“New problems in stellar astrophysics“

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New questions

New questions as a result of :

- New large facilities (high resolution spectrographs on 8m class telescopes, survey telescopes, Hipparcos satellite etc.)
- Large surveys (large homogenous data samples)
- Increased computing capacity (large simulations, 3D stellar atmospheres etc.)
- etc.

Selected questions

Star Formation (How did the First Stars form?

Big Bang predictions of Lithium abundance (Li in metal poor stars?)

First Generations of Supernovae (Do we observe the Yields from early progenitors that models predict?)

What is the age of a star? (Isochrones, radioactive decay, asteroseismology)

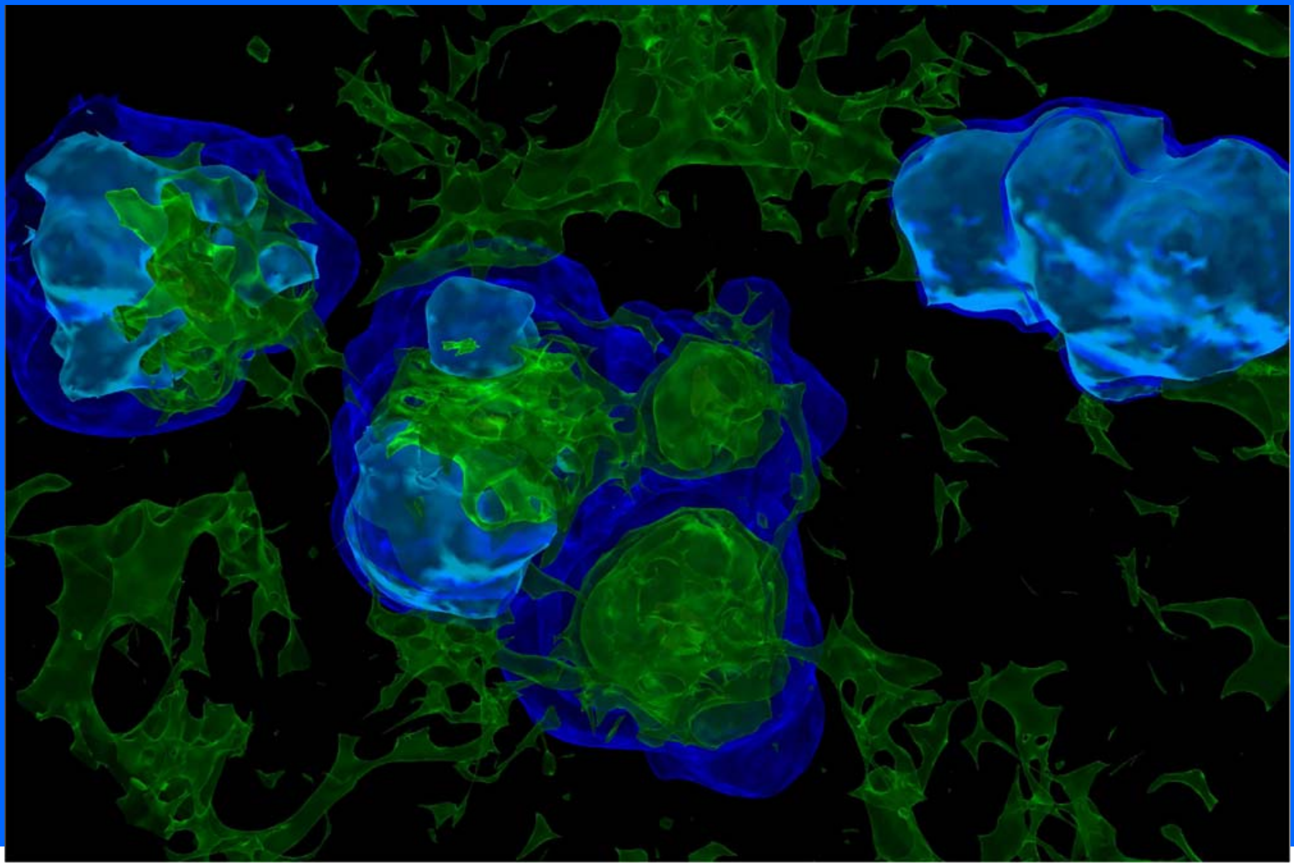
Temperature scale (Why different Teff from photometry and spectroscopy?)

What is the Metallicity ([Fe/H] or ([M/H]) of a star? (derived from spectroscopy, photometry, asteroseismology. Temperature dependent.)

How did the First Stars form?

- Metal Poor stars formed at redshift Z~5 in the Milky Way.
- Mass? (several thousands of M_o?)
- Cooling mechanism? Now shown that molecular H can do it. (Bromm et al.: "*The formation of the first stars and galaxies*", Nature, Volume 459, Issue 7243, pp. 49-54 (2009).
- See also Frebel et al.", *Probing the formation of the first low-mass stars with stellar archaeology* ", MNRAS Letters, Volume 380, Issue 1, pp. L40-L44.

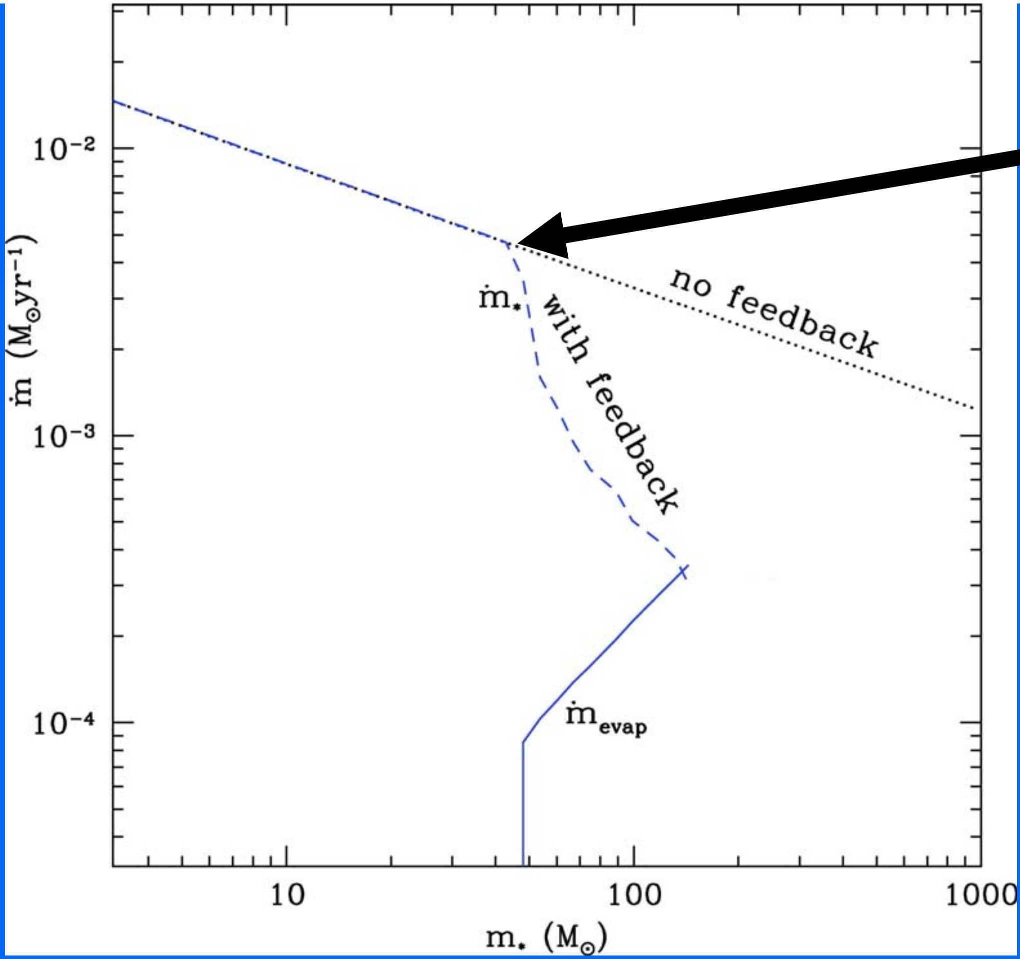
Formation of the First Stars



Radiative feedback around the first stars. Ionized bubbles are shown in blue, and regions of high molecule abundance in green. The abundance of HD molecules allows the primordial gas to cool possibly leading to the formation of Pop III.2 stars after these regions have re-collapsed so that gas densities are sufficiently high again for gravitational instability to occur. (Bromm et al.,in Nature, 20009)

Formation of the First Stars (cont.)

Accretion rate



Final Pop III mass

Numerical simulations of feedback limited accretion. The accretion rate vs. protostellar mass is shown in the cases of “no feedback” and “with feedback”. Even as an H II region is built up, accretion continues through an accretion disk.. Also shown is the corresponding rate. The intersection of the two curves determines the final Pop III mass. (Bromm et al., Nature 2009)

Big Bang theory predicts

- Universe expands (Hubble's expansion law)
- Cosmic microwave background
- First nucleosynthesis (abundances)

  Deuterium

  ^{4}He

  ^{7}Li

Big Bang Nucleosynthesis

Theory predicts:

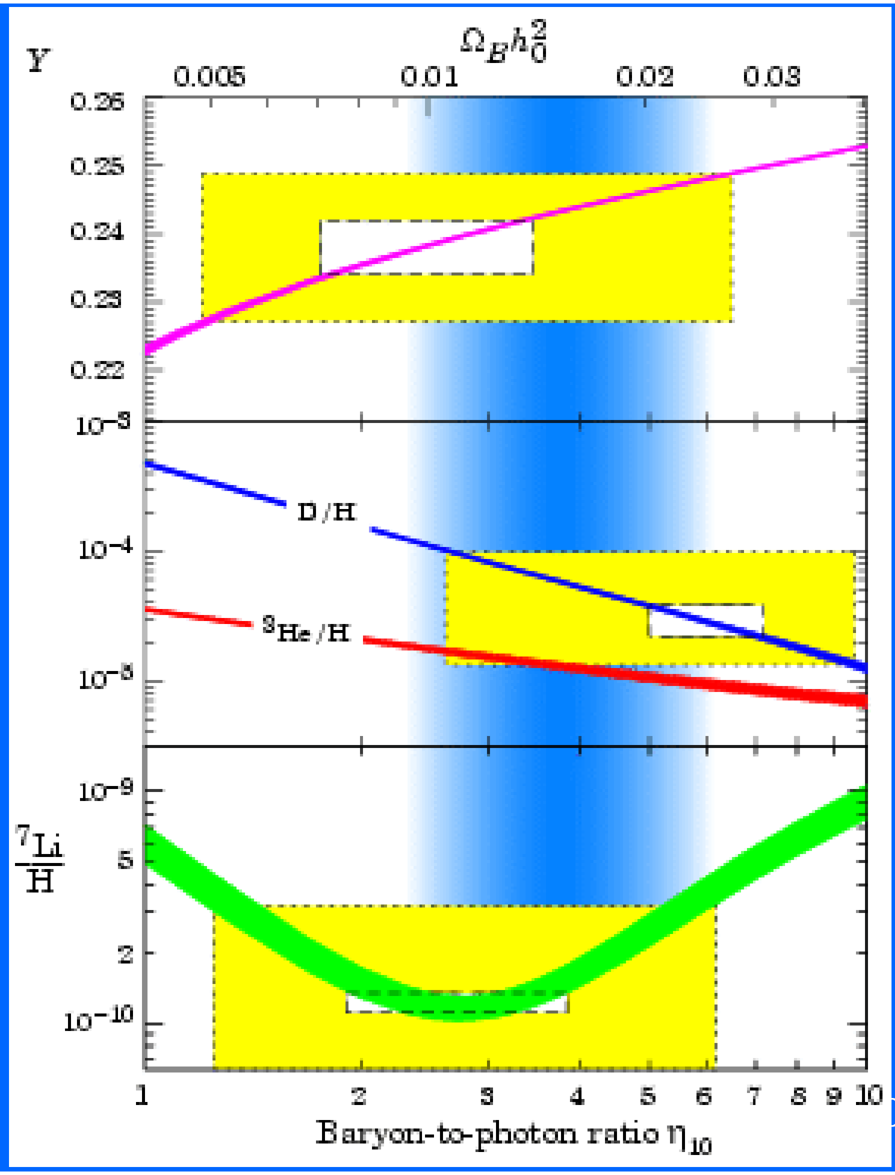
Light element abundances

as function of baryon density.

Observations:

measure abundances of light elements in astrophysical environments.

Get cosmic baryon content



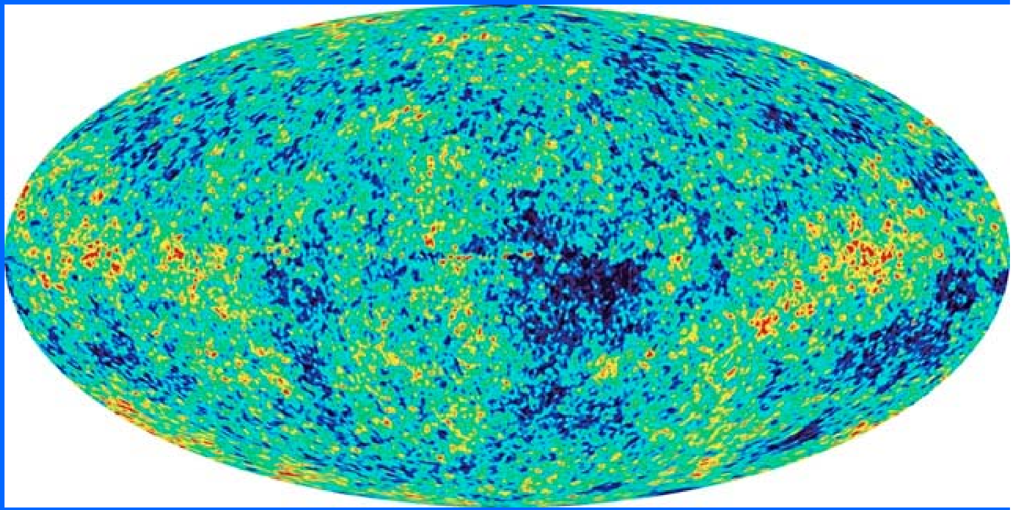
Big Bang Nucleosynthesis Tested

Cosmic Microwave Background (CMB)

Snapshot of universe T~eV

ionized ➡ neutral

opaque ➡ transparent



T Fluctuations (Anisotropy)

sensitive to

baryon content of plasma

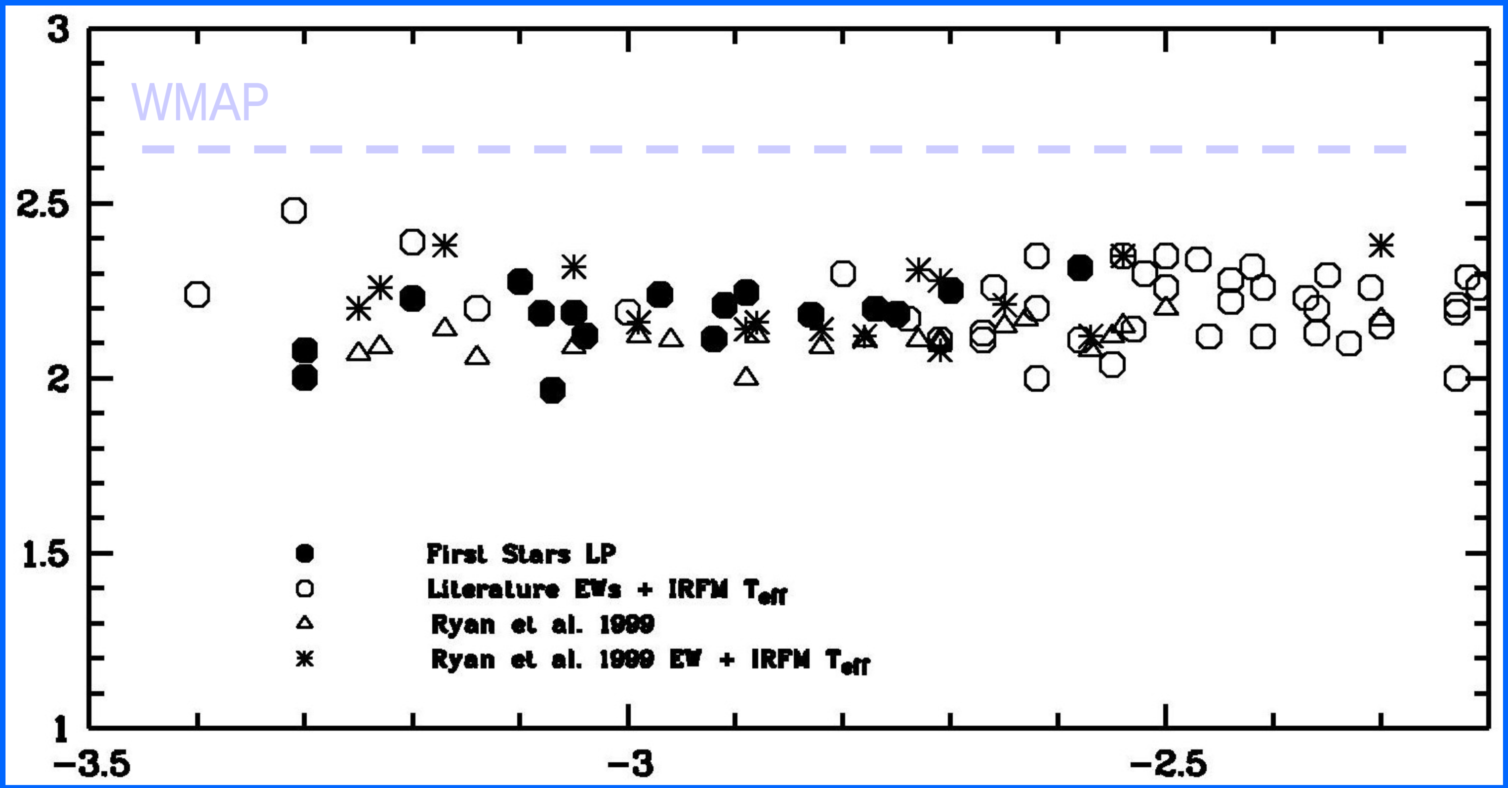
Indep. measure of baryon density

$$\delta\rho \rightarrow \delta T$$

Wilkinson Microwave Anisotropy Probe (WMAP)

Bennett et al 2003

Tracing primordial elements : Li



Measured Li in stars much below value predicted by WMAP & BBNS
Hard to explain the ***uniform*** depletion (diffusion)

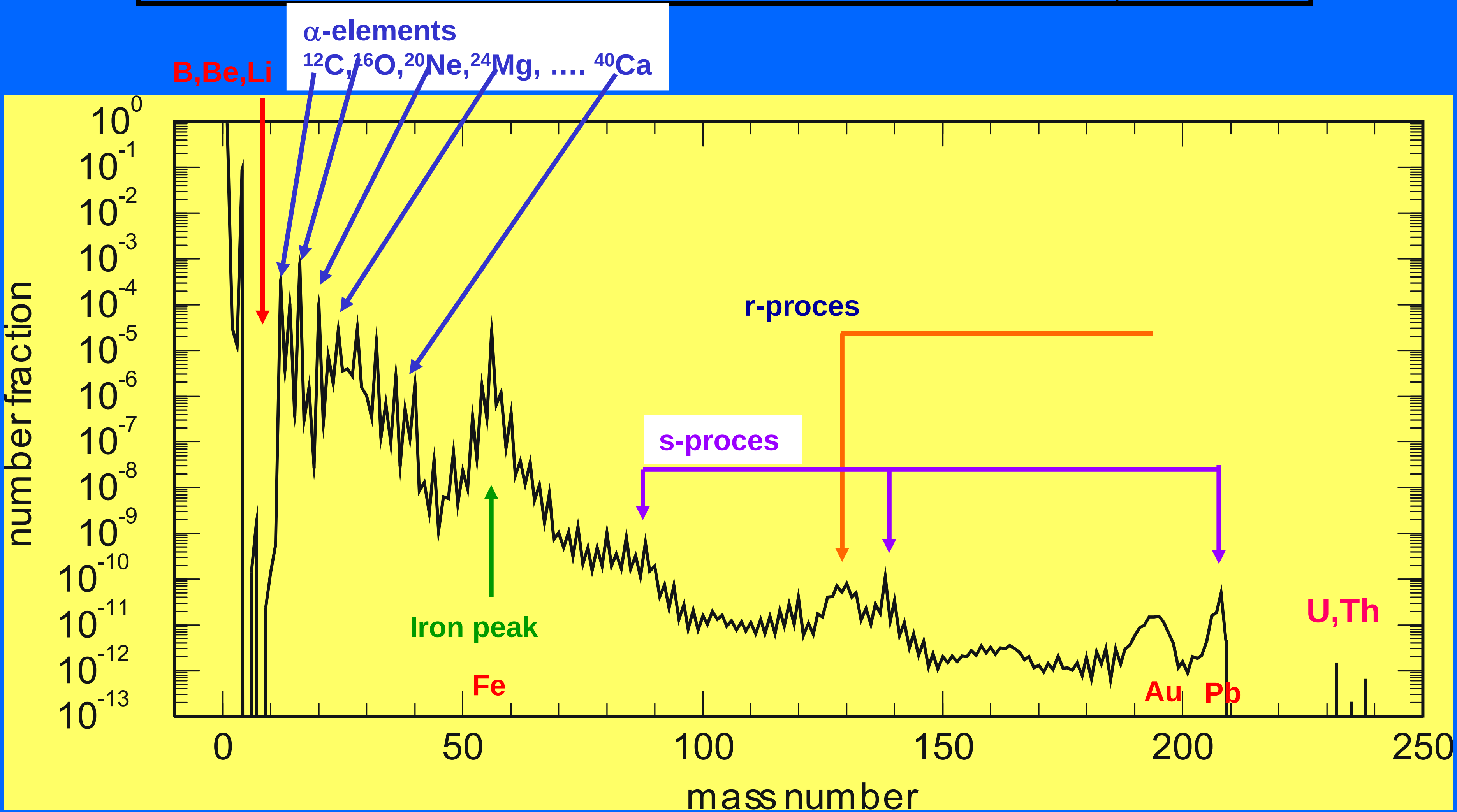
Possible explanation
Diffusion in Stellar atmospheres

Korn et al.: Nature 442, Issue7103 pp. 657-659 (2006) "*A probable stellar solution to the lithium*"

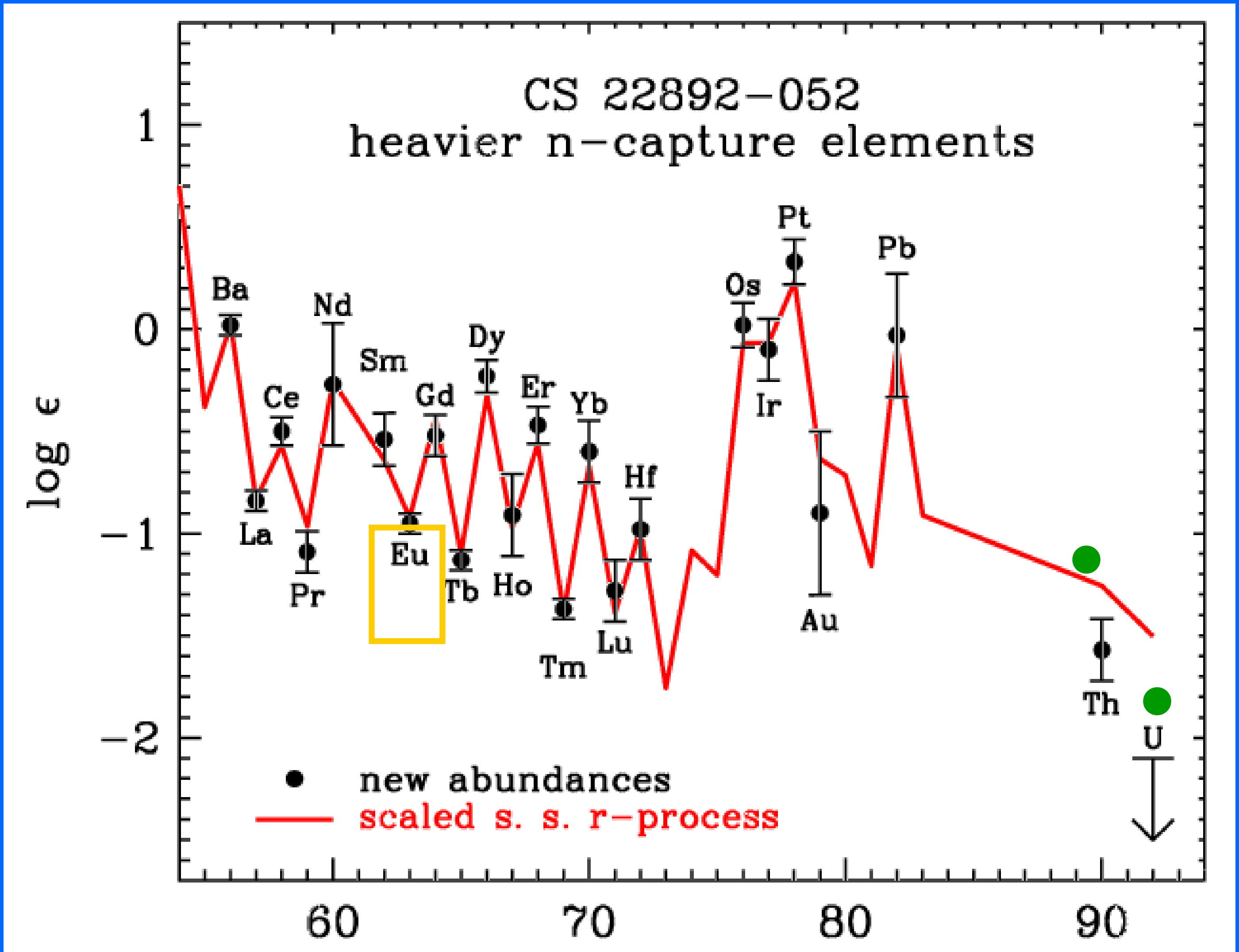
No clear conclusion

Solar abundances

Hydrogen ratio of mass	X = 0.71
Helium ratio of mass	Y = 0.28
Content of heavier elements	Z = 0.019
Elements heavier than Ni	0.000004



Z≥56 stable *n*-capture elements: excellent match to solar r-process.



Supernova Predictions of yields

Theoretical predictions be checked with elemental abundances from high resolution spectra of Metal Poor stars

Comparison with models:

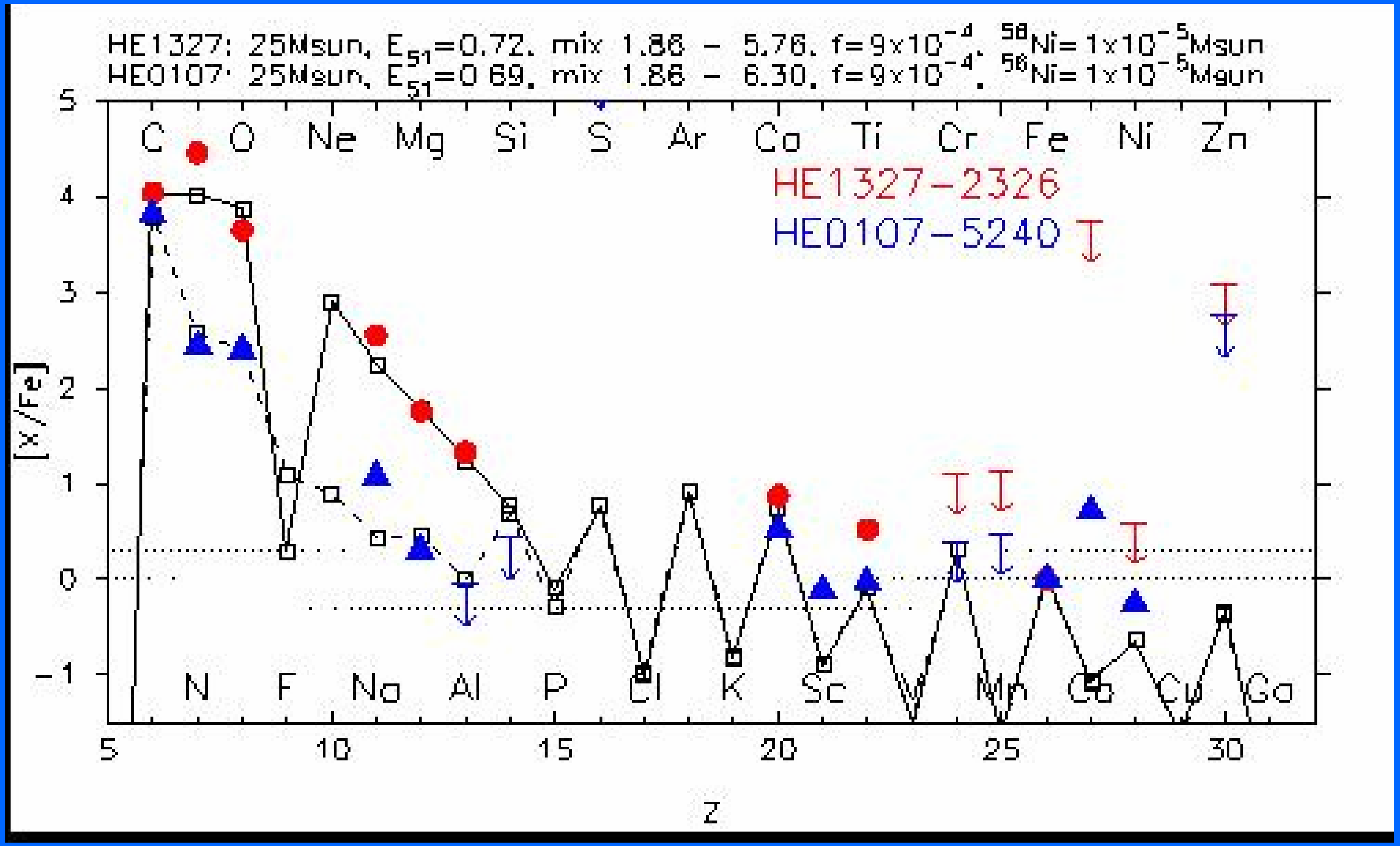
Tominaga et al. (2007)

Nomoto et al.   (2005)

Limongi Chieffi (2000, 2006)

Heger and Woosely (2002, 2008)

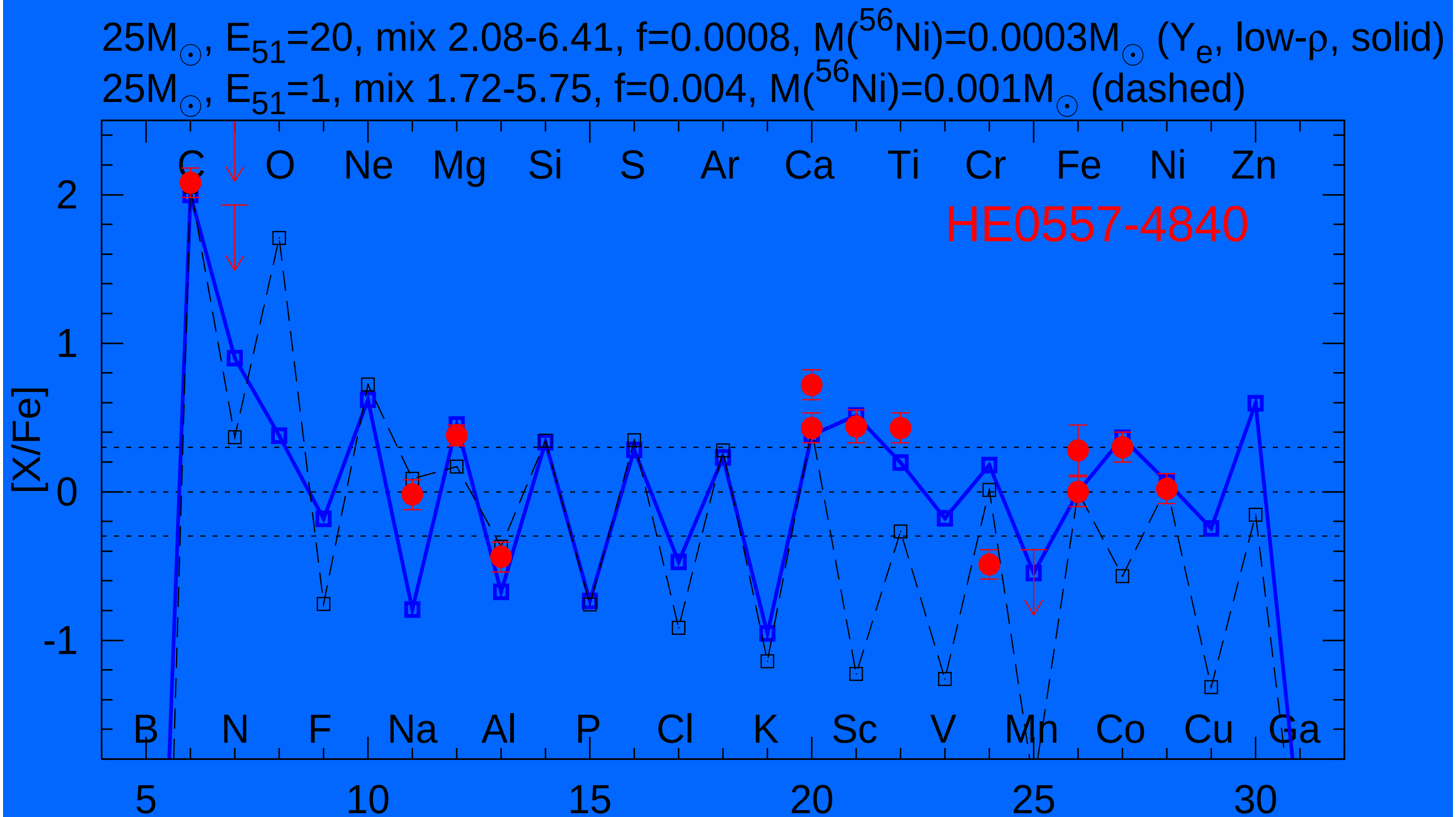
HMP stars: 1D Low Energy models (E_{51}< 1) mixing & fallback ➔ Models low in [Co/Fe]



Iwamoto et al. (2004)
Limongi & Chieffi (2006)
Heger & Woosley (2008)

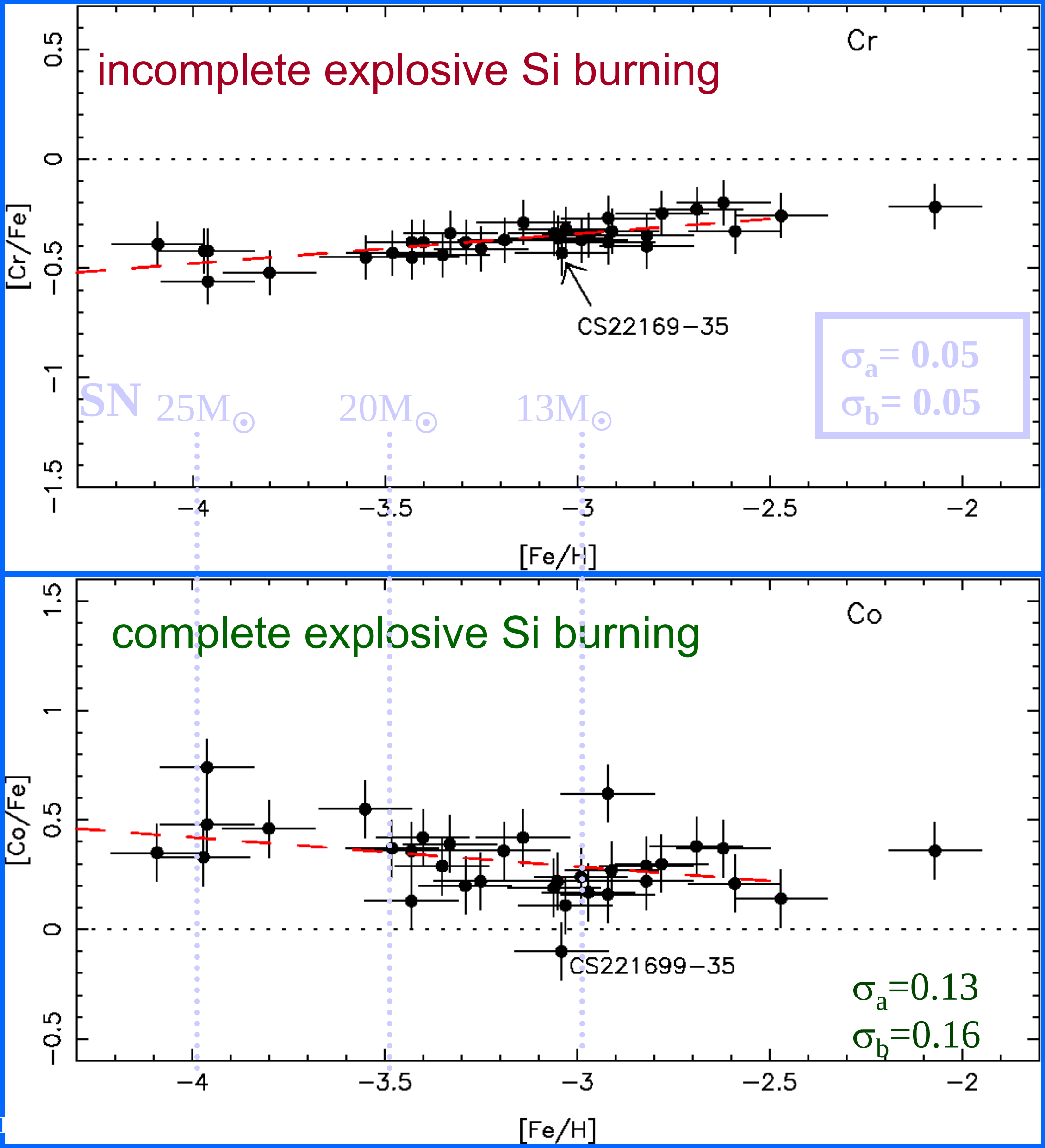
[Fe/H] = - 4.75

Hypernova model (E_{51}=20:1D)➔Co



(Norris, Christlieb, et al. 2007)

Autopsy of the first supernovae?



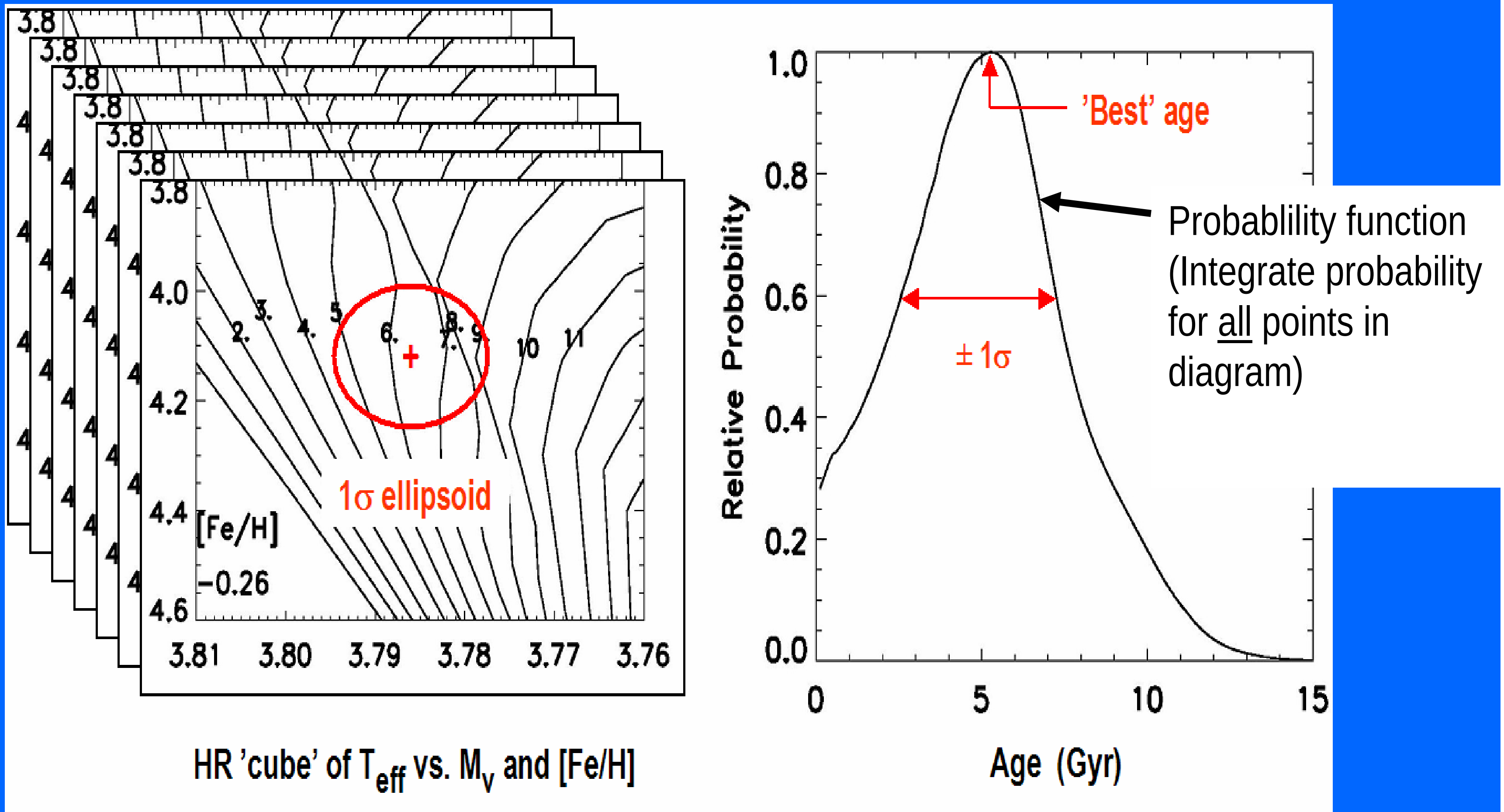
Incredibly low scatter!

- cosmic origin unliklely
- differential NLTE??

Supernovae of low mass retain more of the core (Fe, Co, Ni) during collapse to a BH or neutron star

Ages

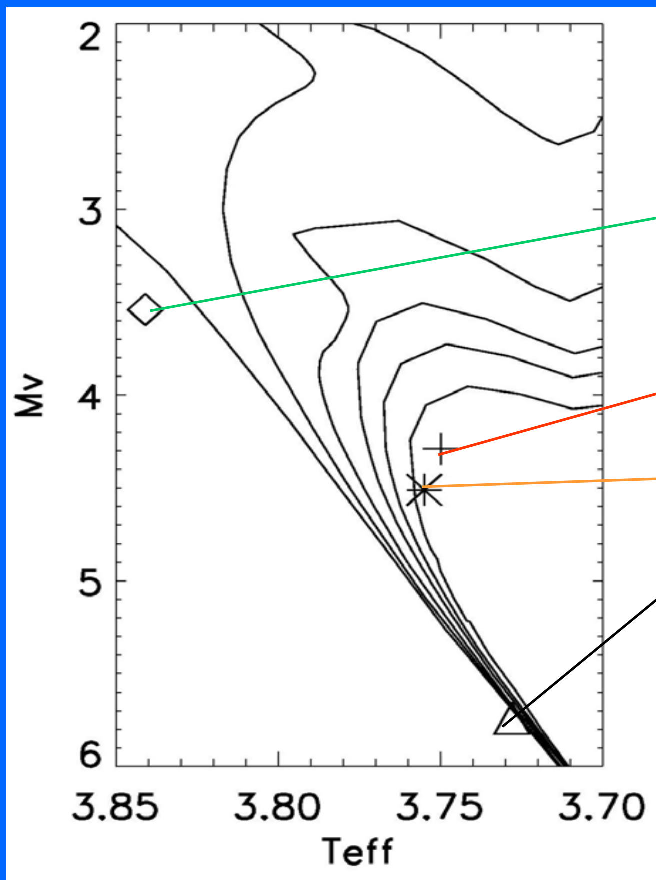
Age determination of F,G stars from isochrones



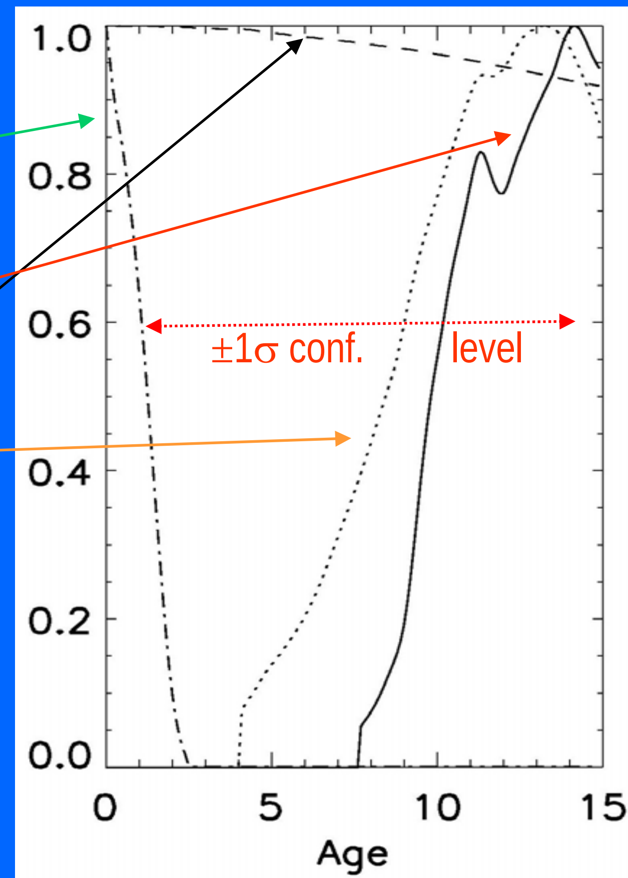
Method by Jørgensen & Lindegren (A&A 2005), age calculations by Jørgensen in Nordström et al. A&A, 2004

NB: Need to adjust Teff scale to match observed ZAMS @ low [Fe/H] !

When isochrone ages are uncertain :



HR diagram

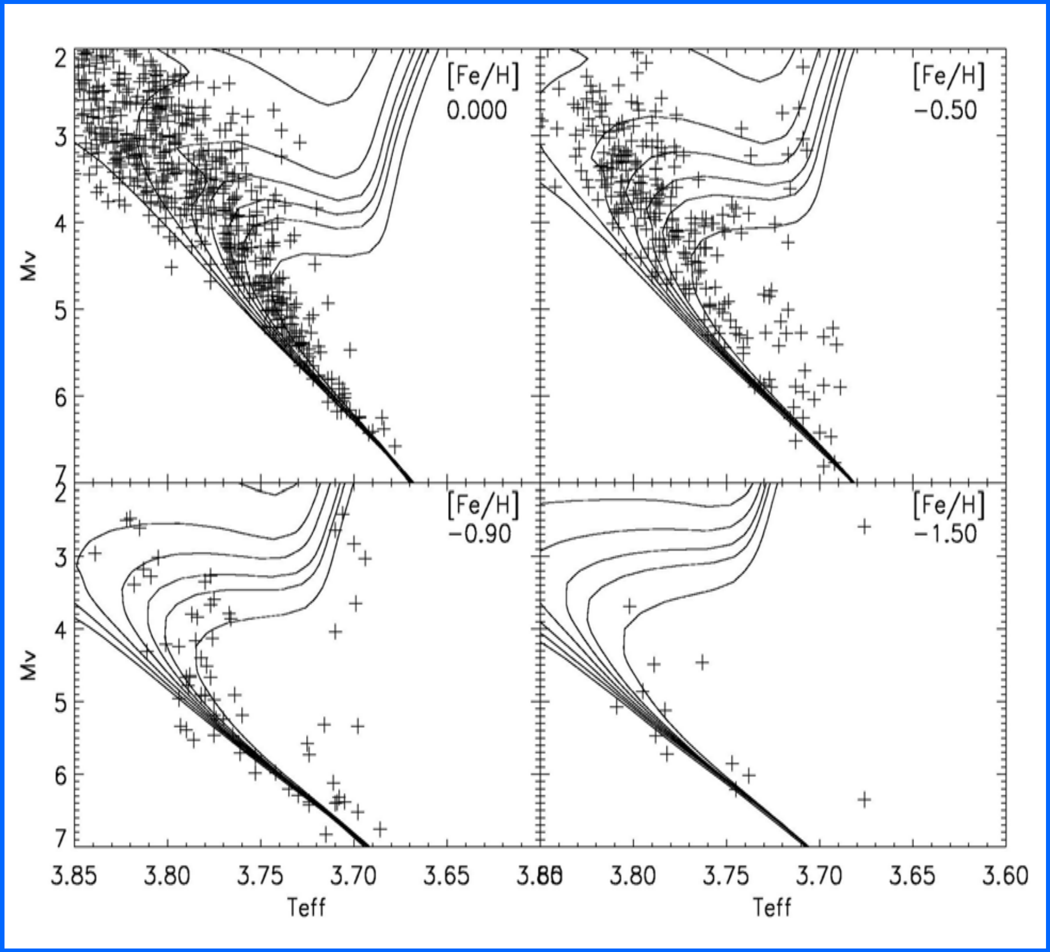


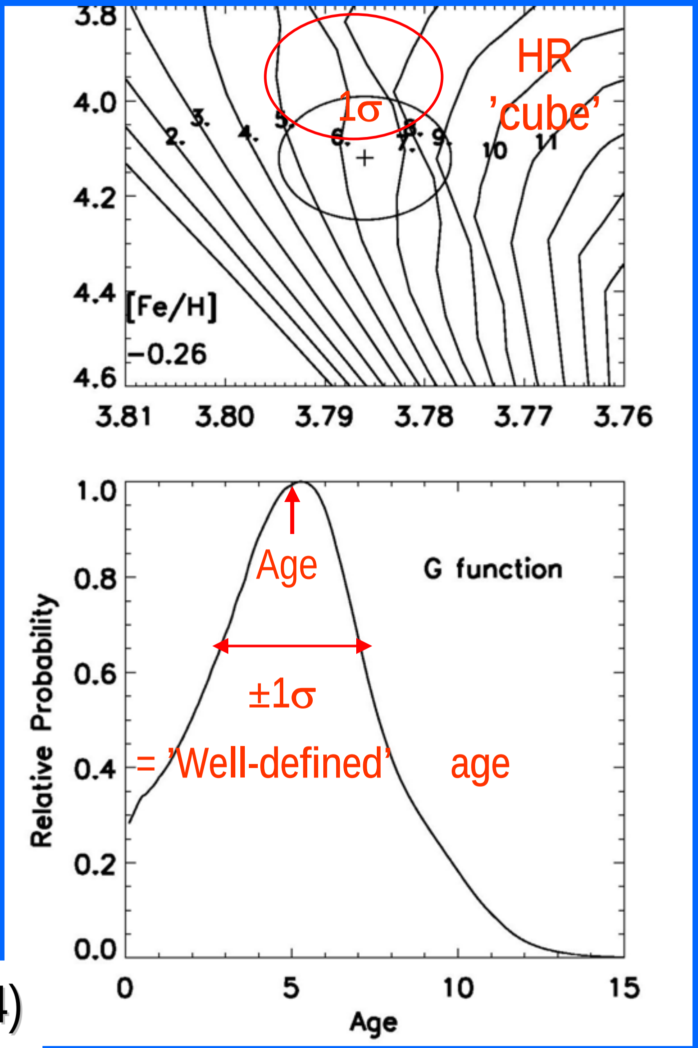
Probability functions

Ages not well-defined outside favourable parts of the HR diagram!

Computing isochrone ages

Method by Jørgensen & Lindegren (2005)





Age calculations by Jørgensen (in Nordström et al. 2004)

Need to adjust Teff scale @ low [Fe/H] !

Age from uranium-thorium

$$\text{Time} = 46.67[\log(\text{Th/S})_0 - \log(\text{Th/S})_{\text{now}}]$$

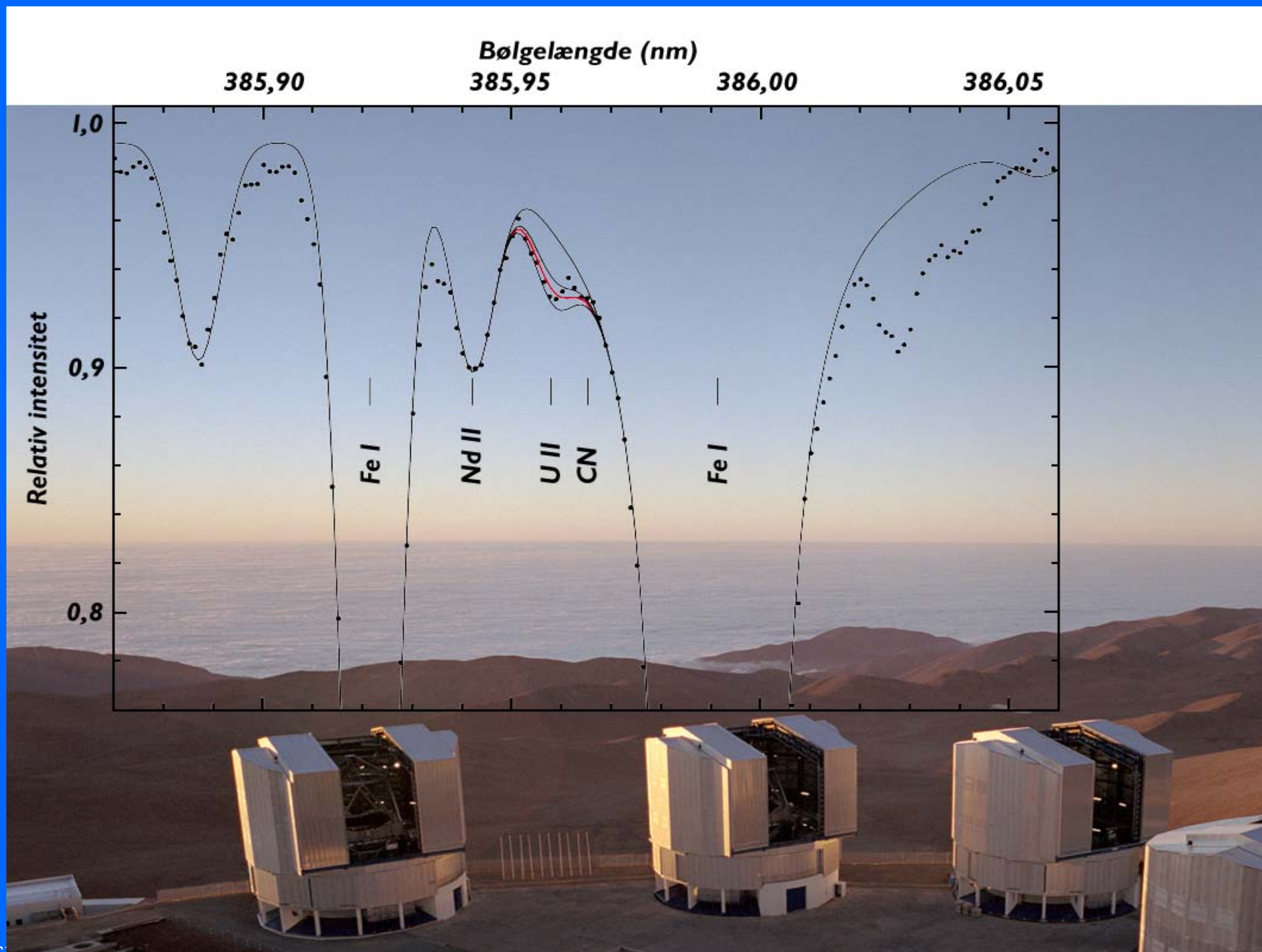
$$\text{Time} = 14.84[\log(\text{U/S})_0 - \log(\text{U/S})_{\text{now}}]$$

initial

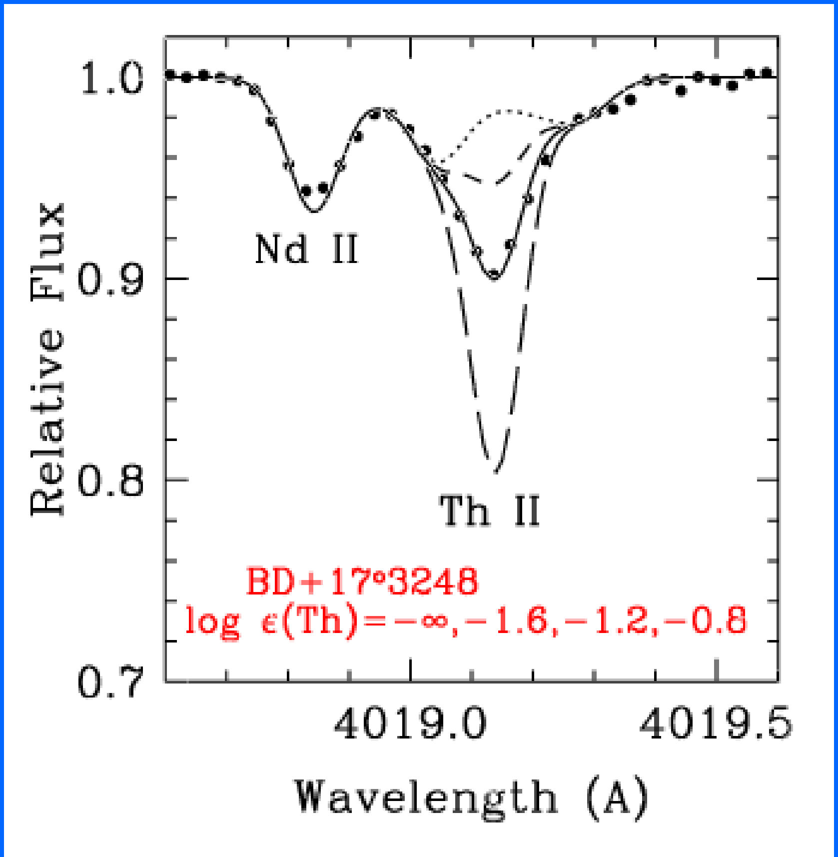
$$\text{Time} = 21.76[\log(\text{U/Th})_0 - \log(\text{U/Th})_{\text{now}}]$$

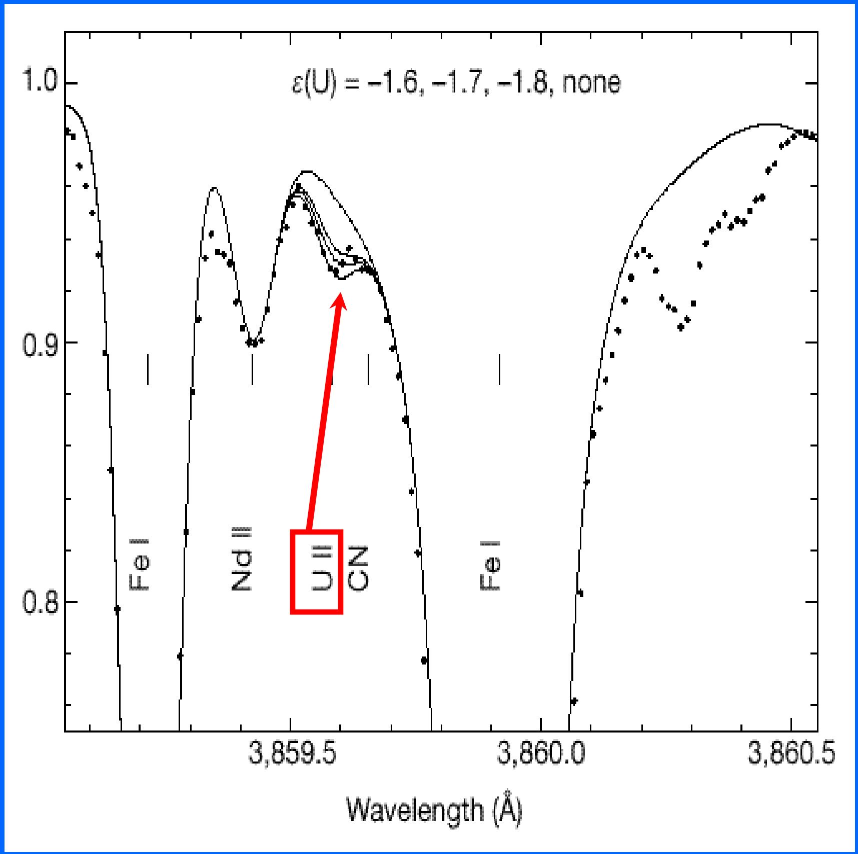
The ESO VLT/2...

First uranium in a very old star – Radioactive age dating



Th II and U II lines





BD +17°3248

CS 31082-001

Cayrel *et al.* (Nature 2001)

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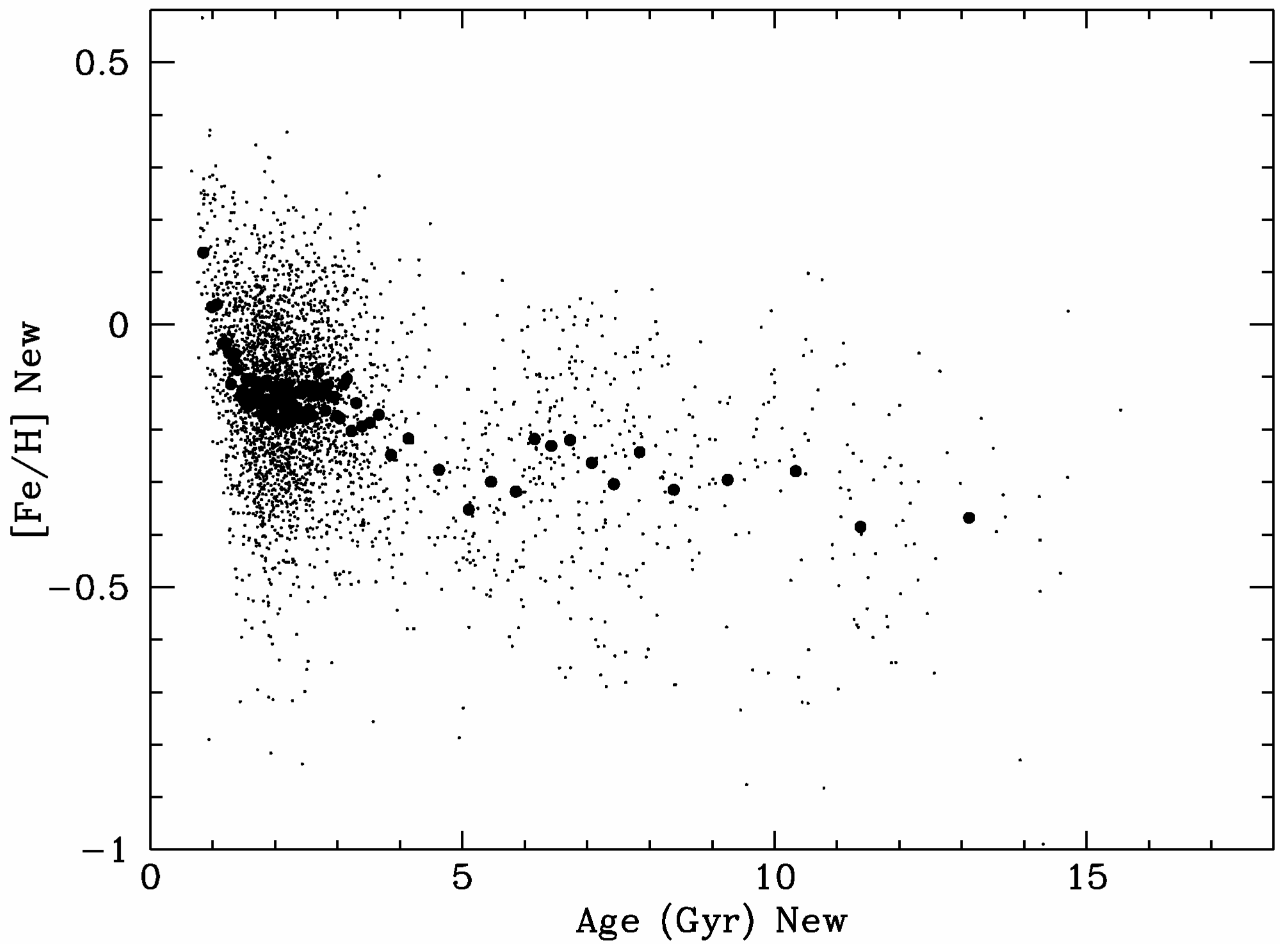
Result = 13.5 Gyr +/- 2 Gyr

Future: Ages from asteroseismology

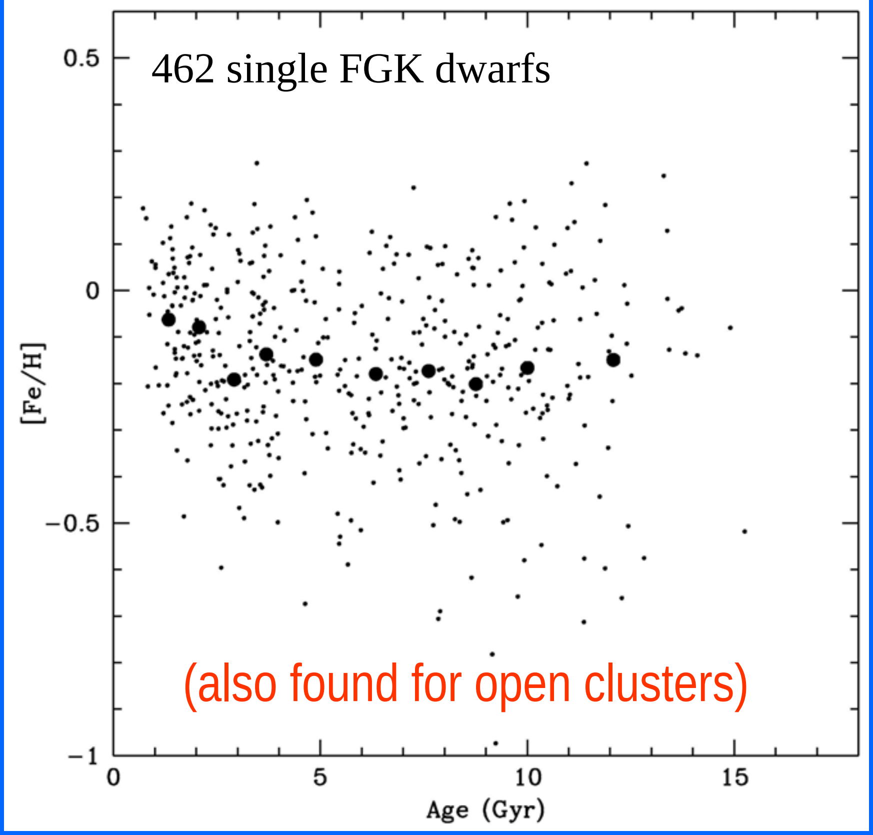
Age-Metallicity (GCS 14000 stars)

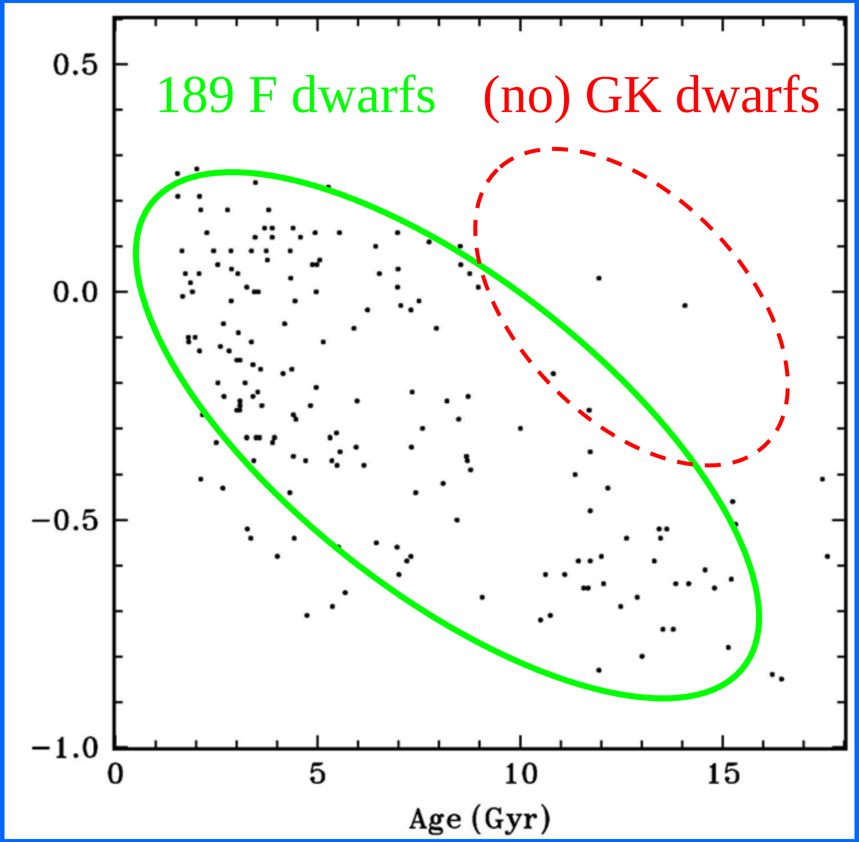


Nordström et al. 2004

Age - metallicity relations: Now & then

(single stars, well-defined ages)





Volume-limited sample (d < 40 pc)

Nordström et al. 2004, Holmberg et al. 2007

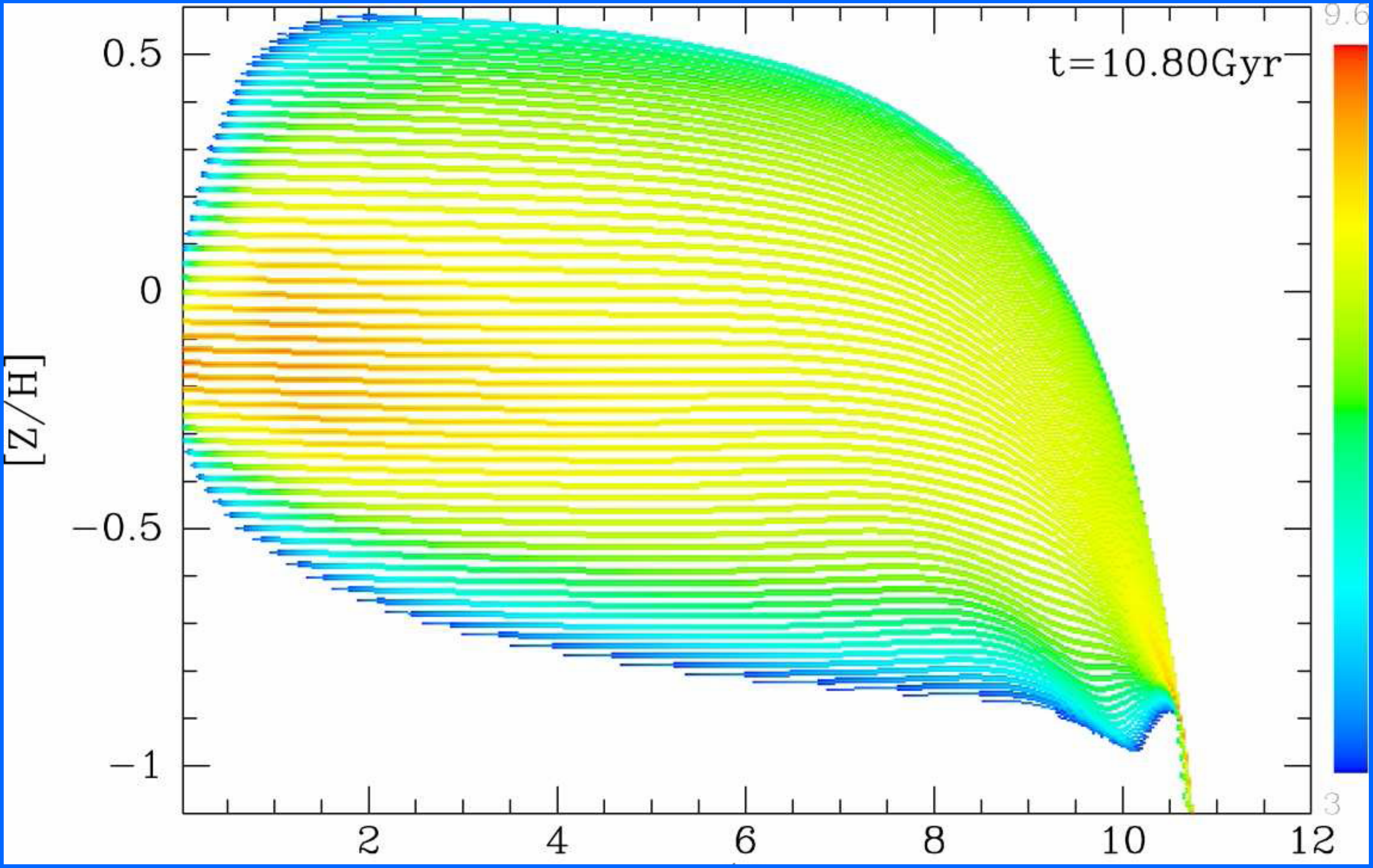
Edvardsson et al. (1993)

Stellar migration (Schönrich, Binney, 2009)

Radial mixing

already suggested by Chen, Y.Q et al (2003) from observations of old metal-rich stars in Sn

Metallicity

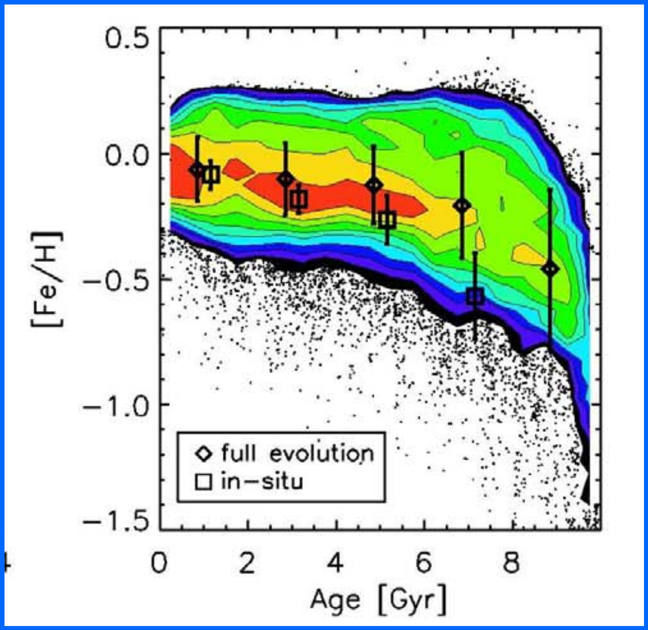


age

Stellar migration (Roškar ApJ, 2008)

High resolution N-body calculations; SPH code GASOLINE.
Resonant scattering by transient spiral arms – circular orbits conserved.

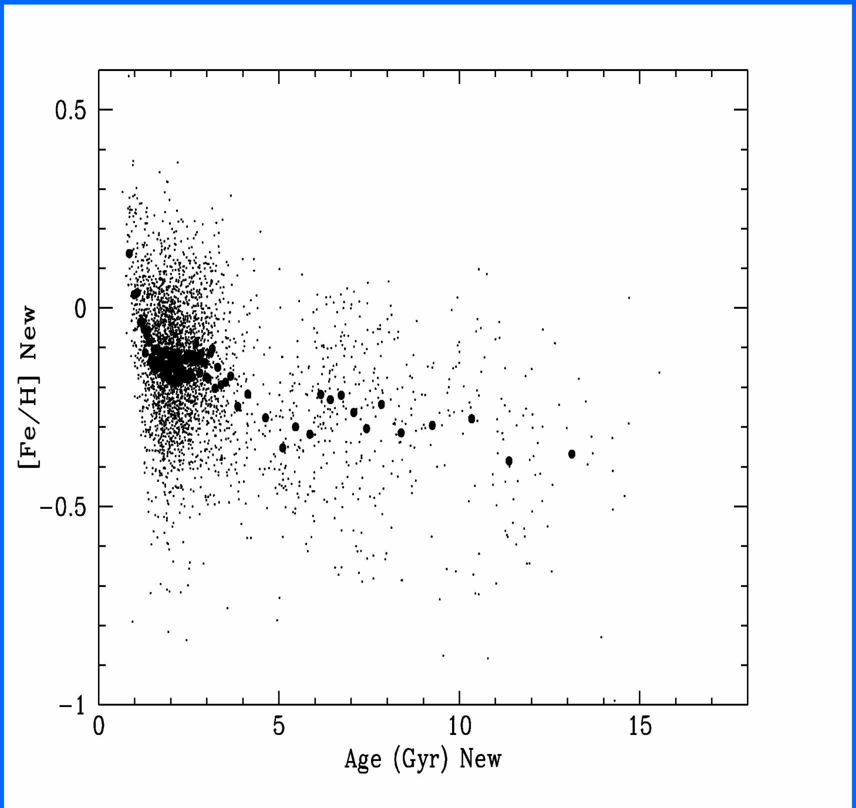
Radial migration also explains flatness and spread in Age-metallicity relation



AMR: Conclusions from GCS sample

- Scatter more significant than any trend of the mean

Any theory that cannot explain why a large scatter exists is missing a crucial piece of the physics!



Possible explanations:

⇒ Stellar migration, transient spiral arms etc.

⇒ Accreted satellites,

⇒ Planet formation and [Fe/H] dependence - small, but not negligible (Melendez 2009)

- etc.

AMR: Conclusions from GCS sample (cont.)

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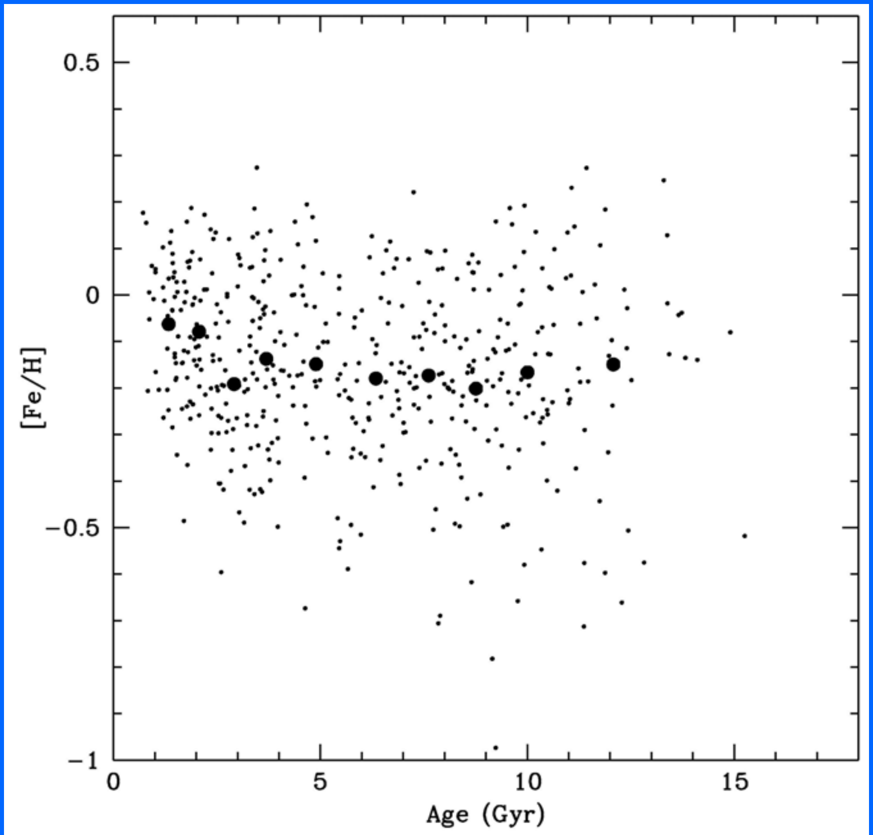


Volume complete 40pc, single stars

Nordström et al. 2004, Holmberg et al.2007

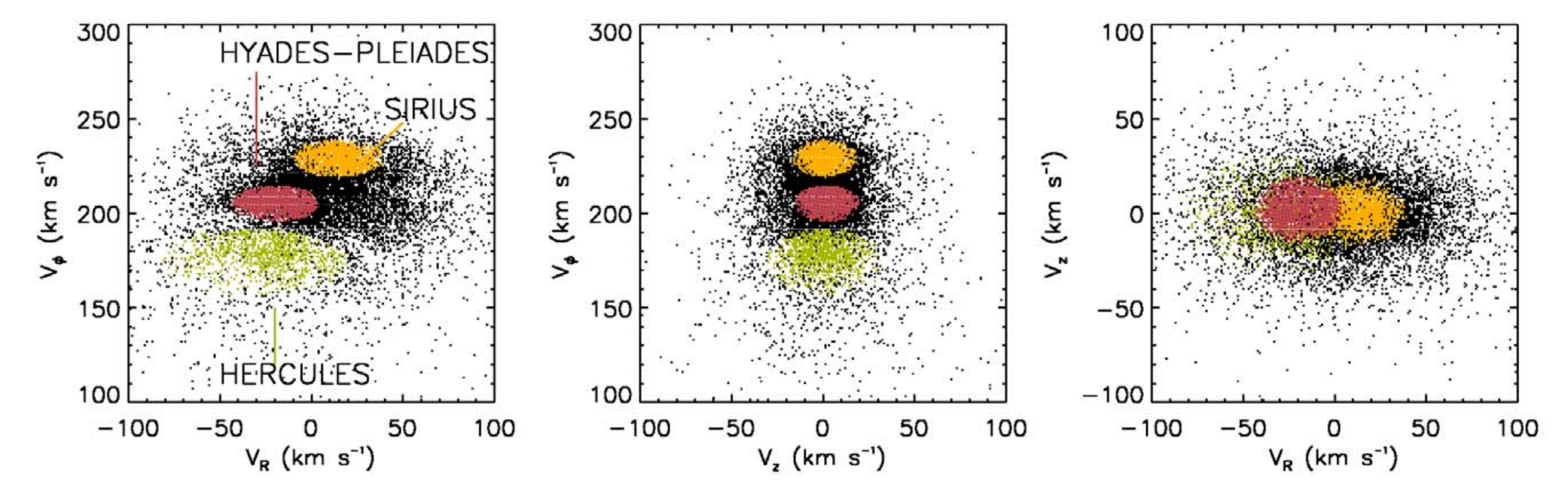
Dynamical history of the Galaxy (Solar neigbourhood)

Known dynamical substructures

"Dynamical streams" as identified by Famaey et al. (2005), Nordström et al. (2004).

Which process(es) created these features?

These groups are most probably related to dynamical perturbation by transient spiral waves (De Simone et al. 2004, Roškar 2008), NOT disrupted star clusters (different ages, Fe/H)



How to distinguish these dynamical features from the substructure due to past mergers?

Can we find the remains of accreted satellites?

Space of conserved quantities:

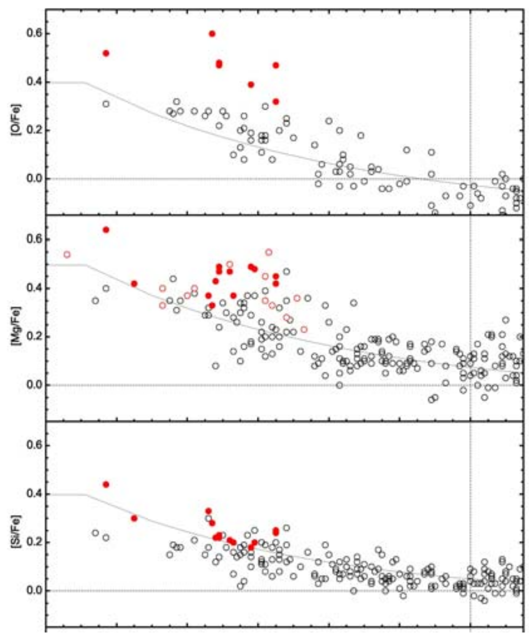
- Apocentre, Pericentre and z-angular momentum L_z (APL)-space shows very specific features. Roughly conserved quantities.
- Look for a projection of phase-space such that a satellite galaxy defines a coherent "lump" at all times.

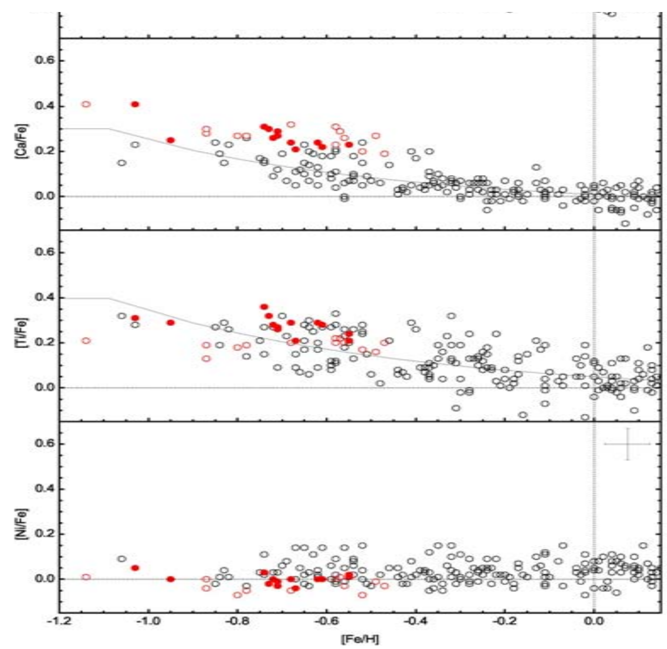
Several groups showed up as overdensities in APL space in Geneva-Copenhagen survey (Helmi et al. 2006).

Debris from infall?

Stonkuté, Nordström, Tautvaisiene (2009, work in progress)

Indicate that groups in APL space might be overabundant in α-elements



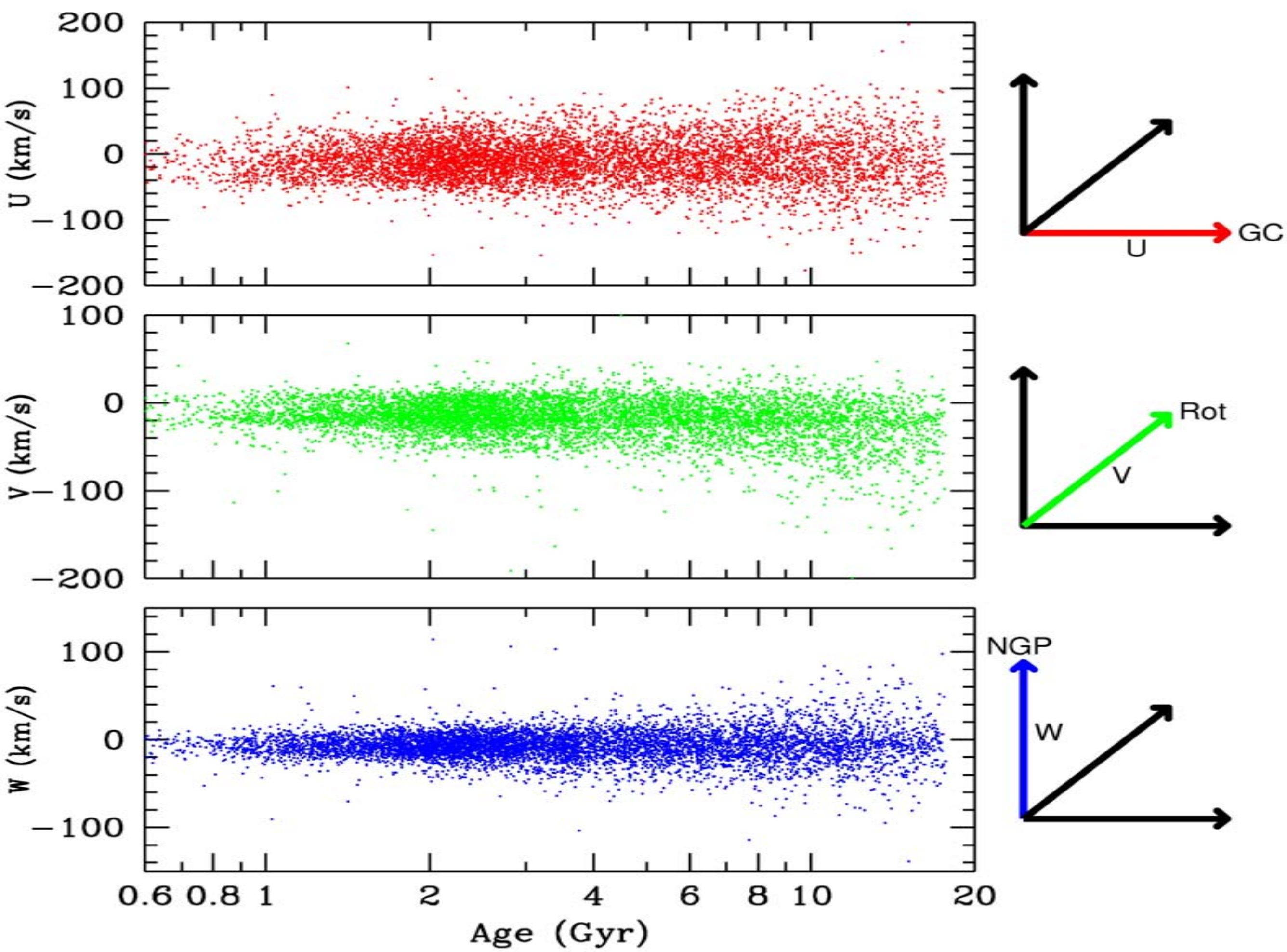


O, Mg, Si

Ca, Ti, Ni

FIES spectrograph at the NOT telescope

Age – velocity (-dispersion) relation



Velocity dispersion for FG stars

•Parallaxes from the new Hipparcos catalogue (van Leeuwen 2008).

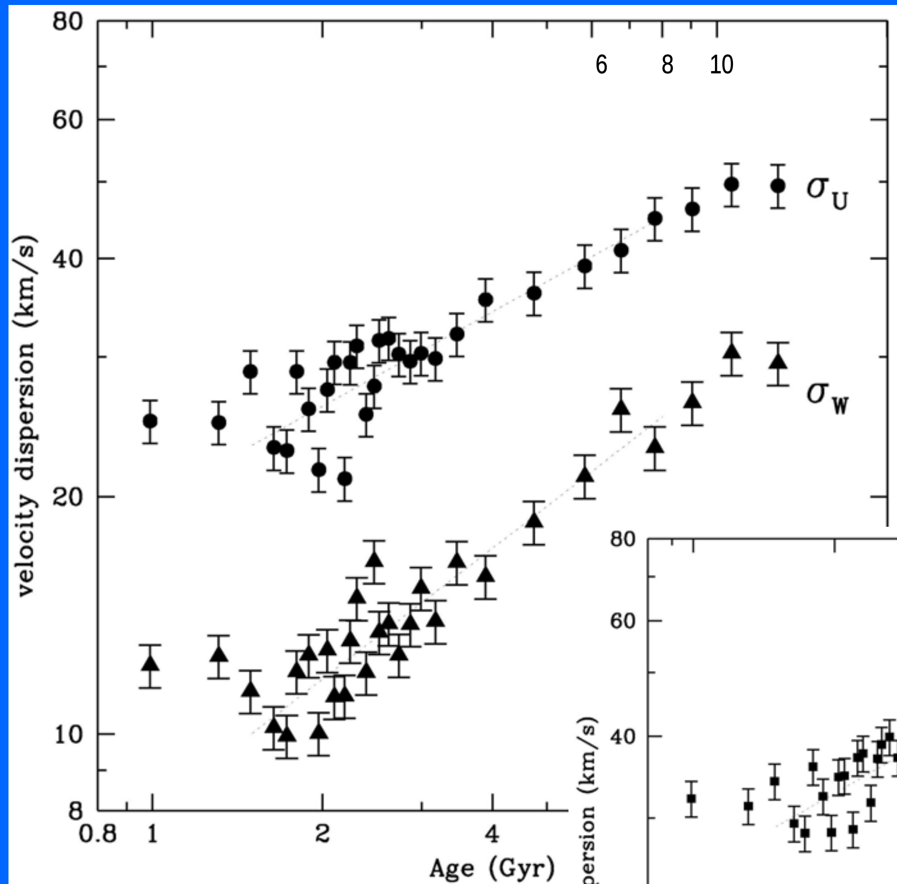
•New ages: Holmberg, Nordström, Andersen (A&A 2007).

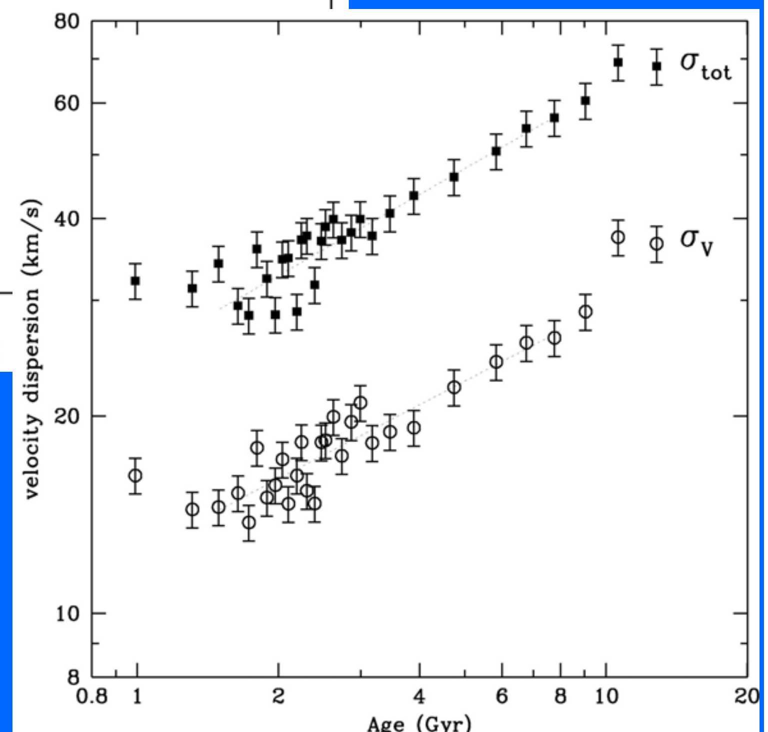
•New UVW Holmberg, Nordström, Andersen 2009.

Exponents of Power law fits to velocity dispersion:

U: 0.40, V: 0.37, W: 0.55

UVW $_{tot}$: 0.41





Birgitta Nordström

Conclusions & outlook for solar neighbourhood

- Our knowledge of the nearby solar-type stars has improved
- This allows many classical results to be revisited / revised
- Classical, local evolution models fail all classical tests

Studies continuing to:

- Derive SFH of local disk, LSR (Francis 2009, . .)
- More simulations of disk heating mechanisms
- Look for passing debris trails from disrupted satellite galaxies
- Study chemistry, ages, kinematics of carefully selected samples
- (like Edvardsson et al. but larger samples with modern techniques)
- etc.

Outstanding problems

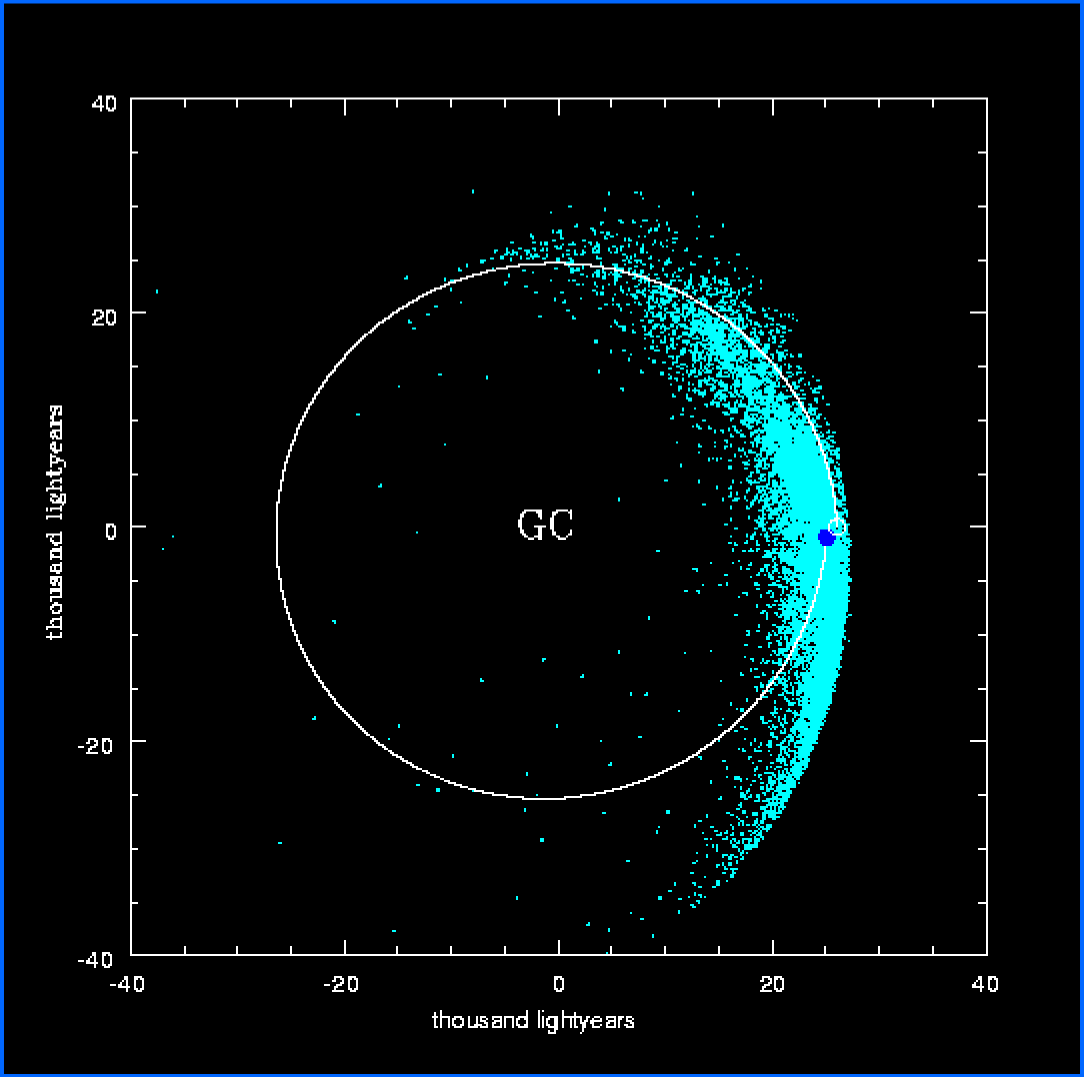
Temperature Calibrations (more stellar diameters, solar analogues etc.)

Better physical models (chemical and kinematical)

Samples to larger distances:

- RAVE: not all-sky, not parallaxes etc.)
- Gaia (launch in 2012, data in 2017; RV accuracy, completeness?)

Thank You!



From ESO Press release 2004