# Lecture IV

# Thick disk

## Old and dominated by SNII nucleosynthesis
## …but non negligible SNIa contribution

Thick disk formed fast as it is composed of old (>9-10? Gap with thin disk?) stars which have metallicities [Fe/H] between -1.0 and -0.2(+0.3?) with a peak around -0.5 dex

In the local volume sampled by observations, thick disk stars make 2-15% of the stars…. But could be more…

# Uncertainties + lack of information lead to different views for the formation of the thick disk of the MW

- Existing thin disk heating due to accretion of small satellites (e.g. Villalobos & Helmi 2008)

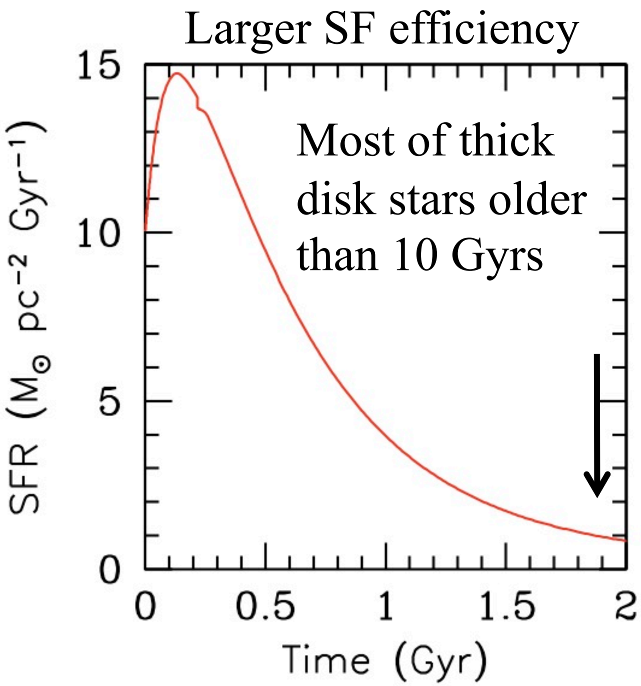
- Accreted thick disk – formed by mergers of early building blocks (e.g. Abadi et al. 2003)

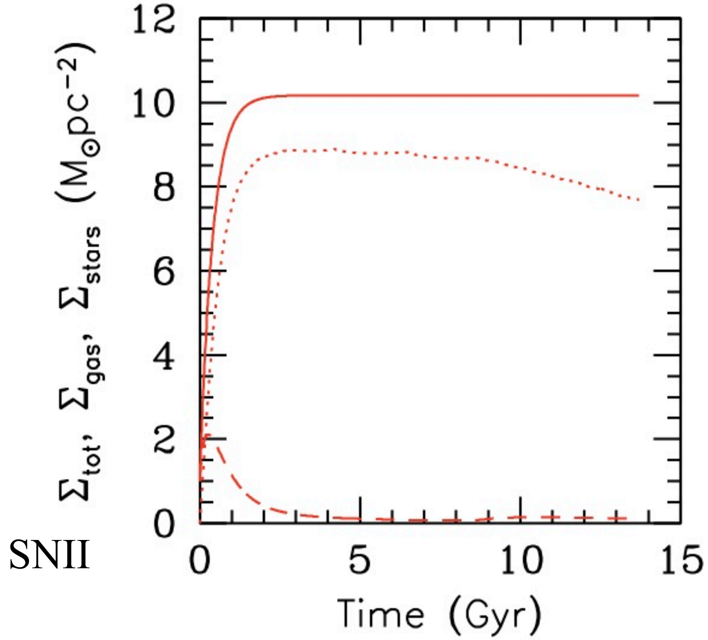
- Fast gas accretion in early Universe/turbulent SFR/ in situ formation (e.g. Bournaud et al. 2009) – in the lines of what chemical evolution models indicate!

- Secular thin disk evolution can mimic a thick disk via radial migration (Shoenrich & Binney 2009)

# Thick Disk

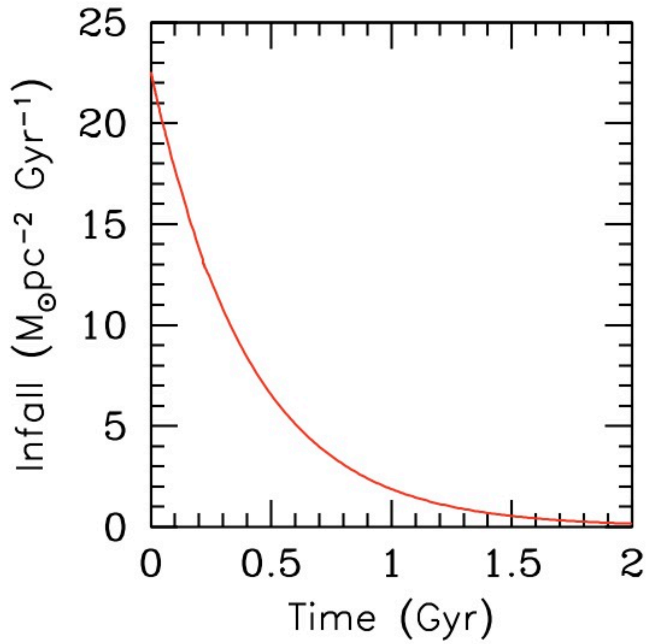
$f$ = A exp(-t/τ)
τ < 0.4 Gyr



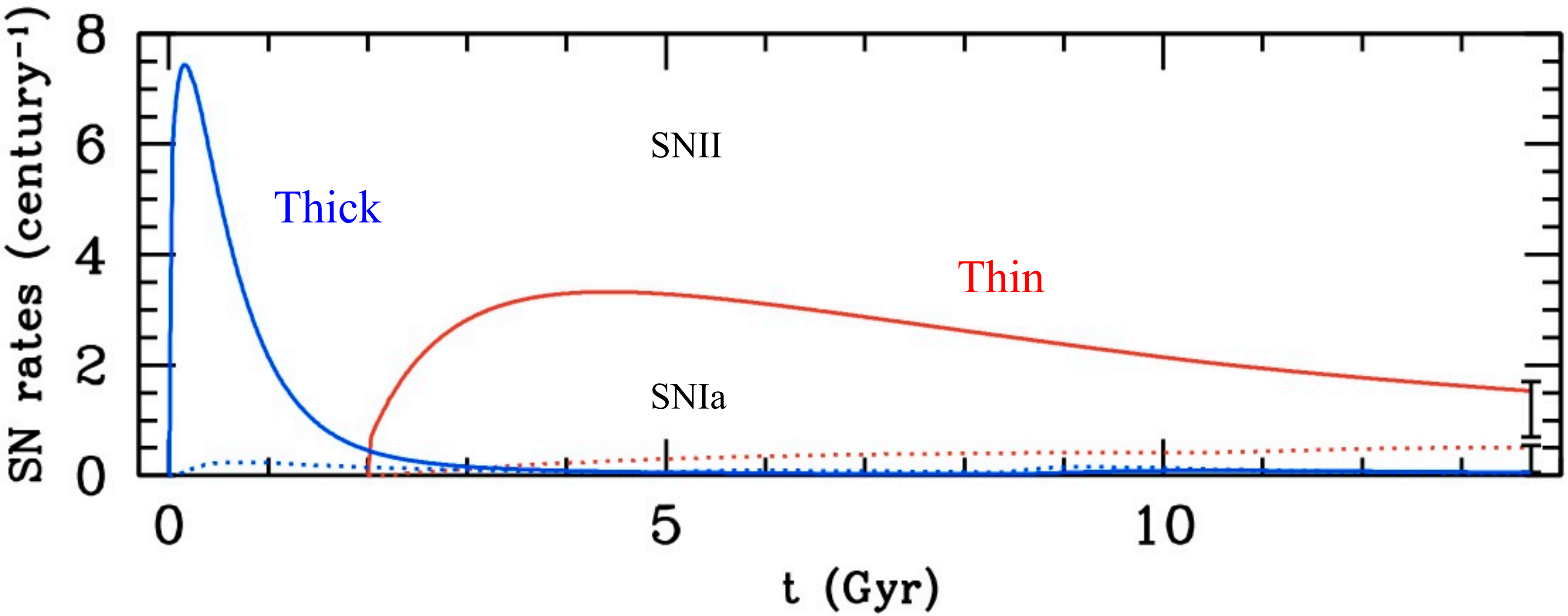




Metallicity Distribution still uncertain!

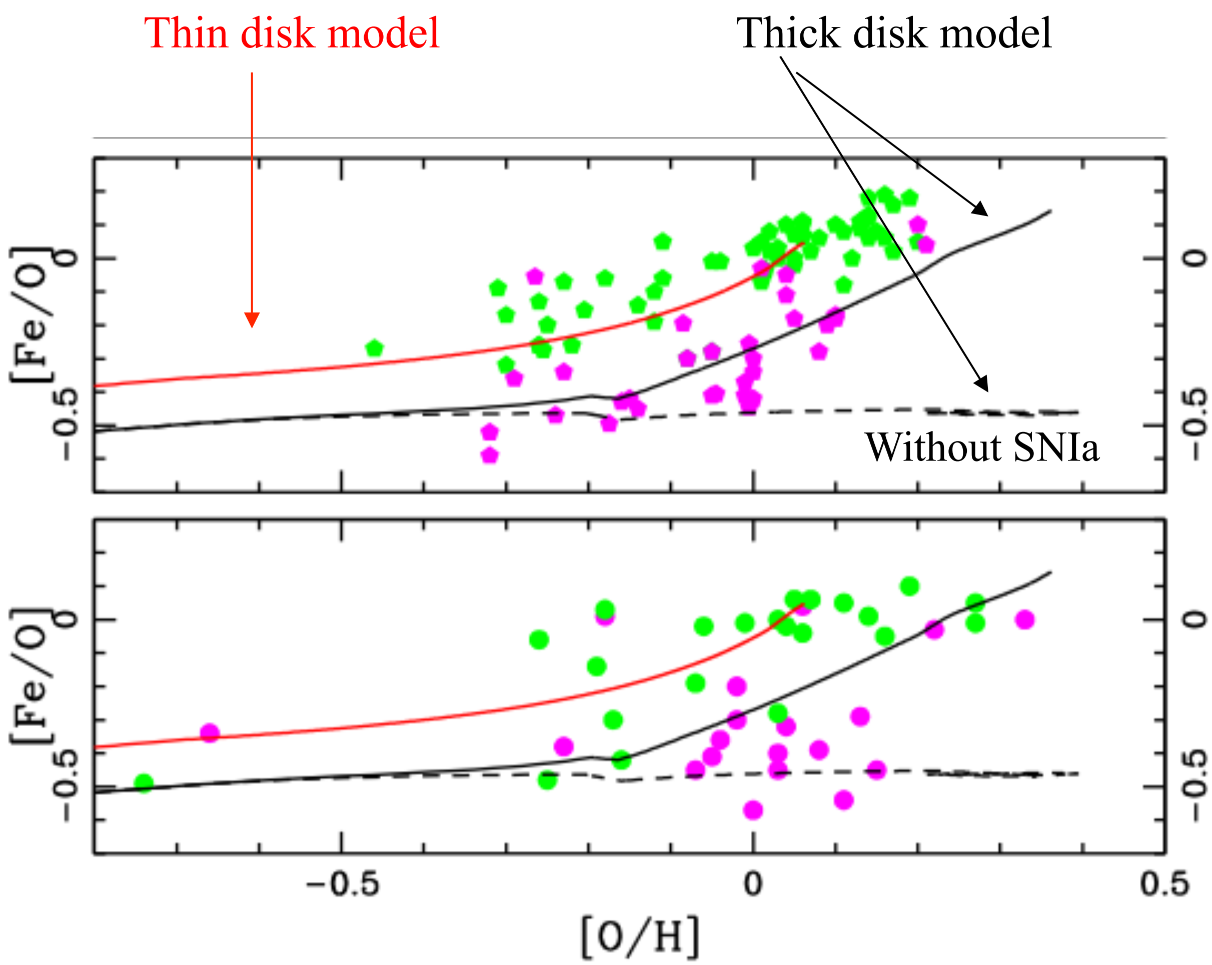
Hope for improvement with SEGUE/APOGEE



# Predicted SN rates



Green dots: Thin disk data
Magenta dots: Thick disk data




True thick disk stars: up to which metallicity?

# Summary Thick

- **If thick disk extends up to [Fe/H] solar**: There is a trend of the abundance ratios with metallicity (with small scatter) => Well explained by a CE model where the thick disk formed from gas accretion, on short timescales with larger SFE than in the thin disk, with some contribution from SNIa. This component could have pre-enriched the thin disk.

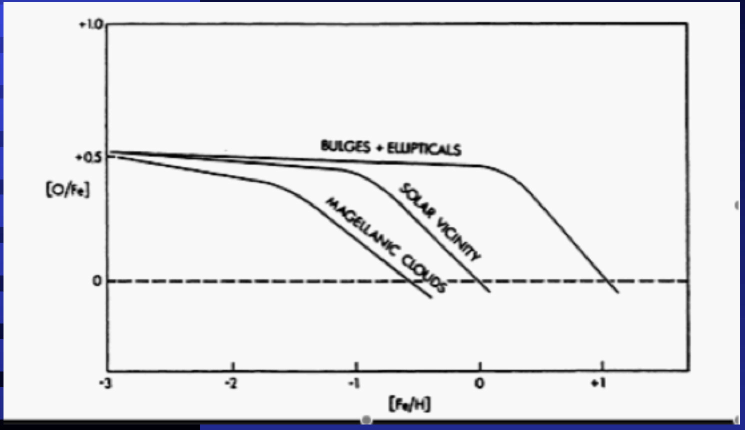
- These CE model can account for the details of the abundance trends found up to solar (and above) for several elements (not only alphas, but also Mn, Ba, etc…). Consistent with contribution from SNIa.

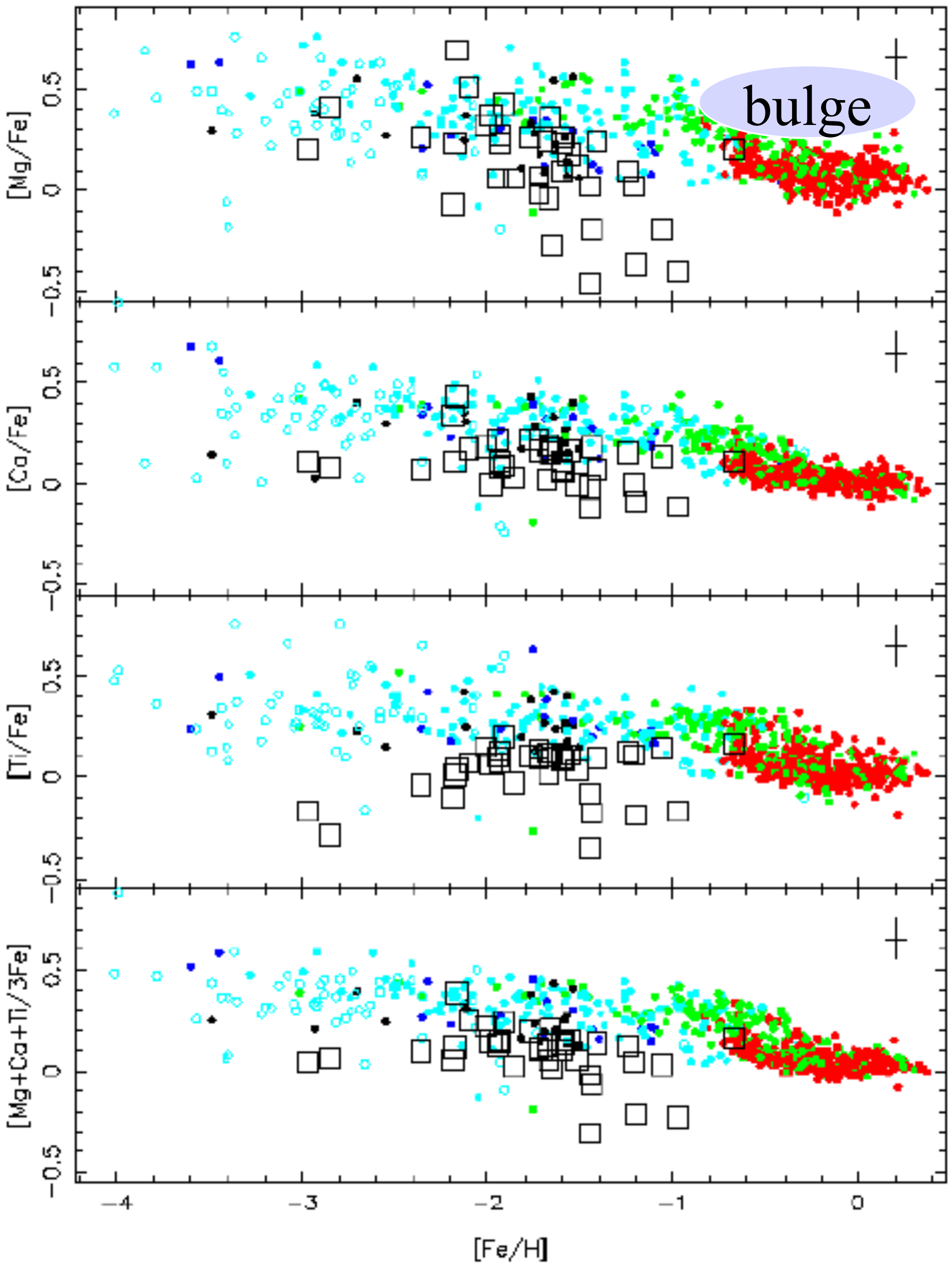
- These trends would be a challenge for models in which the thick disk formed from accreted stellar building blocks and hence favors in situ turbulent scenarios (gas accretion + turbulence, e.g. Bournaud & Elmegreen simulations).

# Lecture IV
# MW: Leaving the Solar Vicinity

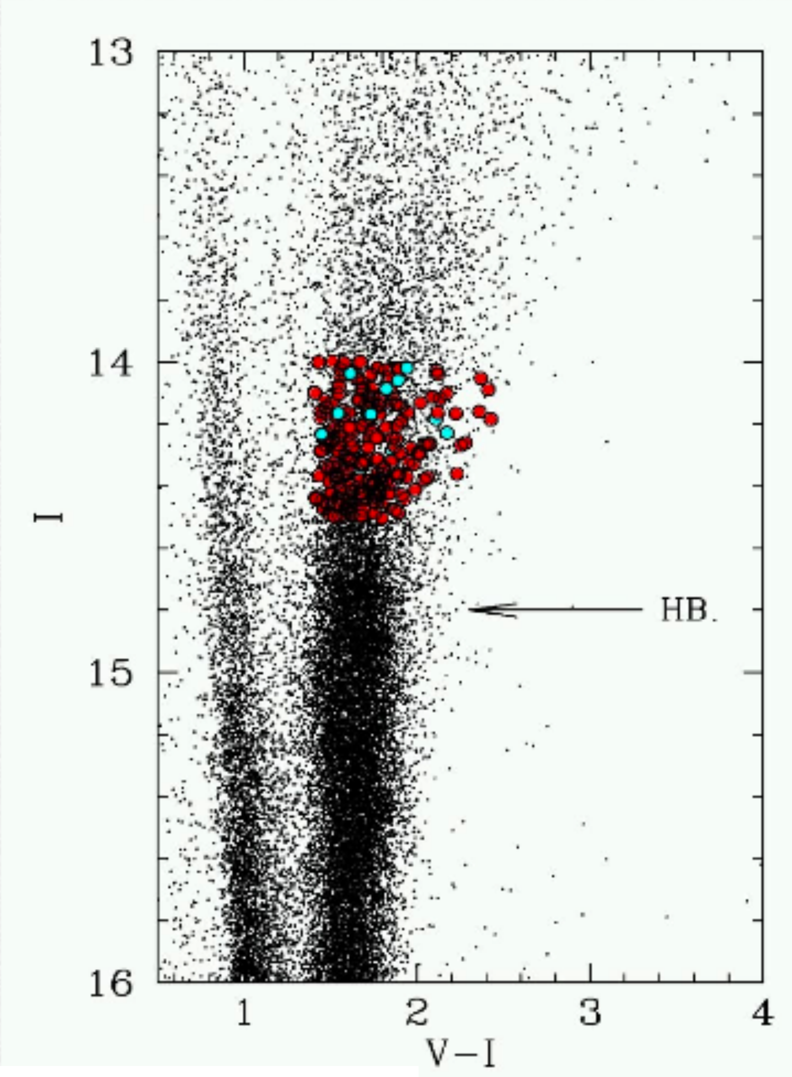
# The Bulge

# Time delay model



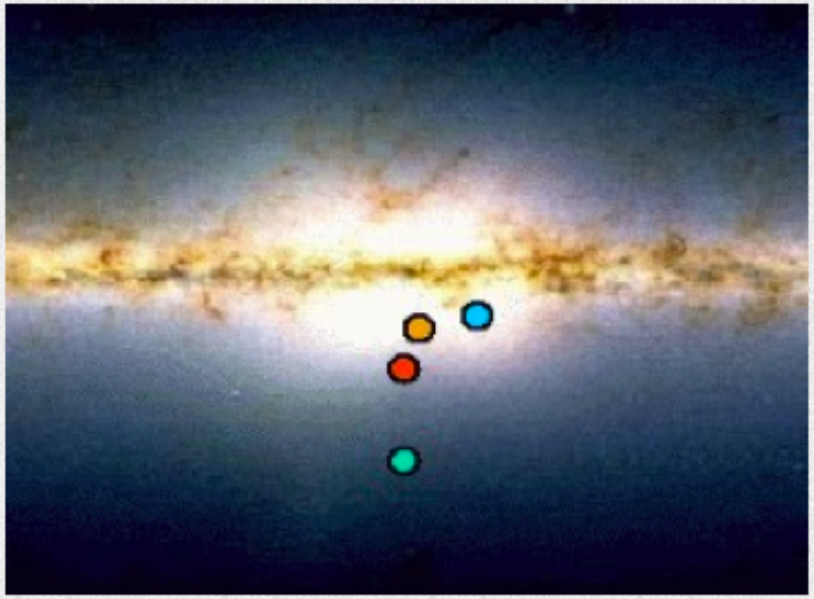



# Chemical Abundances in the Galactic Bulge with FLAMES



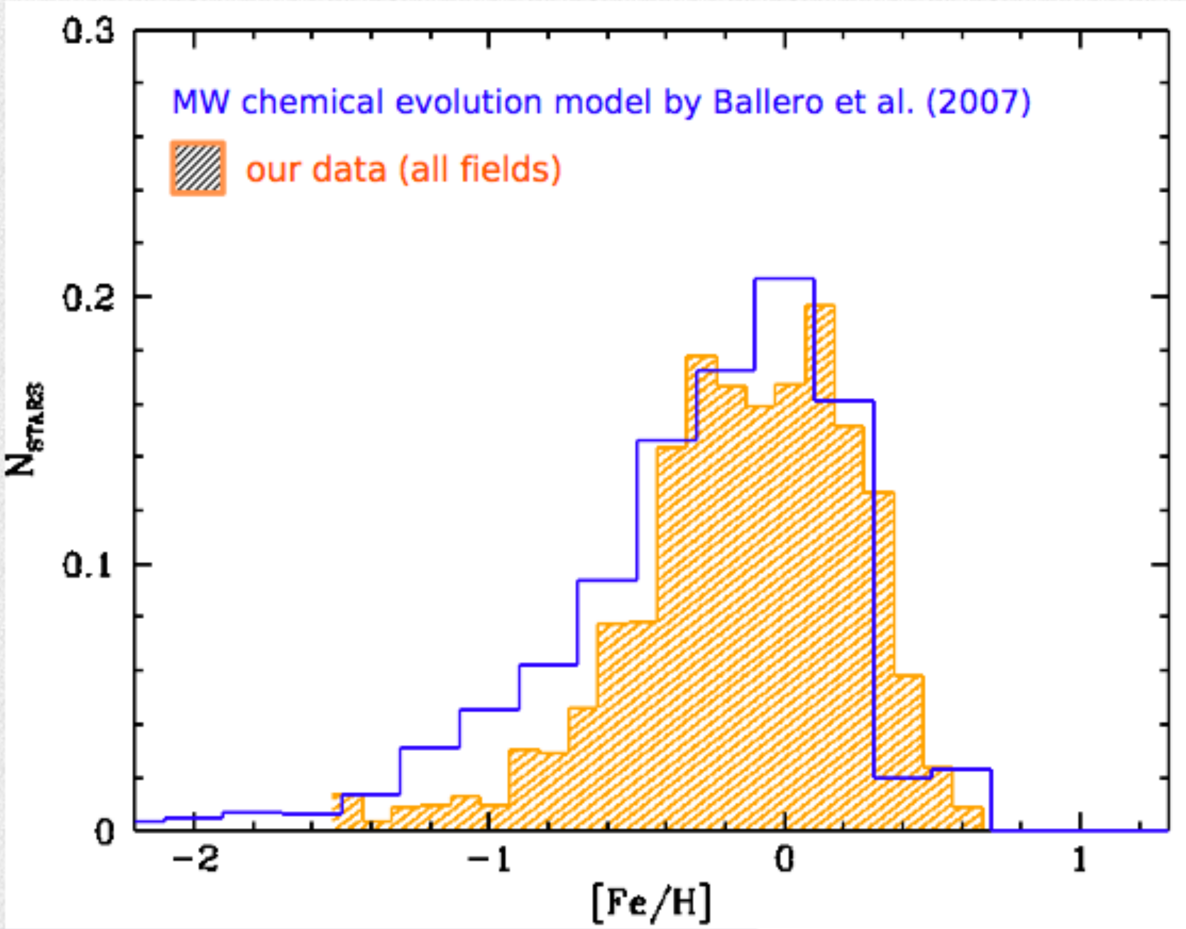

| | | | |
|---|---|---|---|
| V. Hill | (Meudon) | A. Renzini | (Padova) |
| A. Lecureur | (Meudon) | A. Gómez | (Meudon) |
| B. Barbuy | (São Paulo) | S. Ortolani | (Padova) |
| D. Minniti | (PUC) | F. Royer | (Meudon) |

- **900** GIRAFFE targets (R=22000)
- **50** UVES targets (R=45000) all in common with GIRAFFE



From Zoccali 2007

## comparison with models




Star Formation Efficiency: $\psi(r,t) = \nu \frac{\sigma_{gas}(r,t)}{\sigma_0(r,t)}$ $\nu = 20\ Gyr^{-1}$

Infall timescale: $\tau = 0.1$ Gyr

Initial Mass Function: $\phi(m) \propto m^{-1.30}$ $(M<1M_\odot)$

$\propto m^{-1.95}$ $(M>1M_\odot)$

Zoccali & Barbuy

# Summary for the Bulge

- The best model for the Bulge suggests that it is very old and formed by means of a strong starburst
- The efficiency of SF was higher than in the thin disk
- The IMF was flatter ???, as it is suggested for starbursts (more massive stars)
- The timescale for the Bulge formation was around 0.1 Gyr and no longer than 0.5 Gyr

# Thick disk/Bulge similarities

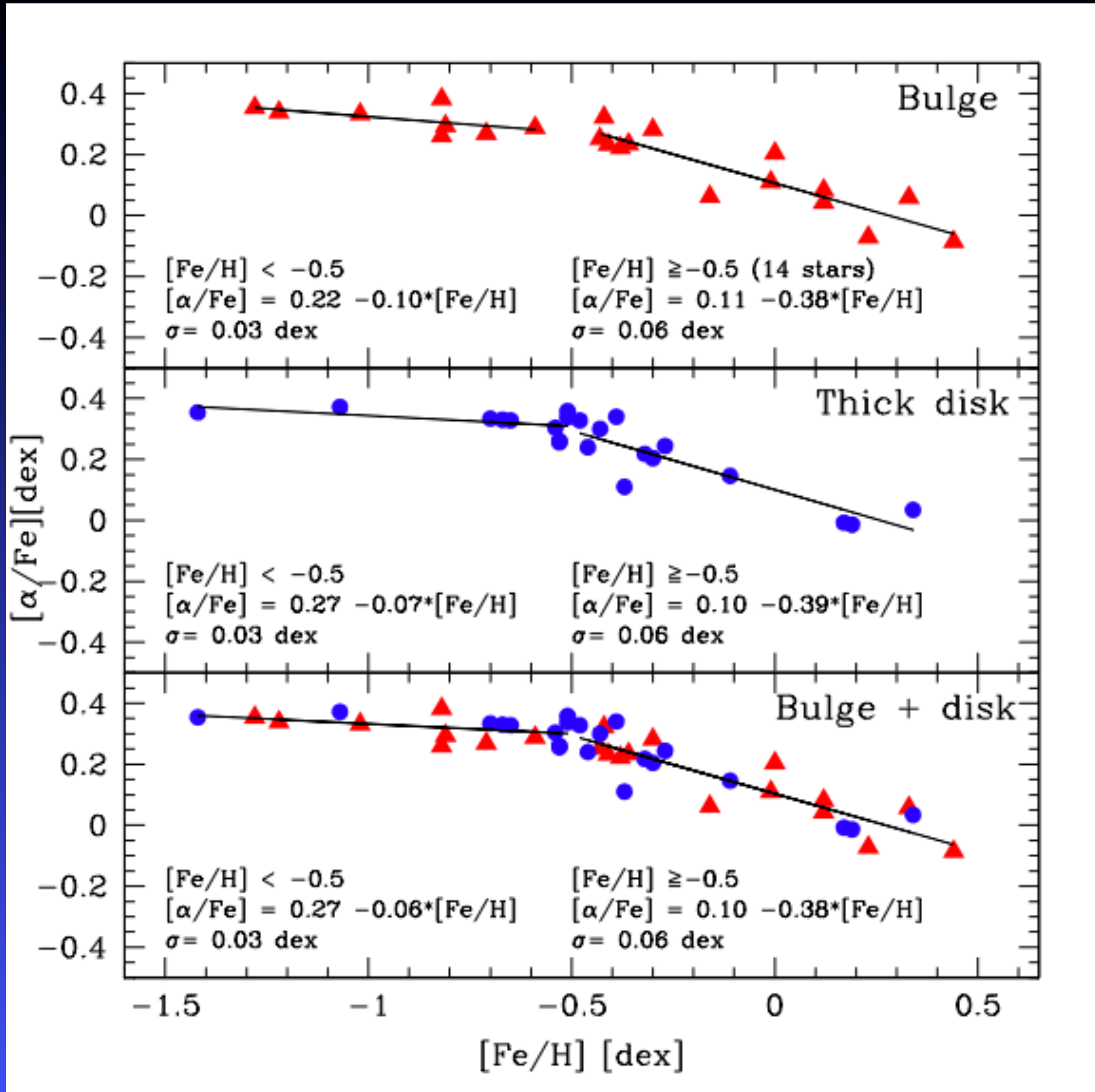
Recent Results: Despite the very different mean metallicities, the Bulge and Thick Disk abundance ratios are similar!

Meléndez, J.; Asplund, M.; Alves-Brito, A.; Cunha, K.; Barbuy, B.; Bessell, M. S.; Chiappini, C.; Freeman, K. C.; Ramírez, I.; Smith, V. V.; Yong, D. 2008 A&A Letters

Cescutti, Matteucci, McWilliam & Chiappini, 2009, A&A

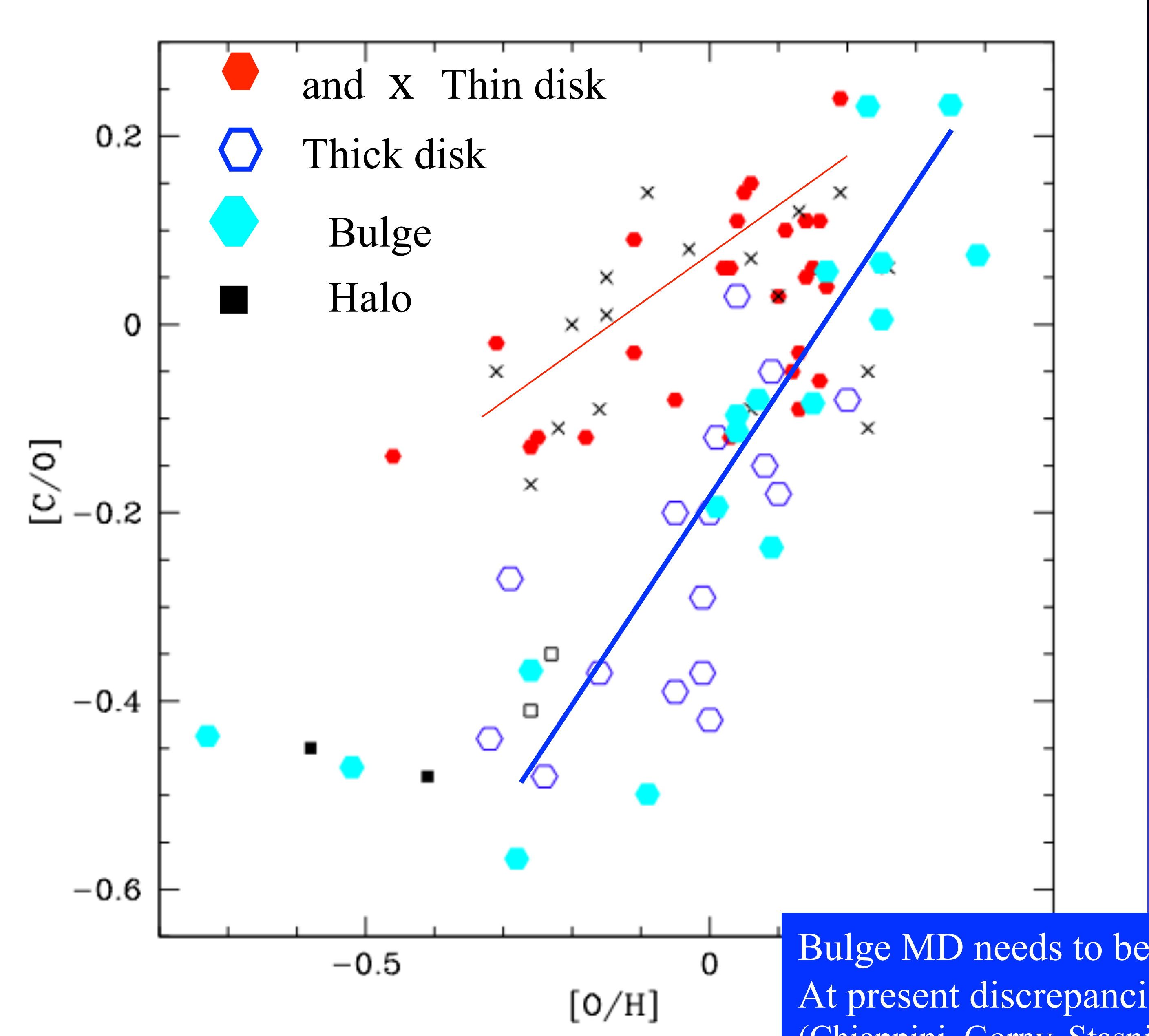
Alvez Britto et al. 2010, A&A

Suggest similar IMFs and formations timescales for bulge & thick disk




Alves-Brito et al. 2010, Melendez et al. 2008 A&A Letters

Cescutti, Matteucci, McWilliam & Chiappini 2009 A&A




Bulge and Thick disk show the same C/O vs. O/H !

Bulge MD needs to be better constrained.
At present discrepancies giants/PNe/dwarfs
(Chiappini, Gorny, Stasniska & Barbuy 2009)

# Summary of main conclusions for MW from pure chemical arguments

(Chiappini 2009, Chiappini et al. 2010 in prep)

**-The thin disk formed by slow gas accretion (Infall)**

**- The thick disk formed by fast GAS accretion**

- Short timescale for gas accretion < 1Gyr)
- SFE_thick_disk = 10 x SFE_thin_disk

**- Formation timescales of thick disk & bulge were similar**

**Same IMF but different SFEs?**

**Encouraging agreement with high-z observations (e.g. Genzel et al. 2008) and disk/bulge formation simulations (Elmegreen & collaborators)**

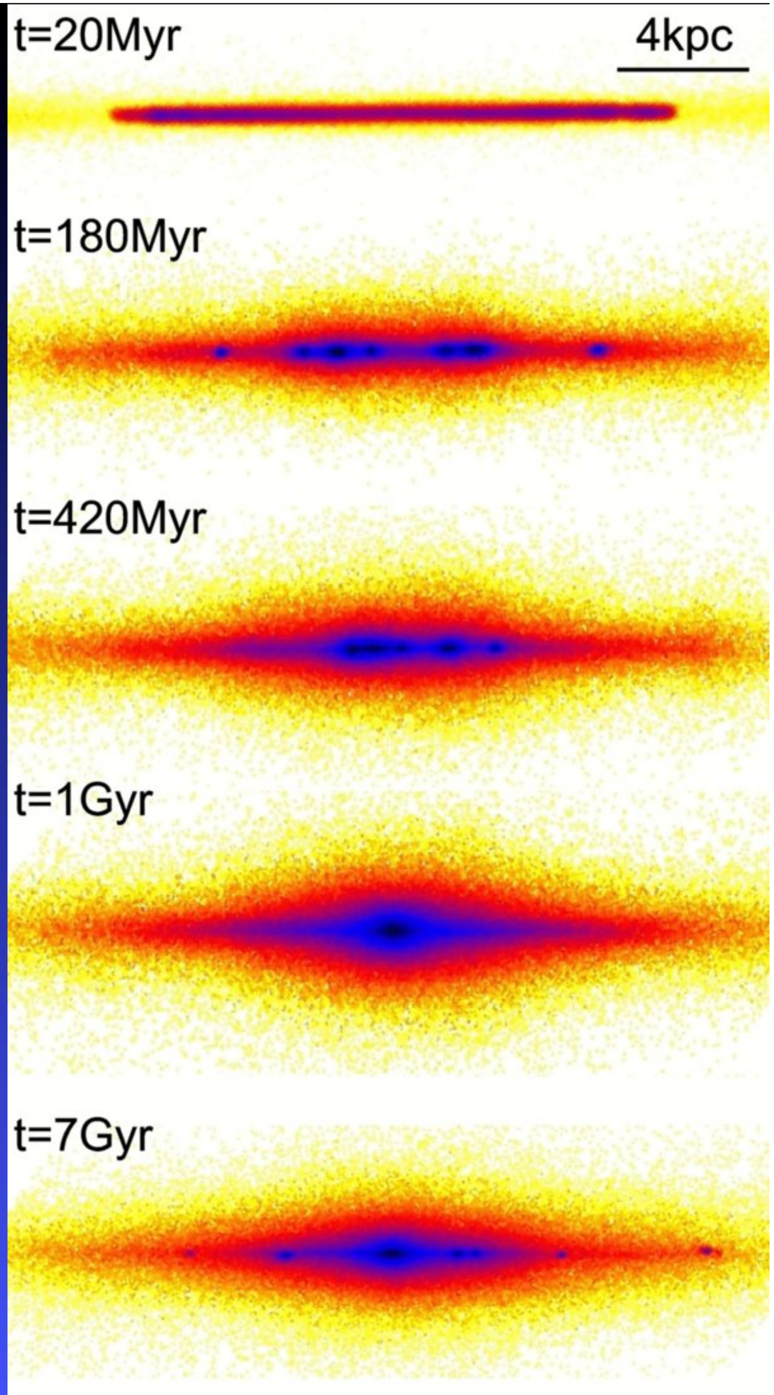
# High z Observations

- SINS Survey (Genzel & collab): Turbulent rotating star forming disks + bulge at z=2
- Chain Galaxies in HUDF (Elmegreen & collab) : Star formation clumps aligned on a plane

**INTERPRETATION:** Buildup of the central disks and bulges of massive galaxies at z~2 driven by the early secular evolution of gas-rich 'proto'-disks. Disks highly turbulent due to rapid 'cold' accretion flows along filaments of the cosmic web => dynamical friction and viscous processes proceed on a time scale of <1 Gyr, at least an order of magnitude faster than in z~0 disk galaxies

(e.g. Bournaud & Elmegreen 2009 ApJL)

We are seeing thick disks, with assembly timescales of a few Myrs, with apparent no major mergers



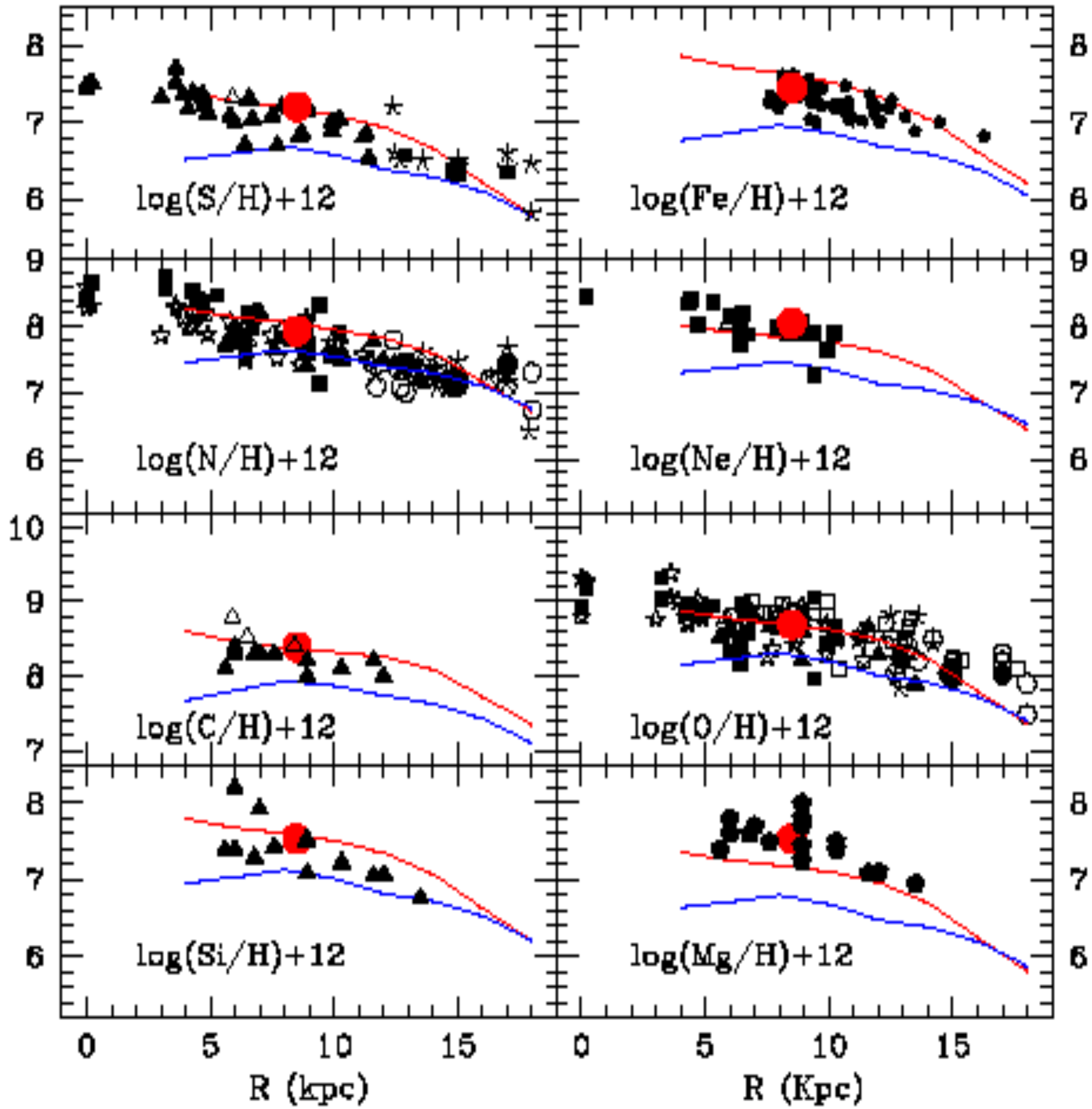
# The whole disk

Abundance gradients

At 2 Gyrs
Today

Chiappini et al. 2001

Data: HII regions and PNe




Other usefull gradients tracers are Cepheids, open clusters

Temporal evolution: strong dependent on initial conditions (e.g. Chiappini et al. 2001, Prantzos 2008, Hou et al. 2000)

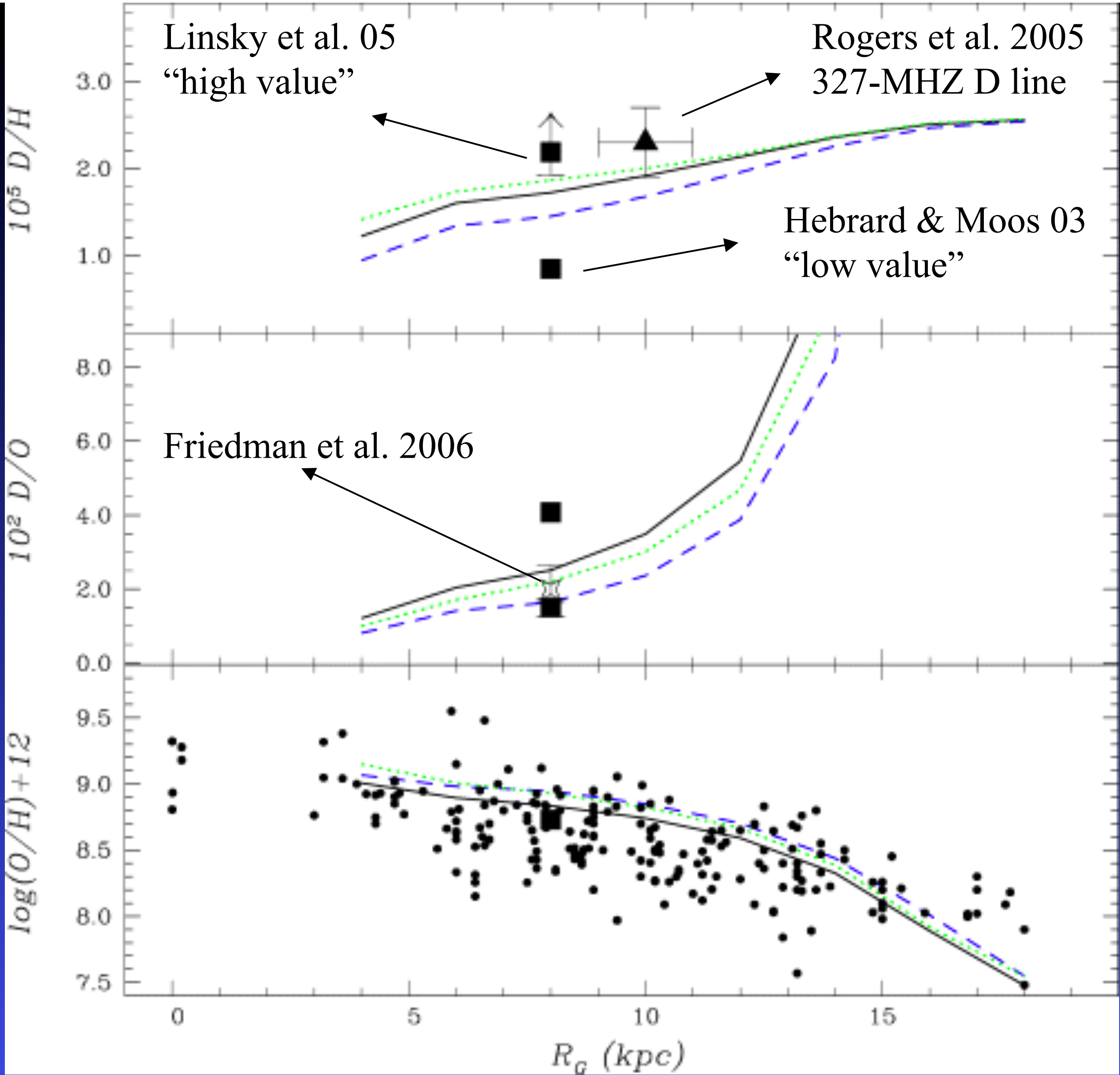
# How does the gradient form?

- If one assumes the disk to form inside-out, namely that first collapses the gas which forms the inner parts and then the gas which forms the outer parts
- This can be done by assuming an infall timescale for the formation of the disk which increases with the galactocentric distance:

$$\tau_d(R) = 0.875R - 0.75$$

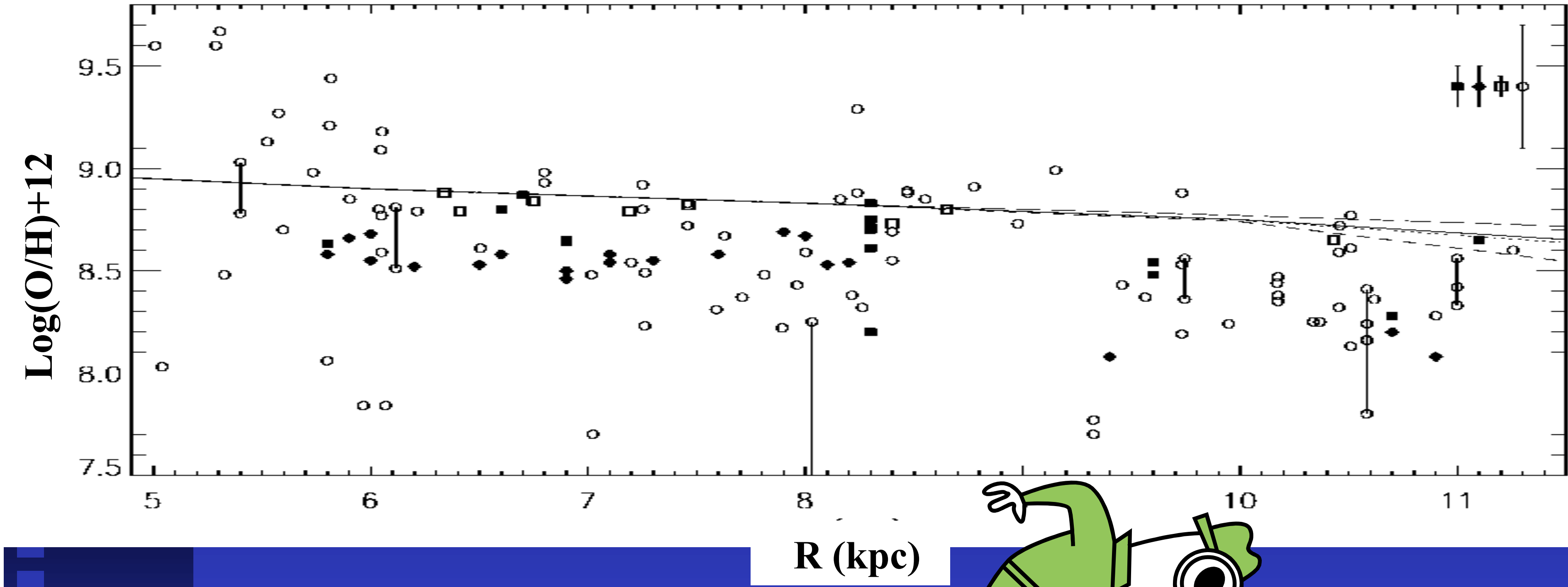
Chiappini et al. 2001

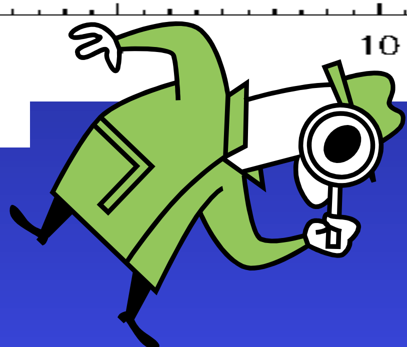
Models from Chiappini et al. 2002, now computed for different IMFs/stellar lifetimes (Romano, Tosi, Chiappini & Matteucci 2006)




In Cescutti, Matteucci, Francois & Chiappini 2007: abundanced gradients for O, Mg, Si, S, Ca, Sc, Ti, Co, V, Fe, Ni, Zn, Cu, Mn, Cr, Ba, La, Eu (based on the timescale law of Chiappini et al. 2001)

# Galactic Abundance Gradients



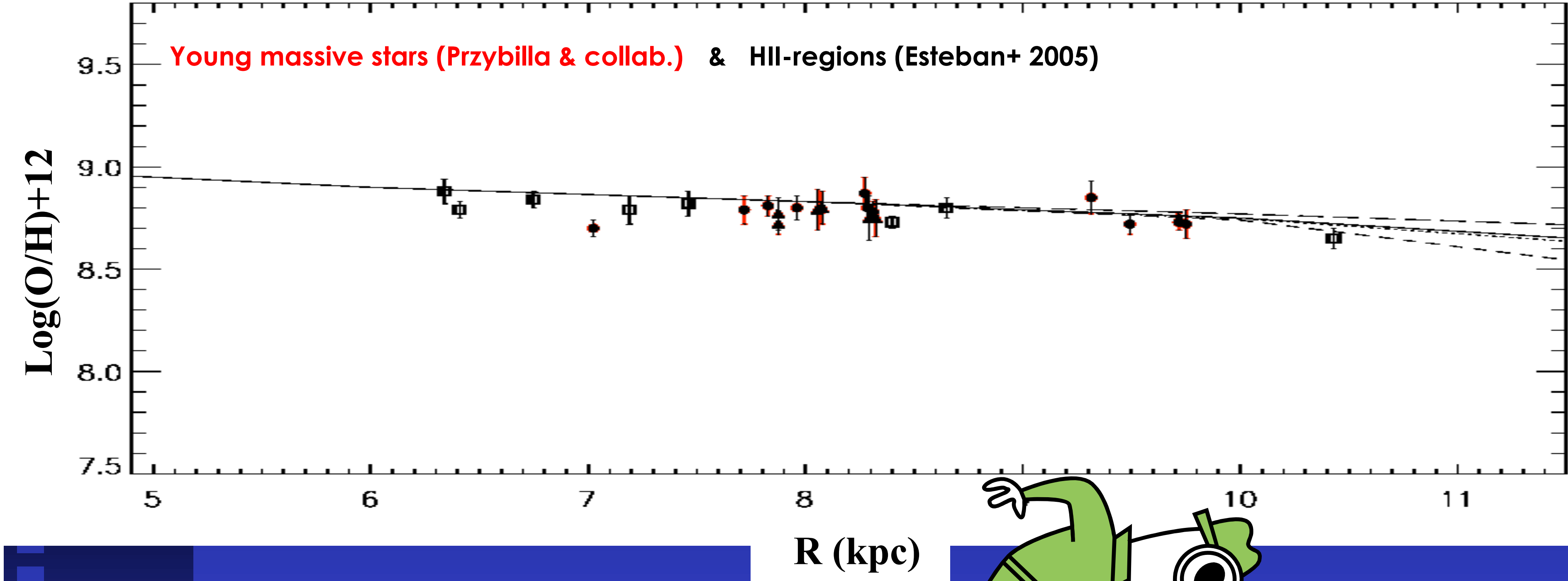



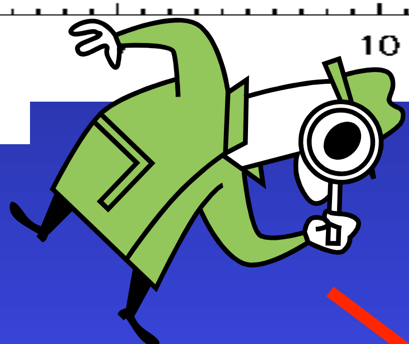
Models: Chiappini et al. (2001)

**Large scatter @ every R**

(From Przybilla 2008)

# Galactic Abundance Gradients



Models: Chiappini et al. (2001)

~~Large scatter @ every R~~

No scatter, flat gradient: -0.04 dex/kpc

(From Przybilla 2008)

But what is the disk was like scrambled eggs? …. Local samples are not at all local… and do not represent the CE at the R position…

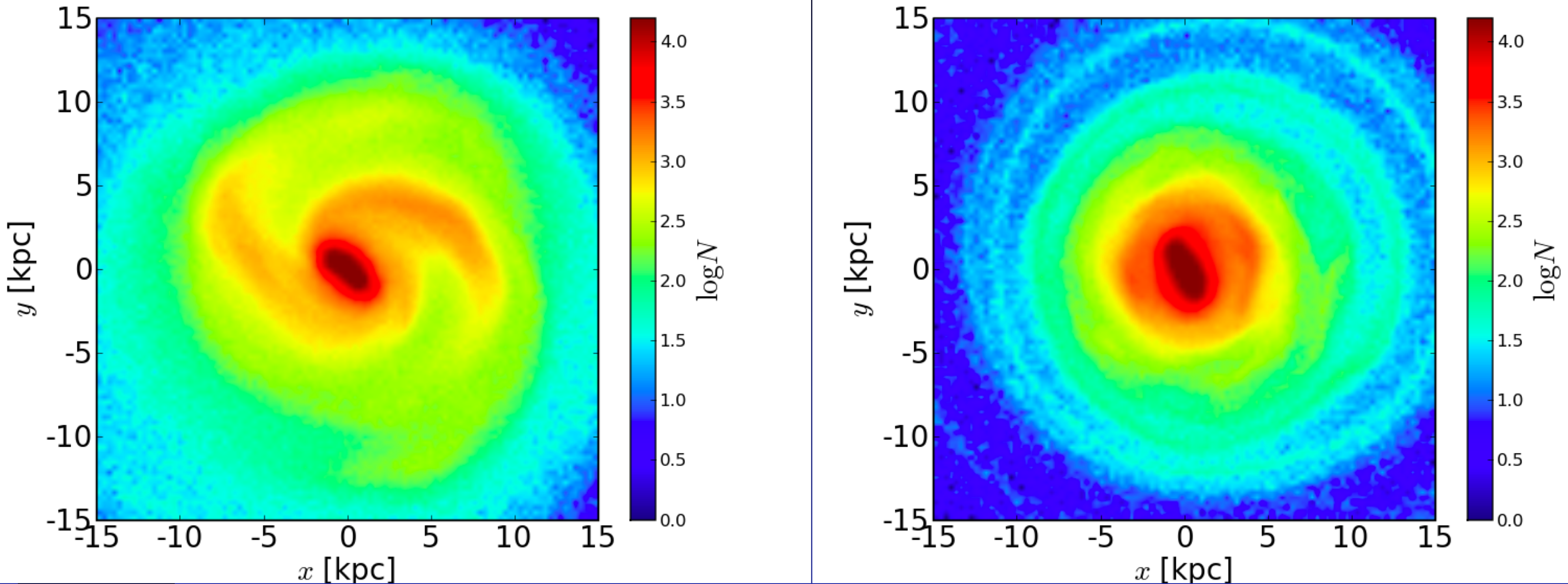
# Preparing for GAIA
# The need for combining detailed chemistry and dynamics

Important extra constraints from dynamics/structural parameters: e.g. orbital eccentricity distribution (Sales et al. 2009); variations of scale-height with galactocentric distance (Bournaud et al. 2009) + Radial mixing (Minchev & Famaey 2009).

**Stellar Migration**

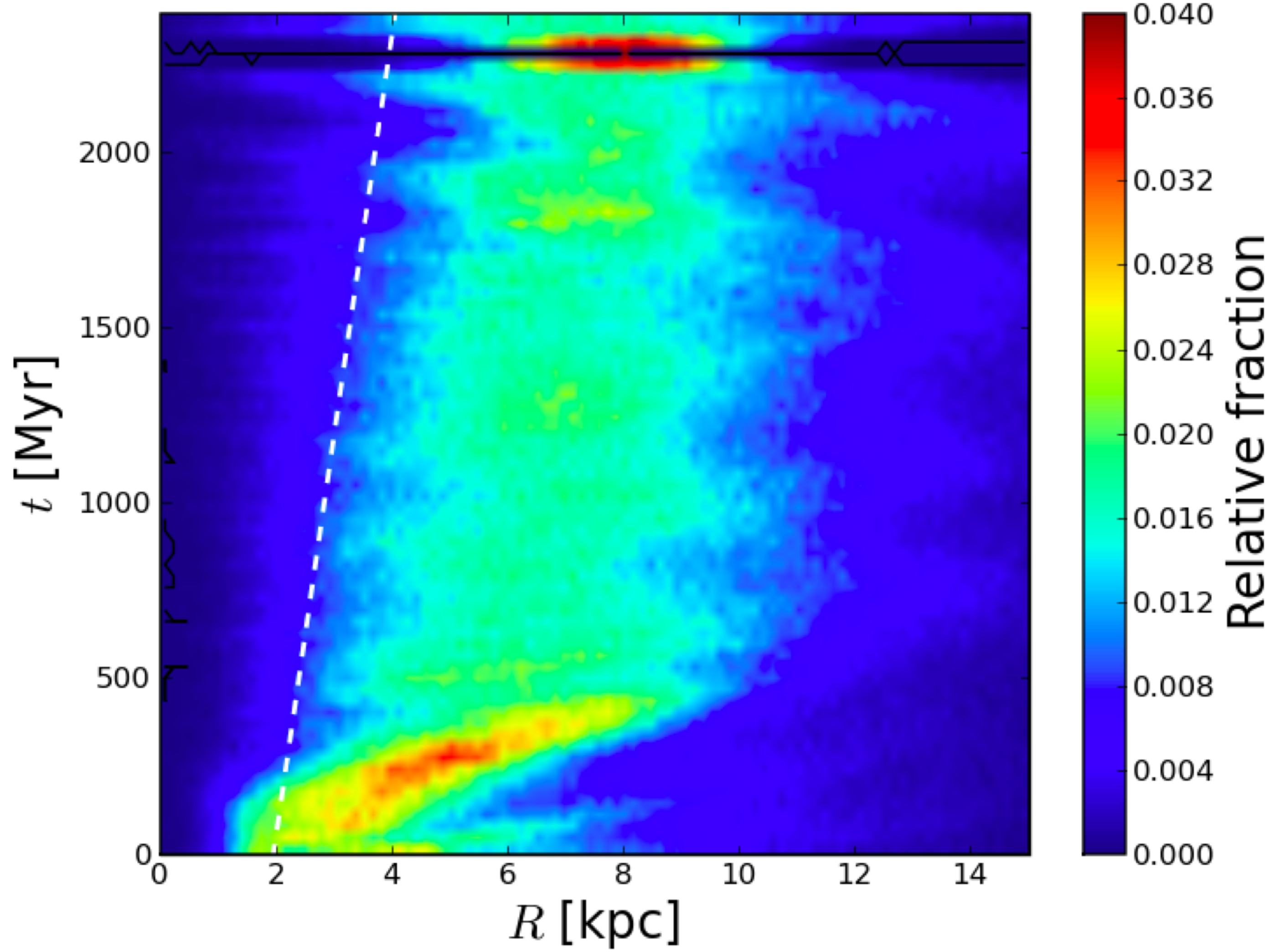
Crucial role played by the MW Bar: kicks stars from the inner to the outer regions (Brunetti, Pfenniger & Chiappini 2010 sub)

More spiral arms/less massive bar (without halo) | More massive bar/less spiral arms (with halo)




Diffusion Coefficient is not constant and it depends strongly on the bar strength

# Radial migration of stars which at time t = 2.2 Gyrs are in R=8kpc



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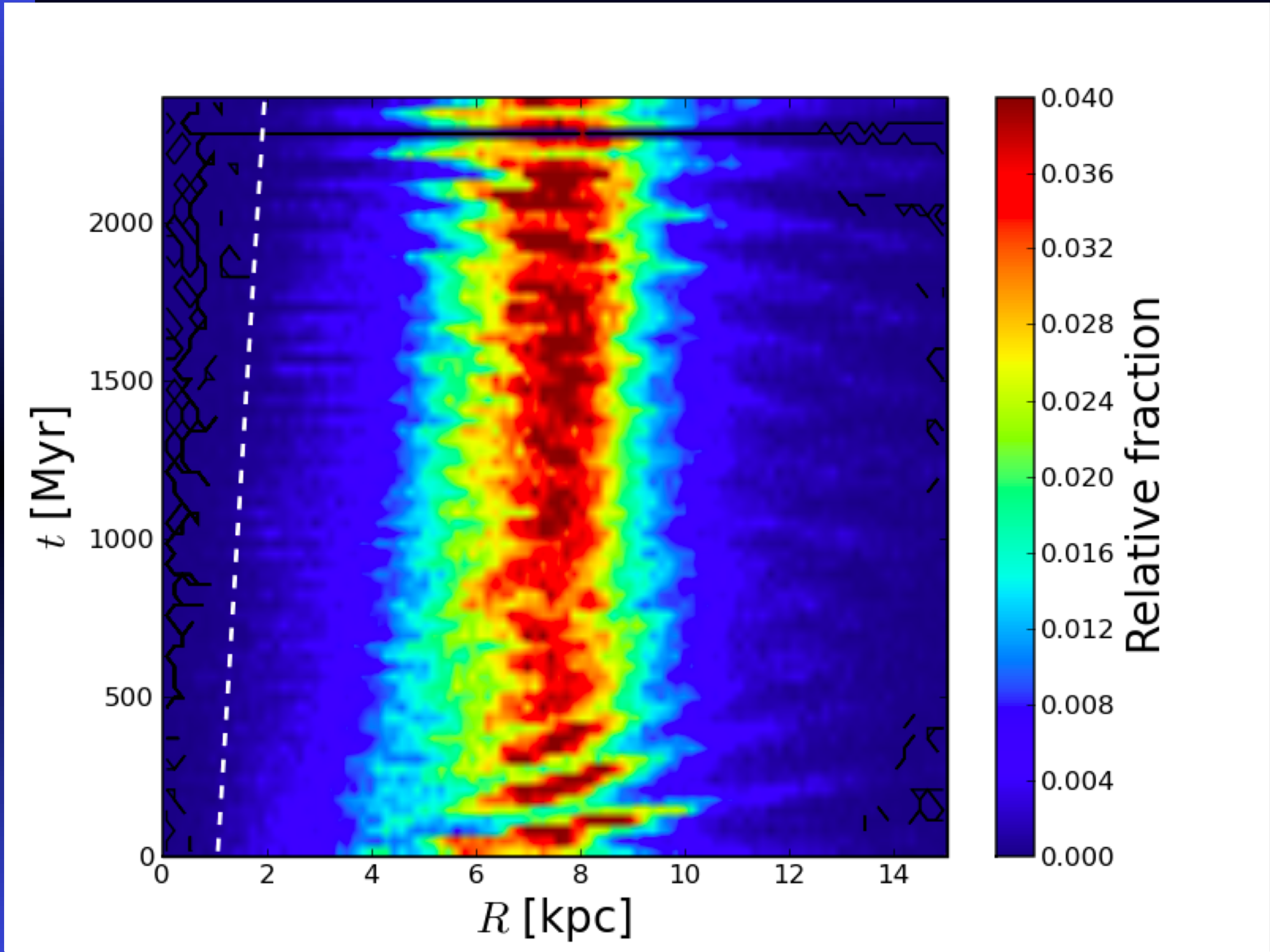

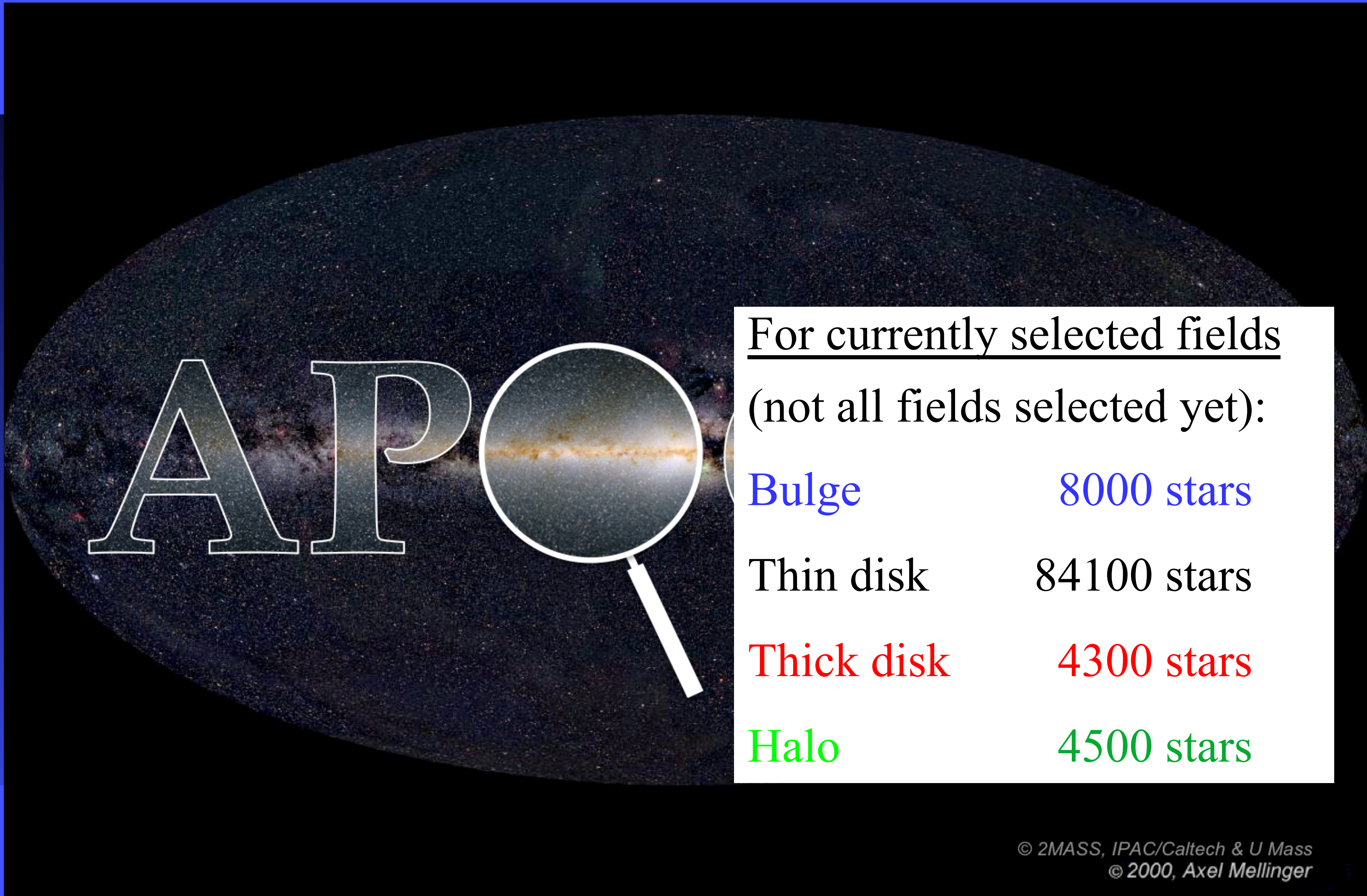


For currently selected fields (not all fields selected yet):

| | |
|---|---|
| Bulge | 8000 stars |
| Thin disk | 84100 stars |
| Thick disk | 4300 stars |
| Halo | 4500 stars |

# APOGEE: Core Science Goals (Complementary to GAIA*)

- *Chemical Evolution at high precision, multi element level* (0.1 dex precision for ~15 elements).
- *Metallicity distribution functions* across disk, bulge, halo
- Constrain the *IMF and SFR of bulge/disk* as function of radius, metallicity/age, chemical evolution of inner Galaxy.
- Determine nature of *Galactic bar and spiral arms* and their influence on abundances/kinematics of disk/bulge stars thanks to precise velocity measurements.

300 fiber, R = 30 000, H band 1.51-1.68μ, 105 2MASS-selected giants

* Large number of chemical elements + can see towards high extinction regions