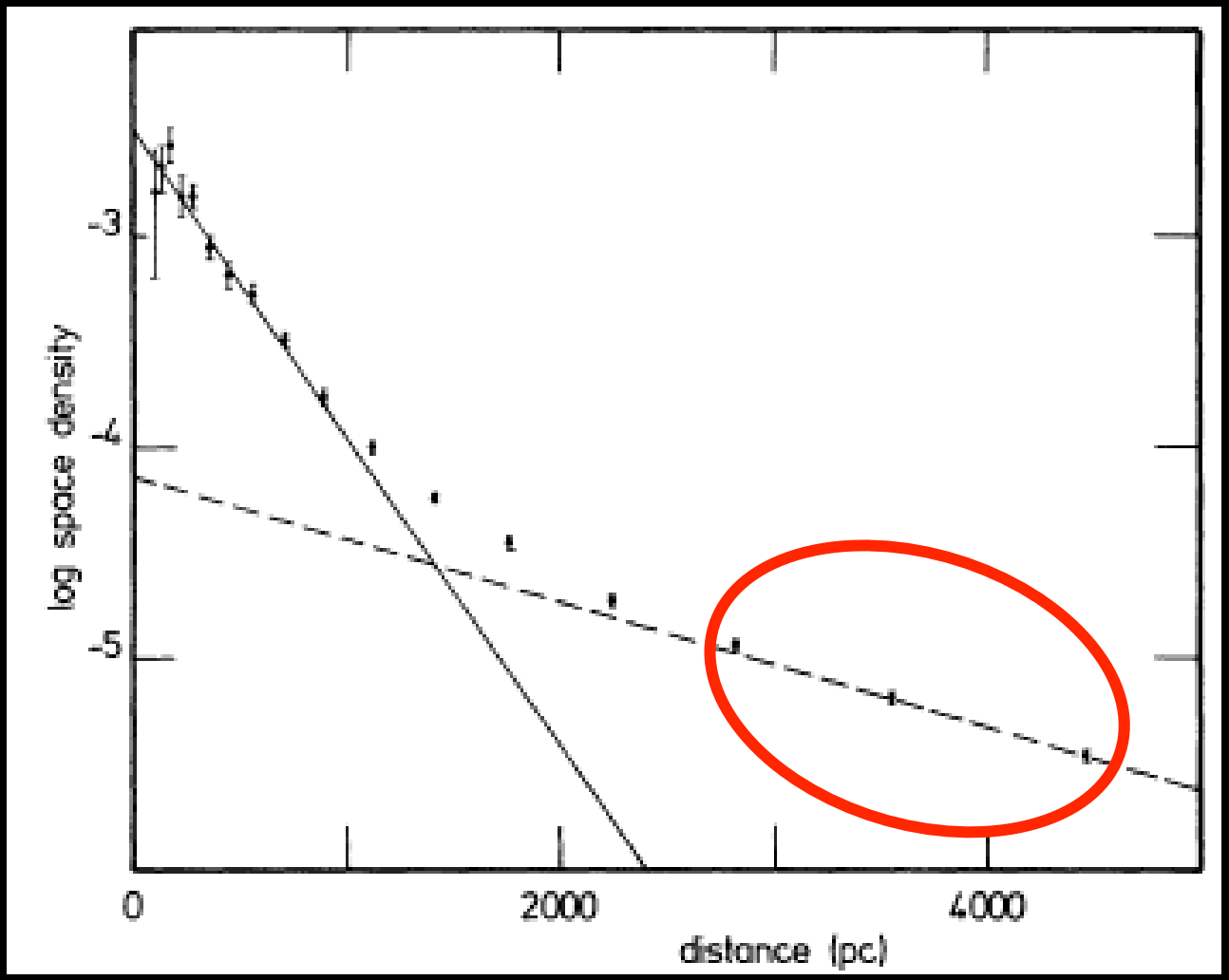
Discovery of the Thick Disk

Gilmore & Reid 1983

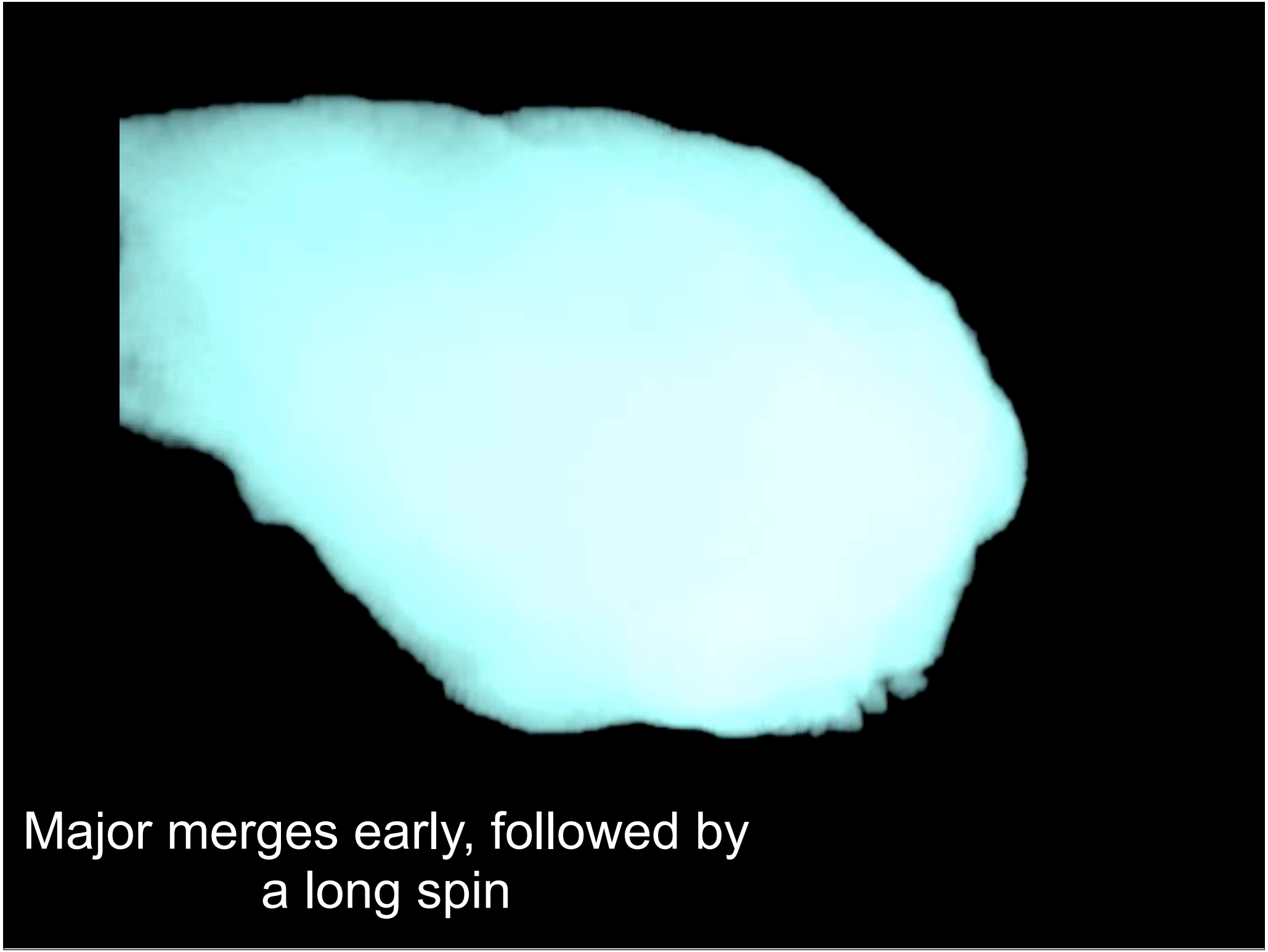


"While it suggests that the thick disk is real, data from just a handful of extra stars could substantially weaken the case. A man could not be safely hanged on such evidence." B&T



How the heck do stars get that far out of the disk?

Maybe stars could scatter off giant molecular clouds--but calculations showed you would need multiple encounters.

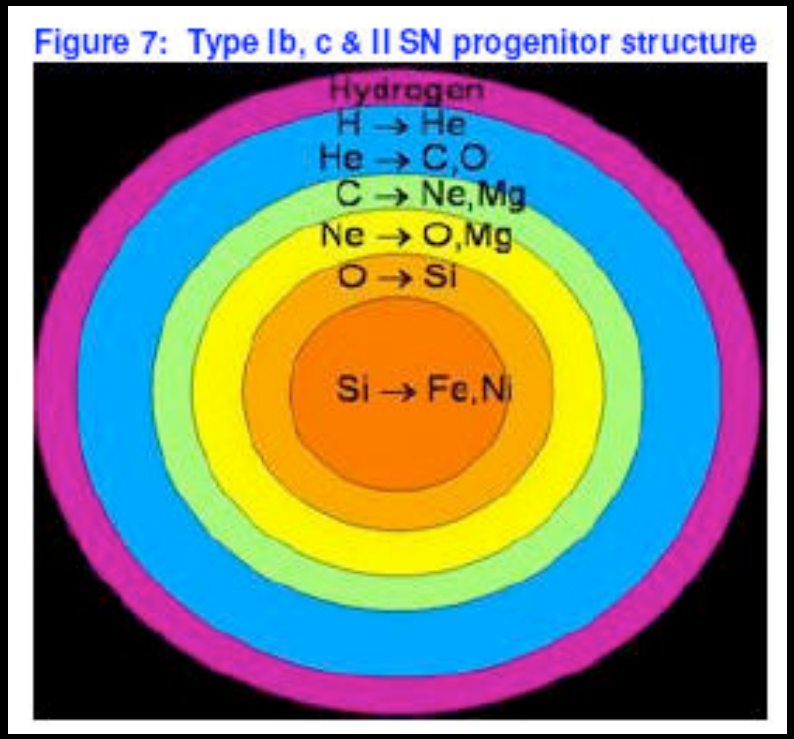

Major merges early, followed by
a long spin

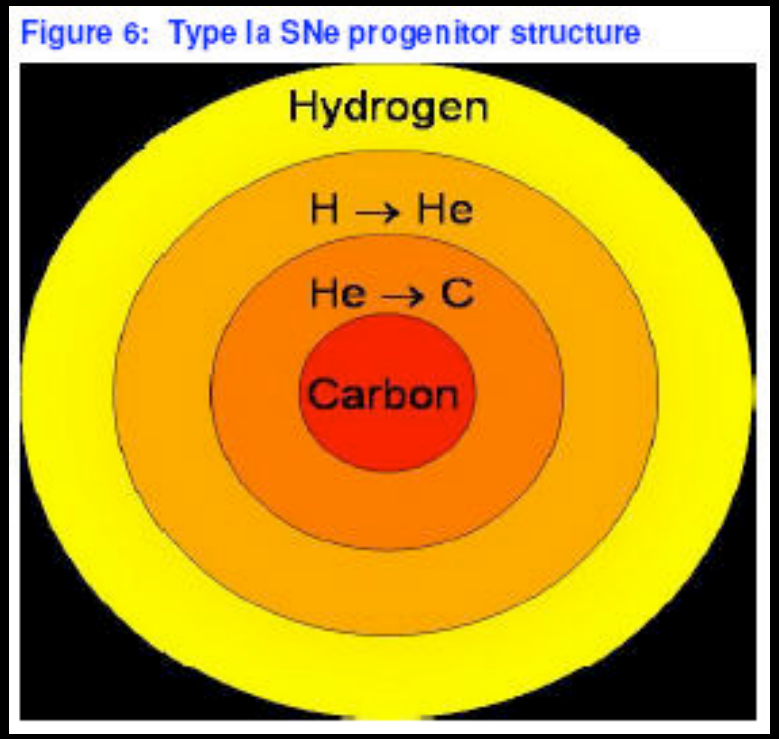
How can we tell stars were formed together?

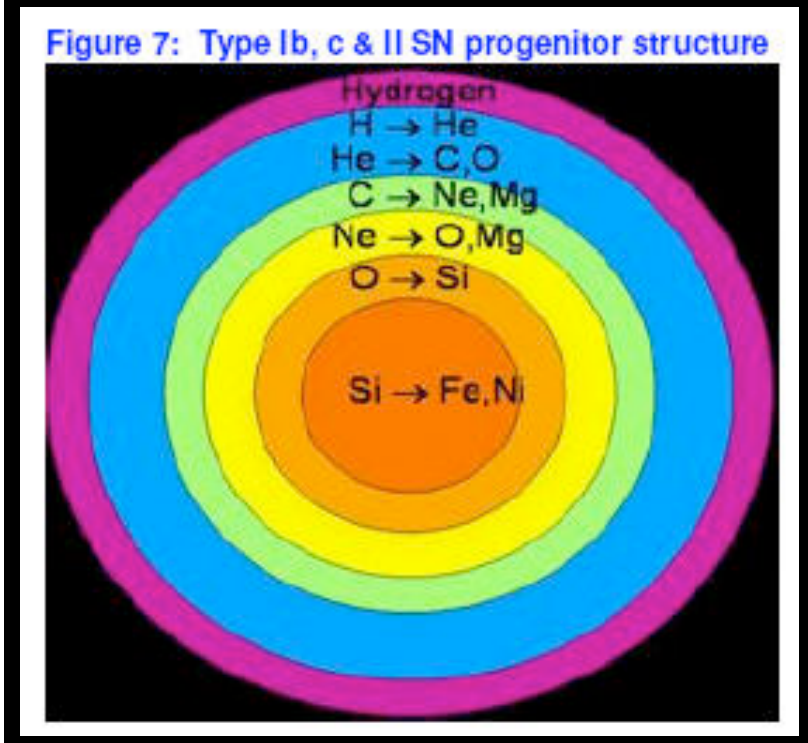
1. Same age (hard for individual stars)
2. Similar location
3. Similar kinematics
4. Similar composition

Composition of stars

Get heavy elements from supernovae

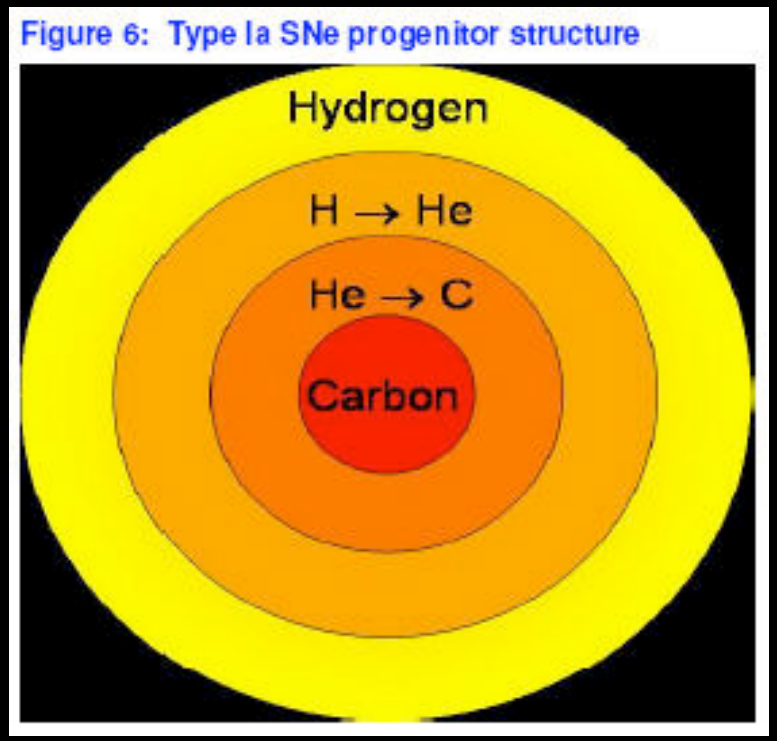






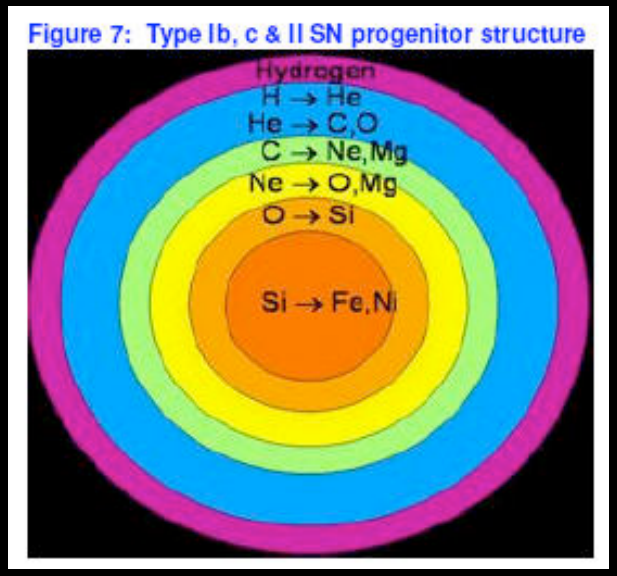
Massive stars

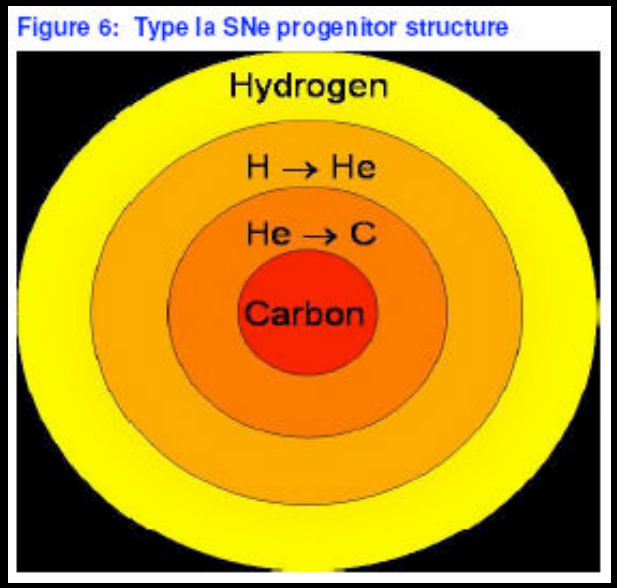
- Fe gets locked up in neutron star or black hole
- All those outer shells get blasted out, releasing lots of alpha-elements (C,O,Ne, Mg, etc)
- High mass stars have short lifetimes



Low mass stars

- run-away fusion burns the entire core into Ni and Fe
- all the material gets blown out
- low mass stars have long lifetimes

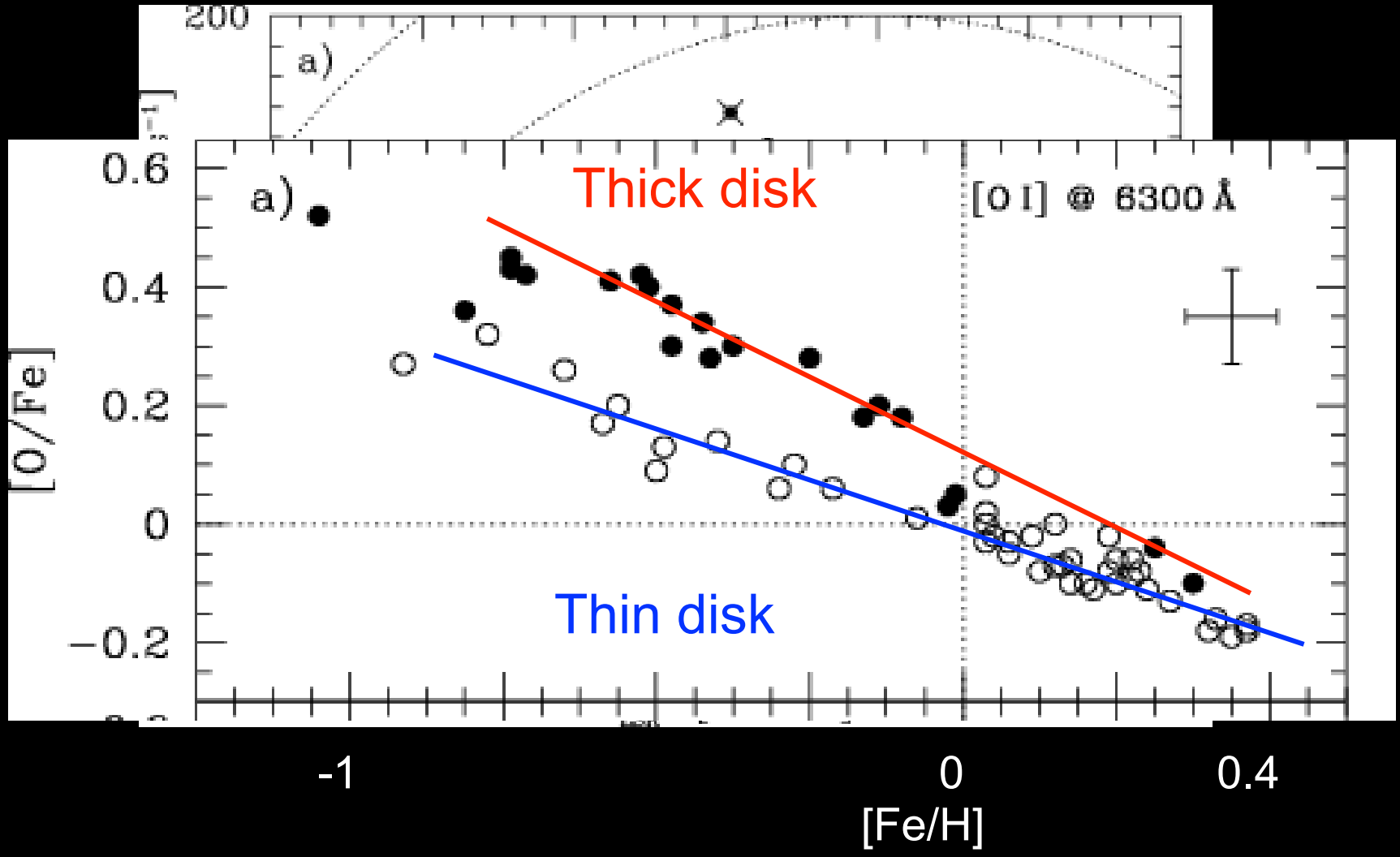




So, if there is a burst of rapid star formation:
Type II Sn go off and we start forming stars rich in alpha-elements

If we have gradual extended star formation:
Type I Sn dominate, and stars start forming rich in Fe.

Abundance trends show MW thin and thick disks are chemically distinct

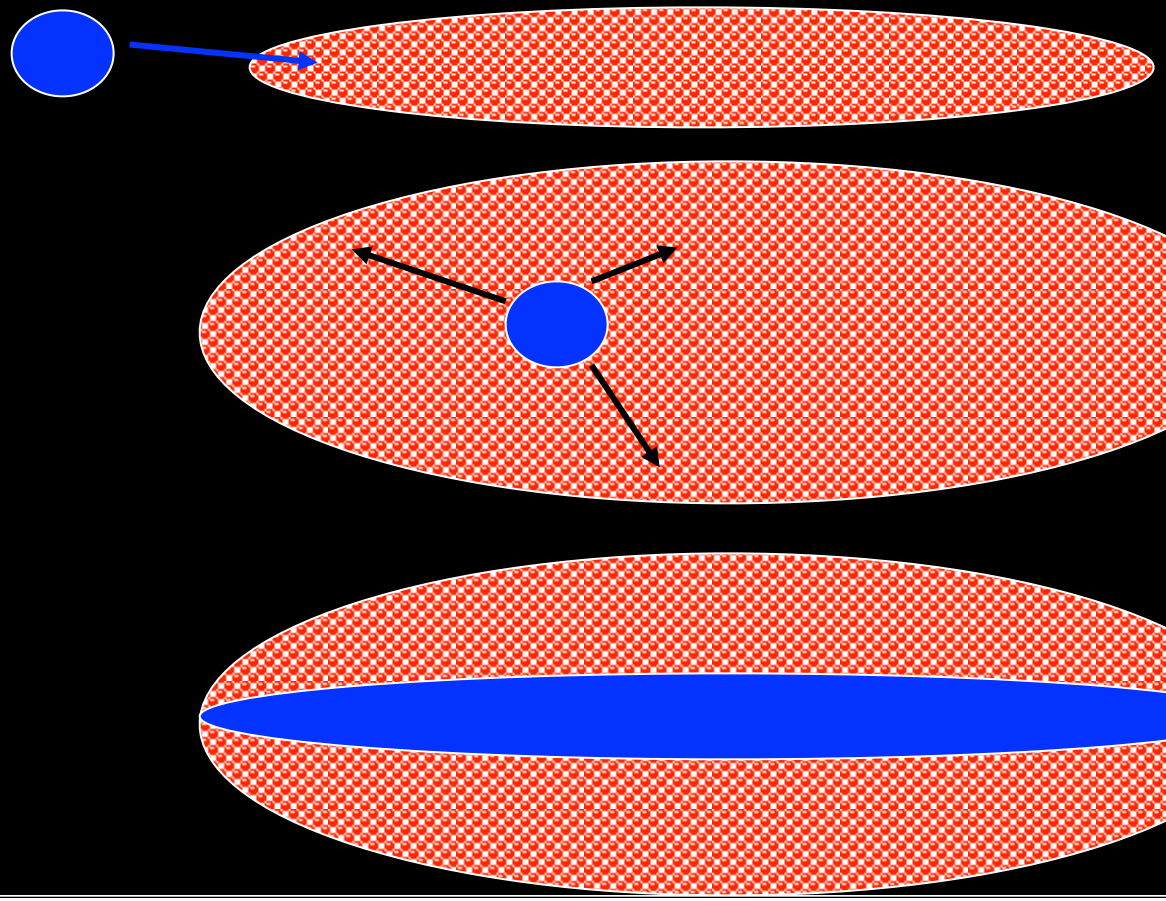


Bensby et al., 2004

Blue=gas Red=stars

How to Form a Thick Disk 1:

Heat a thin disk with a major merger



Satellite galaxy hits thin stellar disk

Deposited energy heats the stellar disk

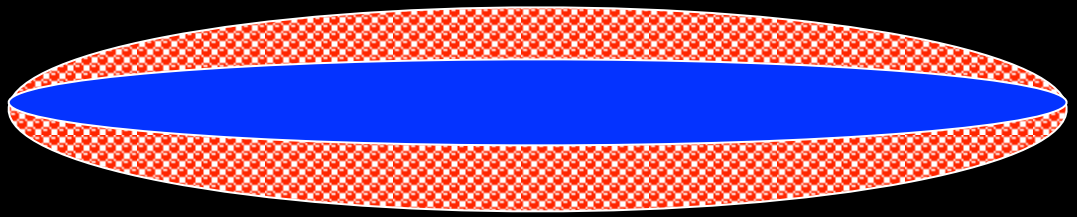
Gas collapses to form a new thin disk

Blue=gas Red=stars

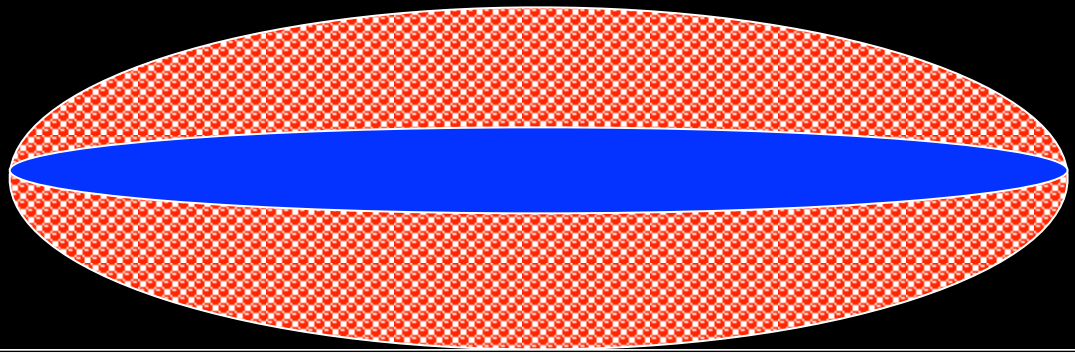
How to Form a Thick Disk 2:

Gradual stochastic heating

Stars form in a thin disk



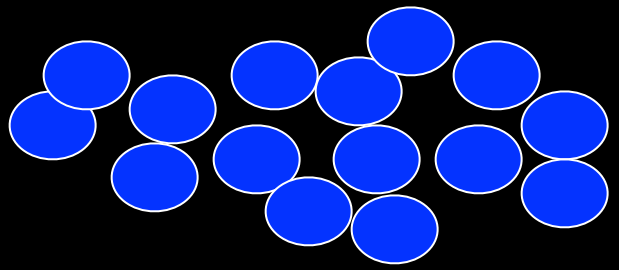
Over time, stars scatter and heat



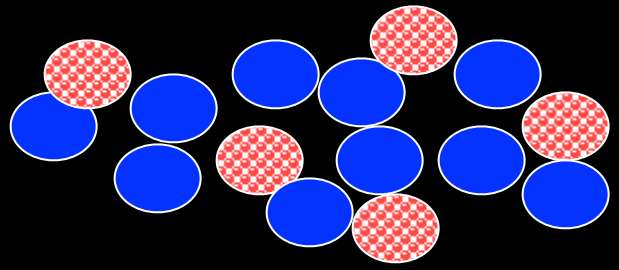
Gradually a thick disk gets populated

How to Form a Thick Disk 3:

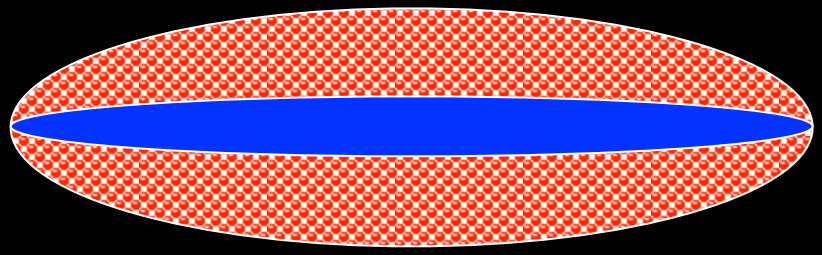
Form stars before the gas has a chance to settle down into a thinner disk



Gas merging/collapsing to a thin disk



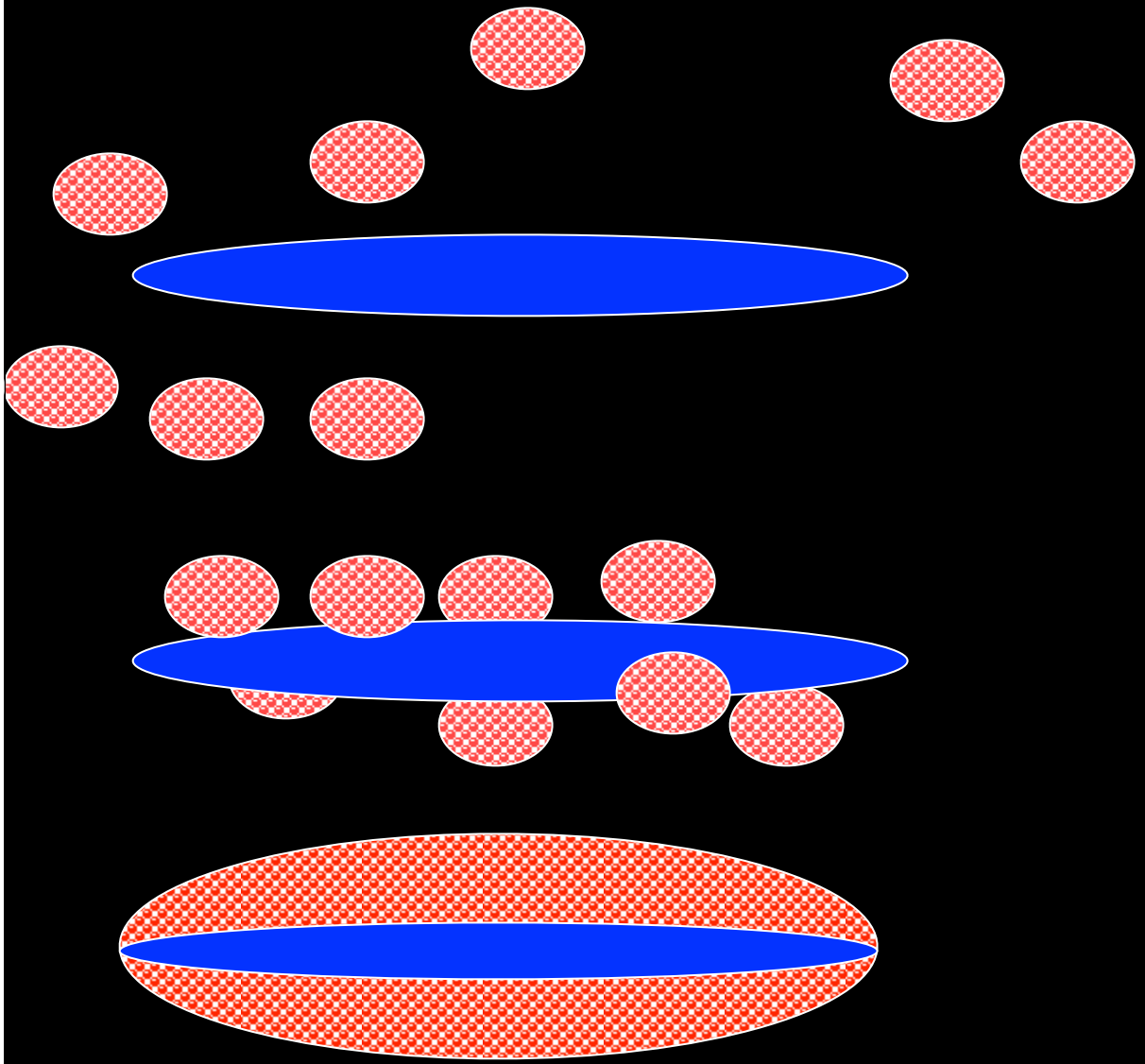
Stars form before collapse complete



Stars can’t collapse more, but gas can

How to Form a Thick Disk 4:

Strip stars from satellite galaxies into a thick disk



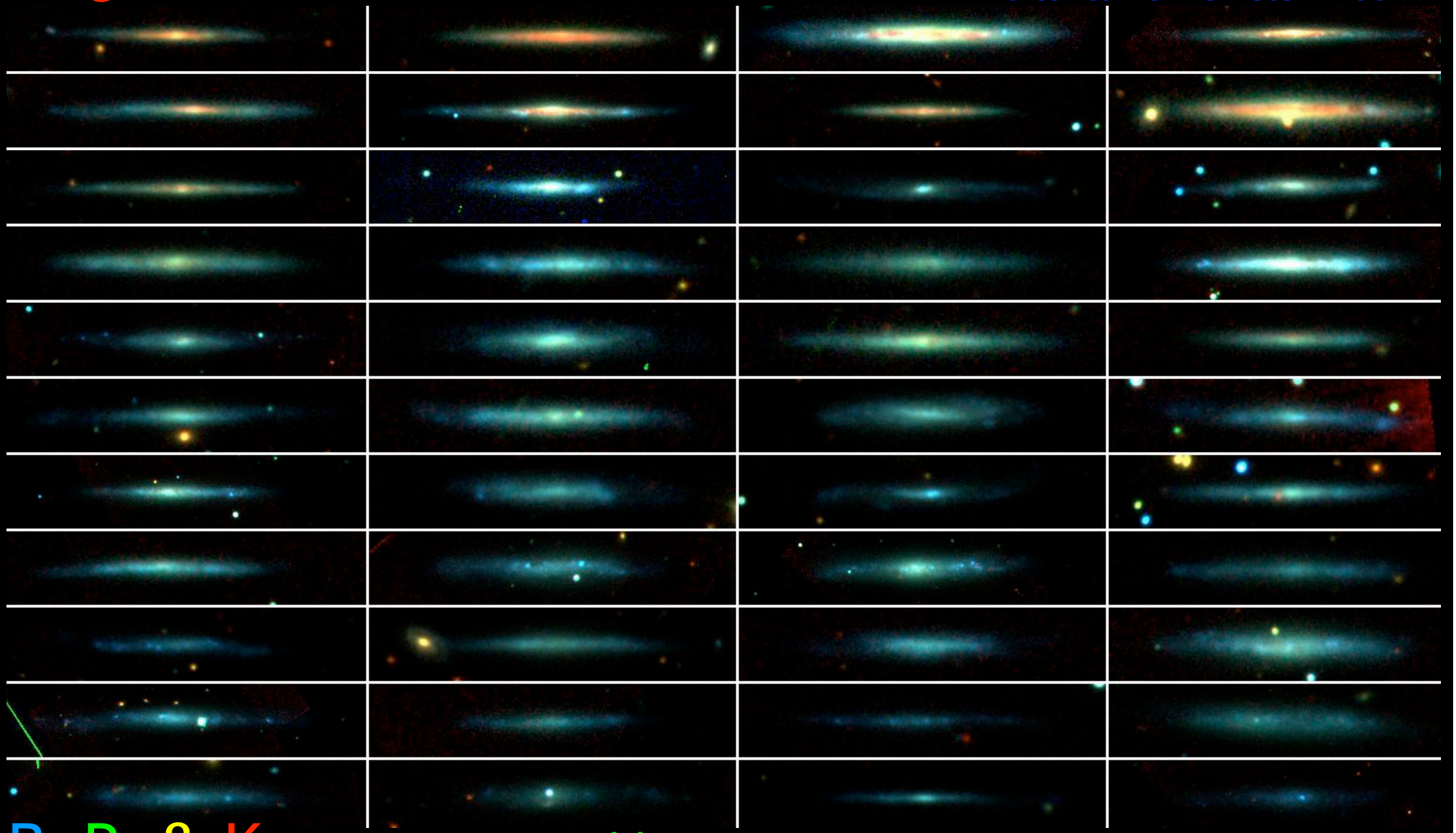
Satellite galaxies with stars get pulled in

Dynamical friction pulls satellites into the plane of the disk

Satellites disrupt and deposit stars on thick disk orbits

Let's look for thick disks in a sample of simple edge-on disks

Dalcanton & Bernstein 2002

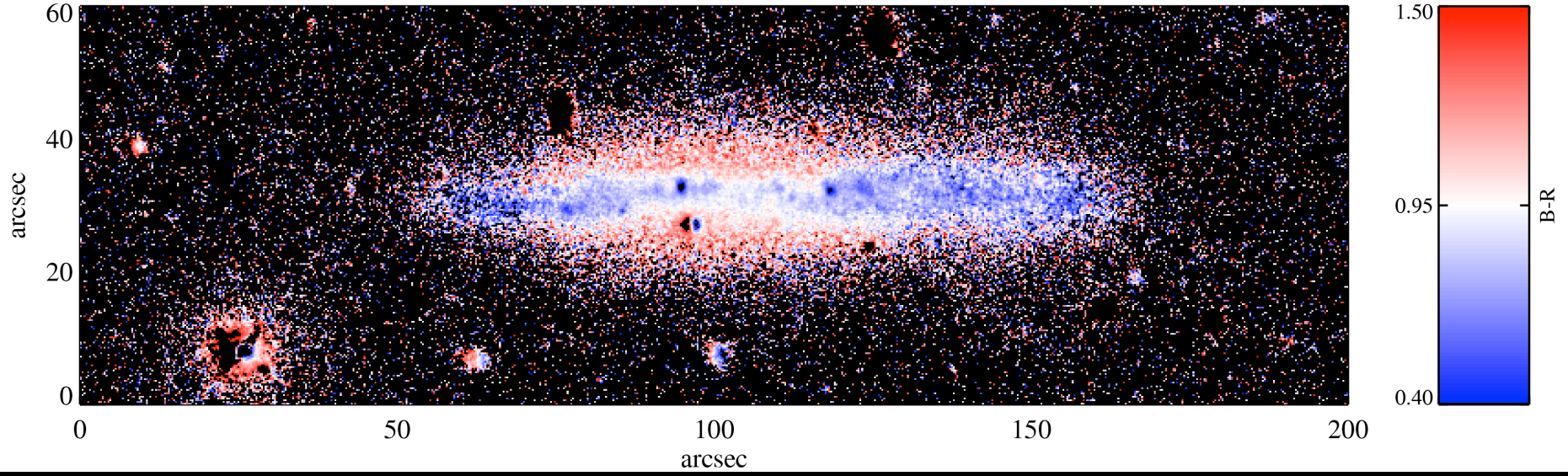


B, R, & K_s images, sorted by decreasing rotation speed

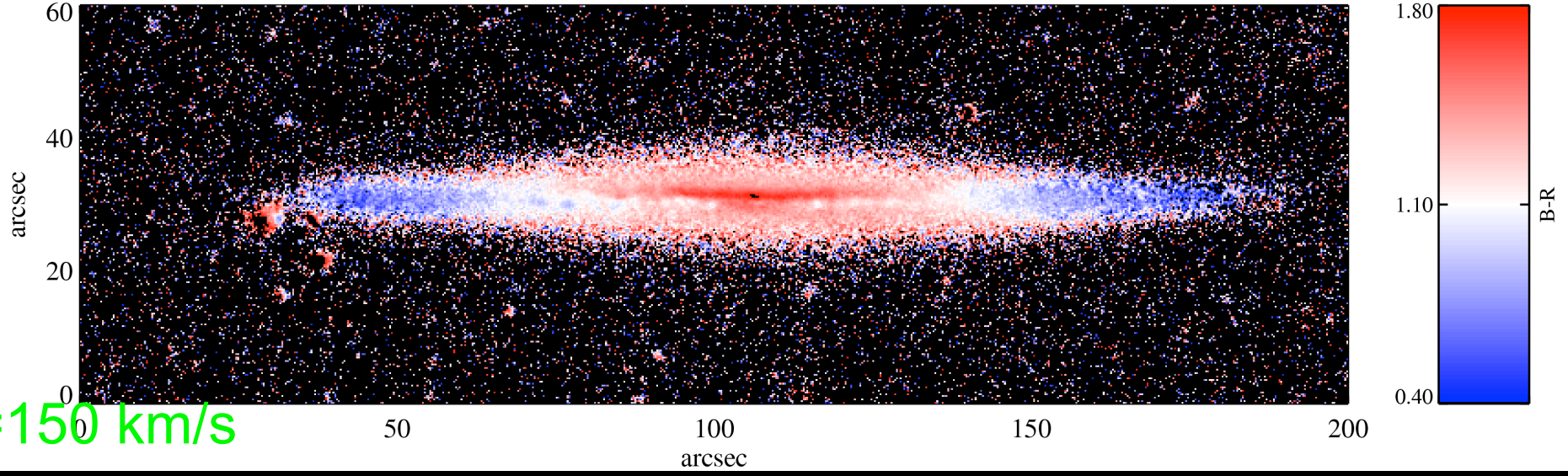
V_c = 35-250 km/s

V_c=75 km/s

FGC 780

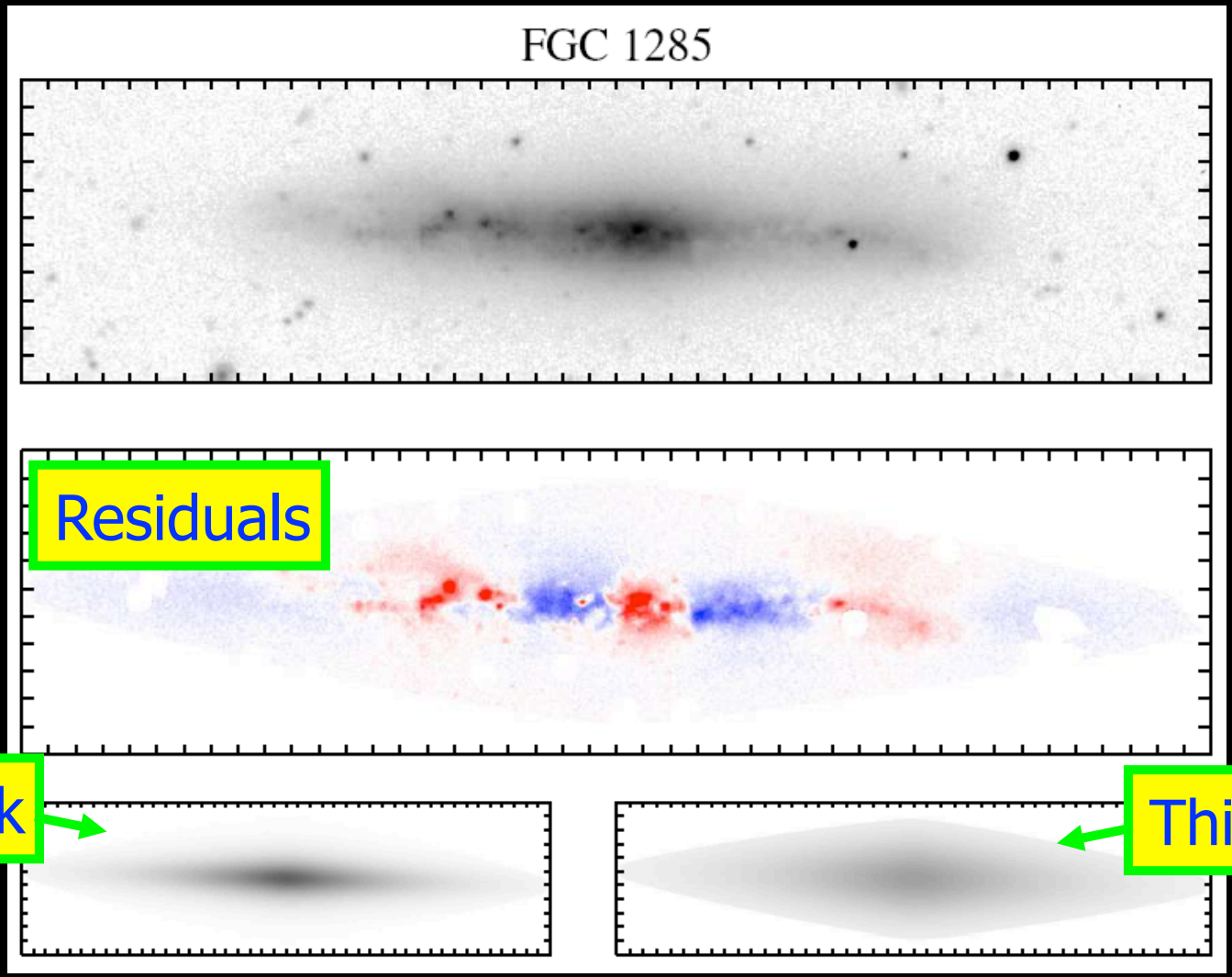


FGC 1440



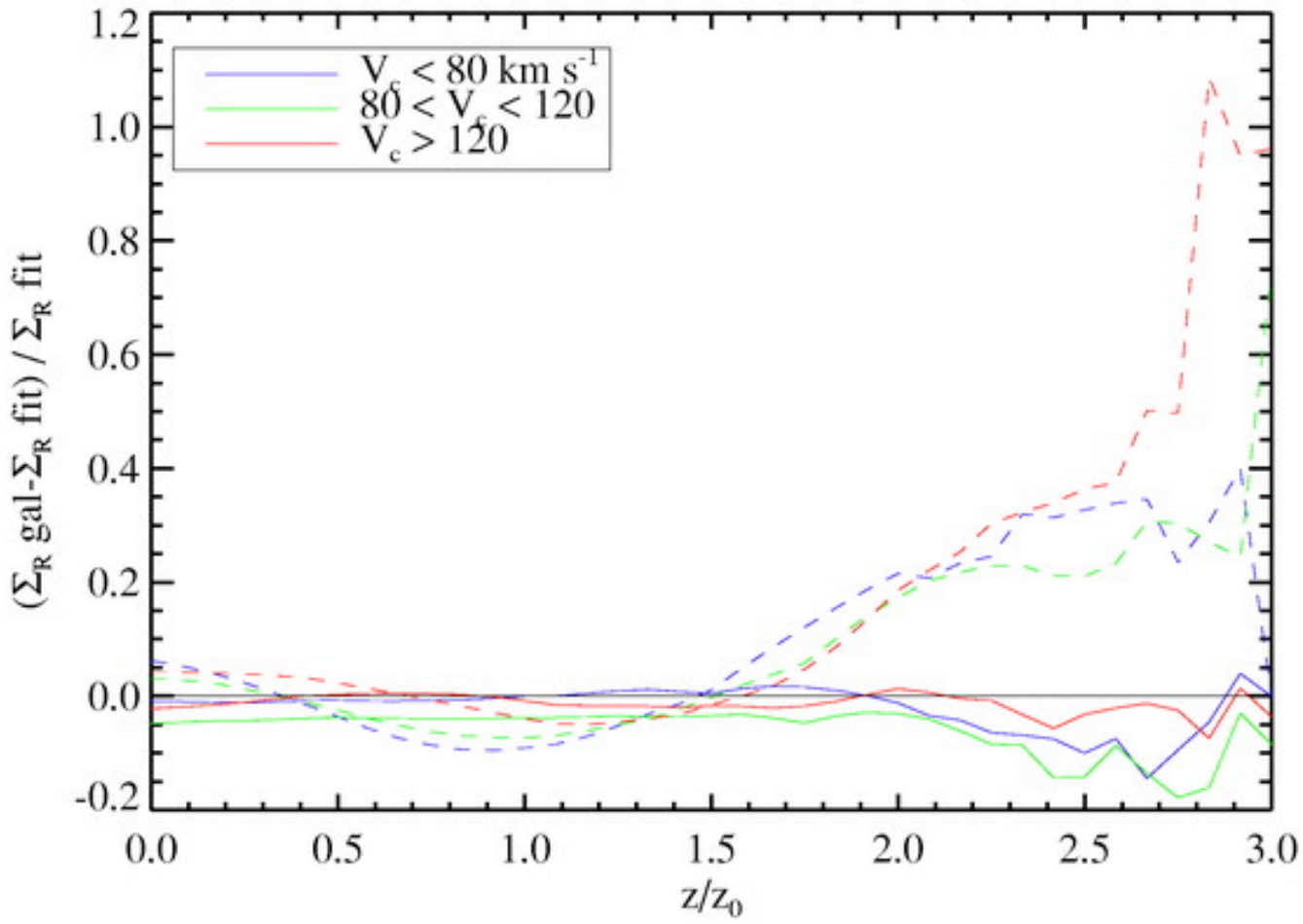
V_c=150 km/s

Thick & Thin Disk Decompositions



For each disk $L=L_0 e^{-r/h_R} \mathrm{sech}^2(z/z_0)$

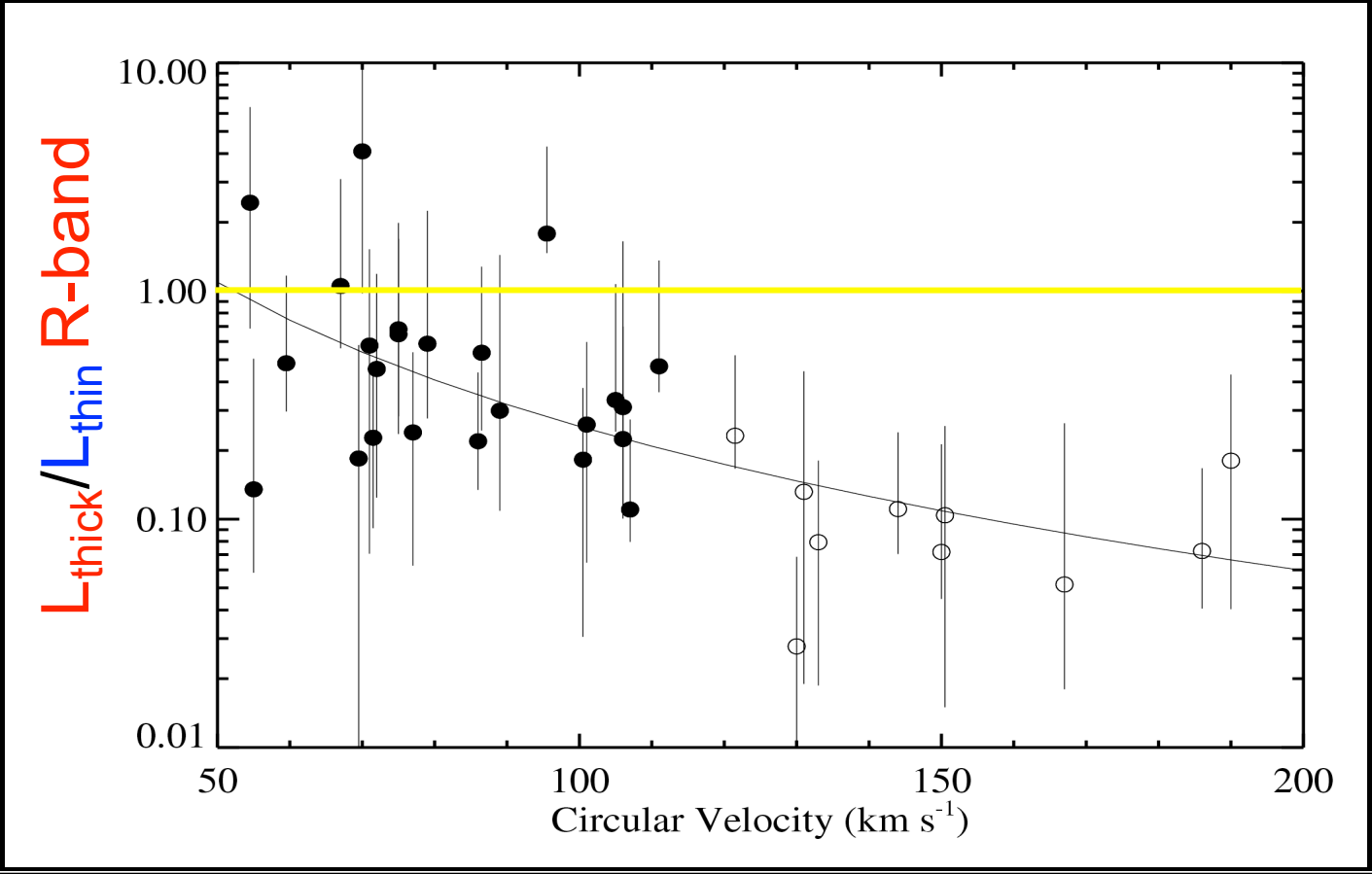
$z_{0,thick} \sim 2 z_{0,thin}$



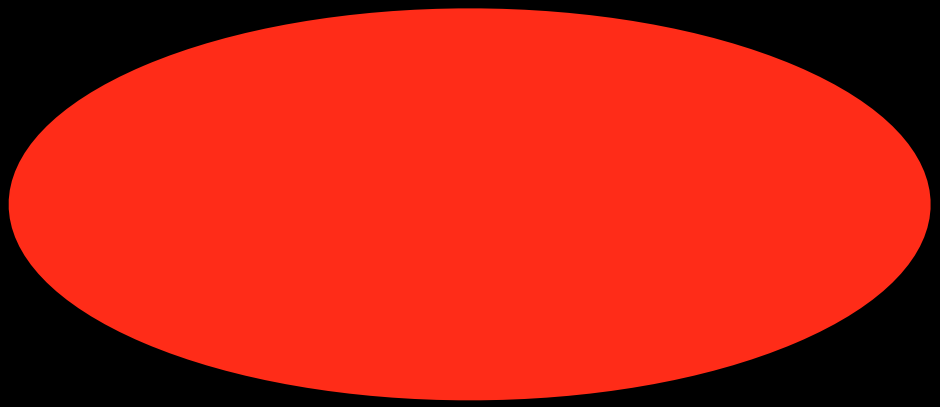
Only using 1 disk doesn't work--leaves excess light at large z

Structural Results

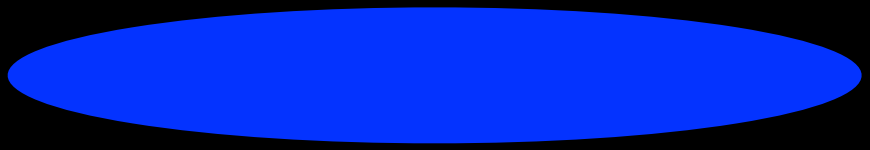
- ***All*** our galaxies show a thick disk component
- $z_{0,thick} \sim 2z_{0,thin}$
- $h_{R,thick} > h_{R,thin}$



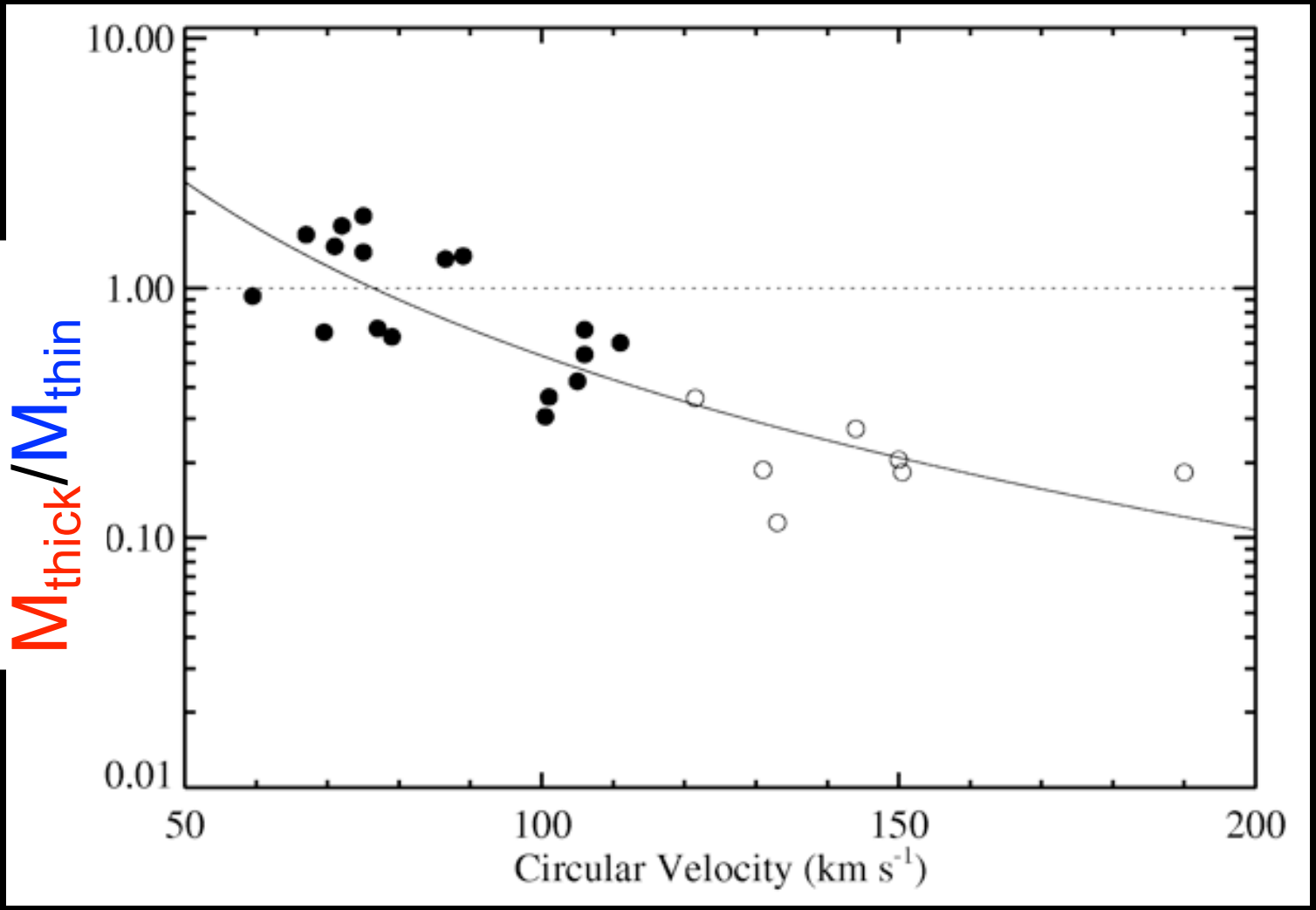
Use color information to convert luminosities into masses



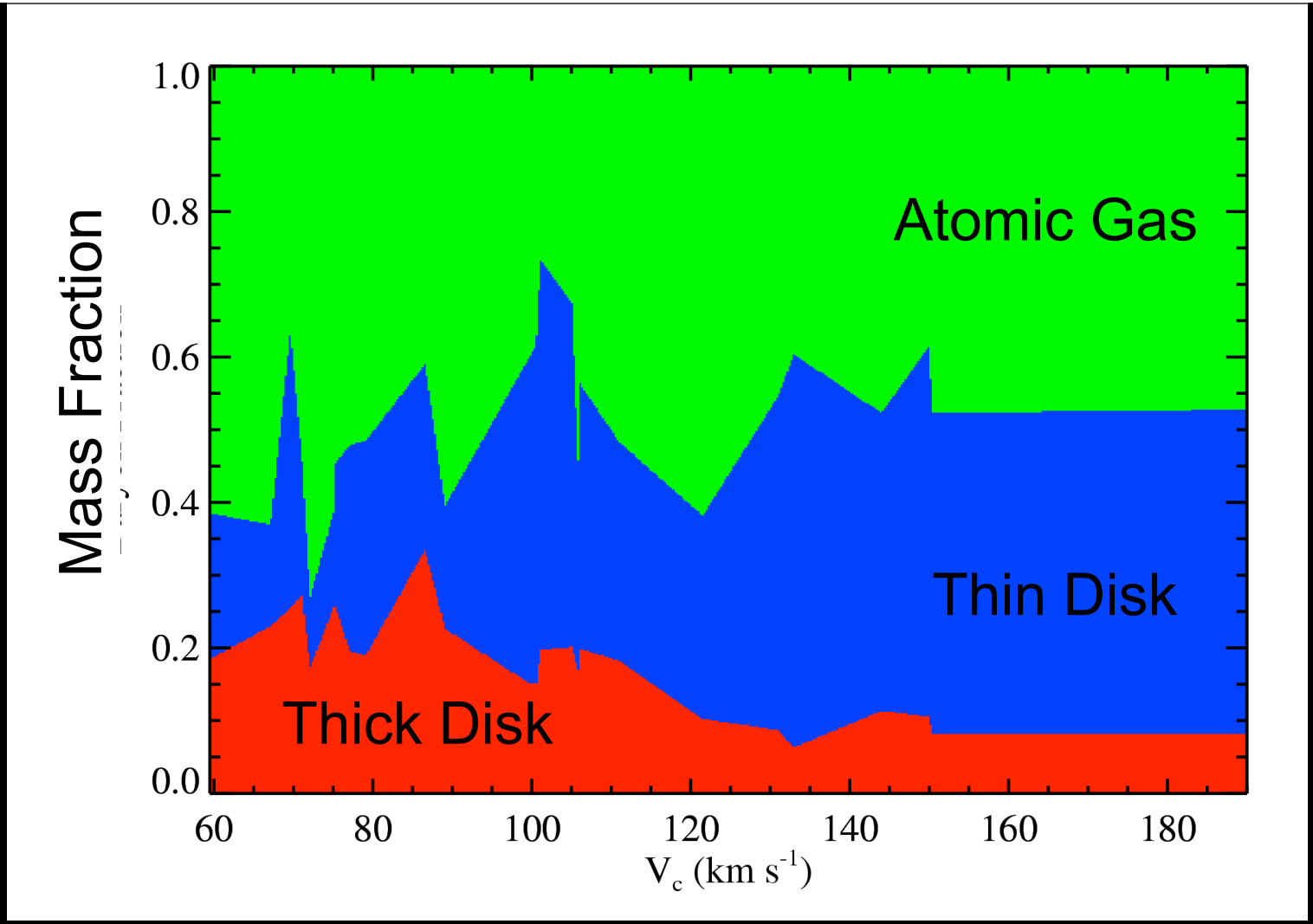
→ **Total Thick Disk Mass**



→ **Total Thin Disk Mass**

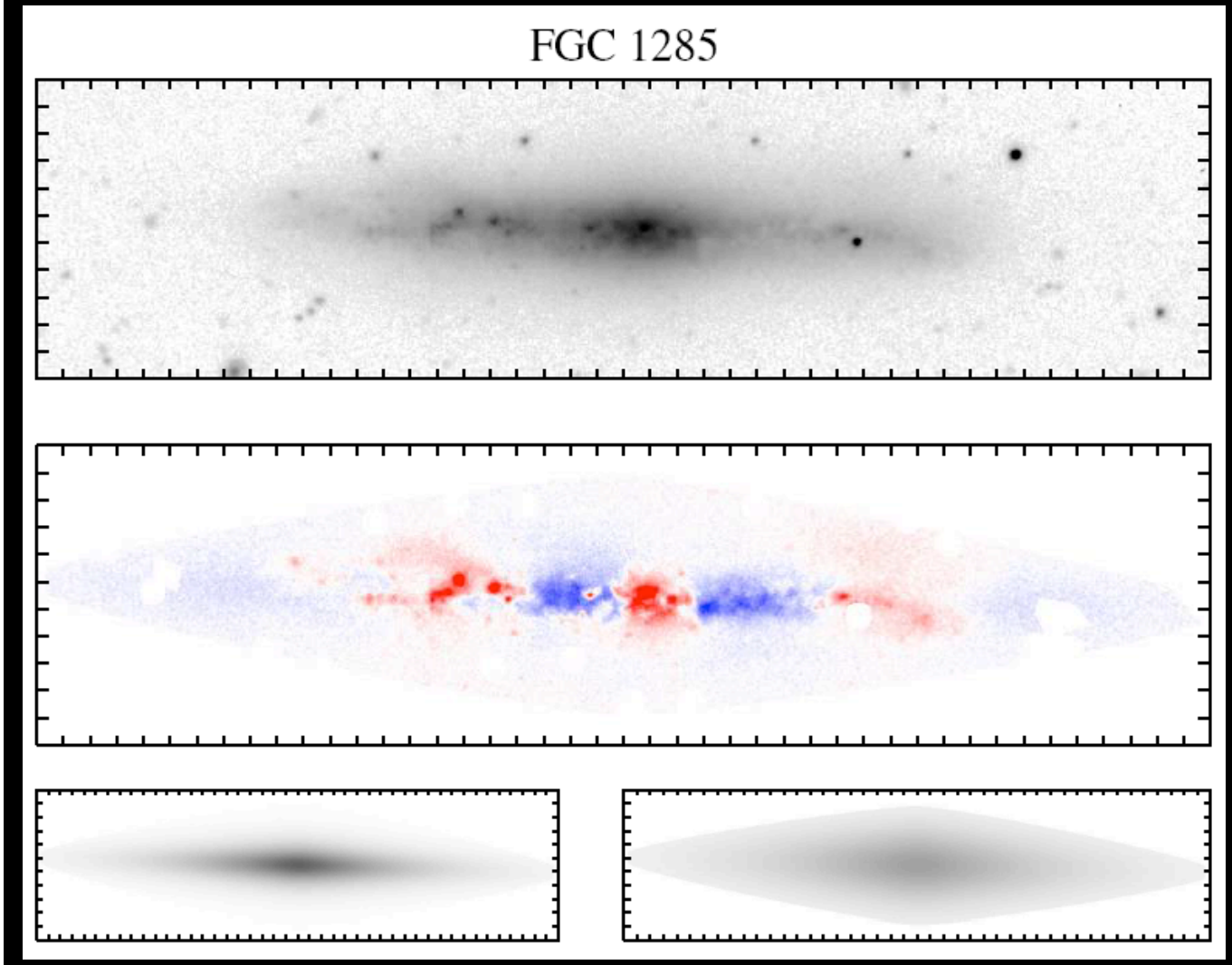

10.00
1.00
0.10
0.01
M_{thick}/M_{thin}
50
100
150
200
Circular Velocity (km s^{-1})

MW



Total baryonic mass budget

Yoachim & Dalcanton 2006

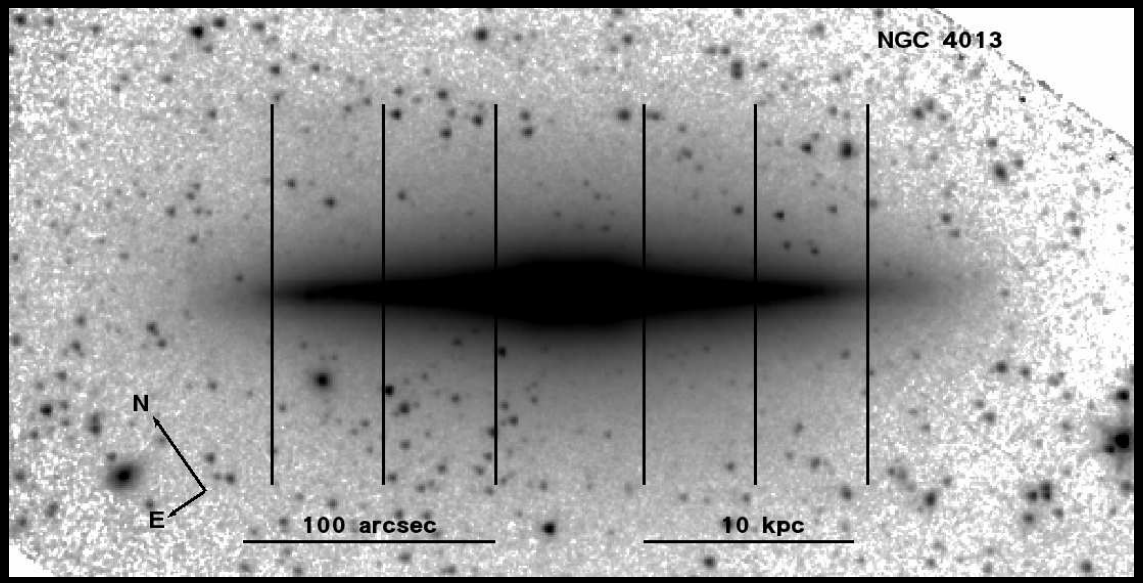


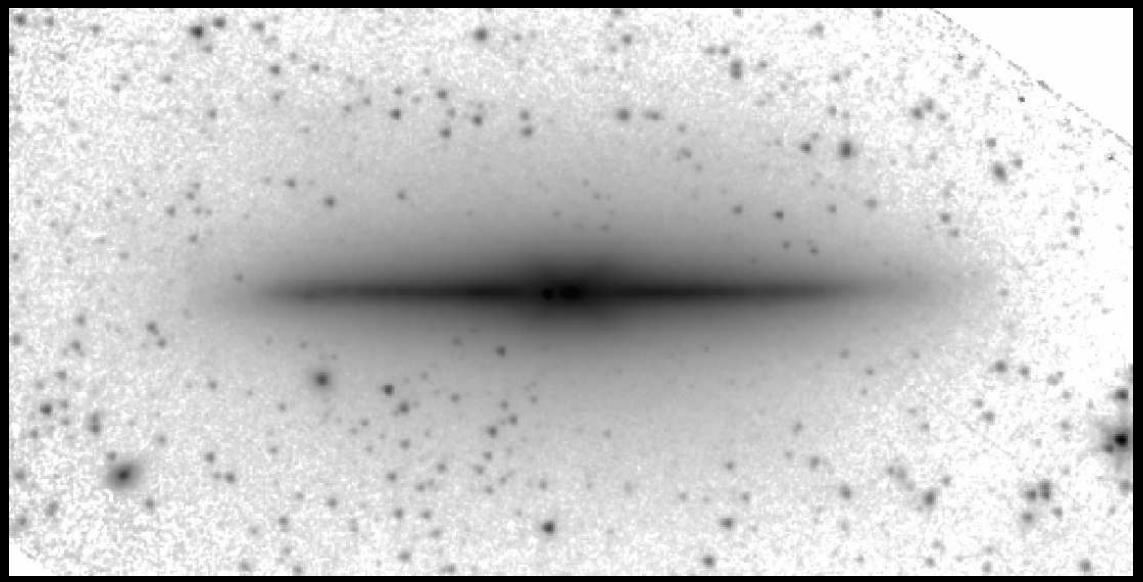
Galaxies are messy-- especially in optical light

dust gets in the way, spiral arms make all kinds of structure

It would be waaaay better to look for thick disks in the IR

Results from the Spitzer Space Telescope

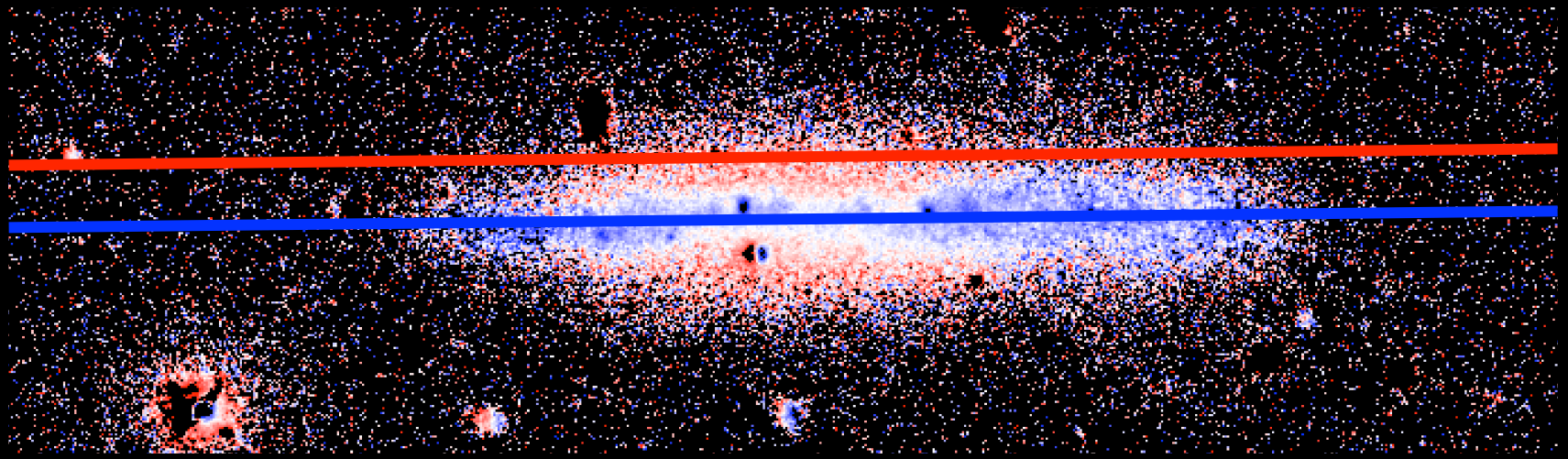




Similar results when you look in the IR (Yay! 6 years of my life spent working on a thesis didn't turn out to be wrong...yet)

Comerón et al 2011

Follow-up Spectra



- 9 galaxies on Gemini 8m's
- Red-Near IR
- Stellar and gas kinematics

- 9 galaxies with Apache Point 3.5m
- Blue+Red
- Stellar Metallicities and ages

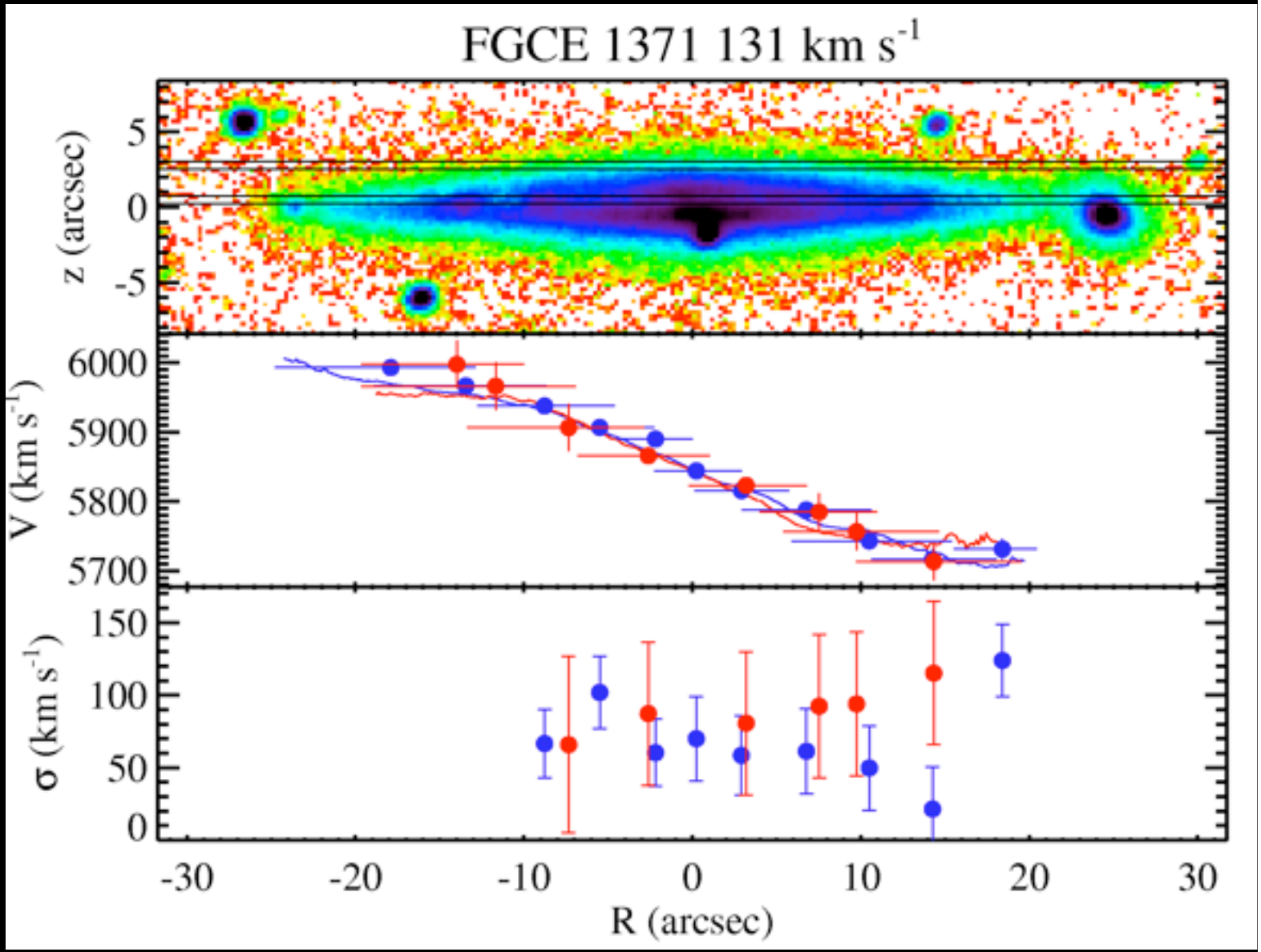
NGC 4631

Projection effects are important

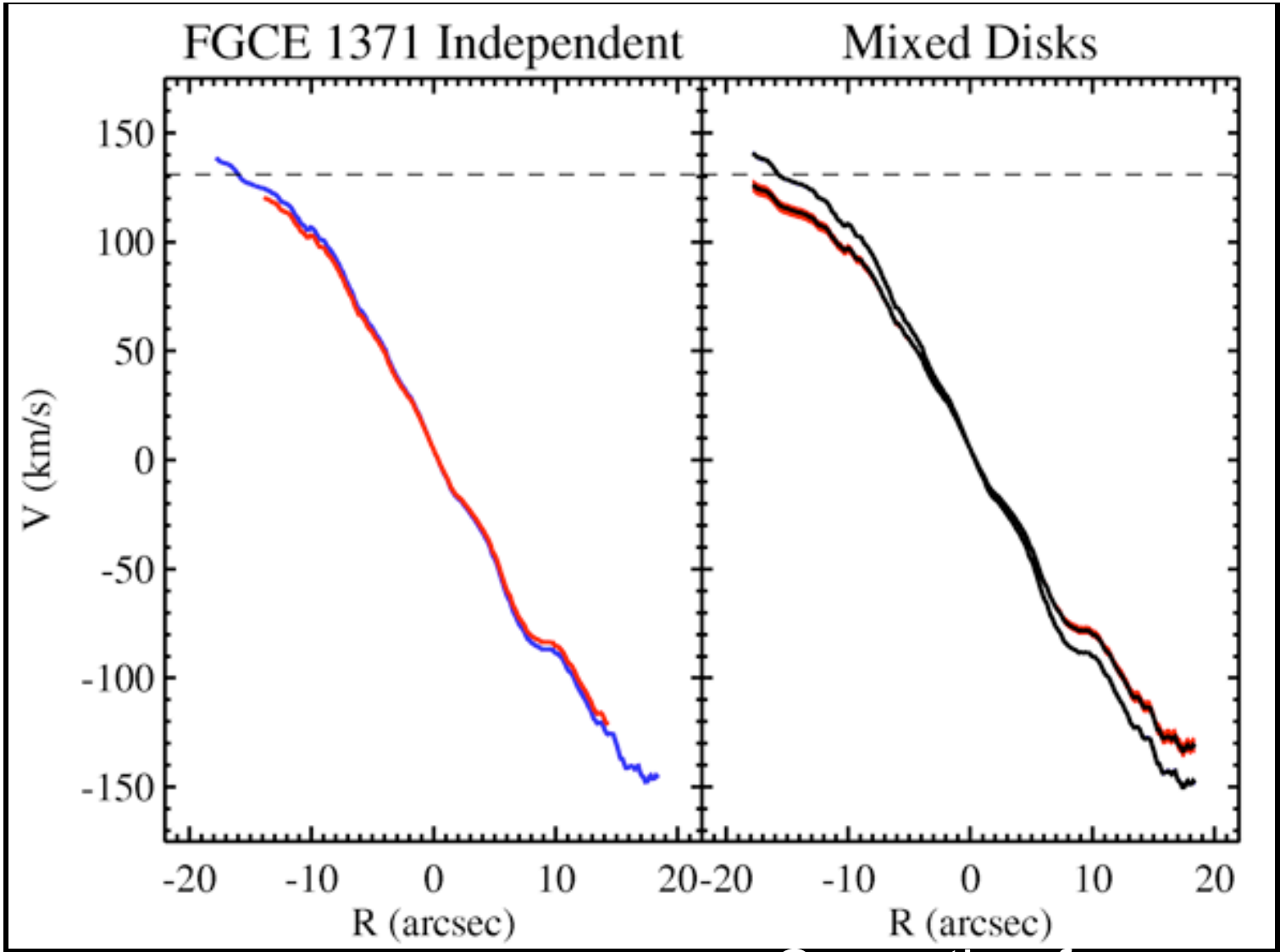
NGC 1672

Blue=midplane, red=offplane

Rotation curves look very similar



Higher mass galaxy



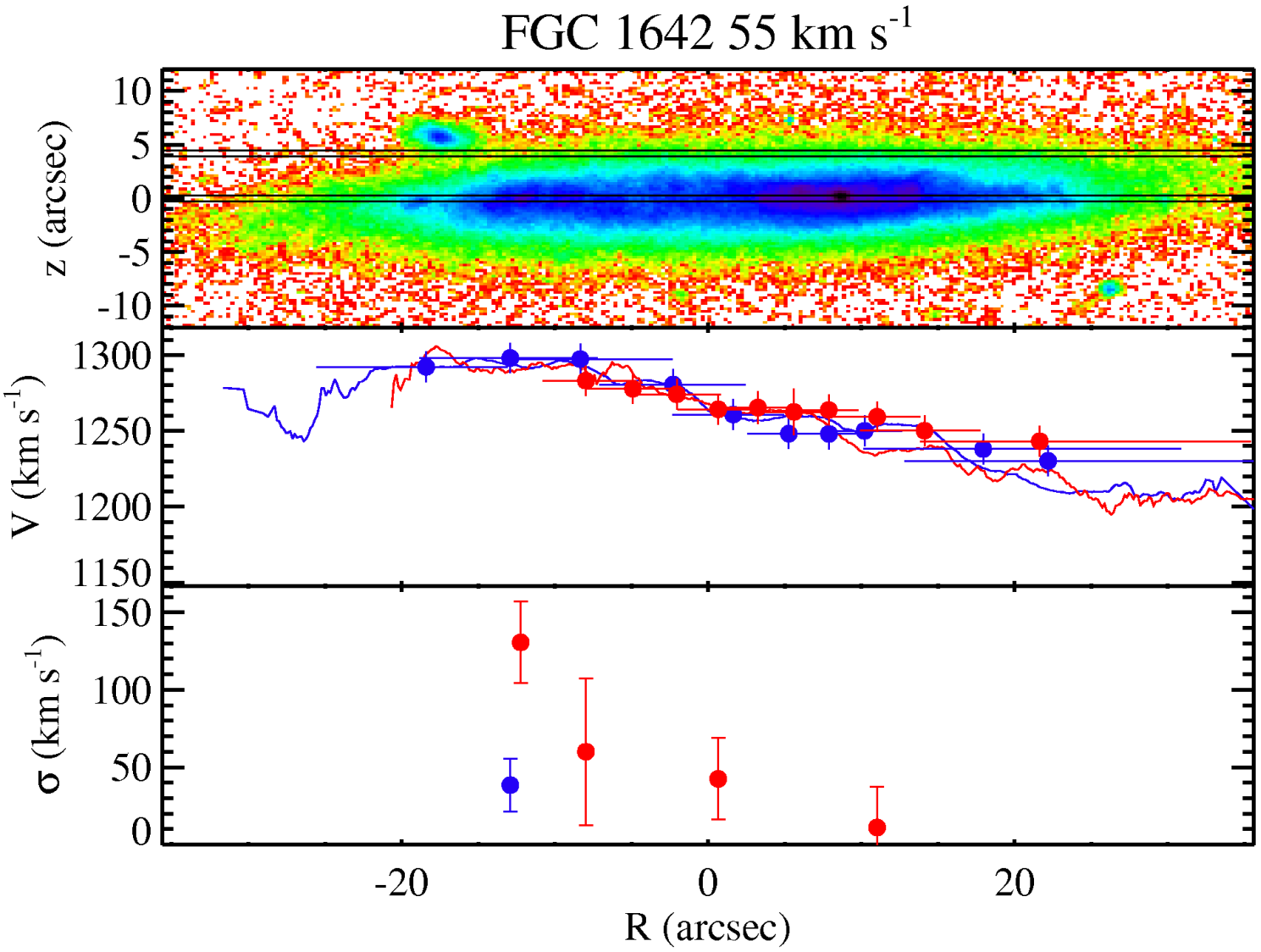
Yup, just about the same

Fitting independently

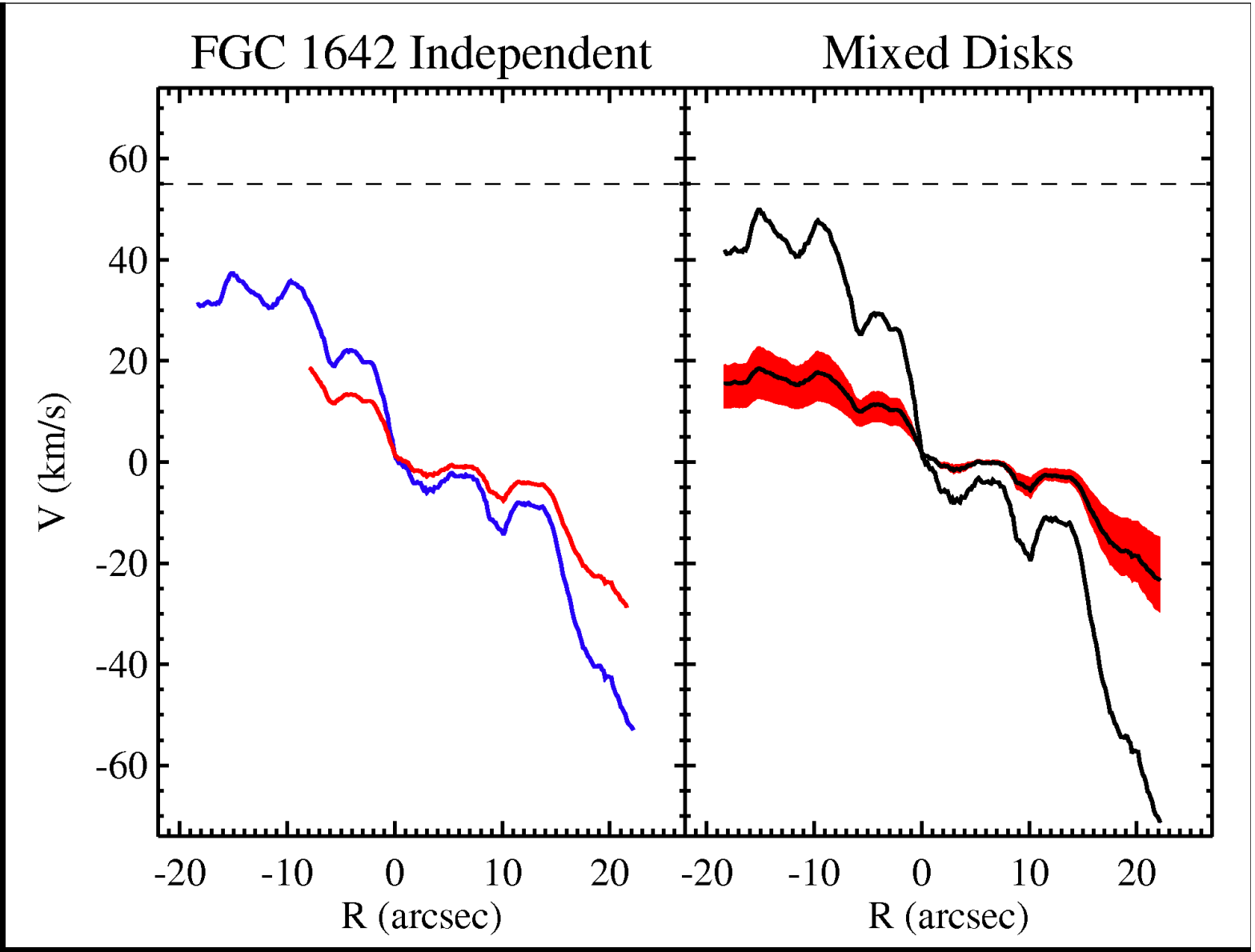
Correcting for cross-contamination

Using Hα rotation curve as a template to reduce free parameters

Hint of a lag



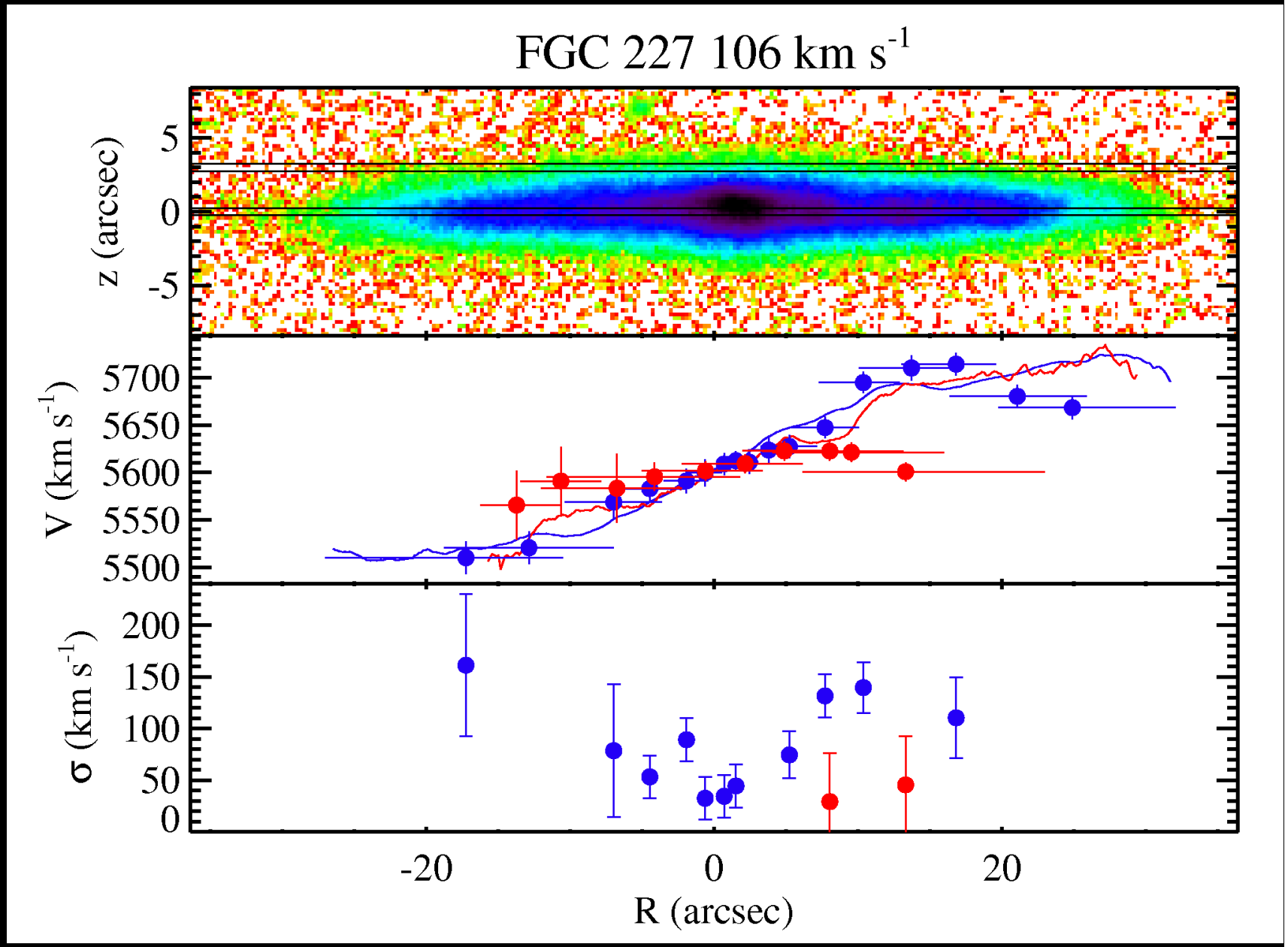
Low mass galaxy

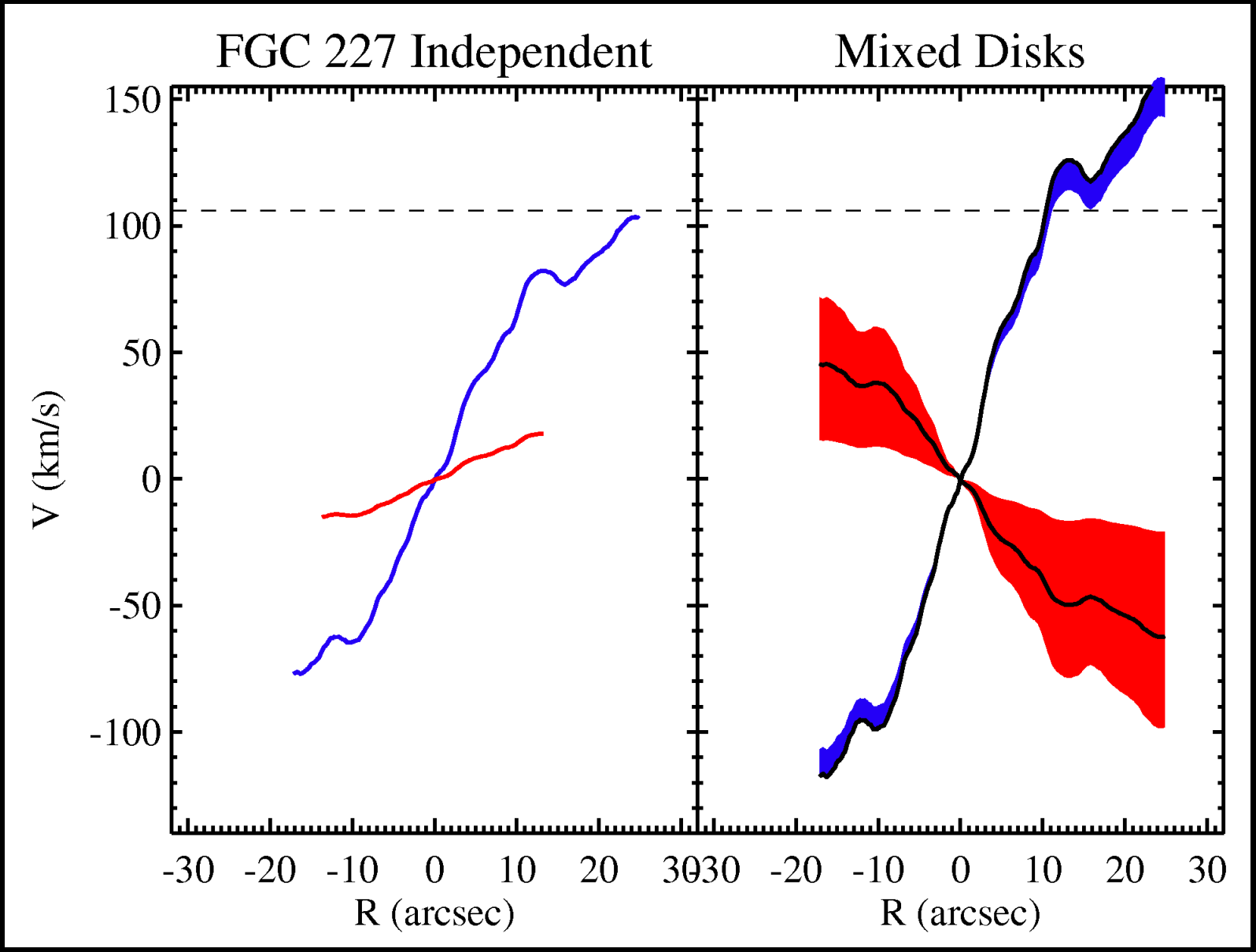


Fitting independently

Correcting for cross-contamination

Nearly flat offplane RC

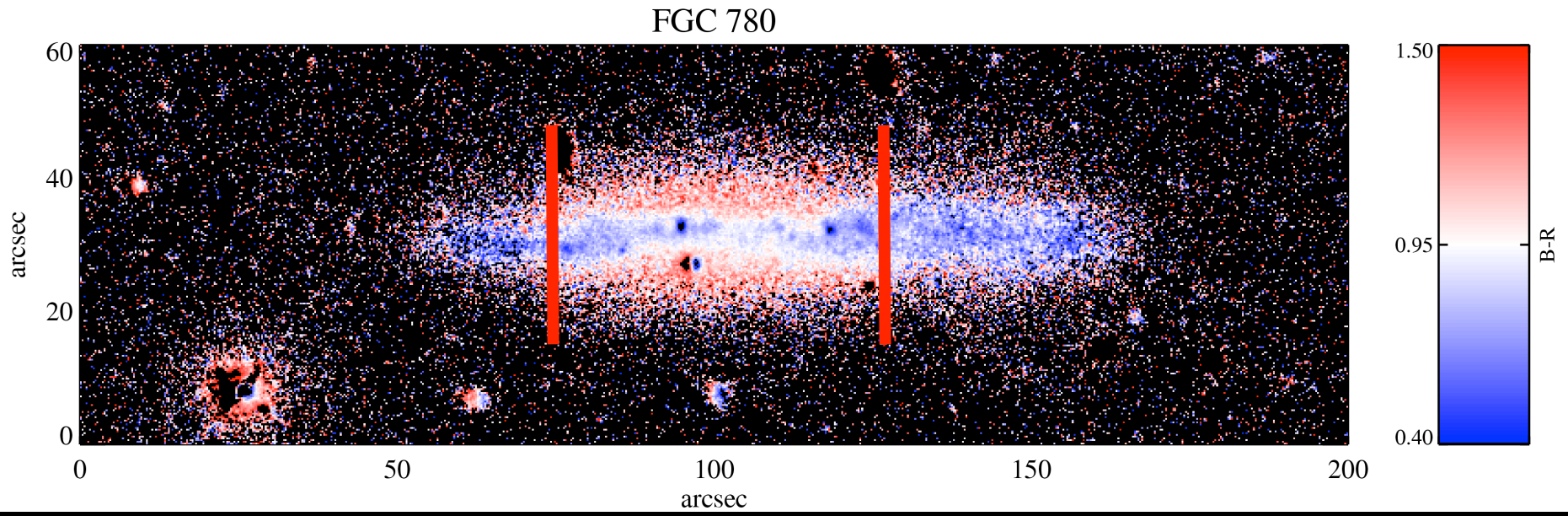




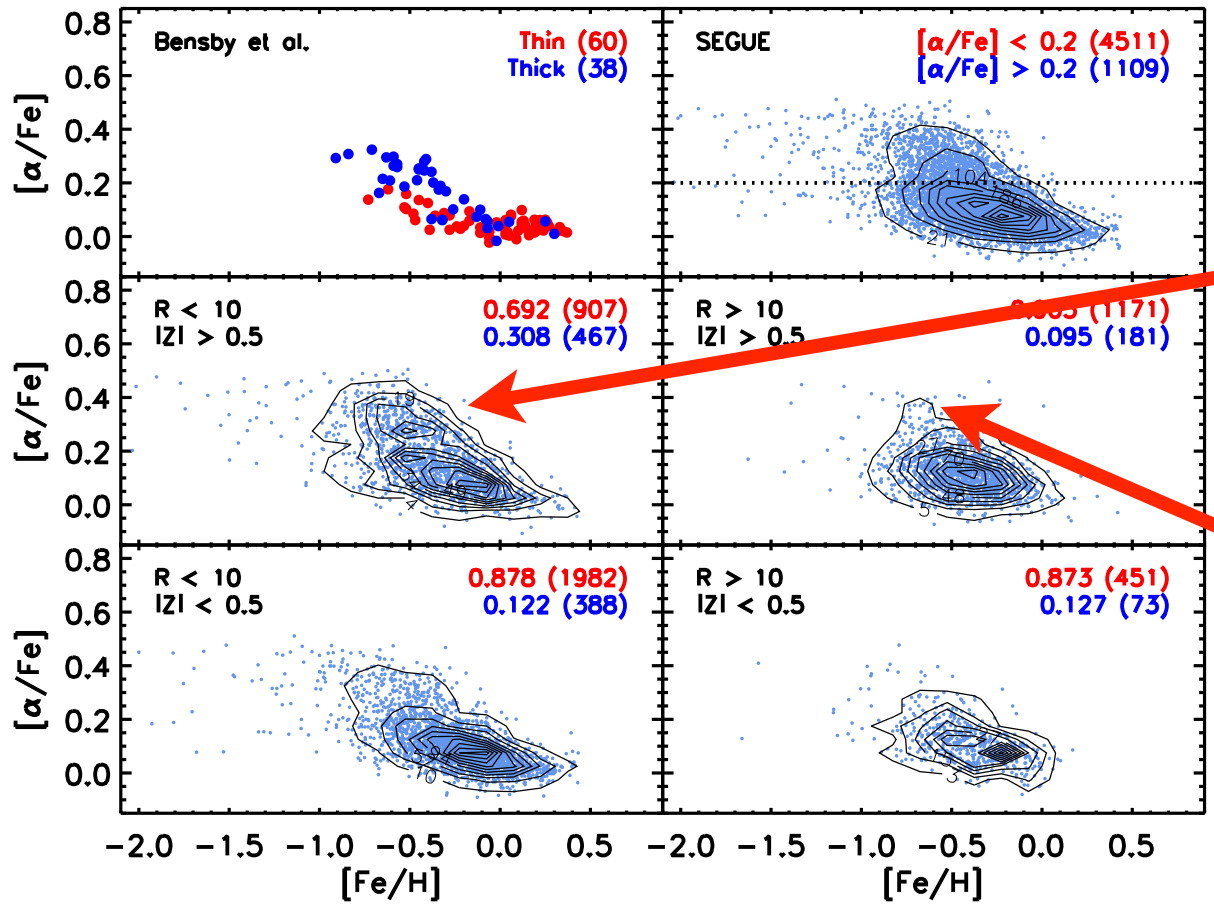
Best fit is counter-rotating!

"You're saying it's counter rotating? That's bull****!"--Neil deGrasse Tyson

The bleeding edge of research



How far out does the thick disk go?



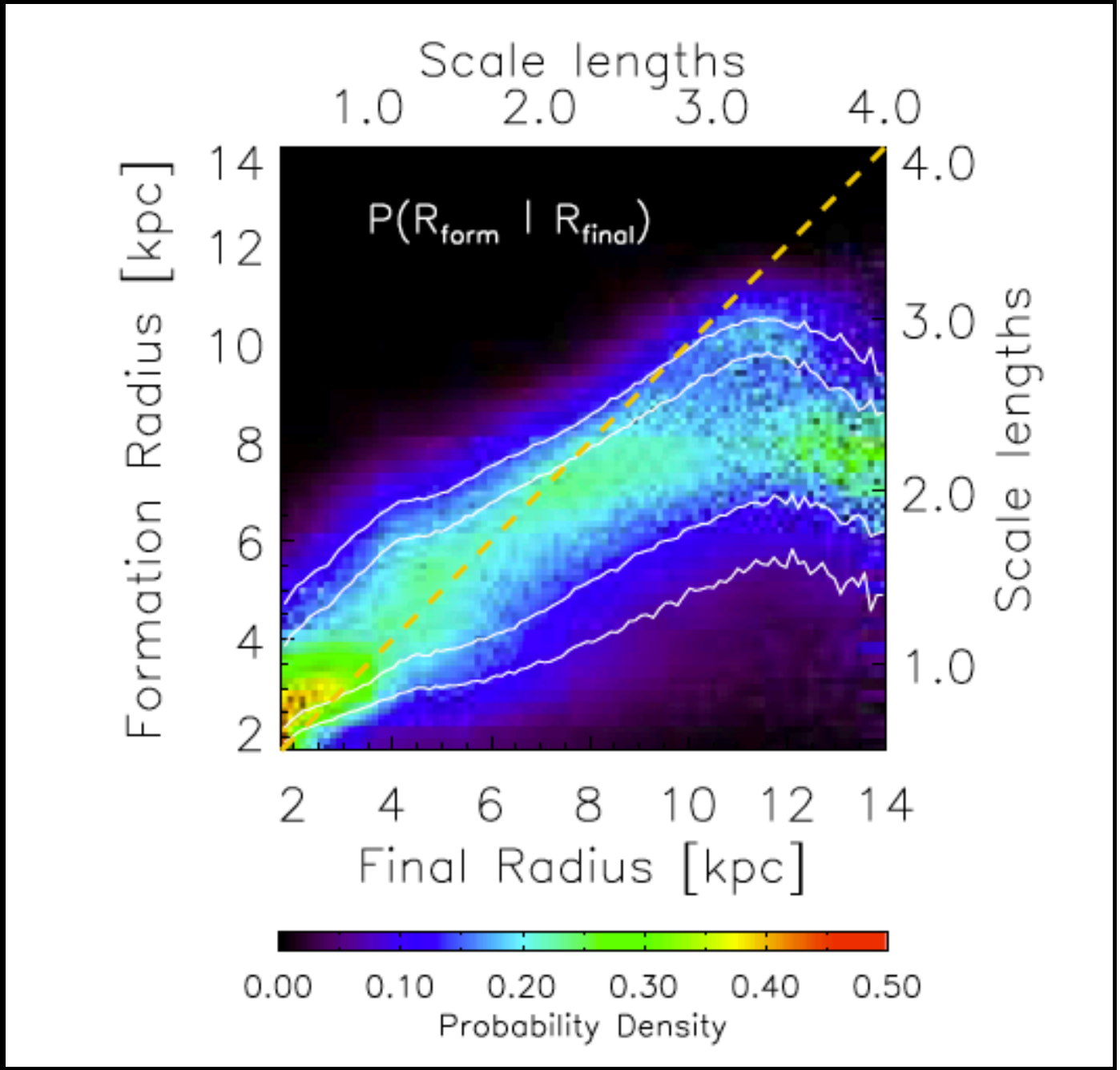
Near the sun, lots of alpha-rich stars

In the outer disk, no alpha-rich stars!

So there are stars high above the plane, but they are not alpha-enhanced in the outer disk

Cheng et al, 2012

Simulations of isolated galaxies show stars can migrate a lot.



Roskar et al. 2011

http://www.astro.washington.edu/users/fabio/movies/MW1hr.mpg

Summary of Thick Disks:

- Looks like ***all*** disk galaxies have a thick disk component
- (embarrassingly) there is still no agreed upon mechanism for forming thick disks

  two main types of contenders:

  a) Mergers. All galaxies should undergo large and small mergers, and these can heat up stars or cause stars to form at high z, or even deposit stars in a thick disk

  b) Secular evolution. Even a totally isolated galaxy can heat stars up and toss them into a thick disk

Wouldn't surprise me if we find that different mechanisms are dominant in different galaxies (or different regions of the same galaxy)