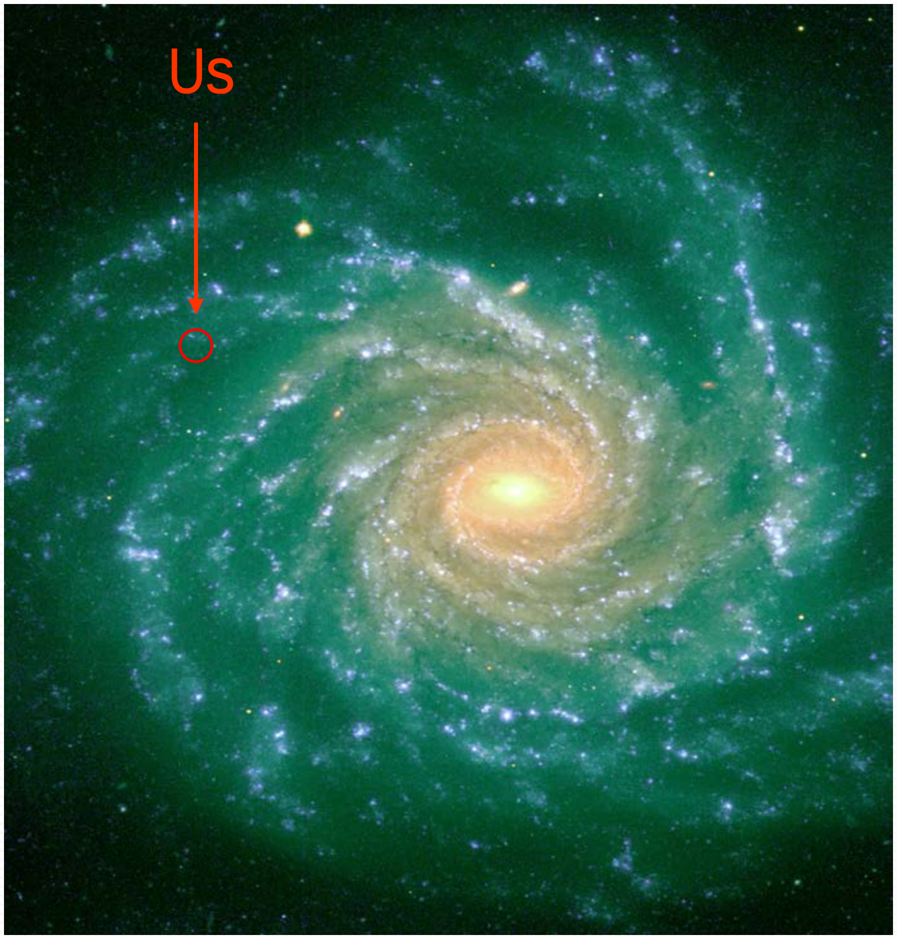
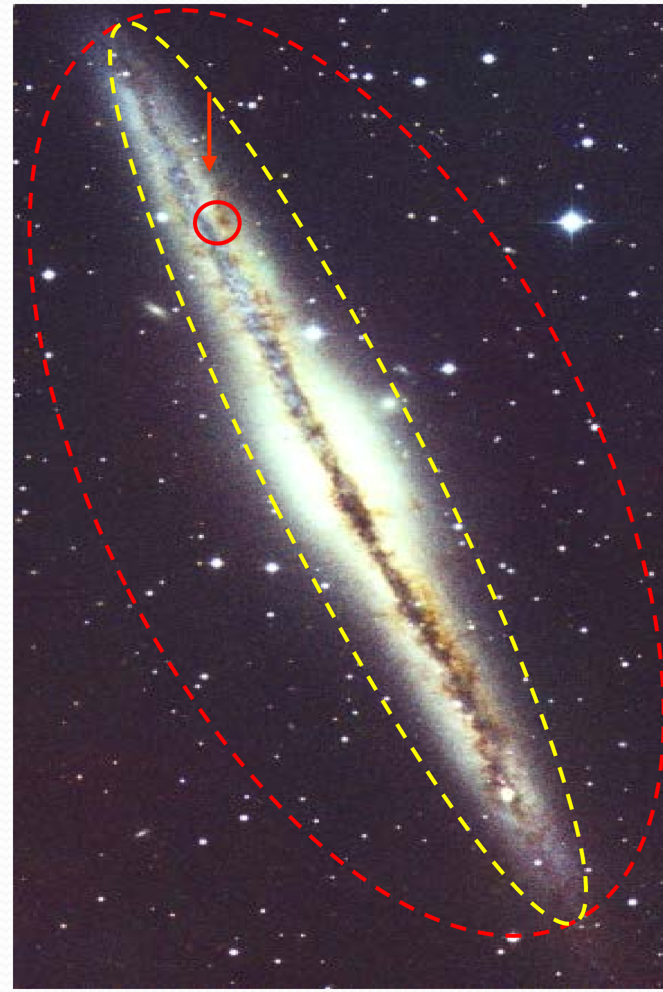
Galactic Projects at ESO
Disk and halo

Birgitta Nordström

Niels Bohr Institute
Copenhagen University
Denmark

1980: Milky Way Structure was Known
- the formation and evolution were not





What to do?

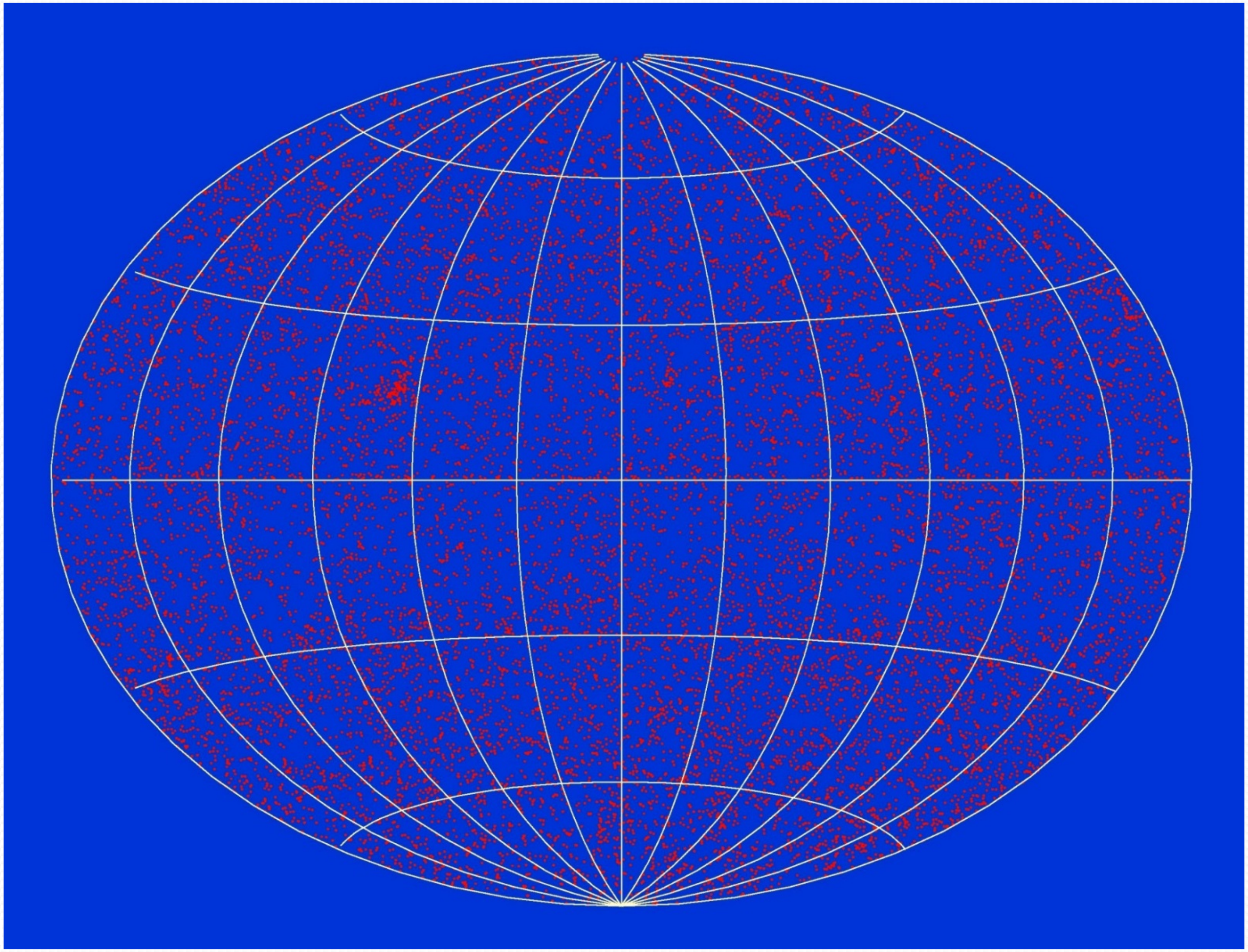
- See where we could make a significant impact
- Use experience and contacts from time abroad to initiate new projects
- Use ESO to obtain complementary types of data to what Danish telescopes could provide
- Define project, apply for ESO observing time

Evolution of the Milky Way

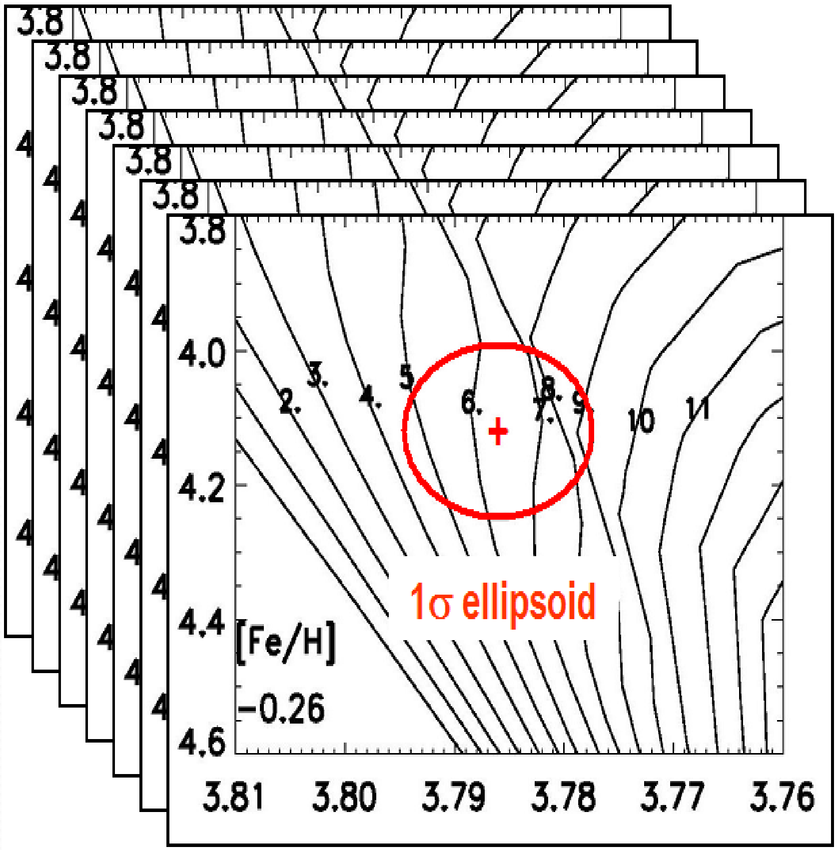
- What **sample** could we then study in detail? Solar vicinity.
- What sample of stars? Solar-type F-G dwarfs.
- What parameters do we then need to know?
  - **Age** (from models; Teff, log *g*, Mv ⇨ *uvbyβ*)
  - **Metallicity** ([M/H] ~ [Fe/H]; [α/Fe], ….)
  - **Distance**, reddening ⇨ π; *uvbyβ*
  - **Space velocities** U,V,W ⇨ μ, RV (*spectra;* CORAVEL)
  - **Galactic orbits** (potential, density waves,…)

B. Nordström
Prague 15 April 2014

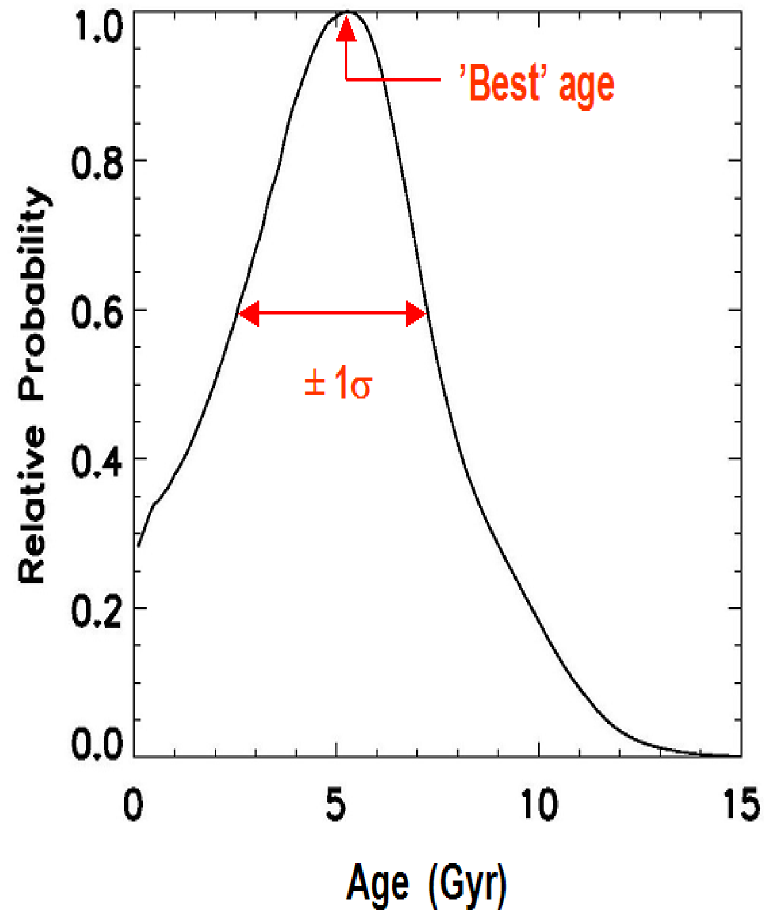
Distribution of GCS Stars on the Sky



Determination of Age and σ(age)

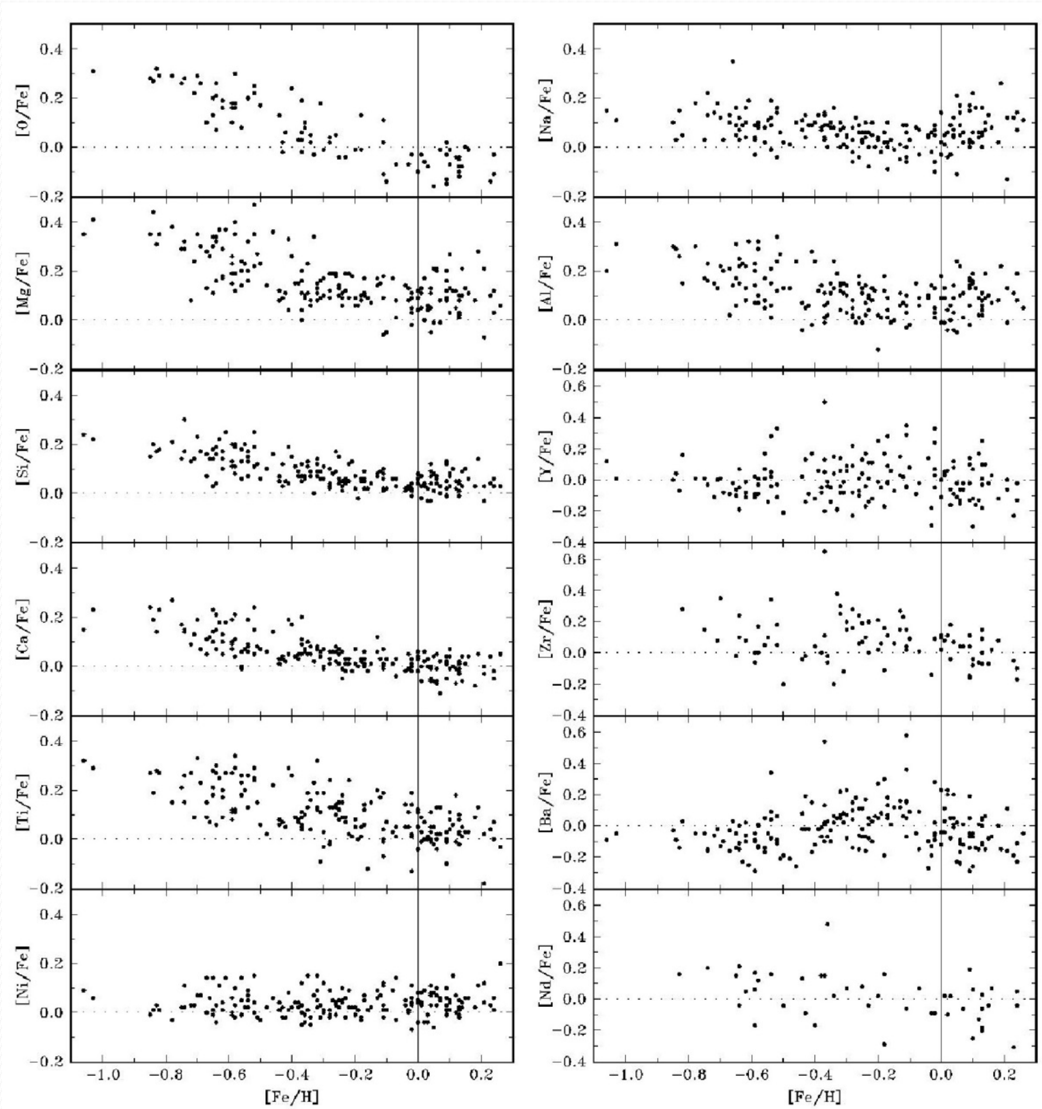


HR 'cube' of T_{eff} vs. M_V and [Fe/H]



Key precaution: Check that Teff scale of observations matches the models!

Evolution of Element Abundances



Subsample of 189 FG dwarfs

CES spectra: Edvardsson et al. (1993)

>1,500 cit

Metallicity Distribution Function & Age-Metallicity Relation

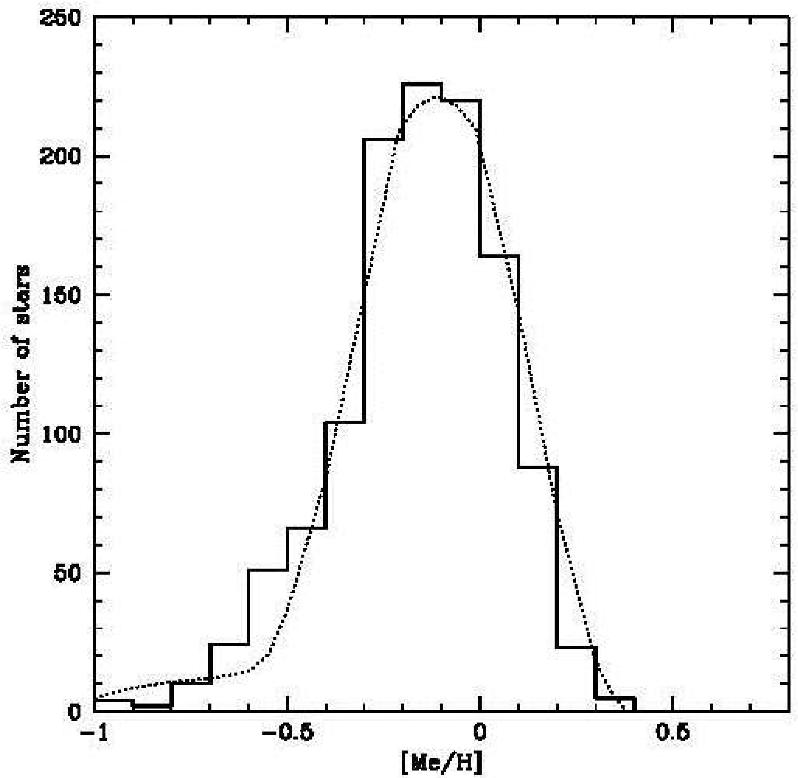


Fig. 26. Distribution of metallicities for the volume complete sample of single stars (full histogram). For comparison the dotted curve shows the reconstructed distribution for G dwarfs from Jørgensen (2000), which is corrected for scale height effects and measurement errors.

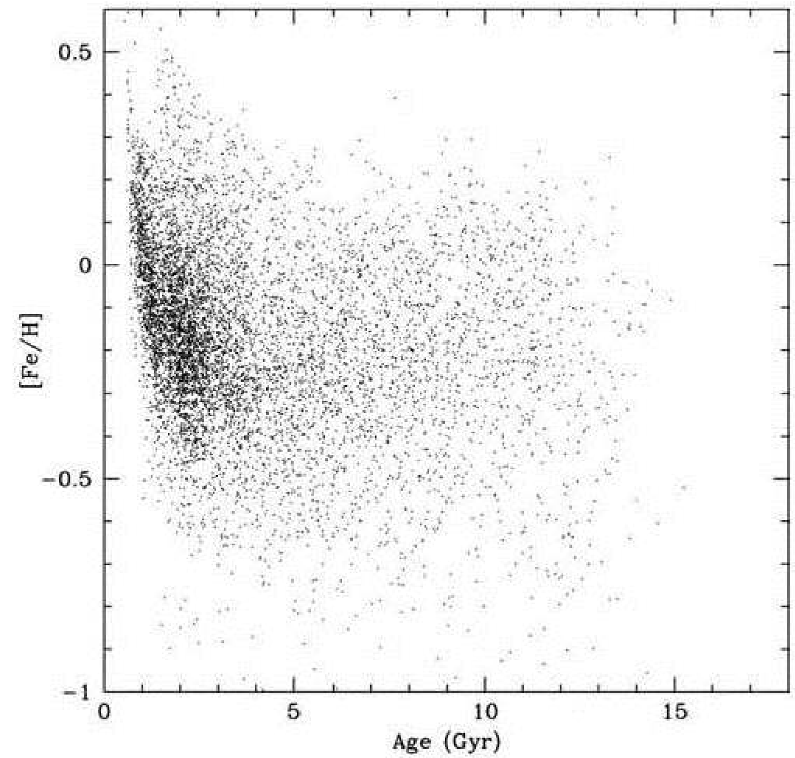
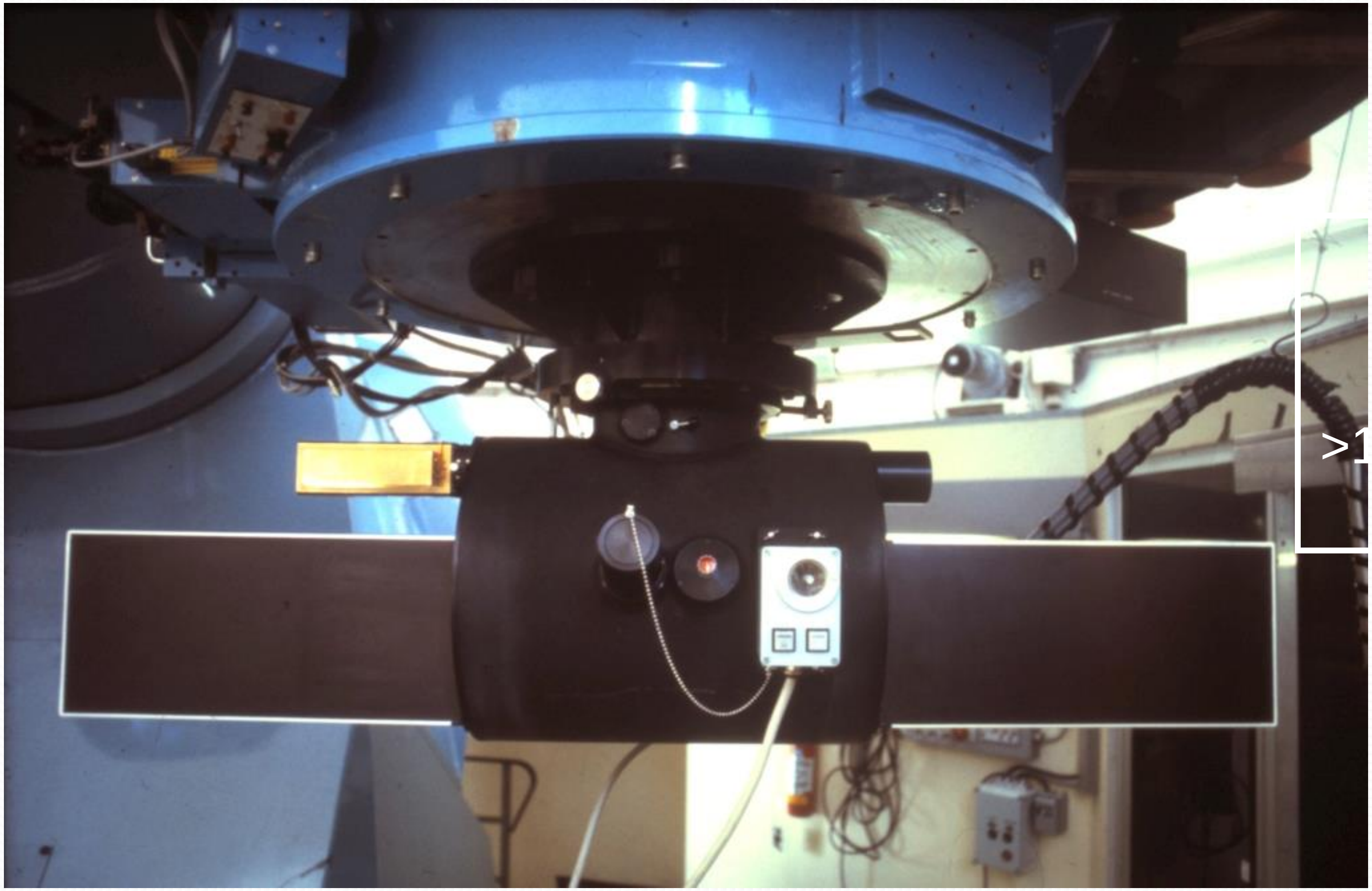


Fig. 27. Age–metallicity diagram for 7566 single stars with "well-defined" ages in the magnitude-limited sample. Note that individual age errors may still exceed 50% (cf. Fig. 16).

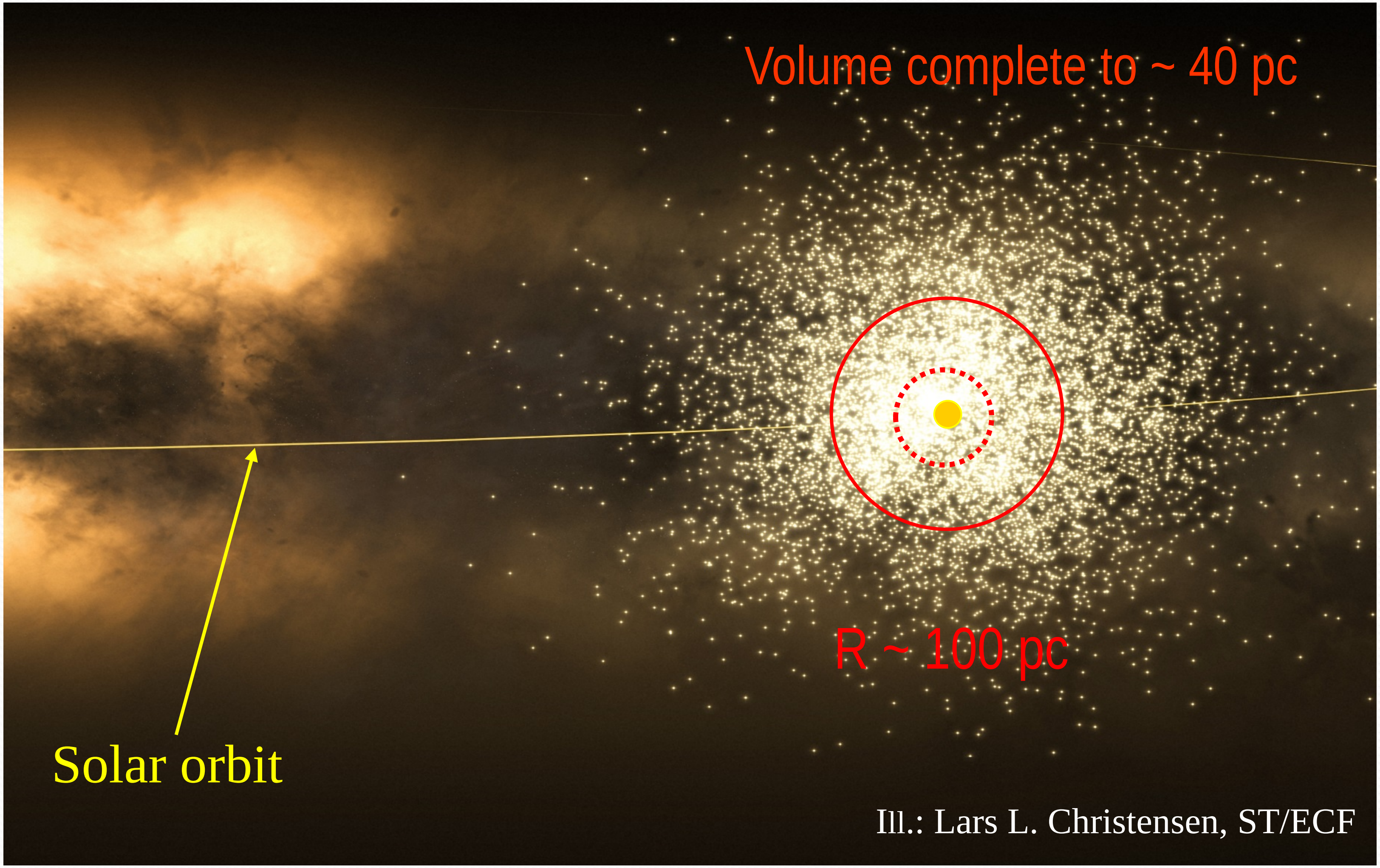
"G dwarf problem" and closed-box chemical evolution

Key complement: Space Velocities

- π and μ: Tradition: meridian circles; final word: HIPPARCOS
- RVs: CORAVEL @ DK 1.54m (and Swiss 1m @ OHP)



3D Distribution and Completenes Limit



In 2004: The GCS is Published

A&A 418, 989–1019 (2004)
DOI: 10.1051/0004-6361:20035959

Astronomy & Astrophysics

The Geneva-Copenhagen survey of the Solar neighbourhood⋆,⋆⋆

Ages, metallicities, and kinematic properties of ∼14 000 F and G dwarfs

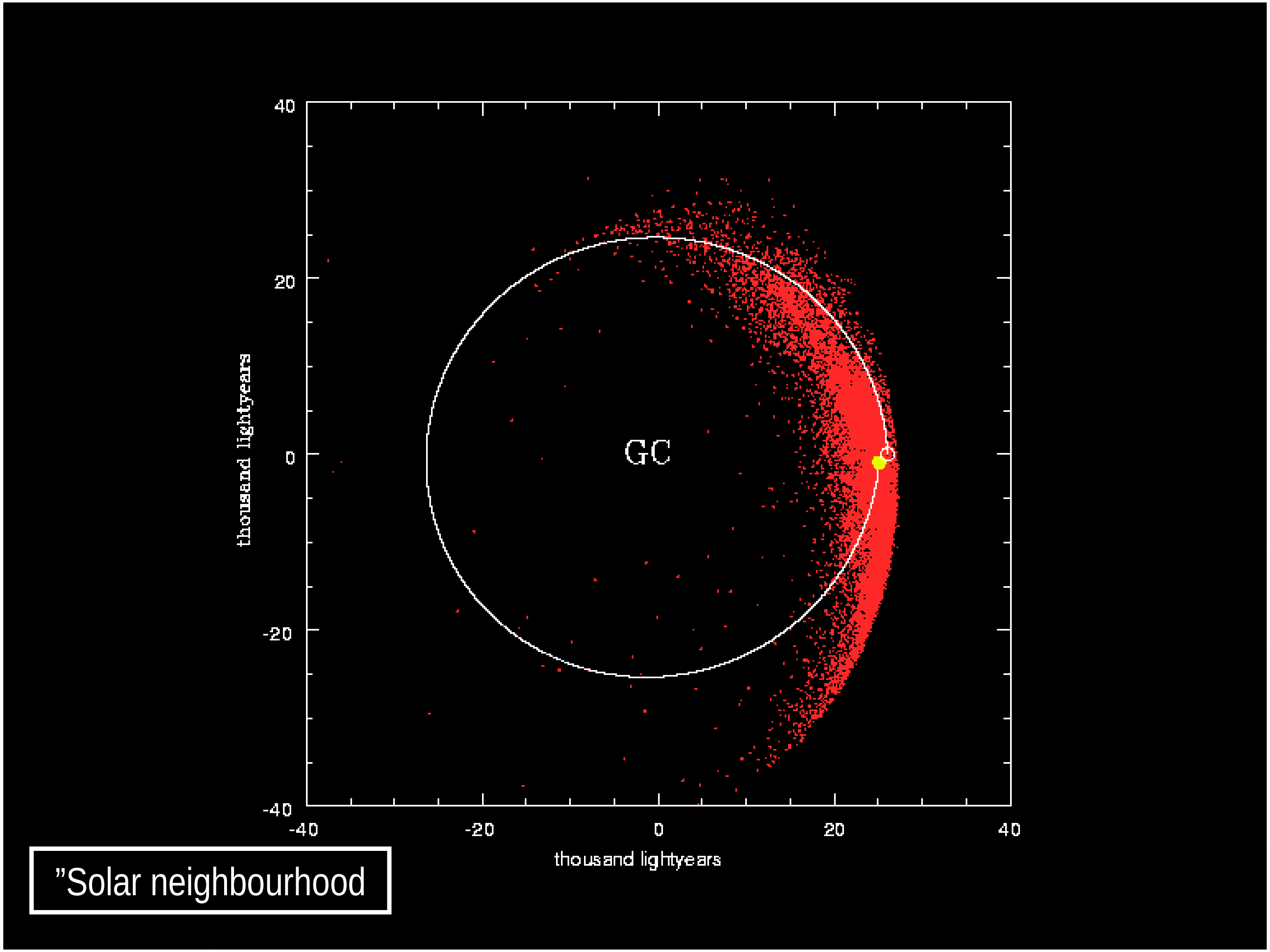
B. Nordström[1,4], M. Mayor[3], J. Andersen[2,5], J. Holmberg[2,5], F. Pont[3], B. R. Jørgensen[4], E. H. Olsen[2], S. Udry[3], and N. Mowlavi[3]

[1] Niels Bohr Institute for Astronomy, Physics & Geophysics, Blegdamsvej 17, 2100 Copenhagen, Denmark
[2] Astronomical Observatory, NBIfAFG, Juliane Maries Vej 30, 2100 Copenhagen, Denmark
[3] Observatoire de Genève, 51 Ch. des Maillettes, 1290 Sauverny, Switzerland
[4] Lund Observatory, Box 43, 22100 Lund, Sweden
[5] Nordic Optical Telescope Scientific Association, Apartado 474, 38700 Santa Cruz de La Palma, Spain

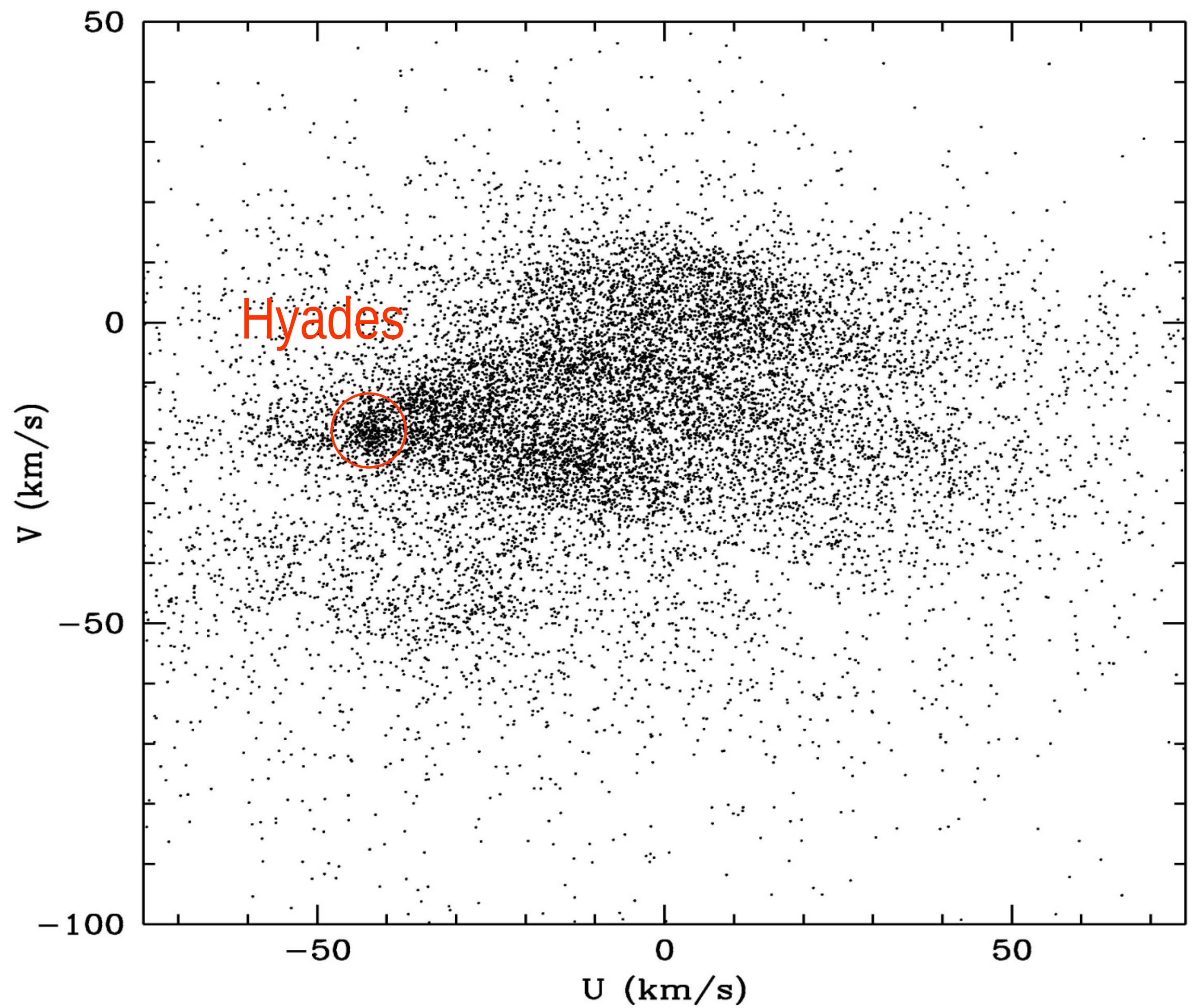
Received 31 December 2003 / Accepted 23 January 2004

Among ESO "top-10" cited papers

"The GCS Movie"



The U-V Plane

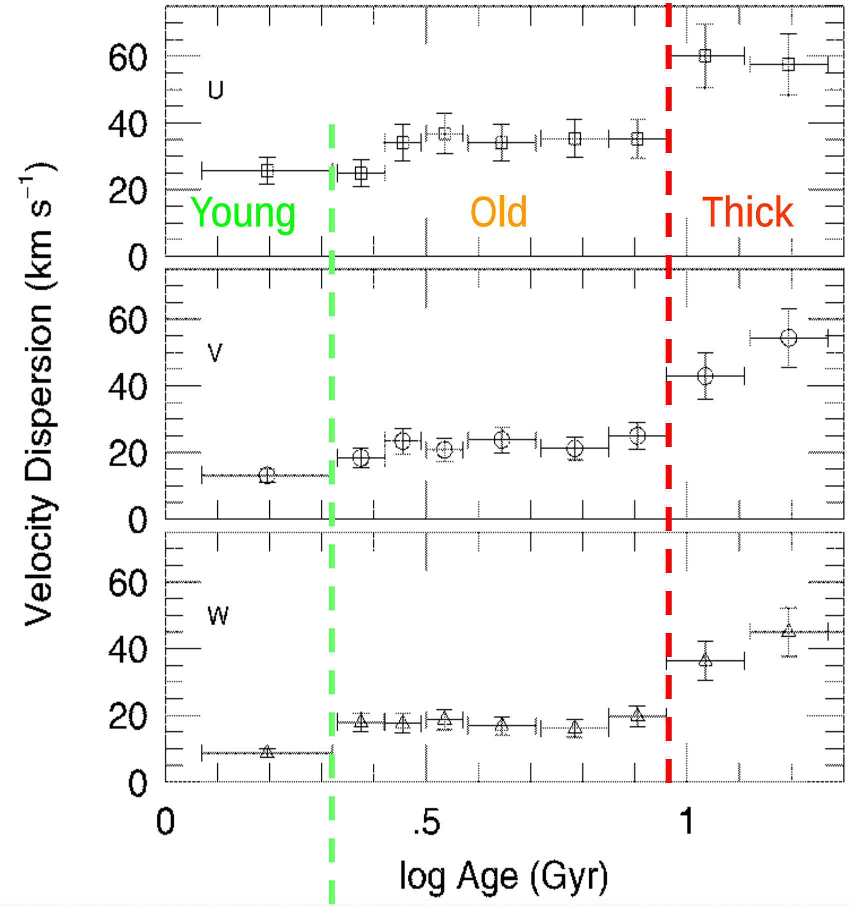


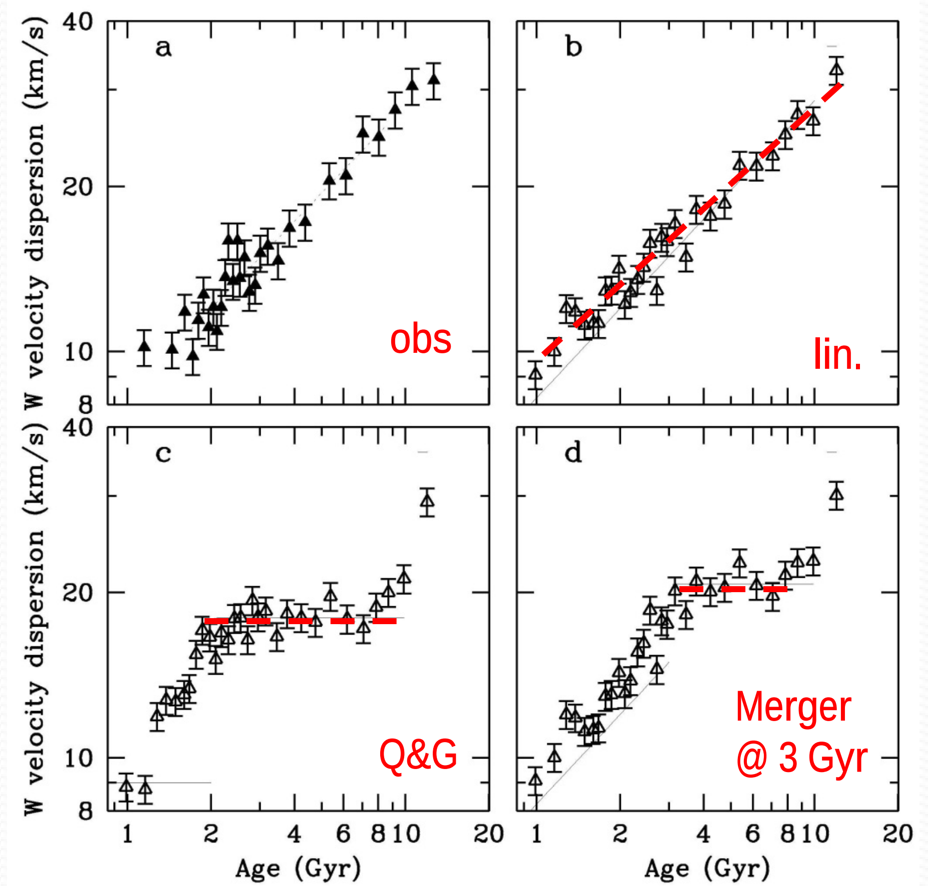
Not thin + thick disk Gaussians!

Dynamical focusing?

Radial migration?

Disk Heating Models

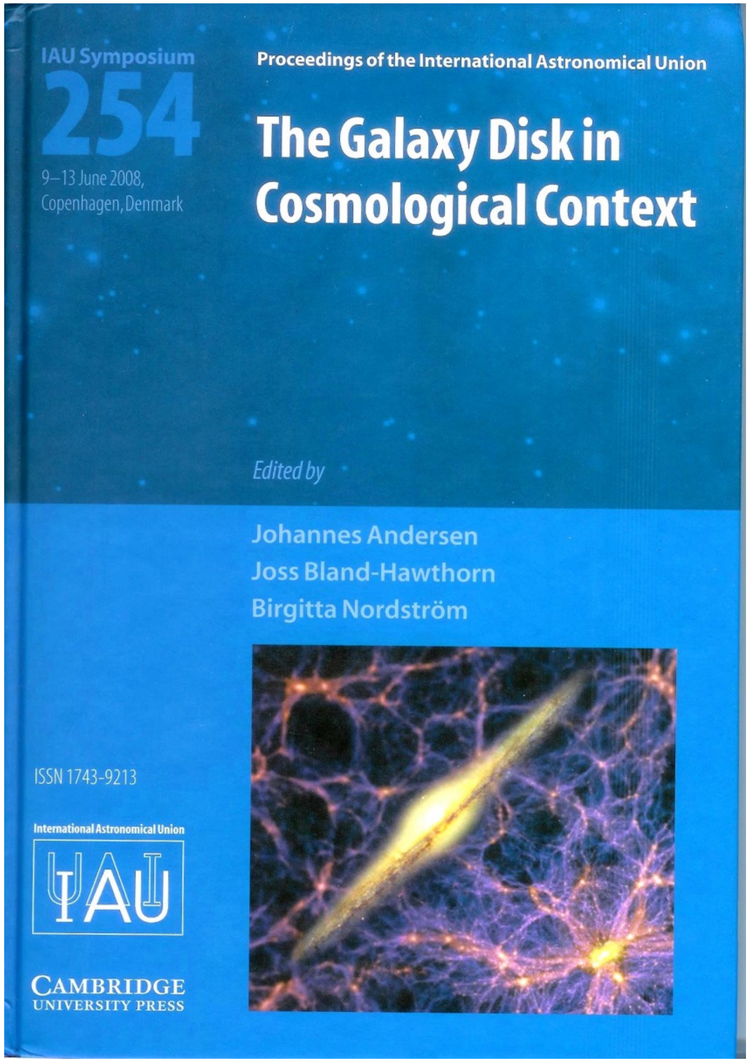




Quillen & Garnett 2001:
189 dwarfs from Edv+ '93

GCS III: 2,626 single stars,
$\sigma_{\Pi} < 13\%$; $\sigma_{Age} < 25\%$

Synthesis @ IAU Symposium 254



Later Follow-Up Projects:

- **GCS II:** Improved T_{eff}, [Fe/H] calibrations, ages (A&A 2006)
- **GCS III:** New HIPPARCOS parallaxes, ages (A&A 2009)
- **NEW:** Testing T_{eff} with new angular diameters (MNRAS 2014)
- **NEW:** Check AMR by adding cool subdwarfs with
  HIP parallaxes, new T_{eff}, [Fe/H] (ongoing)
- **Coming:** Gaia data of MUCH larger sample

Science case for ”First stars”: A Large Programme for UVES@VLT

- Survey of accurate abundances of stars w. [Fe/H] < -2.5
- Planned as a high-impact initial LP for the VLT
- Identify promising targets with La Silla telescopes (2,000 candidates; 5 yr)
- Select ~100 top-priority candidates for the LP
- Apply for VLT time

What make the first stars interesting?

- Zero-metal stars reionised the Universe
- They created the conditions for low-mass star formation (cooling via CO etc.)
- Their Extremely Metal-Poor (EMP) descendants live on
- They may have been the progenitors of the first GRBs
- Test of SBBN (Li abundance)
- Give clues to galaxy formation

The ”First stars” Project (Cayrel et al.)

- Use EMP stars ([Fe/H] < -2.5) to study the early Galaxy.

- Define precise general abundance patterns

- Where and how were the neutron capture elements created and built into the ISM?

- When and how was the first C produced?

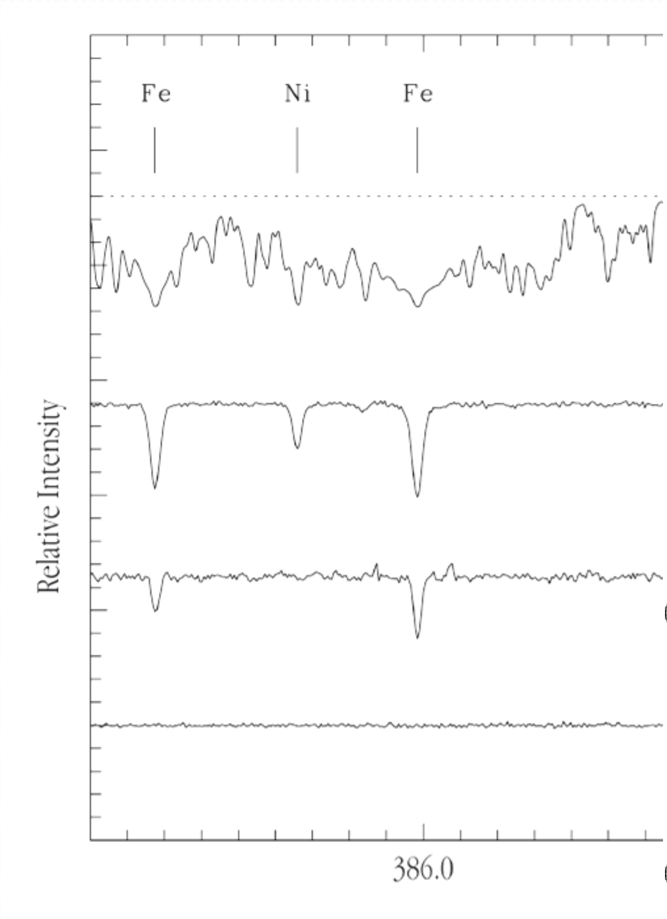
The “First Stars” programme @VLT/UVES

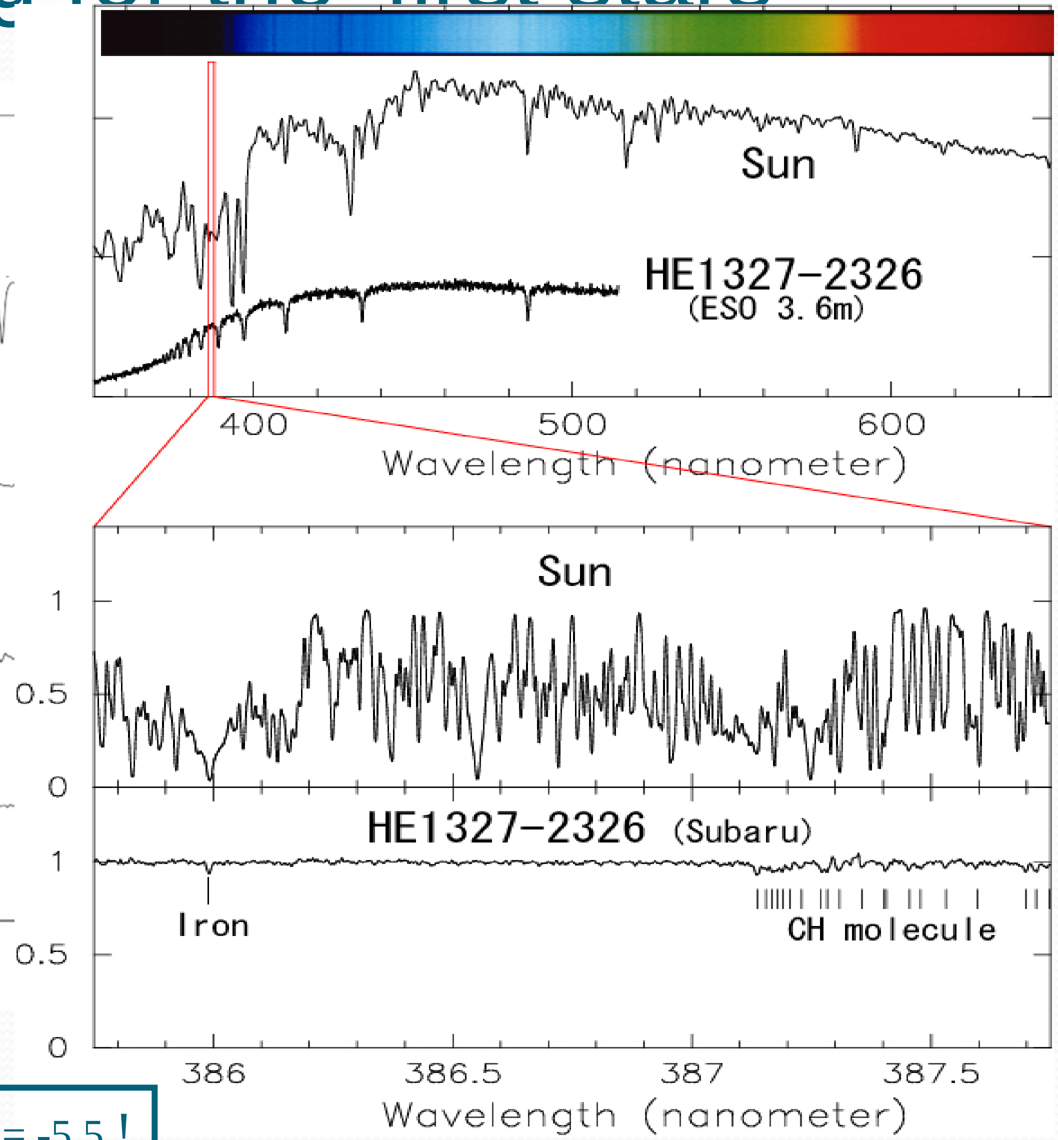
Goal: Analyse a sample of extremely metal-poor stars very precisely and homogeneously

Purpose: to study

- nature and ejecta of the first (heavy?) supernovae
- efficiency of mixing processes in the early Galaxy
- age of the Galaxy (and Universe) via stellar chronometers, thorium & uranium
- etc...

Searching for the 'first stars'





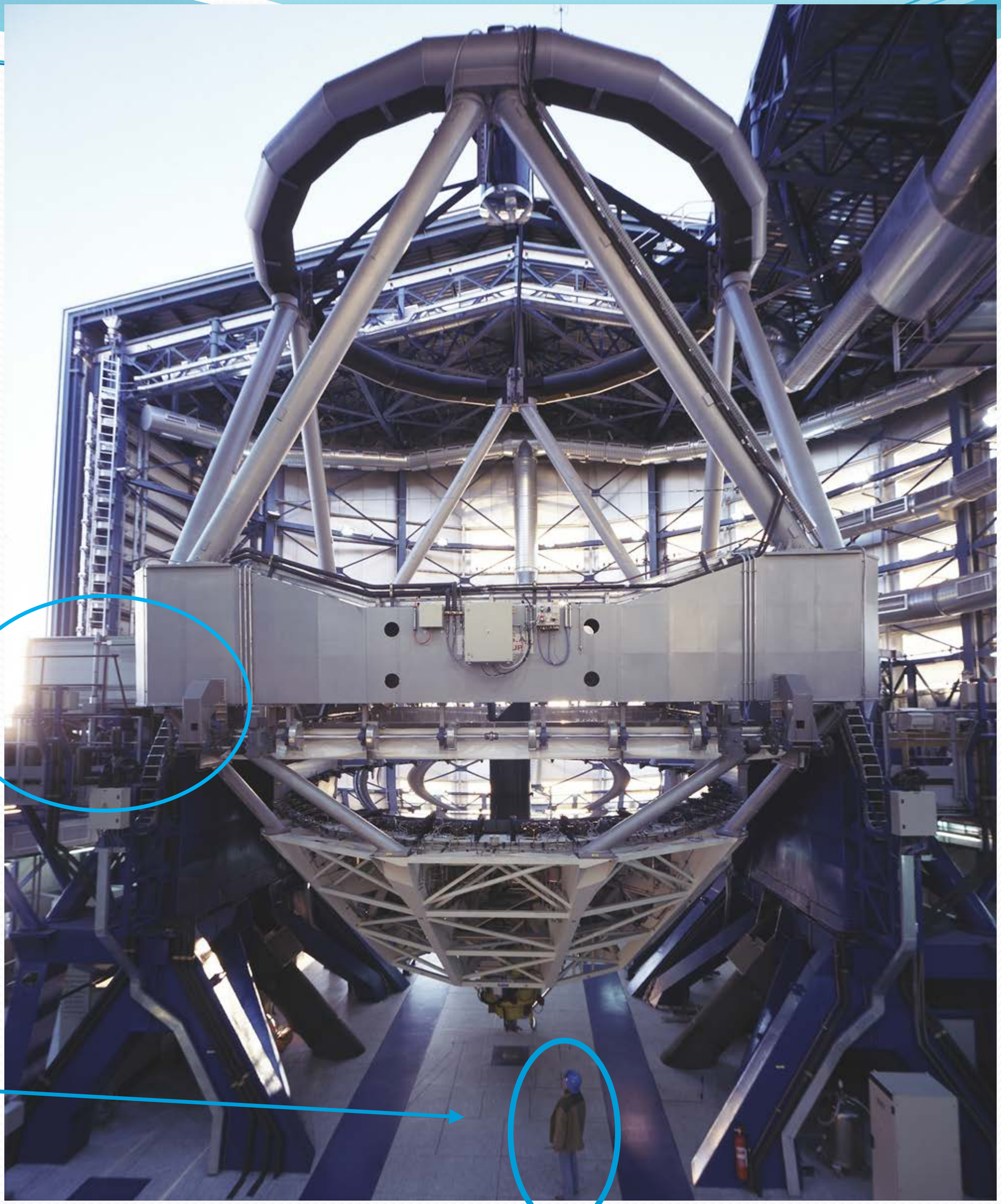
[Fe/H] = -5.5 !

Our tools: The ESO VLT/2…

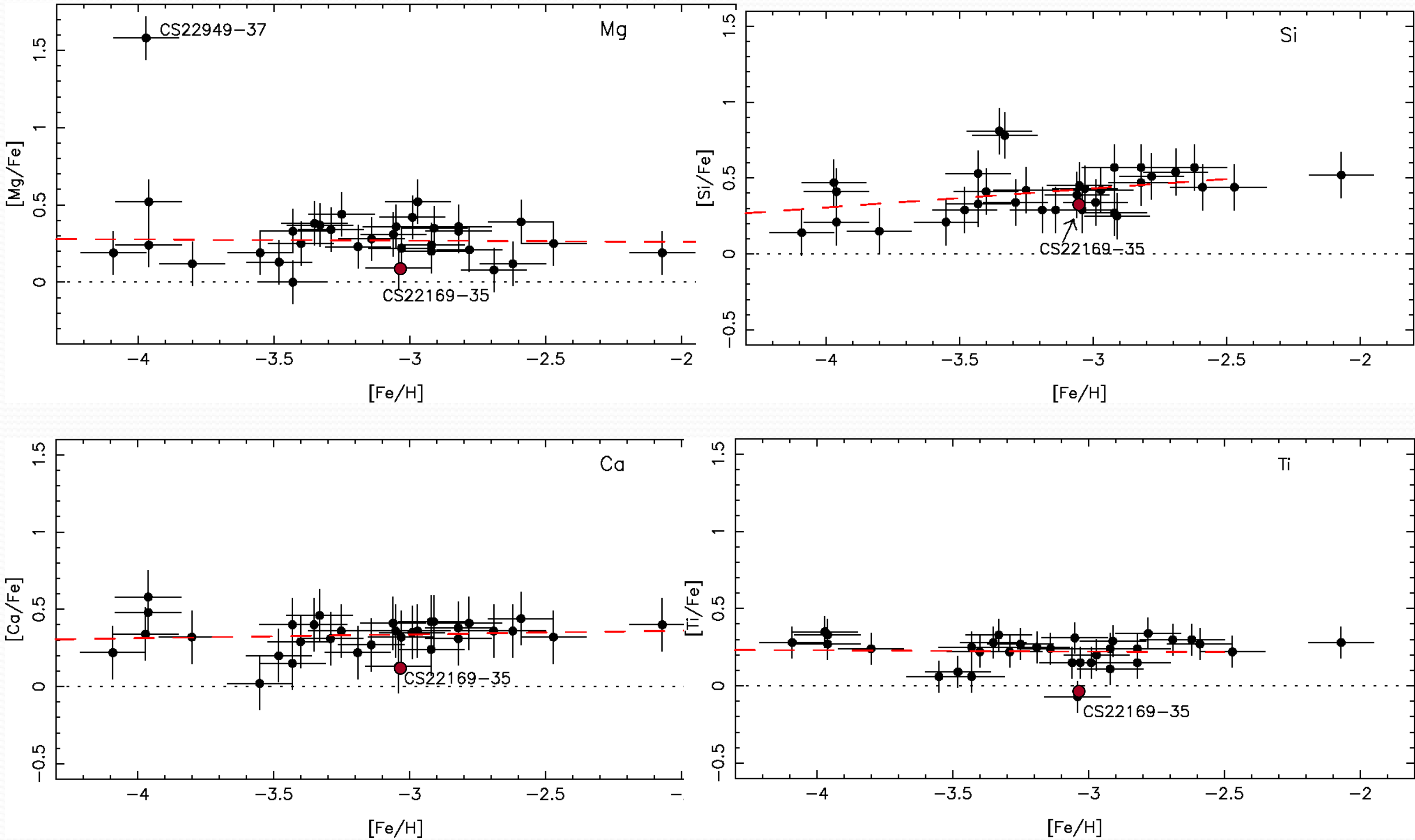
ESO-VLT2 (Kueyen)

UVES

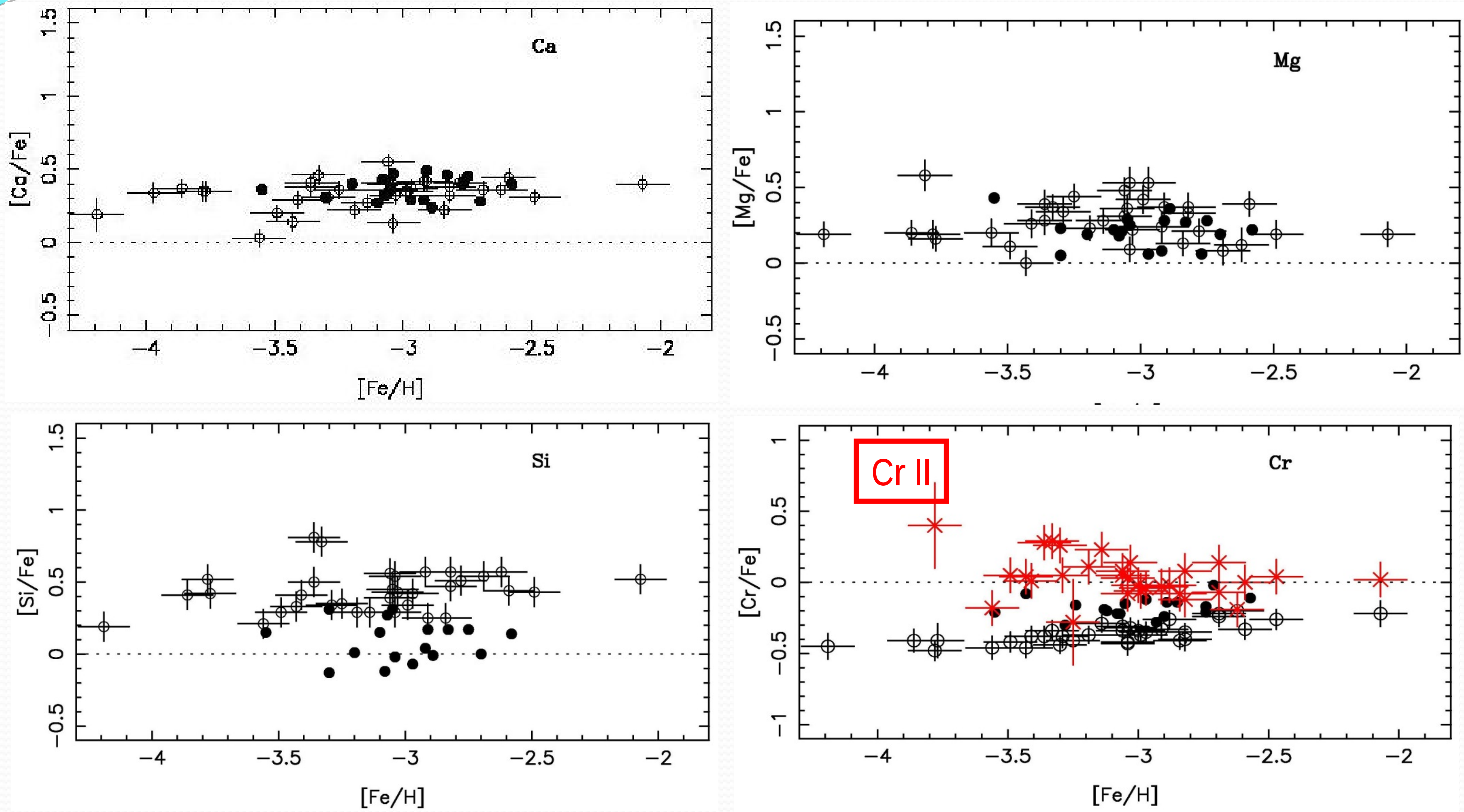
Astronomer (!)



Building the α-elements

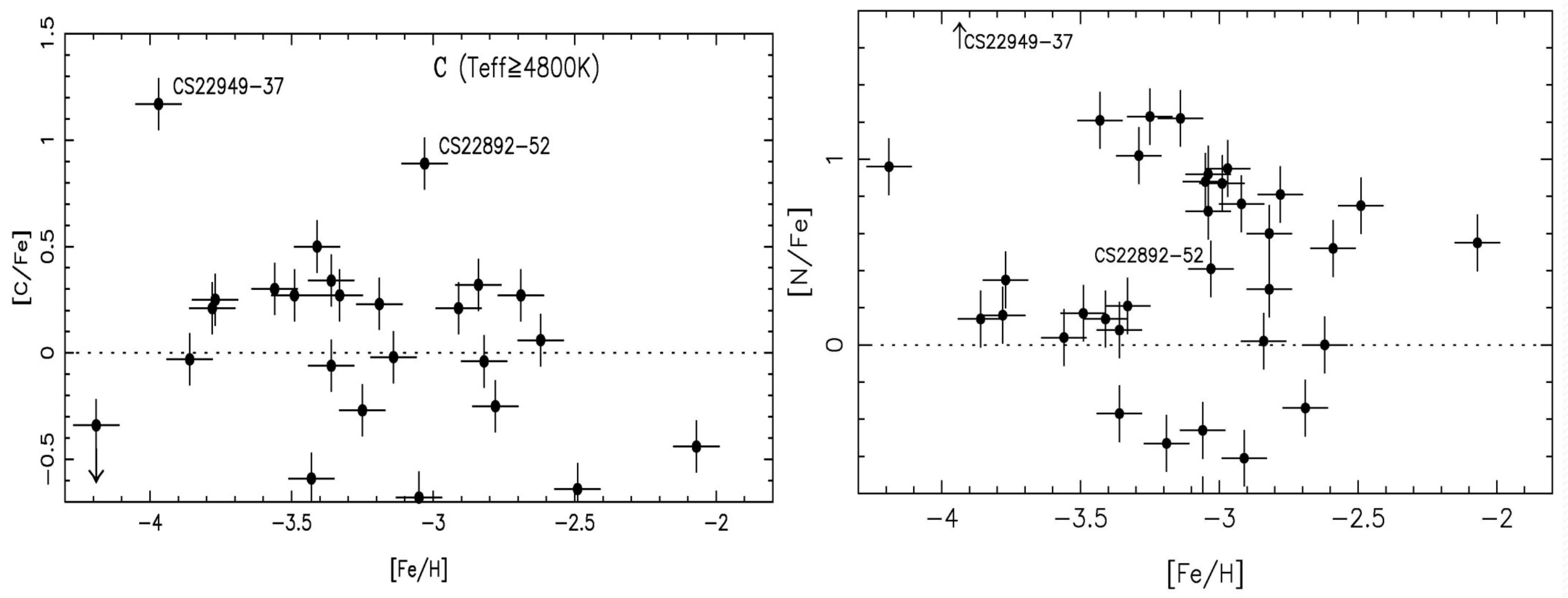


A sanity check: Dwarfs • vs. giants +



Stellar atmospheres to blame (NLTE, 3D convection) - not the Galaxy !

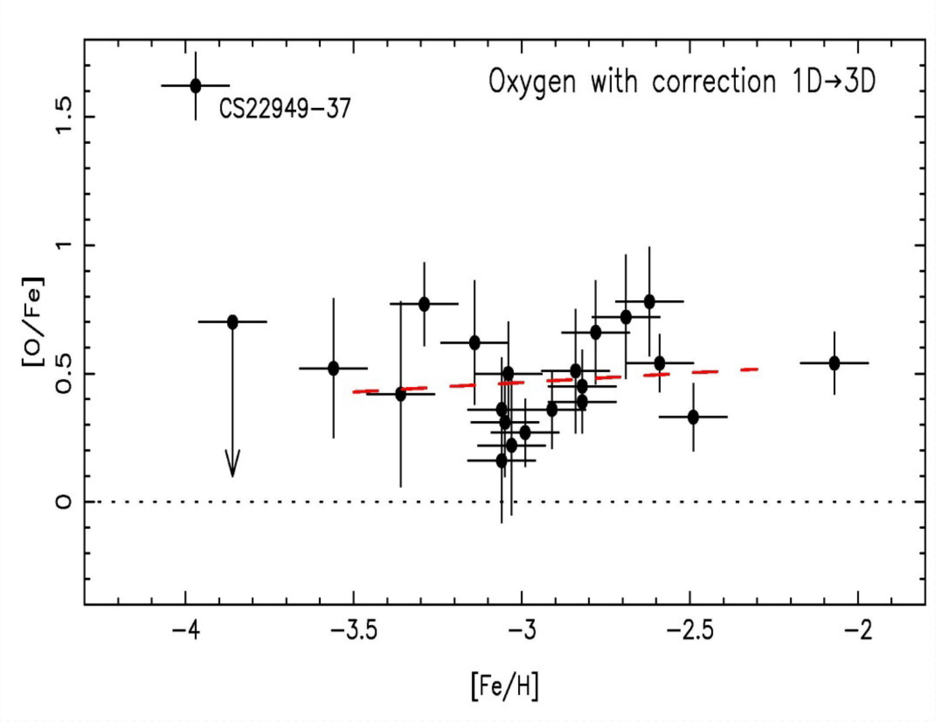
The first new elements: CNO

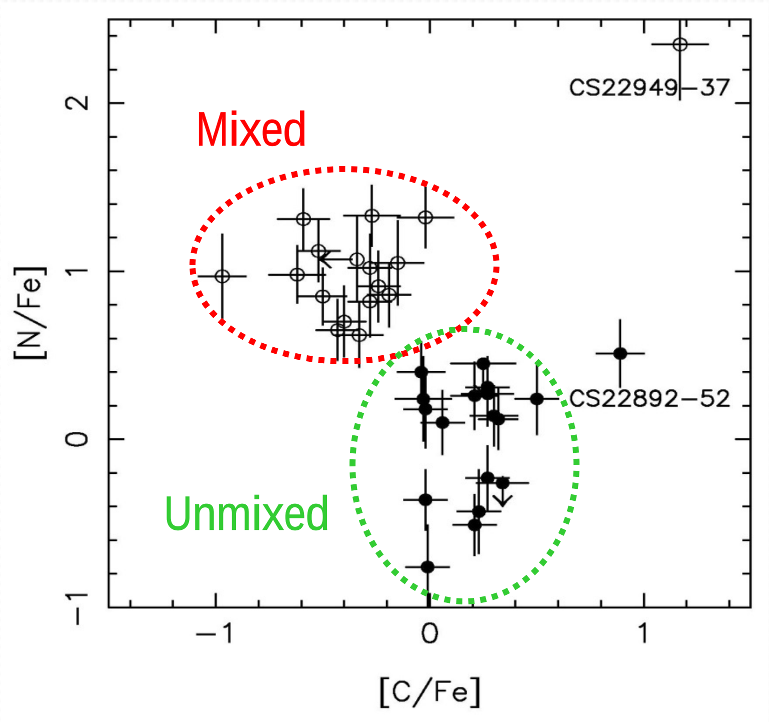


Why this large scatter in C and N ??

Is it intrinsic or due to internal processing?

Origin of the scatter in C & N ?





O behaves much better

Aha – mixing with CNO cycle!

“Normal” EMP Stars: Tightly Defined Abundance Patterns

The “First Stars” project (Cayrel, Spite et al. 2001+++):

- The majority of ‘normal’ EMP halo stars ([Fe/H] <-2.5) exhibit very tightly defined abundance patterns for elements from O through the iron peak.

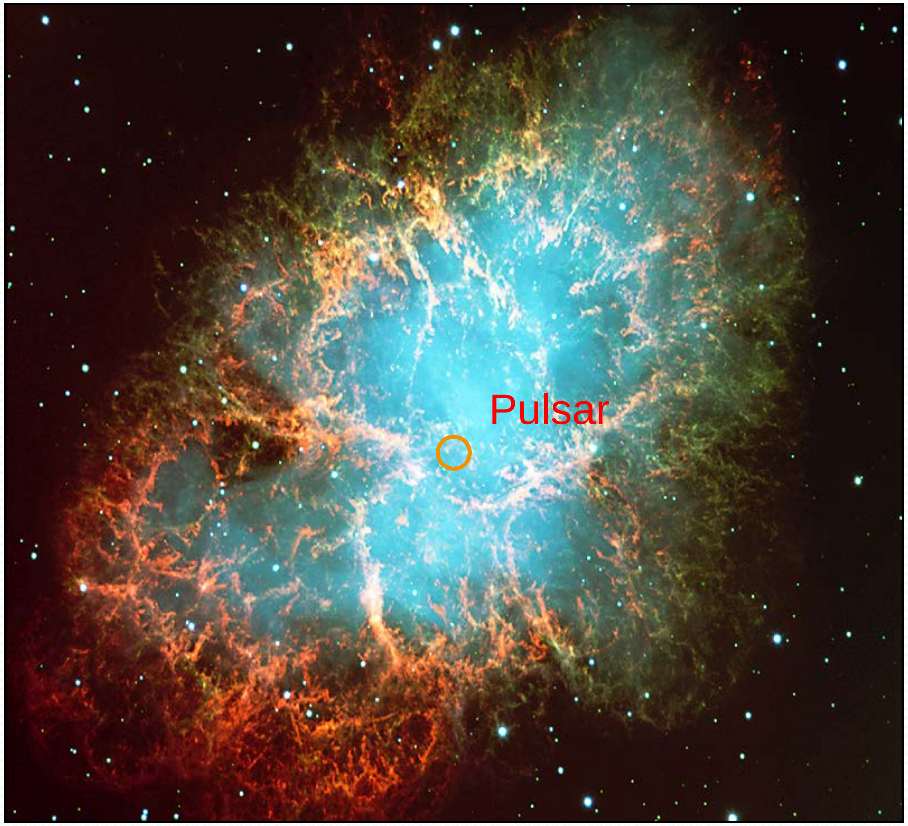
Some results from “First Stars”:

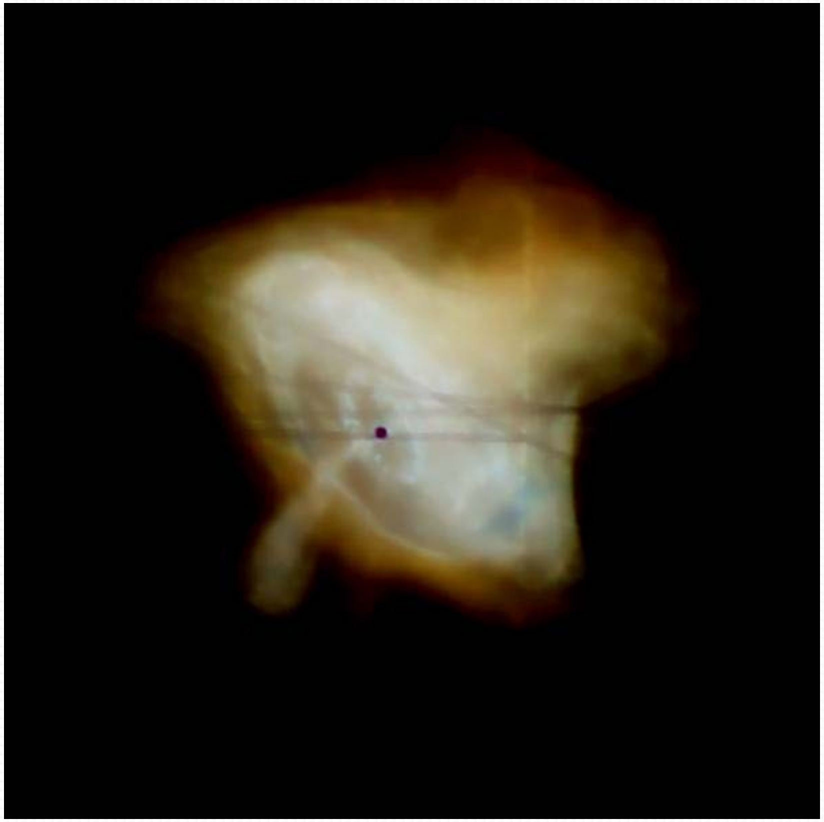
- The first stars seem to have been rather ordinary SNe, with some fallback, extra mixing and/or asphericity
- *Some* halo giants are unmixed and have normal CNO
- Some very early stars show both *r*- and *s*-proc.; SB?
- All heavy *r*-process elements were produced in constant ratios, but light *r* and actinides are different
- 3D and NLTE effects will continue to plague us!

The neutron-capture elements (going beyond Fe)

The site(s?) of the *r*-process ...

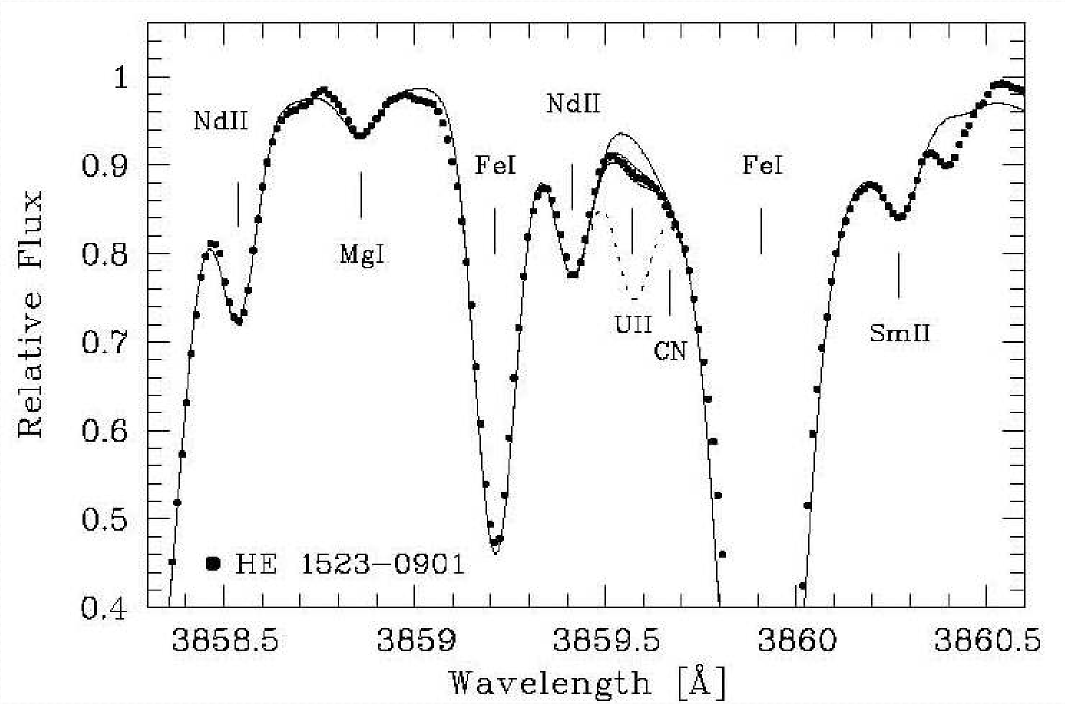
The crab nebula: Supernova 1054 – 955 years later





Optical (ESO VLT) ← → X- rays (Chandra)

Radioactive U as a chronometer

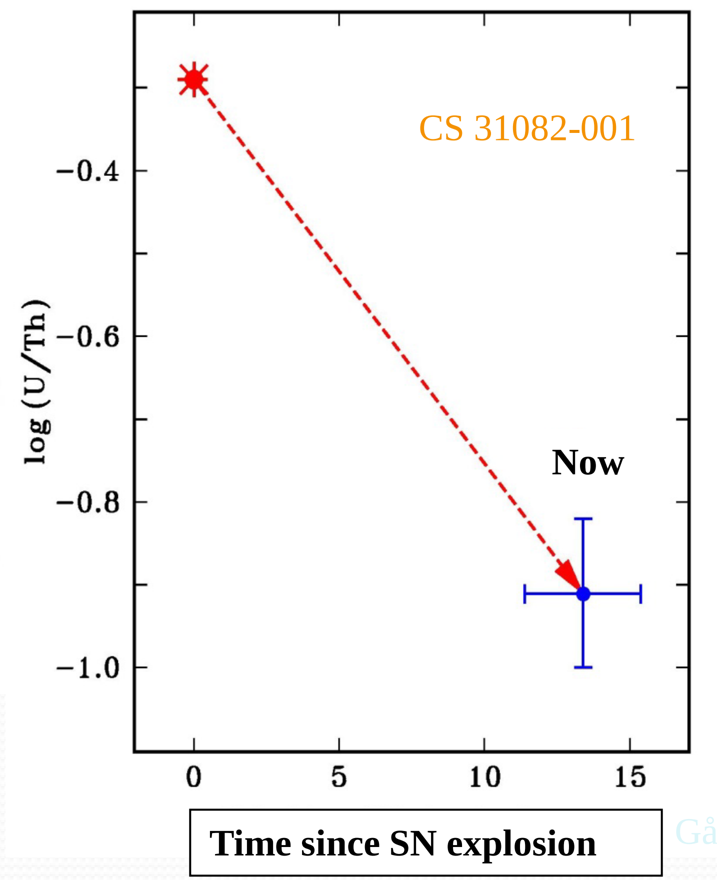


$$\Delta t = 46.7[\log(\mathrm{Th/r})_{\mathrm{initial}} - \log\varepsilon(\mathrm{Th/r})_{\mathrm{now}}]$$

$$\Delta t = 14.8[\log(\mathrm{U/r})_{\mathrm{initial}} - \log\varepsilon(\mathrm{U/r})_{\mathrm{now}}]$$

$$\Delta t = 21.8[\log(\mathrm{U/Th})_{\mathrm{initial}} - \log\varepsilon(\mathrm{U/Th})_{\mathrm{now}}]$$

Cayrel et al. 2001



Age: 13.4 ± 2 Gyr

Decay of ^{238}U (like ^{14}C dating)

Some stars are just peculiar….!

- or are they perhaps trying to tell us something important?

Outliers

R-process enhanced EMP stars (rI - rII stars):

[r/Fe] = 0.3 → ~2 dex; rare: ~3% of EMP giants.

<u>All</u> elements from C to U formed by [Fe/H] ~ -3.

C-enhanced EMP (CEMP) stars:

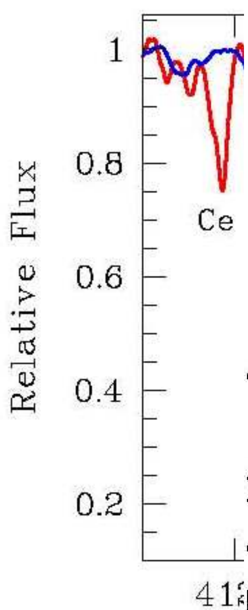
[C/Fe] = 0.7 → 2+ dex; <u>20-40%</u> of EMP giants.

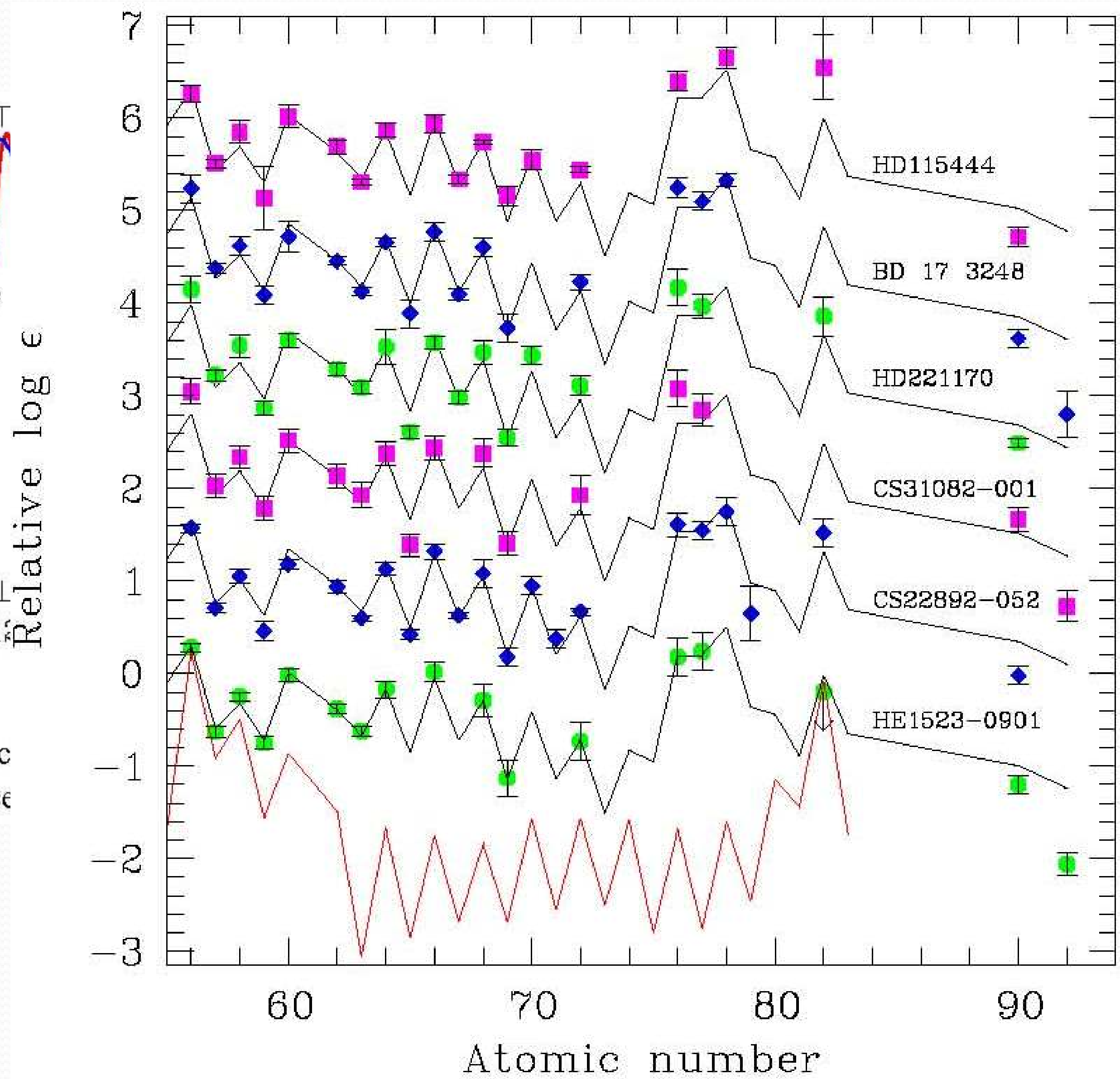
More frequent at low [Fe/H], high z (outer halo)

C excess <u>*may*</u> be combined with high [*r,s*/Fe].

Is this just a surface pollution, or were the stars made so?

U and Th in the "r II" stars





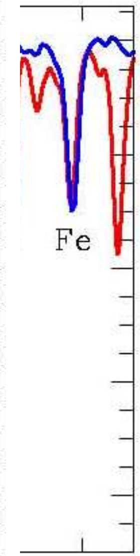


Figure 2: Spec … 2563 anc
the most r-proce … cities.

⇨New programme with FIES@NOT

Theory predicts: These anomalous abundances are due to mass-transfer in interacting binaries, like the Ba and CH giants

Our question: ARE they all binaries?

Test: Long-term RV monitoring in service mode with low S/N spectra with FIES@NOT (8 years and running).

Results in progress: Hansen, Andersen, Nordström

Formation site of the *r*-process elements?

- The frequency (~15%) and orbital properties of *r*-process rich stars are normal.
- ⇨ The *r*-process enhancement has ***nothing*** to do with close binary evolution or mass transfer
- ⇨ The abundance anomalies are ***intrinsic*** and were imprinted on their parent clouds at $z \geq 3$ (?)
- The *r*-process elements were likely ejected in a collimated mannner (beam? jet?) into a clumpy ISM, producing *r*-element over- (and under-!)abundances
- Prominent chemical tags of their birthplaces!

Carbon-enhanced EMP stars:

- Most (but <u>not all</u>) CEMP-s stars seem to be binaries.
- A few CEMP-no stars are binaries, but most seem to be single (observations ongoing). C in outer-halo CEMP stars was not produced by mass transfer from a companion.
- Most (inner-halo) CEMP-s stars may still have (ex-) AGB binary companions, but perhaps with special properties at very low metallicity (e.g. very large $R \longrightarrow$ very long P??).

<u>*Conclusion:*</u> Binary stars did form very early ([Fe/H] ~ -4

THANK YOU !