The Impact of, and Evidence for, Stellar Migration in Disk Galaxies

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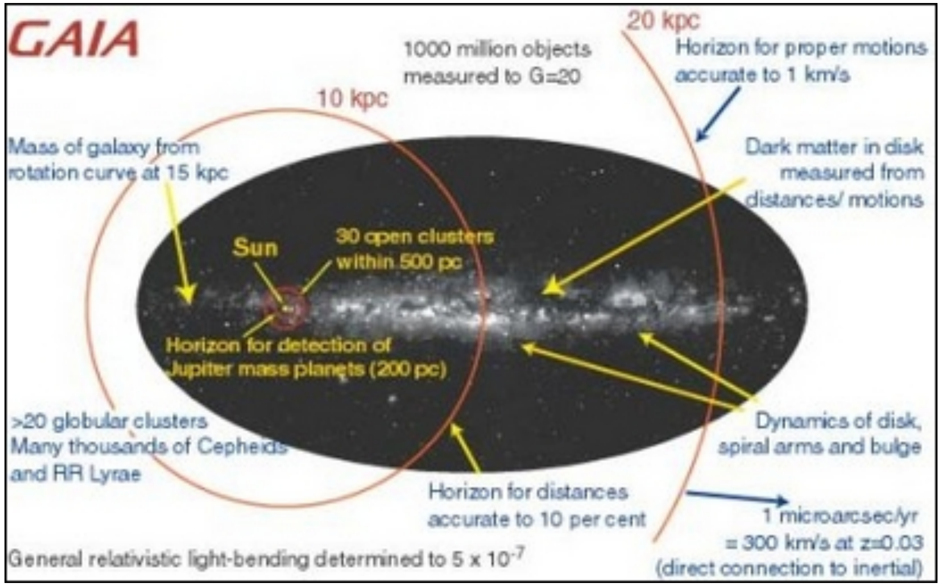
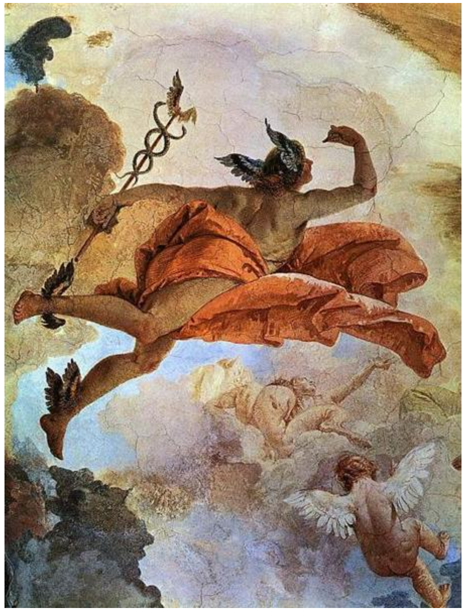
Jeremiah Horrocks Institute

Outline

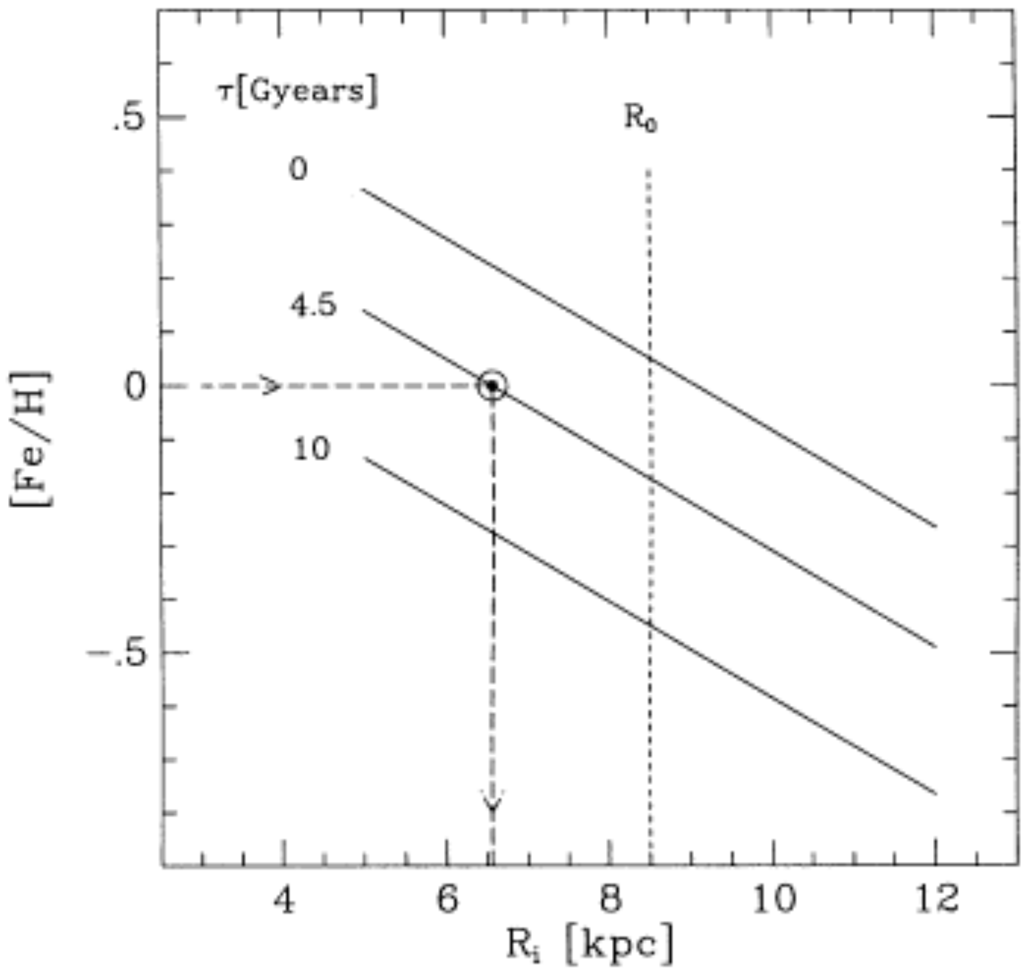
- ***Stellar migration:***
  The mechanism
  The outer disk
  Solar neighborhood
  Thick disk contribution

LSST
Large Synoptic Survey Telescope





Solar Metallicity vs Local



Argued that solar metallicity is much higher than that of stars in the solar neighborhood. Concluded that the sun formed at a radius R ~ 6.6 kpc

Wielen et al. 1996

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Astrophysics

Disk heating and stellar migration in galaxies

J. J. Binney, J. A. Sellwood

*(Submitted on 14 Mar 2000 (this version), **latest version 27 Jul 2000** (v2))*

We show that a typical star is unlikely to migrate from its galacto-centric radius of birth by more than about 5% over its lifetime. Radial migration, or a secular change in a star's angular momentum, is caused by stochastic scattering by spiral waves and by dense gas complexes. The expected change in angular momentum is related to the radial action acquired by the star from these processes and is consequently limited by the measured radial velocity dispersion within the disk. Our conclusion conflicts with recent claims that the solar system was formed some 2 kpc interior to its present position, which were advanced to account for abundance anomalies in the Sun and solar system dust in the context of a well-mixed and steadily polluting ISM. We suggest that abundance variations in nearby stars reflect intrinsic scatter in the metallicity of the ISM at any one galacto-centric radius and time.

Comments: 6 pages; revised version of paper submitted to MNRAS
Subjects: **Astrophysics (astro-ph)**
Cite as: **arXiv:astro-ph/0003194v1**

Submission history

From: James Binney [view email]
[v1] Tue, 14 Mar 2000 14:39:43 GMT (32kb)
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Wielen et al.'s paper provoked this reaction

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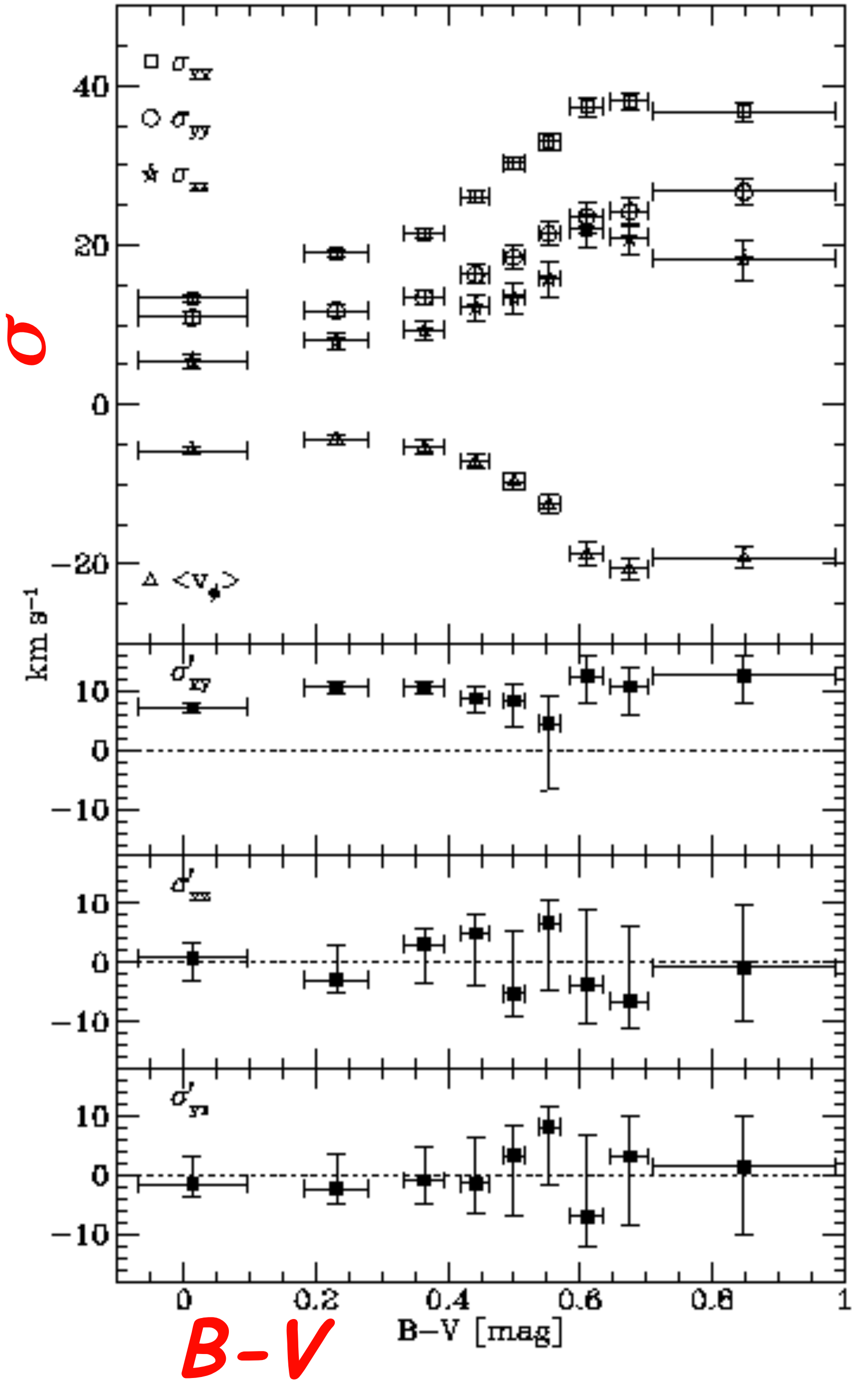

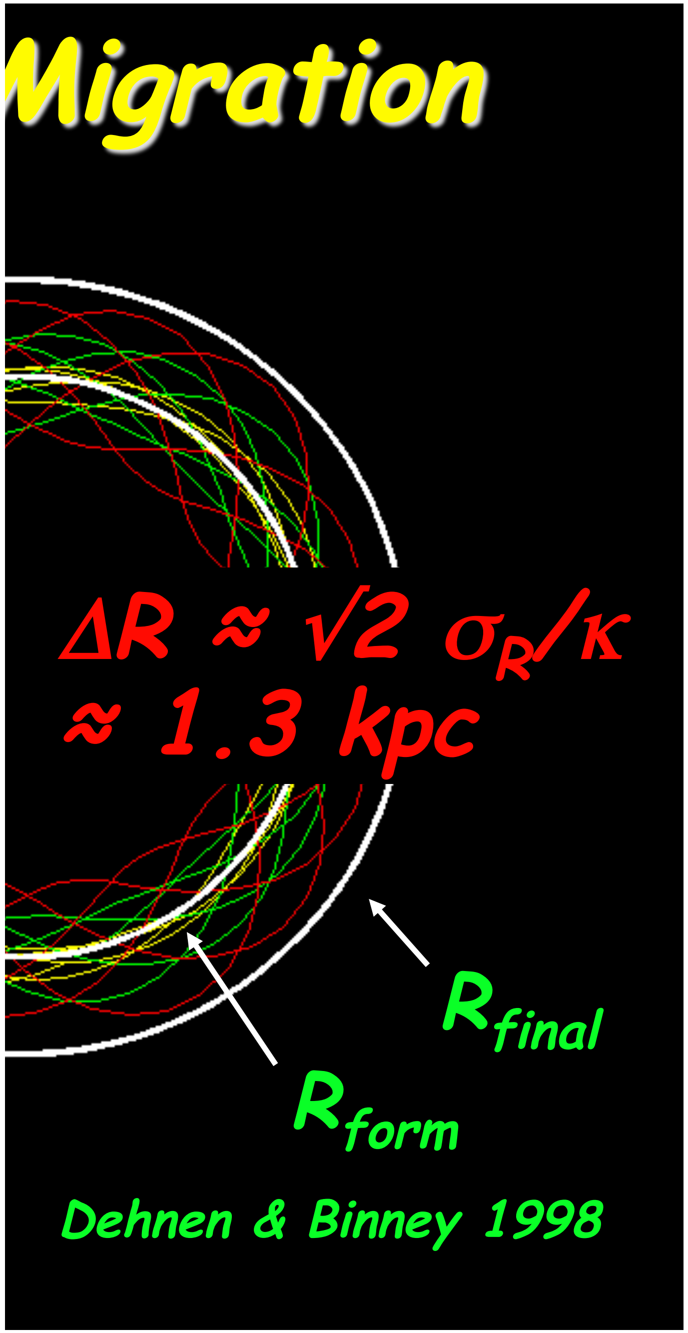

Larger and larger radial excursions require a hotter and hotter disk. Velocity dispersion of disks observable

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Astrophysics

Disk heating and stellar migration in galaxies

J. J. Binney, J. A. Sellwood

(Submitted on 14 Mar 2000 (v1), last revised 27 Jul 2000 (this version, v2))

The paper claimed that significant radial migration of stars in a stellar disk like that of the Milky Way could not occur. We now think that while the treatment of the effects of molecular clouds was correct, the paper seriously underestimated the ability of spiral arms to shift the radii of stars that corotate with them. Consequently, it is likely that significant radial migration_is_ possible.

Comments:	Paper withdrawn because its principal conclusion is proably wrong
Subjects:	**Astrophysics (astro-ph)**
Cite as:	**arXiv:astro-ph/0003194v2**

Submission history

From: James Binney [view email]

[v1] Tue, 14 Mar 2000 14:39:43 GMT (32kb)

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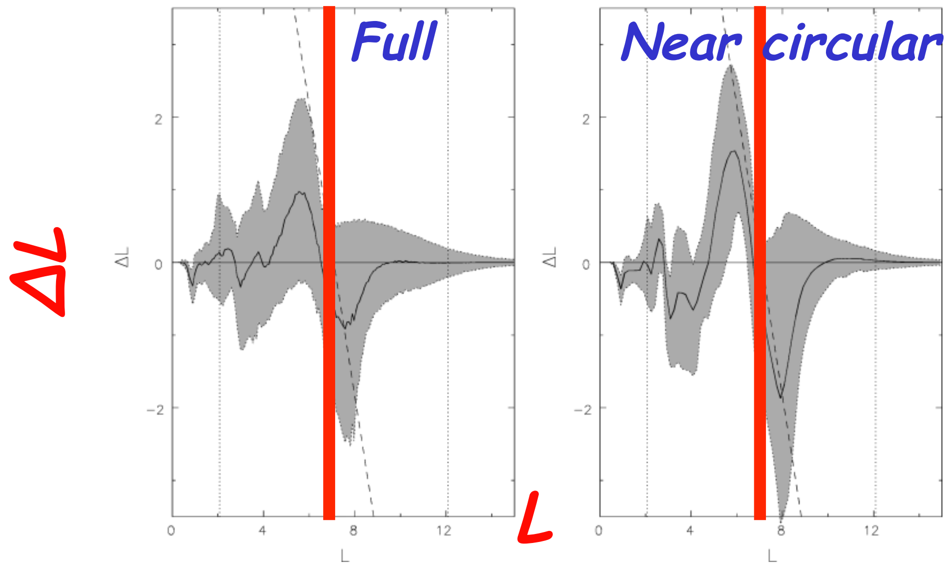
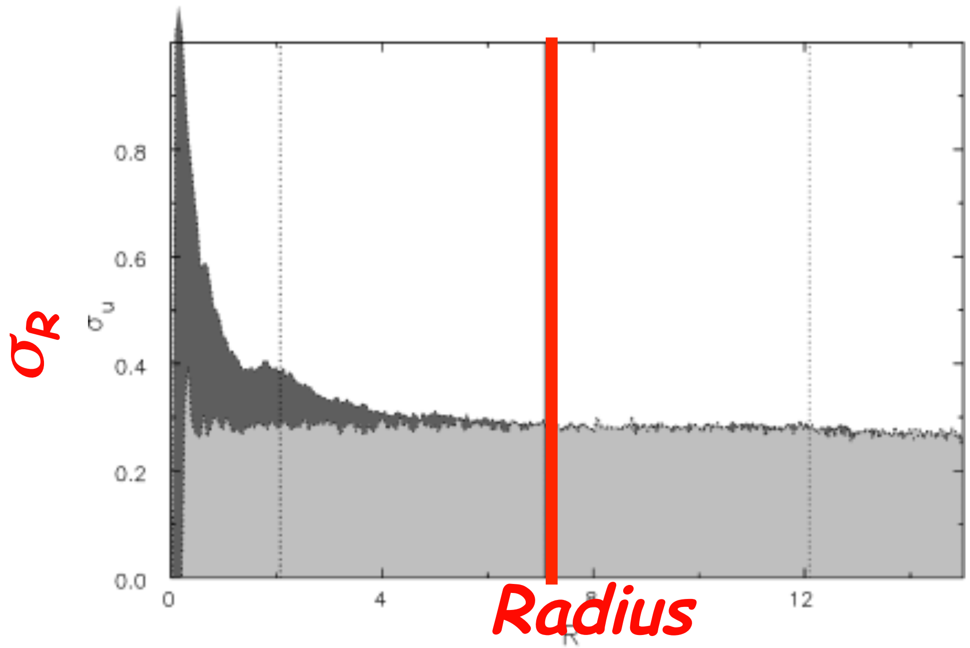
Done

Migration WITHOUT Heating

Shuffling With Little Heating



Strong exchanges at CR resonance; even larger for more circular orbits

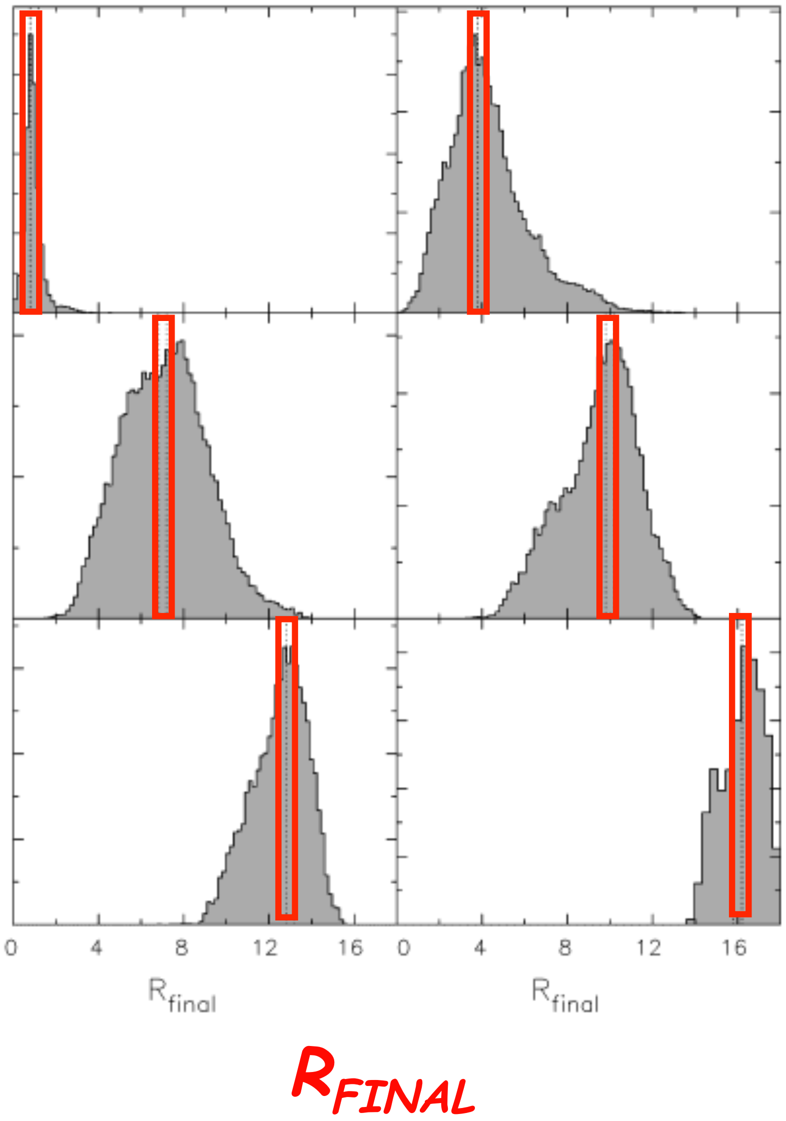


$$\Delta J_R = (\Omega_p - \Omega)\,\Delta L/\kappa$$

But negligible heating associated with the migration

Sellwood & Binney 2002

Unconstrained N-Body Simulation



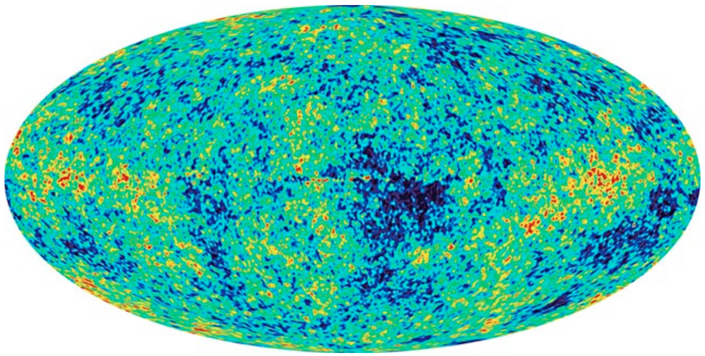
Now many spirals form

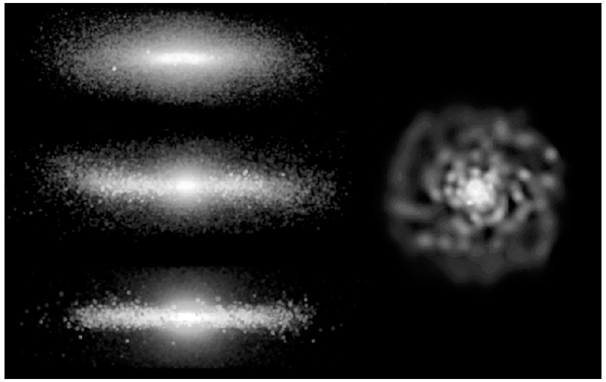
Histograms show final R versus initial range (dotted lines)

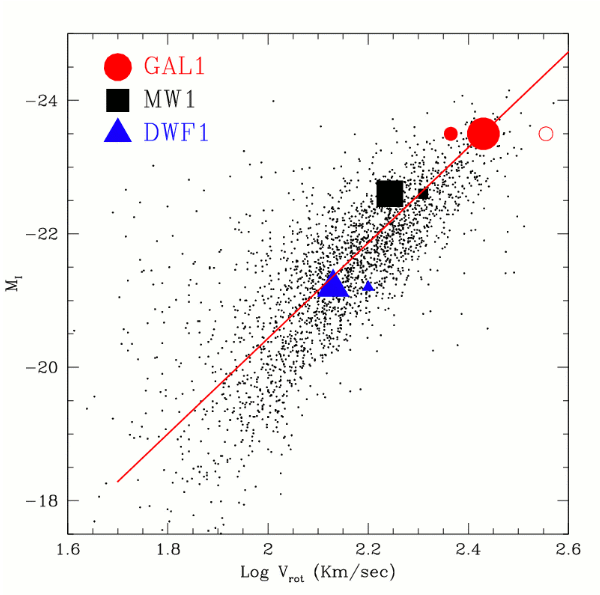
But initial conditions here assume a form for the disk density and kinematics

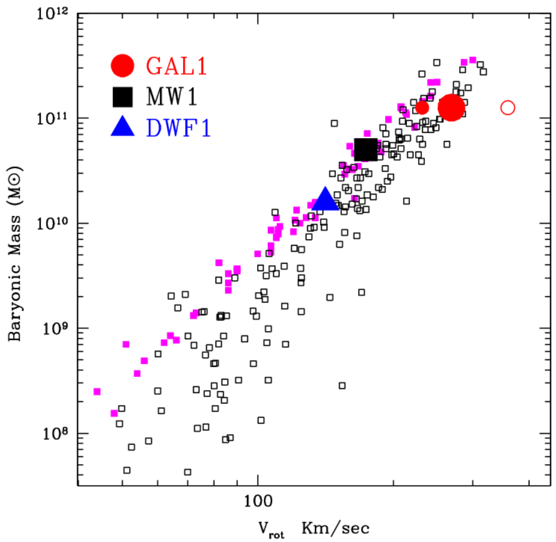
Sellwood & Binney 2002

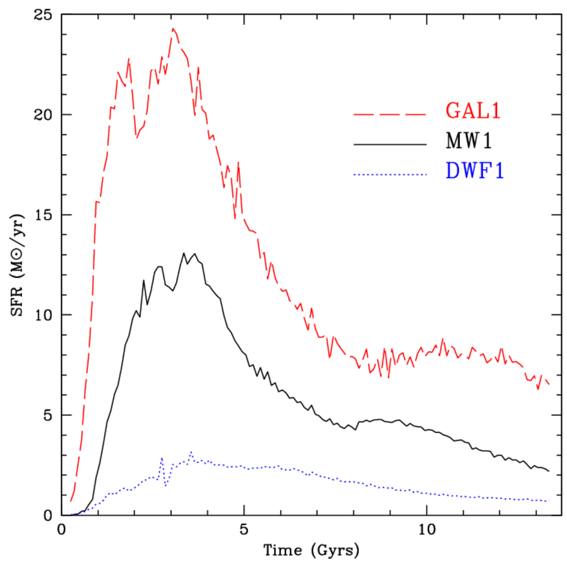
The State of Galaxy Formation Simulations



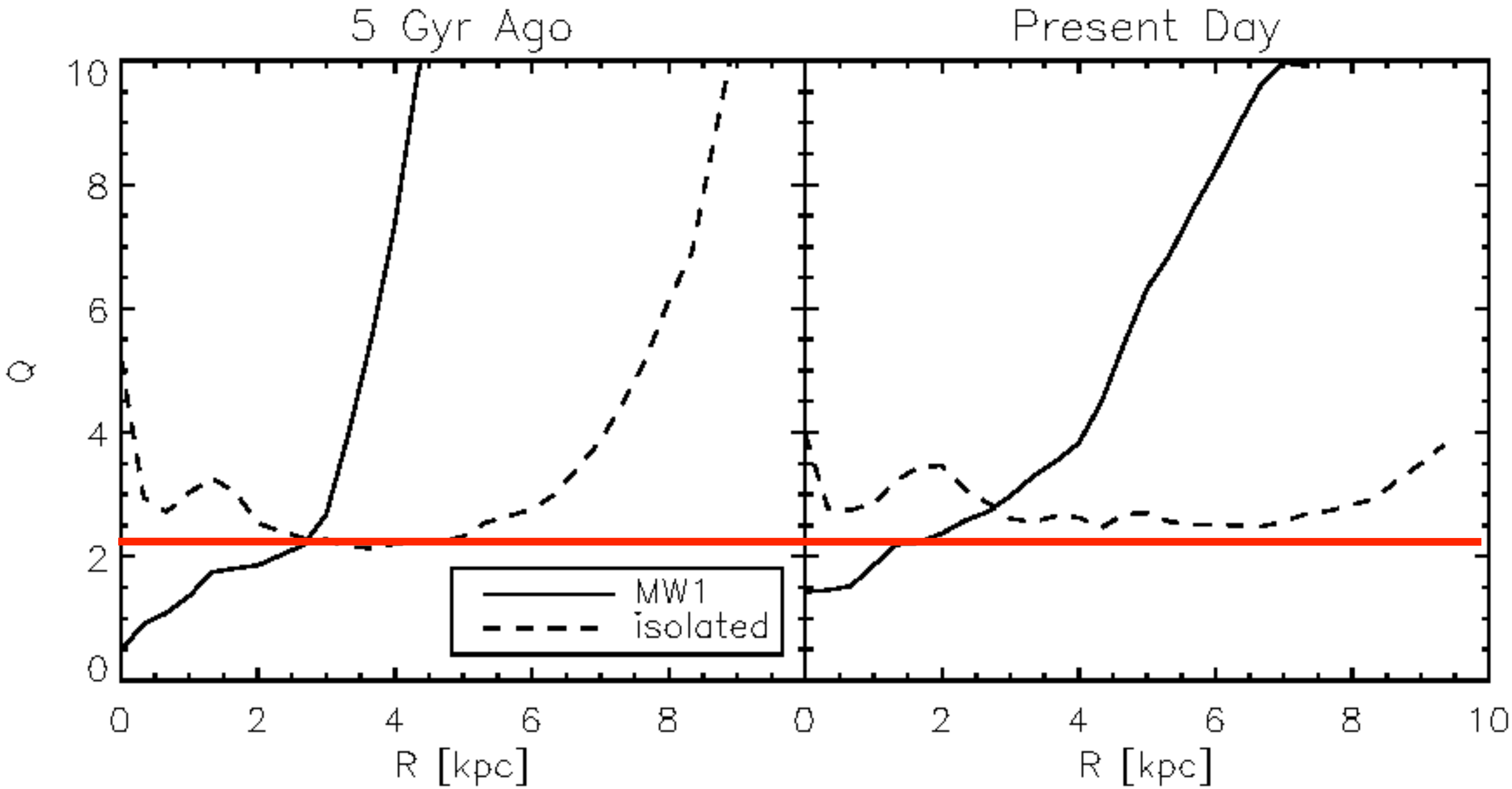






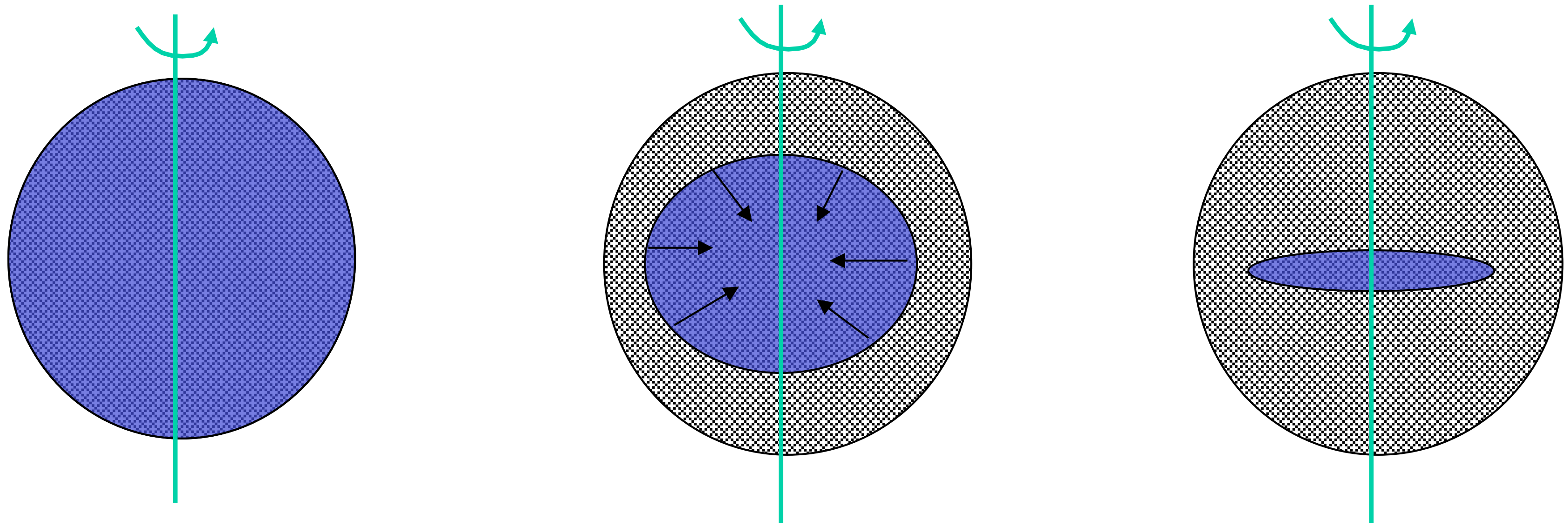


Governato et al. 2006



Roskar et al. 2010

Simple Picture of Galaxy Formation



gas

dark matter
NFW, MW c

e.g. Fall & Efstathiou (1980), Dalcanton et al. (1997)
Also viscous evolution - Lin & Pringle (1987), Ferguson & Clarke (2001)

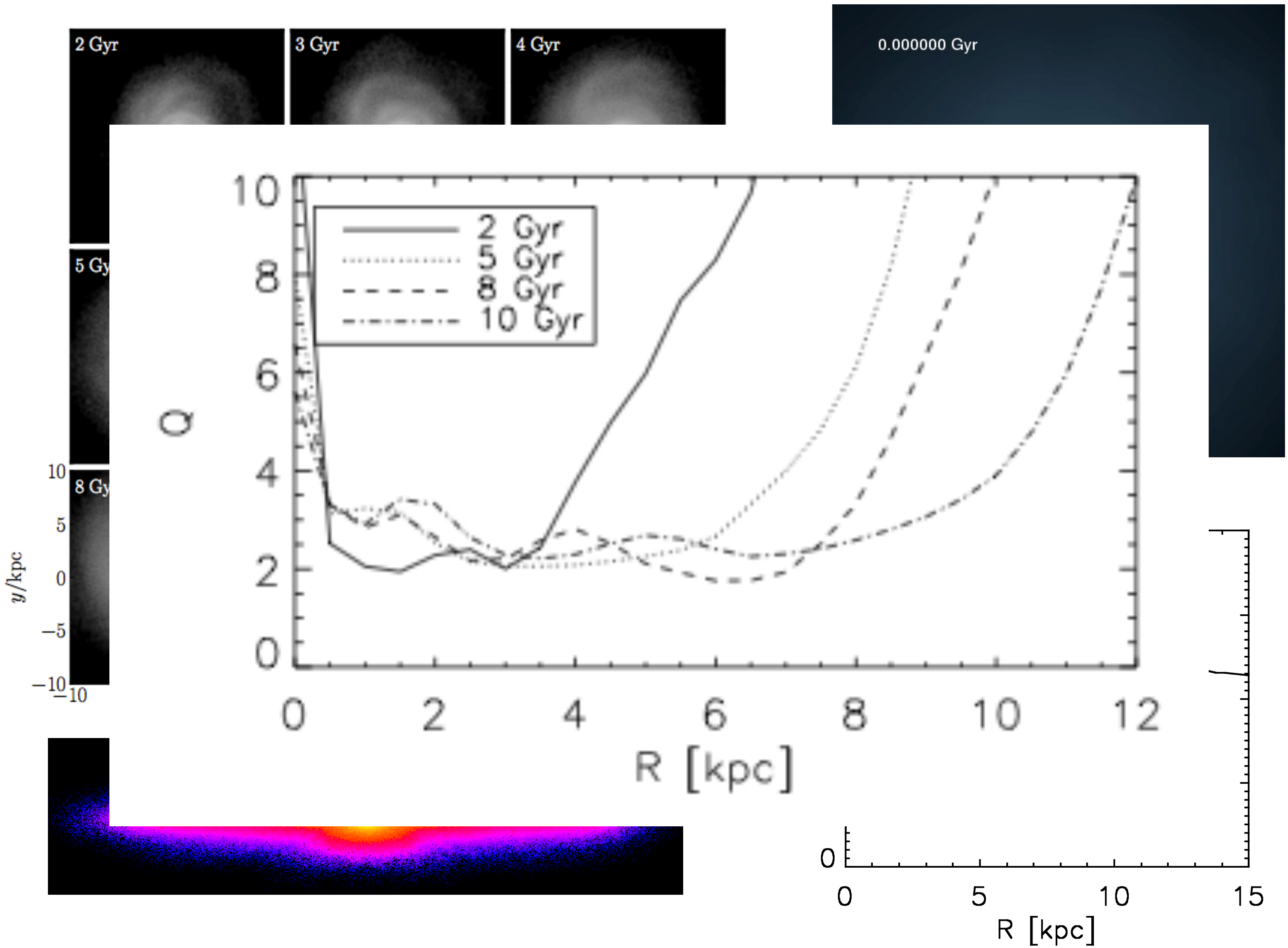
Simulations

Approximate disk formation via dissipational collapse after last major merger using SPH code GASOLINE

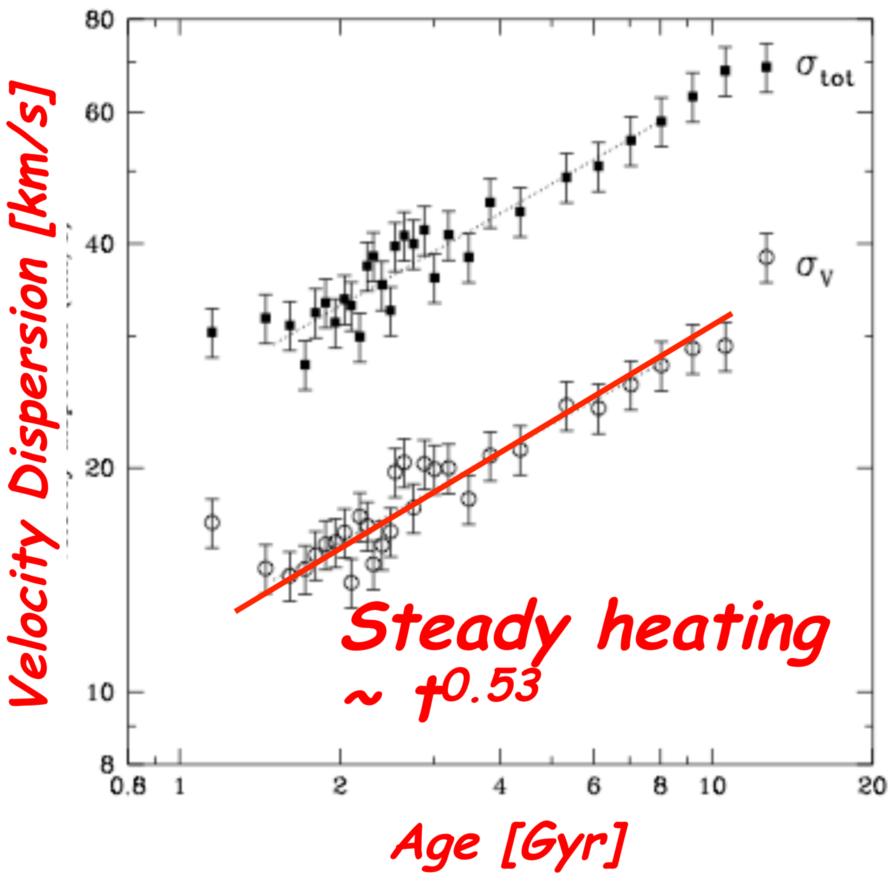
- 1M particles in each component, $M_{vir} = 10^{12}\ M_{\odot}$
- 10% baryons by mass
    - ~ $10^6\ M_{\odot}$ per DM particle
    - initially $1.4 \times 10^5\ M_{\odot}$ per gas $4.6 \times 10^4\ M_{\odot}$ per star
- 50 pc force resolution for baryons, 100 pc for DM
- star formation and feedback (Stinson et al. 2007) including feedback from SN Ia, II and stellar winds

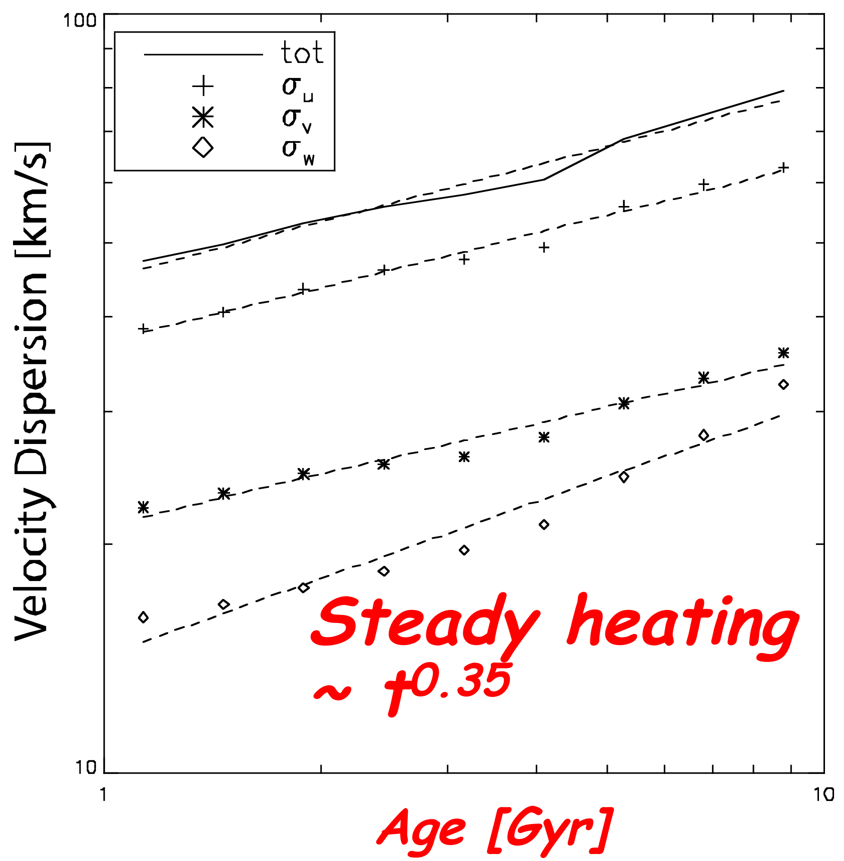
Advantages:

- ***fully self-consistent evolution***
- ***no ad-hoc assumptions about the disk***
- ***full modeling of dynamical processes***
- ***star formation and feedback allow for direct comparisons with observations (age, metallicity (Fe & O), SFR etc.)***



2 Gyr
3 Gyr
4 Gyr
5 Gy
8 Gy
y/kpc
0.000000 Gyr
2 Gyr
5 Gyr
8 Gyr
10 Gyr
Q
R [kpc]
R [kpc]



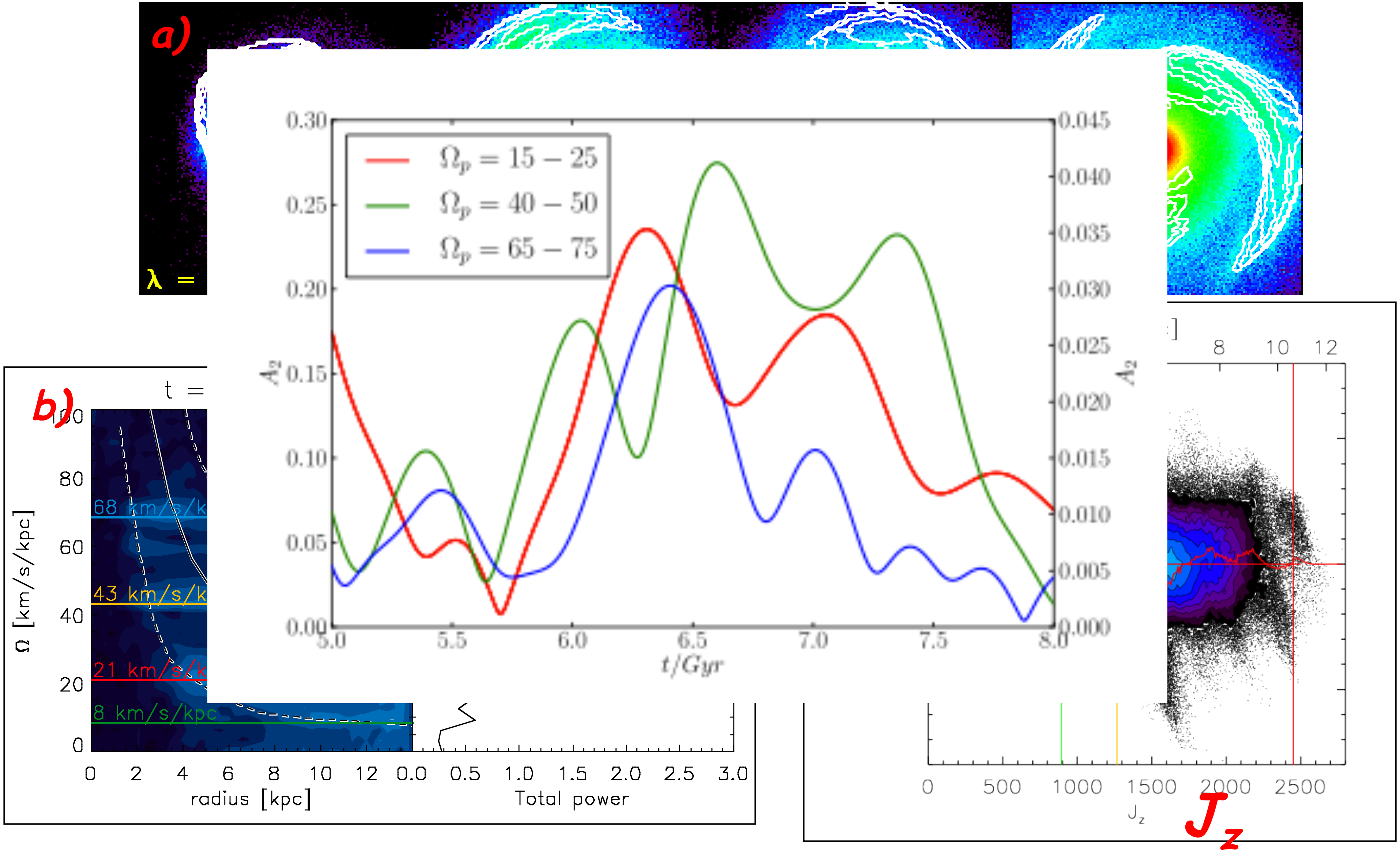


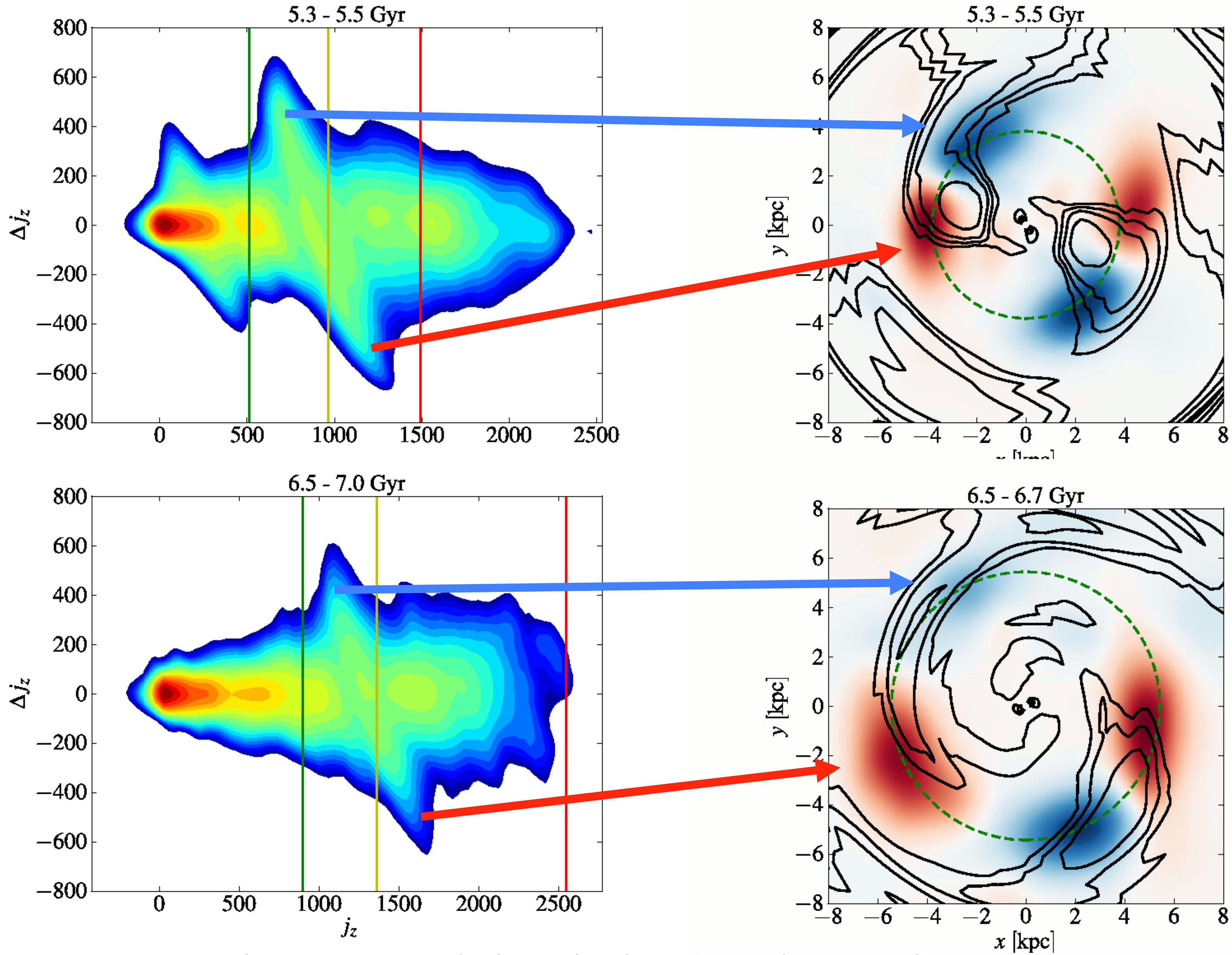
Data: Geneva-Copenhagen survey (Holmberg 2009)

Simulation

Confirming Role of Spirals

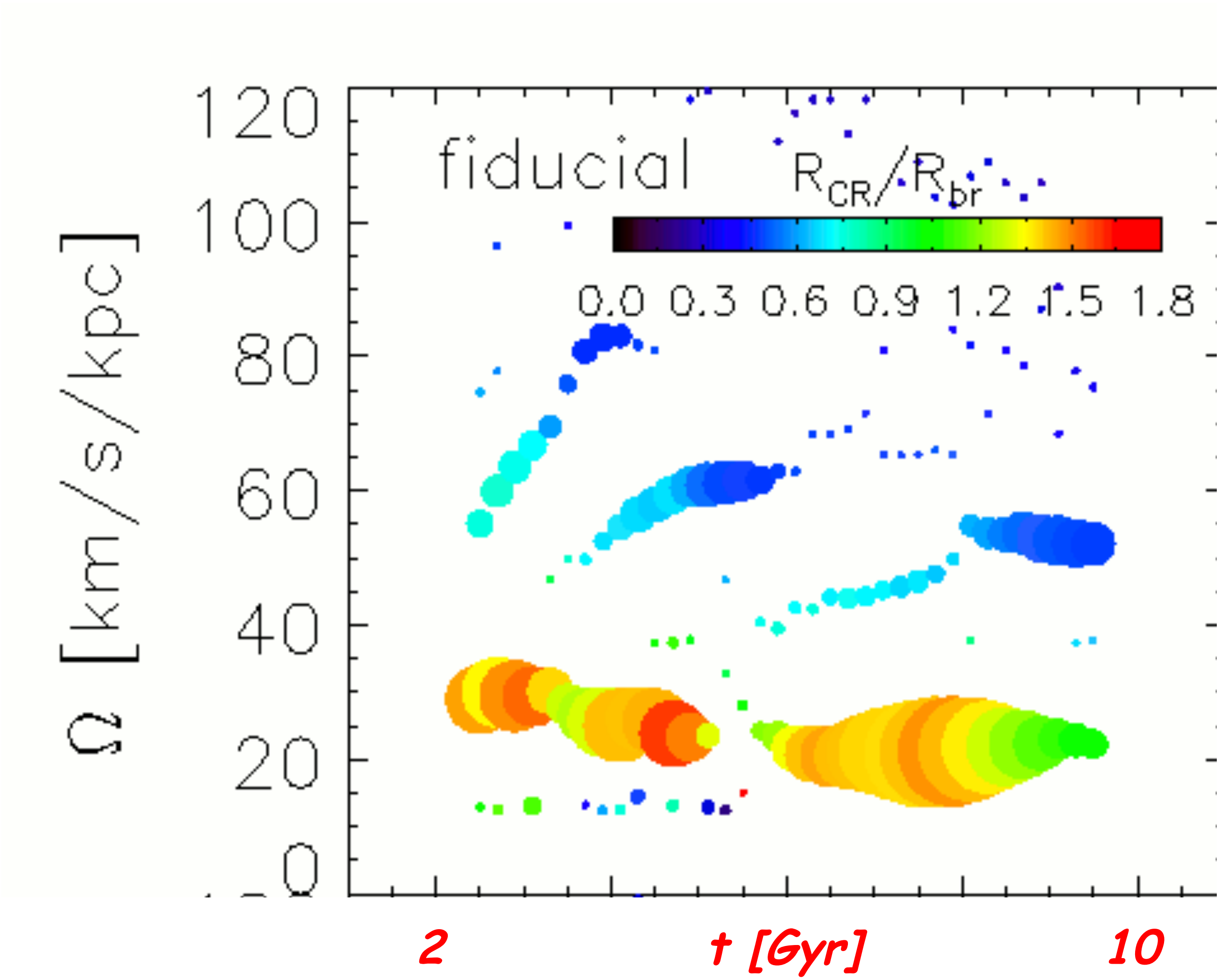
a) Fourier expansion -> b) power spectrum -> c) identify patterns/resonances



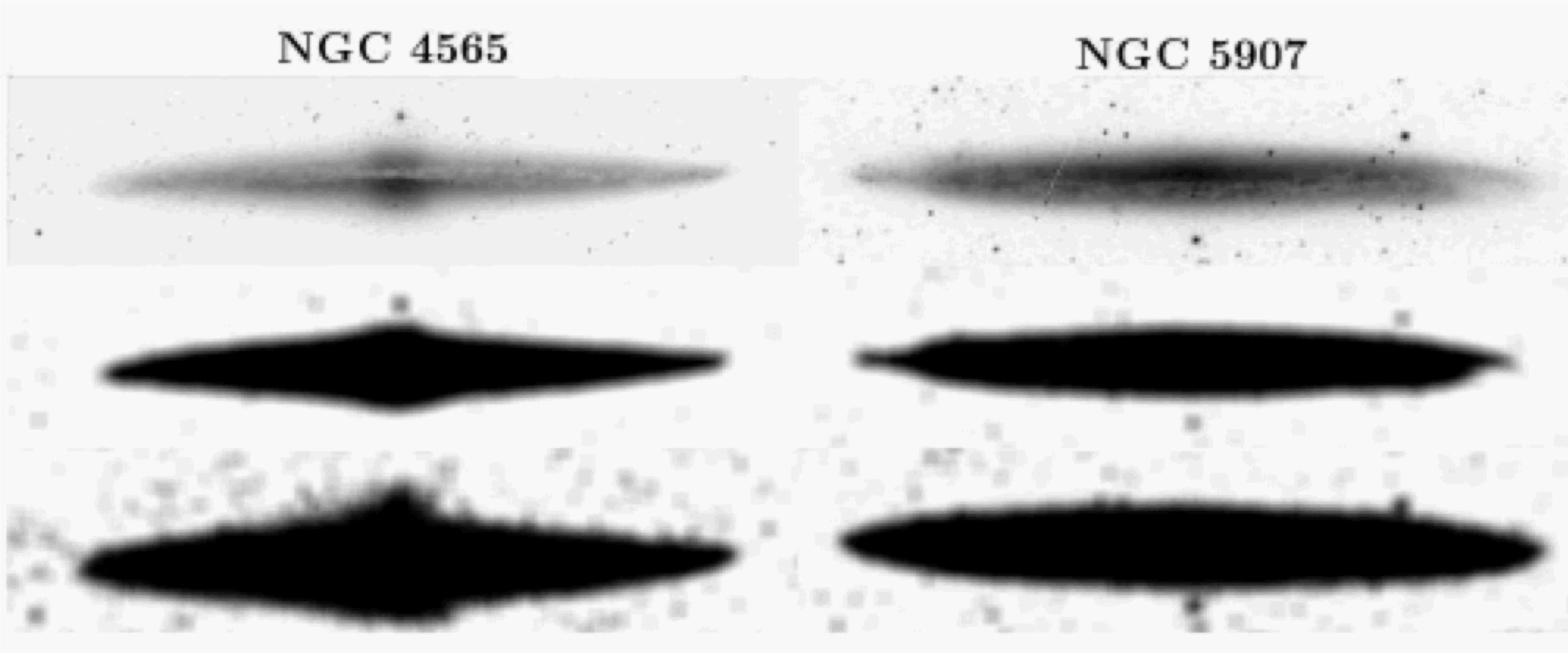


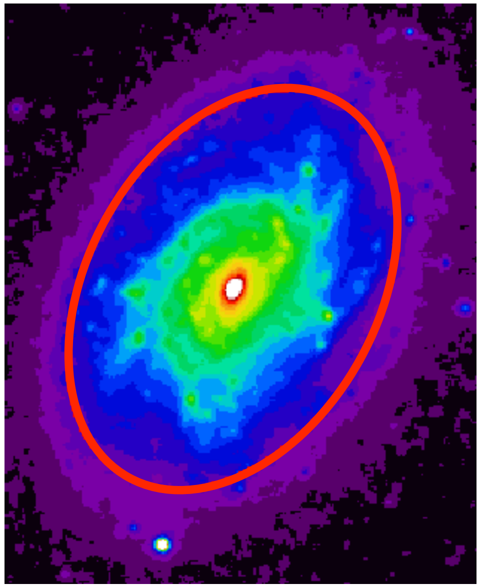
Migrating particles are overwhelmingly found at the CR of spirals: inward migrators ahead of the spiral while outward migrators are behind it

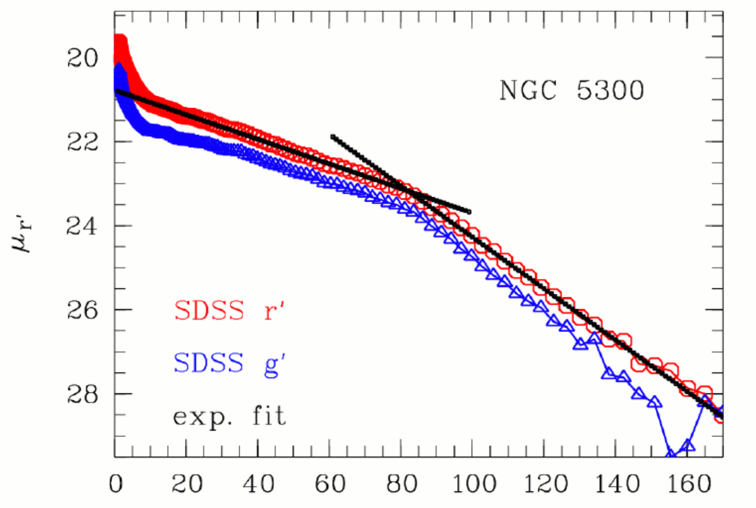
Roškar+ 12



Hints of long-lived modes



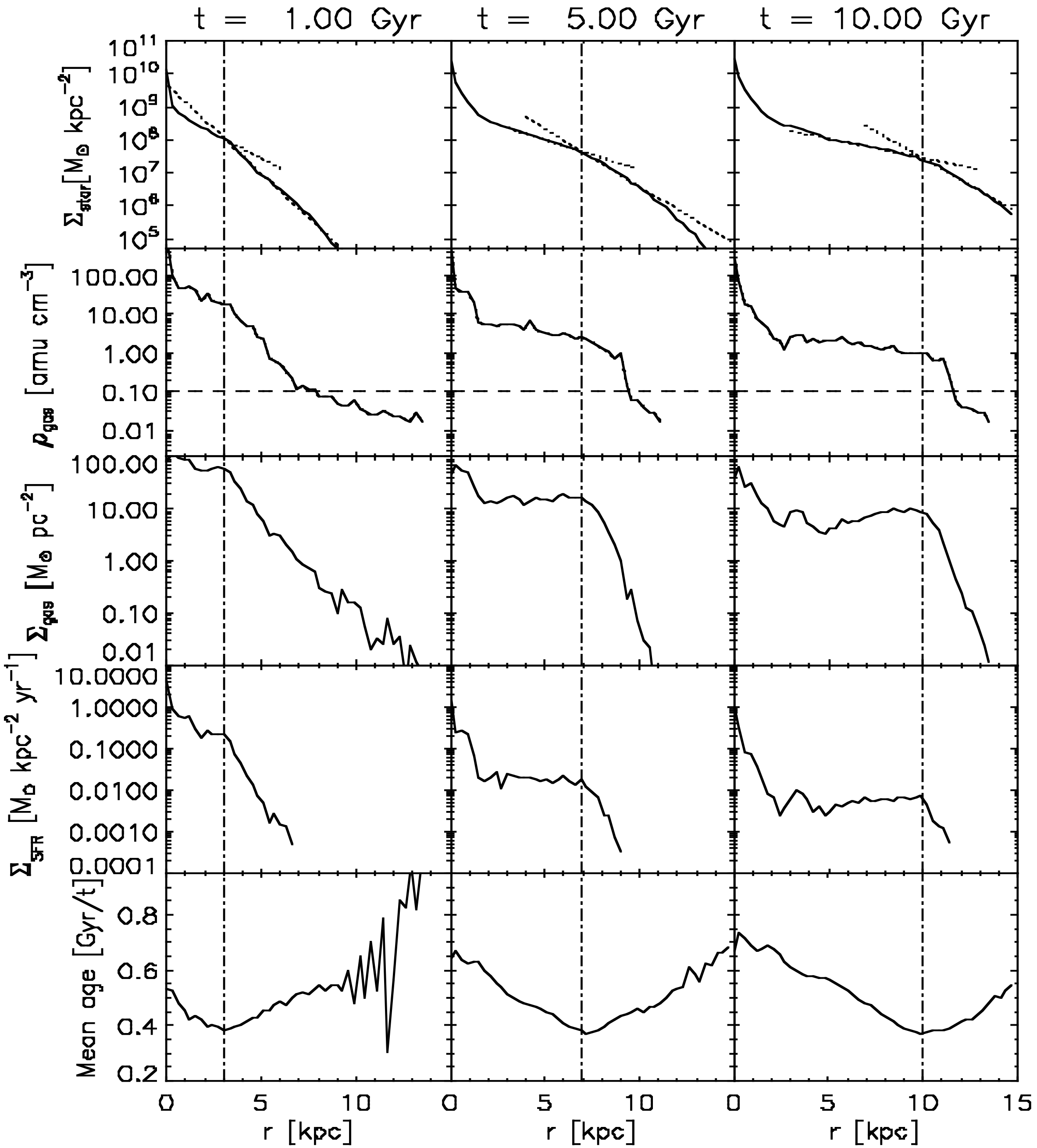




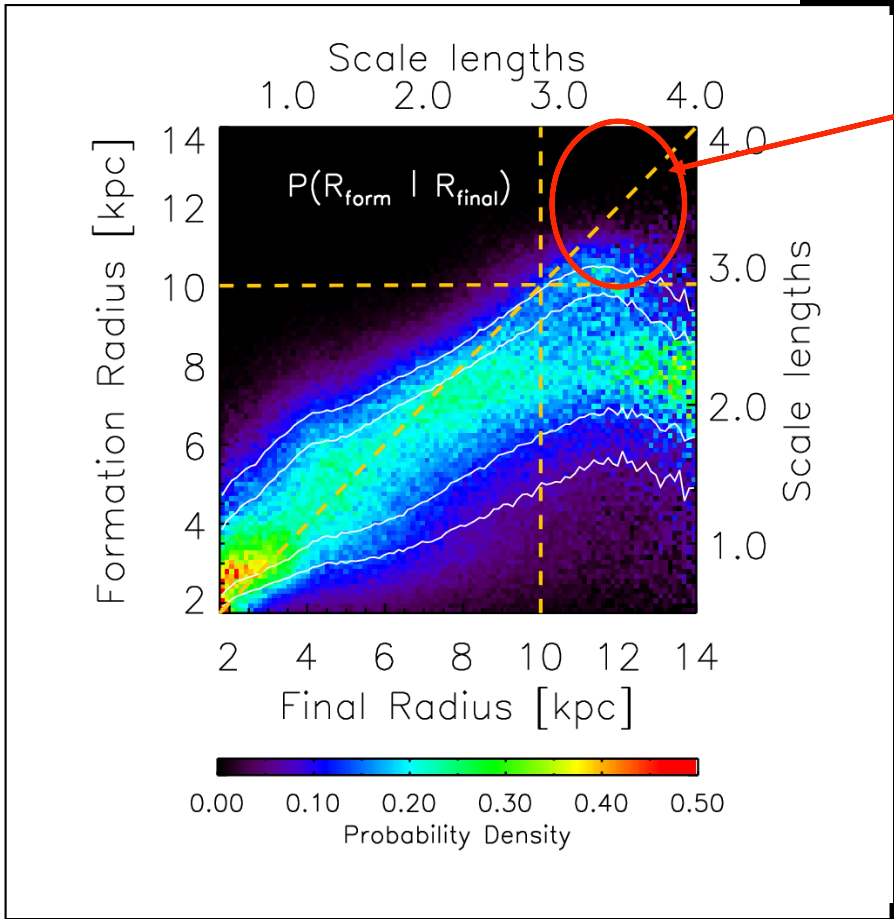
Pohlen & Trujillo 2006

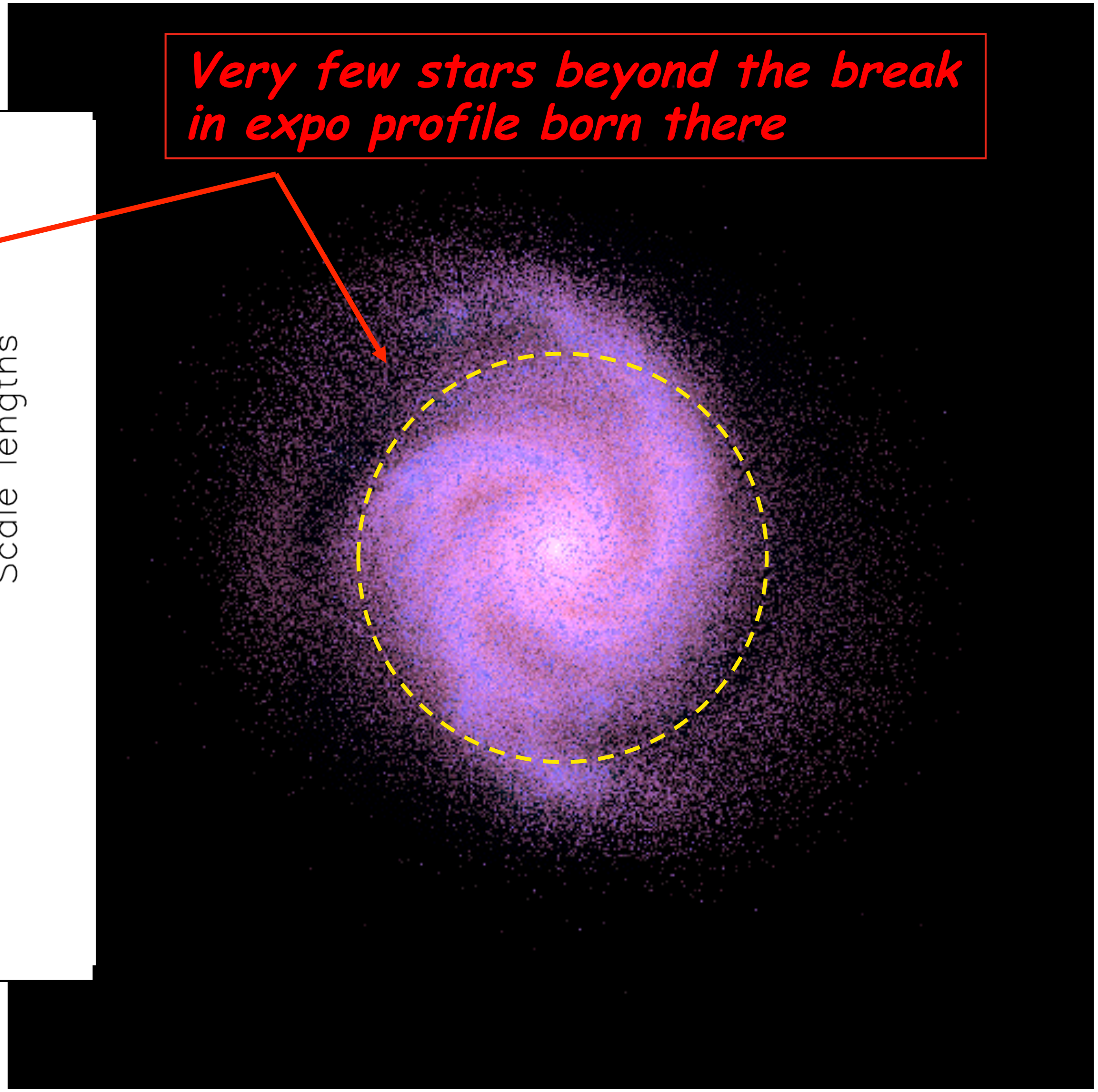
van der Kruit 1979

60% truncated
10% pure expo.



Disk (to break radius) grows from the inside out

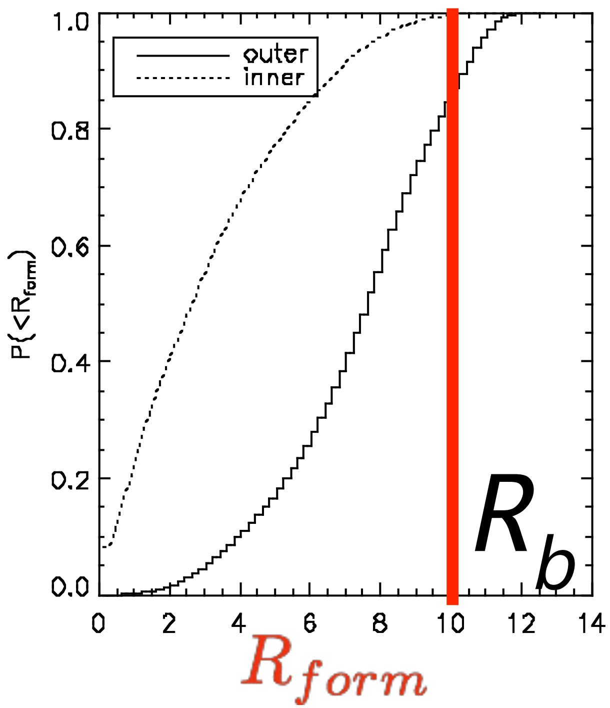




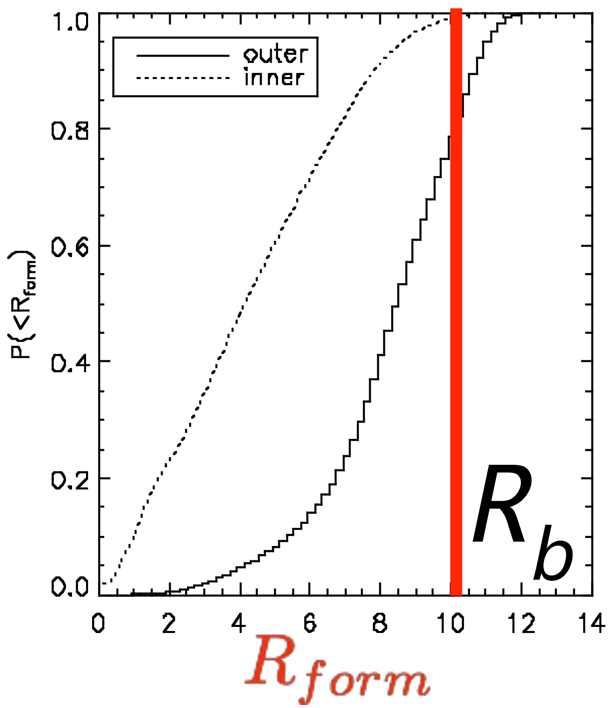
Roškar et al. 2008a

Outer Disk Kinematics

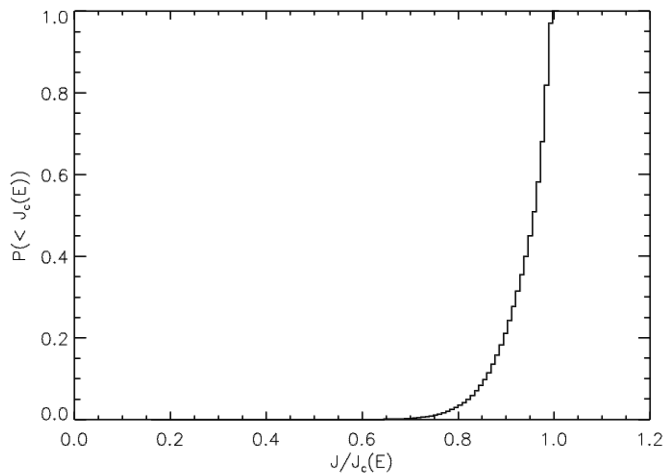
All



Circular



Outer disk only

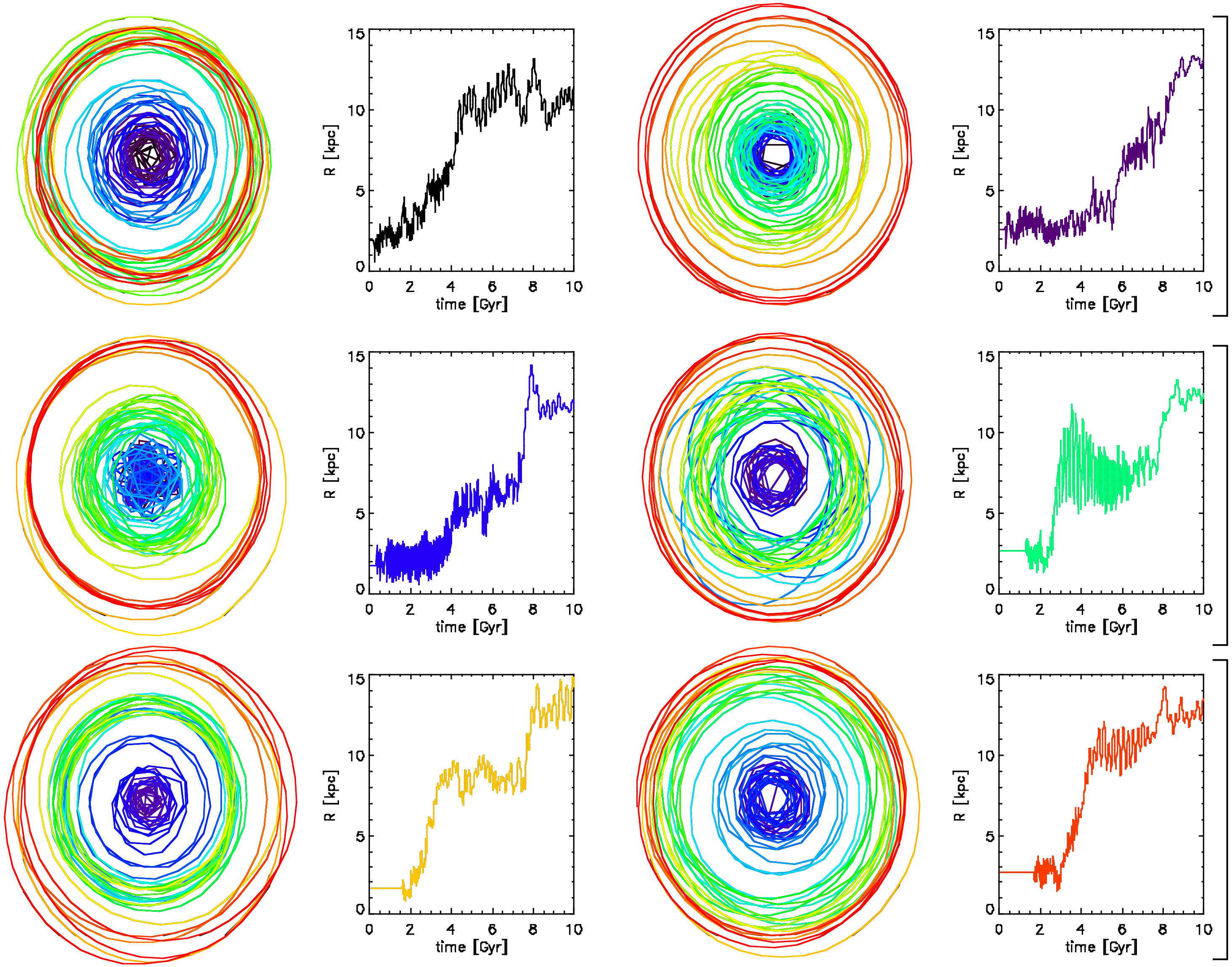


J/Jc(E)

Most particles in the outer disk still retain nearly circular orbits

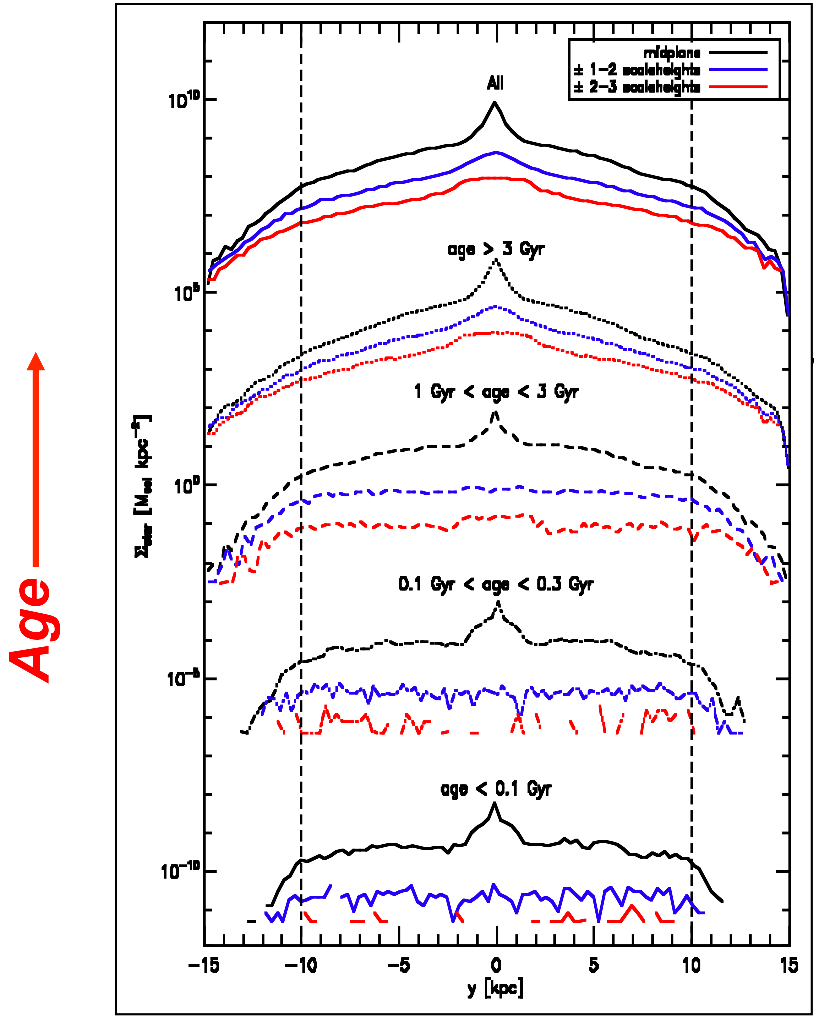
Sample of Orbits Ending in Outer Disk

Typical velocities are $\Delta R/\Delta t \le$ 5kpc/ 200Myr = 25 km/s

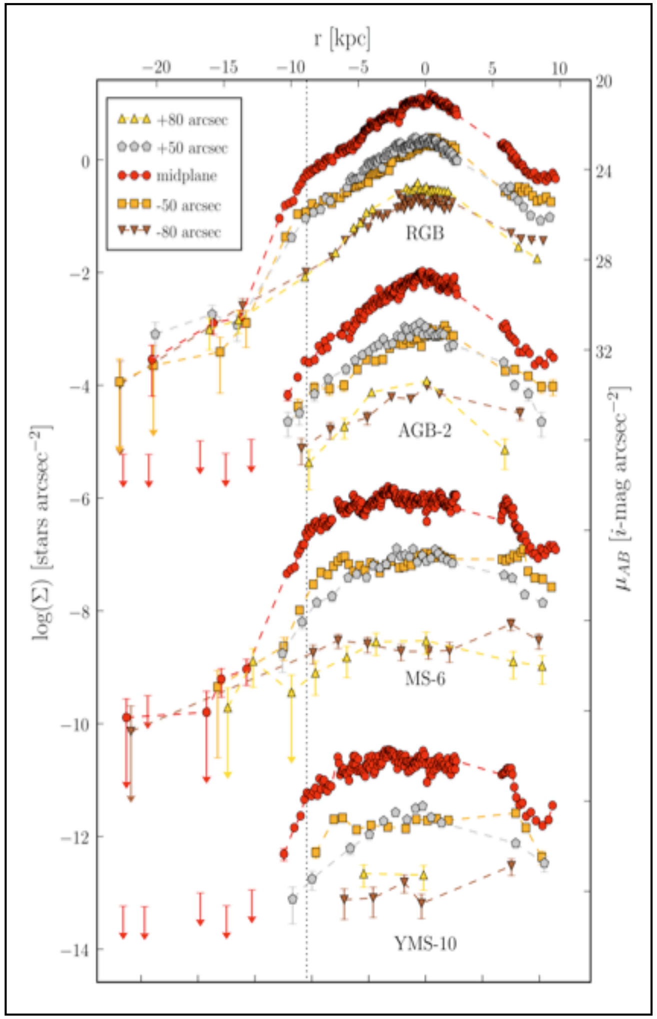


Comparison to NGC 4244

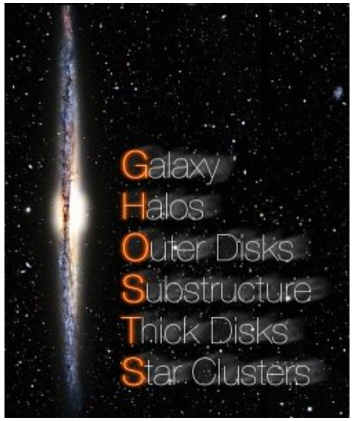
simulation



HST star count profiles

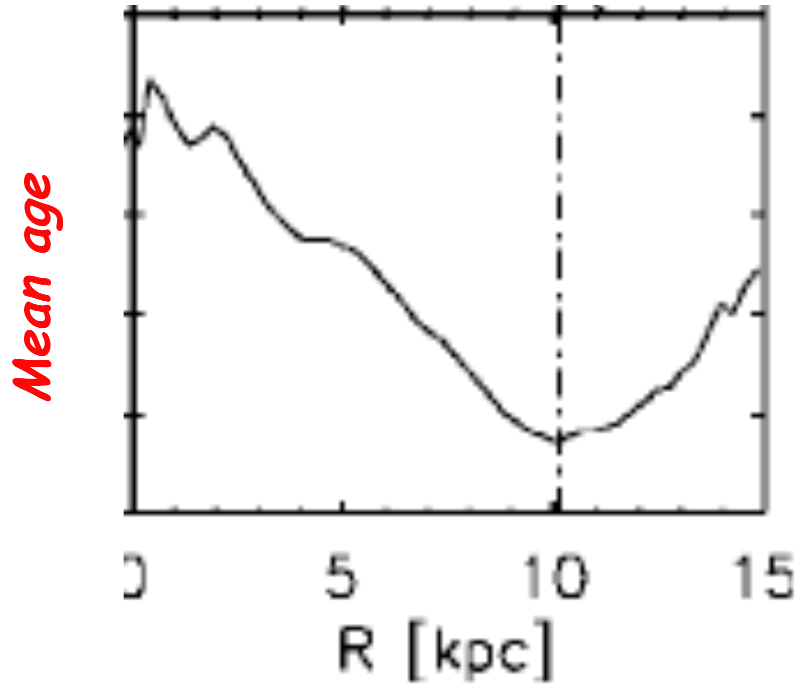


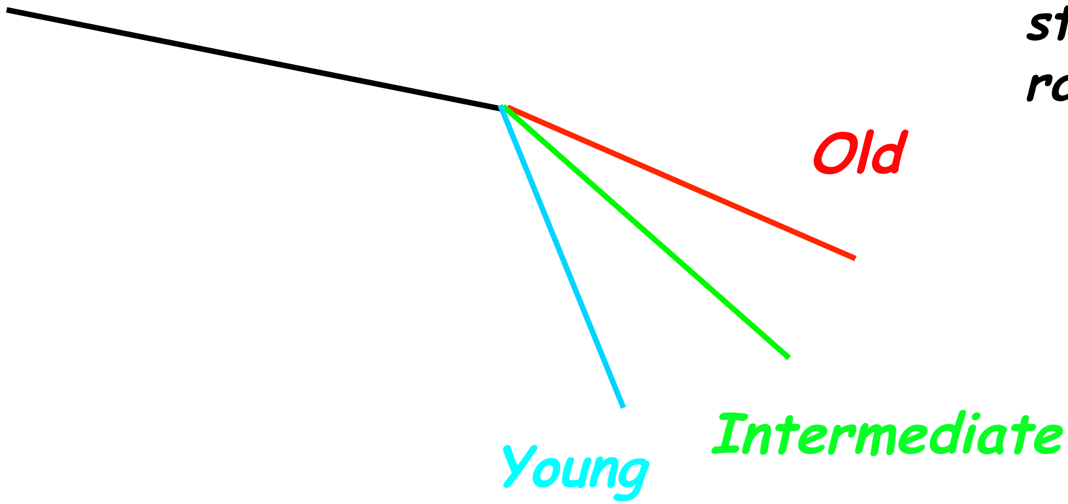
R_{br} the same for all pops



de Jong+ 2007

Outer Disk Stellar Pops



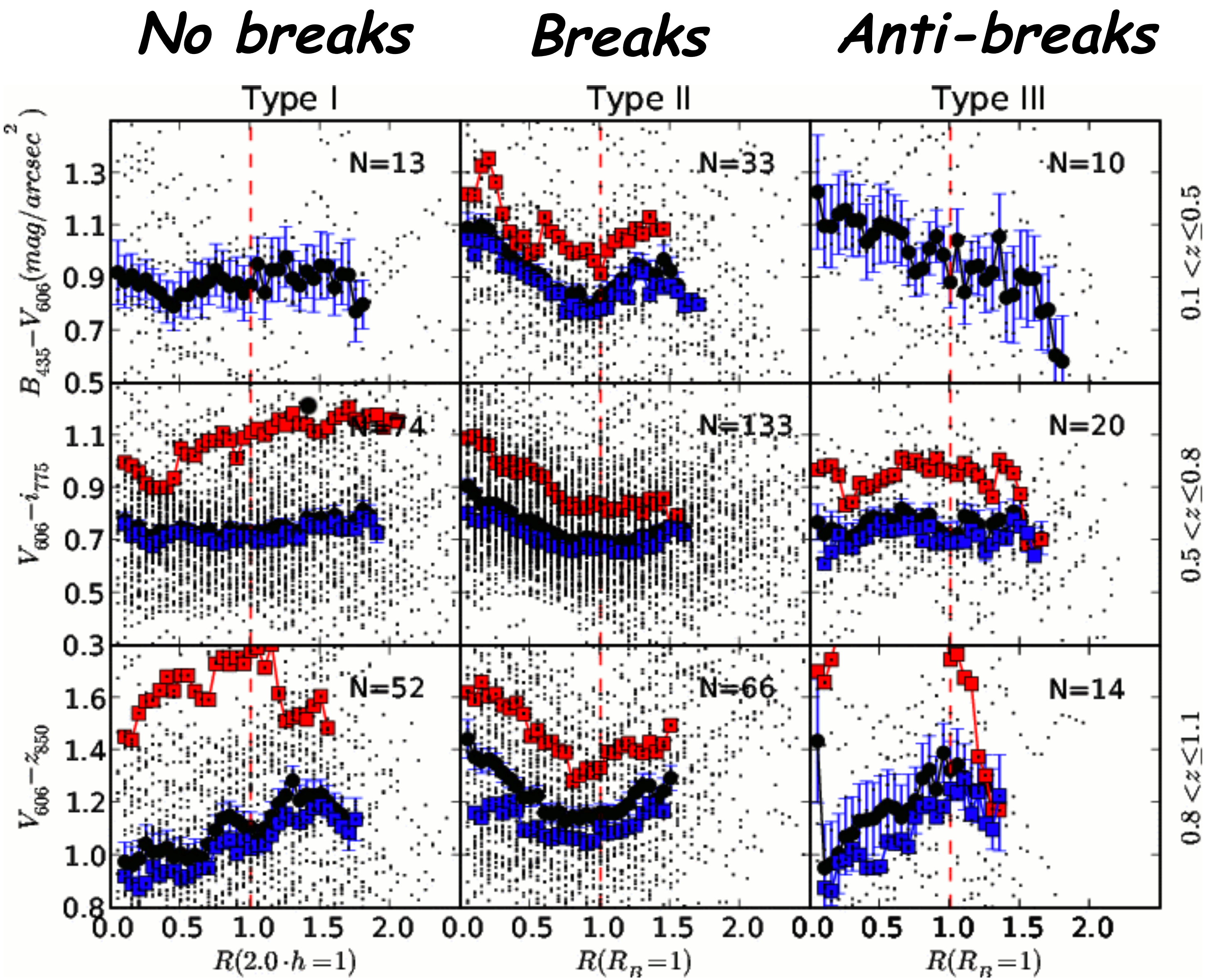


Migration is basically a random walk, so older stars get to larger distance from formation

Expect the mean age of disk stars to increase beyond the break

The variation of outer disk scale-length for different age stellar bins constrain migration rates

Stacking Galaxies

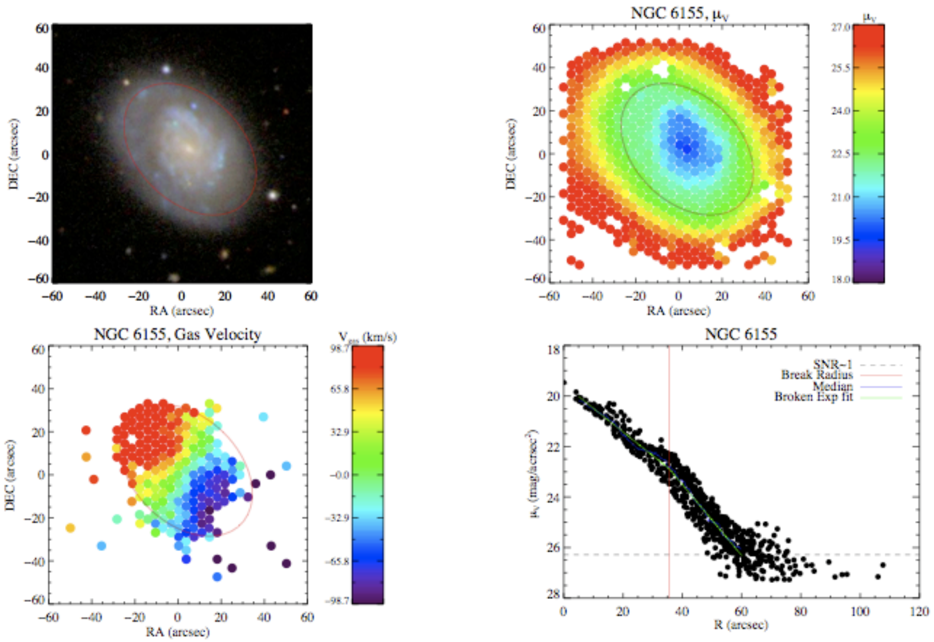


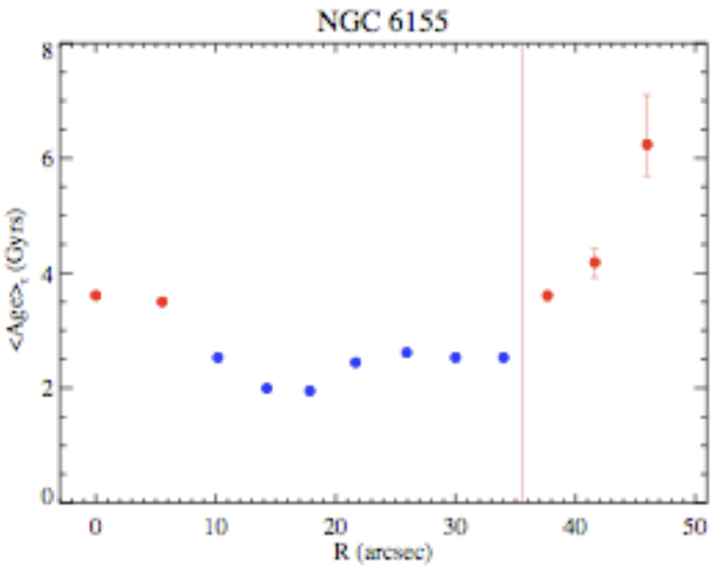
> $10^{10} M_{sun}$

< $10^{10} M_{sun}$

All rest frame ~ u-g

Azzollini+ 2008





NGC 6155

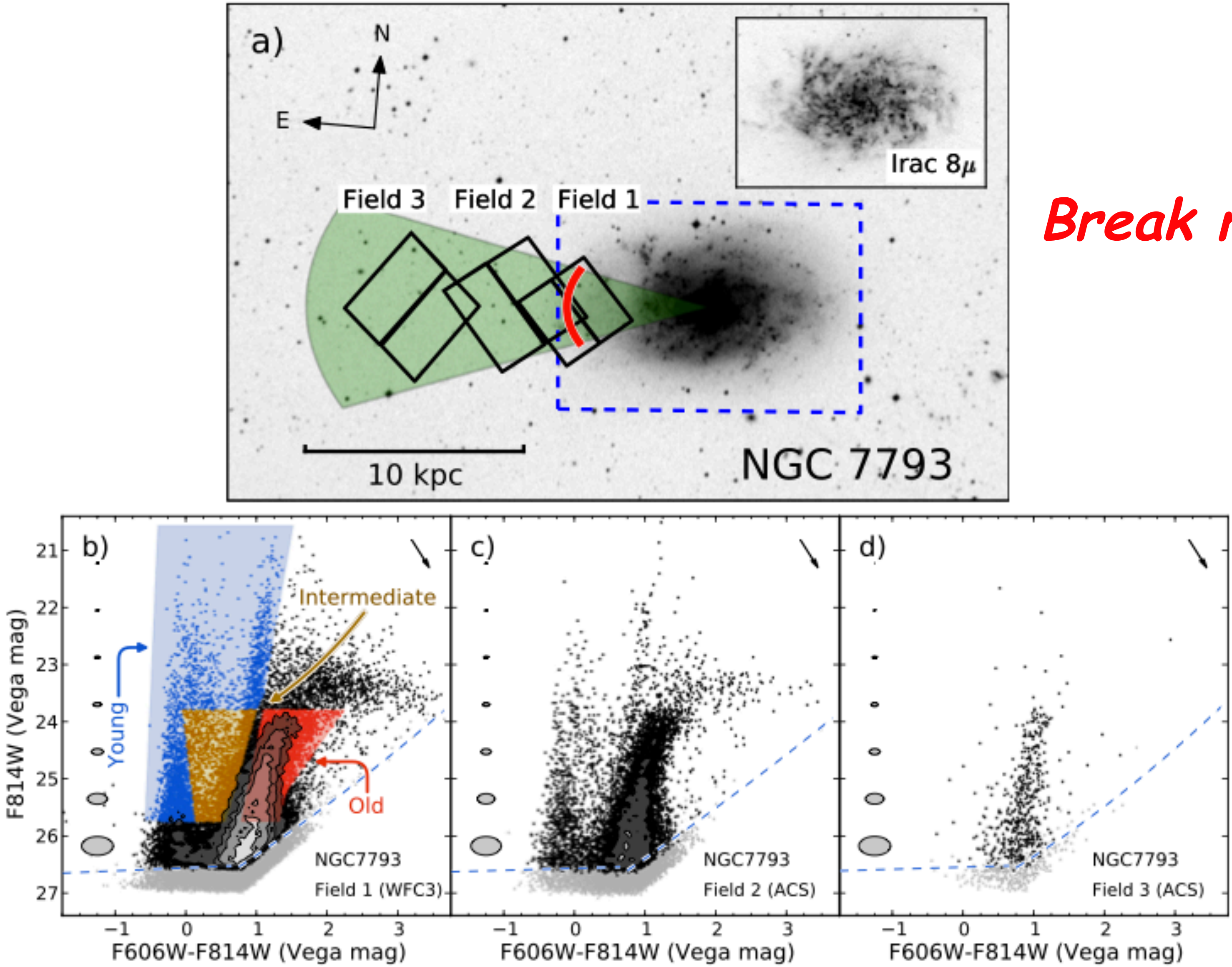
Break at 34" (Pohlen & Trujillo 2006)

Data using VIRUS-P on 2.7-m HJS telescope 1.7' x 1.7' fov. Rebin data to S/N ~45 beyond break

Fit the spectra using GANDALF (Sarzi et al. 2006) assuming exponential SFH and varying metallicity

Yoachim+ 2010, 12

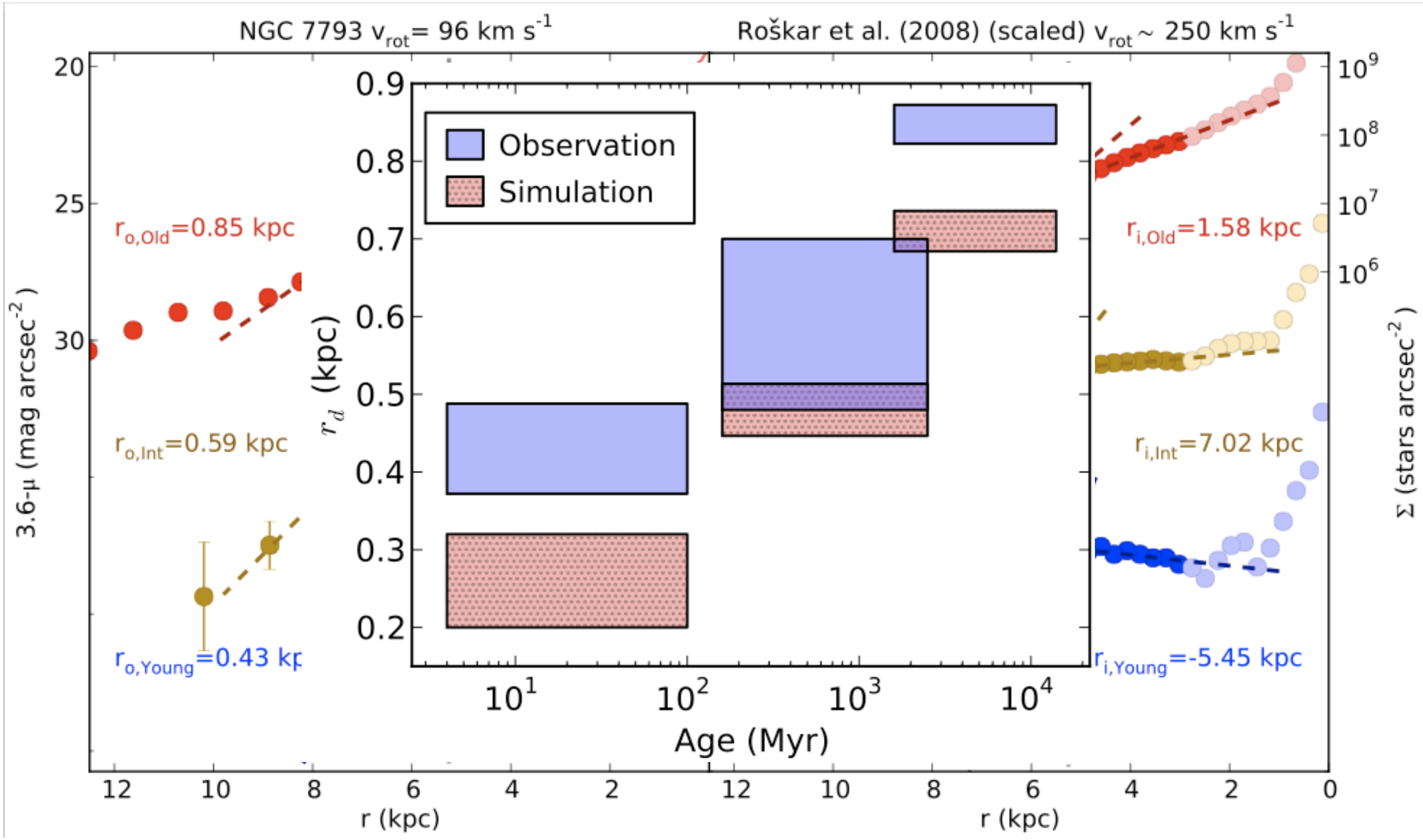
NGC 7793



Break radius

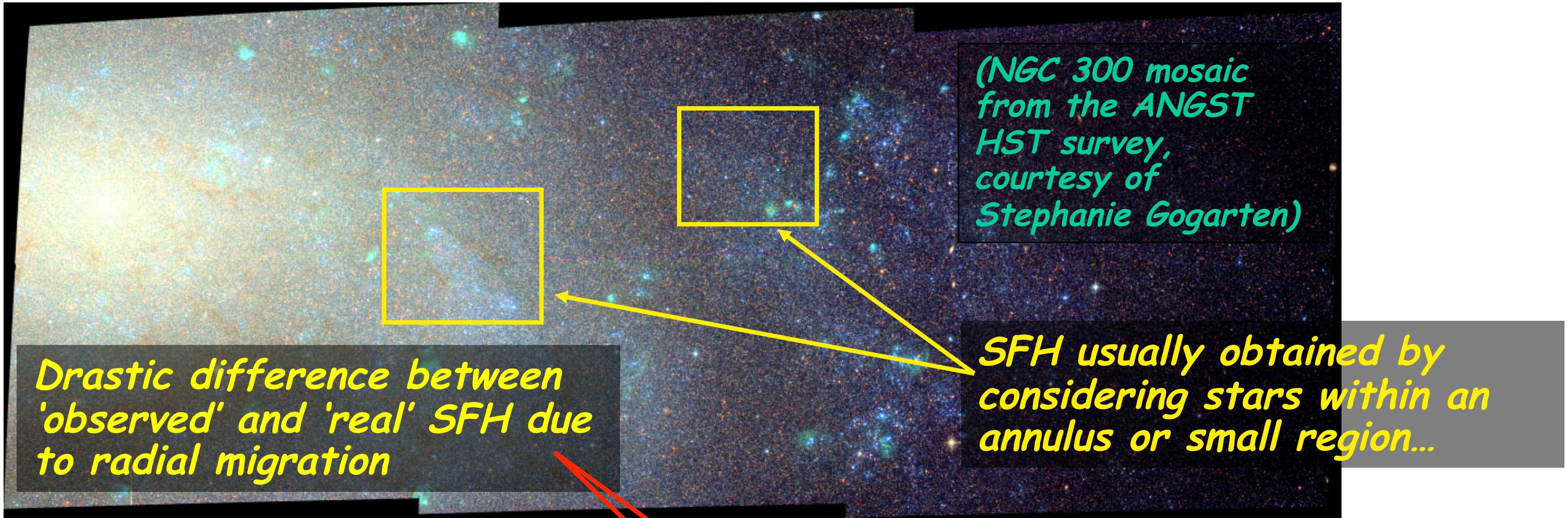
Radburn-Smith+ 2012

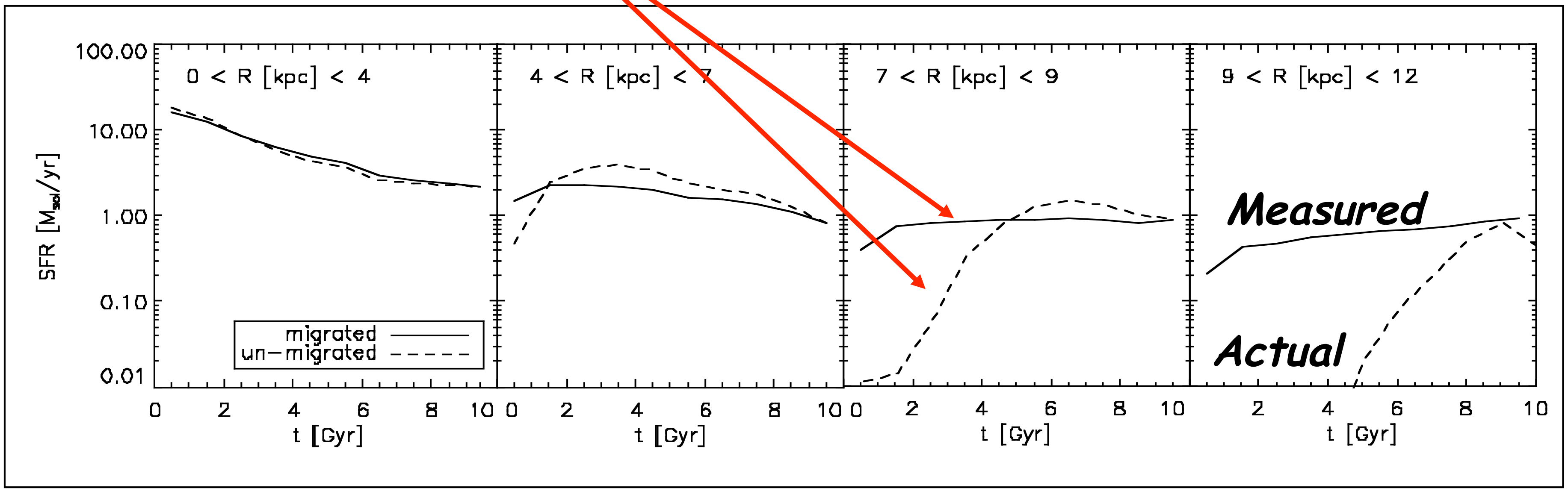
NGC 7793



Radburn-Smith+ 2012

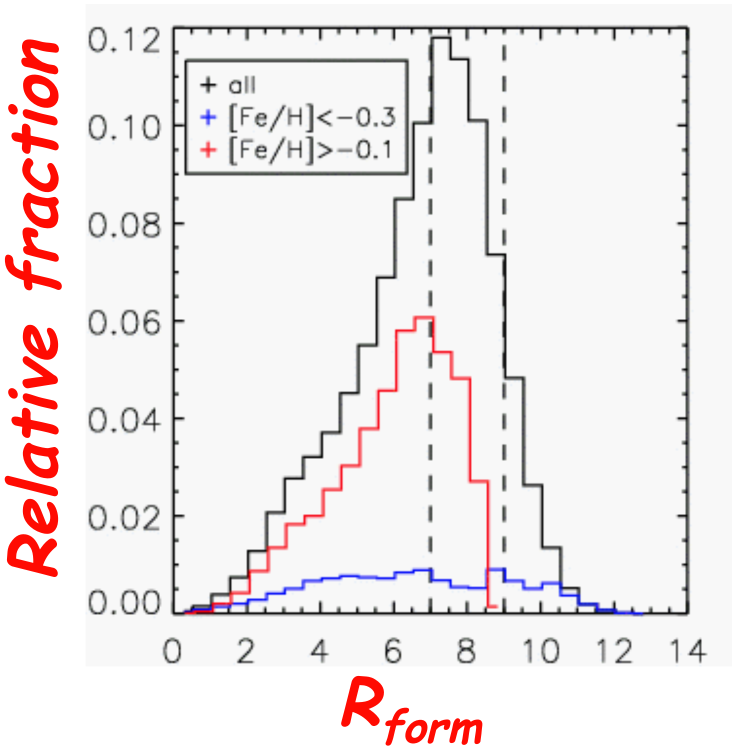
Implications for Galactic Archaeology

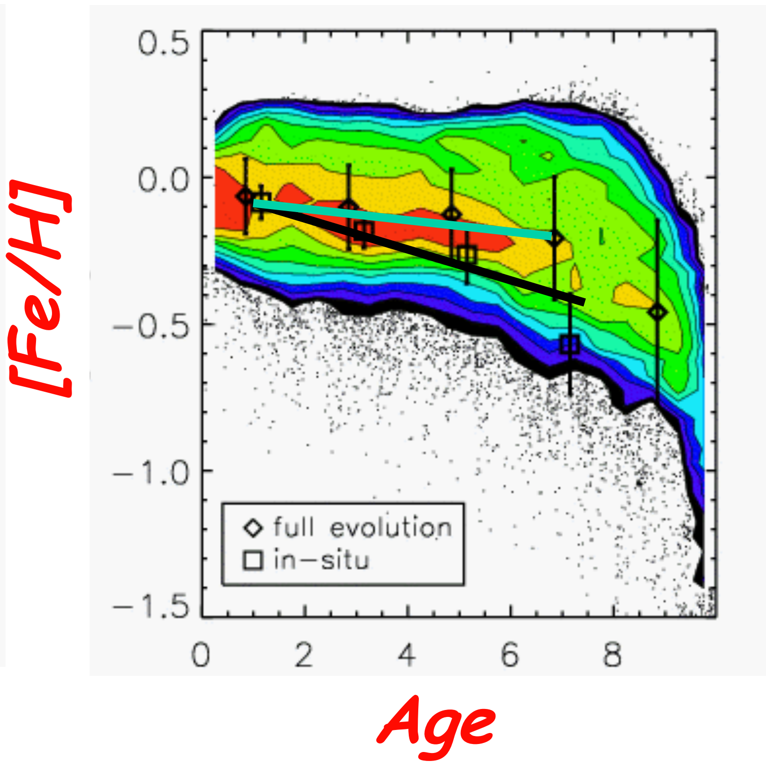




Roškar et al. 2008b

Most of the stars in the solar neighborhood (7 < R < 9 kpc) formed elsewhere. The metal poor ones come from a wide range of radii, including from outside the solar neighborhood, while the metal rich ones come from inside the solar radius.



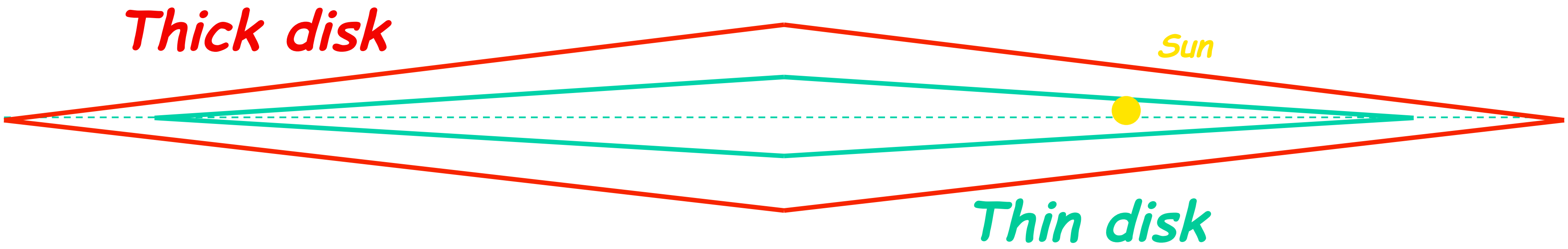


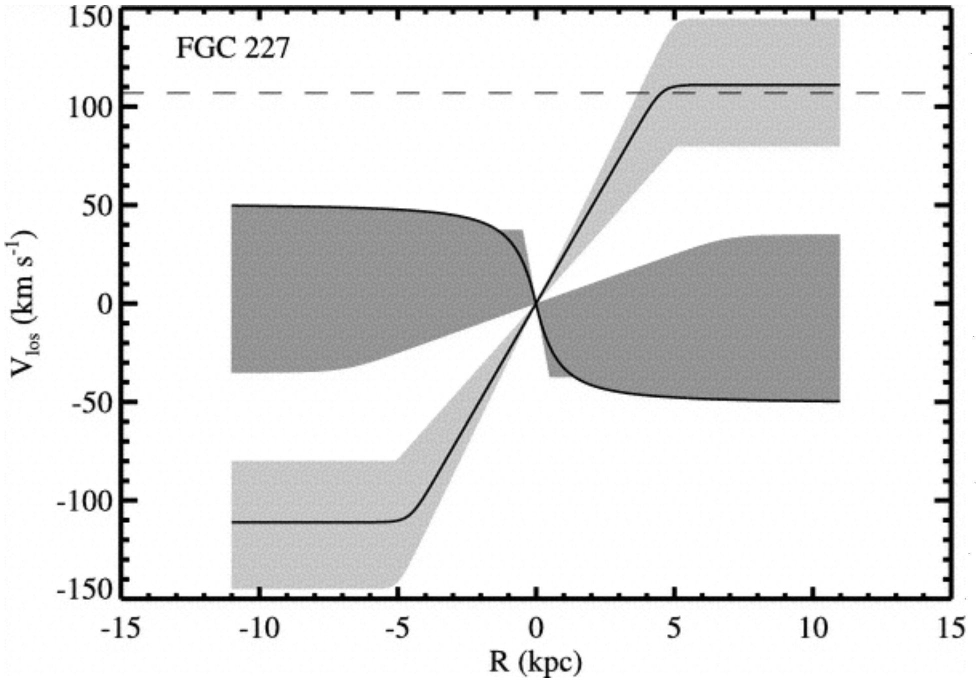
Edvardsson+ 93, Nordstrom+ 04, Haywood 08

Assuming stars remain in situ, we find a significant gradient and low dispersion in AMR. But AMR is flattened & broadened by migration, which is true also for stars on circular orbits. Note: increase in metallicity of old stars and increasing scatter with age

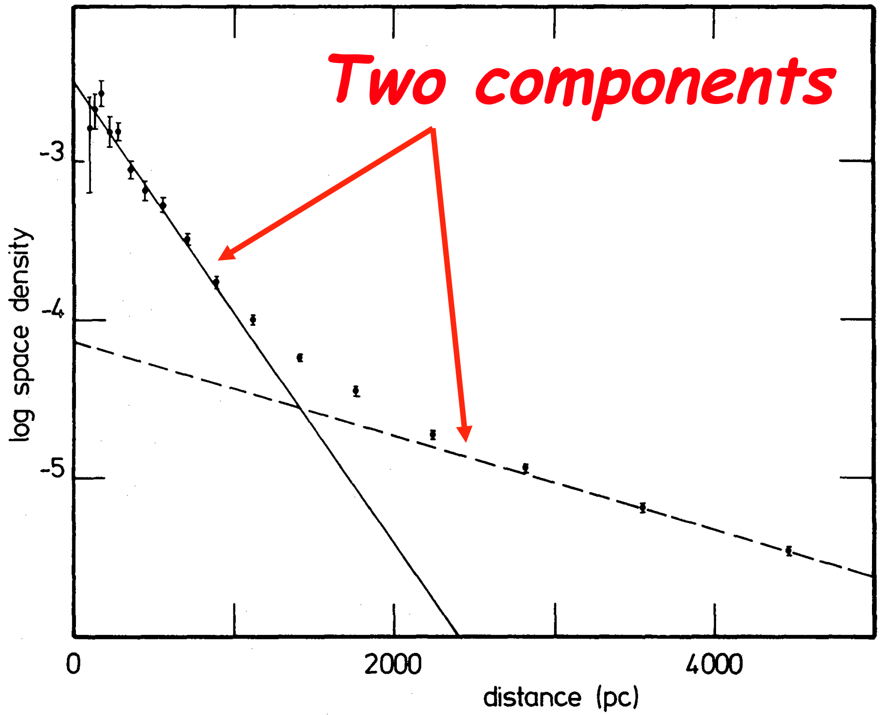
Roškar+ 08b; Schönrich & Binney 09

Thick Disk Formation





Yoachim & Dalcanton 2005



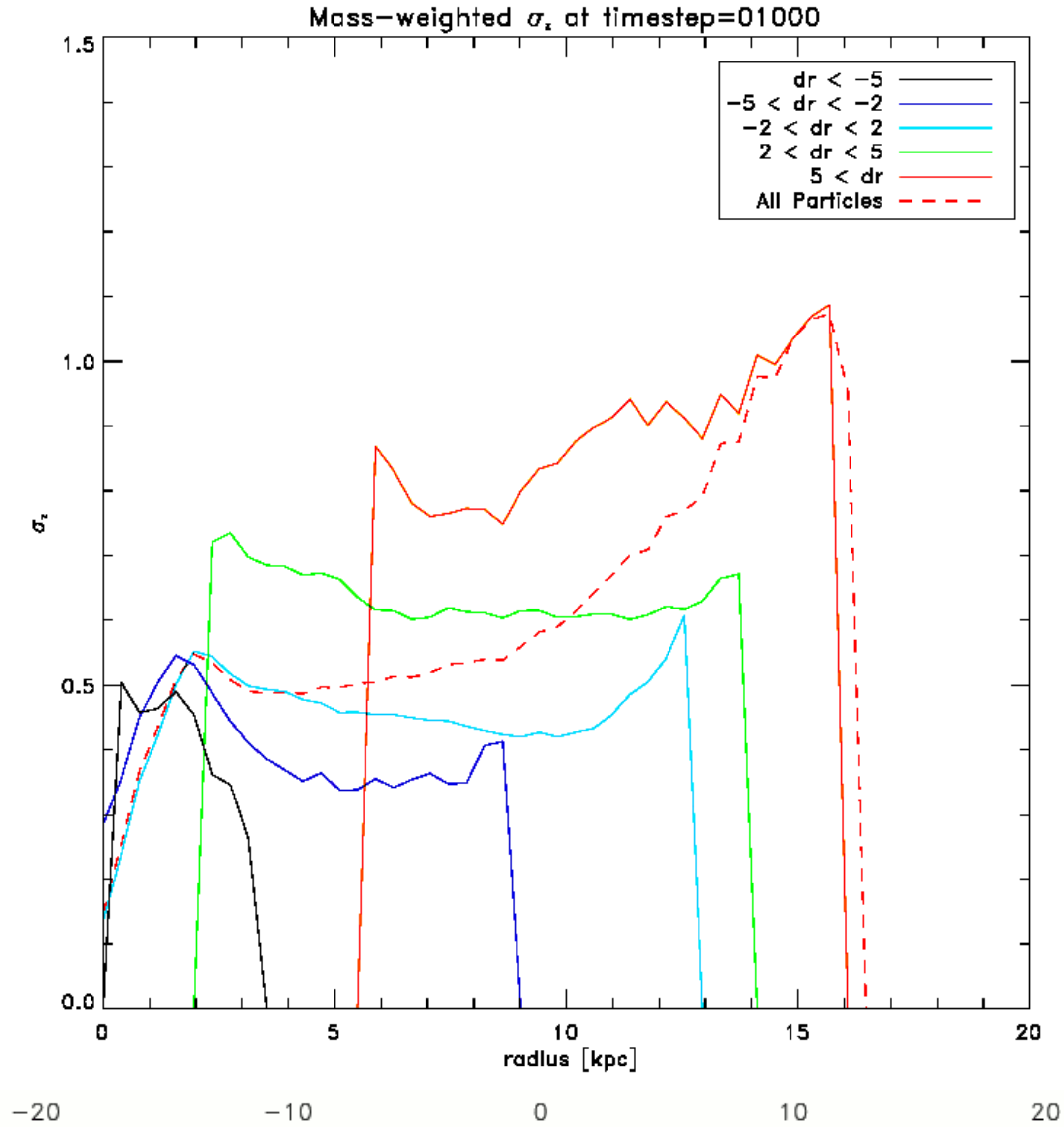
Gilmore & Reid 1983

Effect on Vertical Direction

If vertical action is conserved by migration then stars moving outwards puff up and vice-versa

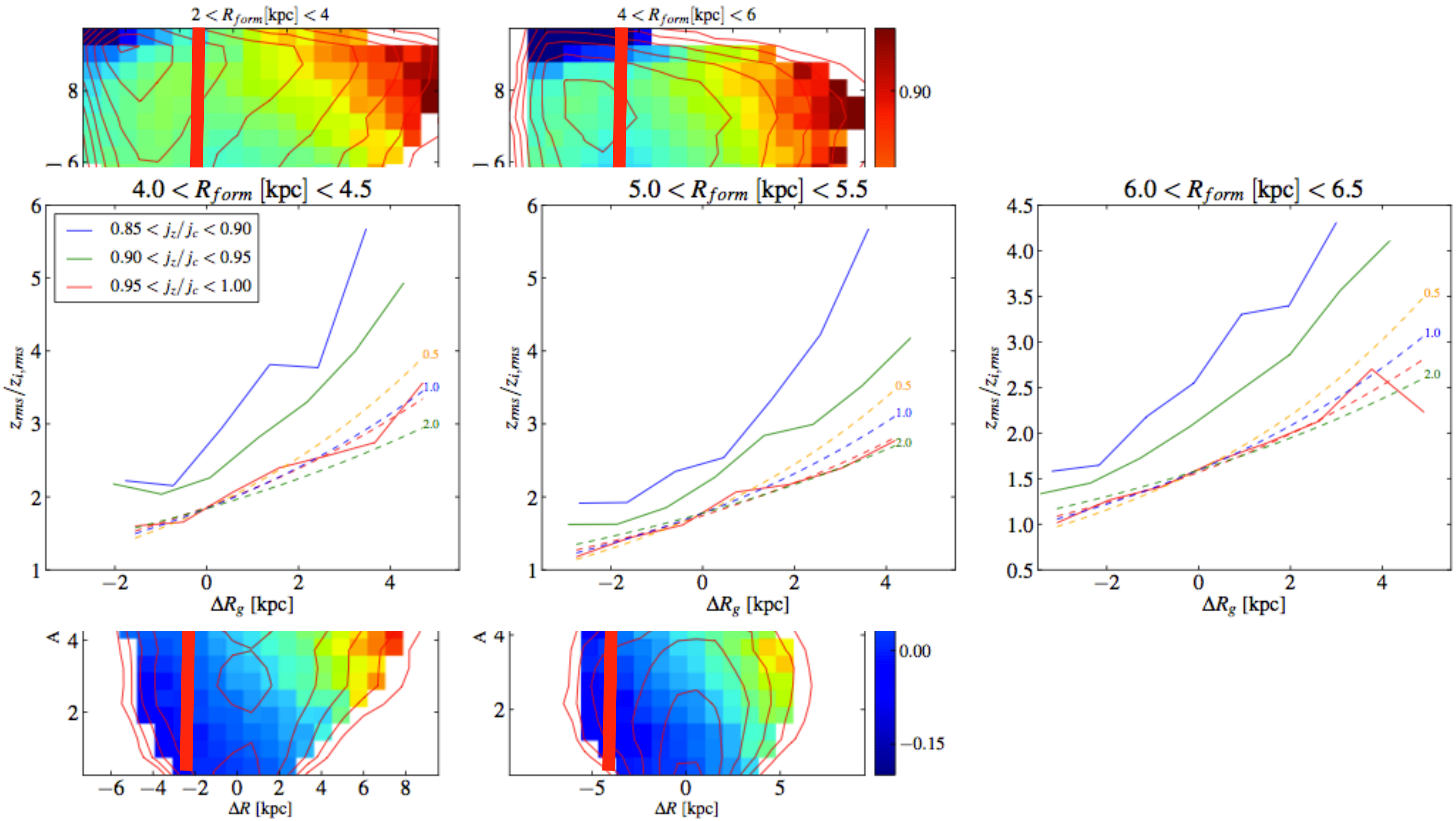
Is there such a thing as a dynamically distinct thick disk?

Schöenrich & Binney 2009



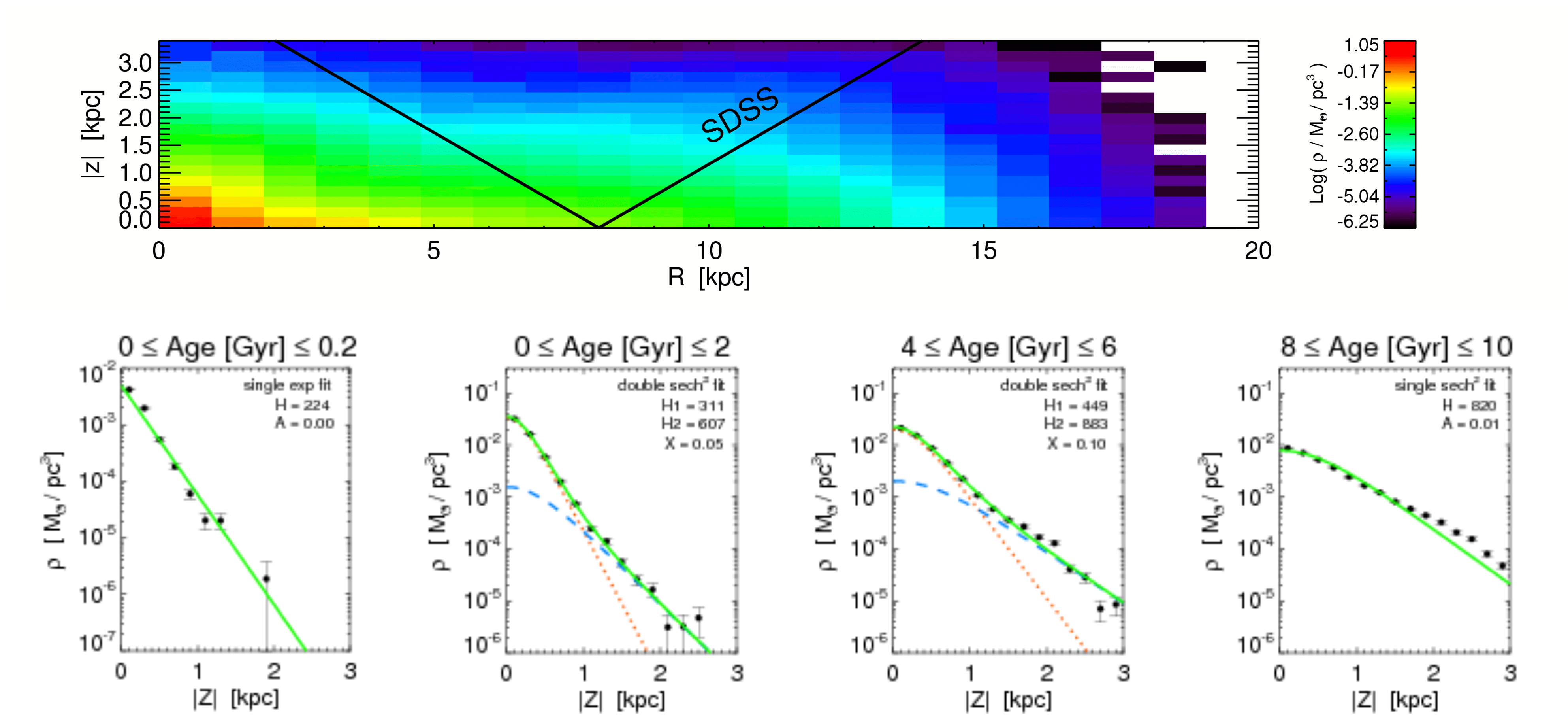
Caruana 2009

Controlling for Age



ΔR [kpc]

Roskar+ 2013



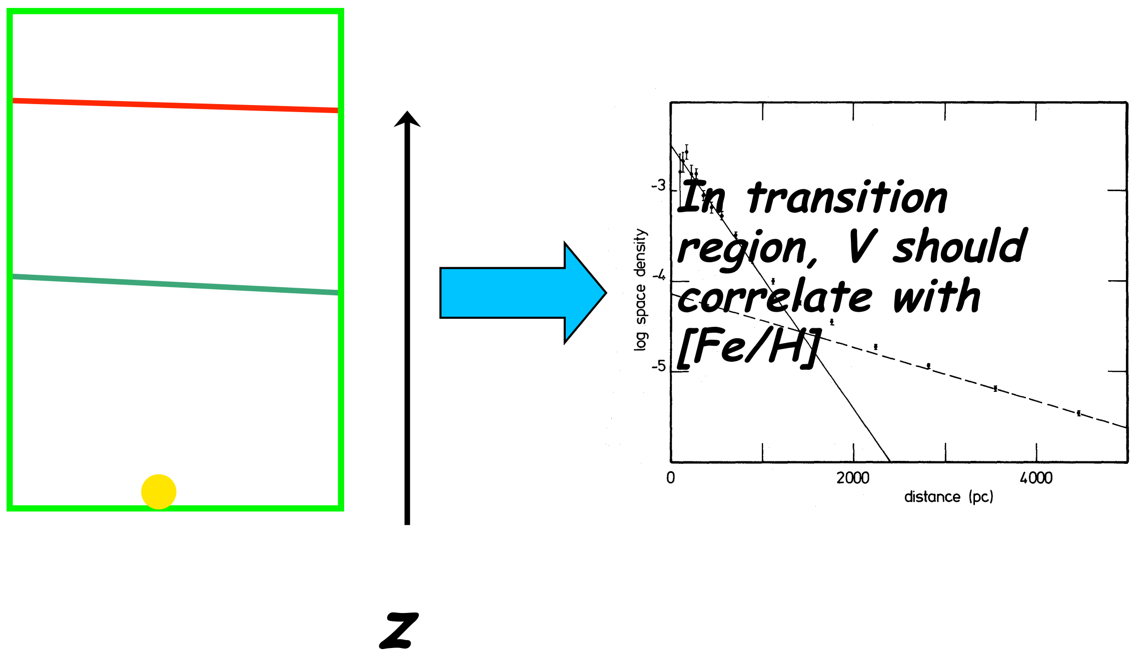
Stars form with a single exponential profile but develop a double component profile

Loebman+ 11

Testing Thick Disk Formation

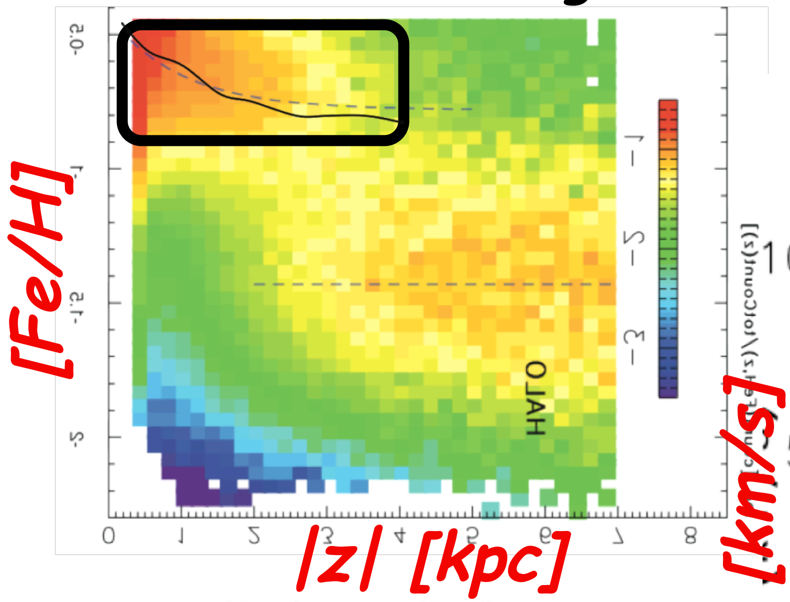
Metal poor + slow rotation

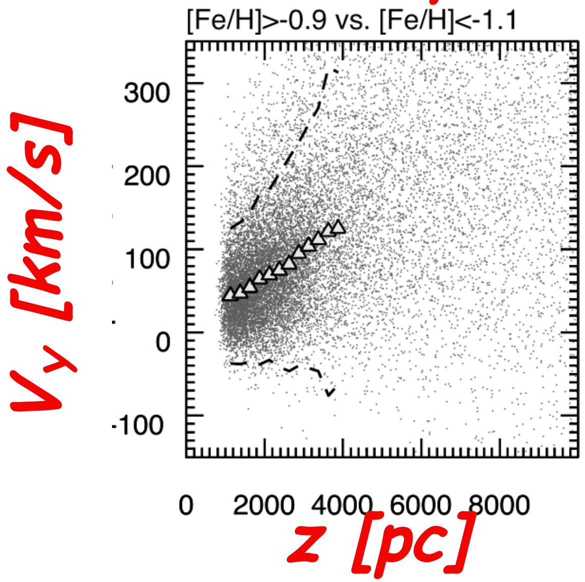
Metal rich + fast rotation

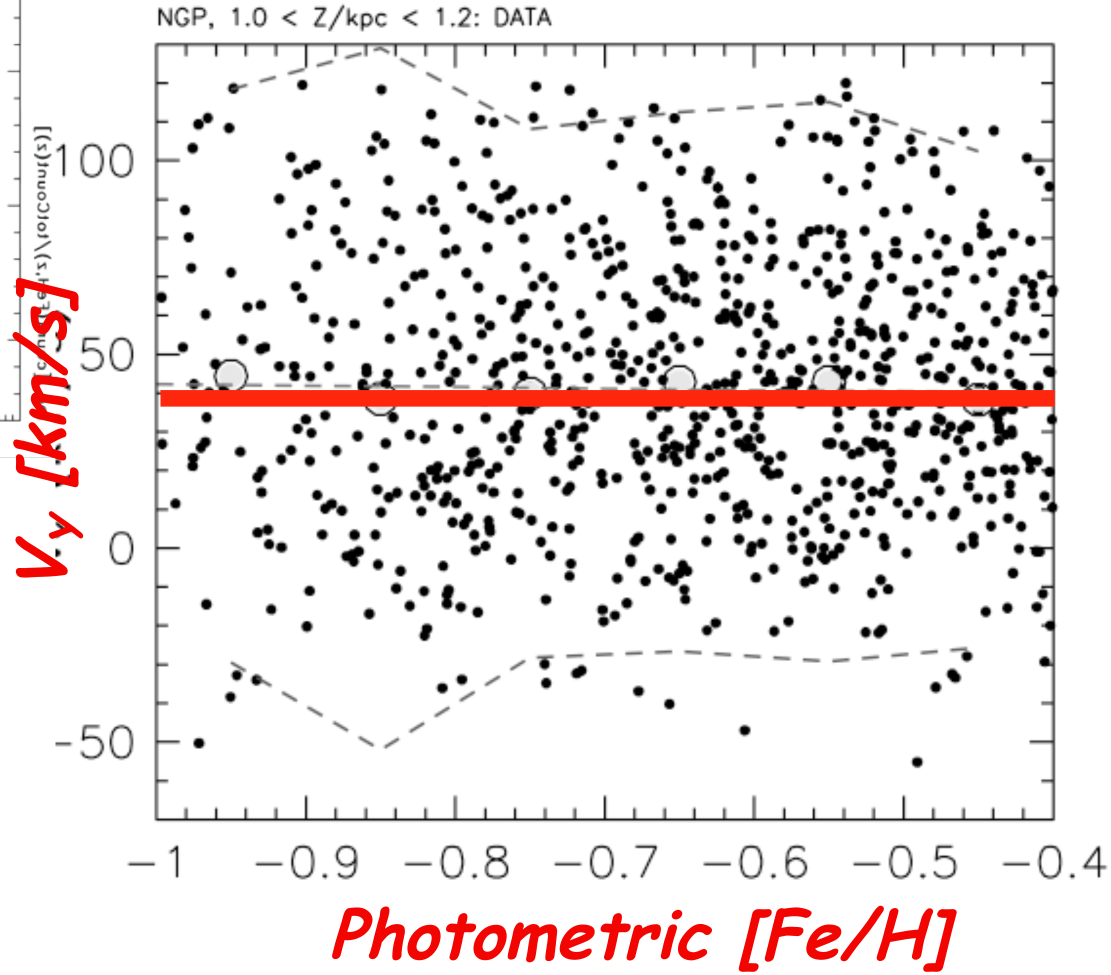


SDSS at Thin-Thick Transition

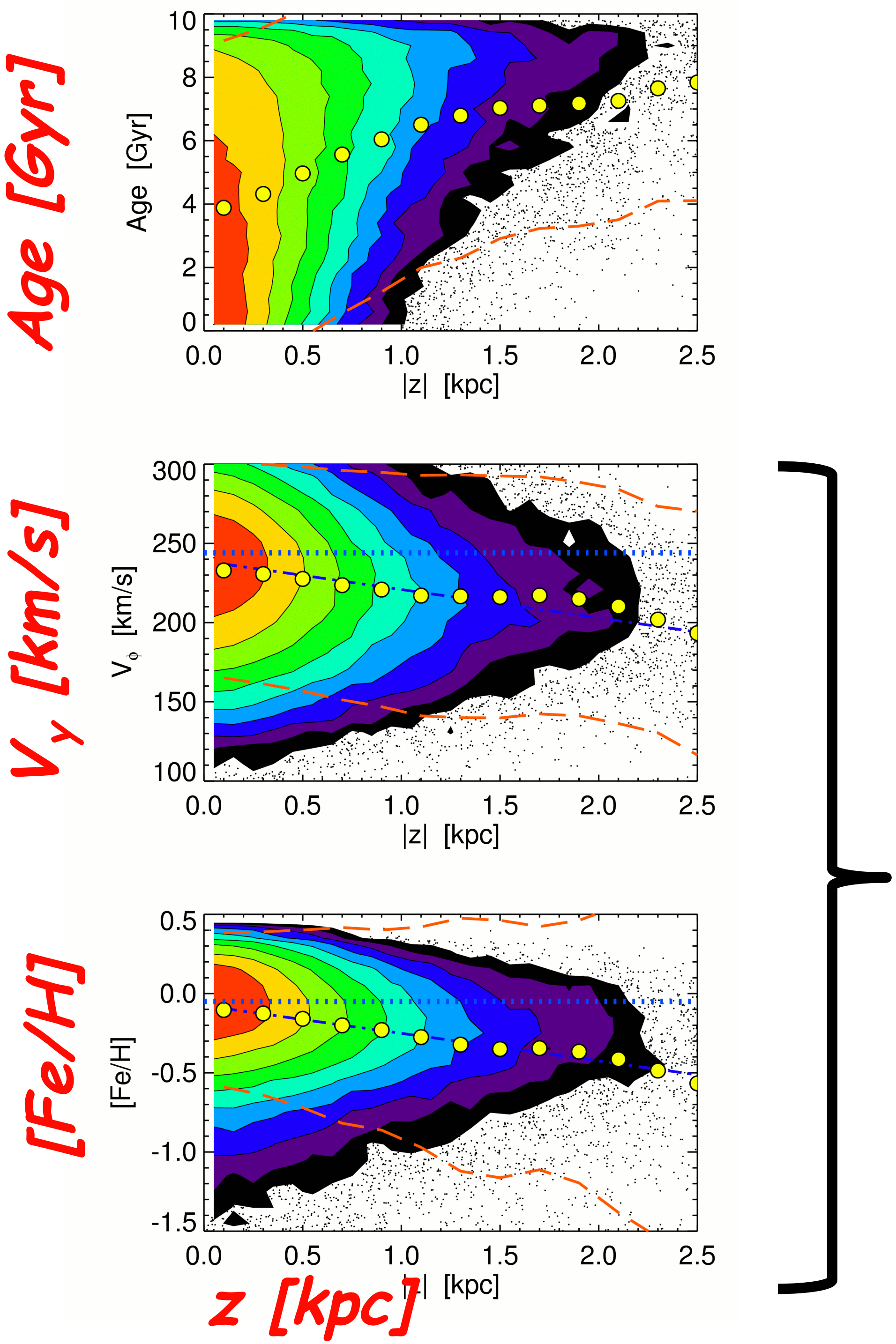
Decreasing metallicity and v_{rot} with height





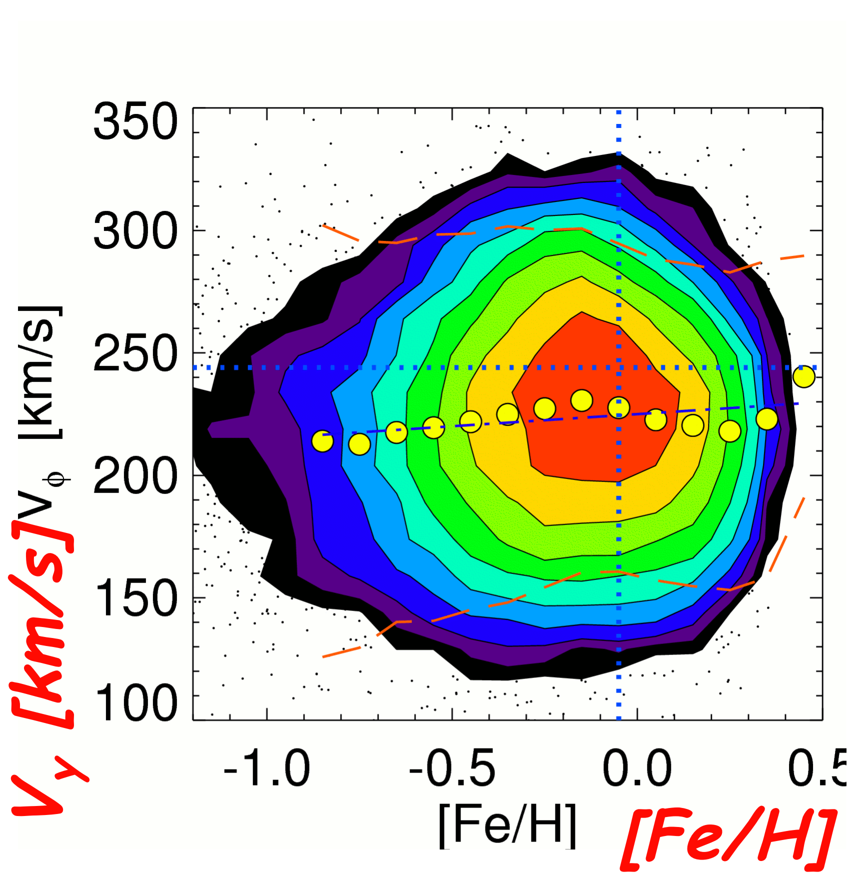


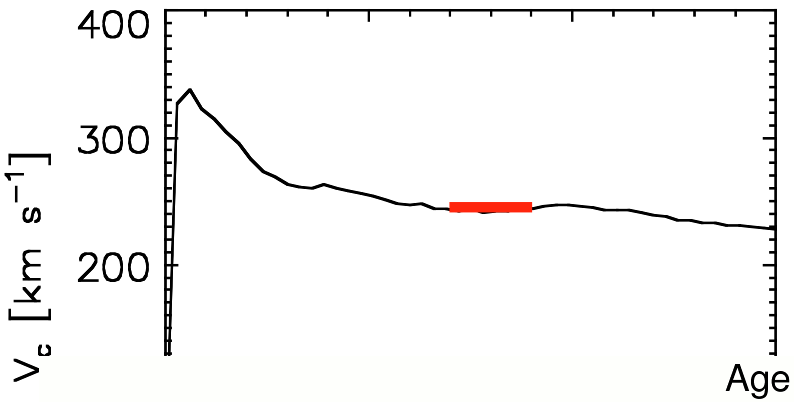
Data from SDSS Ivezic+ 08; Bond+ 10

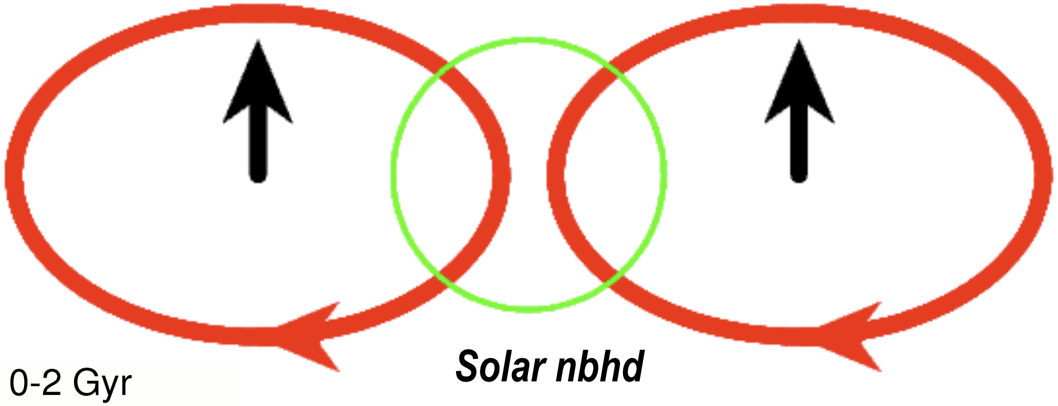


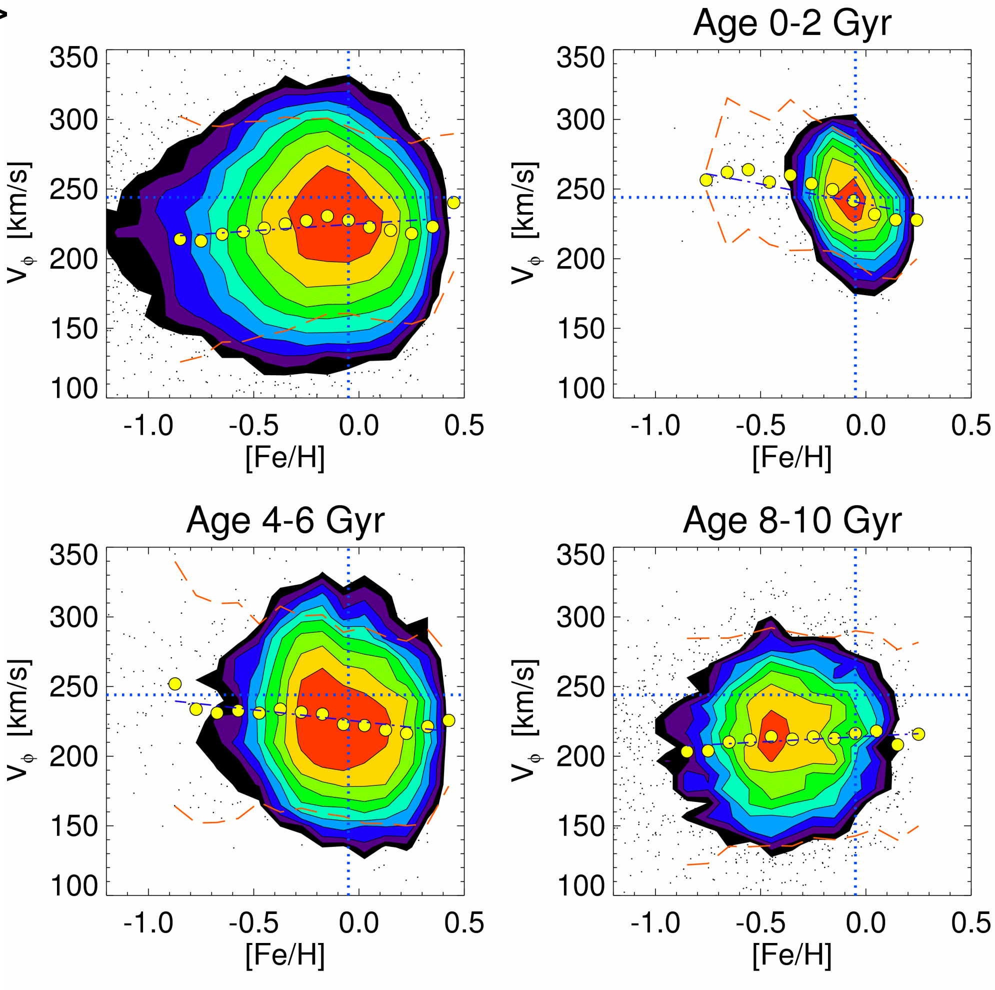
Age, velocity and metallicity all correlate with height above the mid-plane.

But there is little correlation between velocity and metallicity, as found by SDSS







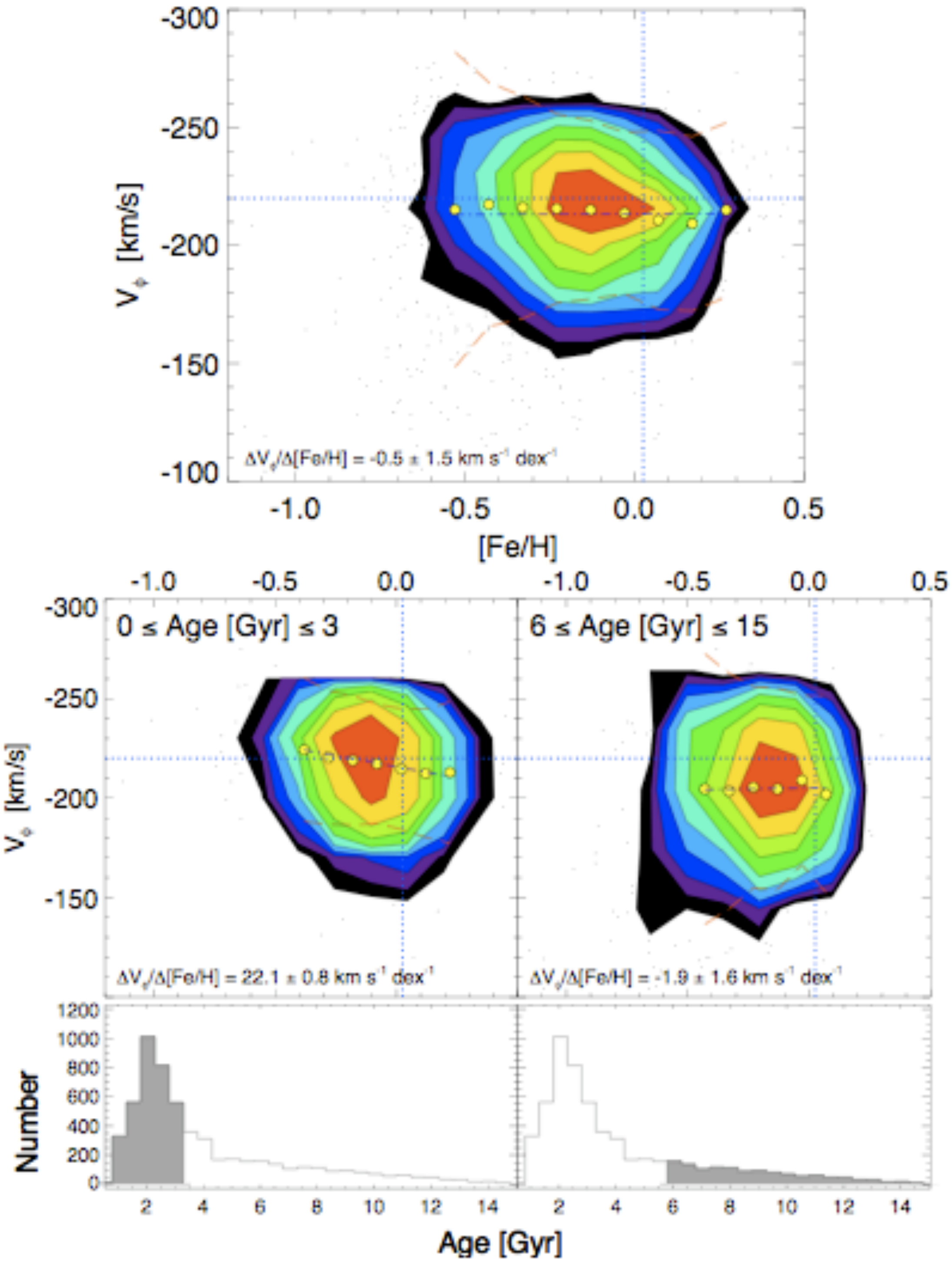


Stars are born on circular orbits and hence have no correlation between V and [Fe/H]. Heating brings stars into the local volume creating a correlation. Migration shuffles [Fe/H] and erases the correlation

Loebman+ 2011

young

all



In the transition zone: 0.5 < z < 1 kpc

Geneva-Copenhagen Survey in mid-plane (after selecting non-binary stars)

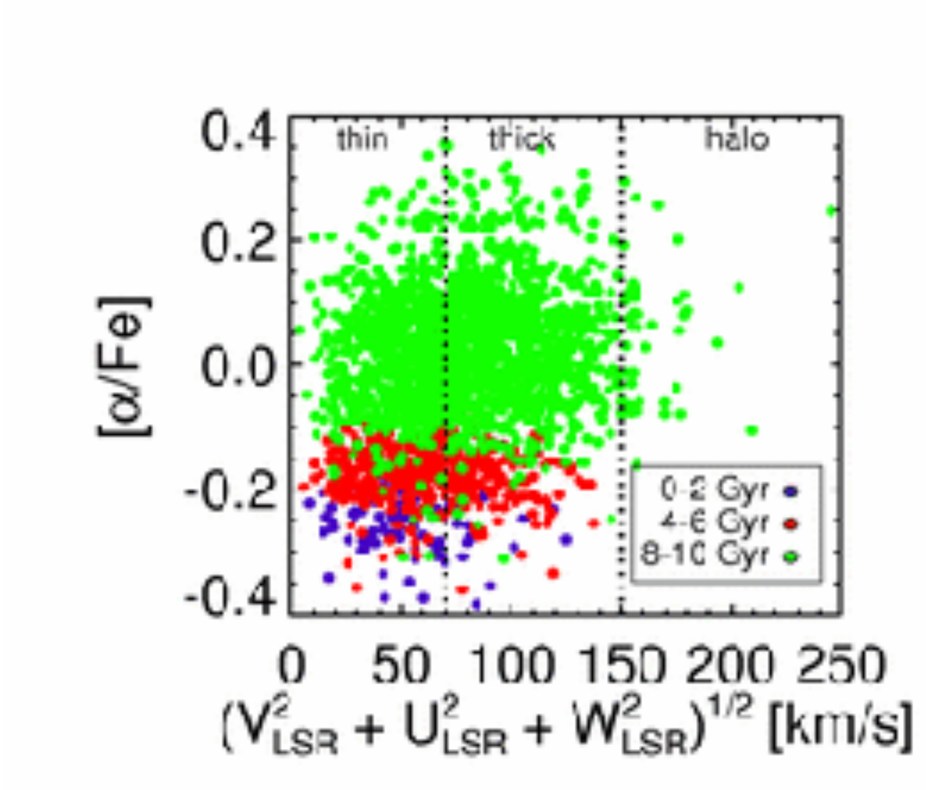
young

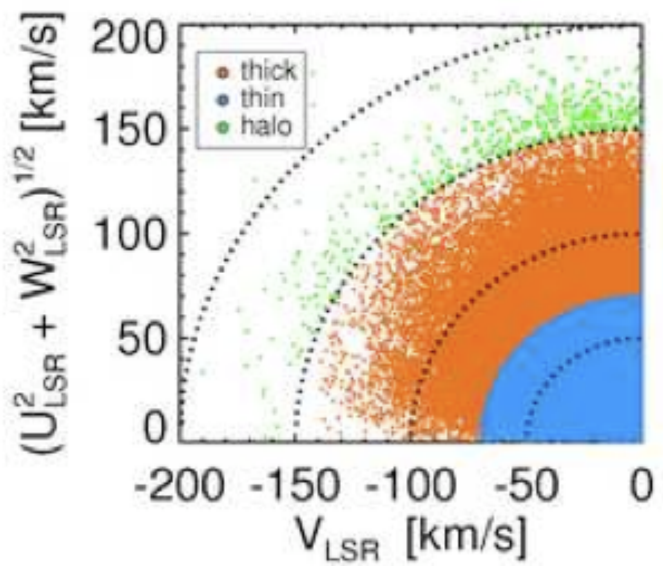
old

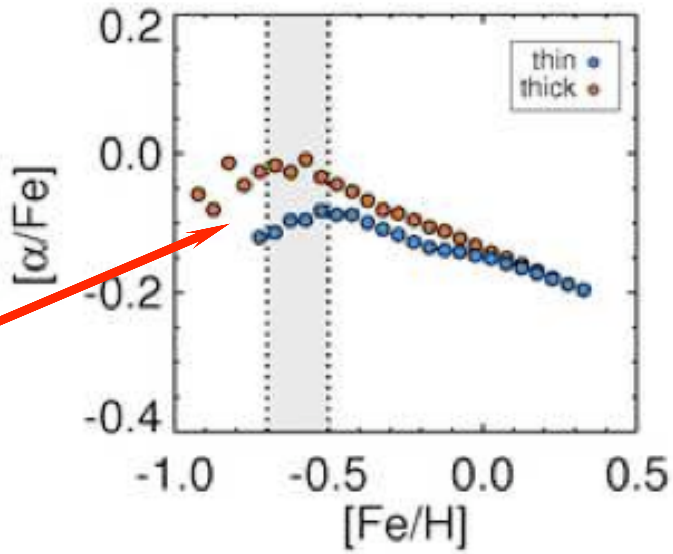
inter

old

Kinematic Selection of Thick Disk







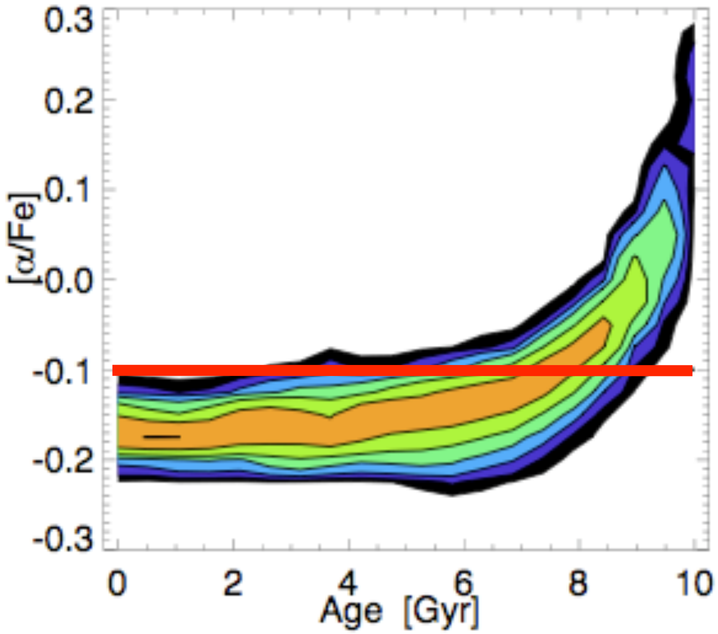
<[α/Fe]> separates for a pure kinematic selection of a local sample: 7-9 kpc in R and 0-0.3 kpc in z.

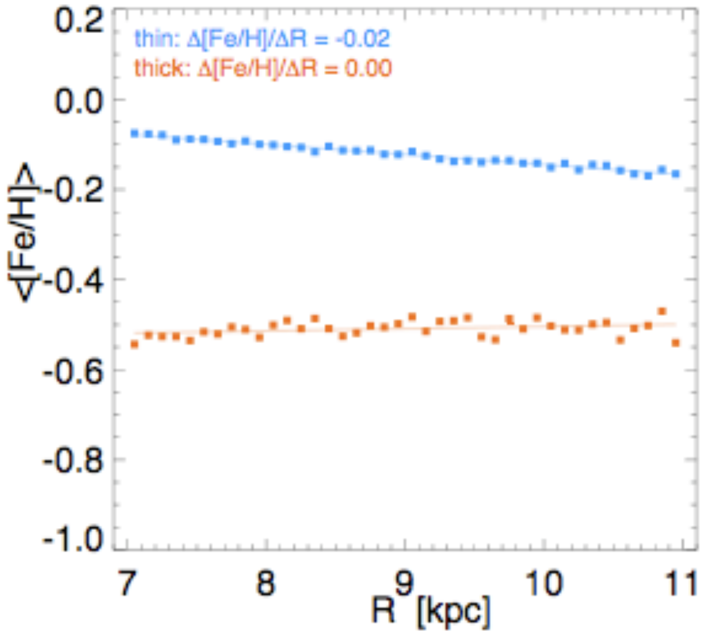
Bensby+2003, 2005; Feltzing 2006

0.1 dex cf Bensby+ 2005

Loebman+ 11

Splitting by [α/Fe]



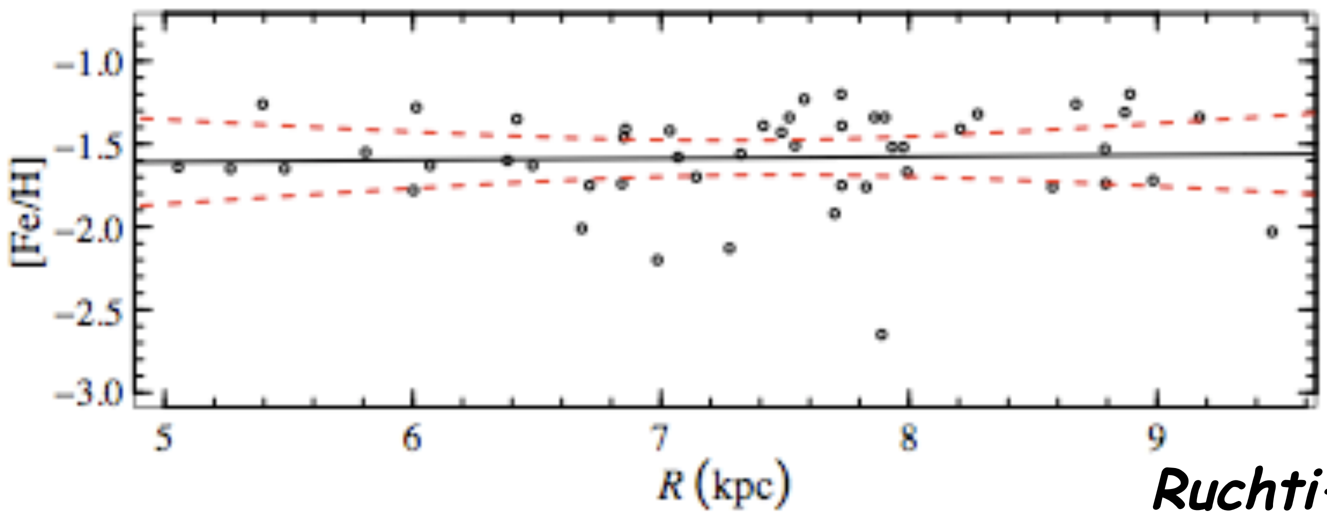


in

.1

.4

+ 11



6

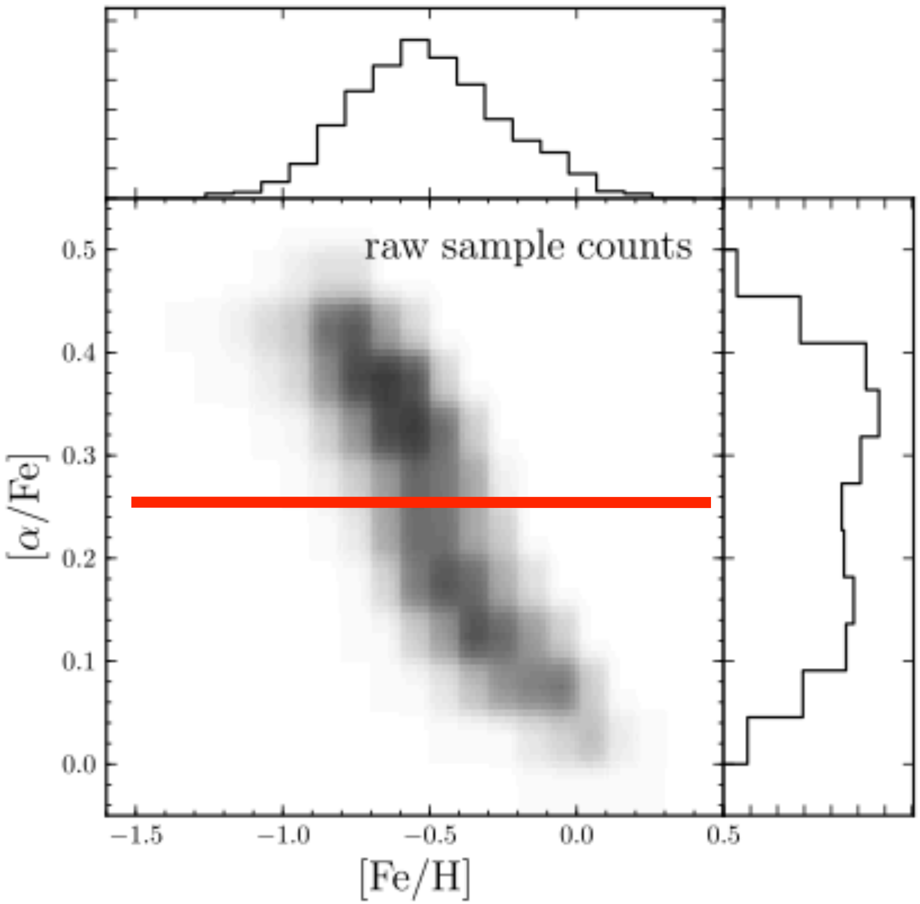
0

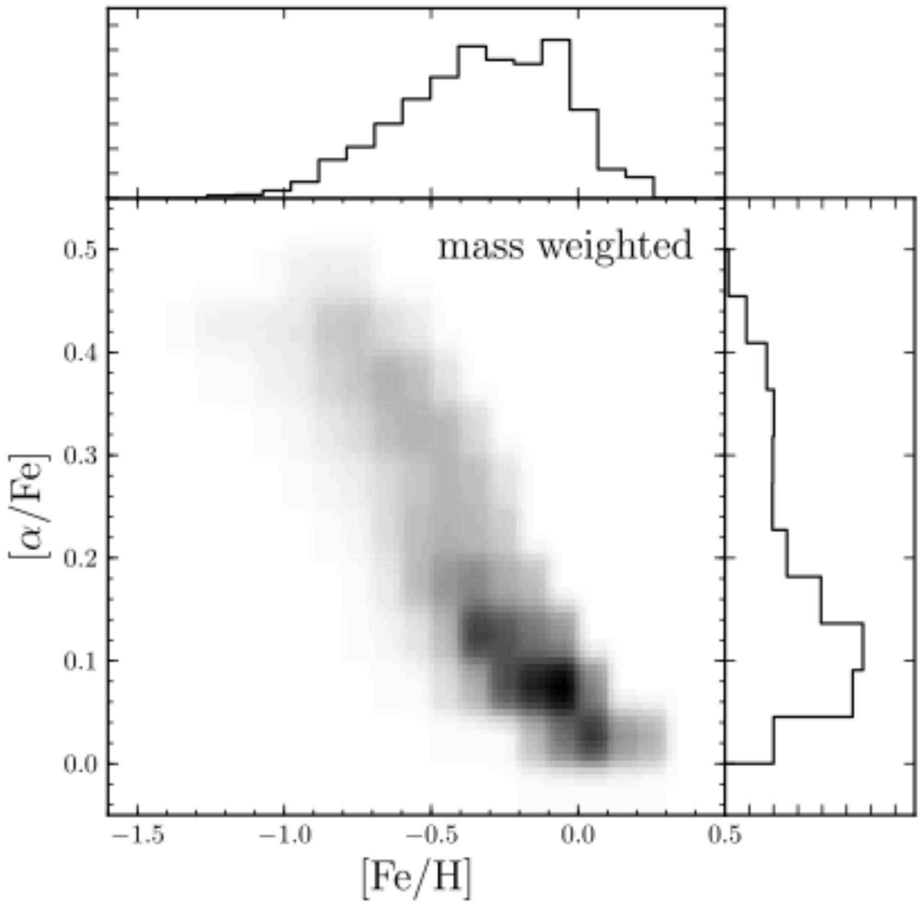
Ruchti+ 11

[Fe/H]

V_ϕ [km/s]

+ 11

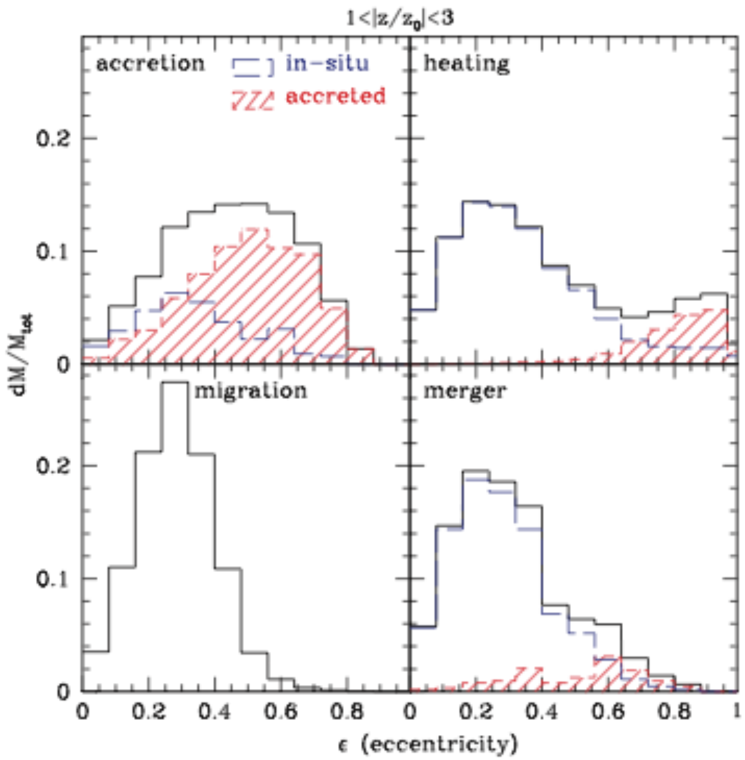




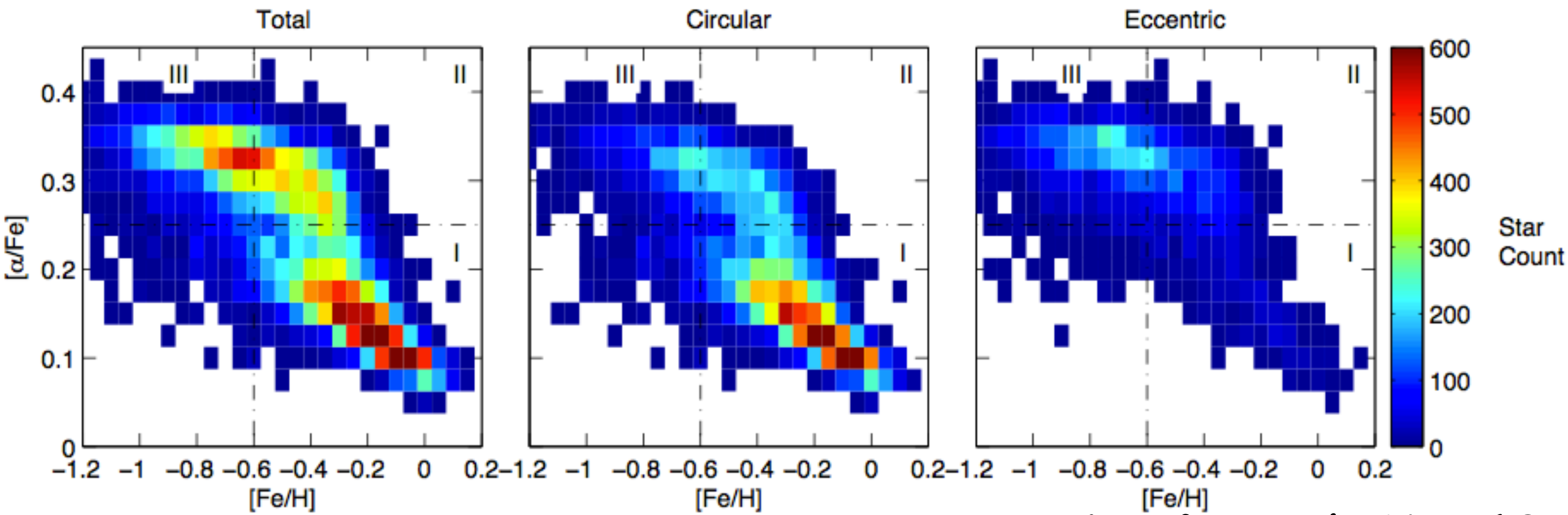
The raw distribution of stars in the [α/Fe]-[Fe/H] plane is double peaked, suggesting separate thin and thick disk populations

Correcting for the selection function, only one peak remains in [α/Fe]-[Fe/H]

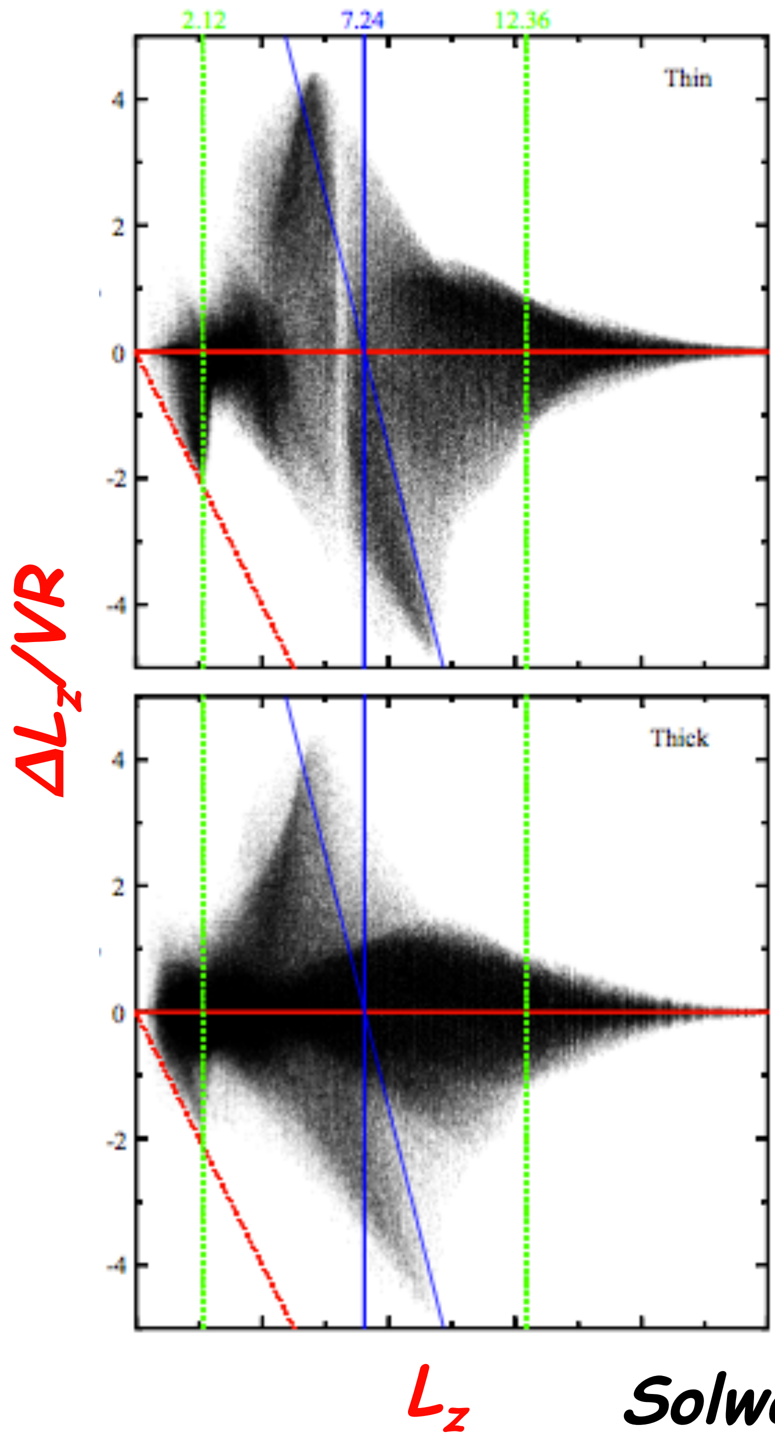
Bovy+ 2012abc



Sales+ 09



Liu & van de Ven 12



Solway+ 12

Thin disk

Spirals arising in the thin disk are able to drive migration also of stars in a dynamically distinct thick disk

Thick disk

Conclusions

★ Contrary to decades of assumption, a mechanism for mixing stars radially without heating exists: scattering at corotation off transient spirals. This can substantially alter stellar populations in disks.

★ A large fraction of stars in outer disks probably formed at smaller radii and migrated outwards. There is a growing body of evidence that disks get increasingly old outwards of the break.

★ In the solar neighborhood, roughly half the stars could have formed elsewhere and migrated here. This means that AMR is flattened and broadened.

★ Migration may also be the explanation for at least part of the thick disk. Many of the properties and trends of the thick disk can be qualitatively matched by migration