Radial migration and its impact on the chemical evolution of the MW disk

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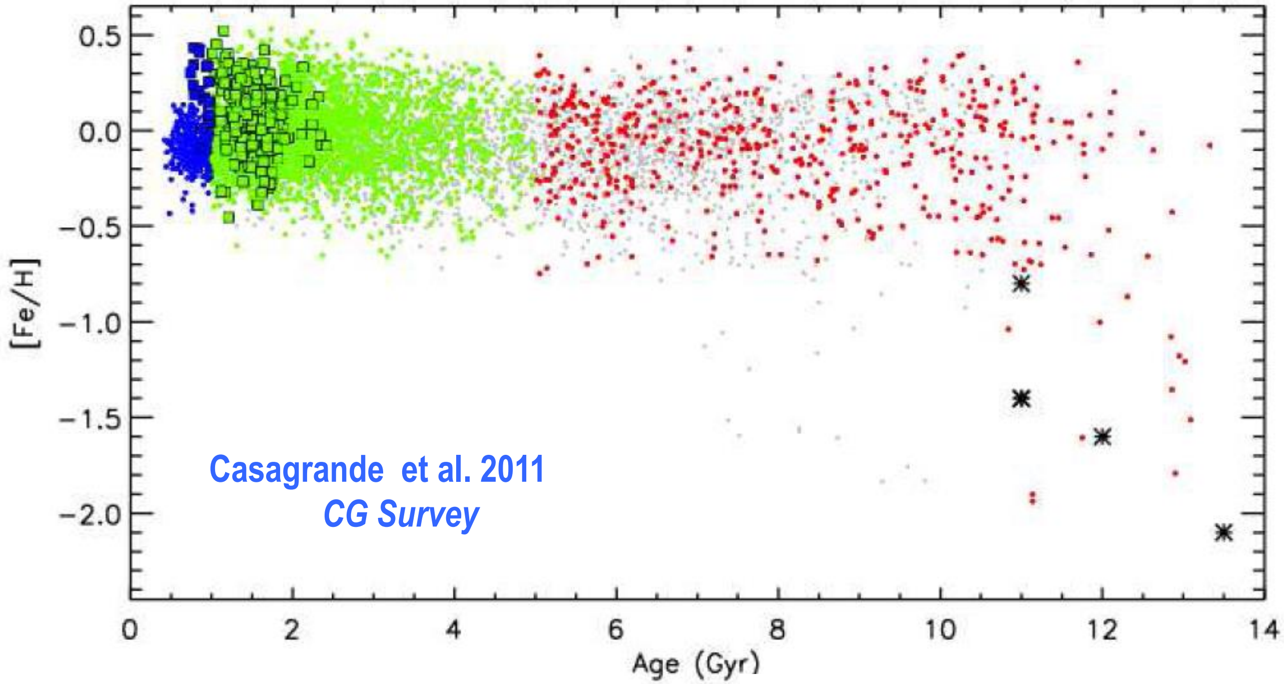
I: arXiv: 1412.0585, ***AA in press***

II: arXiv:1412.4859, ***AA in press***

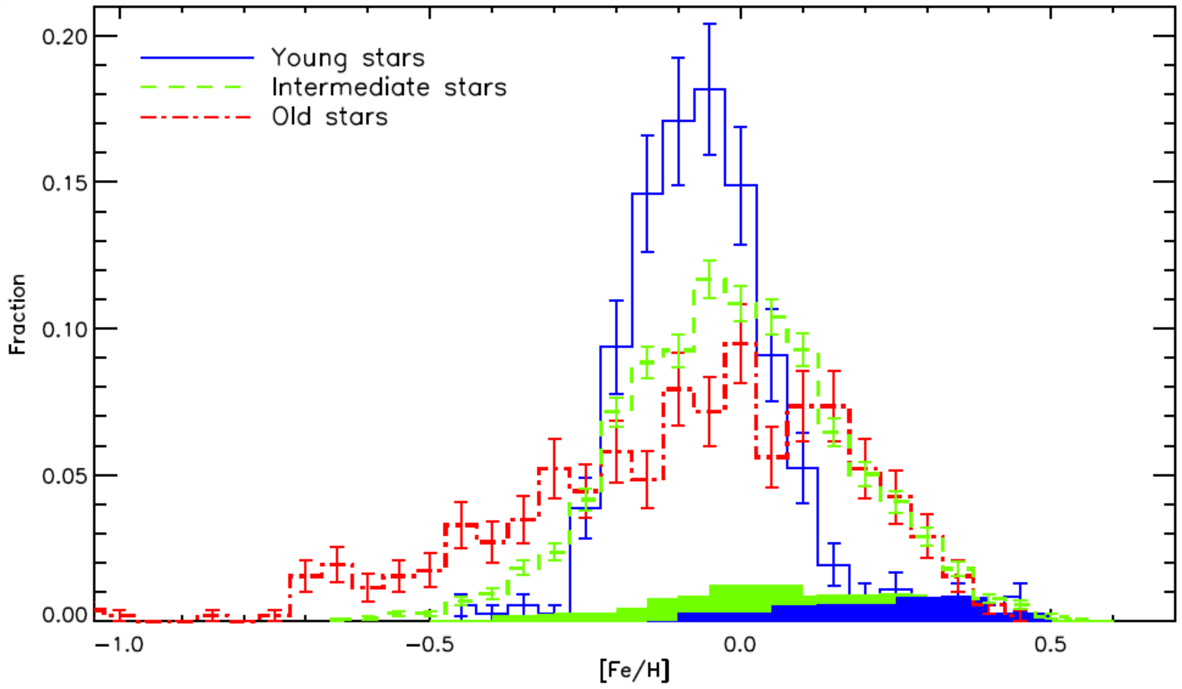
Inadequacy of the simple, independent-ring models for the solar neighborhood

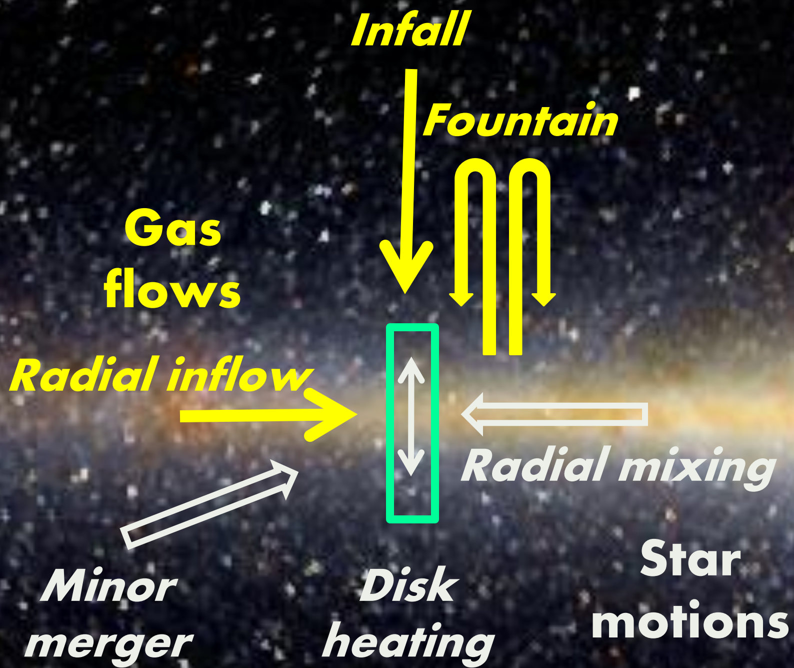


-Little metallicity evolution in the past 10 Gyr

- Large scatter in Fe/H at all ages
(*while local ISM appears well mixed, e.g. Cartledge et al. 2006*)

Old *AND* young stars of **both *high*** and ***low* metallicities**





1D semi-analytical model
with parametrized infall in a DM halo,
SFR from H2,
detailed chemical evolution (H to Ni)
with non-IRA
and observed DTD for SNIa rate

and radial motions of gas (radial inflow)
and stars (with separate treatment of
blurring : analytical
and *churning*: inspired from N-body simulation,
properly re-scaled)

Probabilistic treatment of radial migration
(Sellwood and Binney 2002)

a star born at radius r' at time t' may be found at time t (i.e. after time $\tau = t - t'$) in radius r with a probability $P(r, r', \tau)$

$$P(r, r', \tau) = (2\pi\sigma_\tau^2)^{-1/2} \exp\left[-\frac{(r - r')^2}{2\sigma_\tau^2}\right]$$

$$\sigma_{\tau,r} = (\sigma_b^2 + \sigma_c^2)^{1/2}$$

Blurring (epicycles) $$\langle\sigma_b^2\rangle = \frac{\langle\sigma_v(r)^2\rangle}{\kappa_r^2}$$

Epicyclic frequency $$\kappa_r = \sqrt{2}\,\frac{V_C(r)}{r}$$

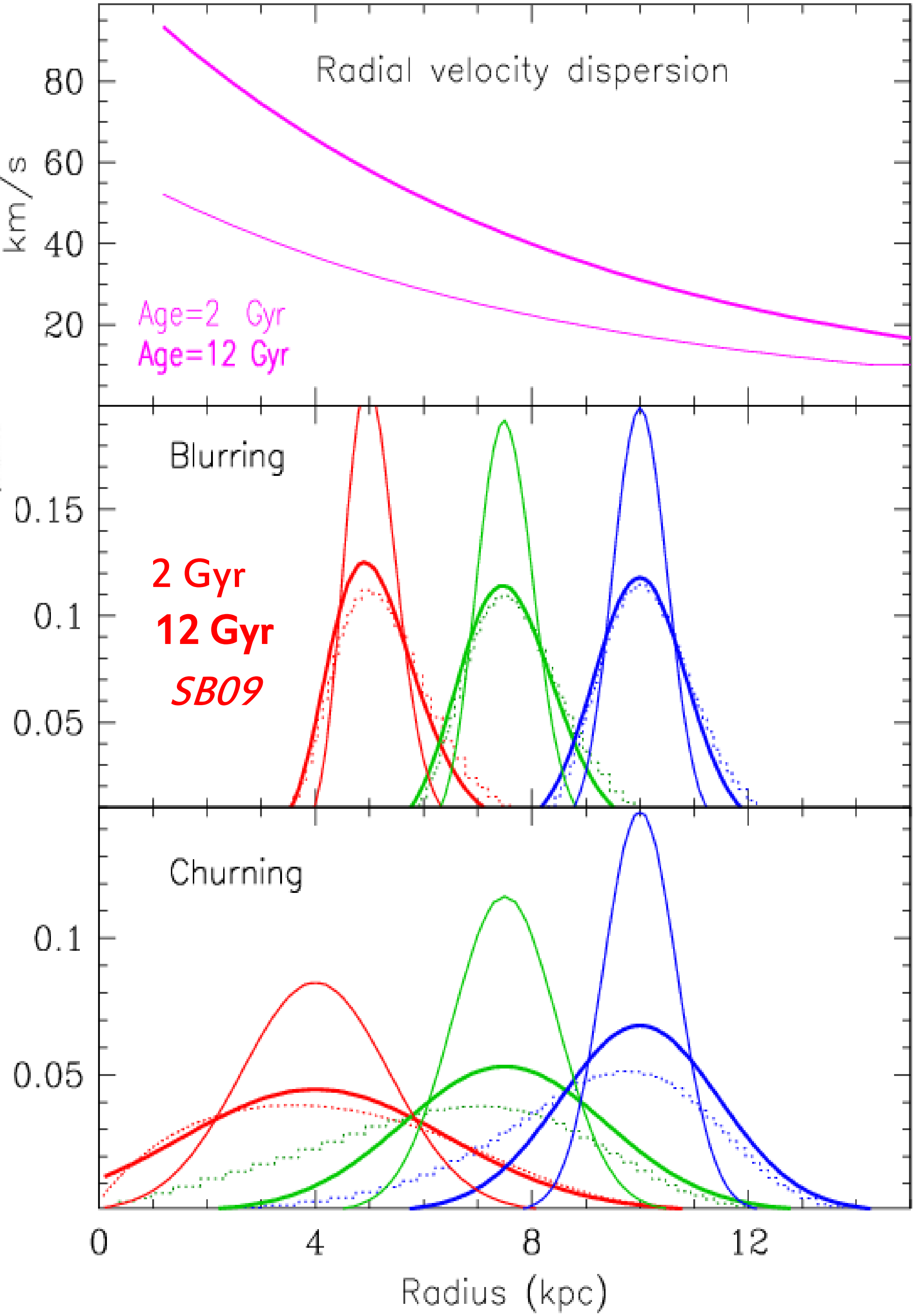
Radial velocity dispersion

$$\sigma_v(r, T) = 40\, e^{-(r - R_\odot)/8\ \mathrm{kpc}}\ \mathrm{km/s}$$

Churning (radial migration)

$$\sigma_C = \alpha(r)\tau^N + \beta(r)$$

Coefficients α(r,t) and β (r,t) extracted from the numerical simulation of KPA2013 ***after re-scaling*** : *at t=2.5 Gyr bar of N_body similar in size to the one of the Milky Way today*

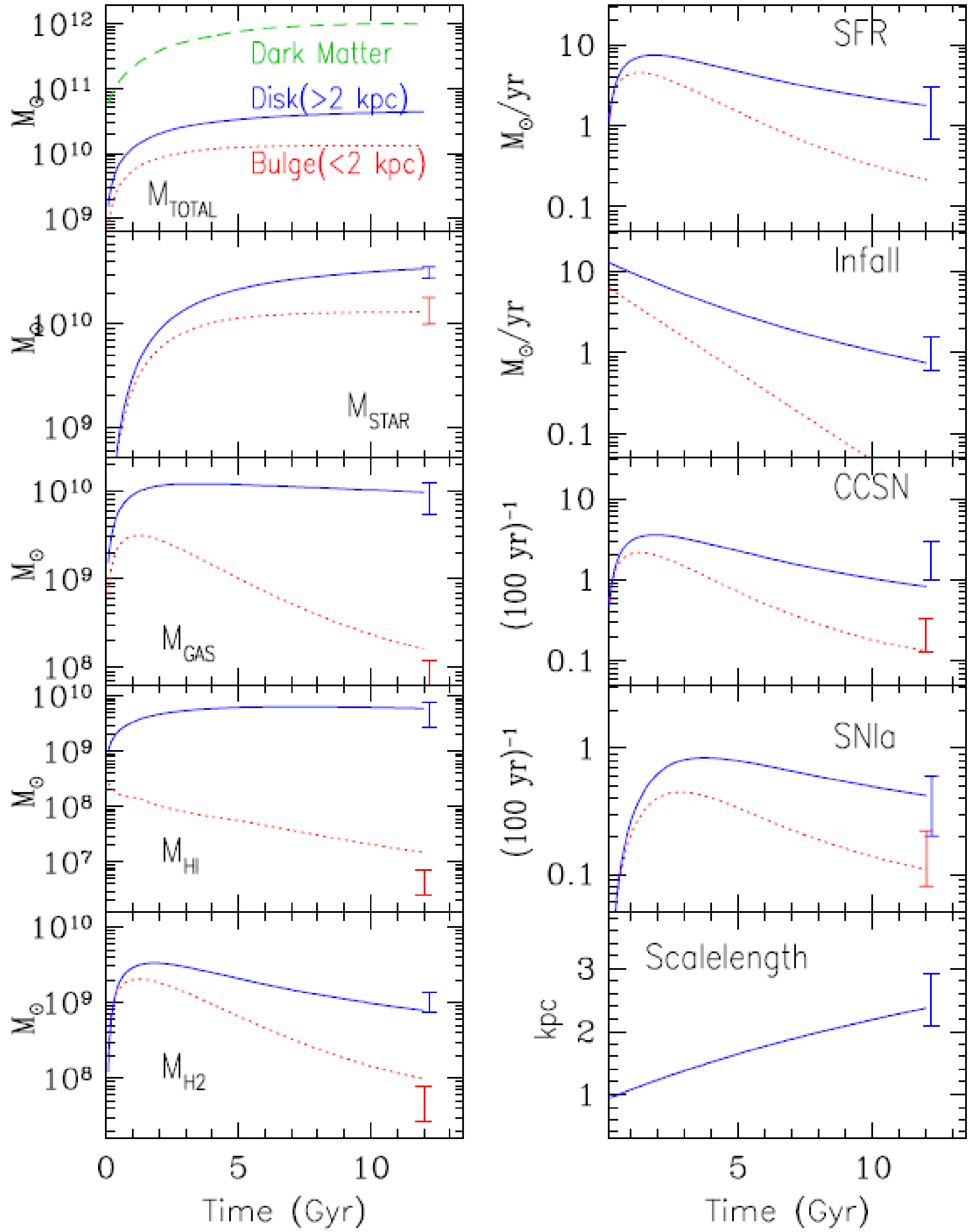


Evolution of global quantities for Milky Way

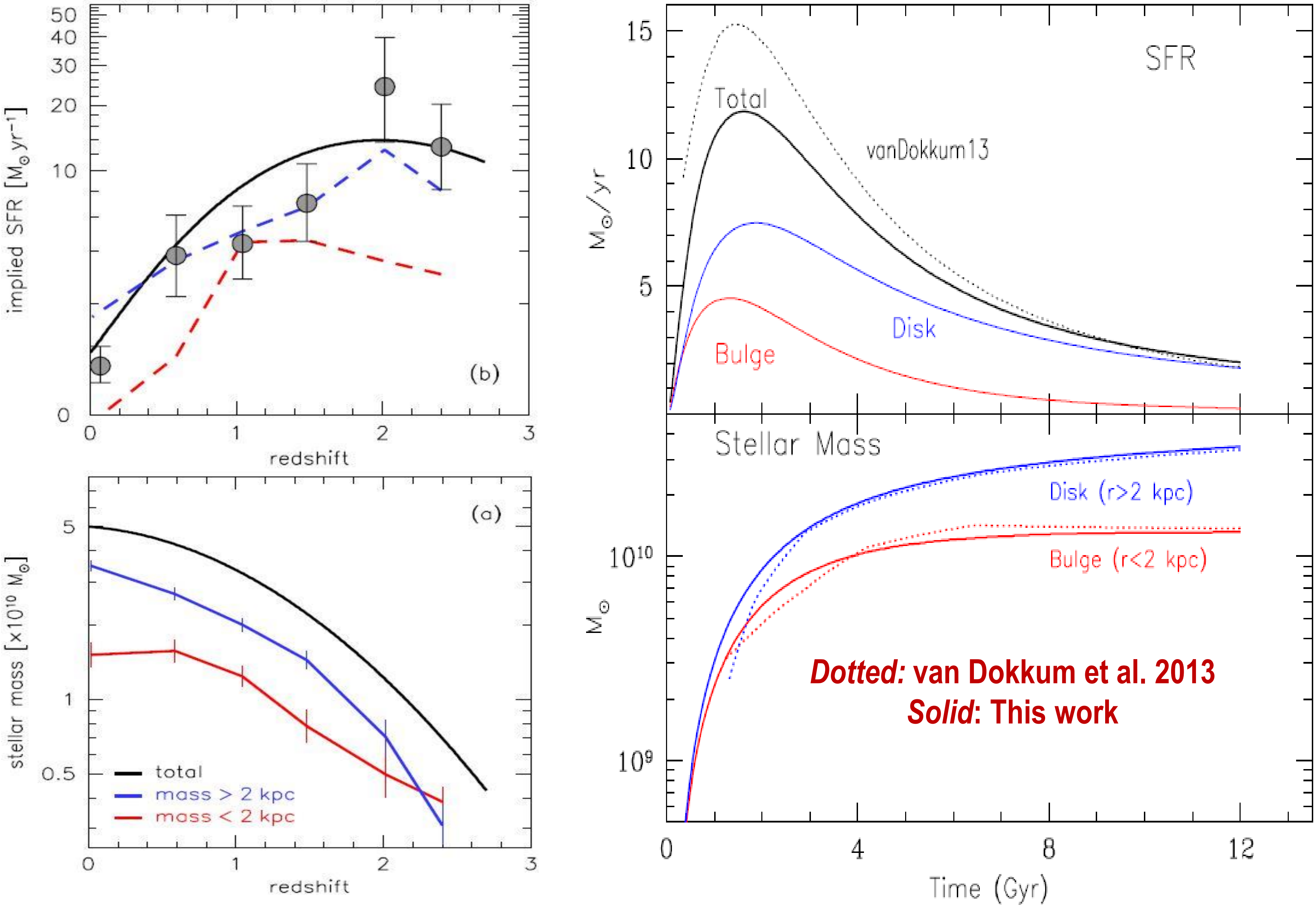
Bulge (<2 kpc)

and

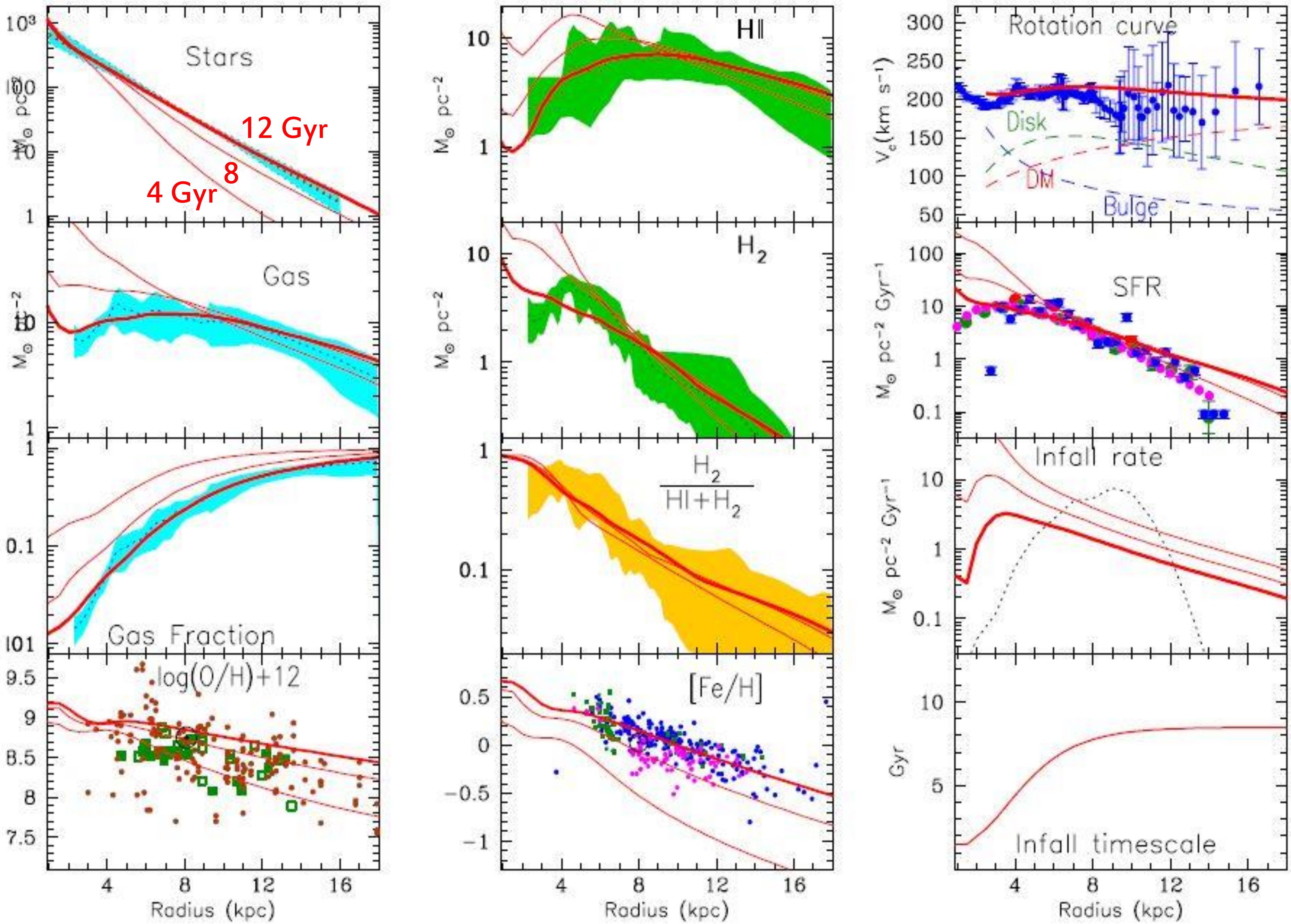
Disk (>2 kpc)

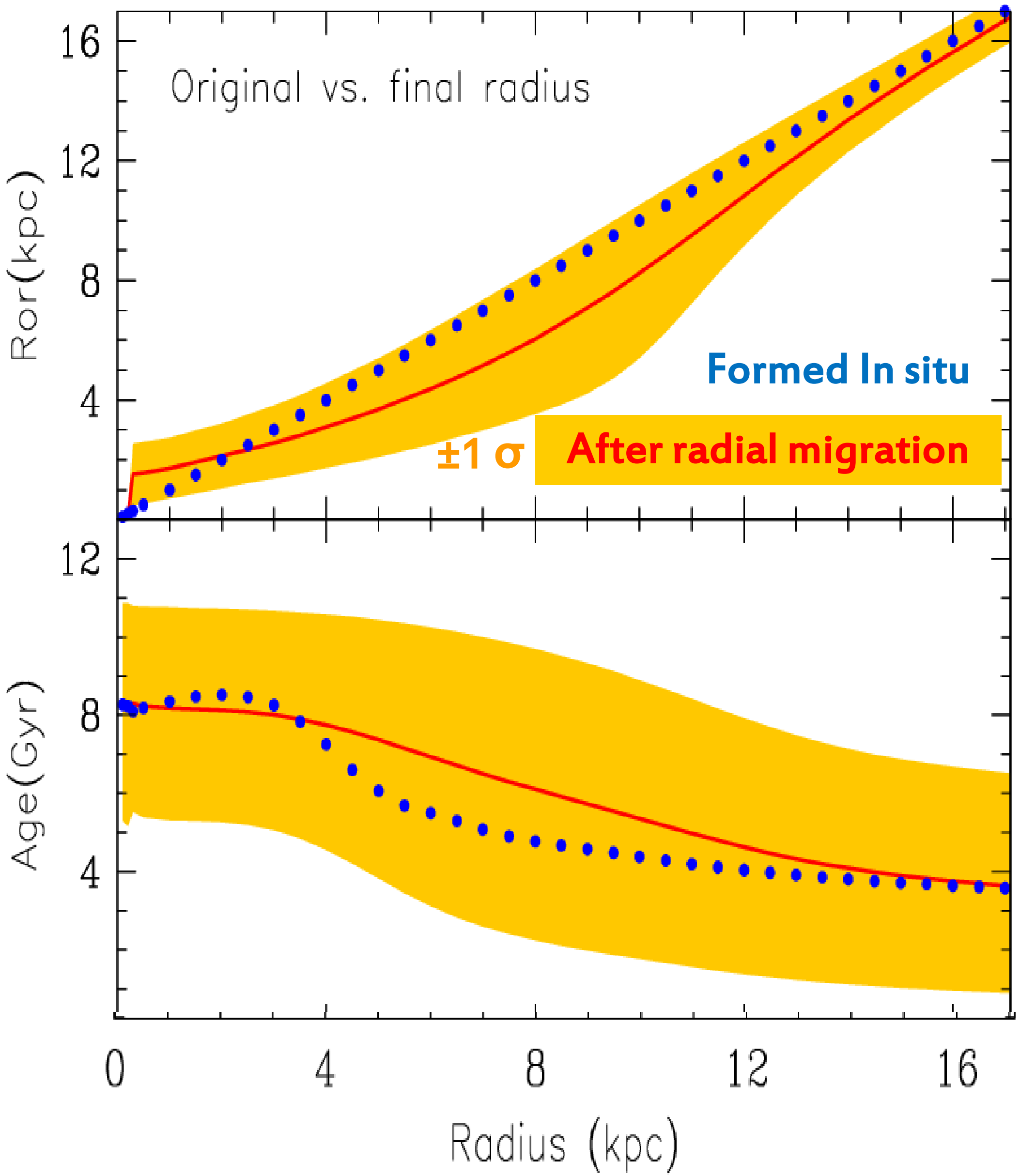


Comparison to observed average (« stacked ») evolution of MW-mass disks
van Dokkum et al. (2013) with 3D-HST and CANDELS data up to z~2.5



Comparison to present-day profiles of MW disk

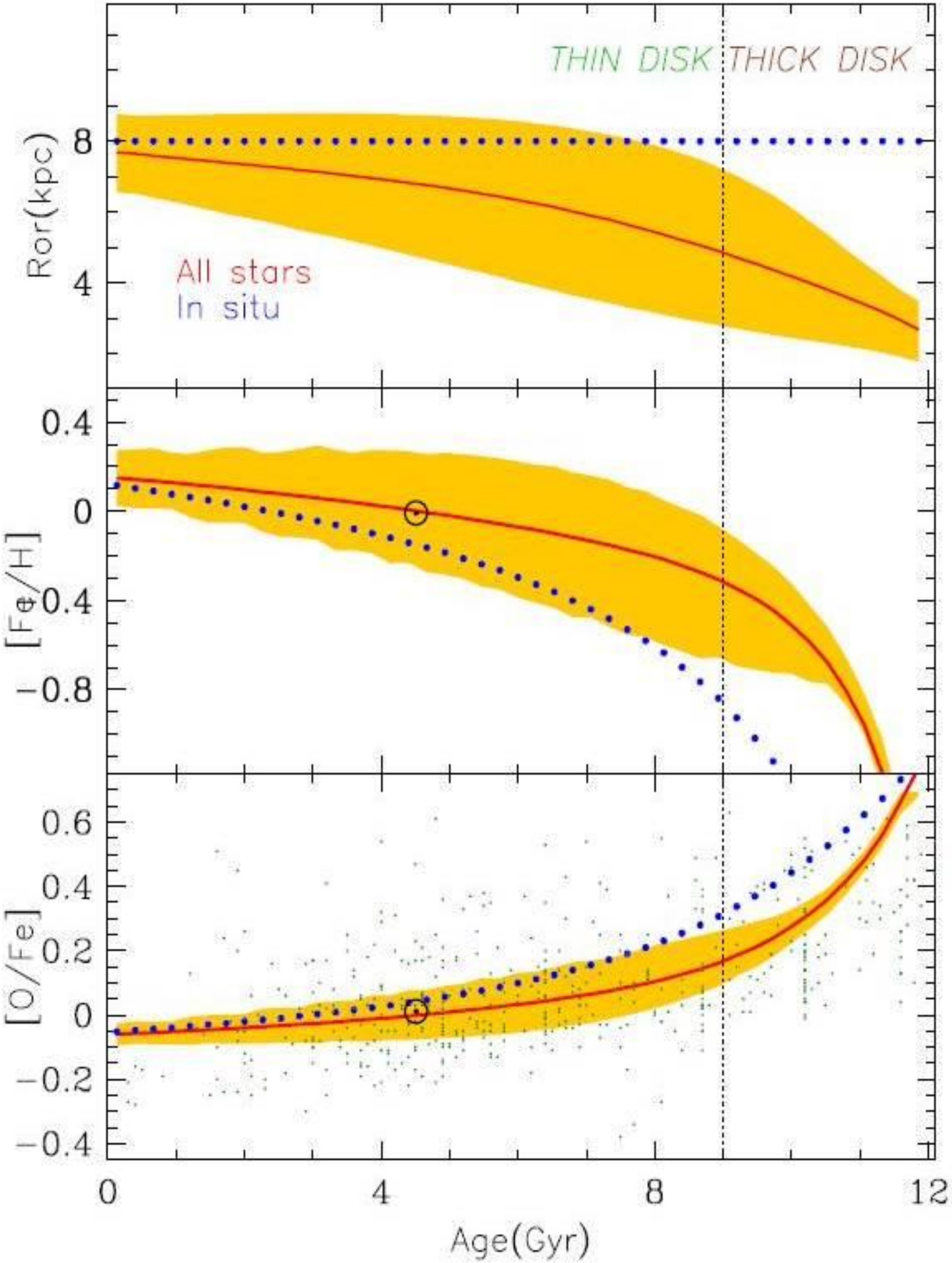




Radial migration affects a large fraction of the disk, up to 12 kpc

In the solar neighborhood it brings stars mostly from inner regions, (on average, *from 1.5 kpc inwards*)

and mostly older than the locally formed ones *(by 1.5 Gyr)*

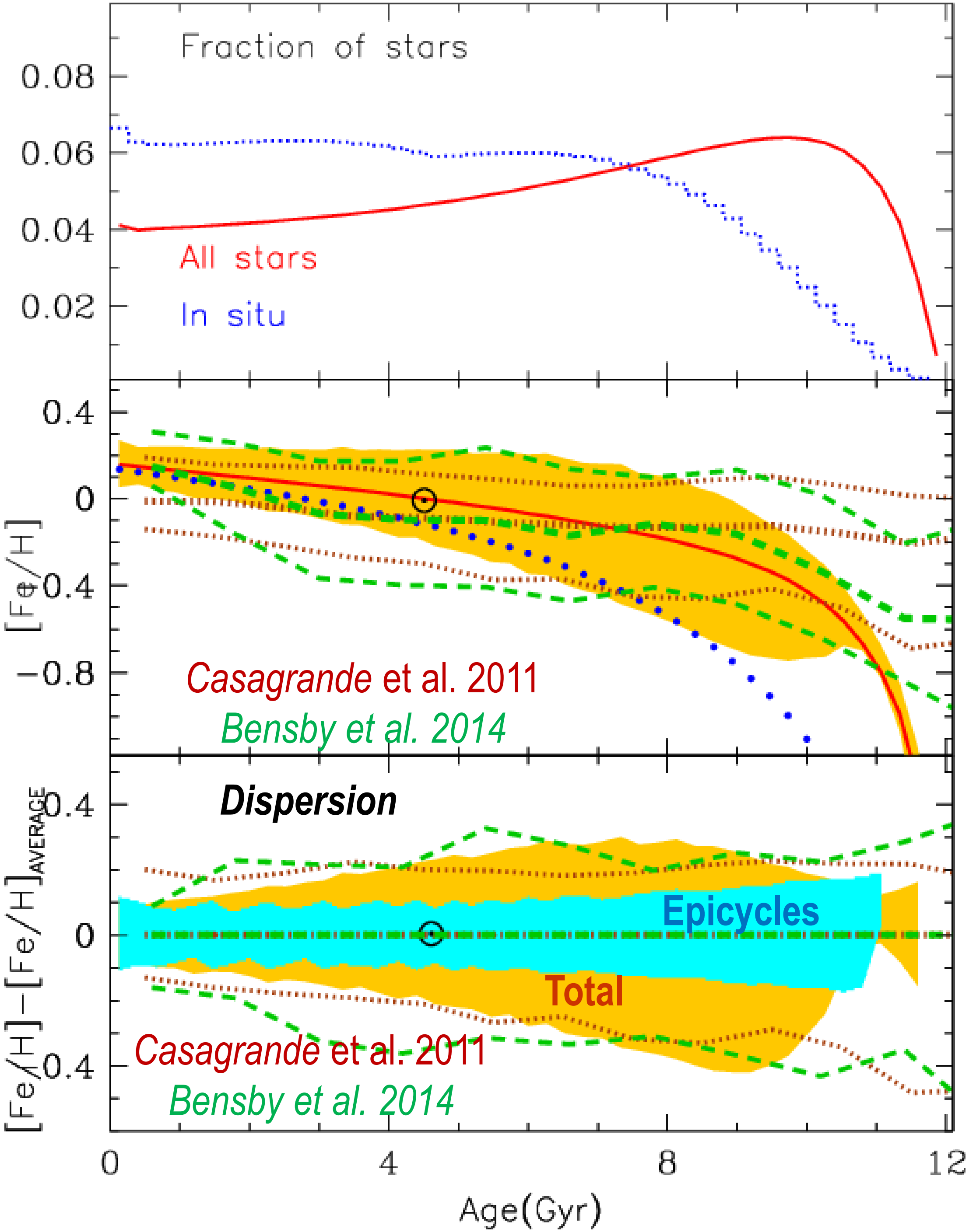


Solar neighborhood

1. Older stars come from inner regions

2. The local age-metallicity relation flattens ; dispersion in Fe/H increases with age except for the oldest stars (thick disk)

3. Very little dispersion in O/Fe (best « chronometer » ?



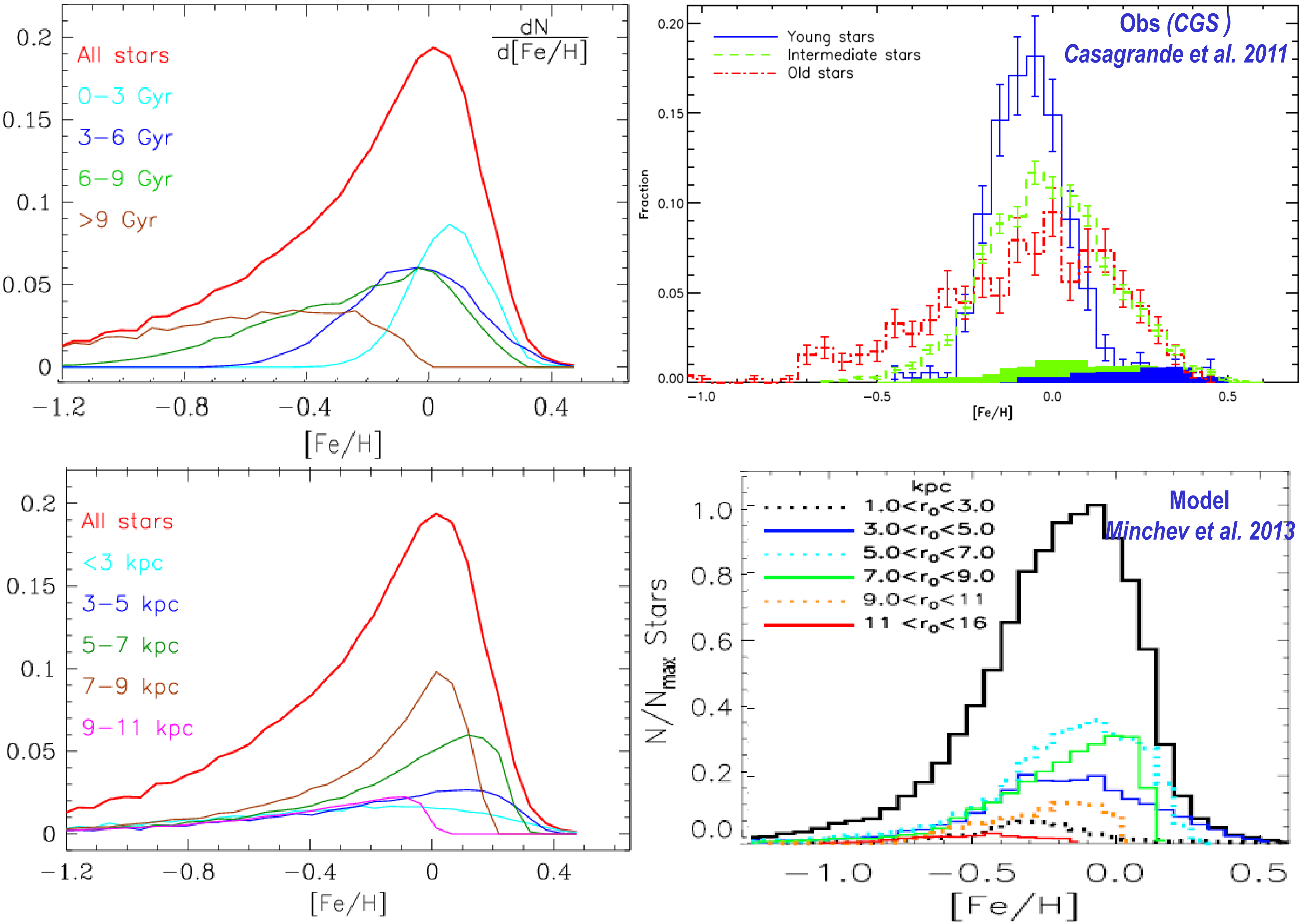
Solar Neighborhood
Radial Migration

1. Modifies the apparent local SFR *(Röskar et al. 2008)*

2. Creates dispersion in the age-metallicity relation… *(Sellwood and Binney 2002)*

3. …more than the epicyclic motion, as required by observations

Solar Neighborhood : stars with different ages and from different regions *at all metallicities*

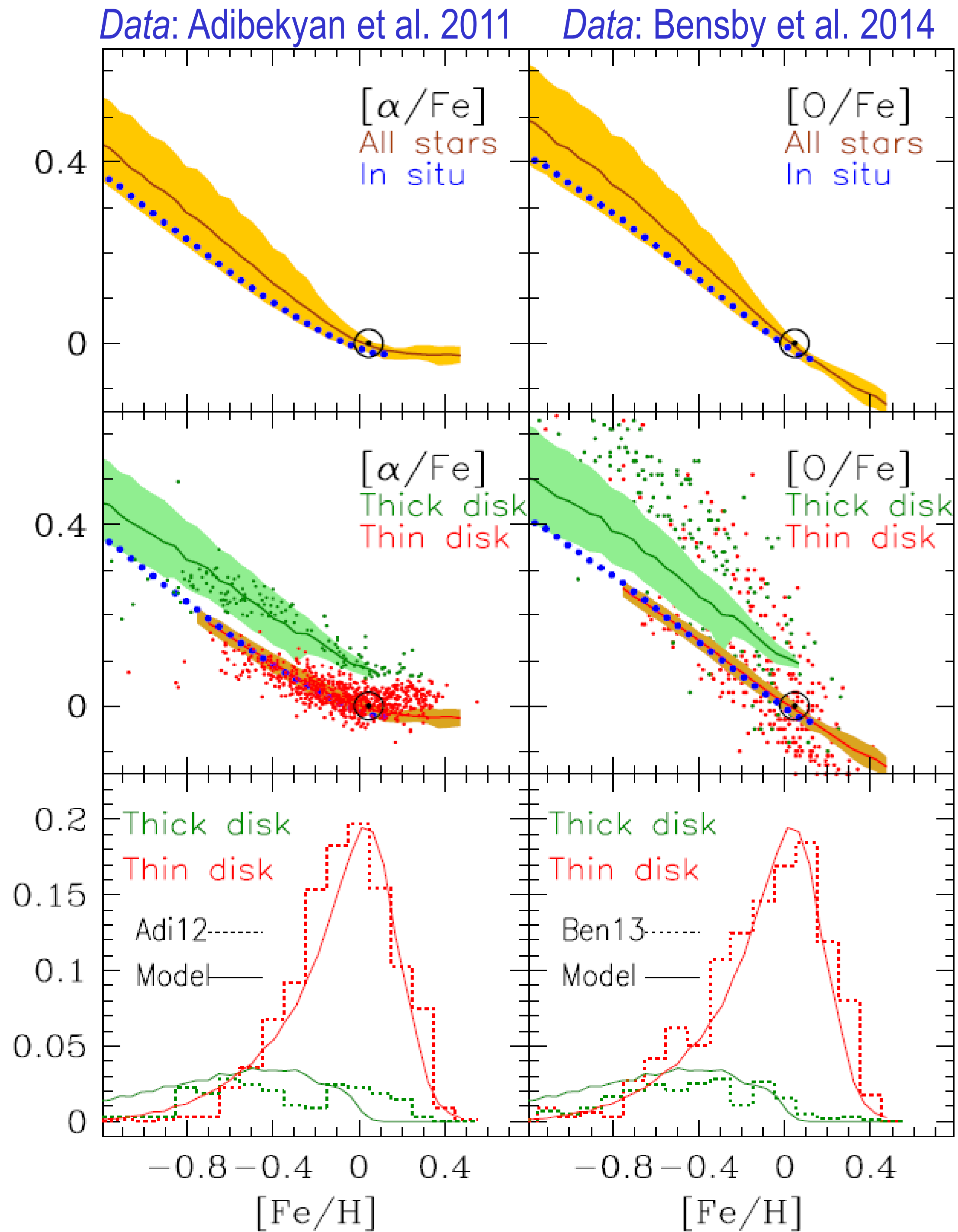


Assuming that
the thick disk is
the old disk (>9 Gyr)

we recover the
[a/Fe] vs Fe/H behaviour

and the
metallicity distributions
of both
the thick and thin disks

(Schoenrich and Binney 2009)

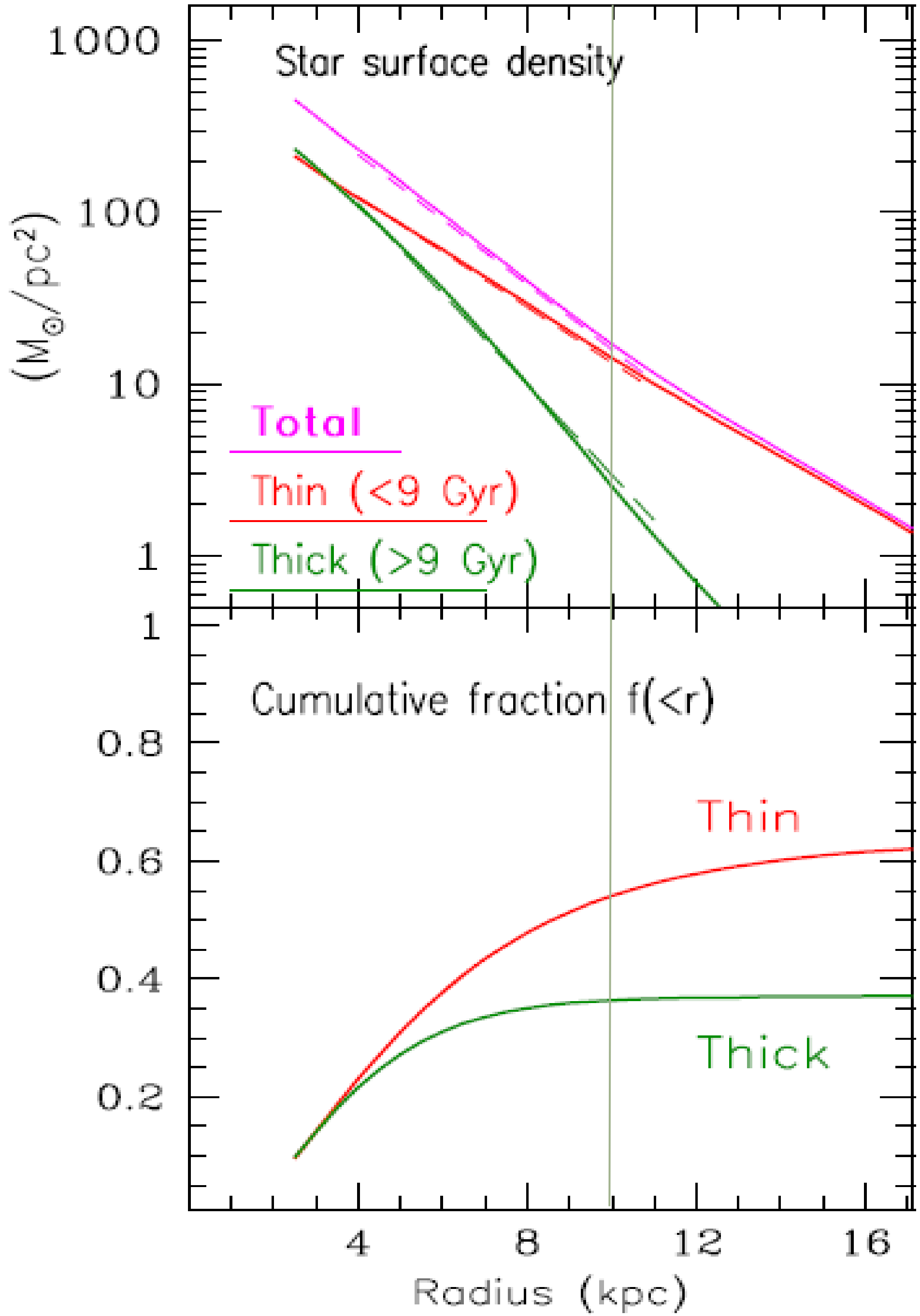


Assuming that
the thick disk is
the old disk (>9 Gyr)

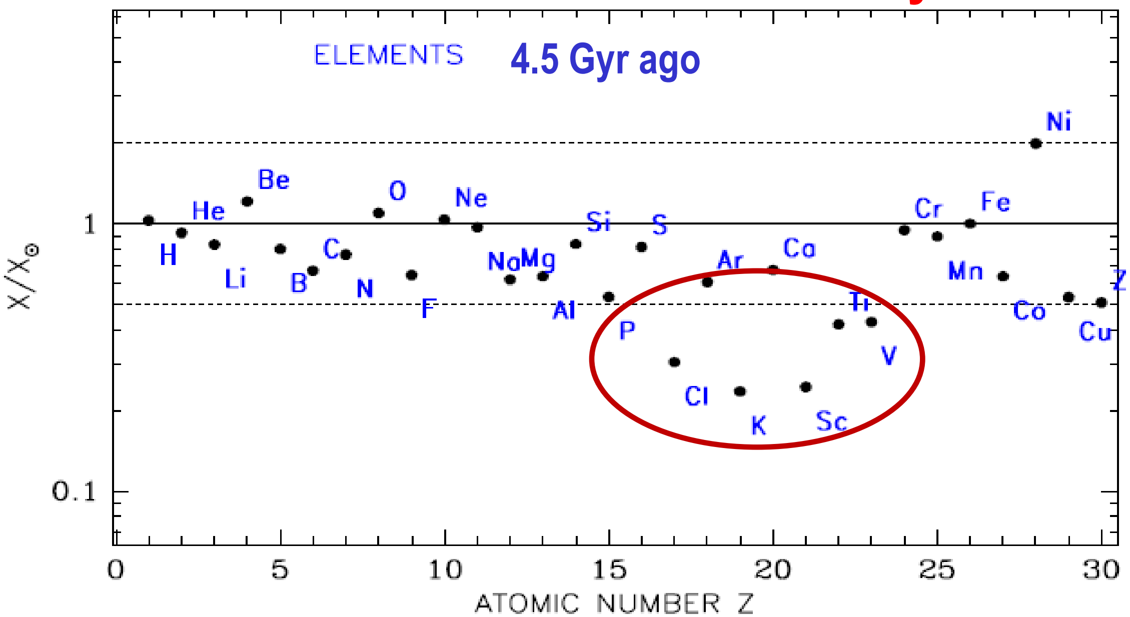
we also reproduce
the local surface densities
of both disks

and the short scalelength
of the thick disk (~2 kpc)

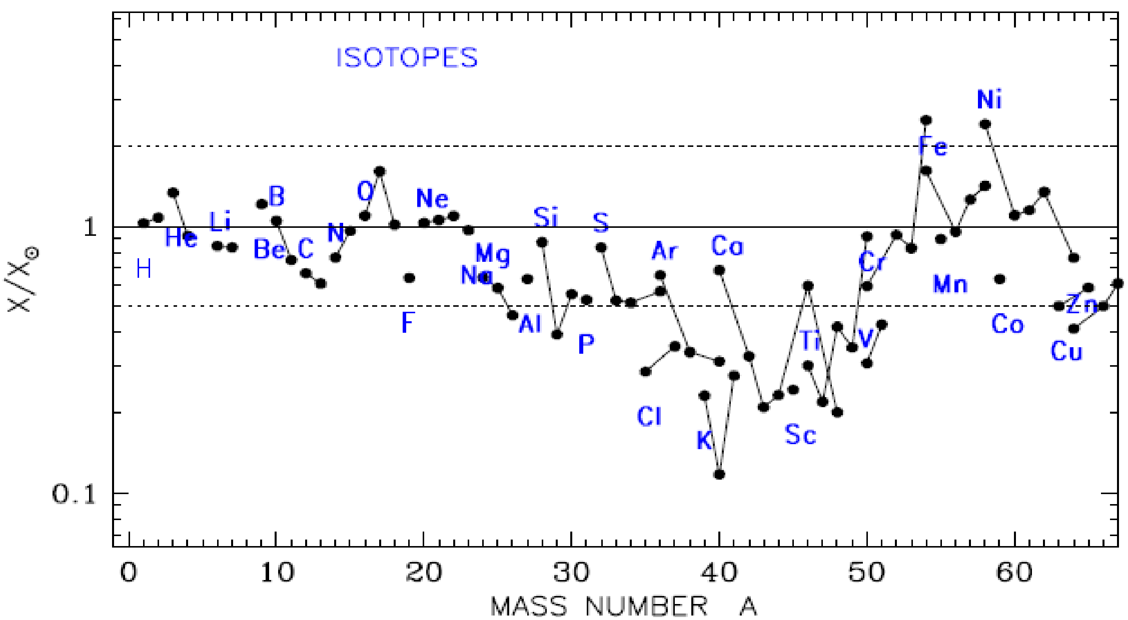
which accounts for ~1/3
of the total disk mass



Nucleosynthesis

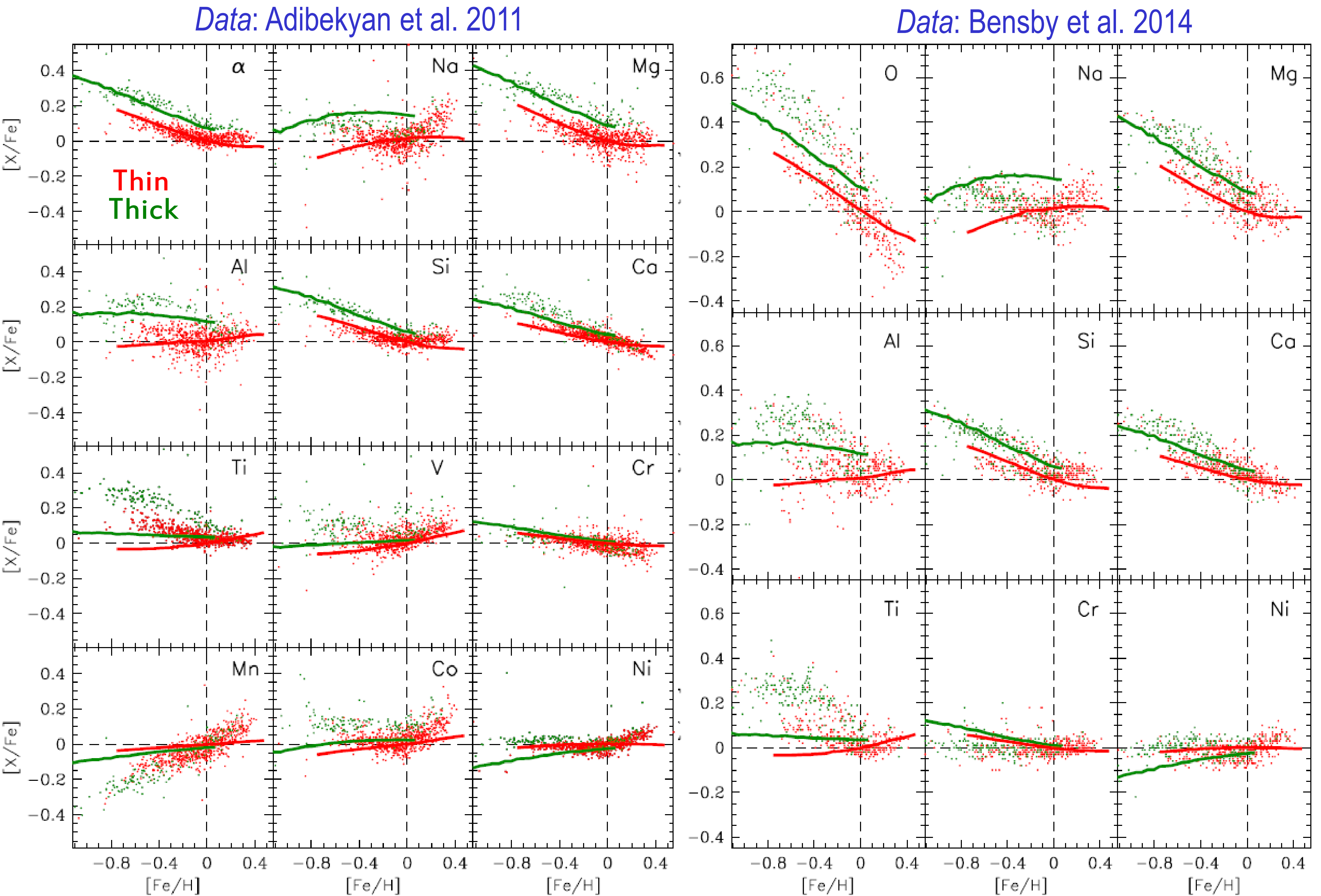


Stellar yields are still affected from uncertainties to various degrees

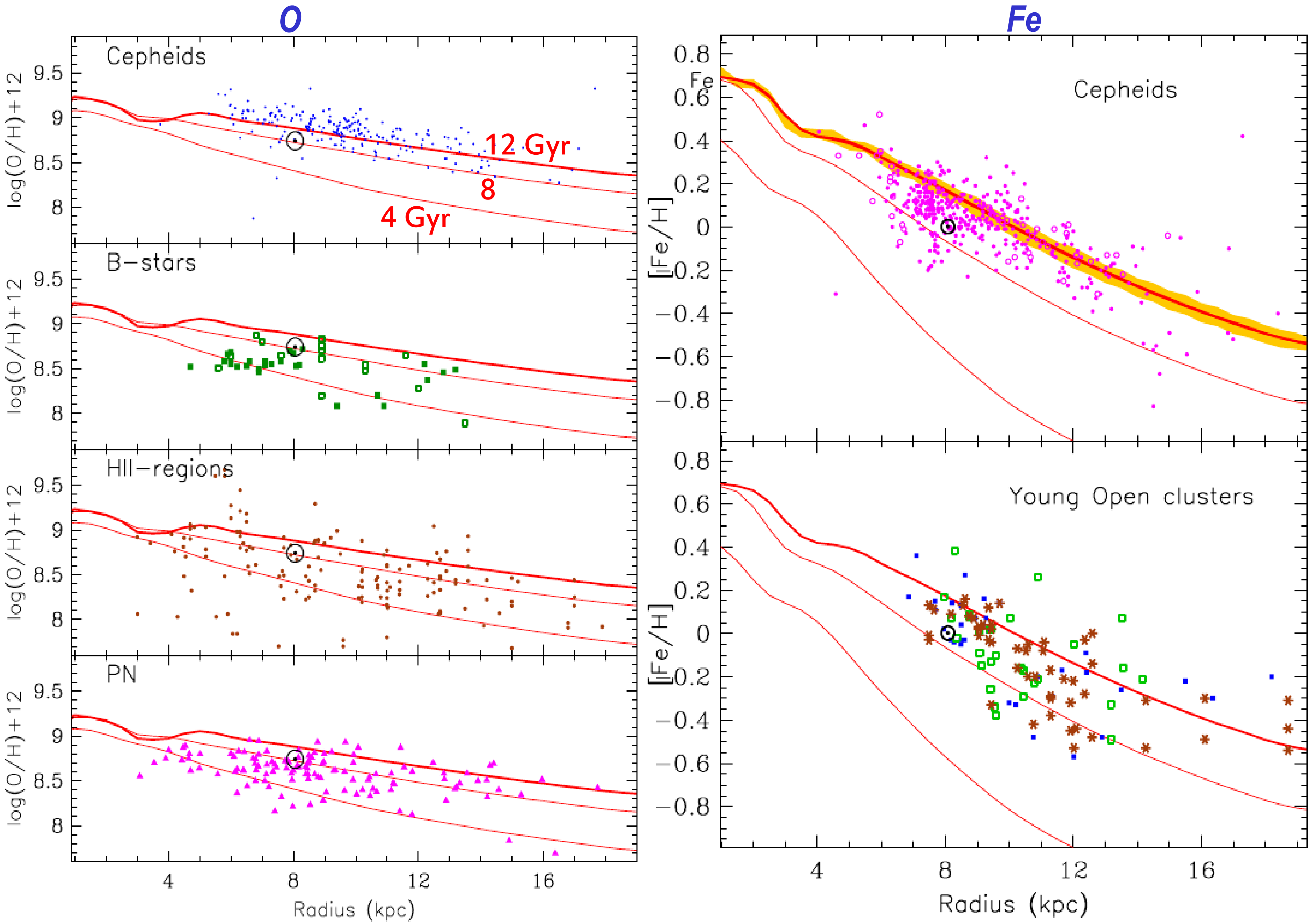


The yields of Nomoto et al. (2013) have some problems in the region P to V

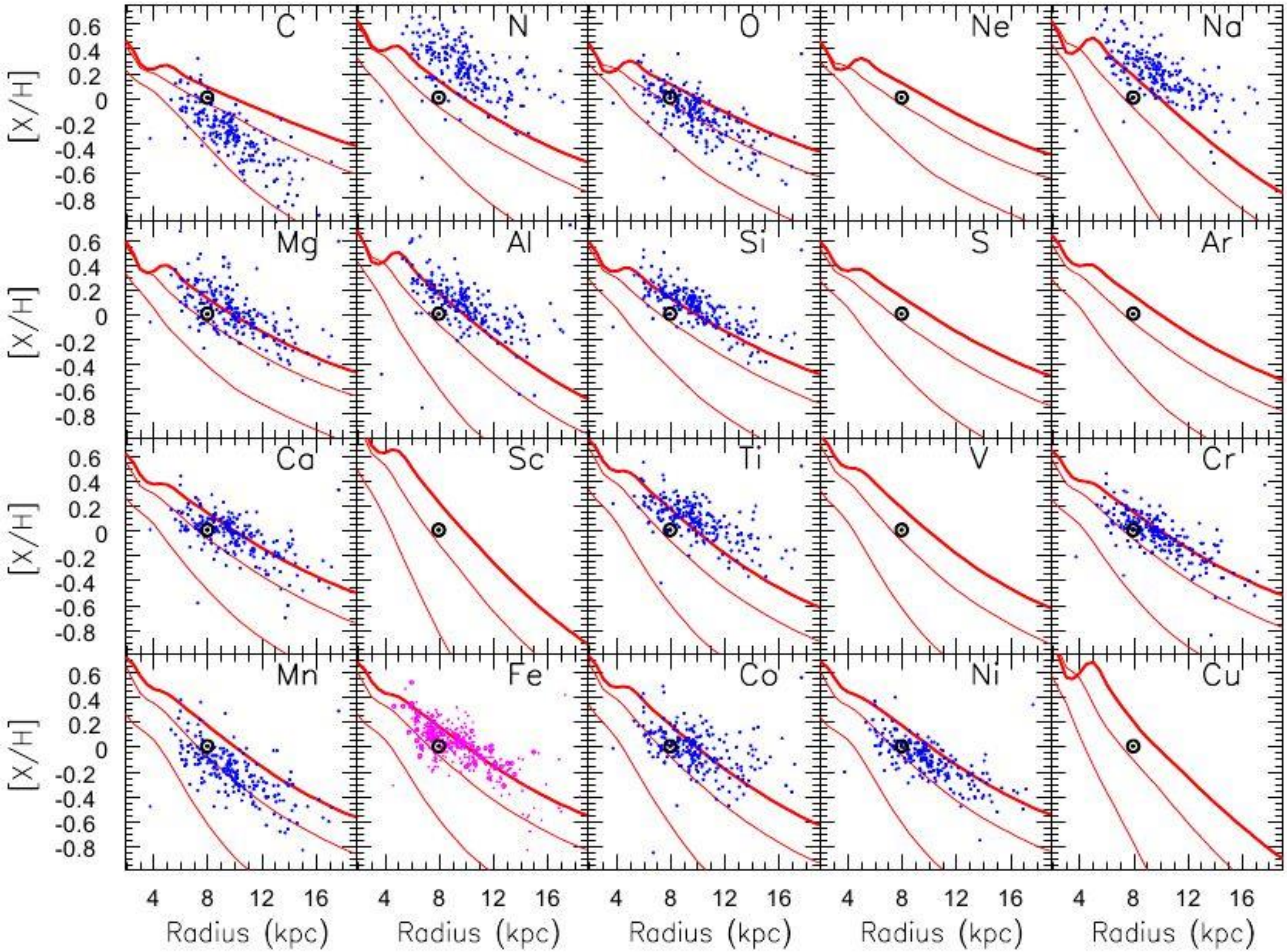
Evolution of thin (<9 Gyr) and thick (>9 Gyr) disks with yields NORMALISED to solar for AVERAGE LOCAL (8 kpc) STAR 4.5 Gyr old

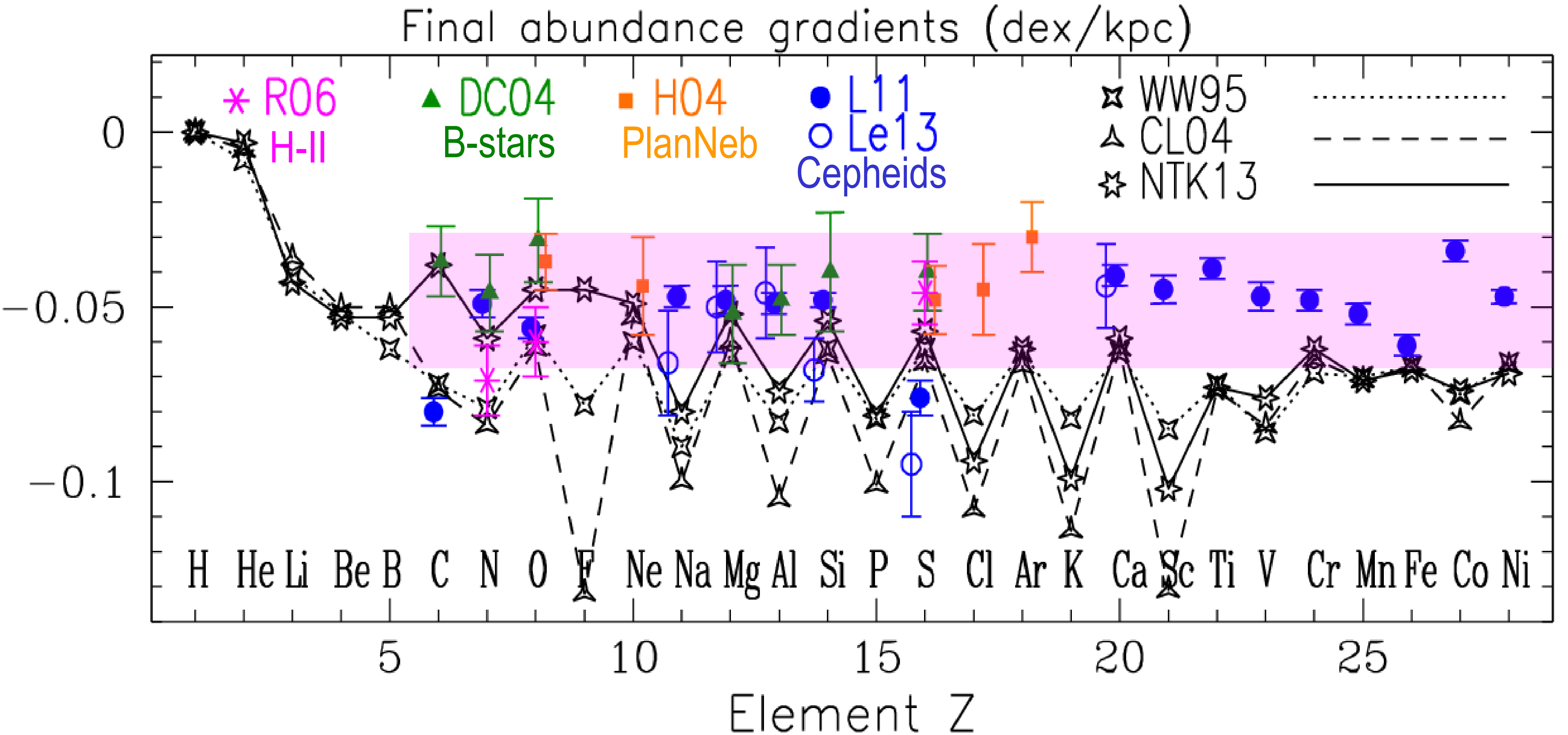


Abundance profiles



Abundance profiles in Cepheids





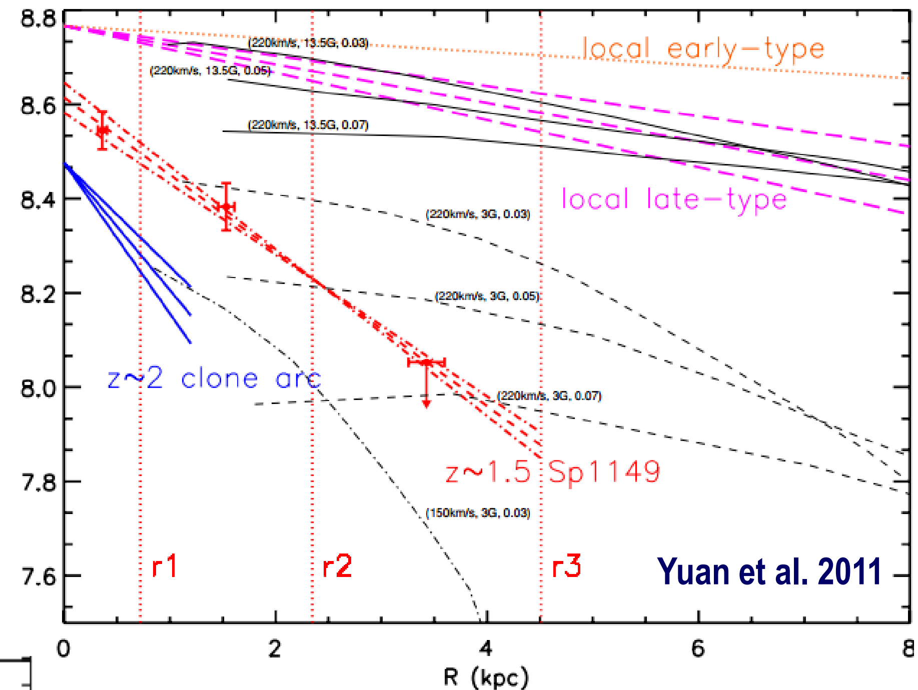
Observed gradients in the range ~ -0.05 ± 0.02 dex/kpc

Models ~OK for even Z elements up to Ca…

Nucleosynthesis predicts an odd-even effect on gradients; *NOT SEEN…*

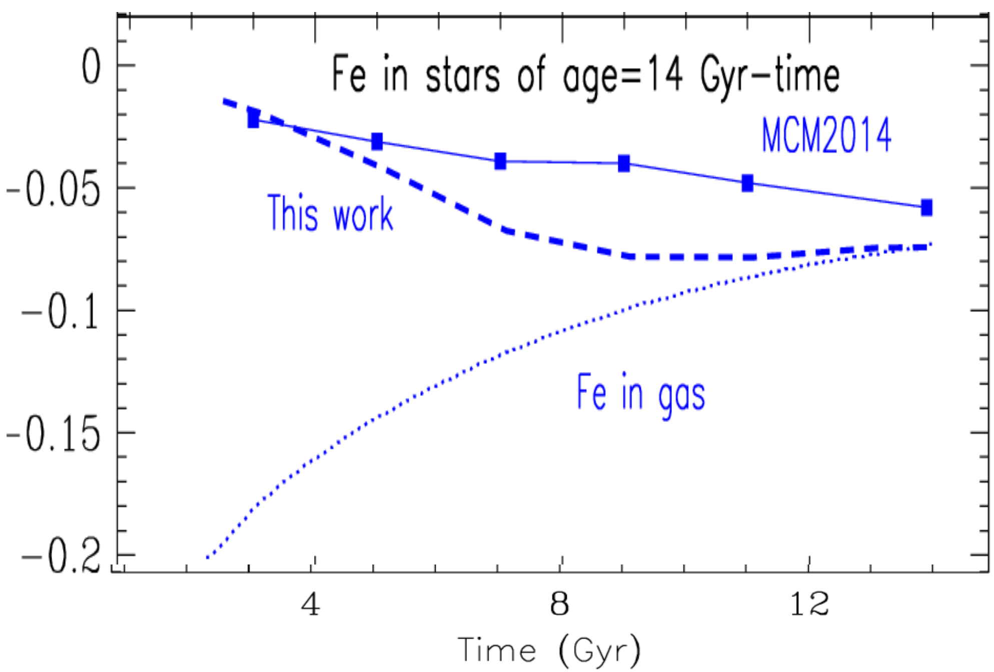
Some problem with gradients in the Fe-peak *(except Fe itself)* :
is SNIa rate = f(t,R) and/or SNIa yields correctly evaluated ?

Evolution of abundance gradients



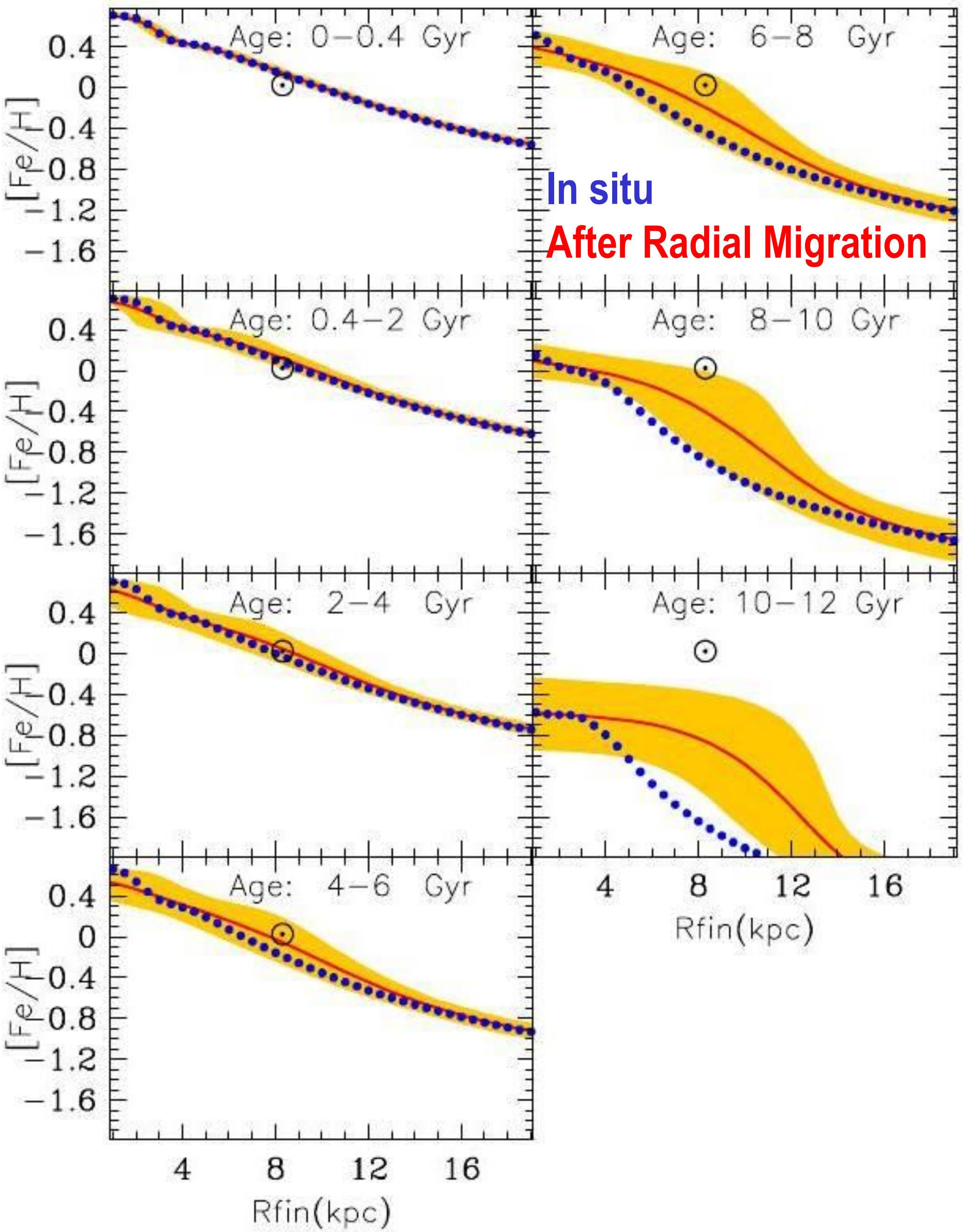
Inside-out disk formation predicts flattening of abundance profiles with time:

profiles *in the gas* were steeper in the past as suggested by observations of high redshift lensed disks



However, radial migration flattens the past stellar abundance profiles
(Roskar et al. 2008)
Bringing stars form the inner disk (more metal rich than their local counterparts) to outer regions

We expect then to observe flatter profiles in older populations



Radial migration flattens the past stellar profiles
(Roskar et al. 2008)

⇒ Flat metallicity profile of thick disk, which extends up to 10-12 kpc

The thick disk was NOT formed with a flat abundance profile but it has one now, due to radial migration

Potential impact of star migration on chemical observables of the disk

LOCALLY:

- **Increases dispersion in age-metallicity relation (*more than epicycles)***
  - Metal-poor and metal-rich stars of all ages
- **Brings the most metall-rich stars (>2 Z☉) from inner disk**
- **- Creates a « two-branch » behaviour of O/Fe vs Fe/H for thin/thick disk**

GALAXYWIDE:

- **Flattens past abundance profiles of X/H**
- **Modifies profiles of X/Y with X and Y produced by different sources:**
  short-lived (0xygen) vs long-lived (Fe or s-elements)
- ***May* produce a *thick disk* (*Schoenrich -Binney 2009, Loebman et al. 2010, Minchev et al. 2013*)**

BUT these observables are ALSO affected to various extents by other factors
e.g. *infall* [dm/dt(R,t) and Z(R,t)], radial gas flows, *galactic fountains/outflows, mergers*…

It will not be easy to disentangle those effects…