Milky Way Chemodynamics

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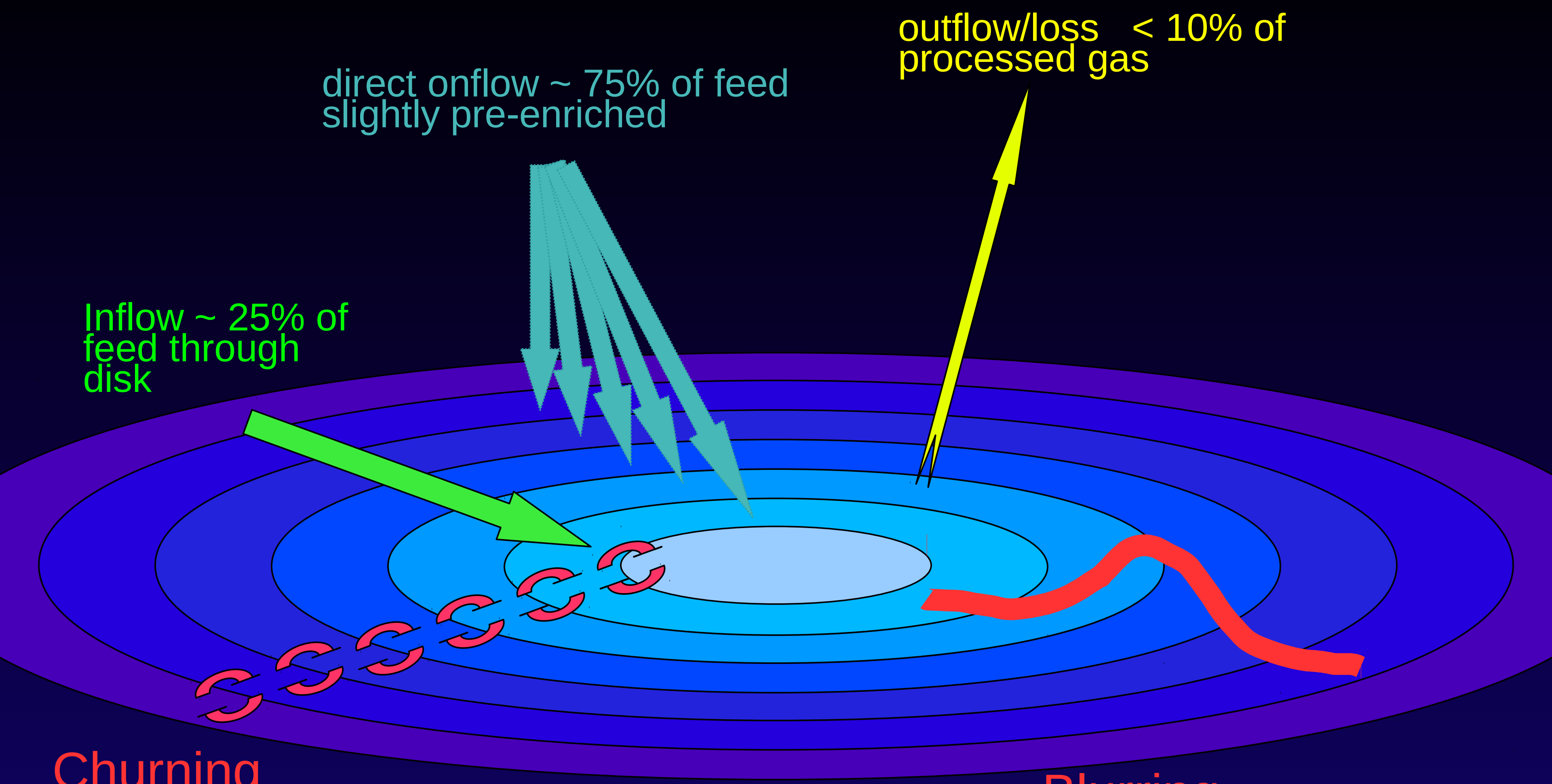
Martin Asplund, Maria Bergemann,
James Binney, Luca Casagrande,
Francesco Fermani, David Weinberg

Disc Model



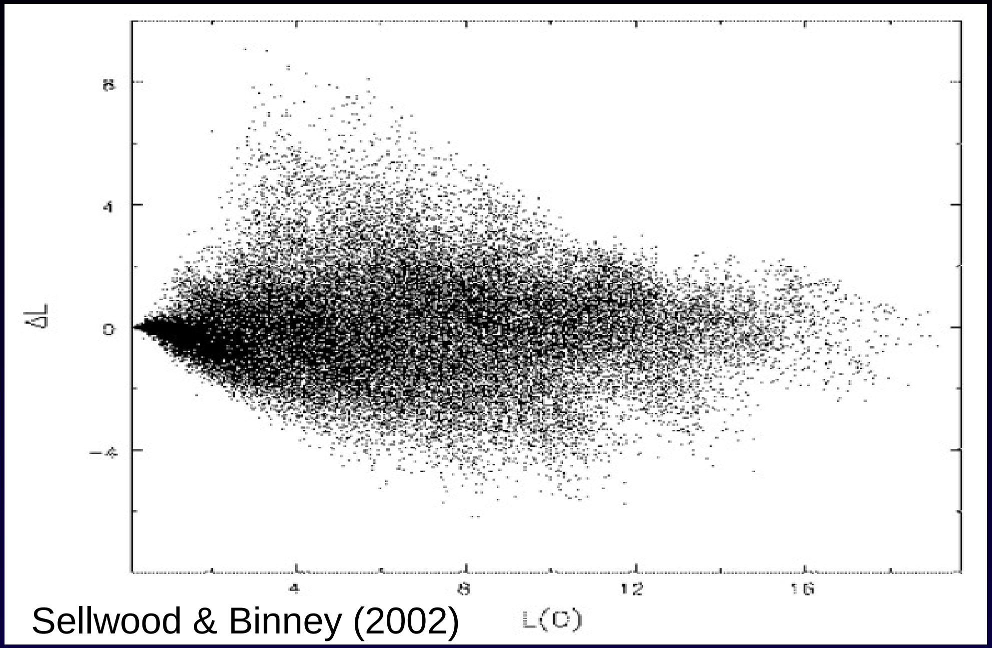
Churning

-mass exchange between neighbouring rings
-cold gas and stars
-no heating of the disc
-cf. Sellwood & Binney (2002)

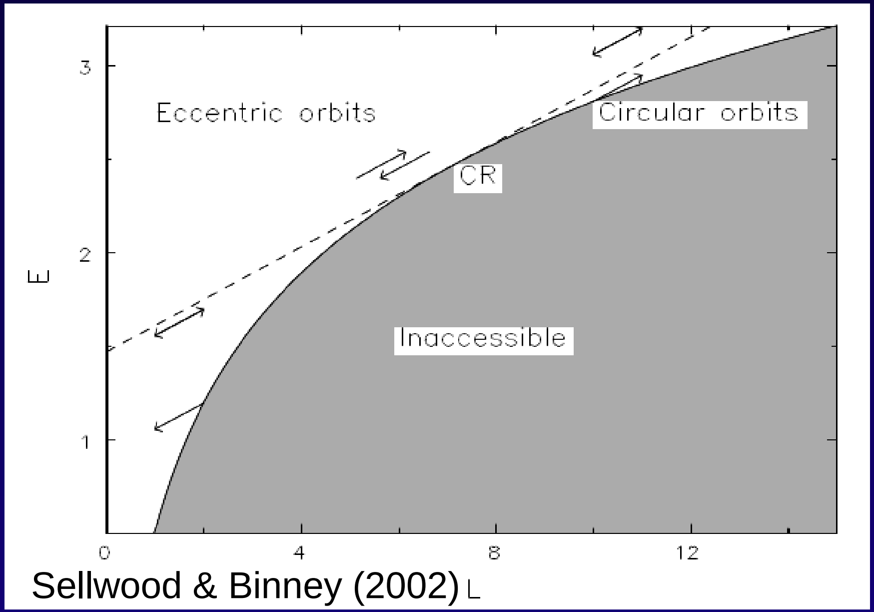
Blurring

-stars on increasingly excentric orbits (heating of the disc)
→broadening of the disc and increasing scale height

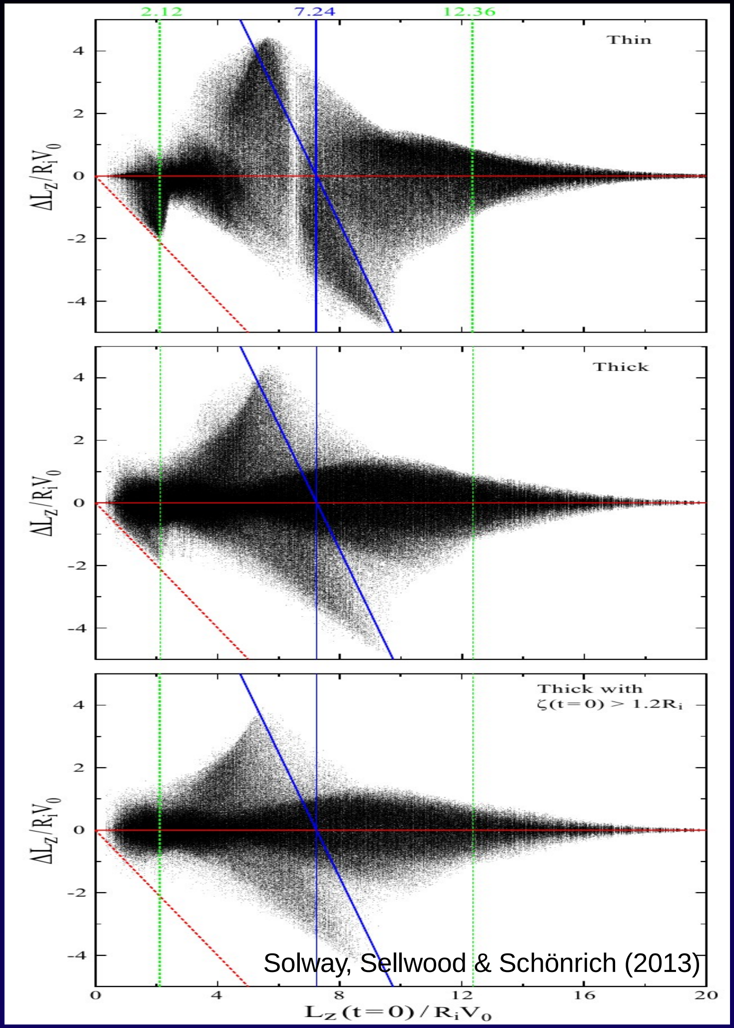
What evidence is there for migration?



Sellwood & Binney (2002)



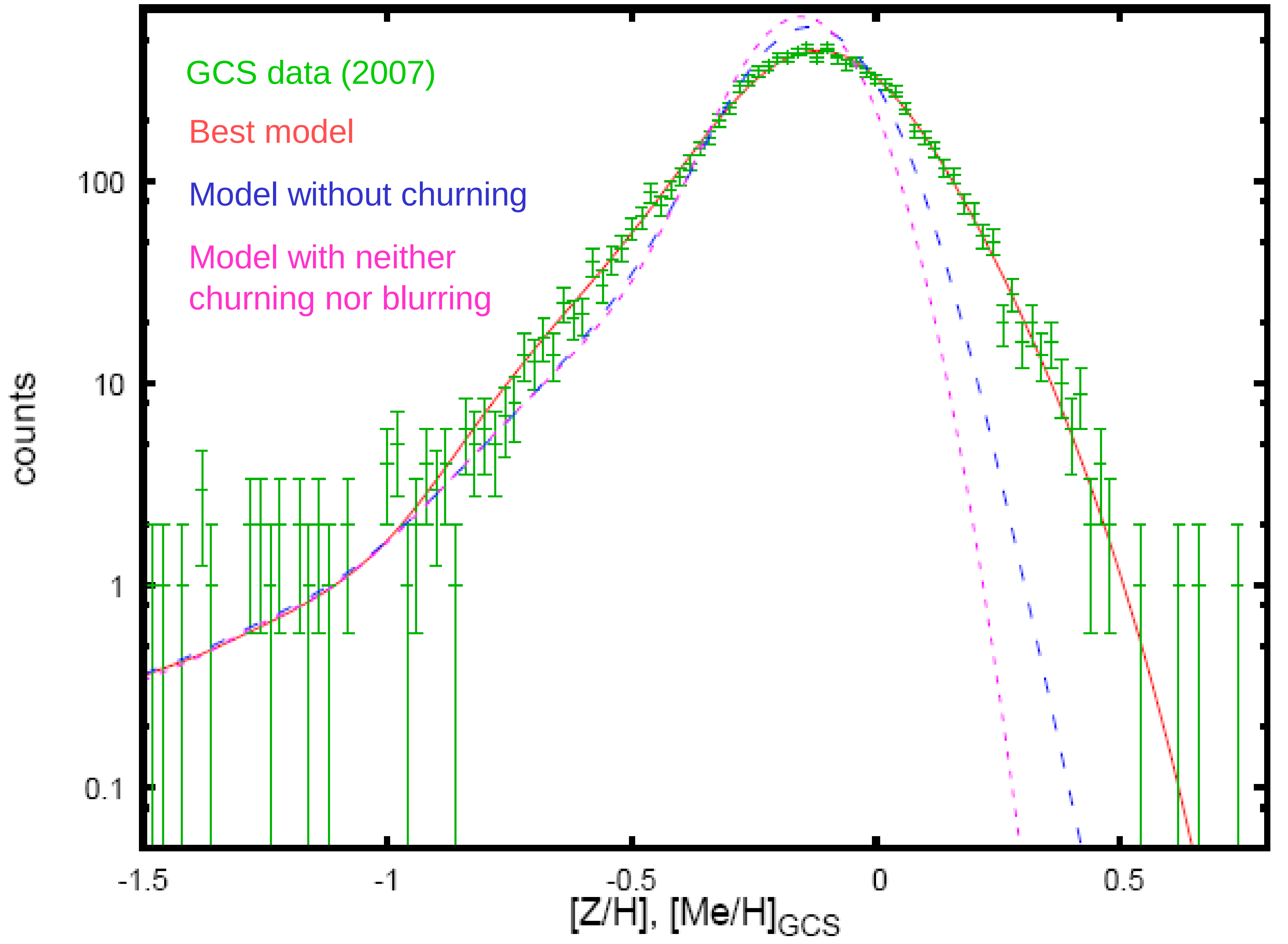
Sellwood & Binney (2002) L



Solway, Sellwood & Schönrich (2013)

Migration is a necessity

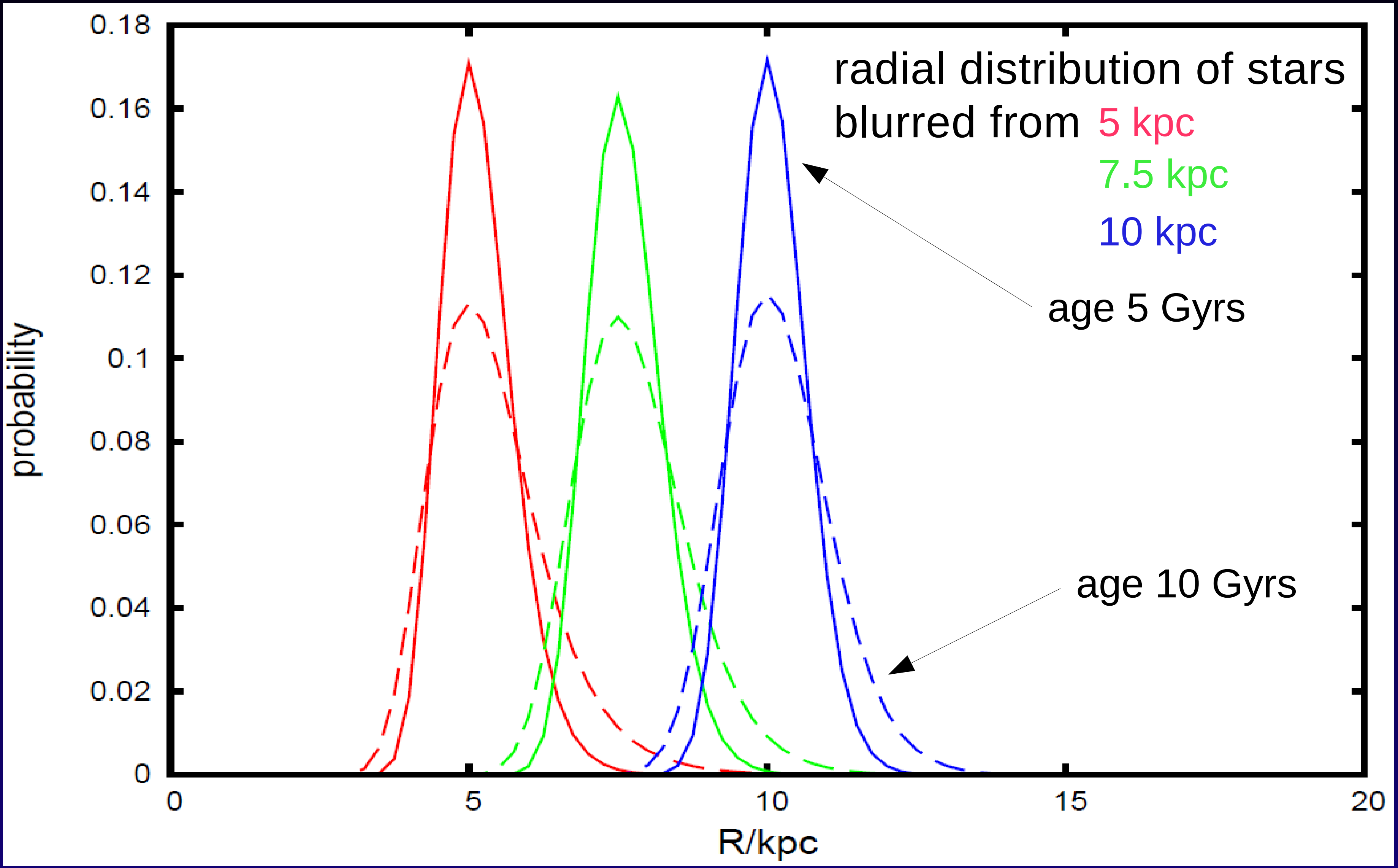
The only question is quantification



GCS data (2007)
Best model
Model without churning
Model with neither
churning nor blurring
counts
100
10
1
0.1
-1.5
-1
-0.5
0
0.5
[Z/H], [Me/H]GCS

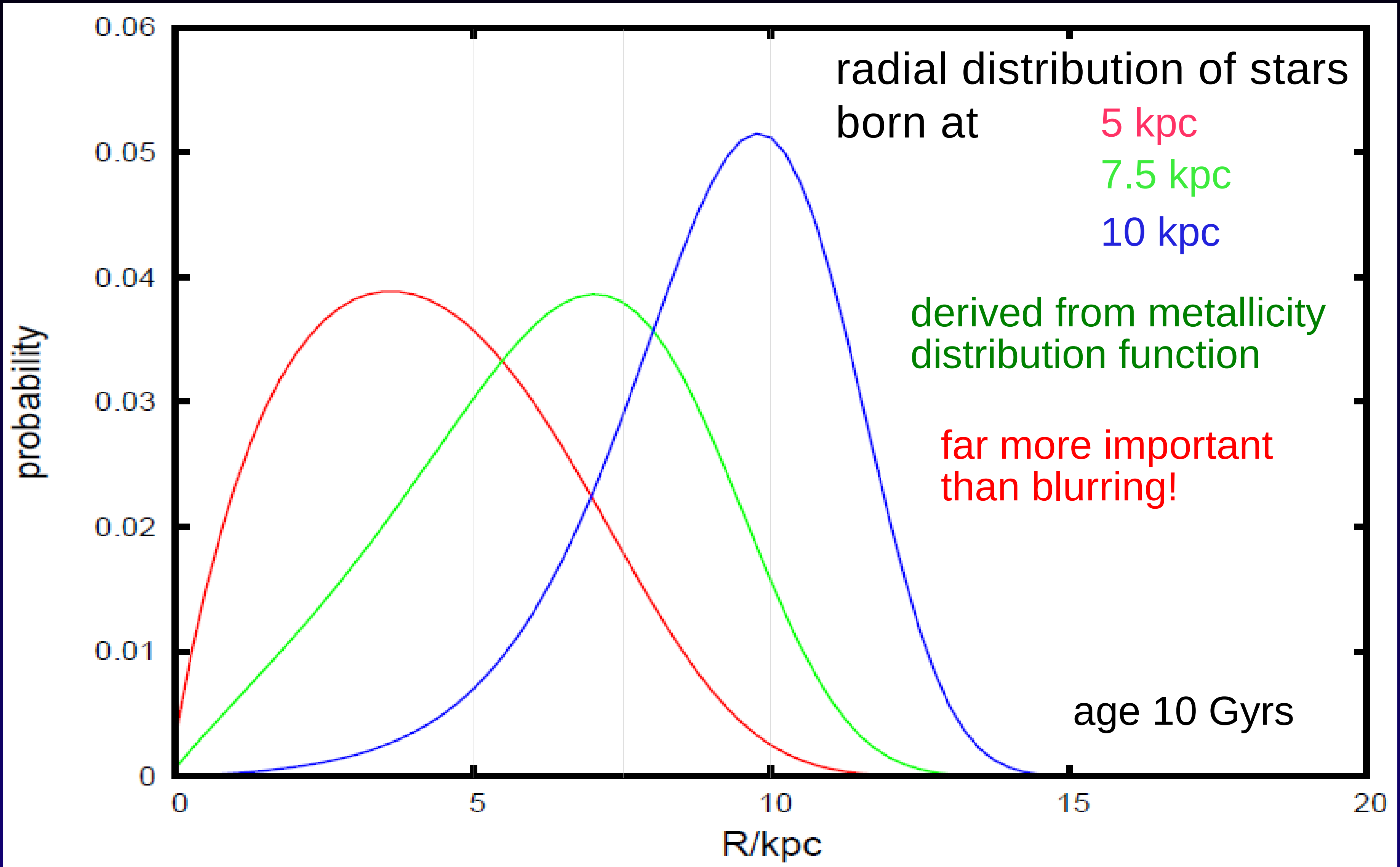
Blurring

(stars on increasingly eccentric orbits)



Churning

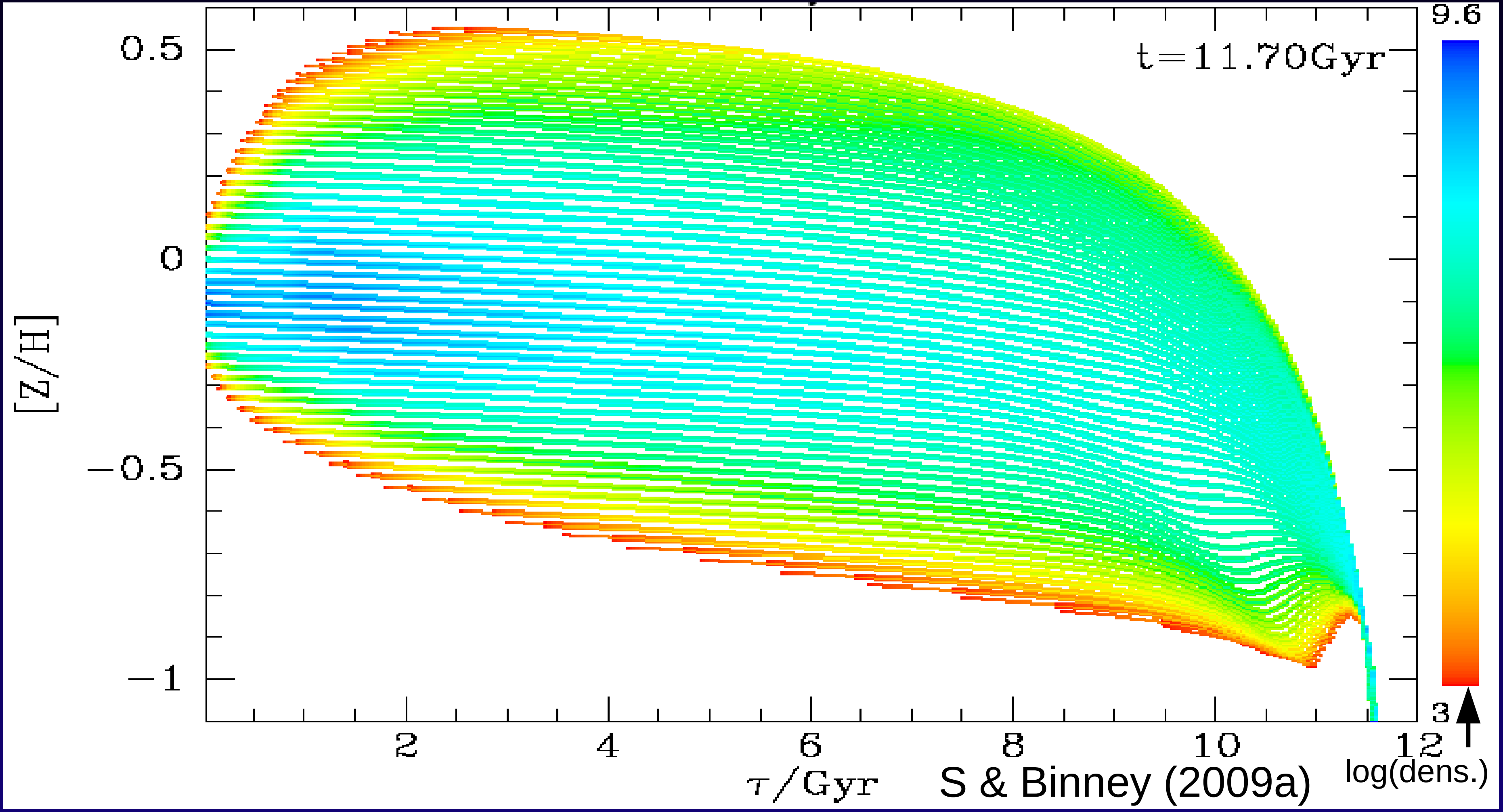
(angular momentum exchange)



Signatures: age-metallicity relation

relatively flat in time (radial migration builds part of the MDF)

Increasing dispersion with time

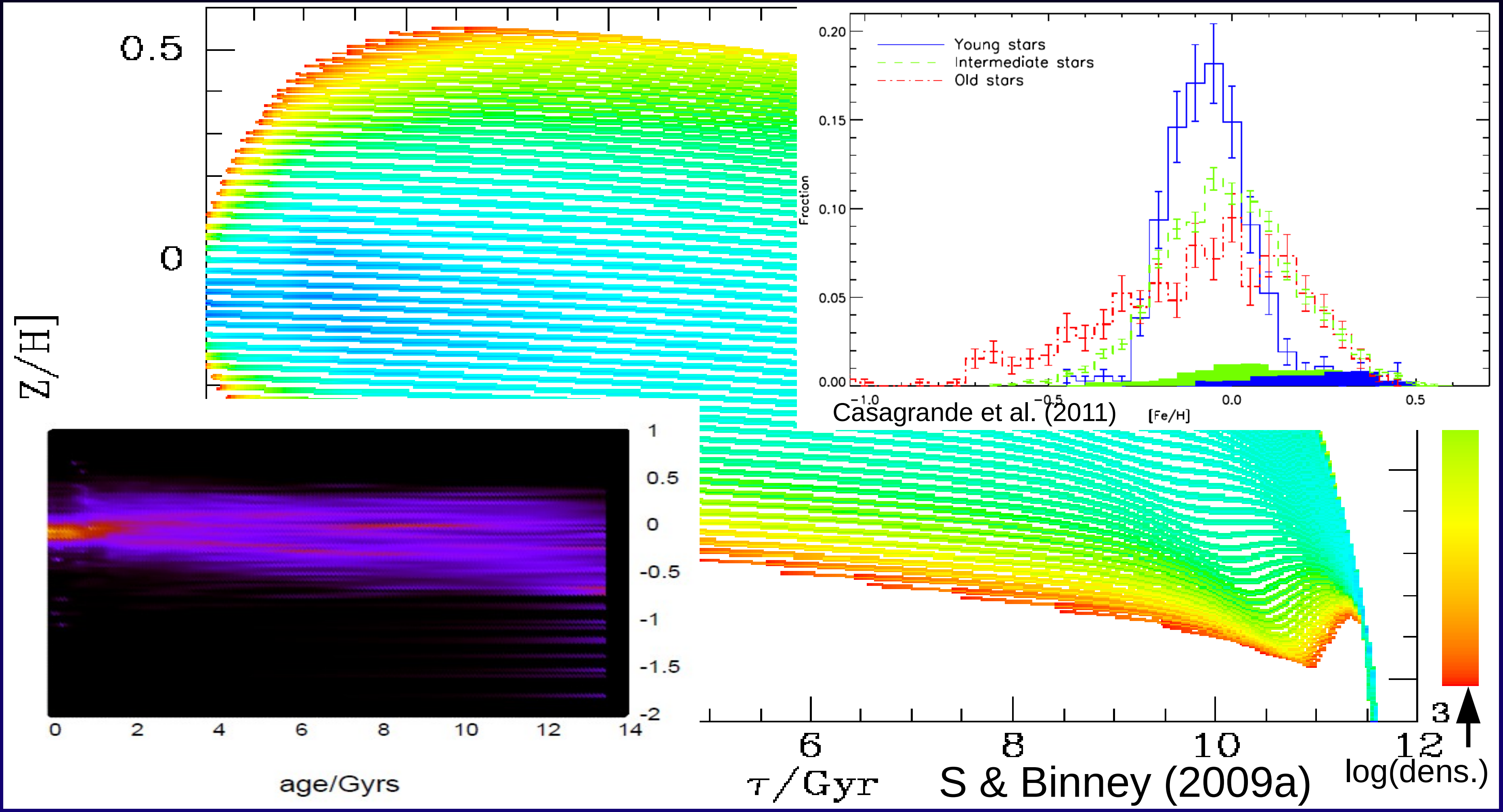


S & Binney (2009a)

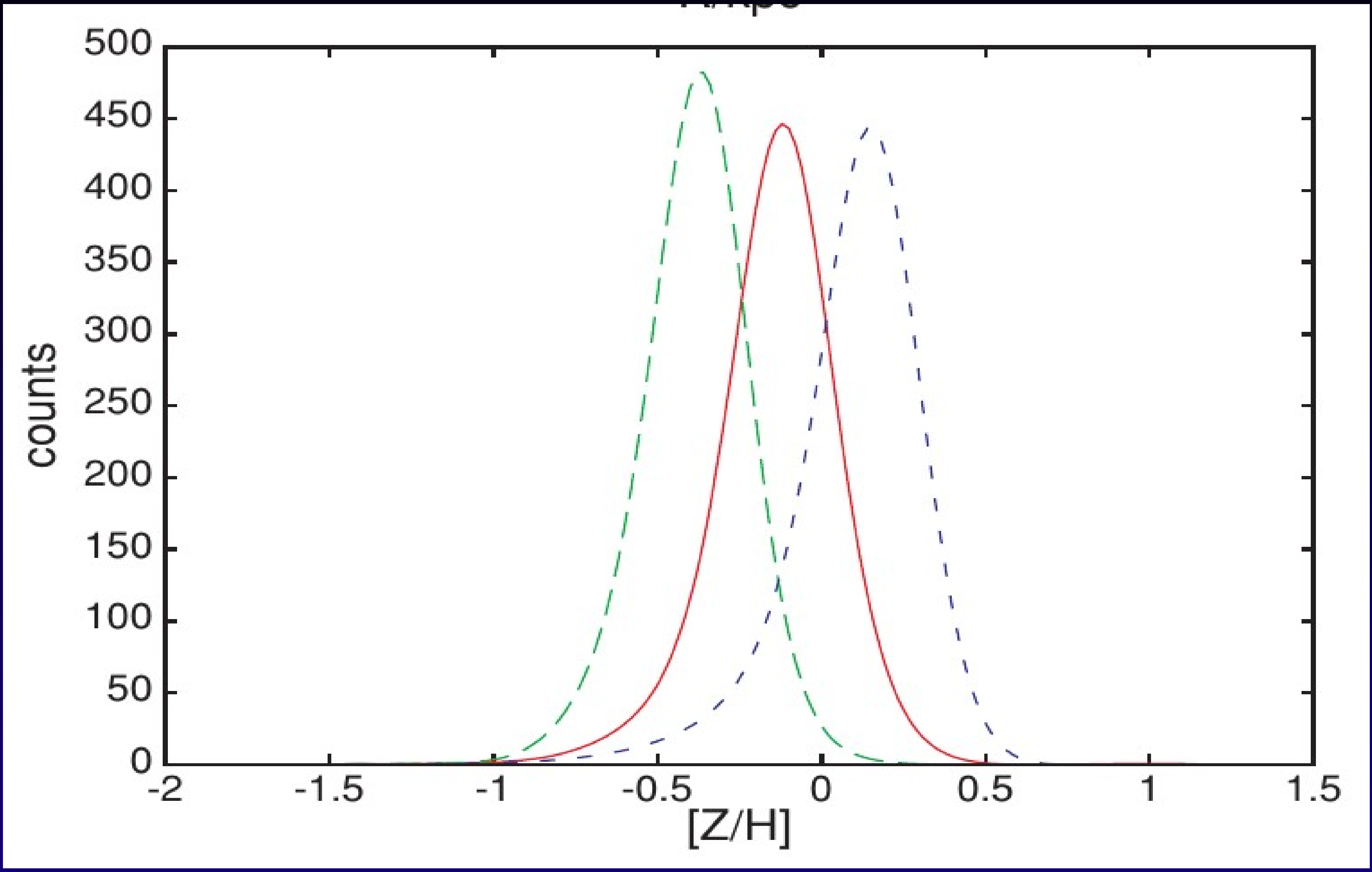
Signatures: age-metallicity relation

relatively flat in time (radial migration builds part of the MDF)

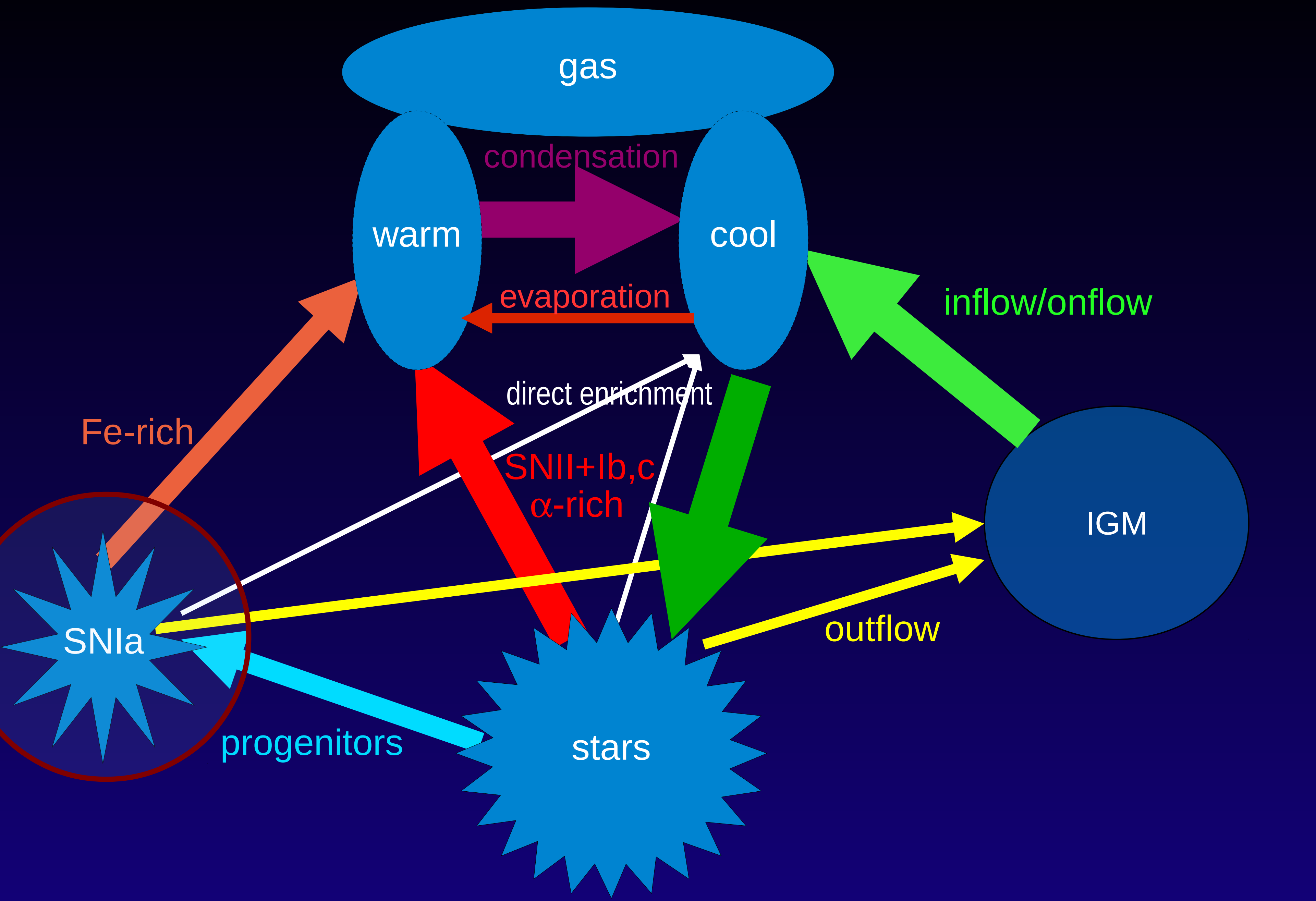
Increasing dispersion with time



Metallicity distributions vs. radius

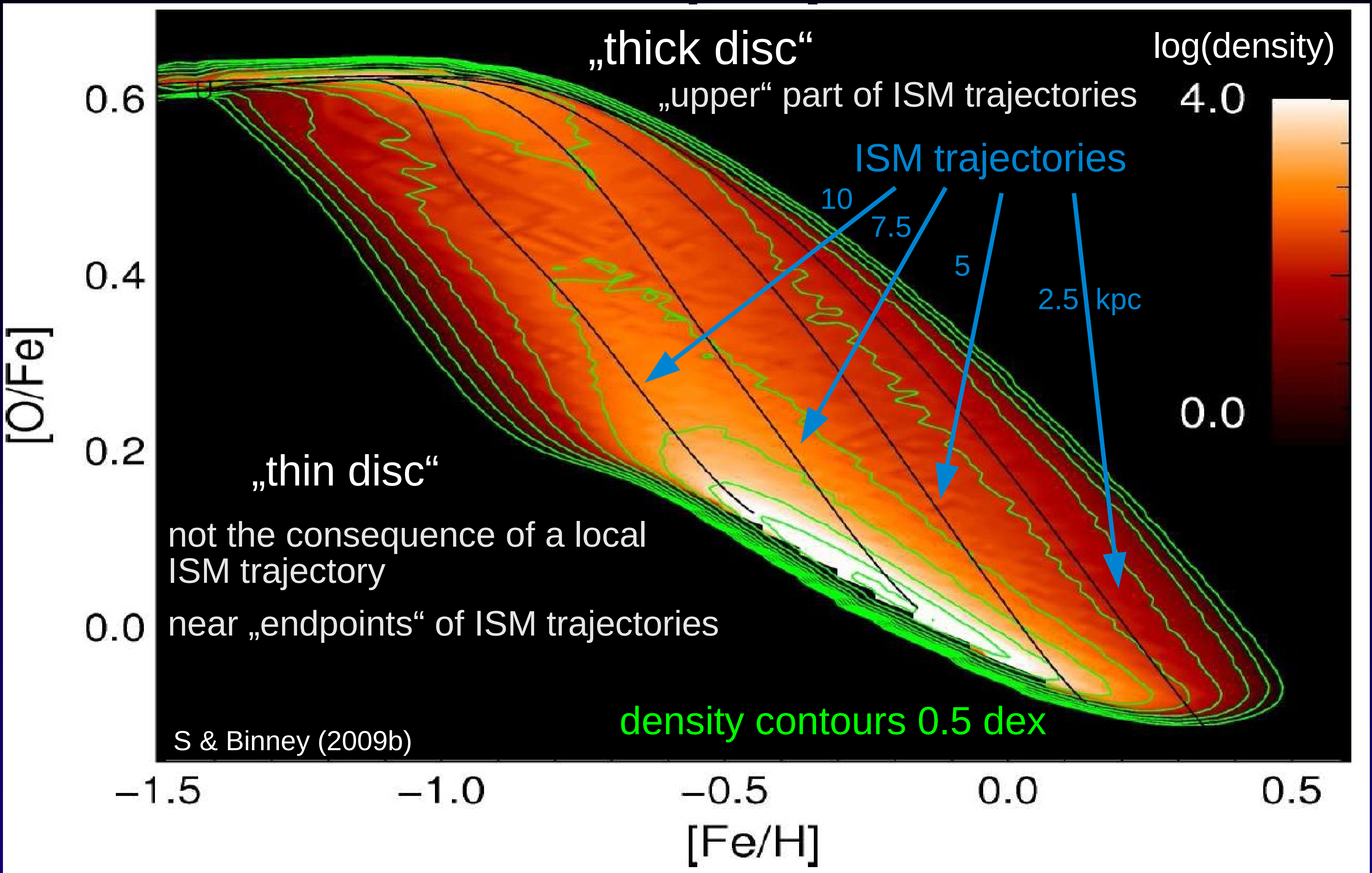


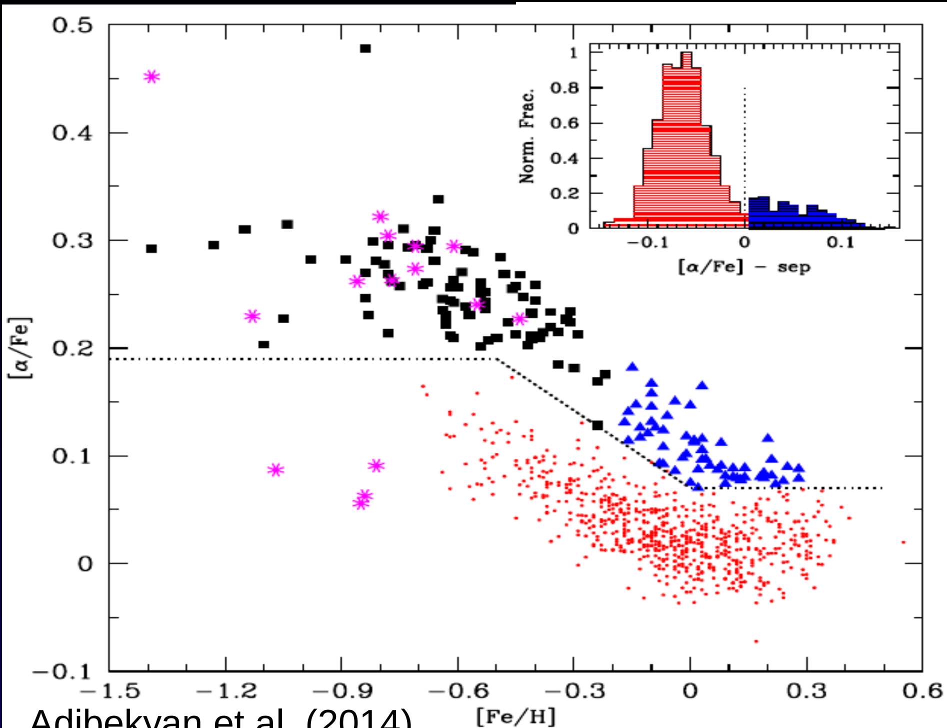
Chemical evolution



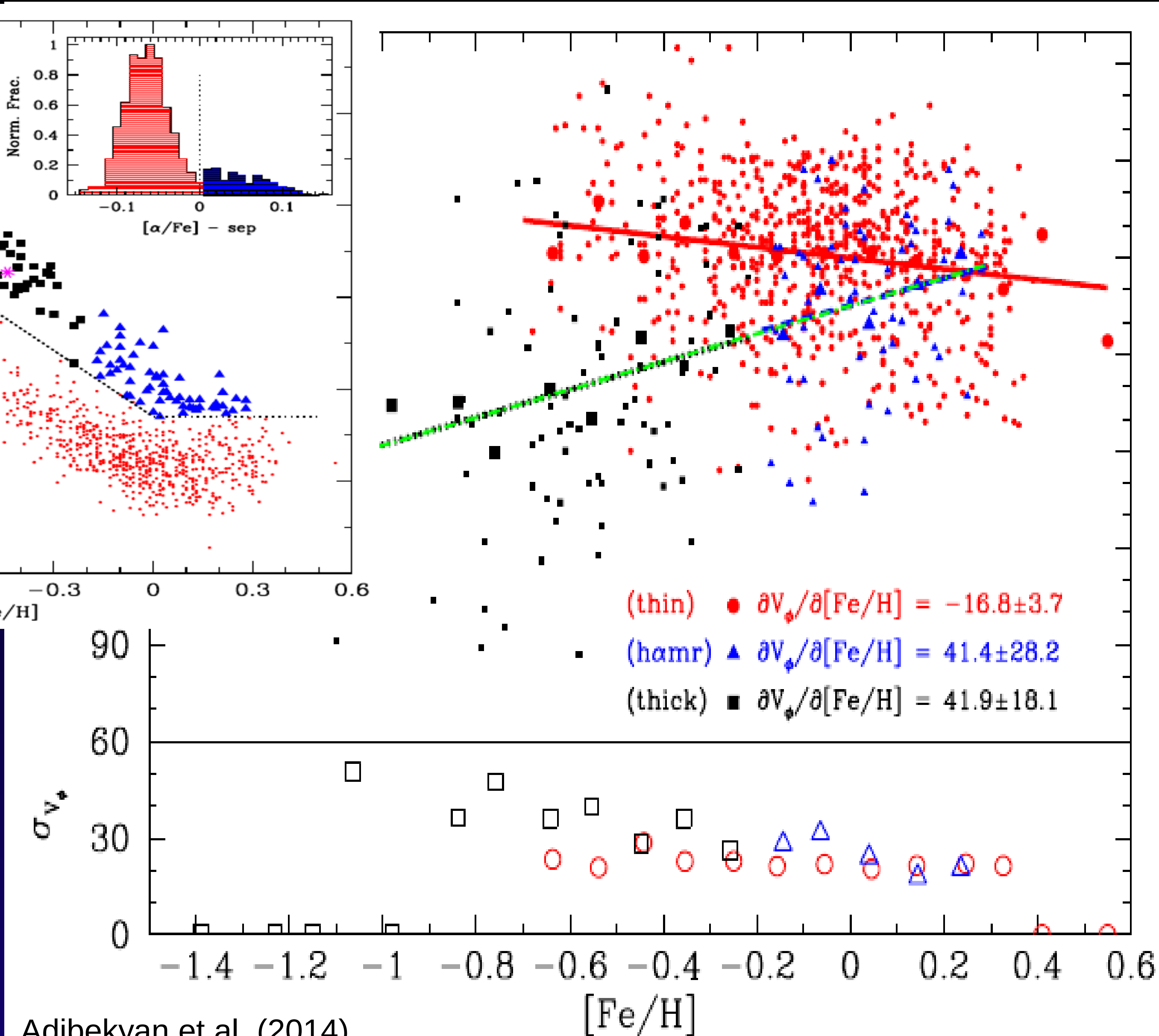
Stellar densities in the [Fe/H]-[O/Fe] plane

stellar radial migration forms naturally the two ridges
no gap in star formation or merger needed



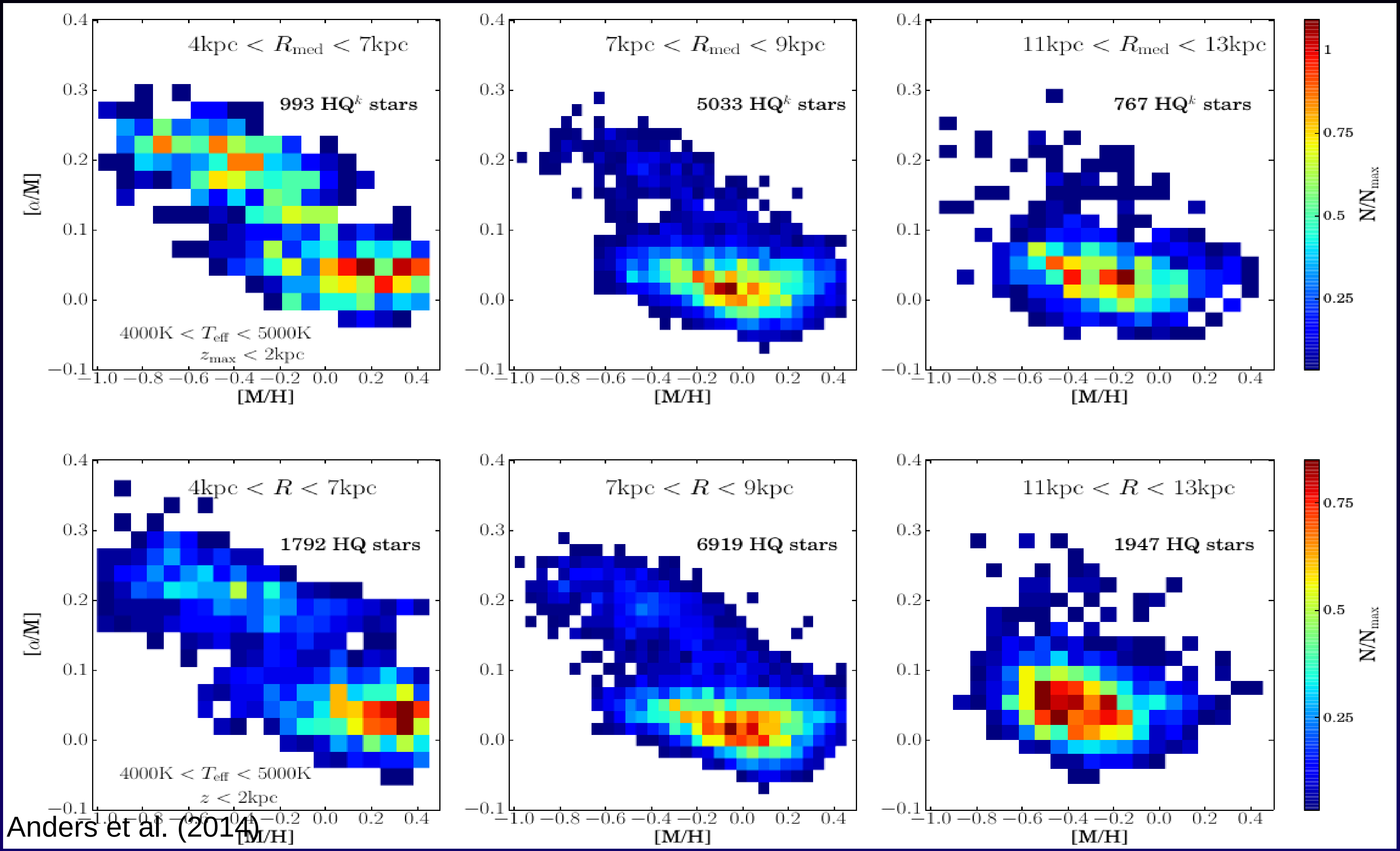


Adibekyan et al. (2014)



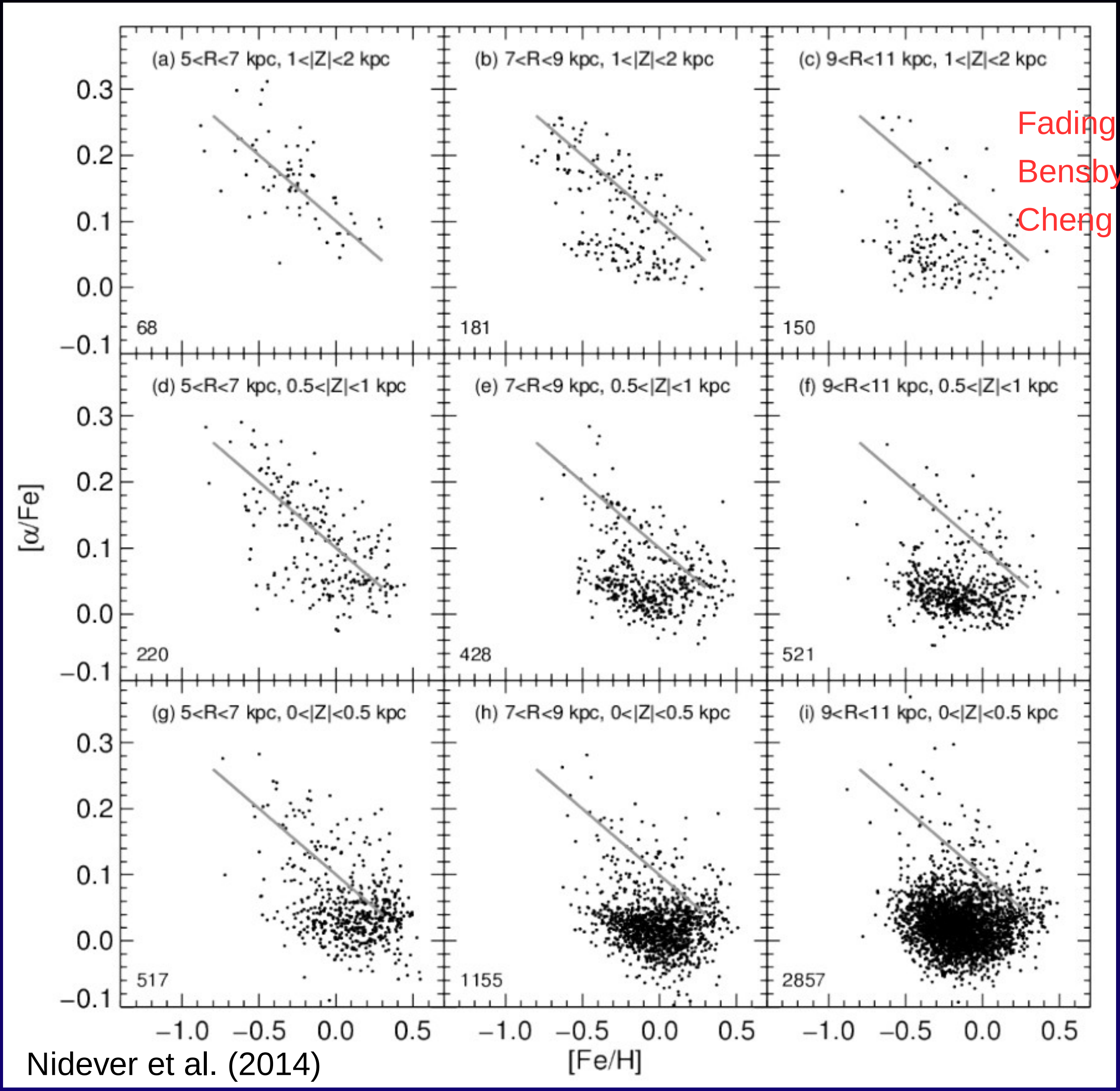
Adibekyan et al. (2014)

The edge of radial migration



Anders et al. (2014)

The edge of radial migration



Fading out – see also
Bensby et al. (2011)
Cheng et al. (2012)

The edge of radial migration

Simplest approximation:

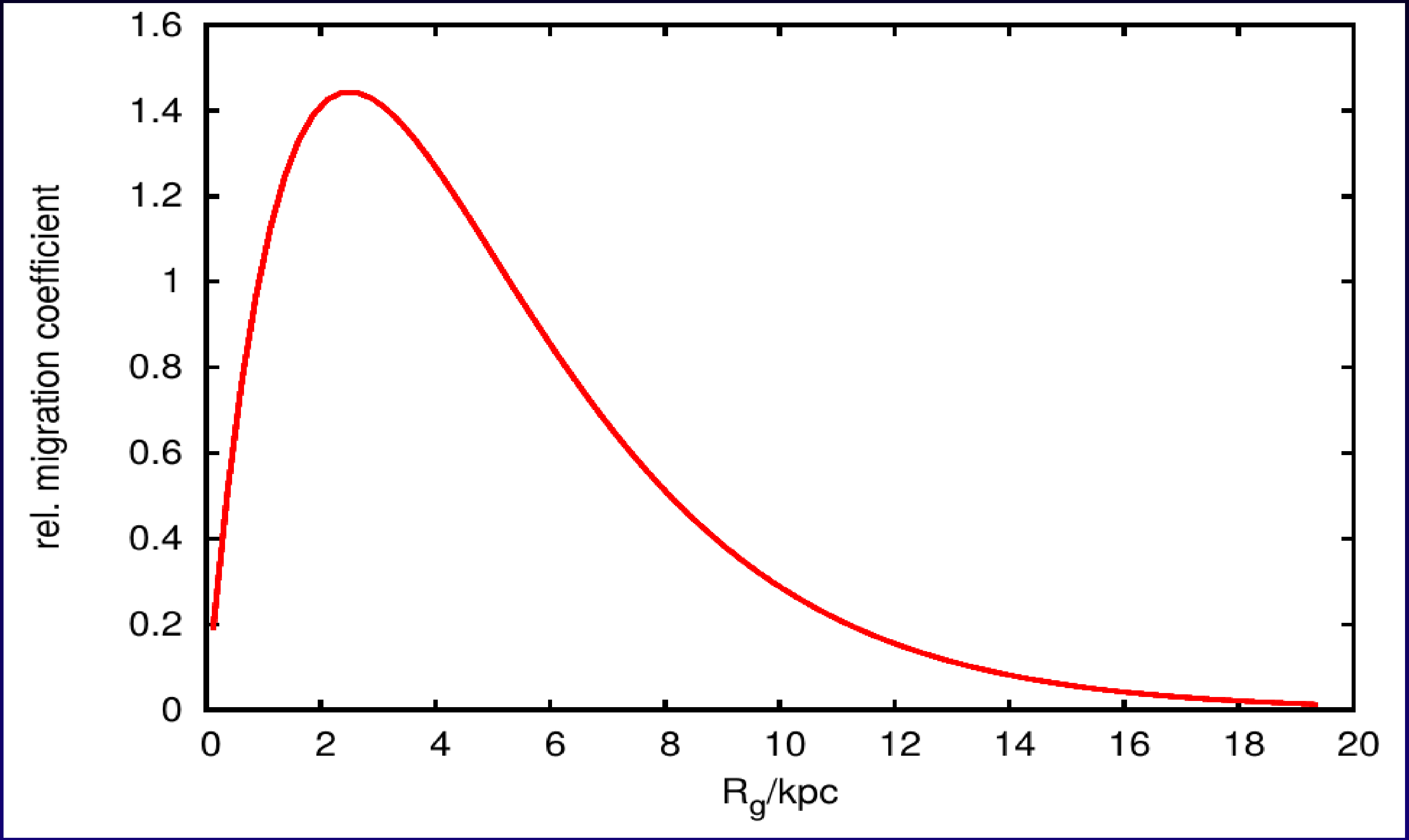
Exchange probability: $P \sim 1 / Q^2$

Ring swap probability: $P \sim l^2 k / Q^2 \sim M$

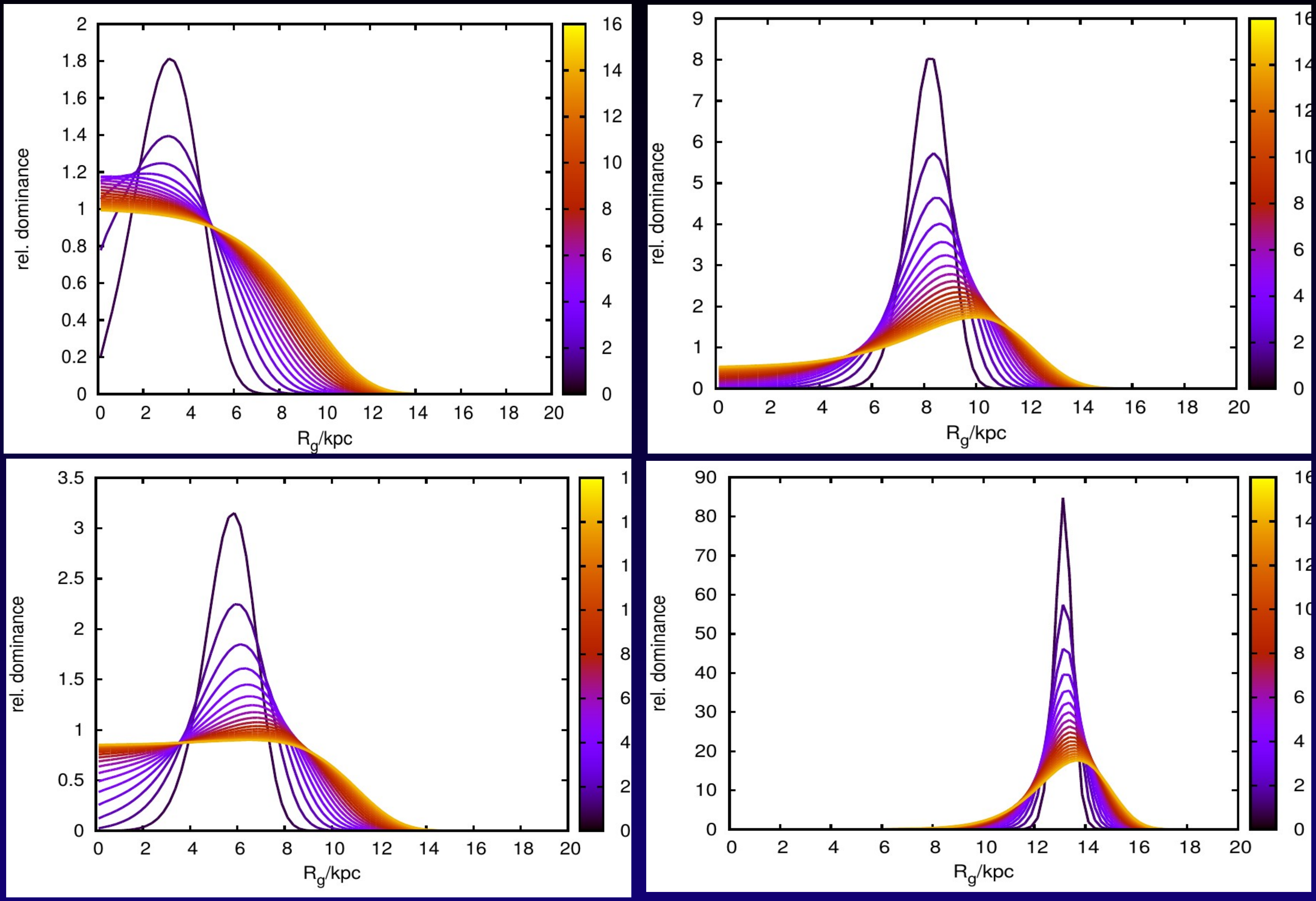
Equivalent results on N-bodies

Bird et al. (2011),

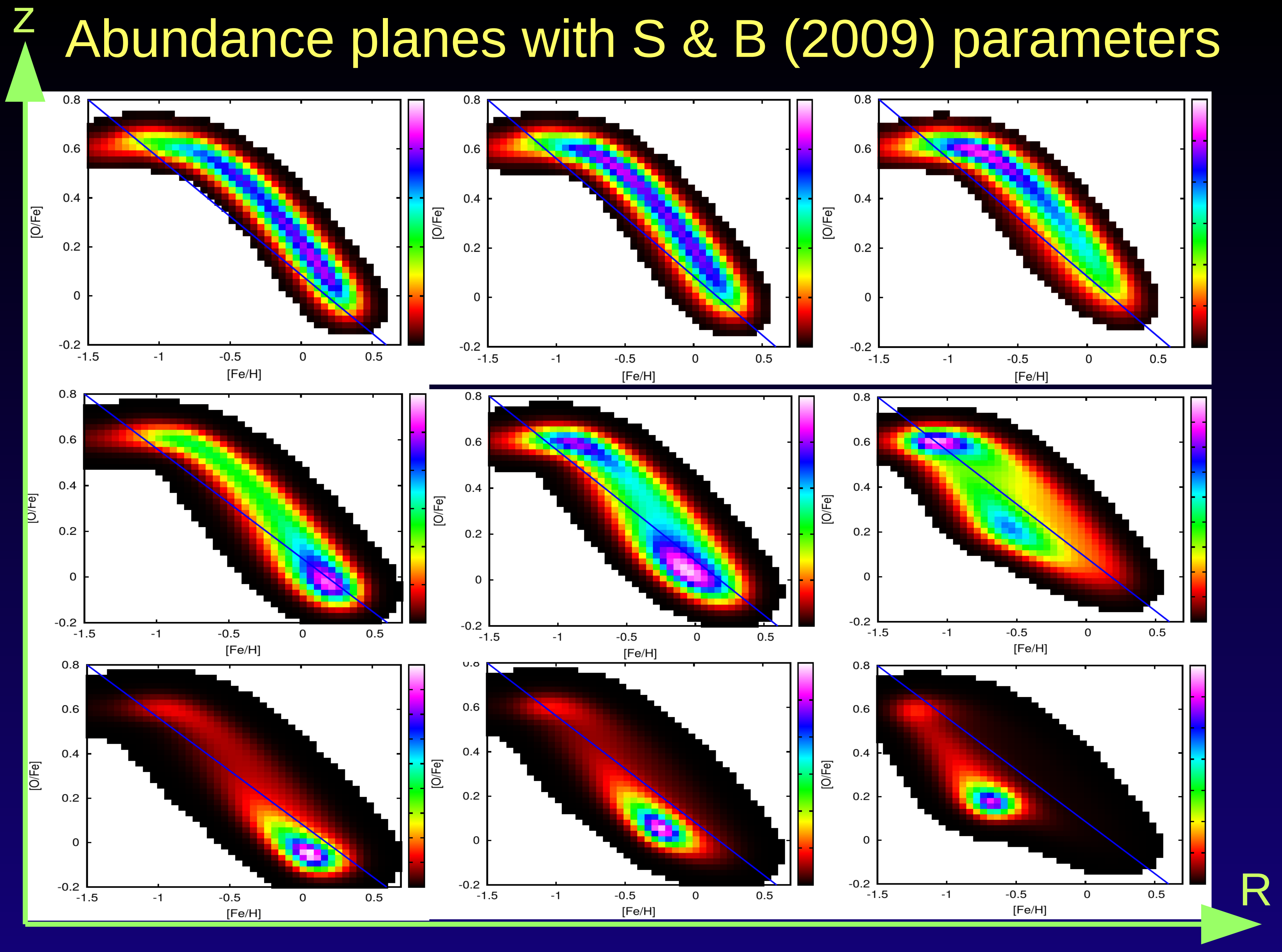
Kubryk et al. (2014)



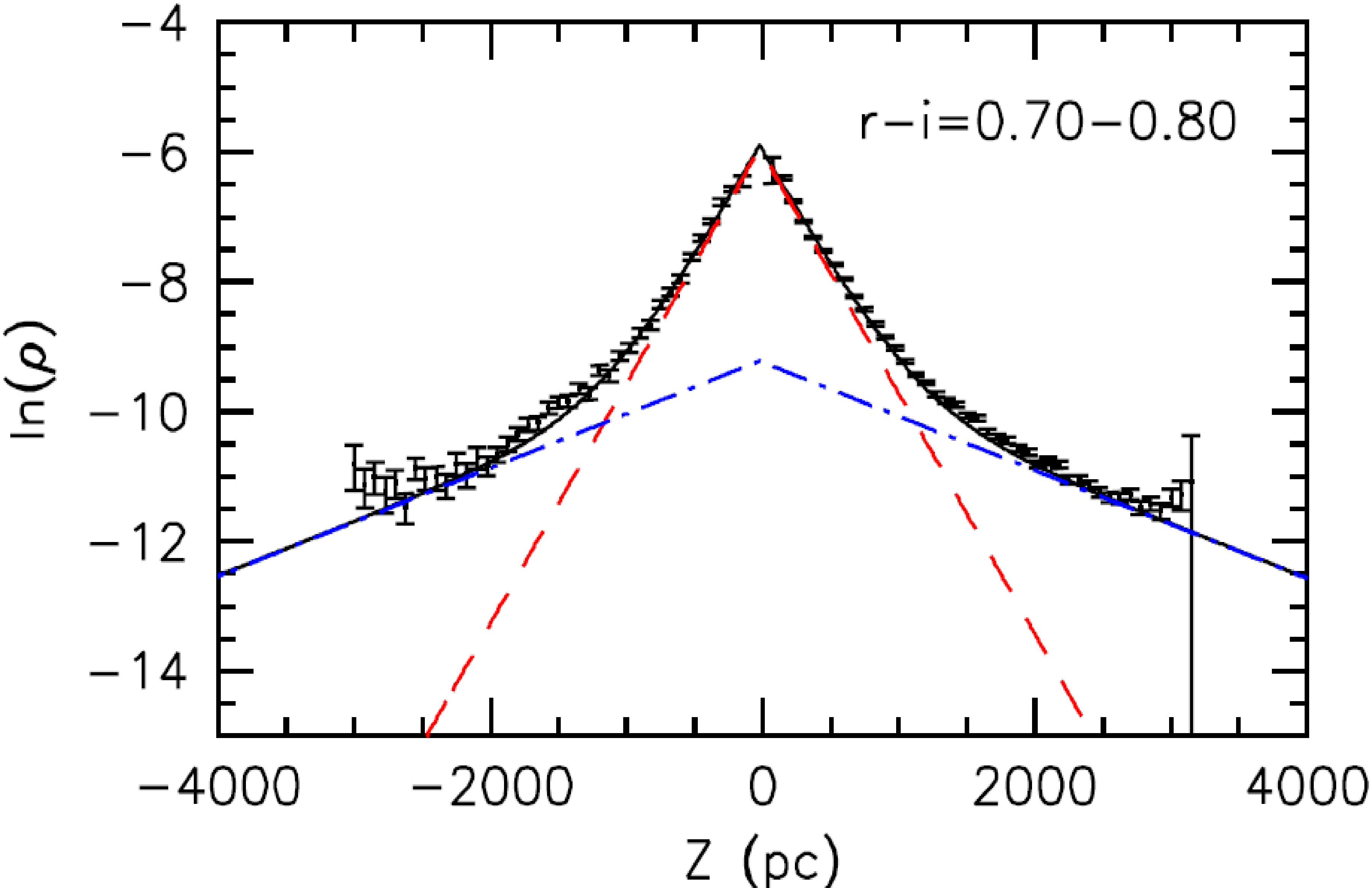
The edge of radial migration



Abundance planes with S & B (2009) parameters

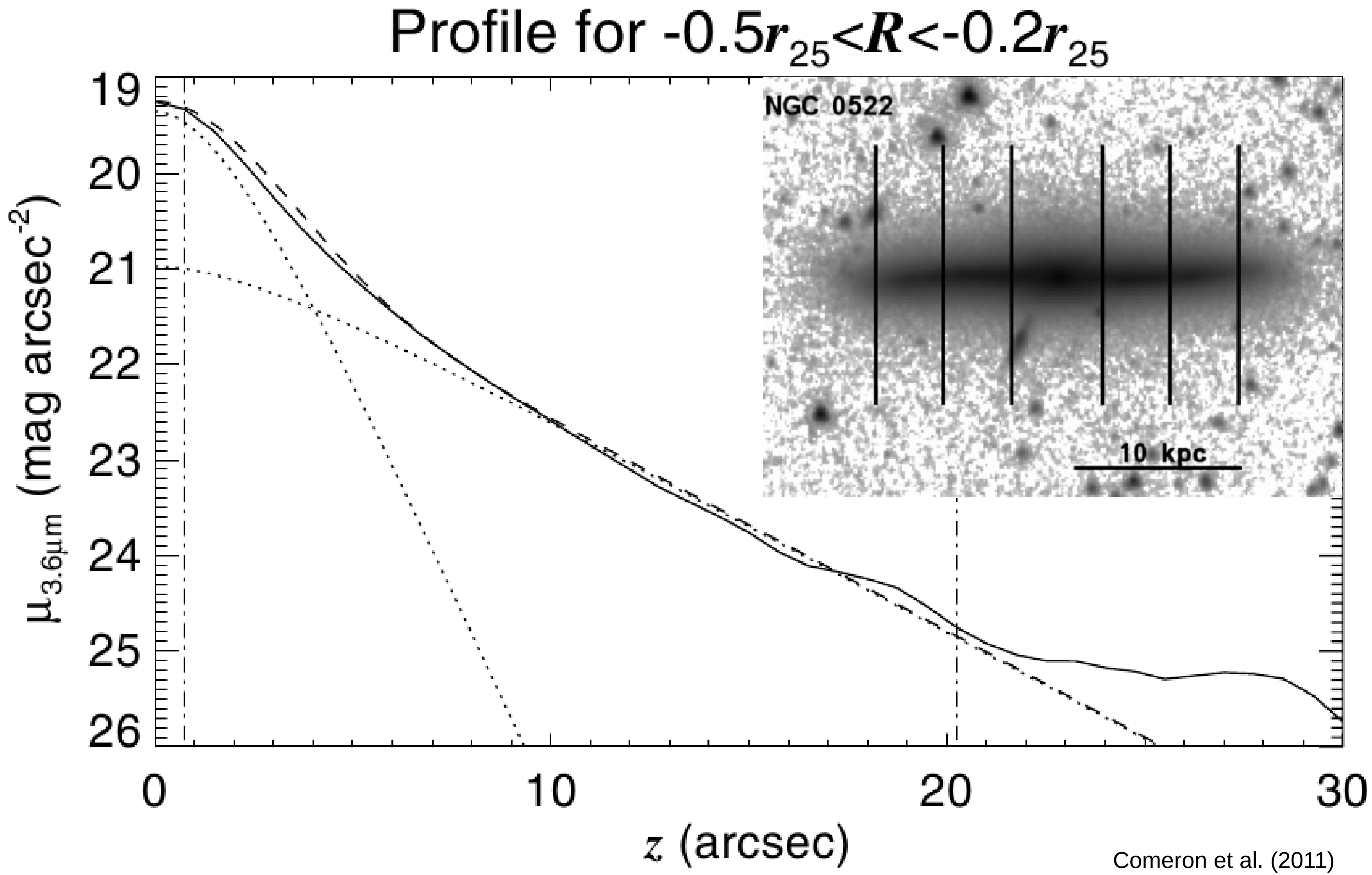


What is the thick disc?



Juric et al. (2007)

Widespread phenomenon

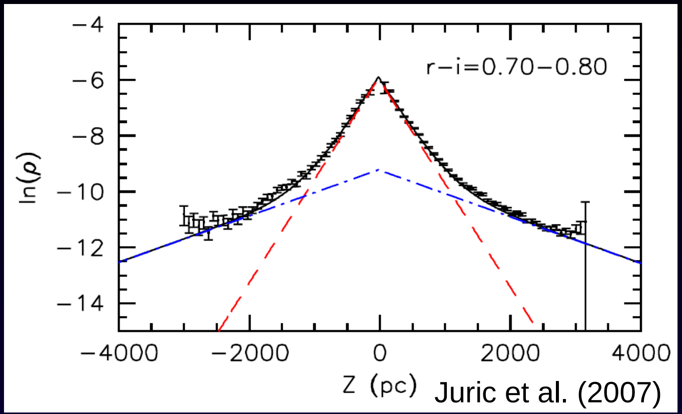


Comeron et al. (2011)

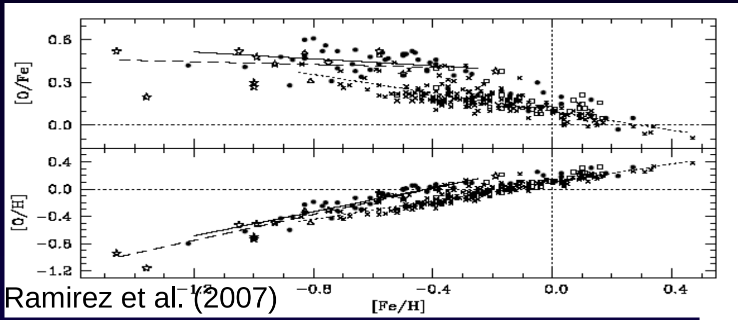
What is the thick disc?

Observables

Two-exponential fit of vertical density profile



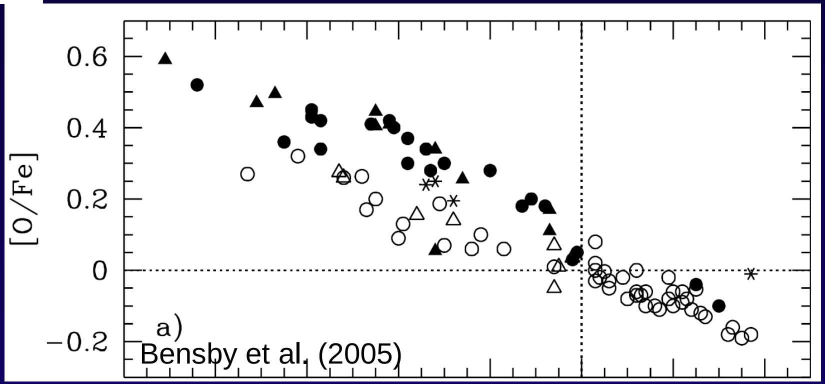
Juric et al. (2007)



Ramirez et al. (2007)

Bimodal behaviour in [α/Fe]

Asymmetric drift



Bensby et al. (2005)

Full chemo-kinematical representation

Modelling: No evidence for a separate component (S & Binney 2009a, b; Loebman et al. 2011; Bovy et al. 2013)

How much does radial migration thicken the disc?

Action conservation means:

$$\frac{h(R_g, R)}{h(R_g, R_g)} = \left(\frac{\Sigma(R)}{\Sigma(R_g)}\right)^{-1/(2+\alpha)} = \exp\left(\frac{R - R_g}{(2+\alpha)R_d}\right)$$

ratio of scale heights

surface density

adiabatic index

disc scale length

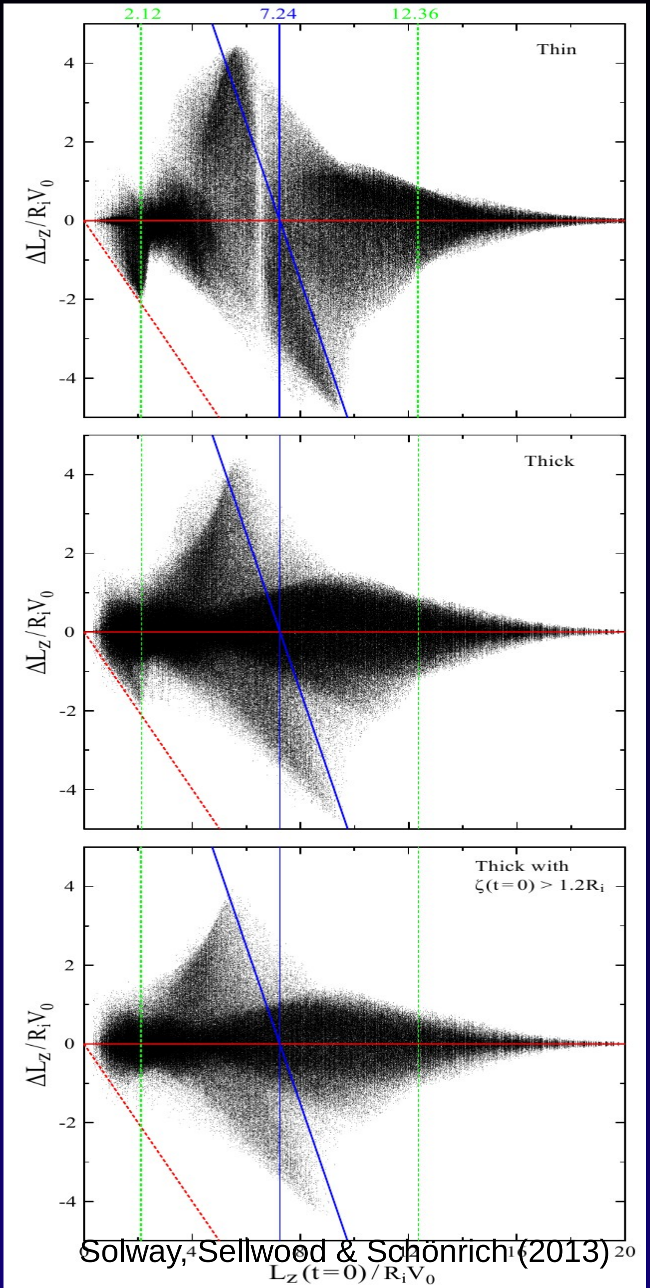
At constant initial scale height → thickening by a factor of 2-3 for 7 kpc

If a disc flares more than this → outwards migration can even cool the disc (so some N-body simulations, e.g. Loebman et al. 2011, find the effect, while others do not, depending on disc setup and internal heating)

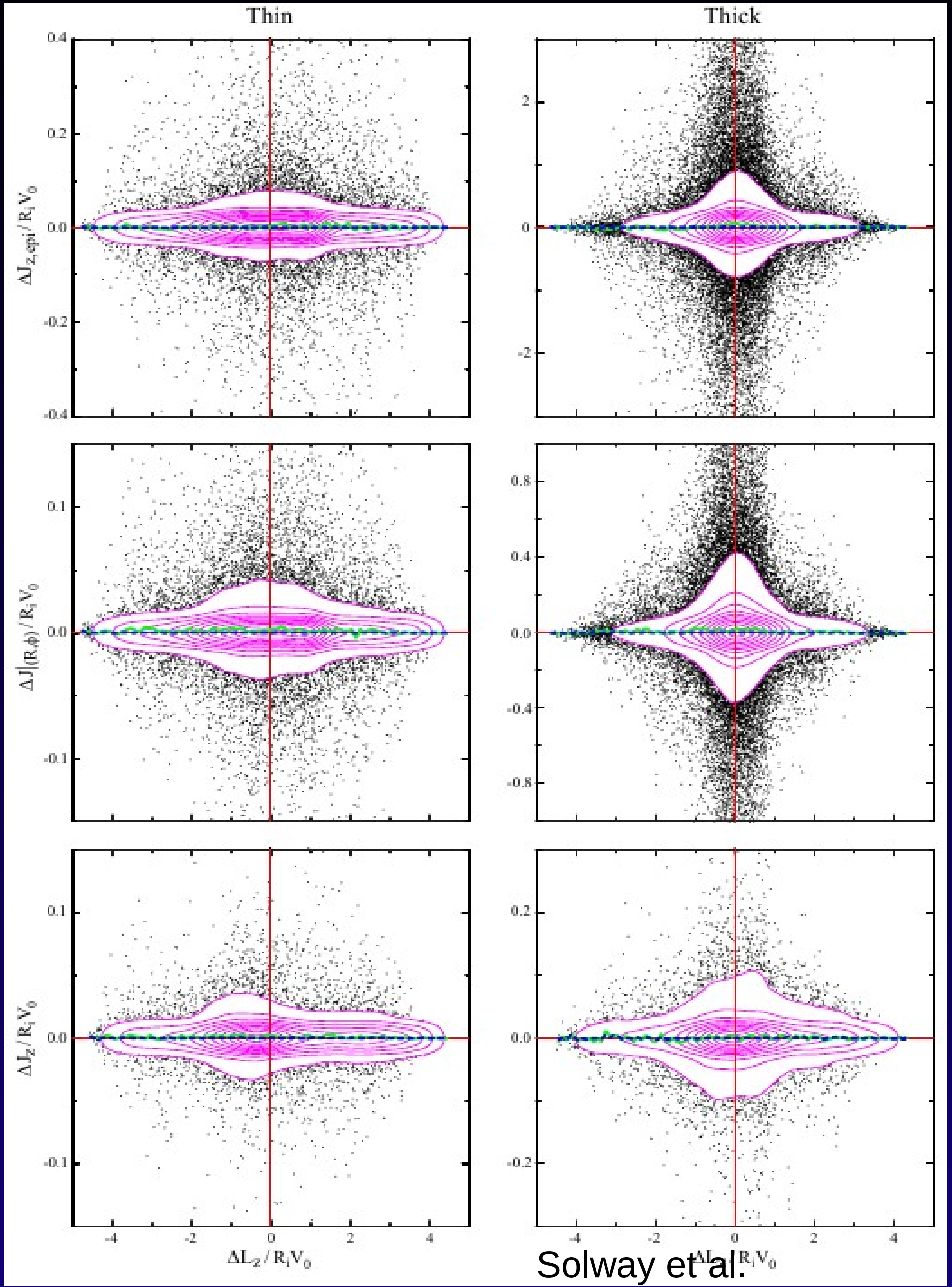
S & B (2012), see also Roskar et al. (2013)

Pseudo-isothermal models may be an issue for vertical profiles

Preferential migration?

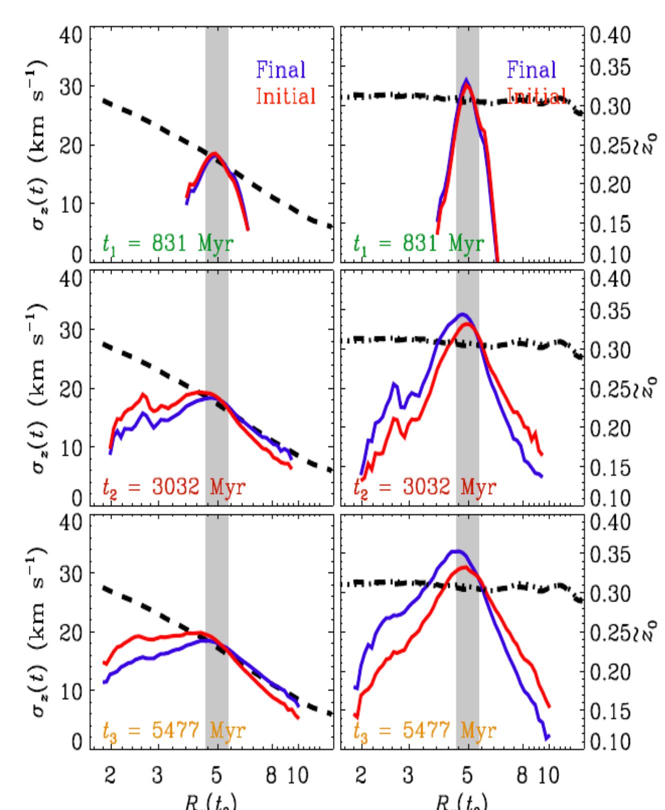


Solway, Sellwood & Schönrich (2013)

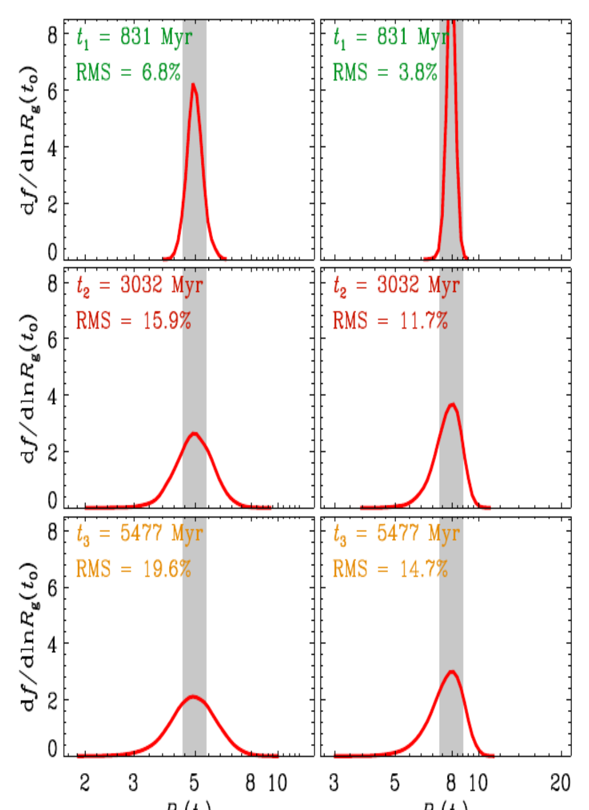


Solway et al.

Preferential migration?



Vera-Ciro et al. (2014)



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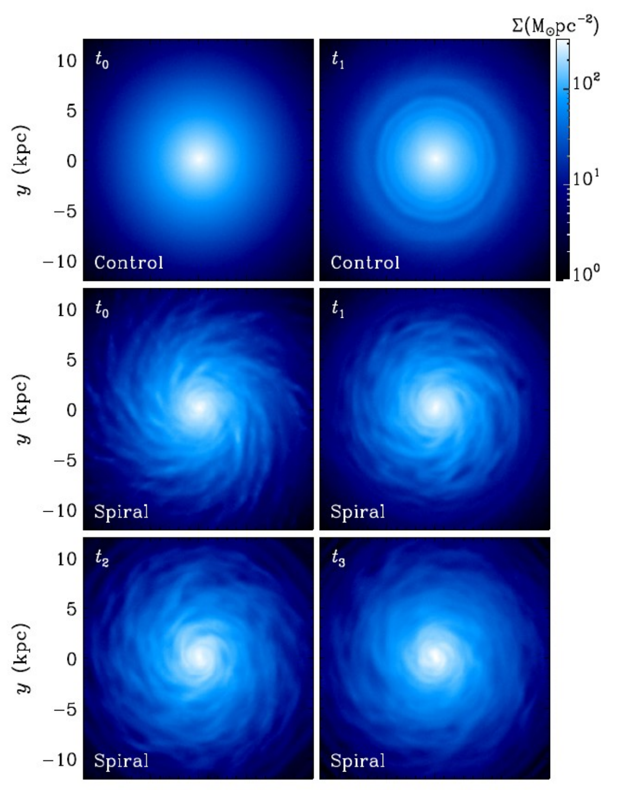

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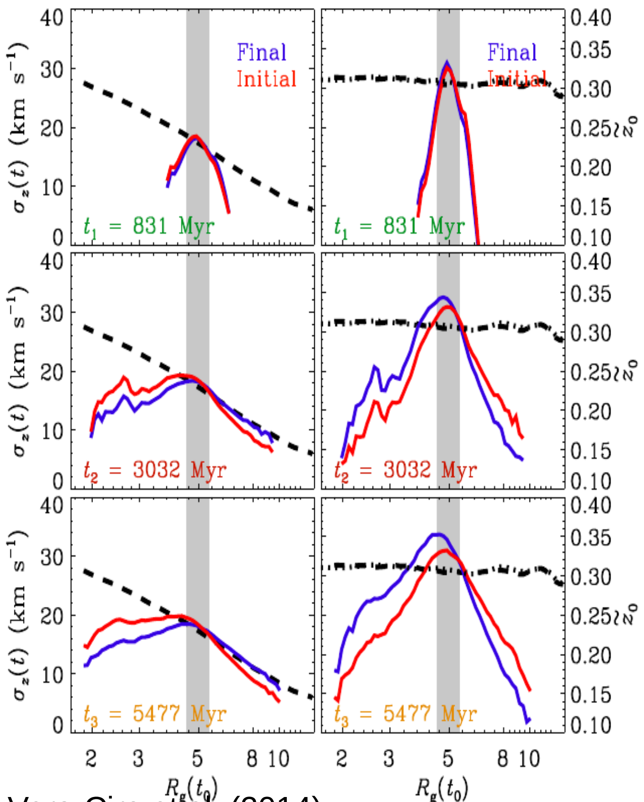
Preferential migration?



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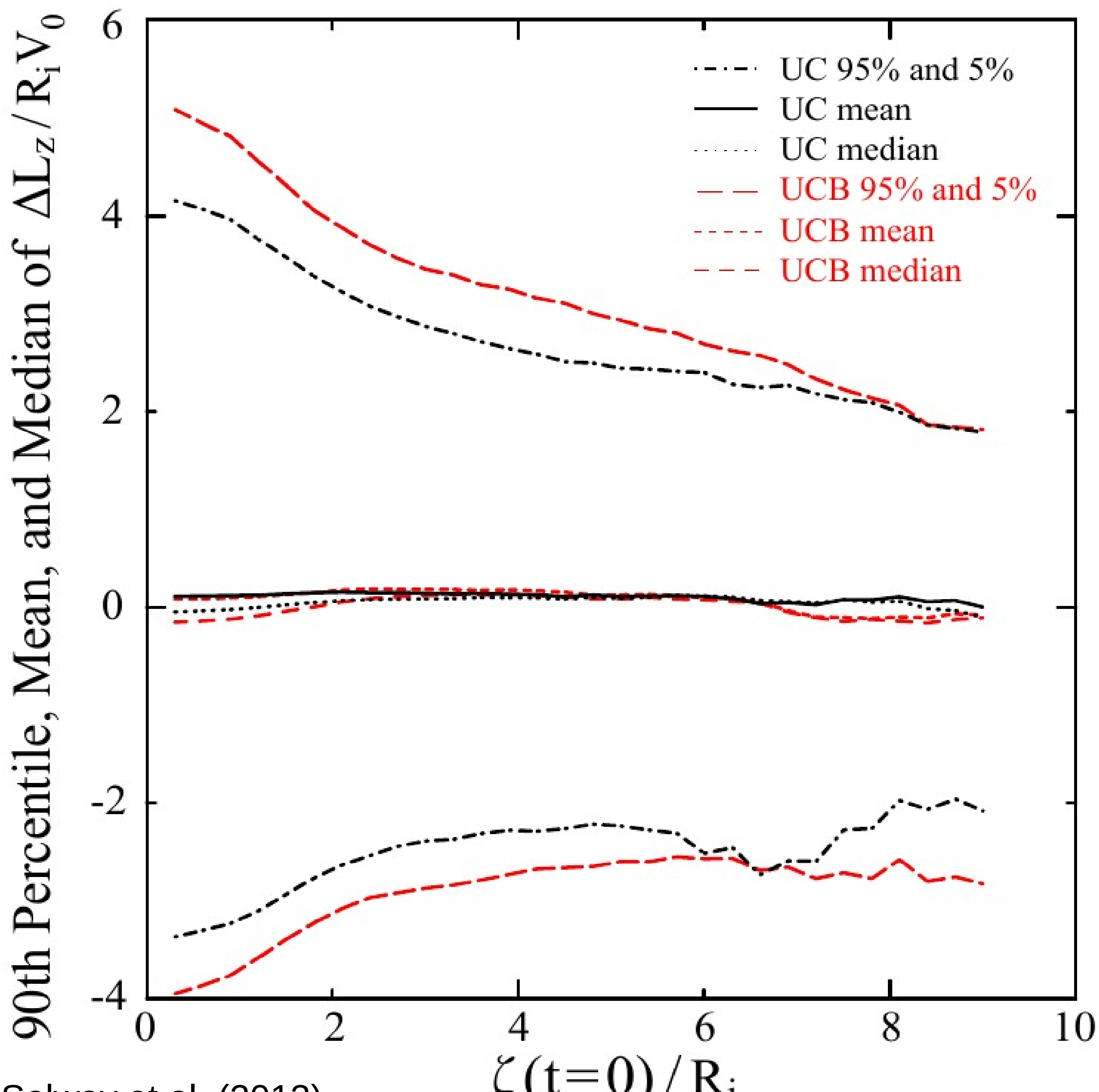
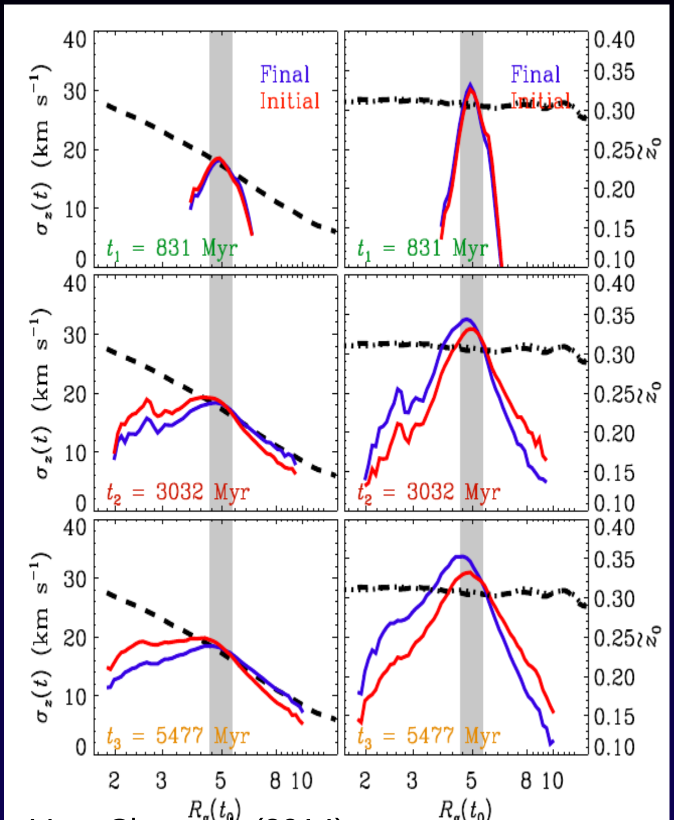


Solway et al. (2013)

Preferential migration?



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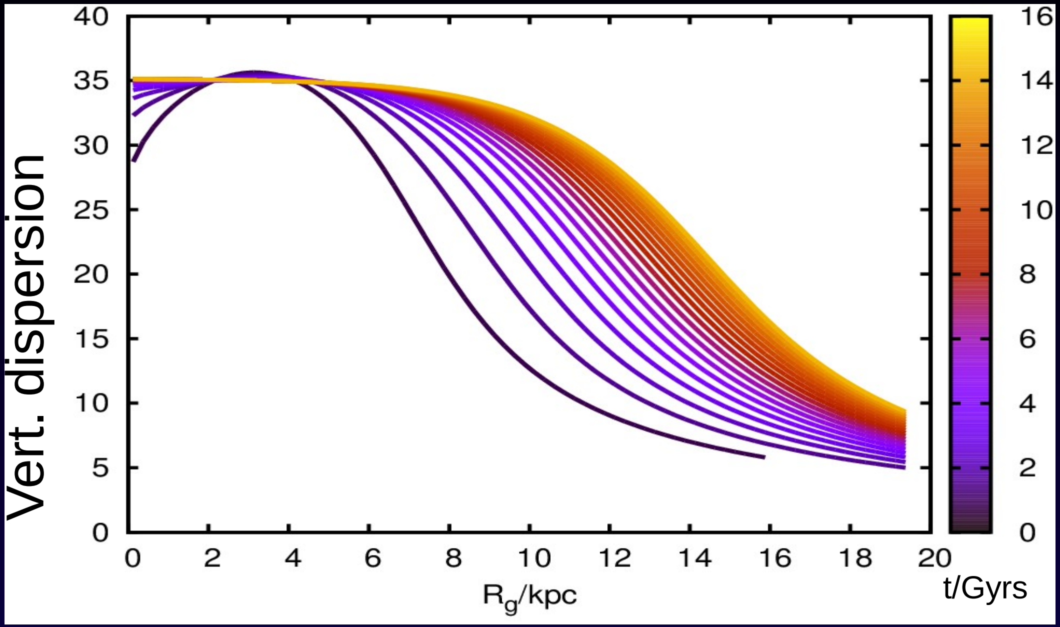
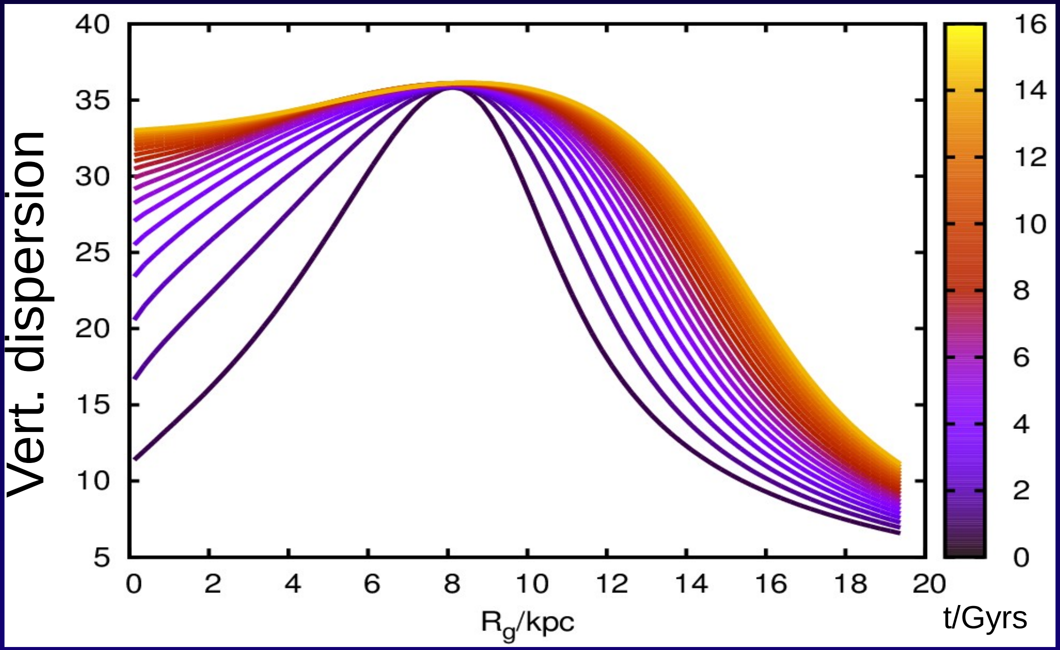
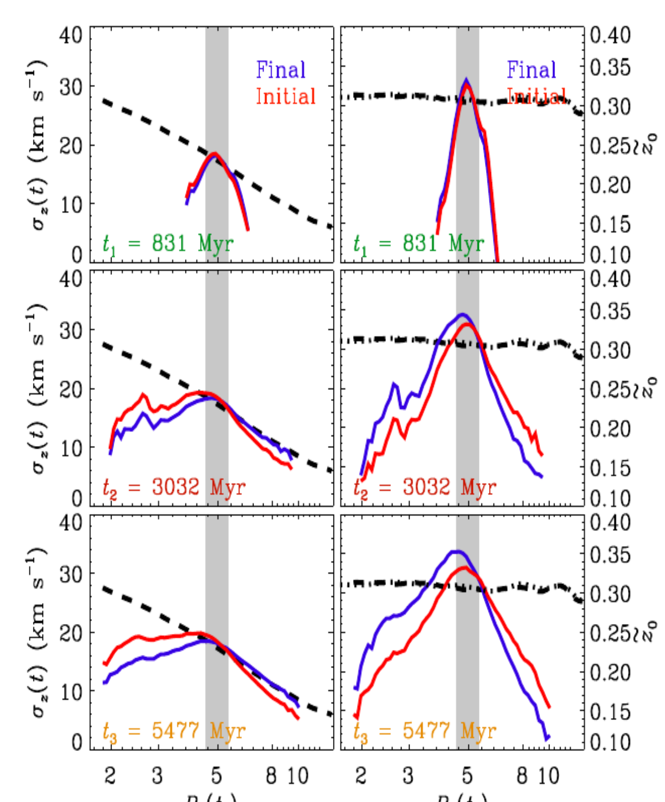




Preferential migration?



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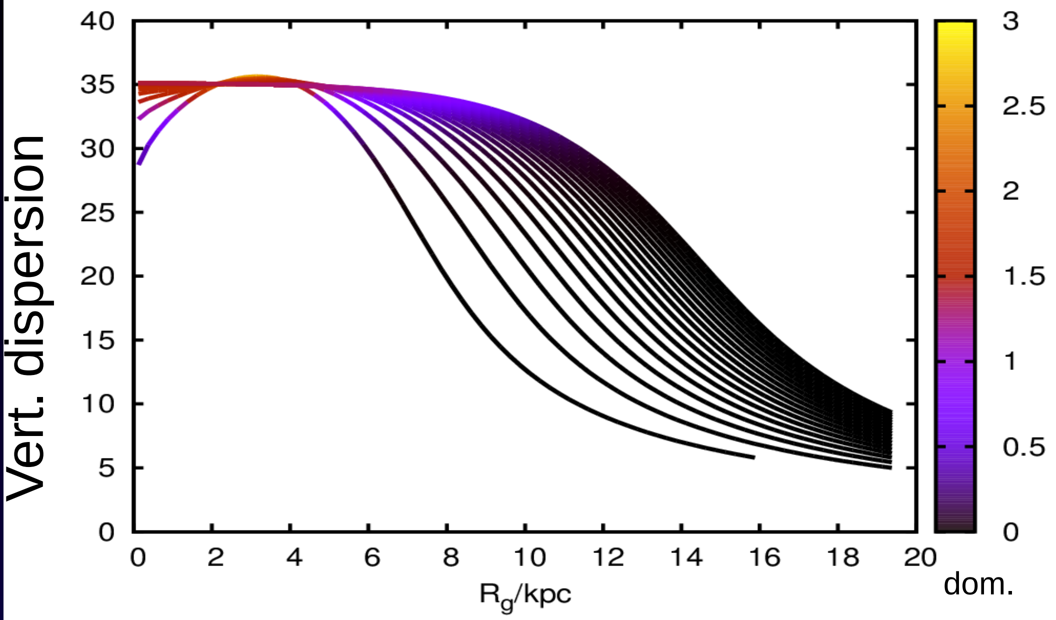
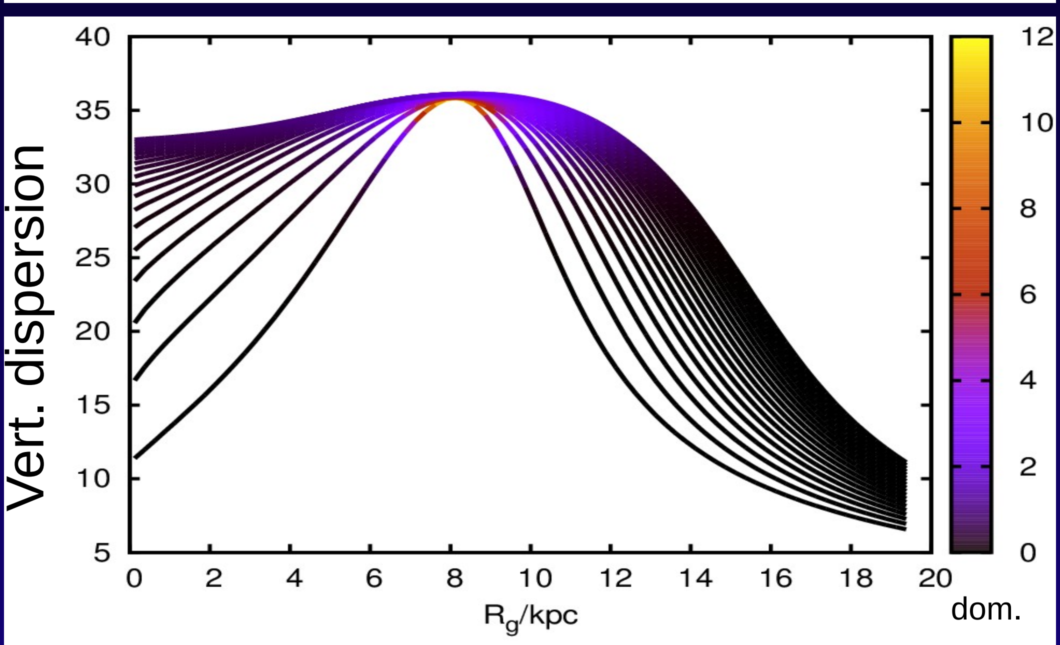
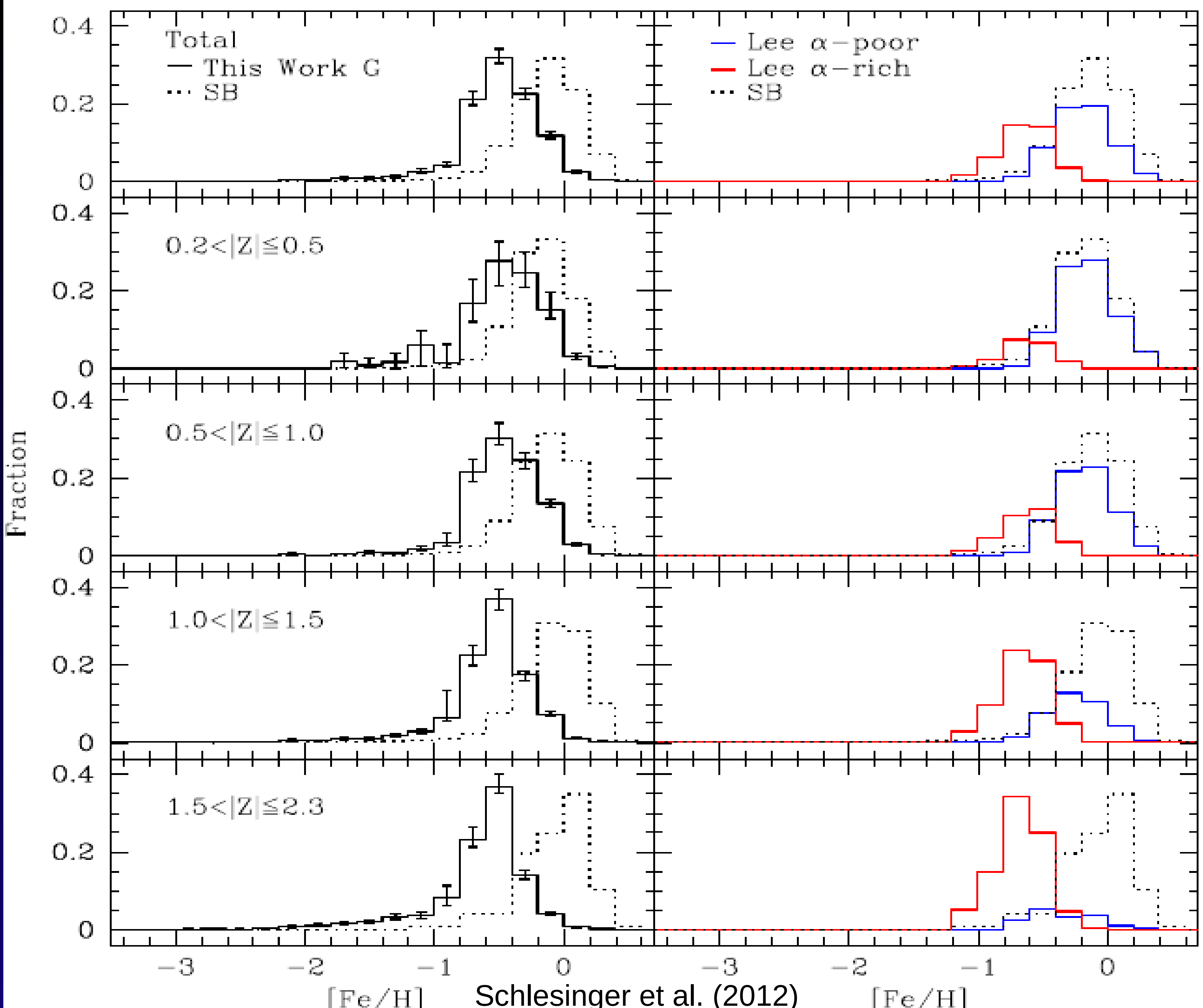
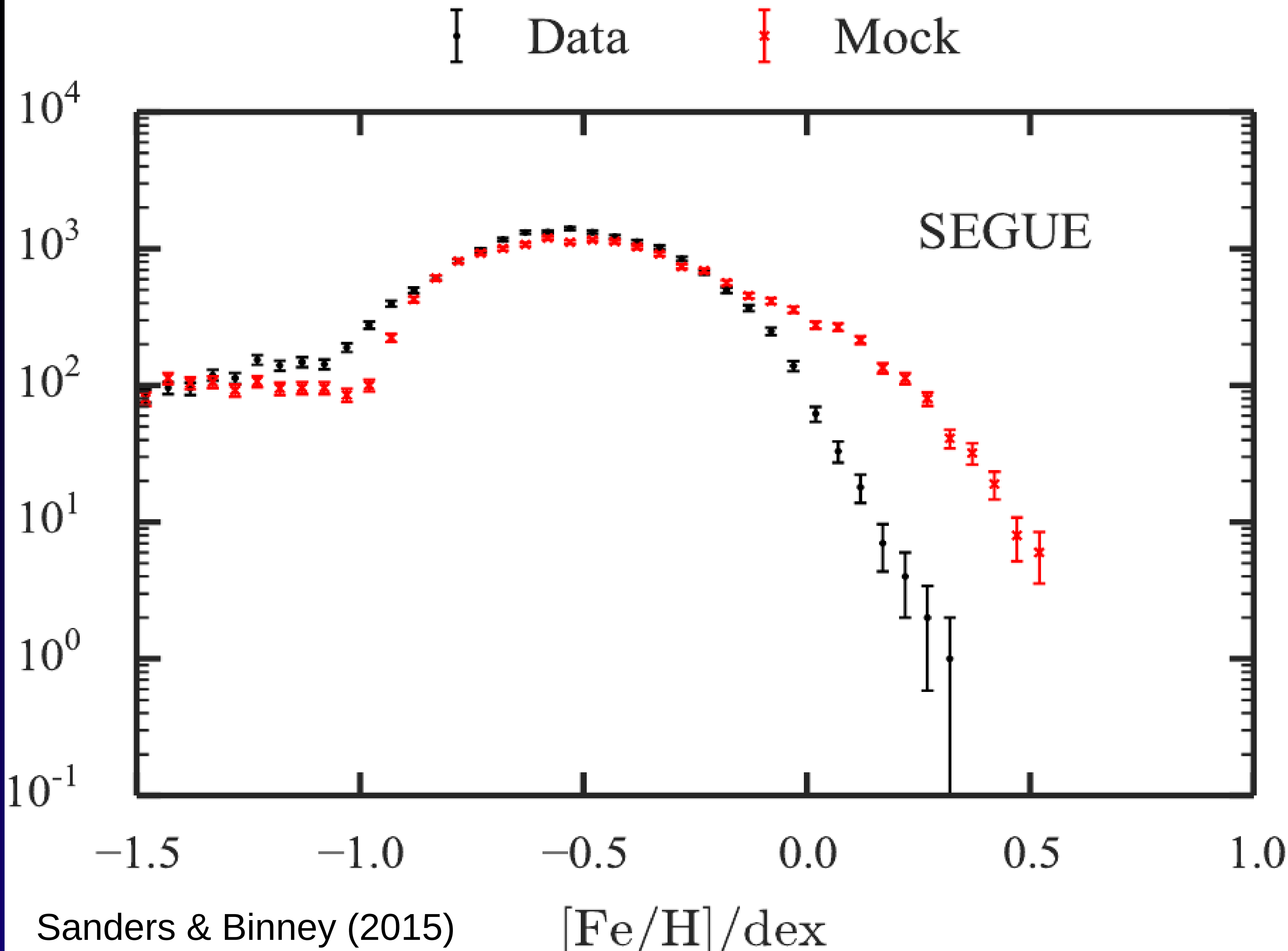






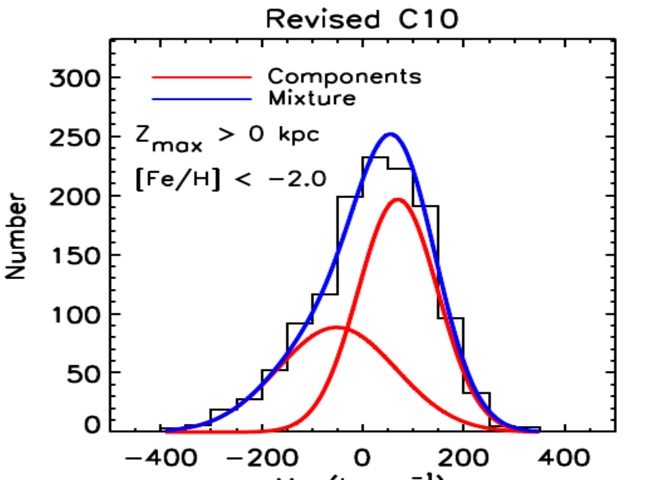
Schlesinger et al. (2012)



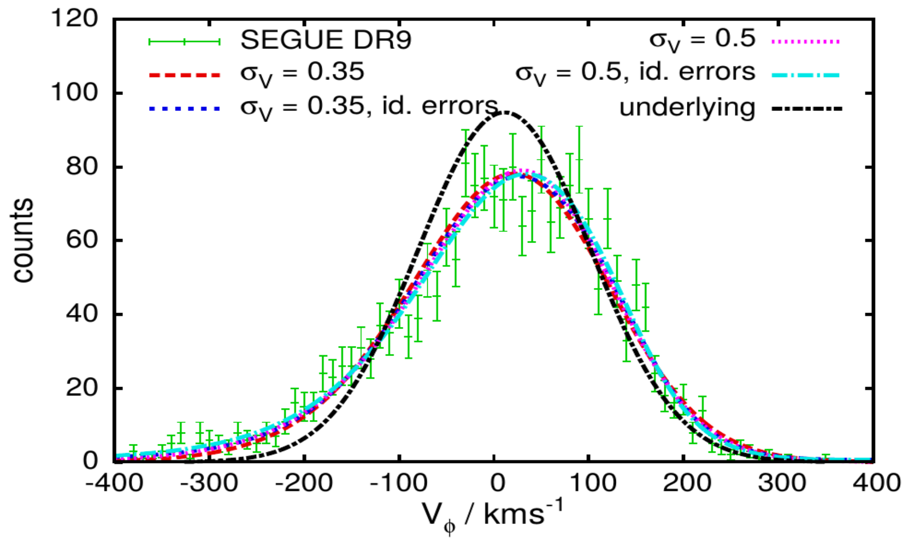
Sanders & Binney (2015)

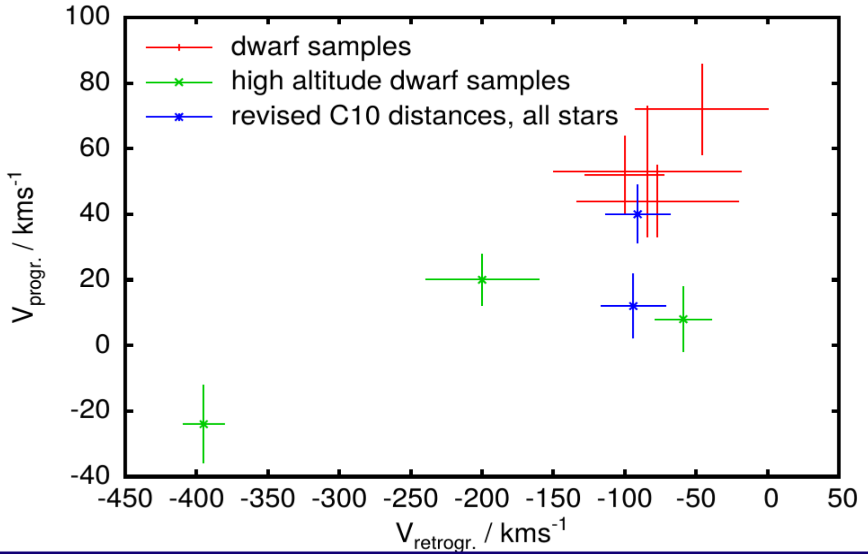
The importance of errors: Gaussian velocity distributions

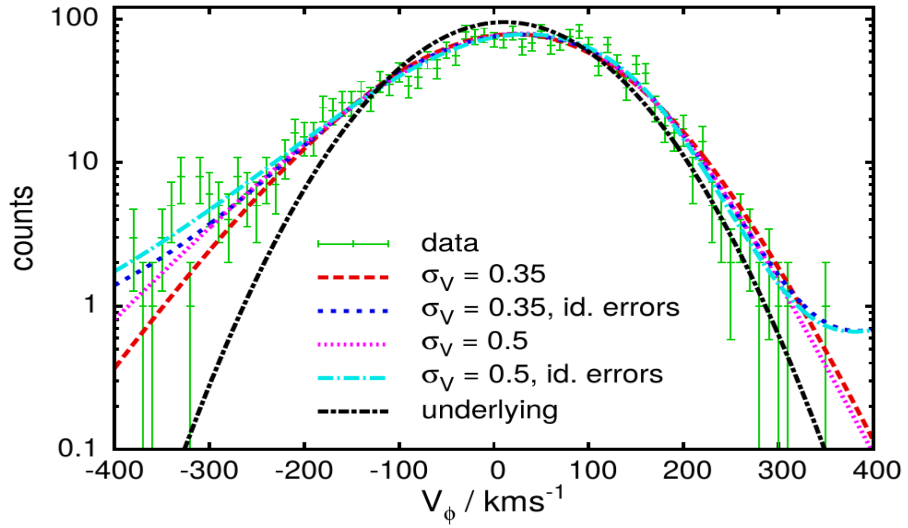
The disc velocity distribution is highly non-Gaussian
(Strömberg 1927, see also Schönrich & Binney 2012)
The error distribution is highly non-Gaussian
(Strömberg 1927, see also Schönrich, Asplund & Casagrande 2011)



Beers et al.(2012)







Probabilistic parameters/Bayesian spectroscopy

Basic problem

Large surveys present huge amounts of stellar data with moderate quality

Vanishing Poisson noise: need to go for quantitative analysis incl. errors

Consistent automated analysis and quality assessment required

e.g. metallicity scales are not on a consistent analysis level
(see e.g. Schlesinger et al. 2012)

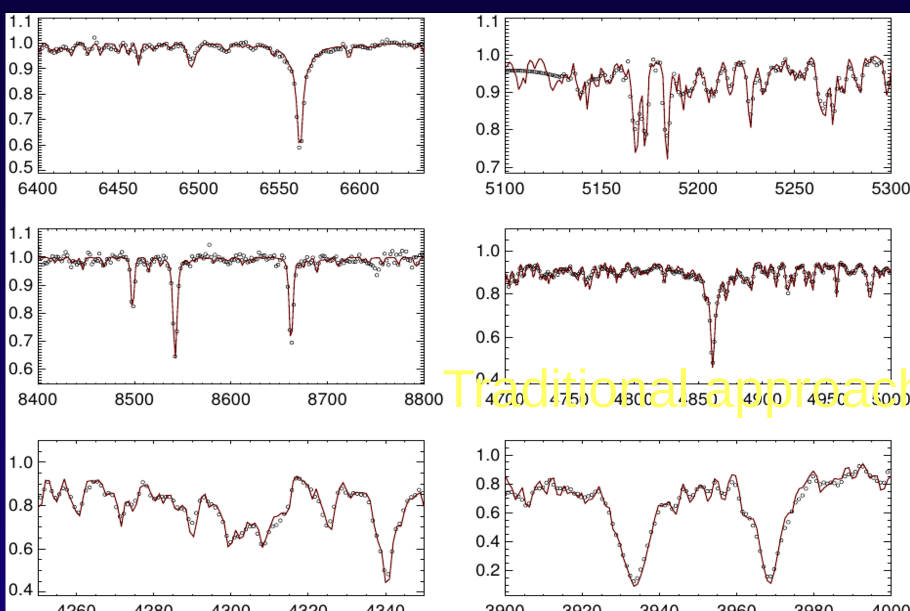
Optimal exploitation of present data requires us to use them at once

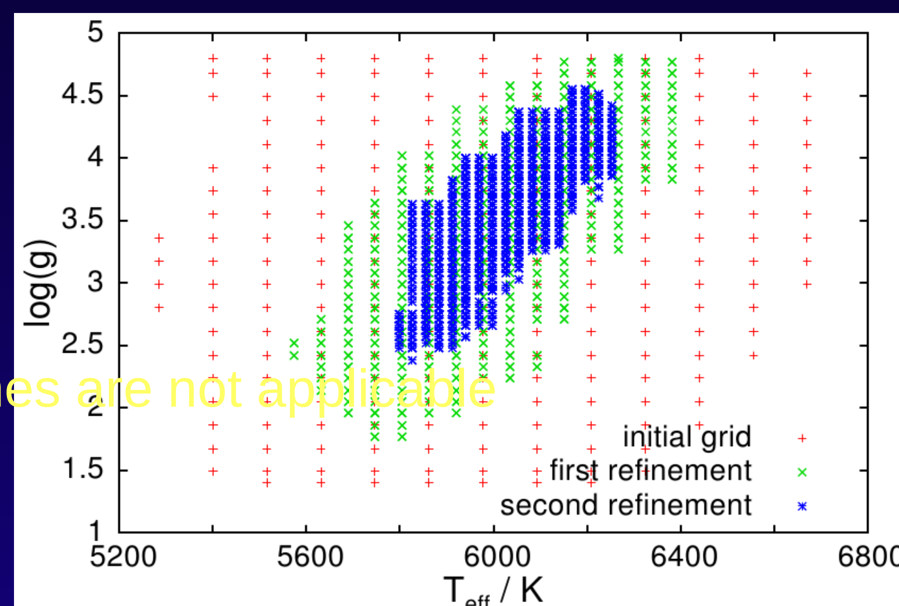
Need a fair assessment of expectation values and errors in datasets

→ need one loop to find and bind all available information

Spectral information

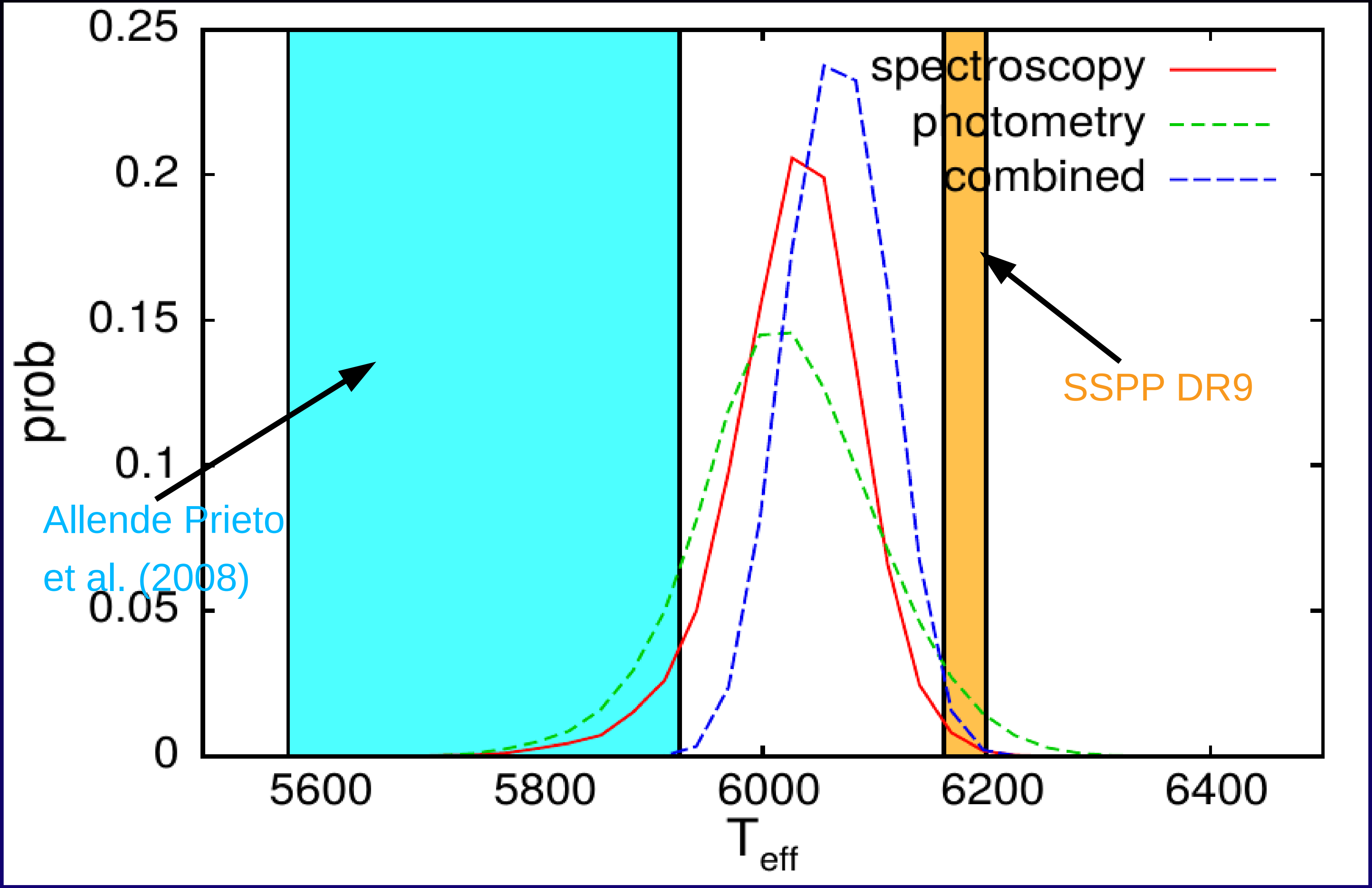
- Require accurate information about the full spectroscopic PDF
- Classical approach of best-fit value + some experienced error estimate is not viable
- Calculate full statistics for synthetic spectra in parameter space
- Use adaptive, iteratively refined mesh guided by photometry + prior
- Created a fully integrated C++ pipeline last year



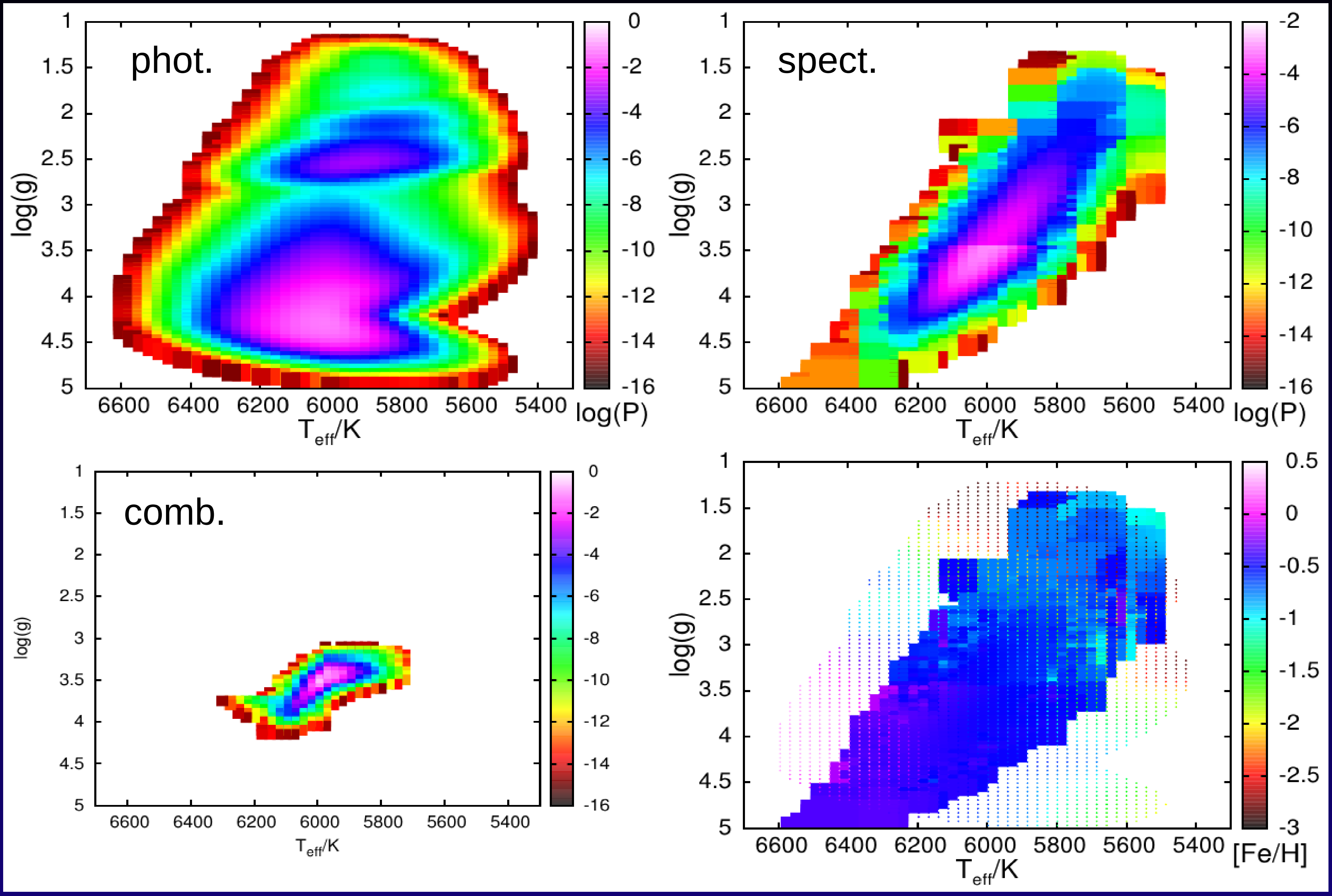


Traditional approaches are not applicable

Data combination is not trivial



Specific parameters



Conclusions

The question is not if there is radial migration, but how strong it is

Qualitative explanation for the current observational constraints

and no signs for a separate origin of the thick disc

High-alpha sequence in Apogee and high alpha disc length consistent

with naive expectation from radial migration

Need full quantitative comparisons

Different claims on thick disk migration due to model differences

Need a Galaxy equivalent of the Millenium Simulations?

No evidence for a halo duality

More importantly: Underlines need for accurate selection functions

Surveys require cross-calibration and accurate error determination

Have created fully integrated pipeline for stellar parameters

Traditional approaches are not applicable

For LSR problems, statistical distances, models,

or Bayesian spectroscopy code – contact me

Open questions

Do we have a sufficient handle on selection functions?

Sources and shape of radial migration patterns?

Dependencies on parameters? Pattern Strength? Lifetime? Overlaps?
Pitch Angle? Wavenumber?

How much preferential migration?

Correlations between migration and heating?

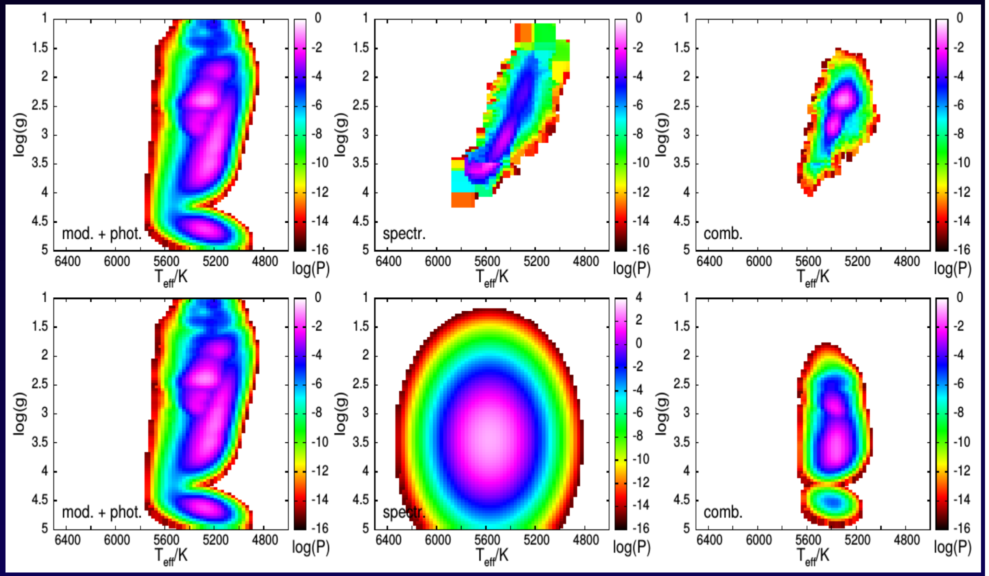
Sources of heat in the disk? Are secular processes sufficient?

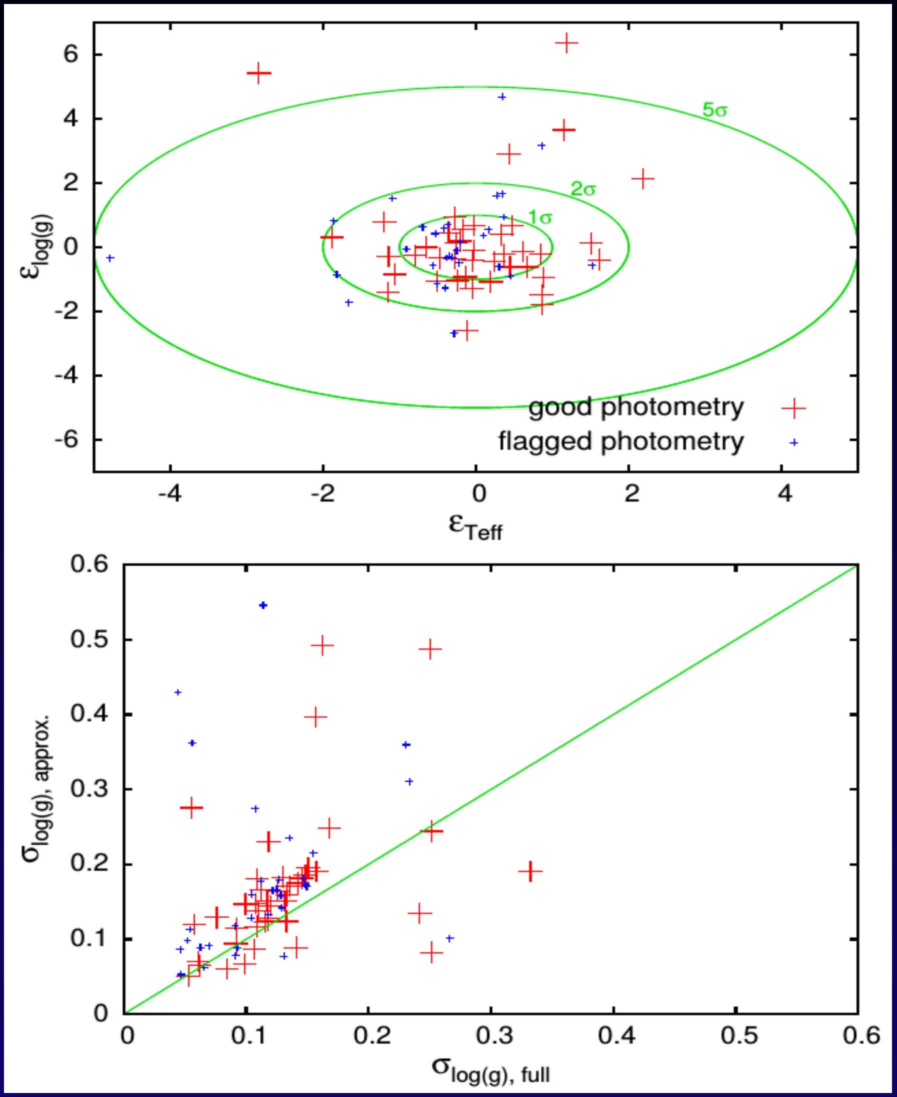
At which level do models have to compare to data?

To which extent are full representations of obs. constraints feasible?

Why do we need this?

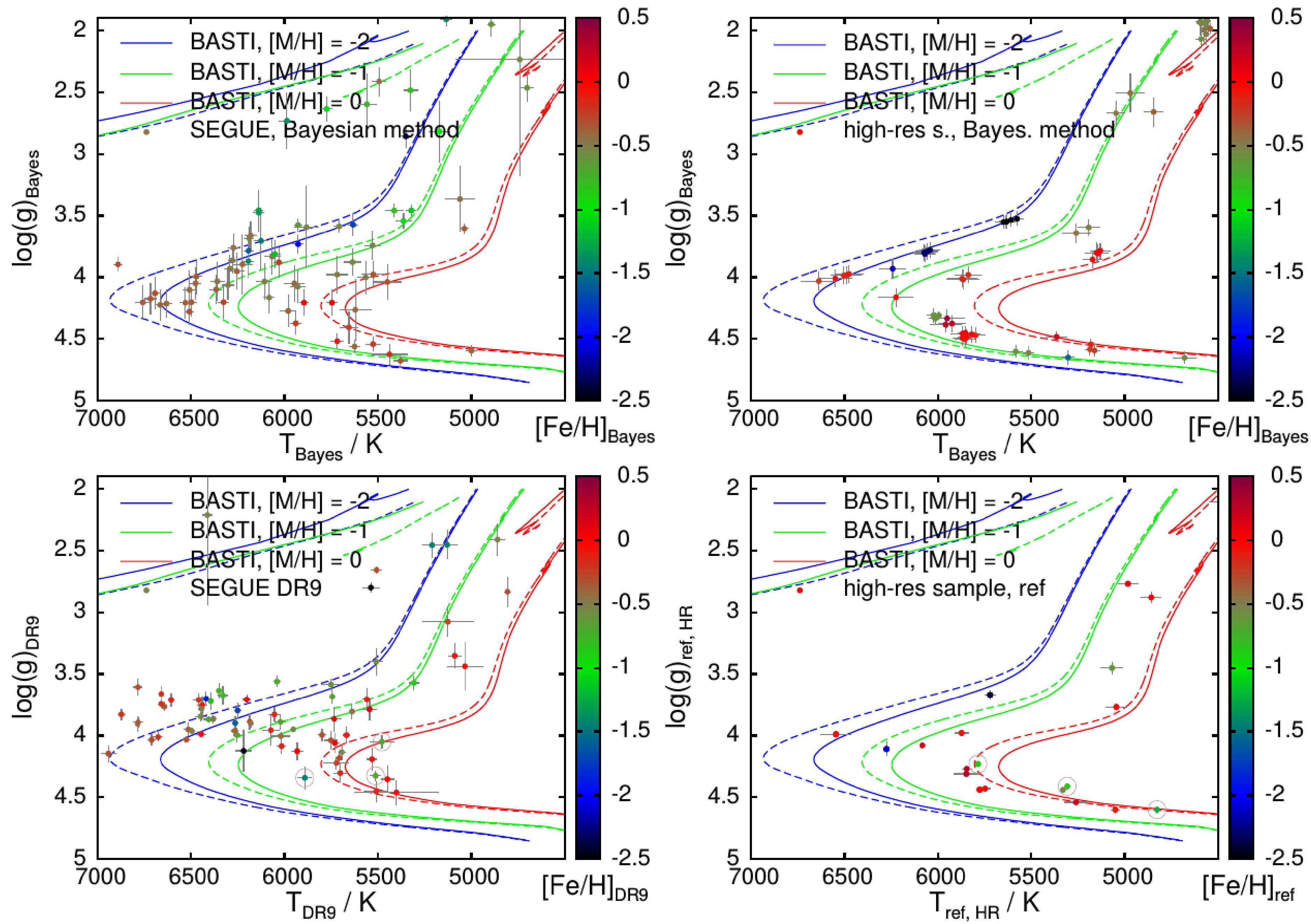
Neglecting full PDF gives large scatter on identical data input!



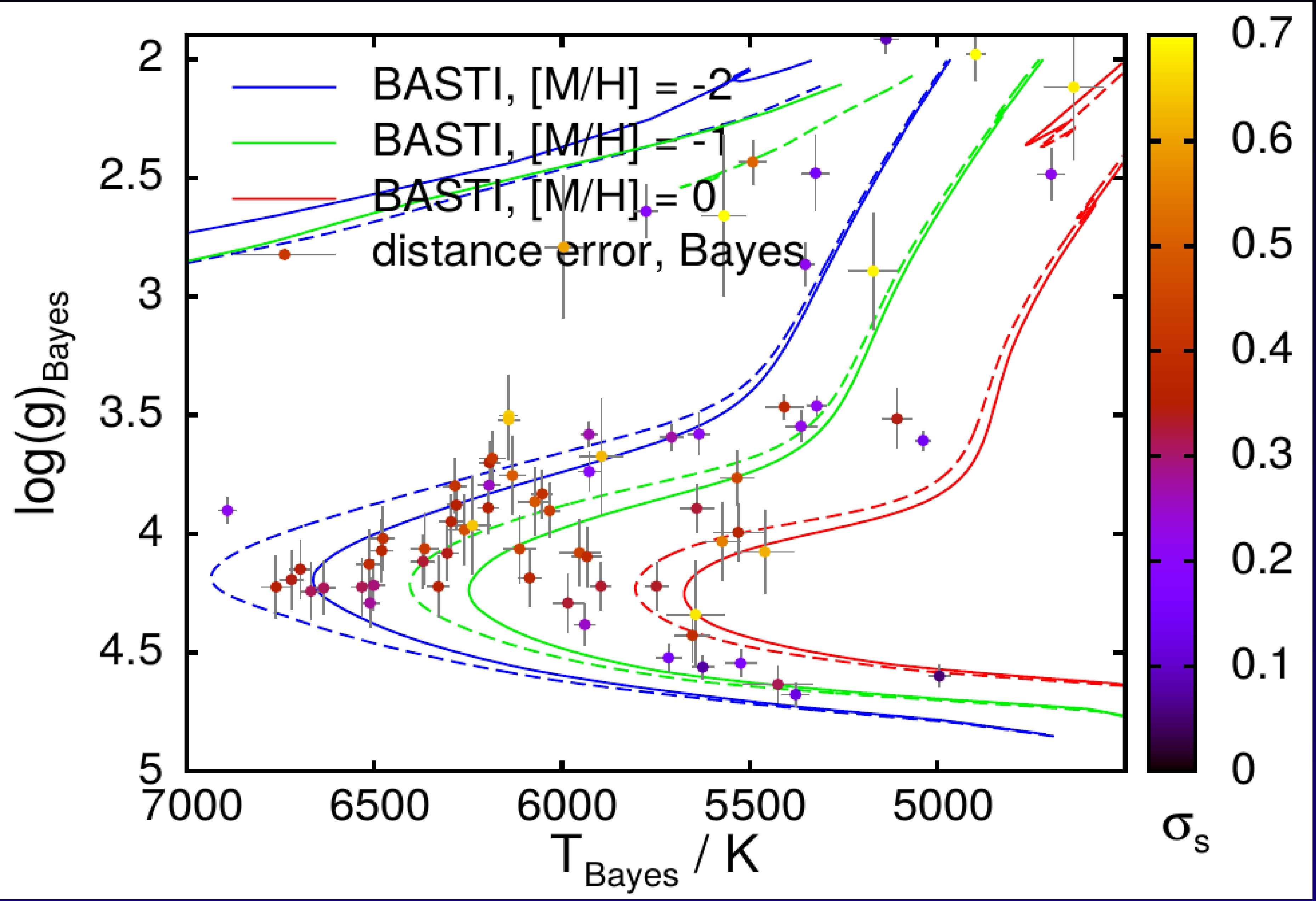


Common approx. are not justified

HR diagram

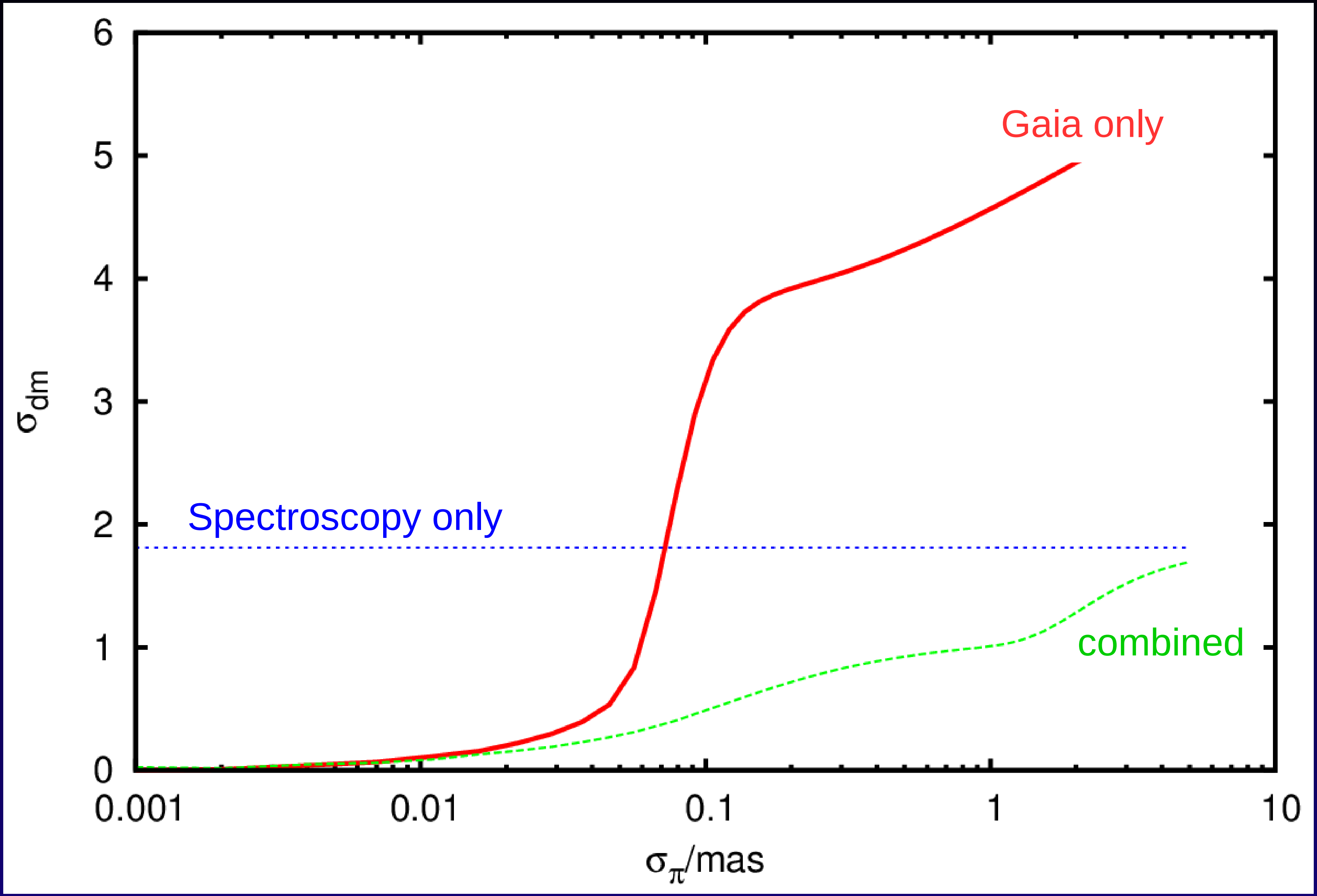

BASTI, [M/H] = -2
BASTI, [M/H] = -1
BASTI, [M/H] = 0
SEGUE, Bayesian method
log(g)Bayes
TBayes / K
[Fe/H]Bayes
high-res s., Bayes. method
SEGUE DR9
log(g)DR9
TDR9 / K
[Fe/H]DR9
high-res sample, ref
log(g)ref, HR
Tref, HR / K
[Fe/H]ref
7000
6500
6000
5500
5000
2
2.5
3
3.5
4
4.5
5
0.5
0
-0.5
-1
-1.5
-2
-2.5

Distances



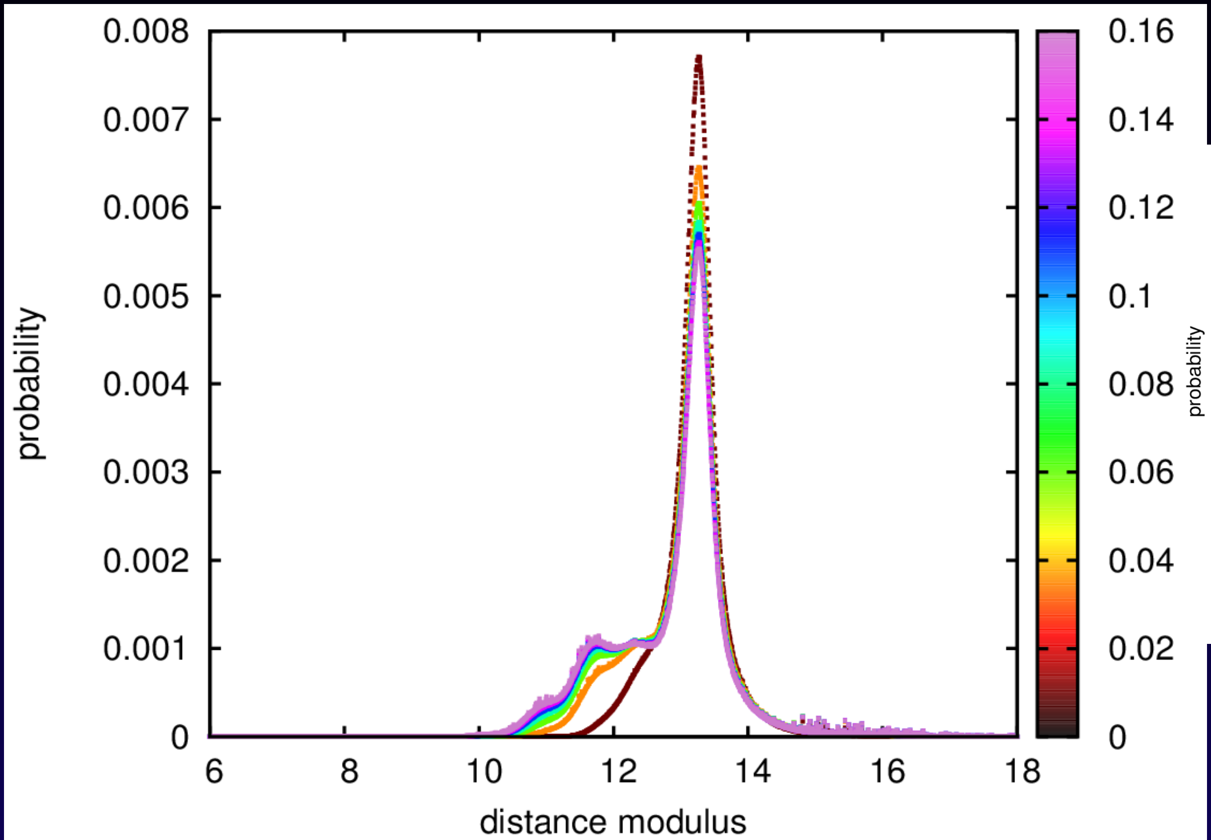
BASTI, [M/H] = -2
BASTI, [M/H] = -1
BASTI, [M/H] = 0
distance error, Bayes
log(g)Bayes
TBayes / K
7000
6500
6000
5500
5000
2
2.5
3
3.5
4
4.5
5
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
σs

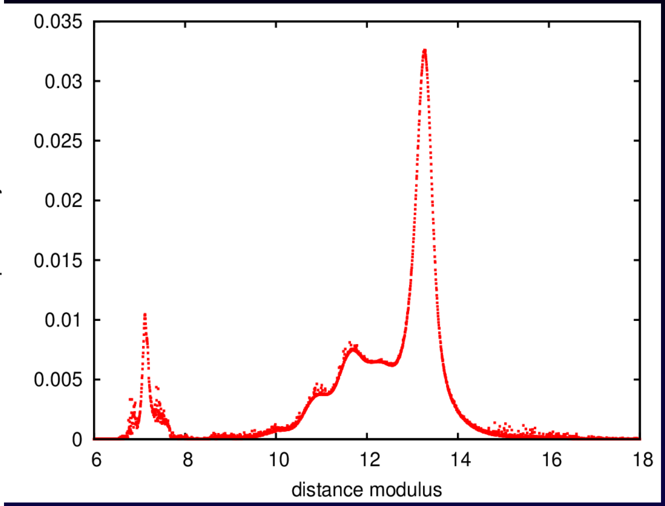
Distances

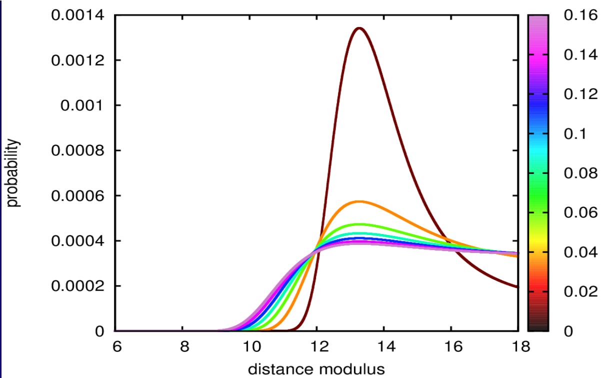


Gaia only
Spectroscopy only
combined
6
5
4
3
2
1
0
0.001
0.01
0.1
1
10
σ_{dm}
σ_{π}/mas

Distances

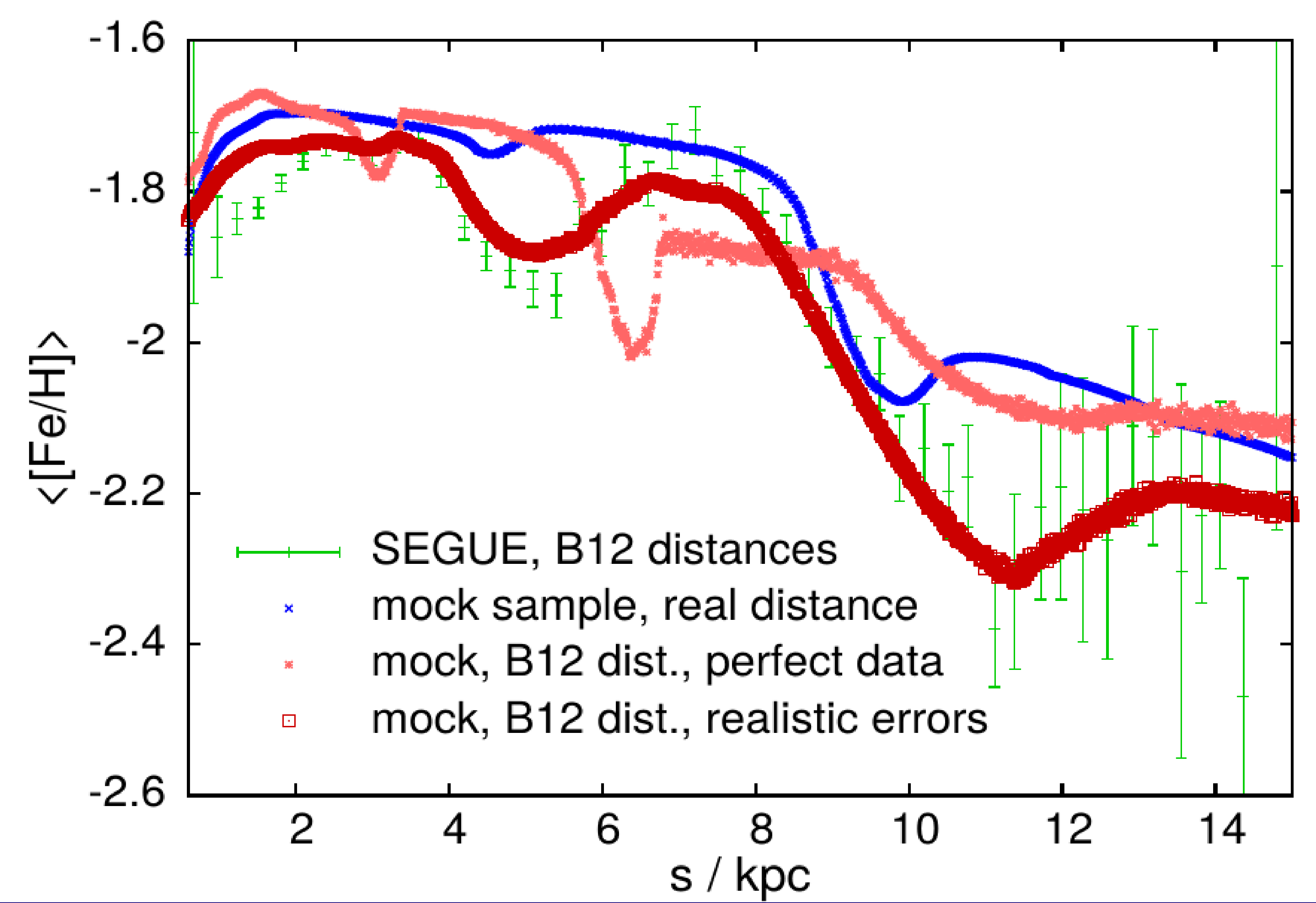




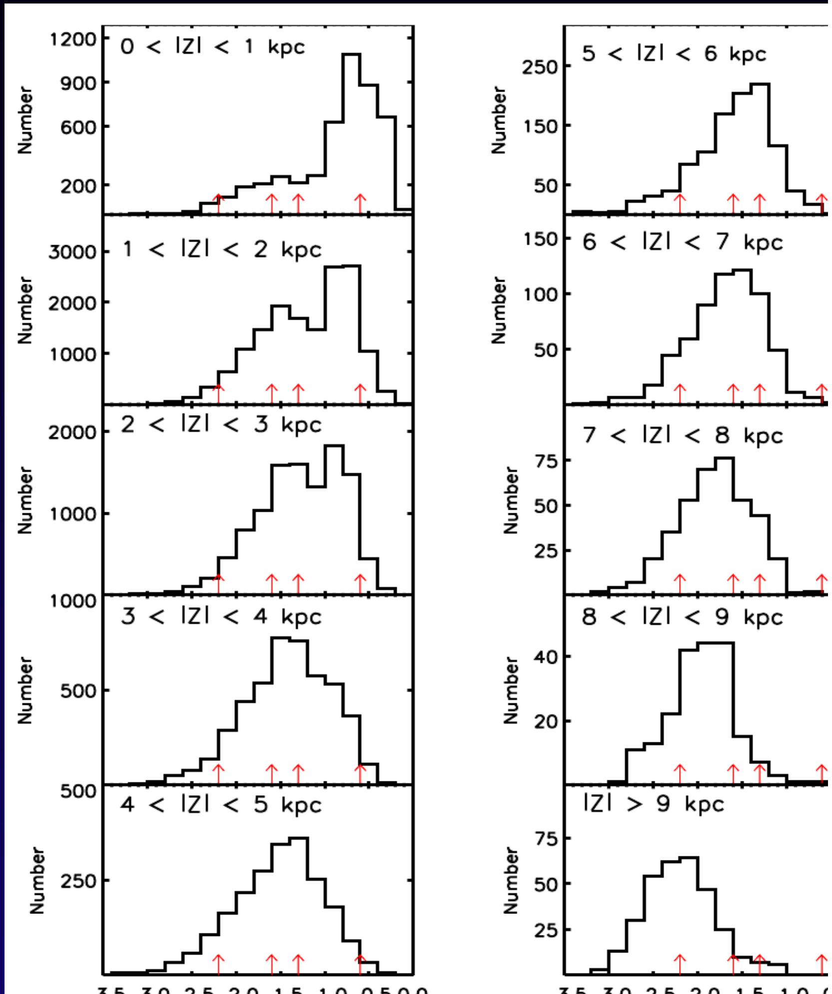


Even uncertain parallaxes cut other branches

Trouble ahead



Altitude dependend trend



Beers et al.(2012)