The Formation of the Thick and Thin disks of our Galaxy

Chemical (+ Dynamical) Imprints

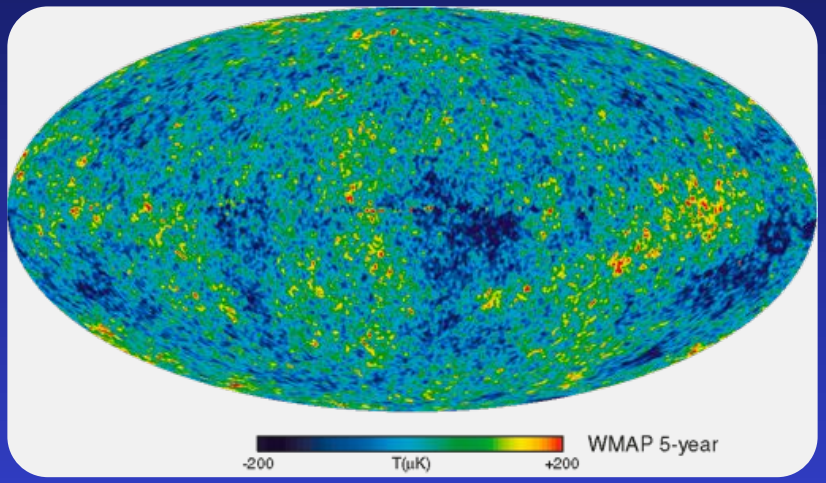
CRISTINA CHIAPPINI

(Geneva Observatory / OAT - Trieste)

M. Brunetti, D. Pfenniger, G. Meynet (Geneva) and G. Cescutti, F. Matteucci (Trieste)

Our Picture of the Universe

300 Myrs after Big Bang: temperature fluctuations (of 1/100 000) -- seeds that grew to become galaxies



Primordial chemical elements: H, D, He, Li

Everything else made inside Stars

Milky Way

Local Benchmark to Cosmology

Access to detailed ages + abundances + space velocities for individual stars

GAIA

Record of continuous star formation during the past 13 Gyrs

Bonus: Origin of chemical elements

Rosetta Stone of Chemical Evolution

Test for LambdaCDM scenario…

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

Fundamental constraints – still uncertain! Big hopes in improving this with Gaia-+

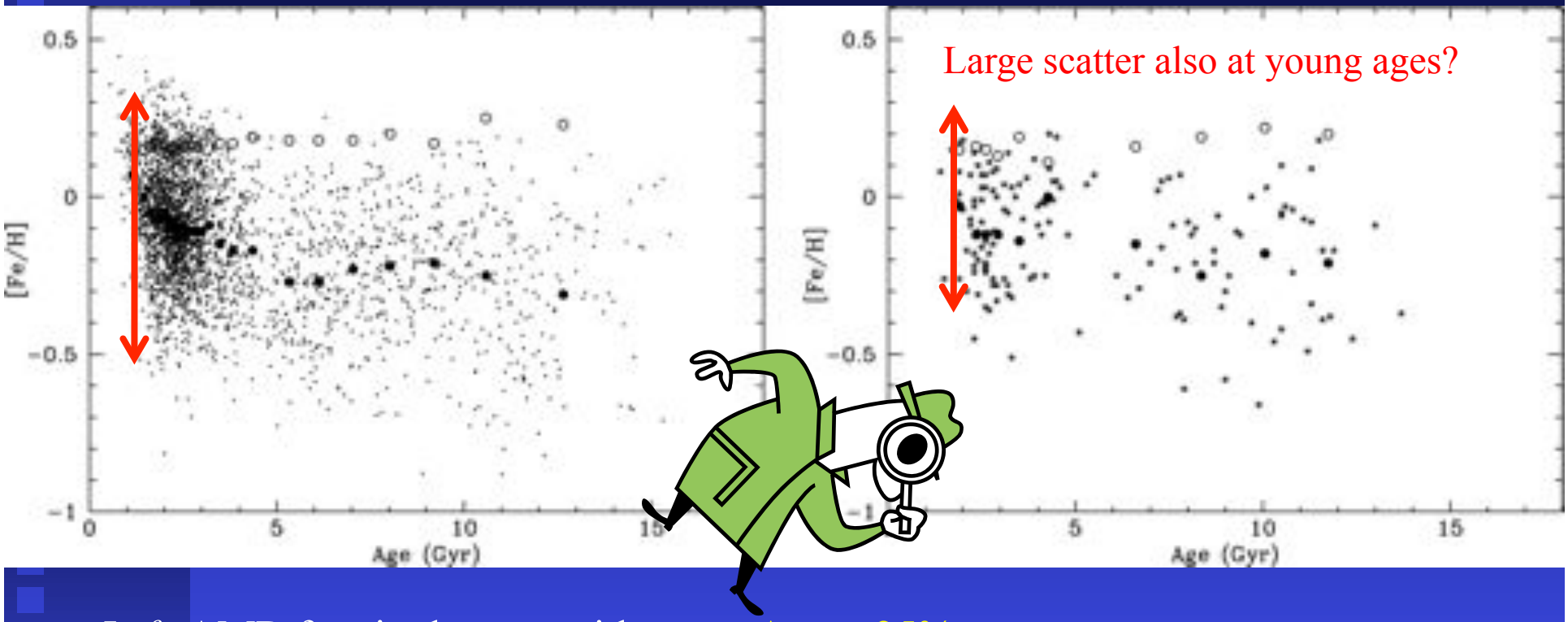
- Age-Metallicity relation (thick vs thin)– scatter real?
- Metallicity distribution – thick/thin/bulge at different Rs!
- Velocities vs. age relationships up to oldest ages
- Abundance gradients and their evolution
- Structural parameters (h_z, h_R) + orbital eccentricity distribution (also SEGUE – Carollo et al. 2010)
- Details on the MW bar (APOGEE)
- **Stepping out the solar vicinity – [X/Y] vs. [Y/H] @ Rs**
- **Building fiducial samples of thick and thin disk stars**

(Cropper, Katz, Freeman, Bonifacio…)

(Turon, Primas, Binney, Chiappini, Drew, Helmi, Robin, Ryan 2008 – ESA/ESO WG report)

Age-Metallicity Relation: is all the scatter real?

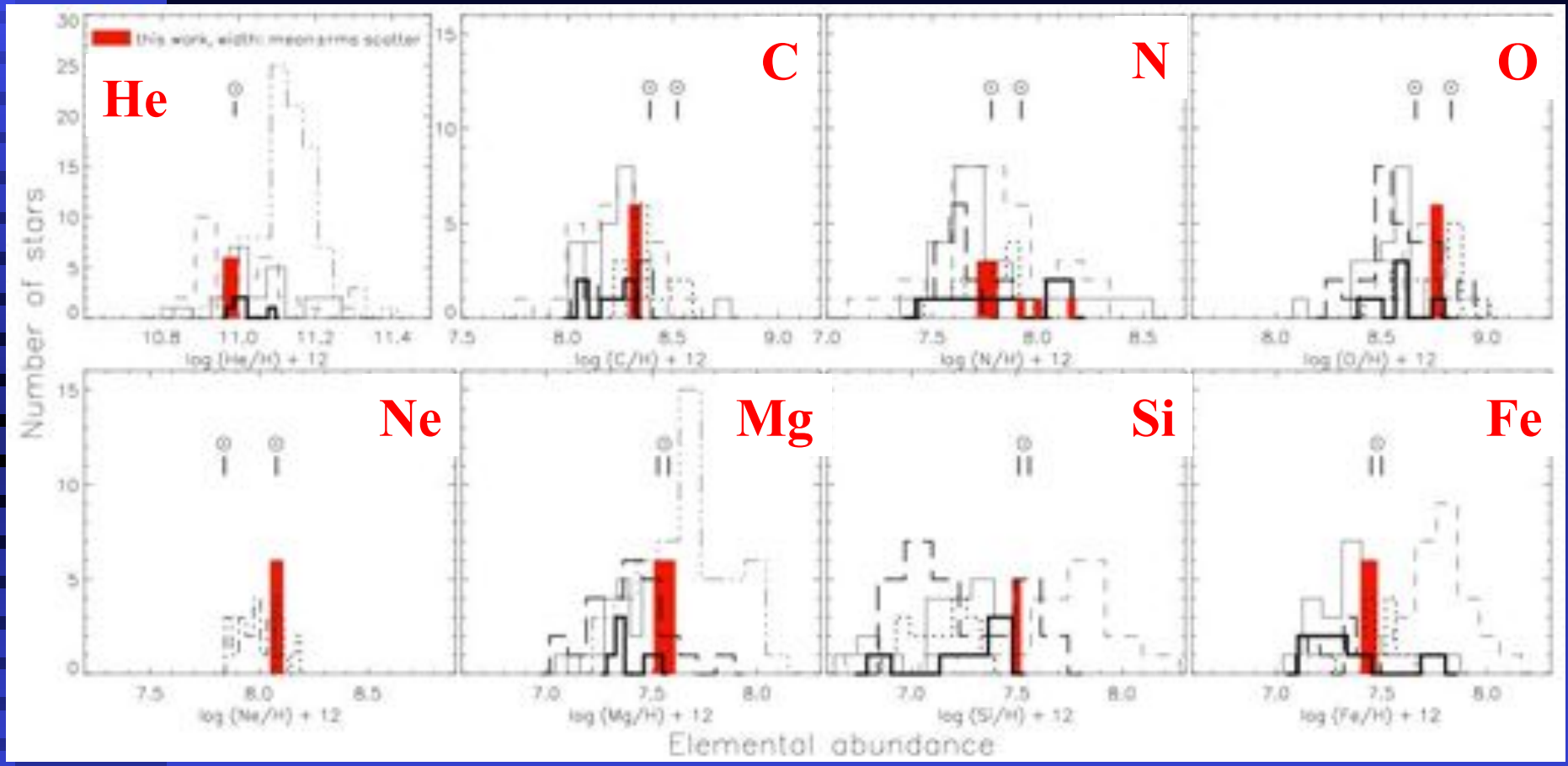
(Holmberg et al. 2009)



Left: AMR for single stars with error_Age < 25%.
Large filled dots = mean values
Open circles = the dispersions of [Fe/H] in bins with equal numbers of stars.
Right: same, but for stars within 40 pc.

Present-Day Abundances/Solar Neighbourhood: B-Stars

Przybilla, Nieva & Butler (2008)



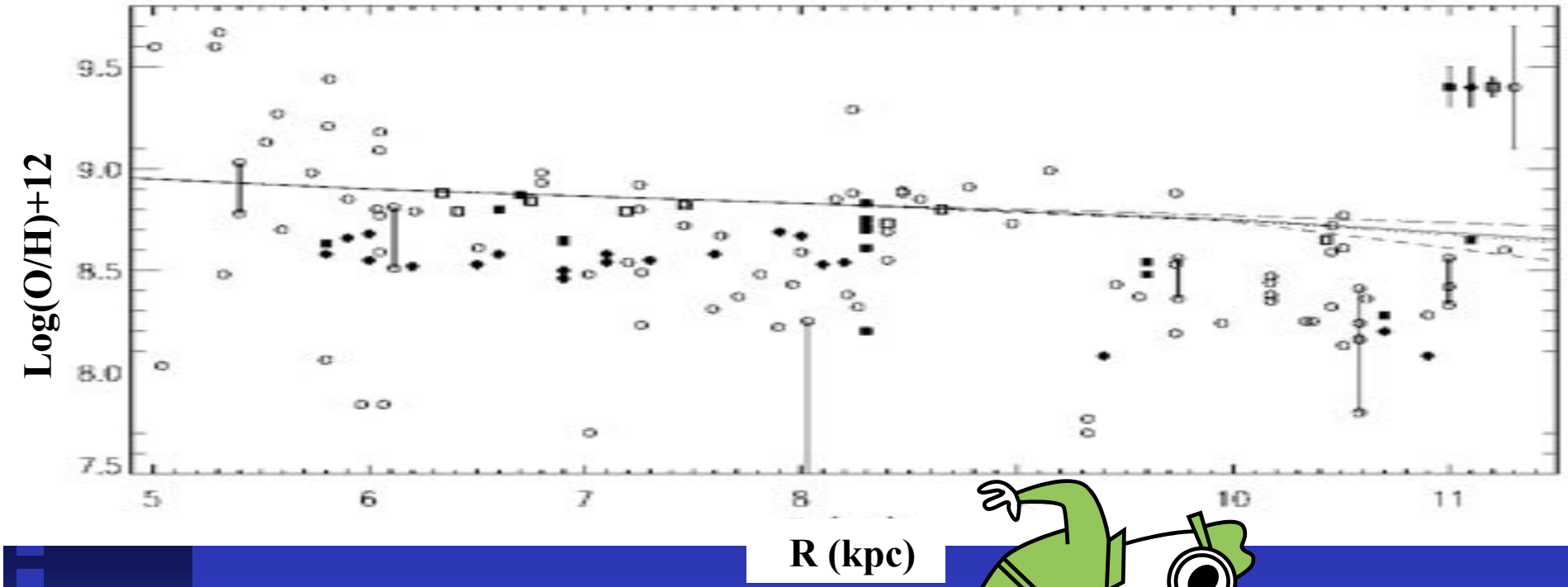
Improved analysis: chemical homogeneity of the solar neighbourhood

Cosmic abundance standard

X=0.715 Y=0.271 **Z=0.014**

Friedrich-Alexander-Universität Erlangen-Nürnberg

Galactic Abundance Gradients

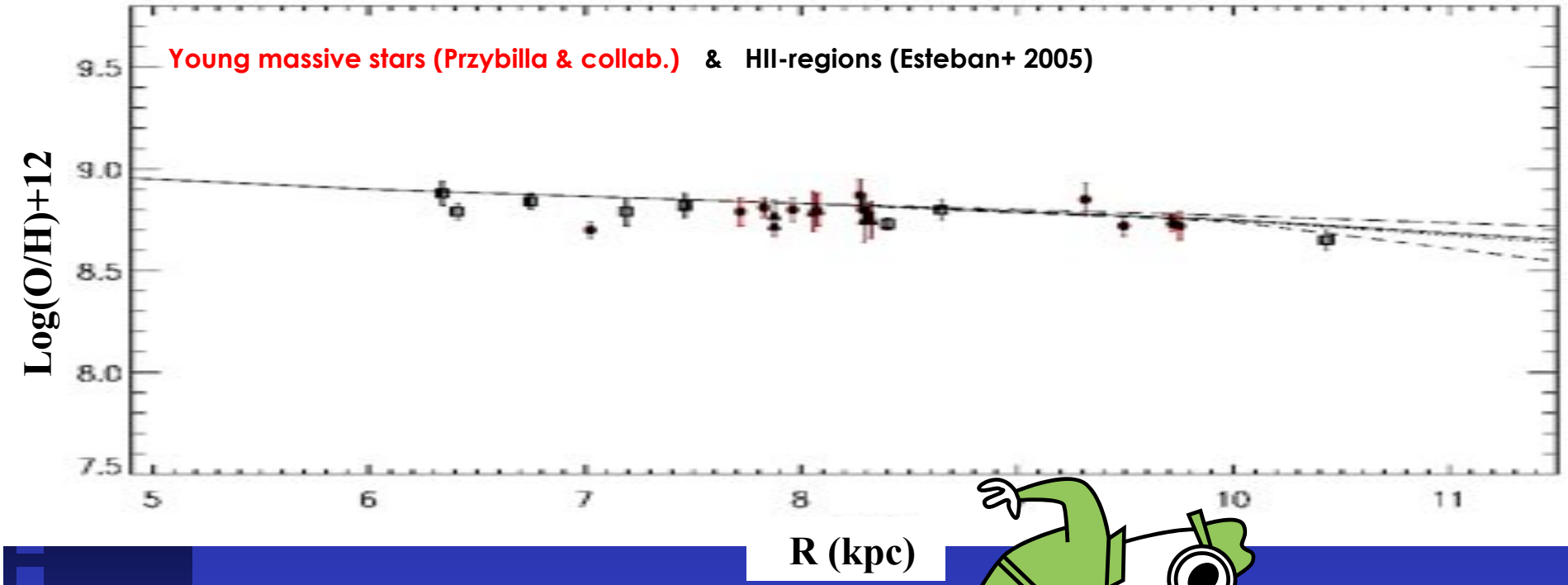


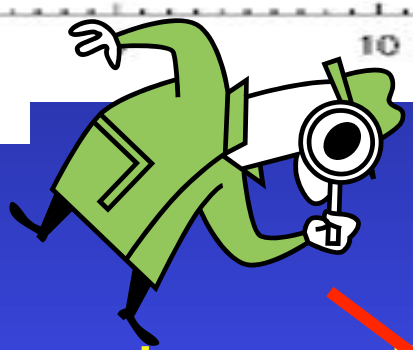
Large scatter @ every R

Models: Chiappini et al. (2001)

(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)

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- S can mimic a thick disk via radial migration
  (S

Chemical Abundances:
Abundance ratios = clocks
Scatter + trends with metallicity

Gold era for chemo-dynamic studies!

Ongoing…

- RAVE
- SDSS – SEGUE
- LAMOST

Near Future…

- Gaia – some elements for nearby stars, but an enormous sample!
- APOGEE – new elements and covering area of high obscuration!

Future – focus on detailed abundances

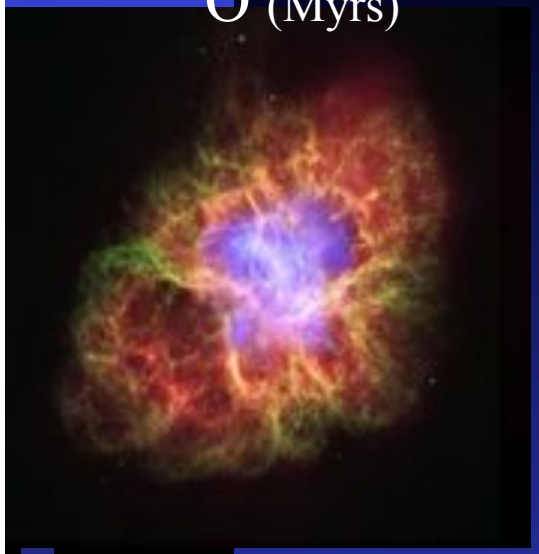
- HERMES
- GYES
- Others…

Our current code: follows 31 chemical elements, essentially all the species covered in these planned/ongoing surveys

Strong synergy with stellar evolution group

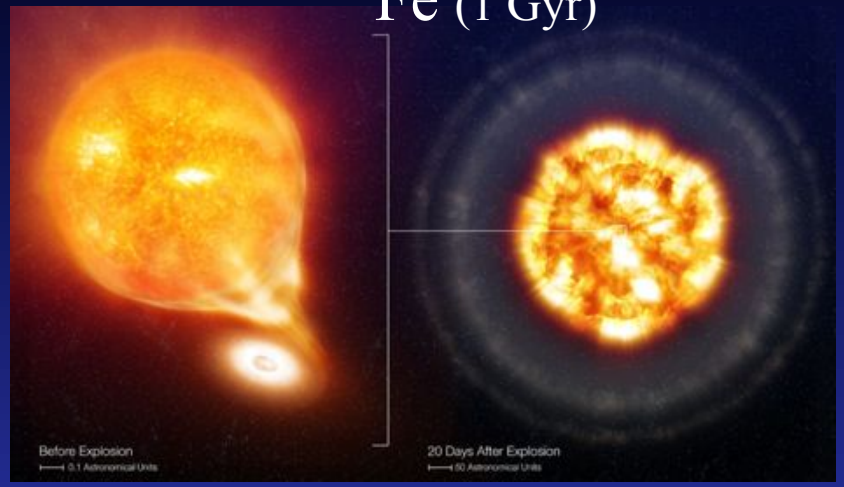
Stellar pollution

O (Myrs)



Core collapse Supernovae

Fe (1 Gyr)



Thermonuclear Supernovae

C, N (Gyrs)

Planetary Nebulae

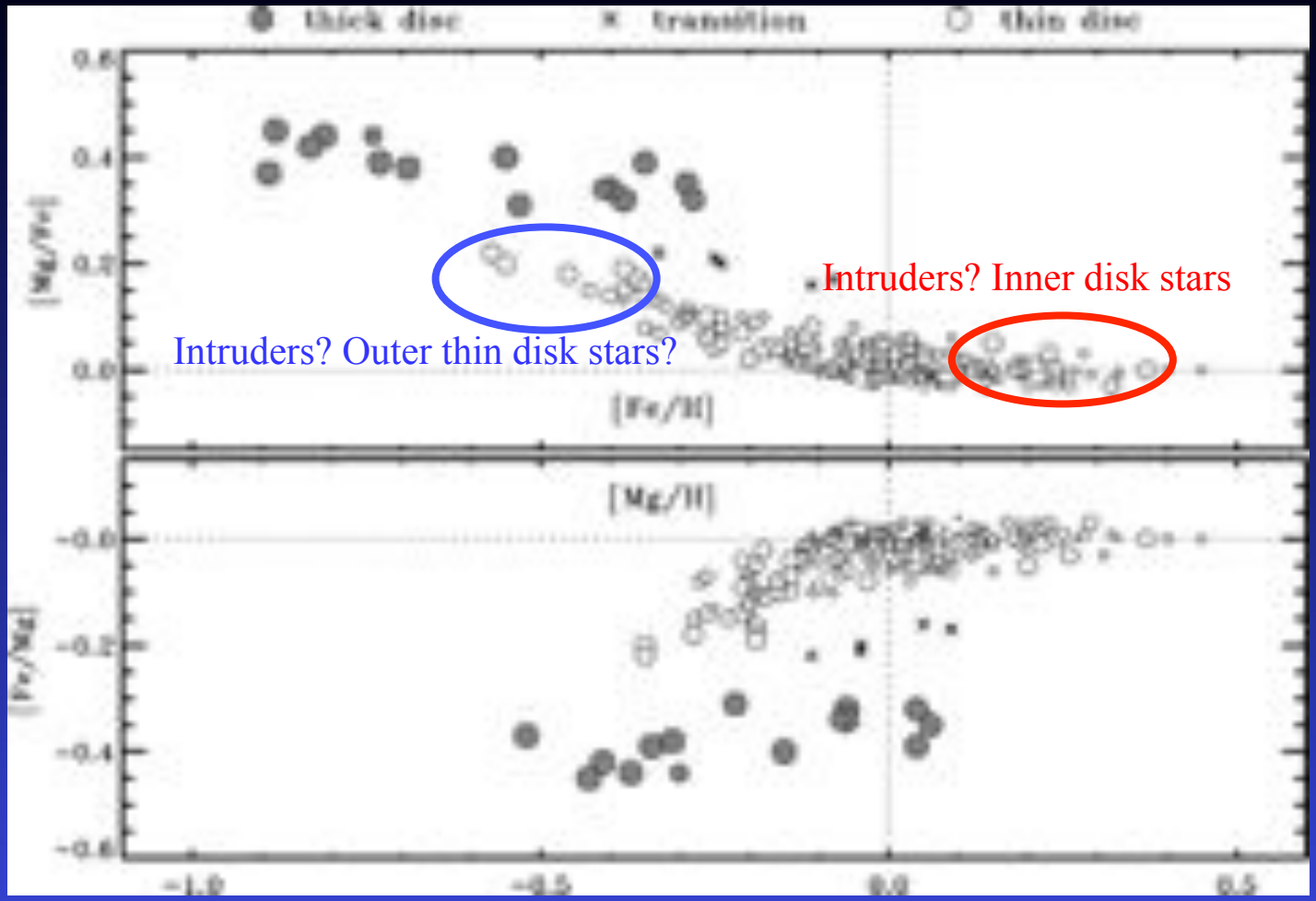
Operating in different timescales f(M,Z,Vrot, mass loss…)

Chemical Signature is FROZEN!

Stars are “Fossil Records” of the Chemical enrichment of the Universe

Grenon
Haywood

Fuhrmann 2008 - Volume complete sample



Lack of scatter (10000 lower than metallicity range!)

Halo, Thick disk, Thin disk: cannot have been made by uncorrelated systems

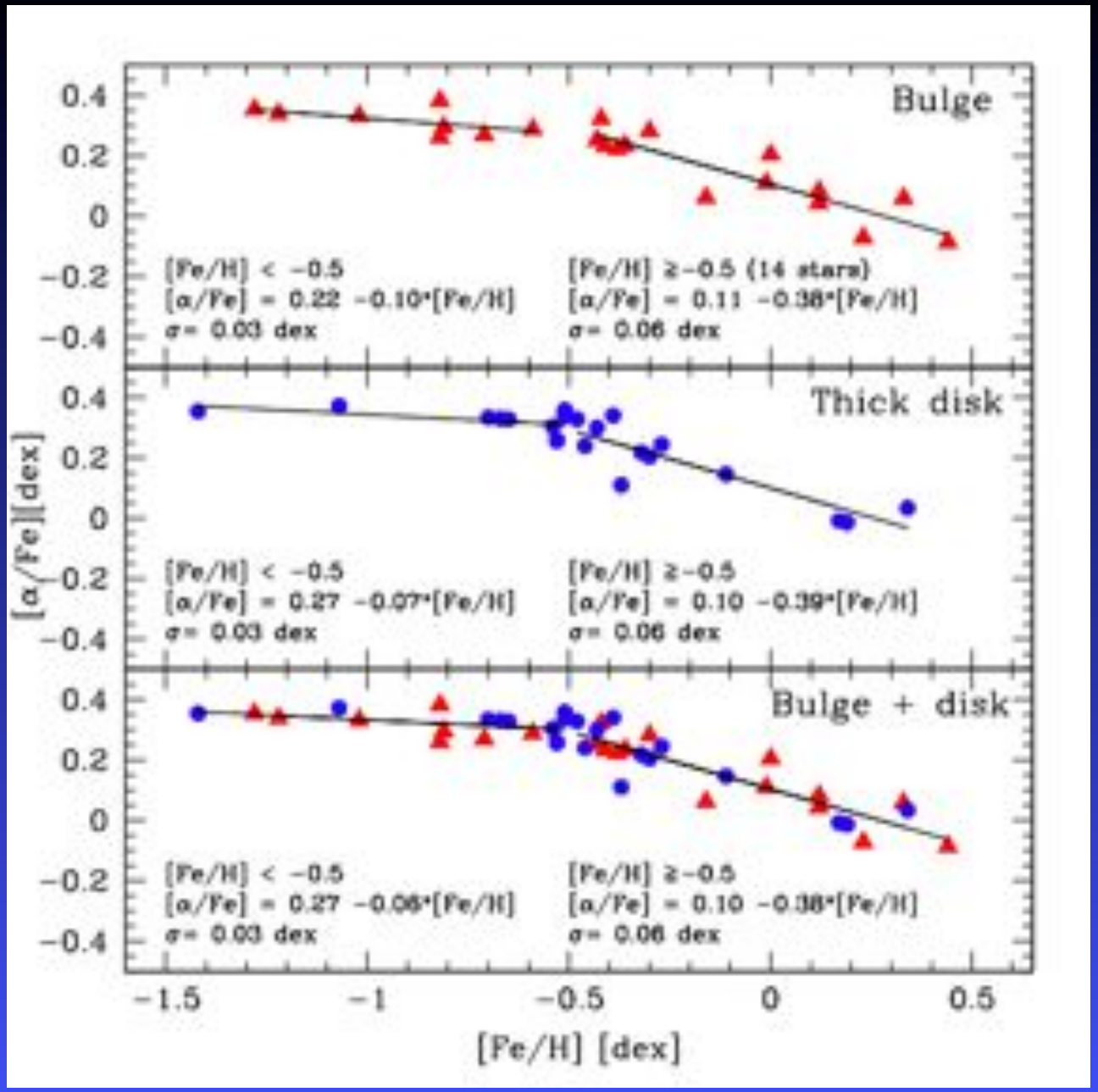
Suggestions of an age gap between thick disk and oldest stars in thin disks

(Liu & Charboyer 2000, Sandage et al. 2003, Bernkopf & Furhmann 2006)

Abundance ratios: Bulge=thick disk

One more Chemical TIP!

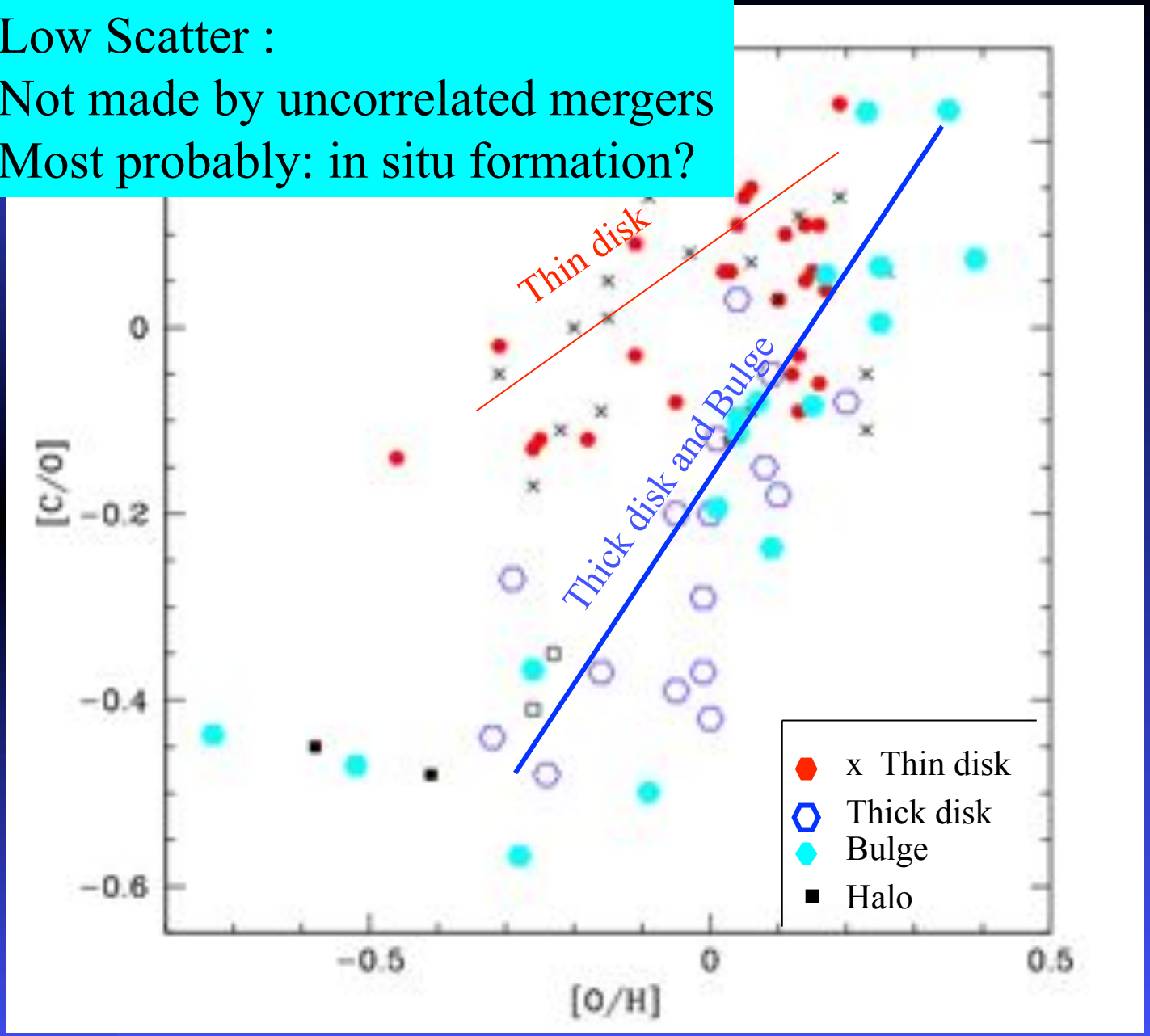
But Metallicity Distributions



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

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

Low Scatter :
Not made by uncorrelated mergers
Most probably: in situ formation?



Cescutti, Matteucci, McWilliam & Chiappini 2009 A&A

Illustrating the effect of different timescales of formation of thick and thin disks (recovering general SFHistory/timescales)

Bulge+ Thick disk - FAST FORMATION (<1Gyr)

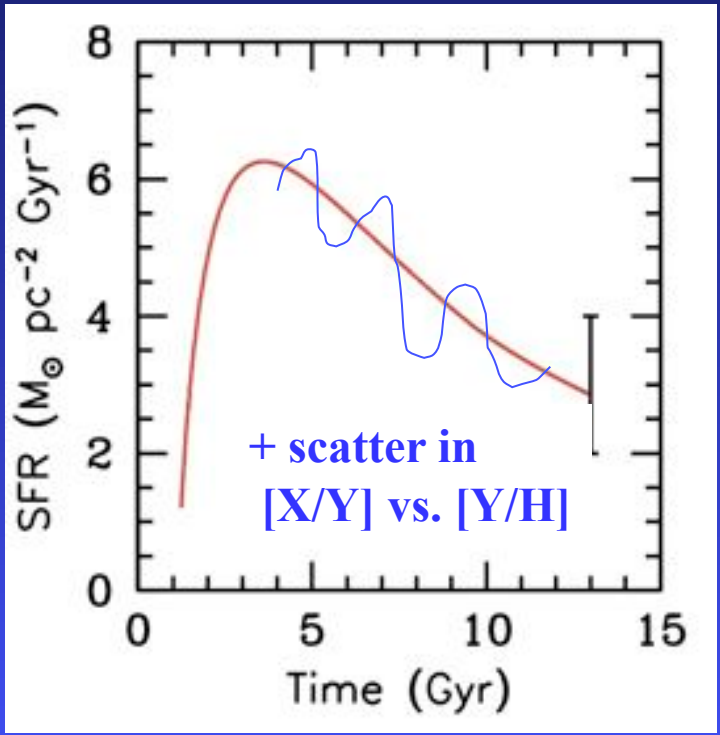
Thin disk – SLOW FORMATION

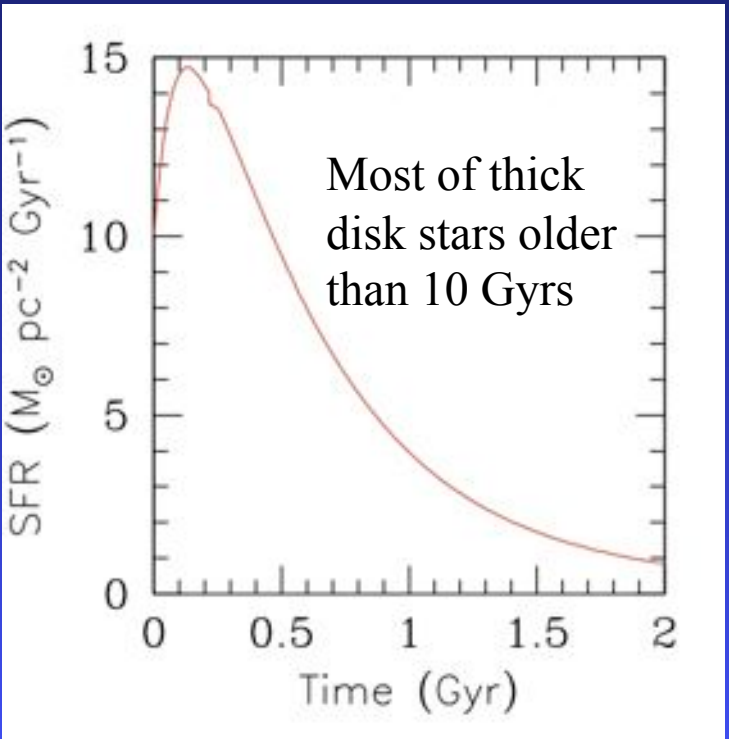
(Chiappini 2009 IAU 254, Chiappini et al. 2010 in prep)

Thick vs Thin

-Different GAS Infall timescales and SFEs

-Resulting into different MDs, Age distributions and SFHs



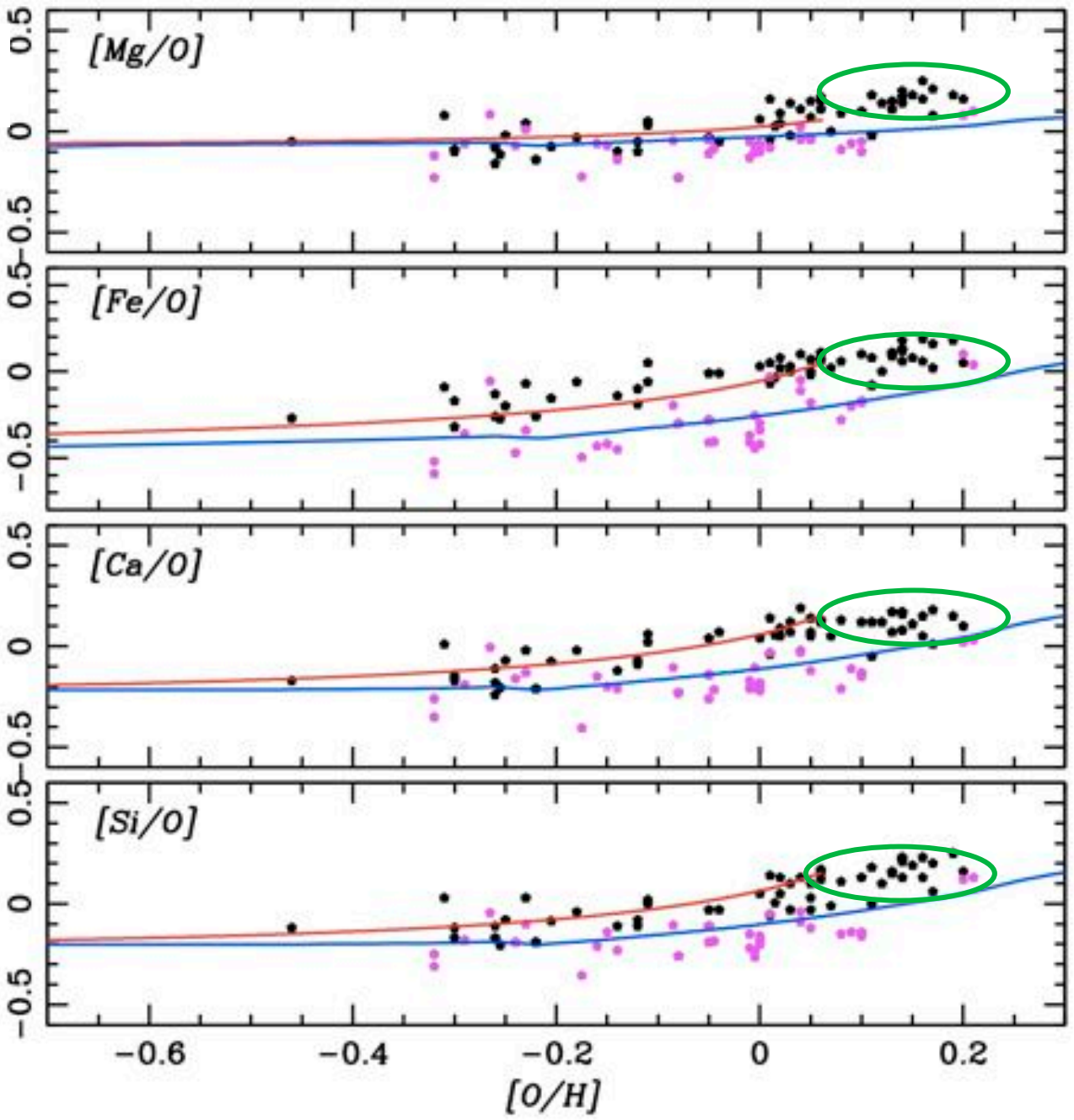


Bulge? (Grenon 1989)
Inner disk (radial migration?)

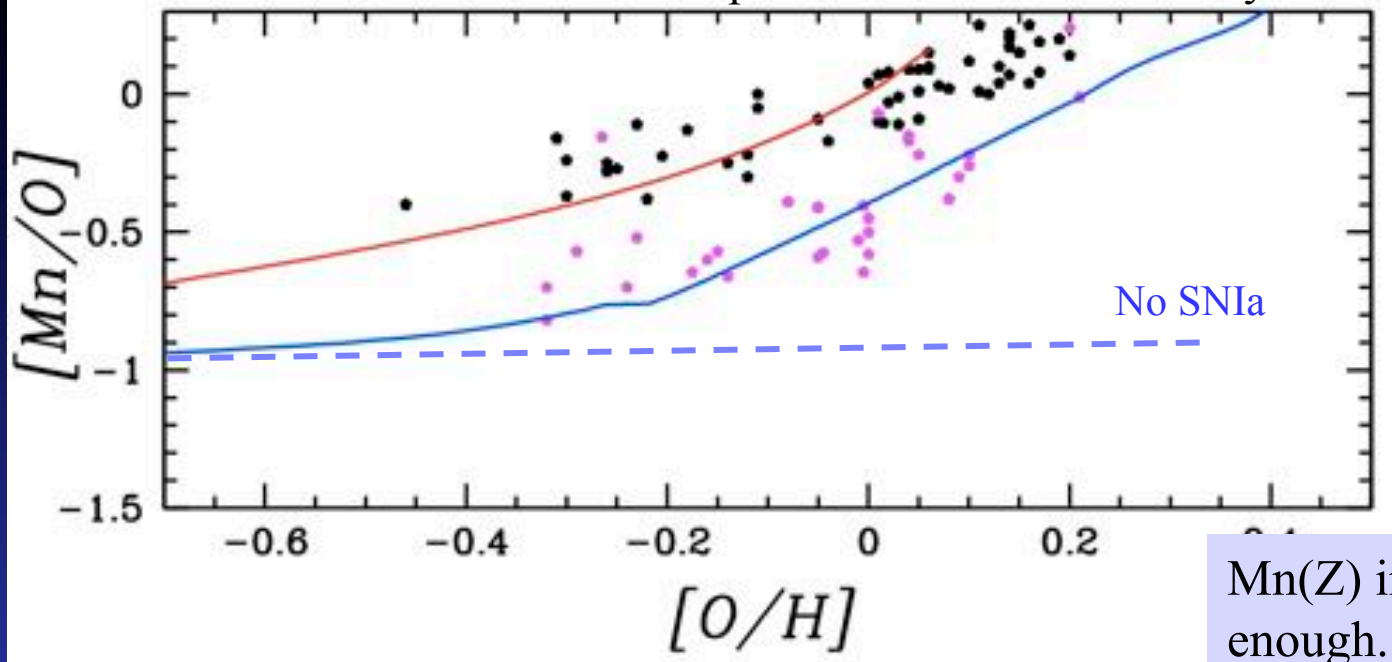
IAU268 – Barbuy et al. - Super Metal Rich Stars: The peculiar kinematics suggests the thin disk close to the bulge as the probable birthplace of these. From Hipparcos data, it appears that the turnoff of this population indicates an age of 10-11 Gyr (Grenon 1999)

Models:
THICK
THIN

Data (Feltzing & collab.):
THICK
THIN



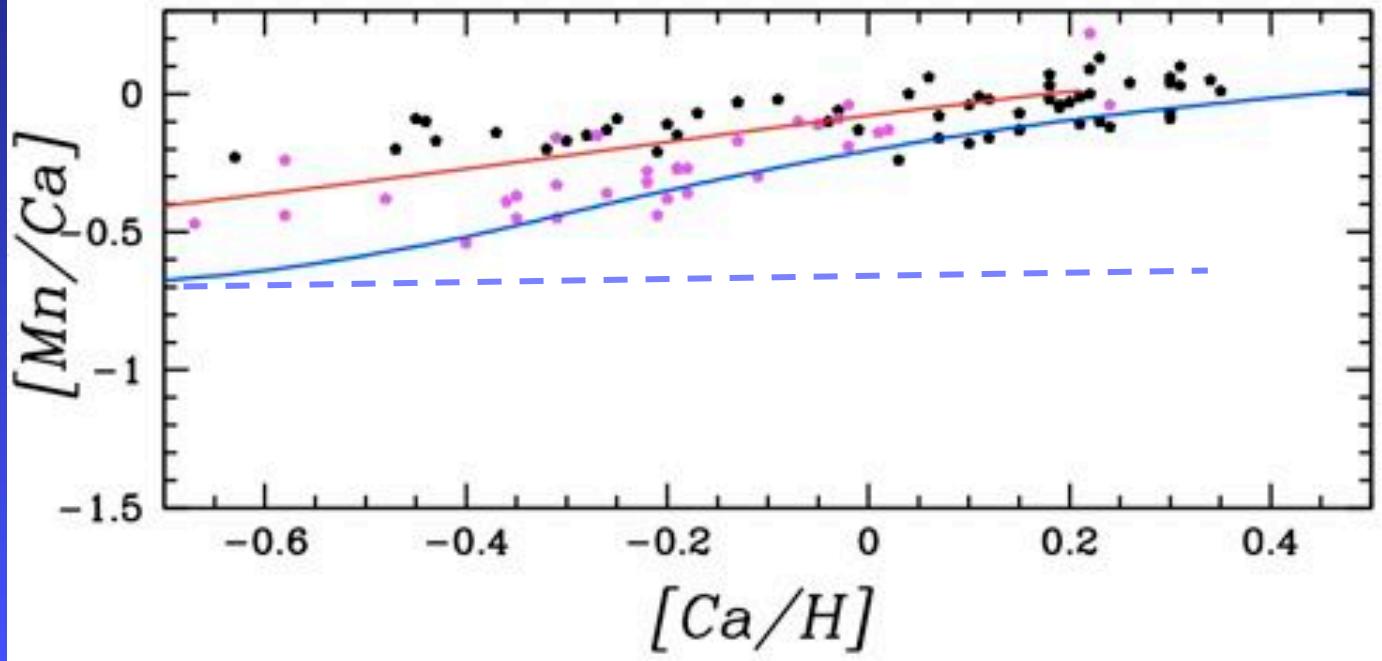
Differences thick/thin could be important to constrain stellar yields



Models:
THICK
THIN

Mn(Z) in SNII not enough. Need SNIa

Data:
THICK
THIN



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

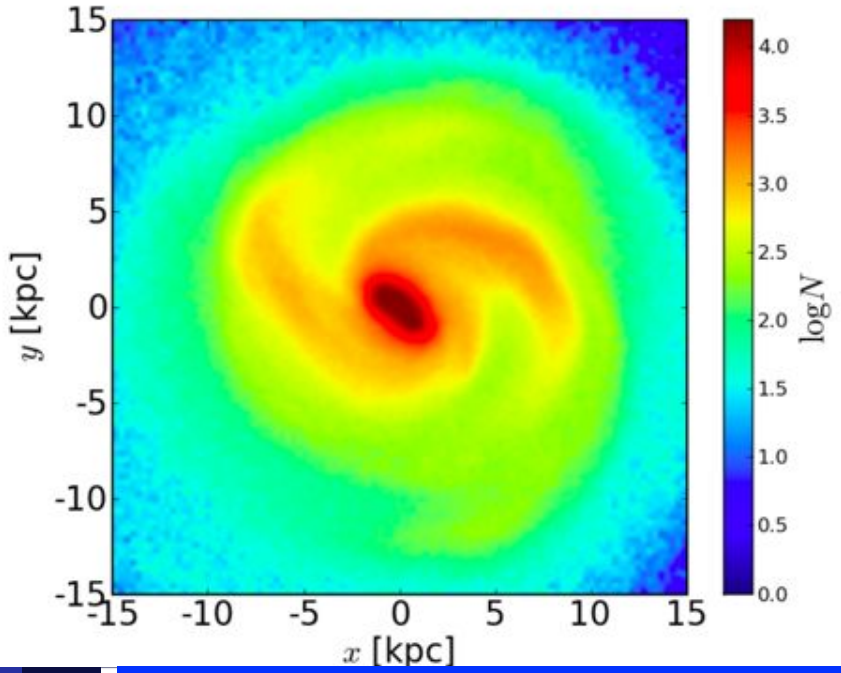
Important extra constraints from dynamics/structural parameters: e.g. orbital eccentricity distribution (Sales et al. 2009); variations of scale-height with galactocentric distance (Bournaud et al. 2009) + Radial mixing (Minchev & Famaey 2009).

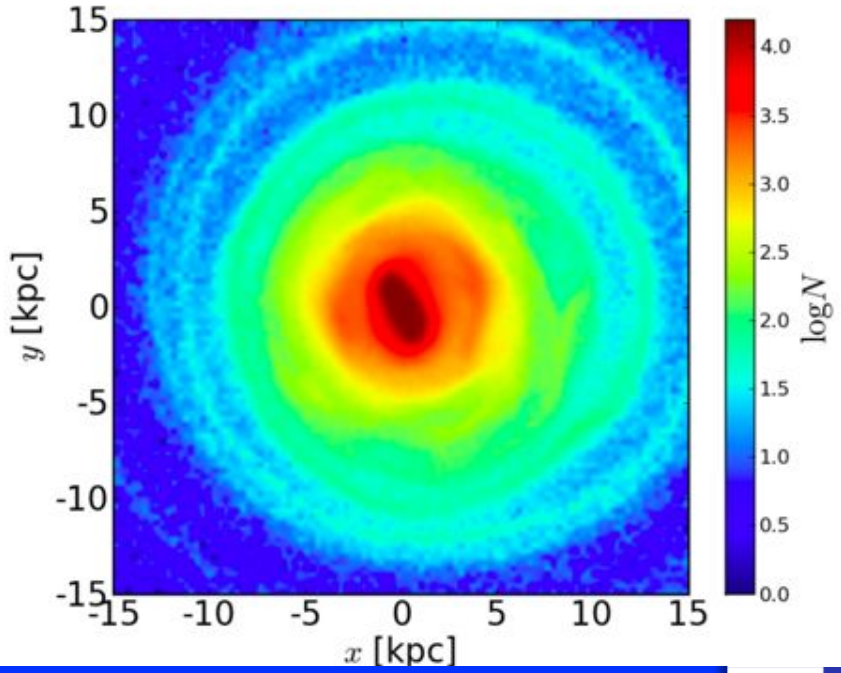
Stellar Migration

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

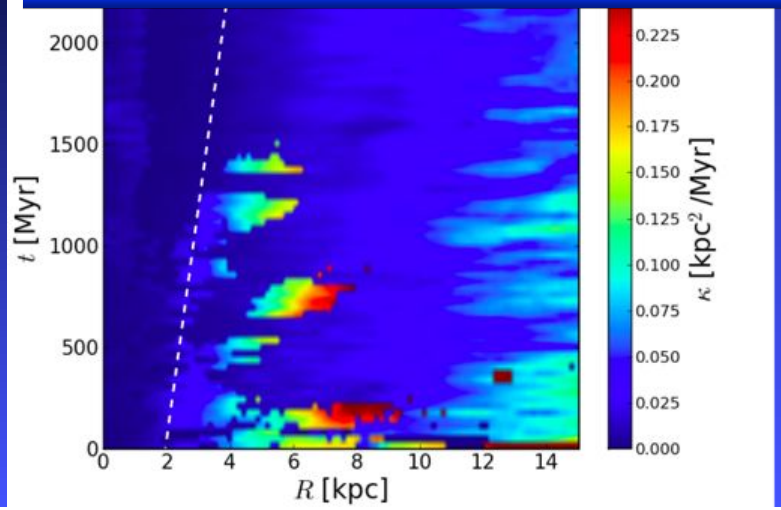
More spiral arms/less massive bar (without halo)

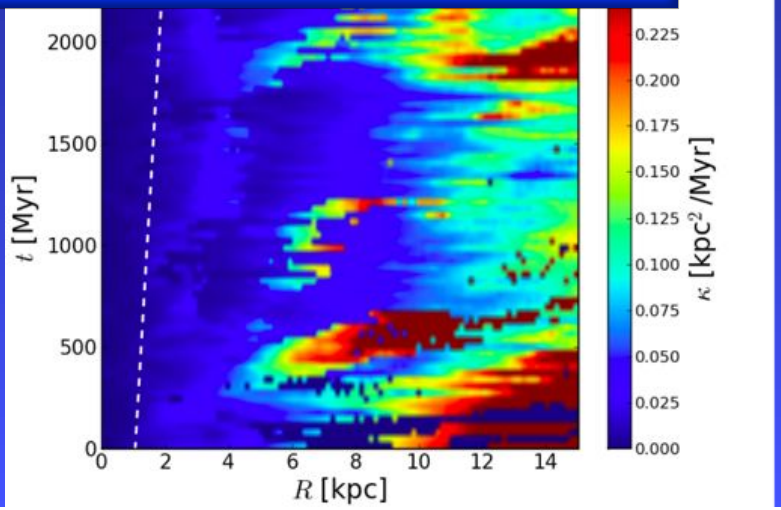
More massive bar/less spiral arms (with halo)



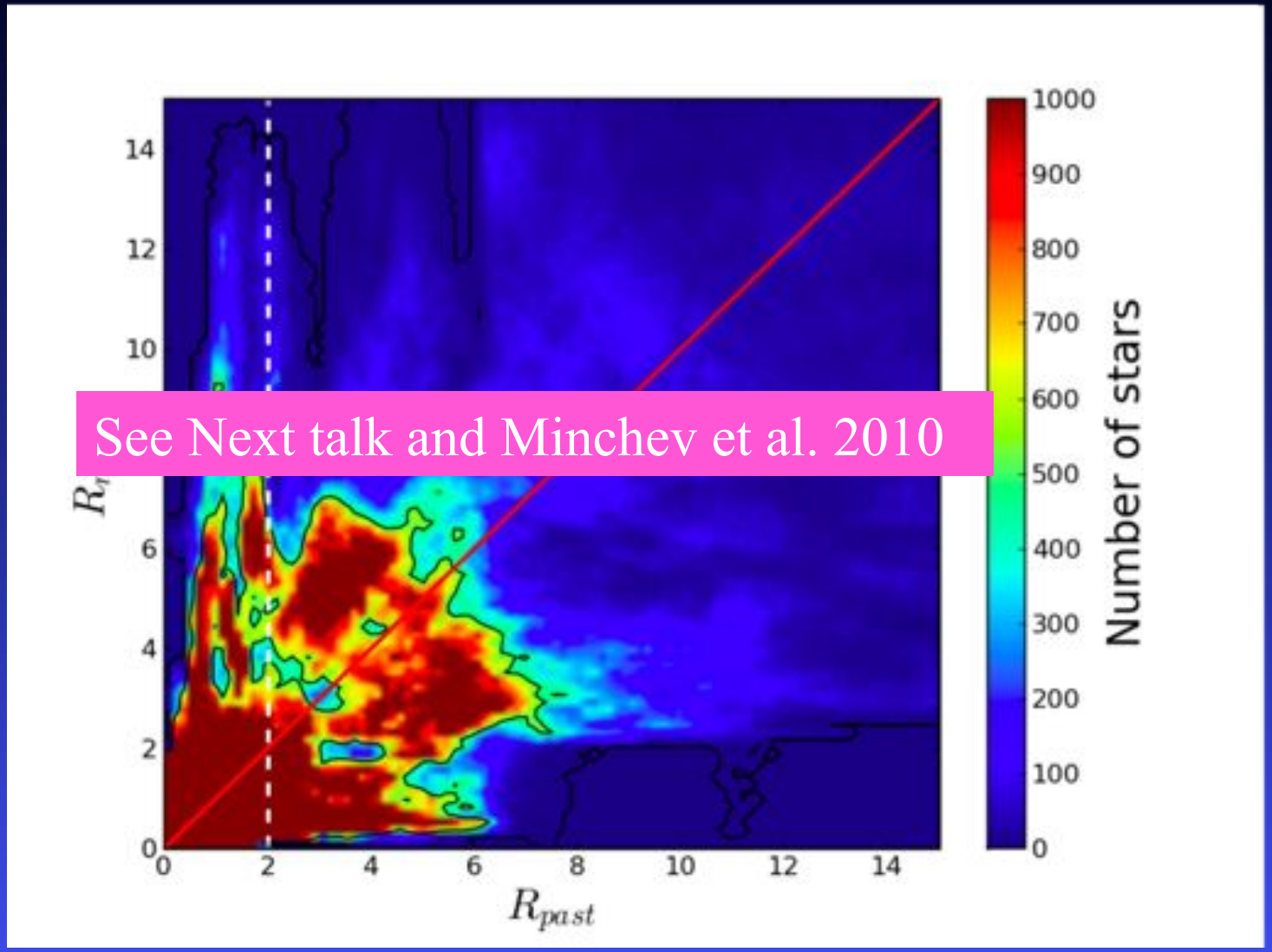


Diffusion Coefficient is not constant and it depends strongly on the bar strength





Present Stars and their radial distribution in the past



Migration of stars in the radial direction is strongly dependent on bar

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

Anticipated Spatial Distribution Model

For currently selected fields

(not all fields selected yet):

Bulge	9000 stars
Thin disk	77800 stars
Thick disk	5600 stars
Halo	2900 stars