Constraints on nucleosynthesis processes and their sites from stellar abundances

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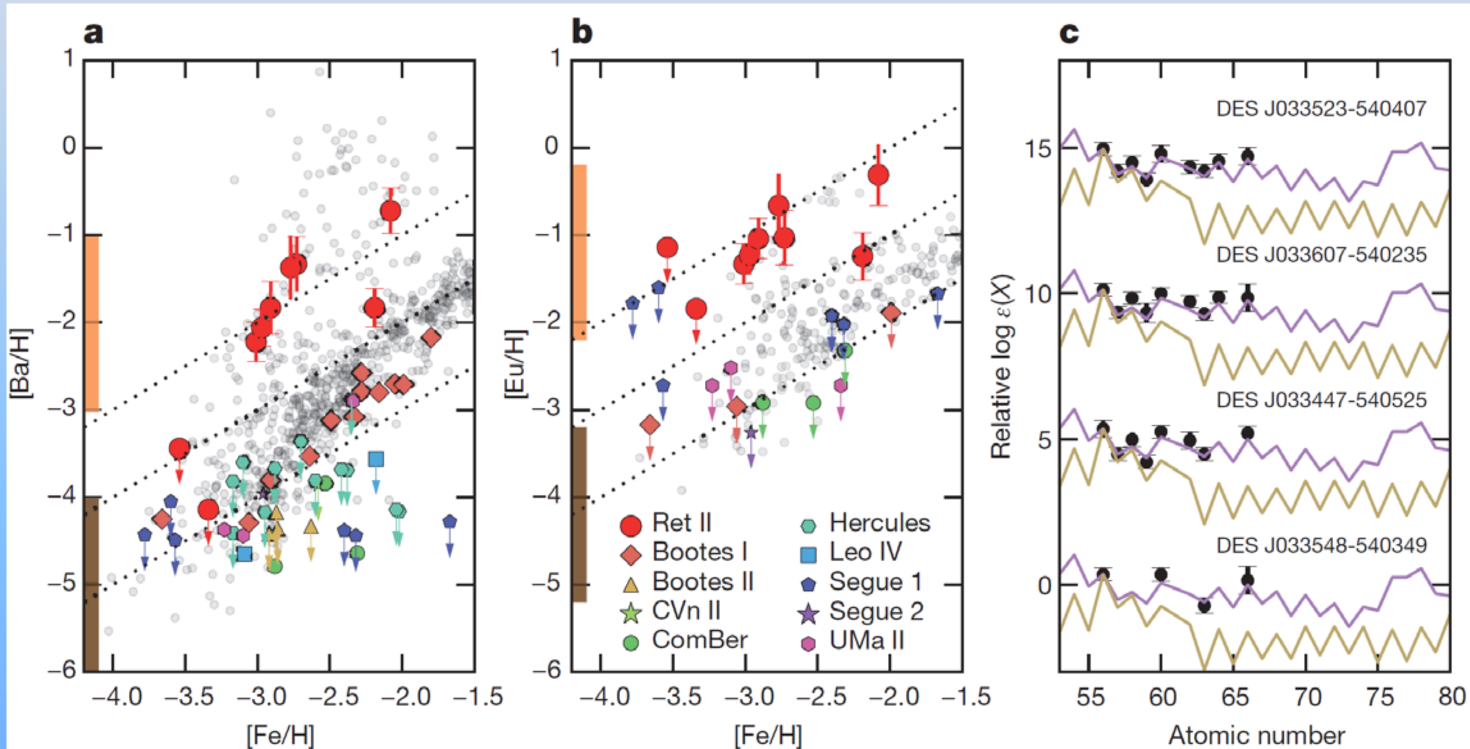

(Ji et al. 2016, Nature 531, 610)

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Contents

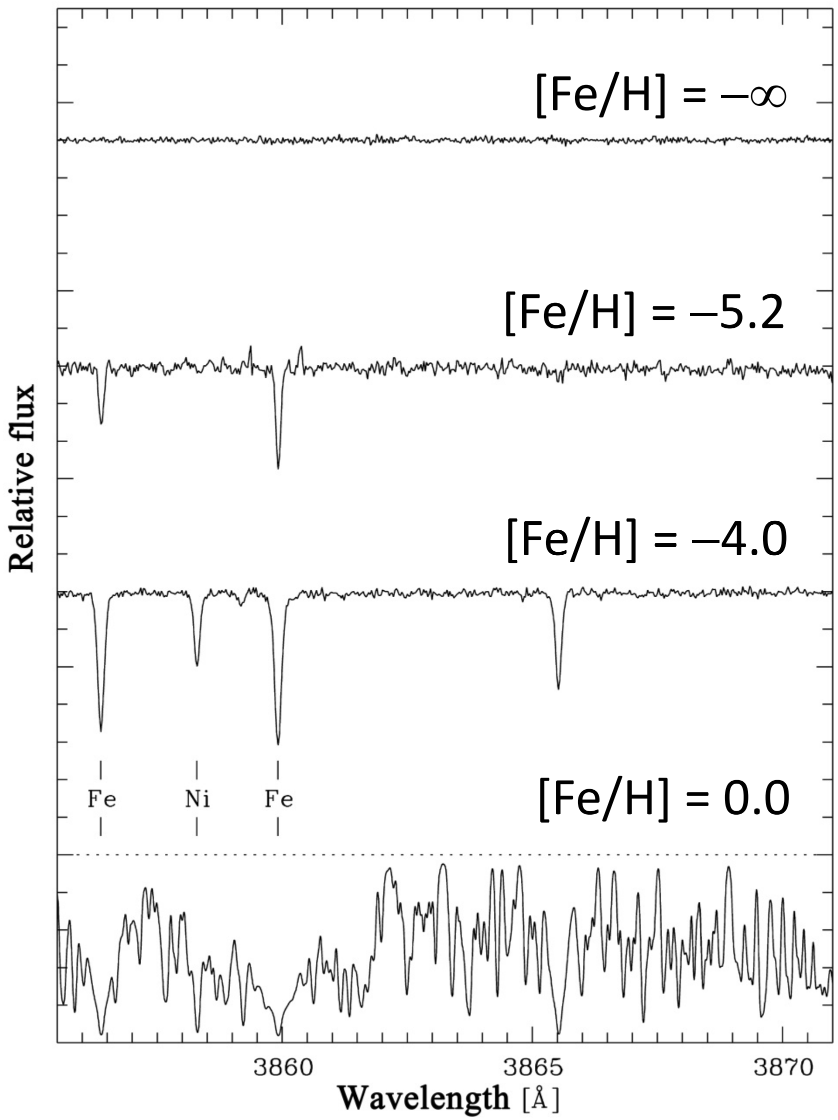
- Introductory remarks
- Measurements of elemental abundances and isotopic ratios in metal-poor stars
- Outlook

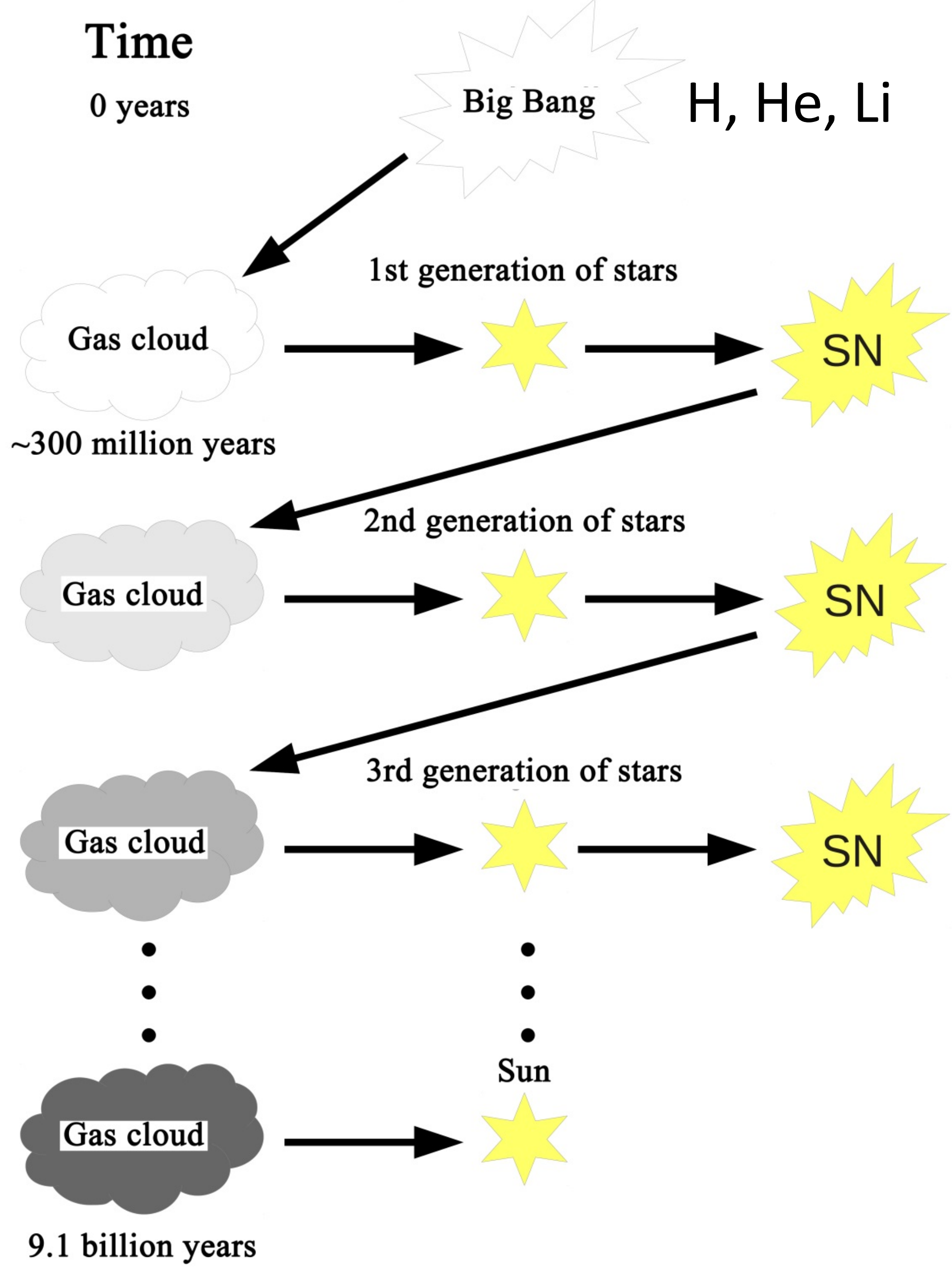
Examples (main-sequence stars)

Mass	10 M_{Sun}	0.8 M_{Sun}
Radius	4 R_{Sun}	0.9 R_{Sun}
T_{eff}	20,000 K	5200 K
Luminosity	3000 L_{Sun}	0.6 L_{Sun}
Spectral type	B2	K0
MS lifetime	10^7 yr	$2 \cdot 10^{10}$ yr

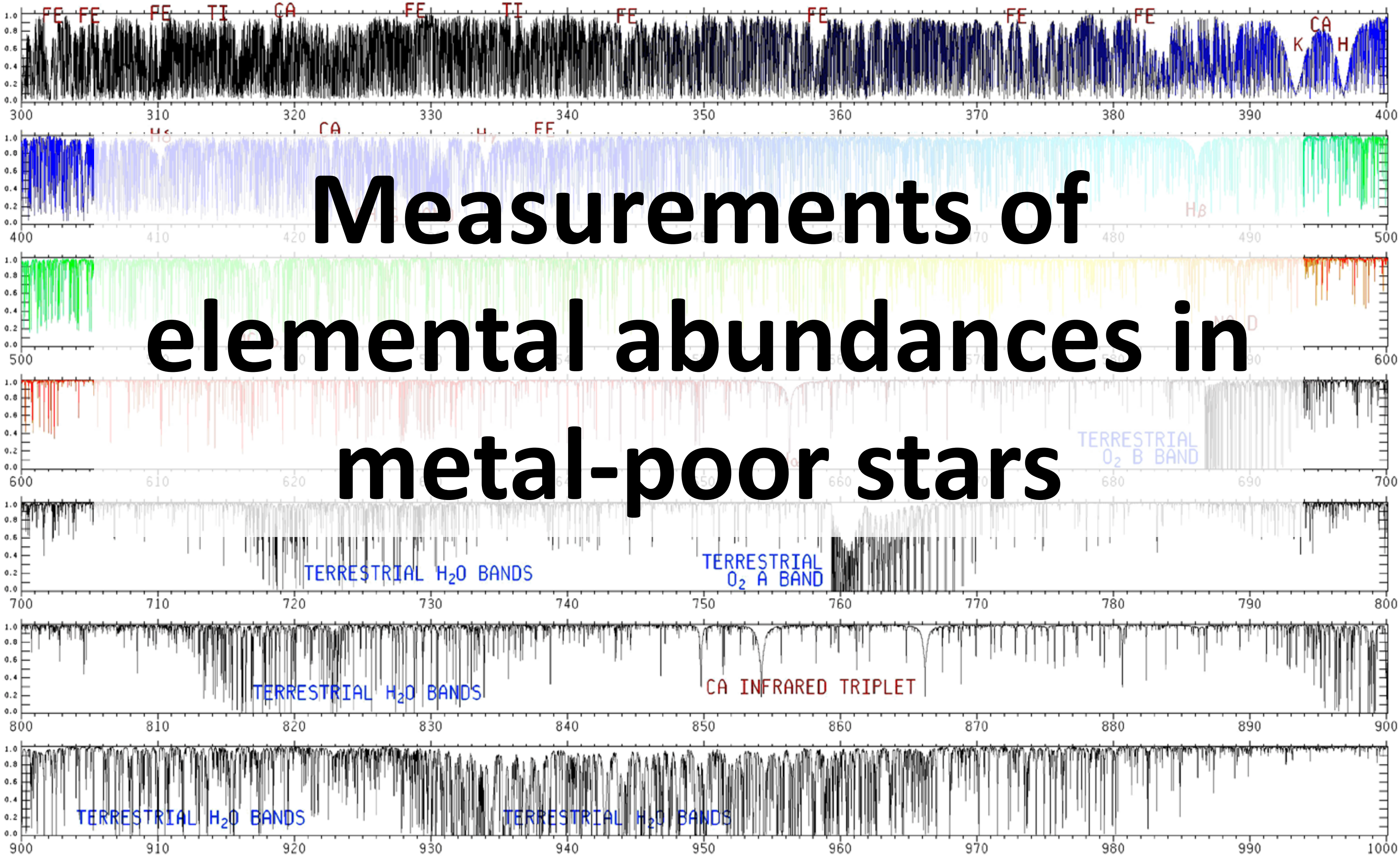
- Use hot stars if you want to study present-day cosmic abundances.
- Use old, cool stars if you want to study chemical enrichment history of the Universe.

Chemical enrichment of the Universe





Measurements of elemental abundances in metal-poor stars



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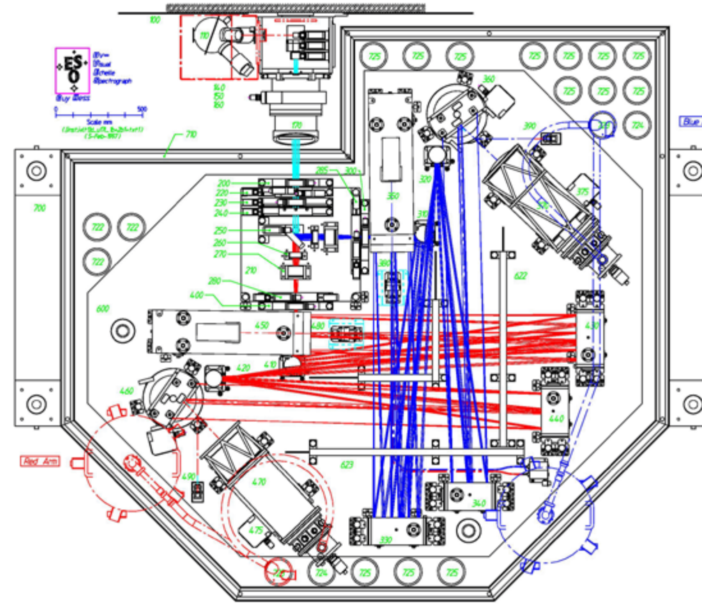

UVES

(two-arm cross-dispersed Échelle spectrograph => high spectral resolution *and* large wavelength coverage)

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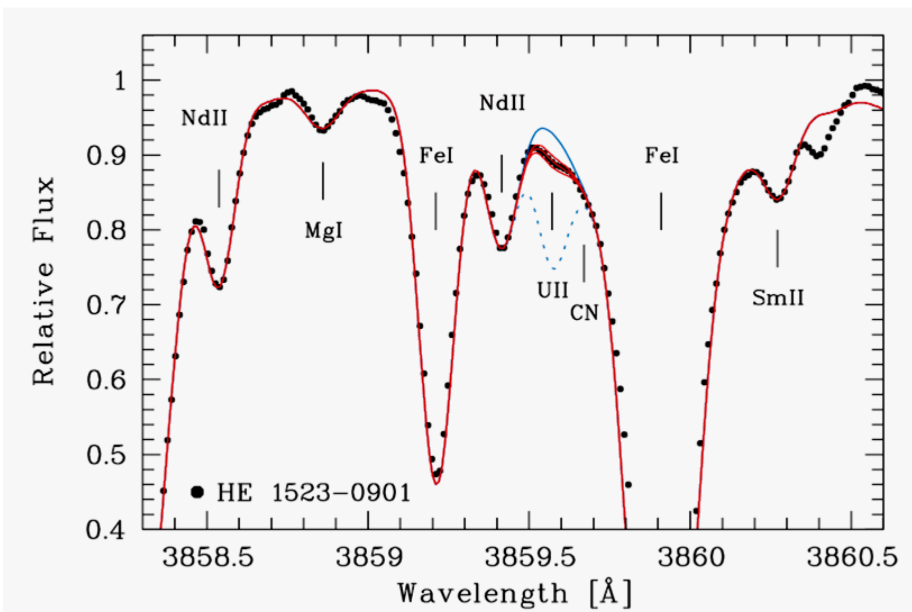
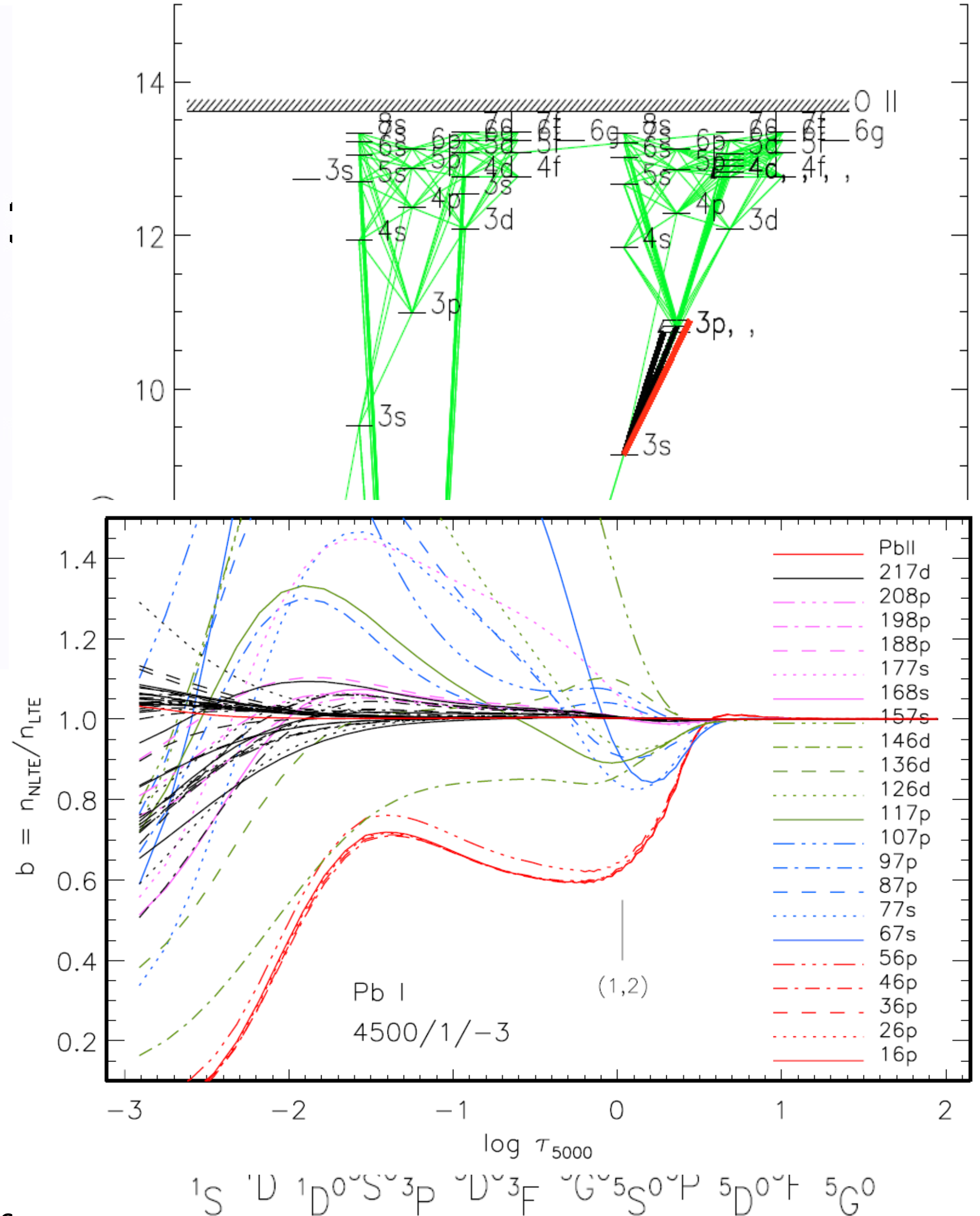


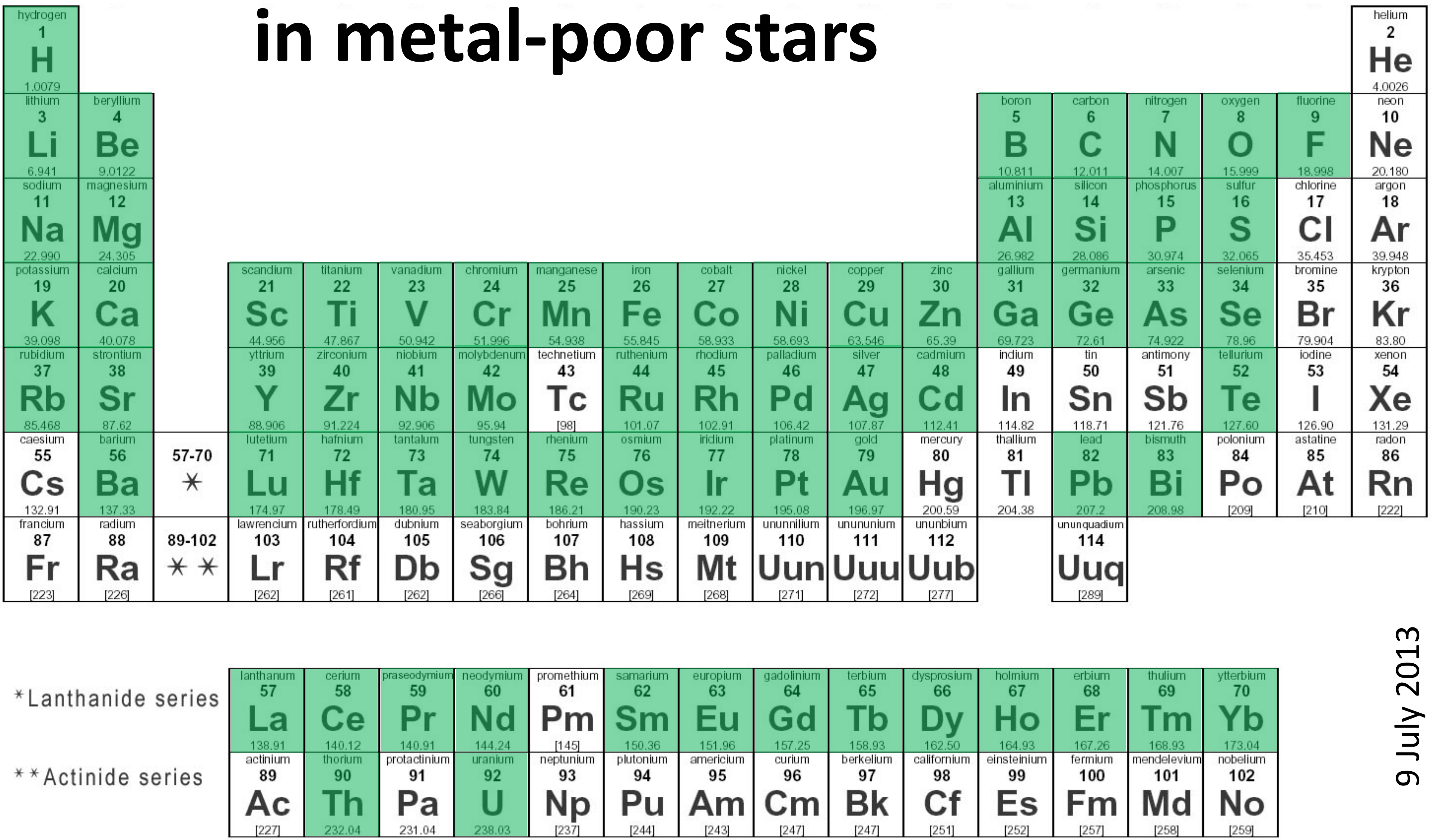
From spectra to abundances

Ingredients:

- Stellar parameters: T_{eff}, log g, [Fe/H]
- Model atmospheres (1D? <3D>? 3D?)
- Atomic data (log gf, λ, χ, partition functions...)
- Line formation calculations (NLTE?)

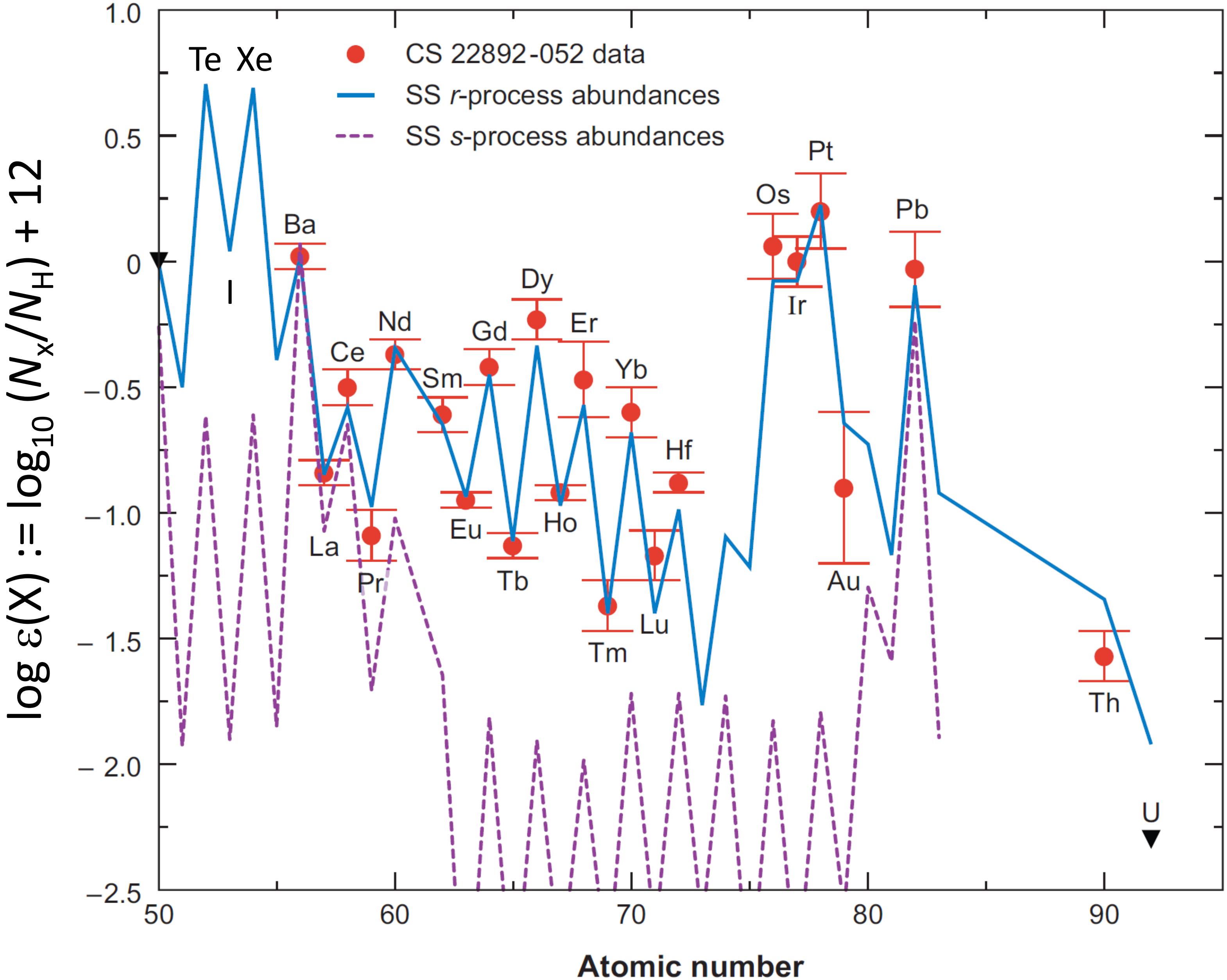


Elements measured in metal-poor stars



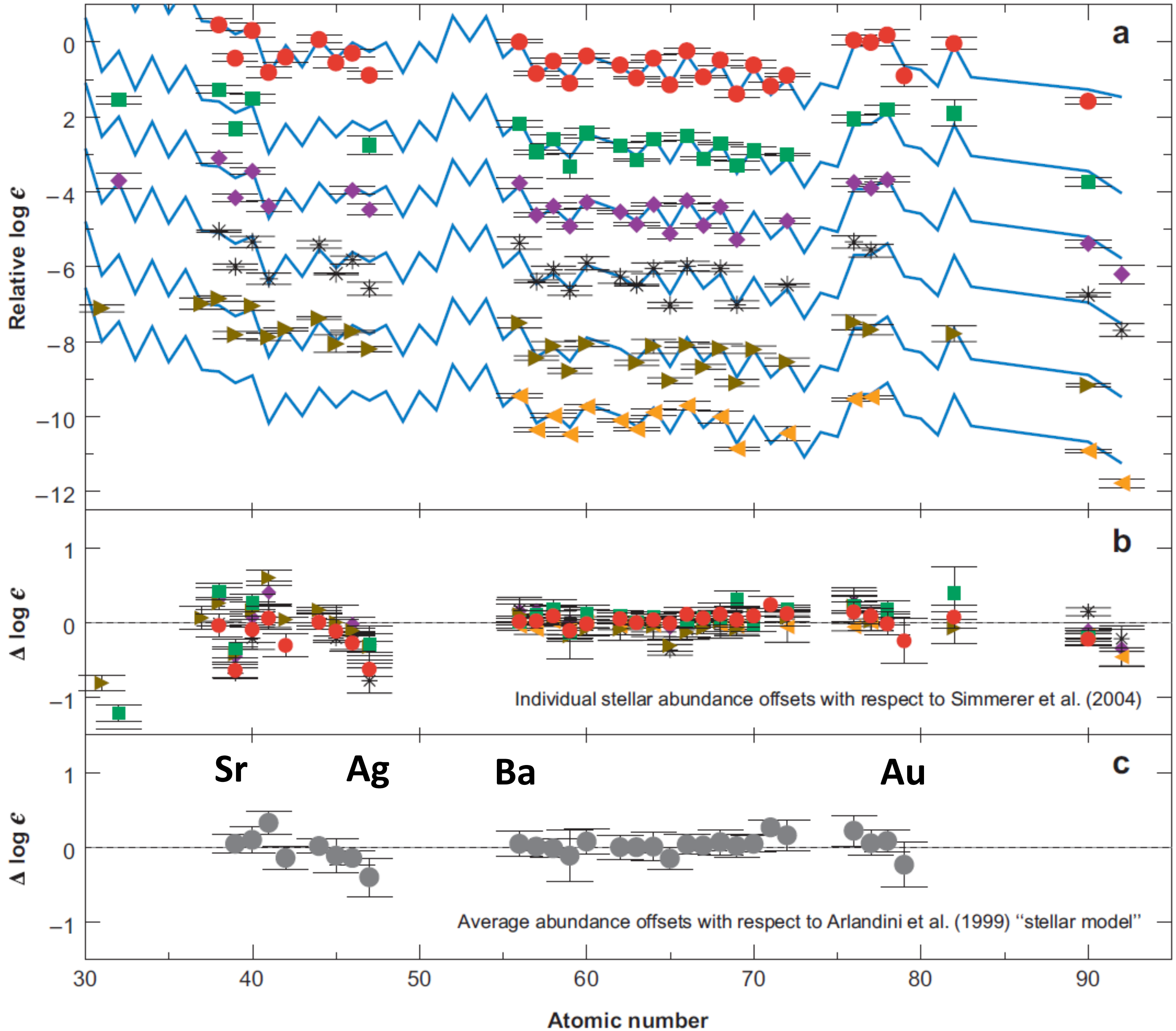
9 July 2013

Strongly r-process enhanced stars



(Sneden et al. 2008, ARA&A 46, 241)

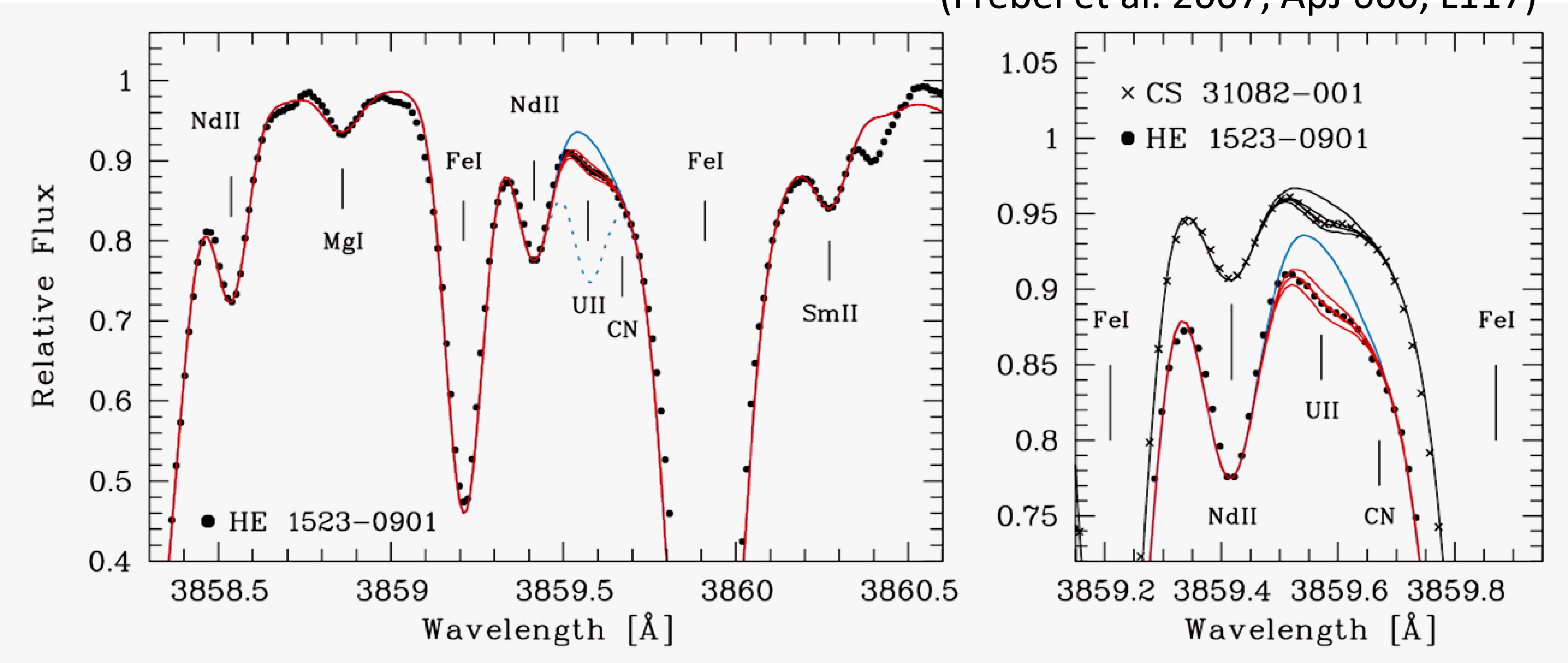
Strongly r-process enhanced stars



(Sneden, Cowan & Gallino 2008, ARA&A 46, 241)

Detection of uranium

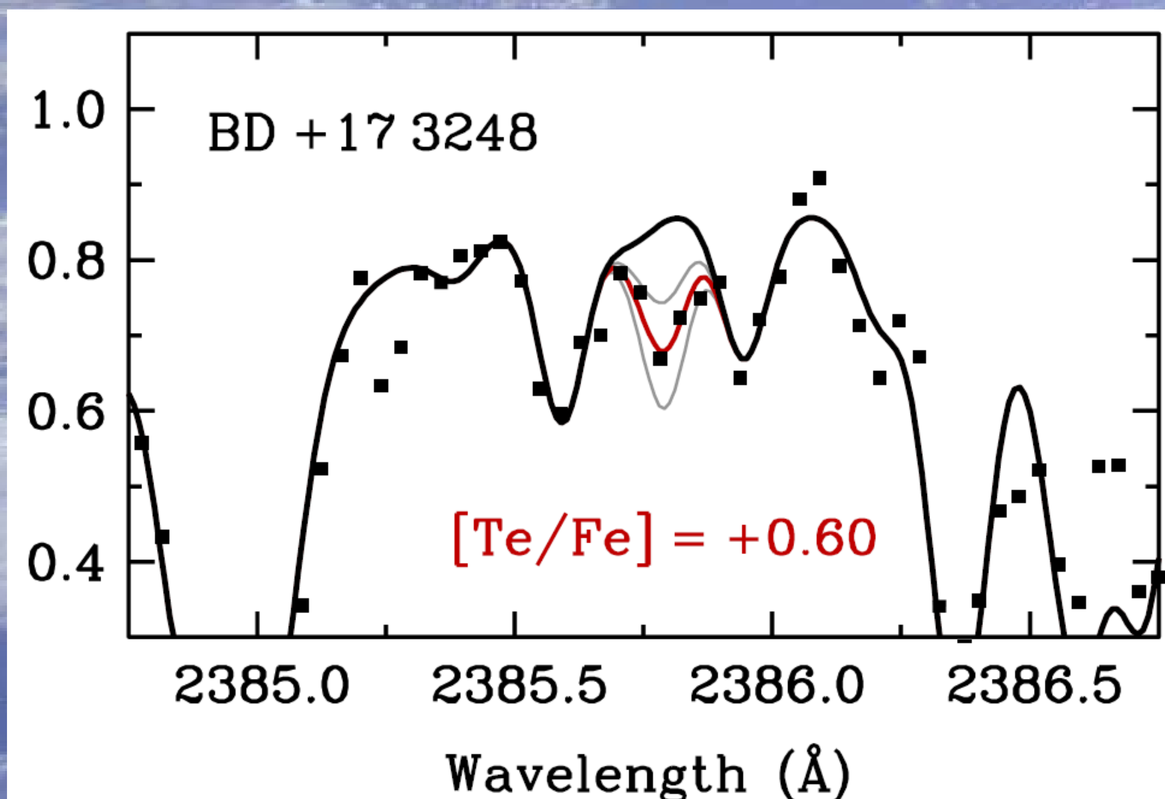
(Frebel et al. 2007, ApJ 660, L117)



log ε(U) = –2.1, where log ε(X) := $\log_{10} (N_x/N_H) + 12$

1 U atom in 10^{14} H atoms!

HST observations of Te

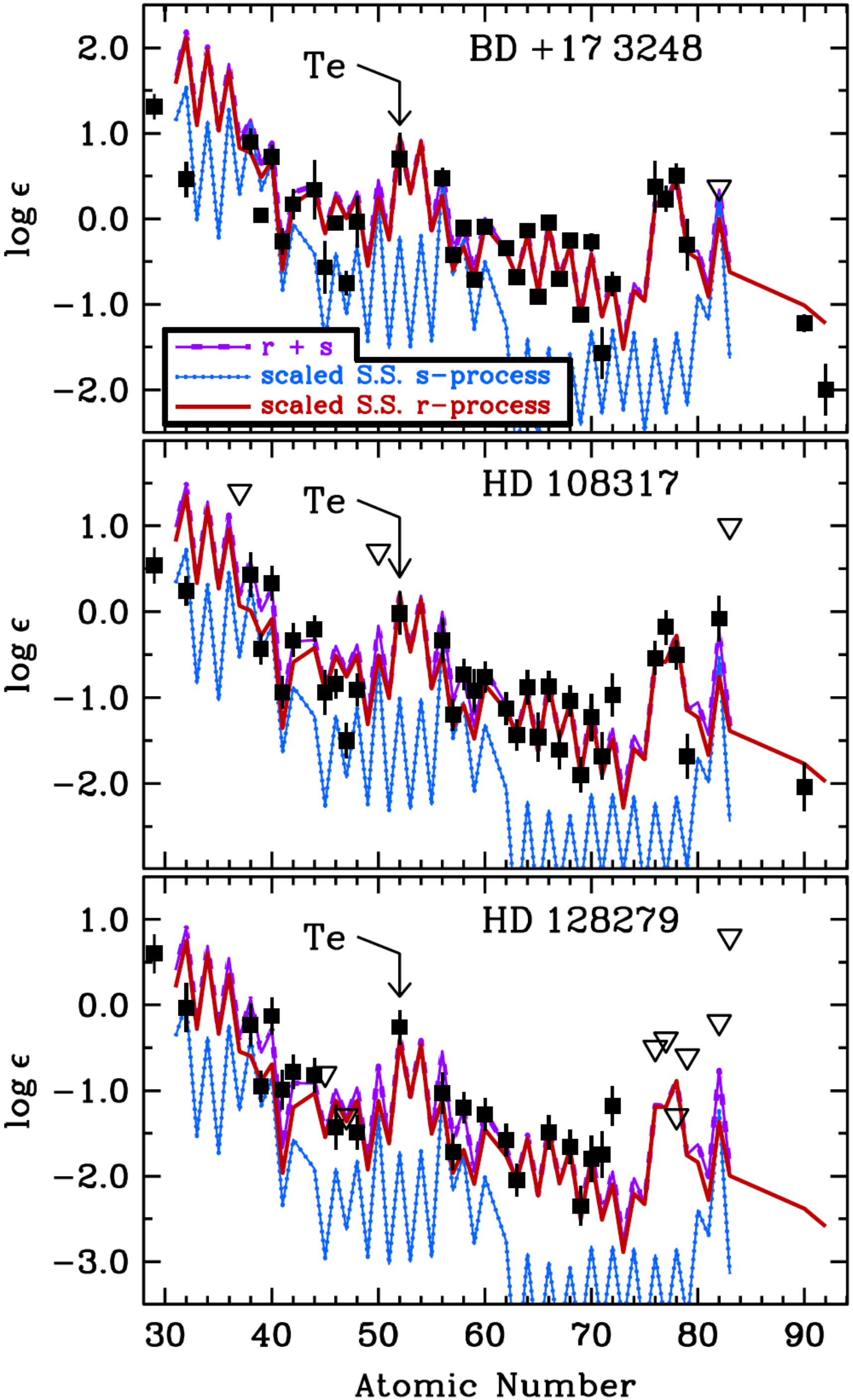


(Roederer et al. 2012, ApJ 747, L8)

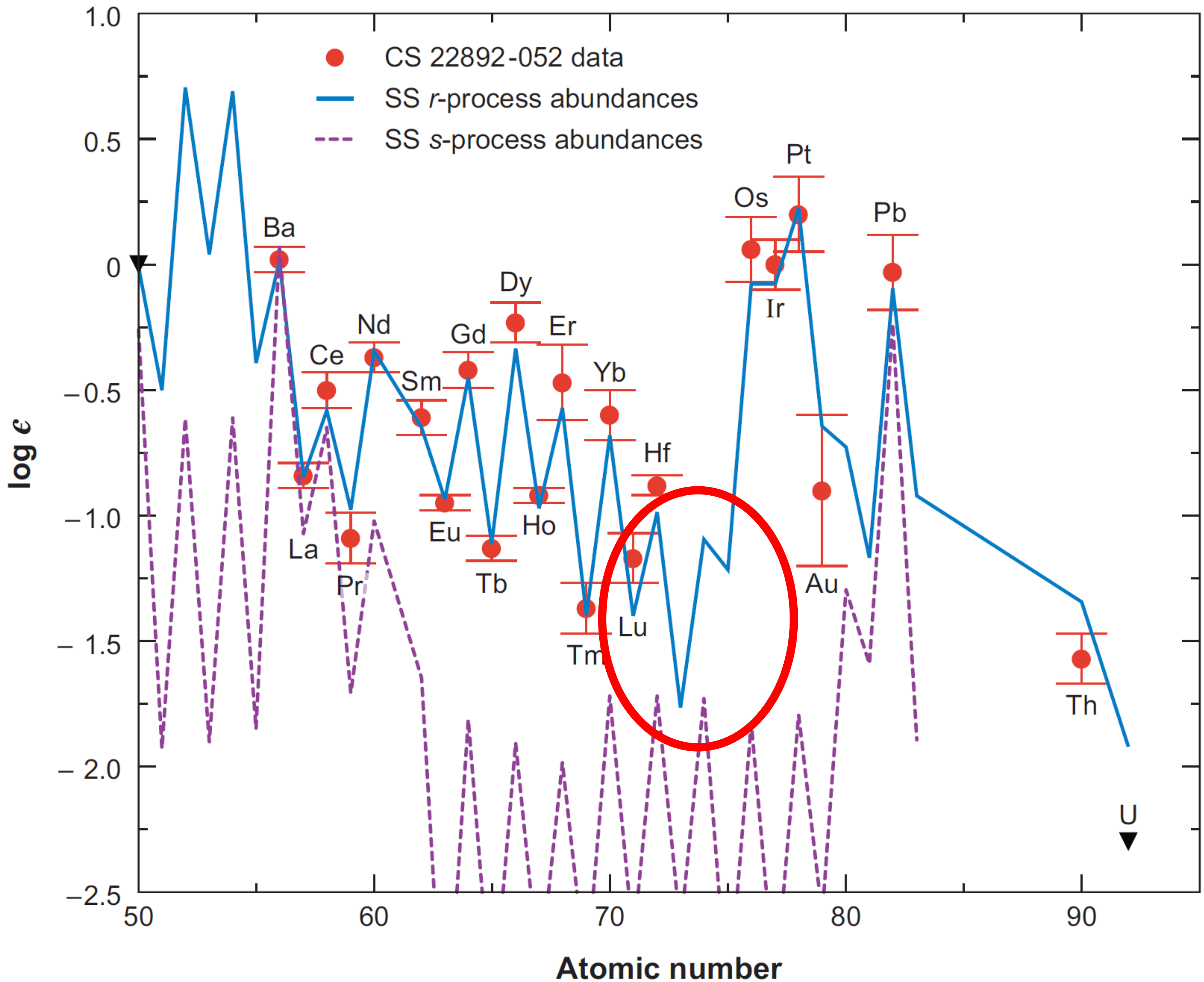
Tellurium

- Roederer et al. (2012, ApJ 747, L8): Observed abundances of Te match scaled Solar “r-process” abundance pattern well.

The stars observe from space you shall!

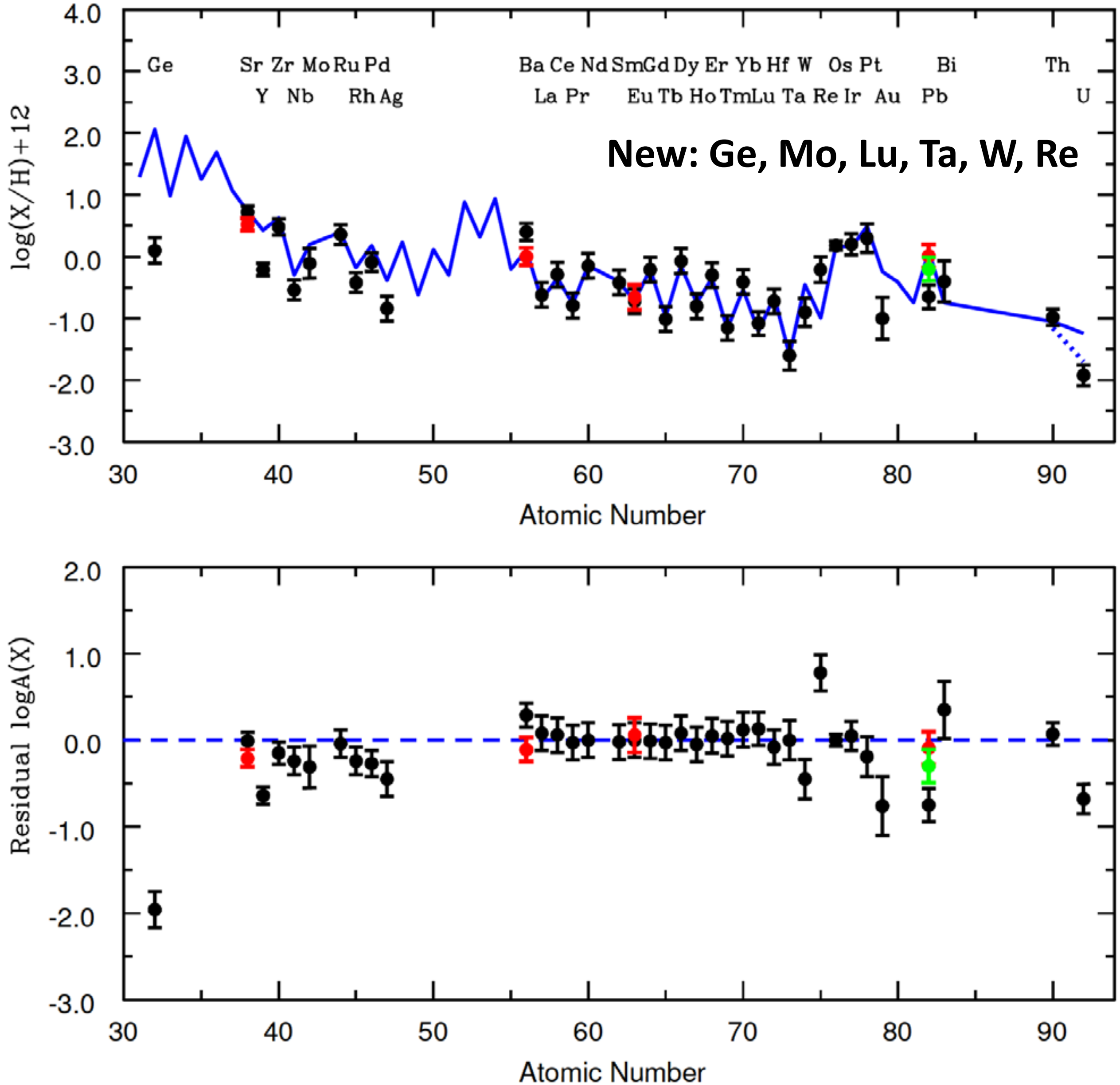


CS 22892–052, the “classical” r-II star



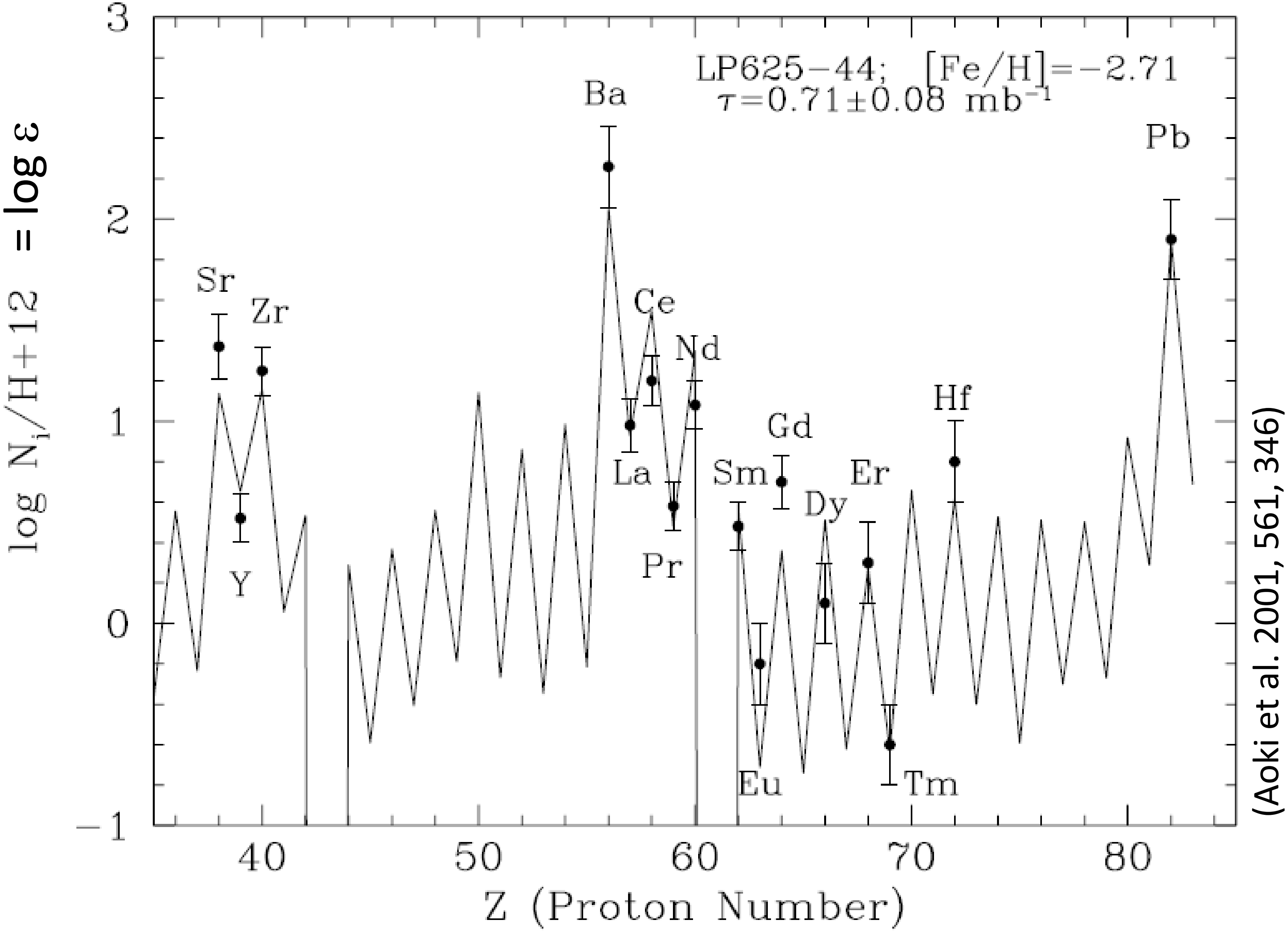
(Sneden et al. 2008, ARA&A 46, 241)

HST/STIS observations of CS31082-001

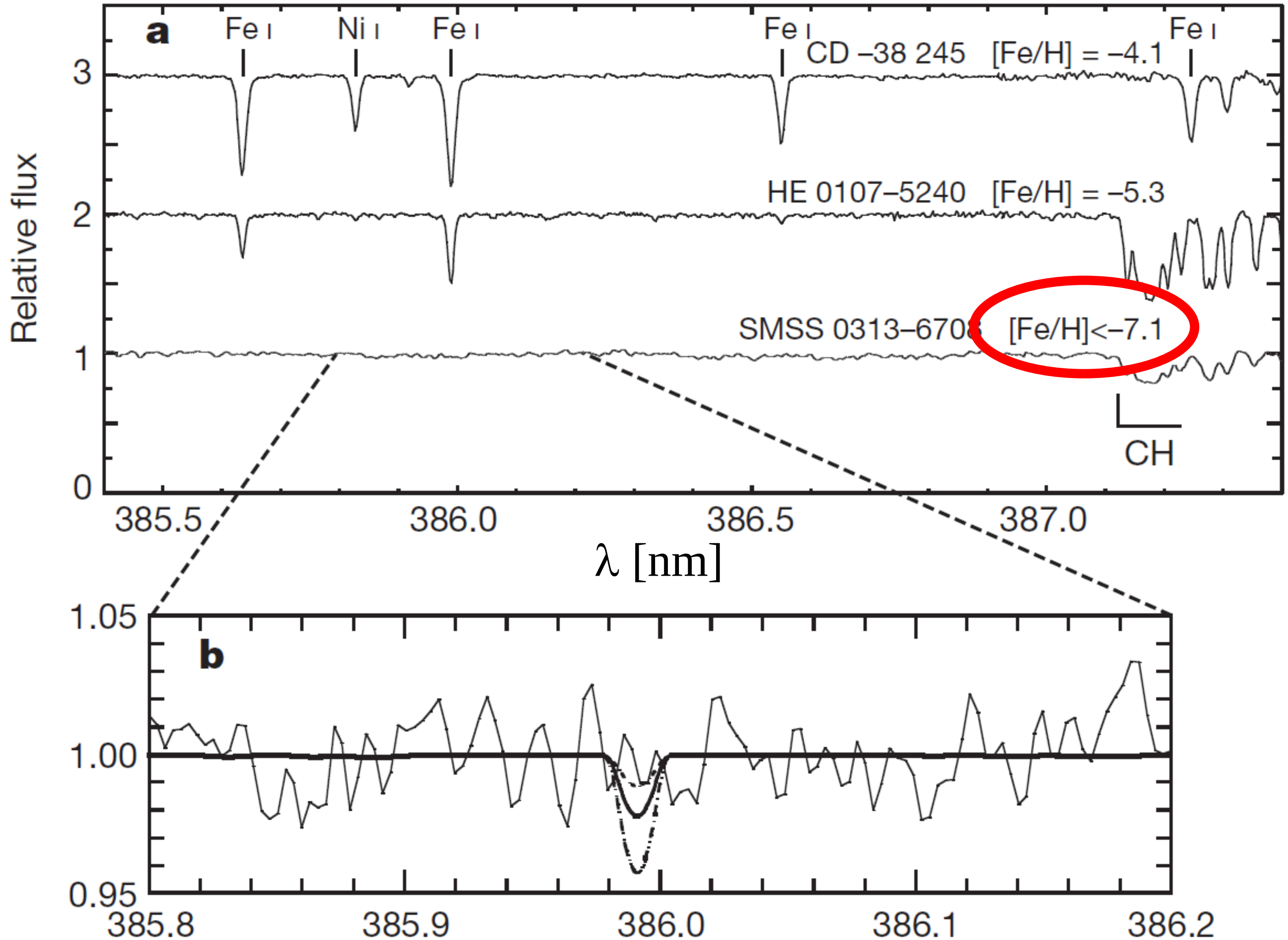


(Siqueira Mello et al. 2013, A&A 550, A122)

Strongly s-process enhanced stars

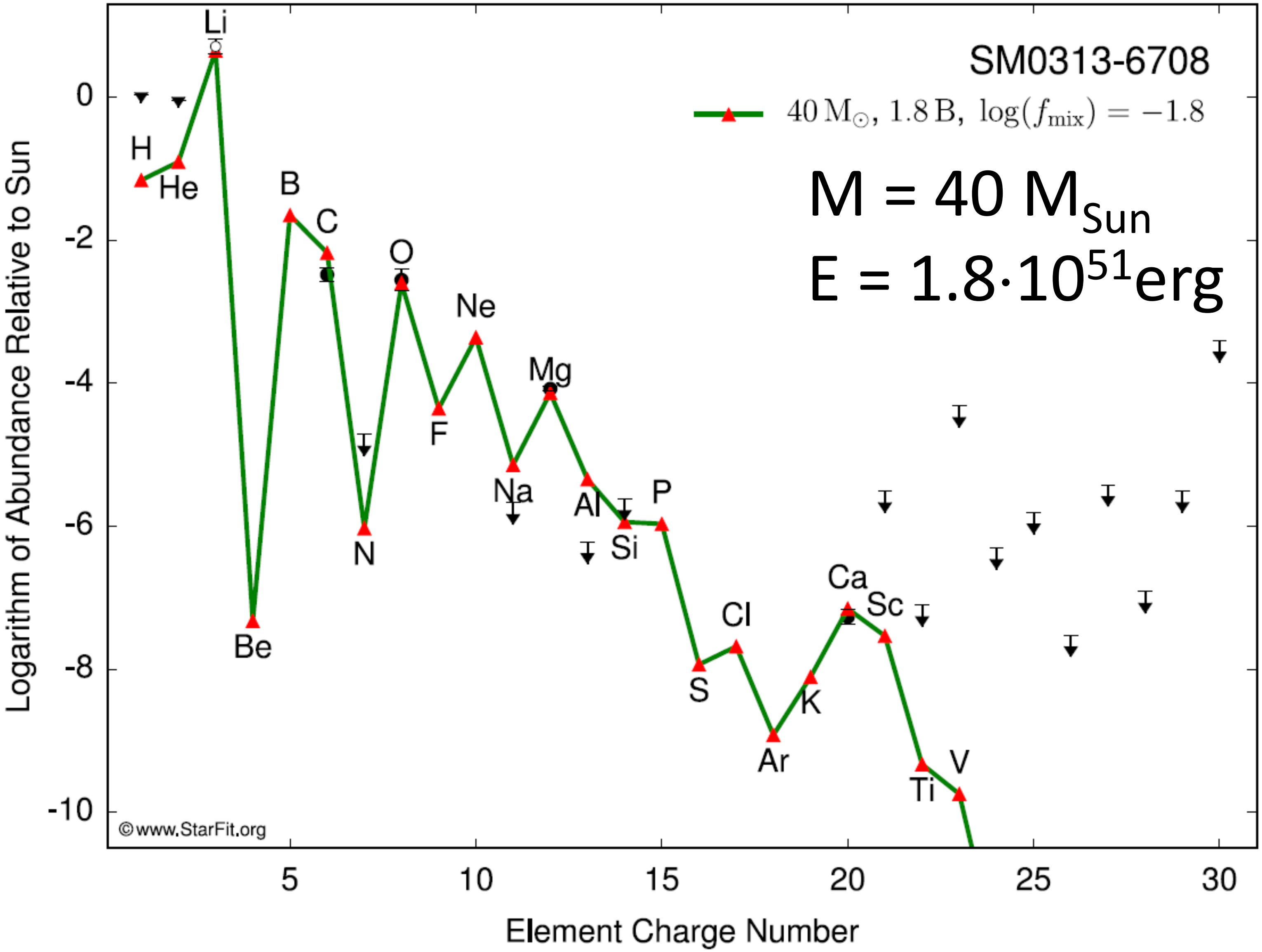


SMSS 0313–6708



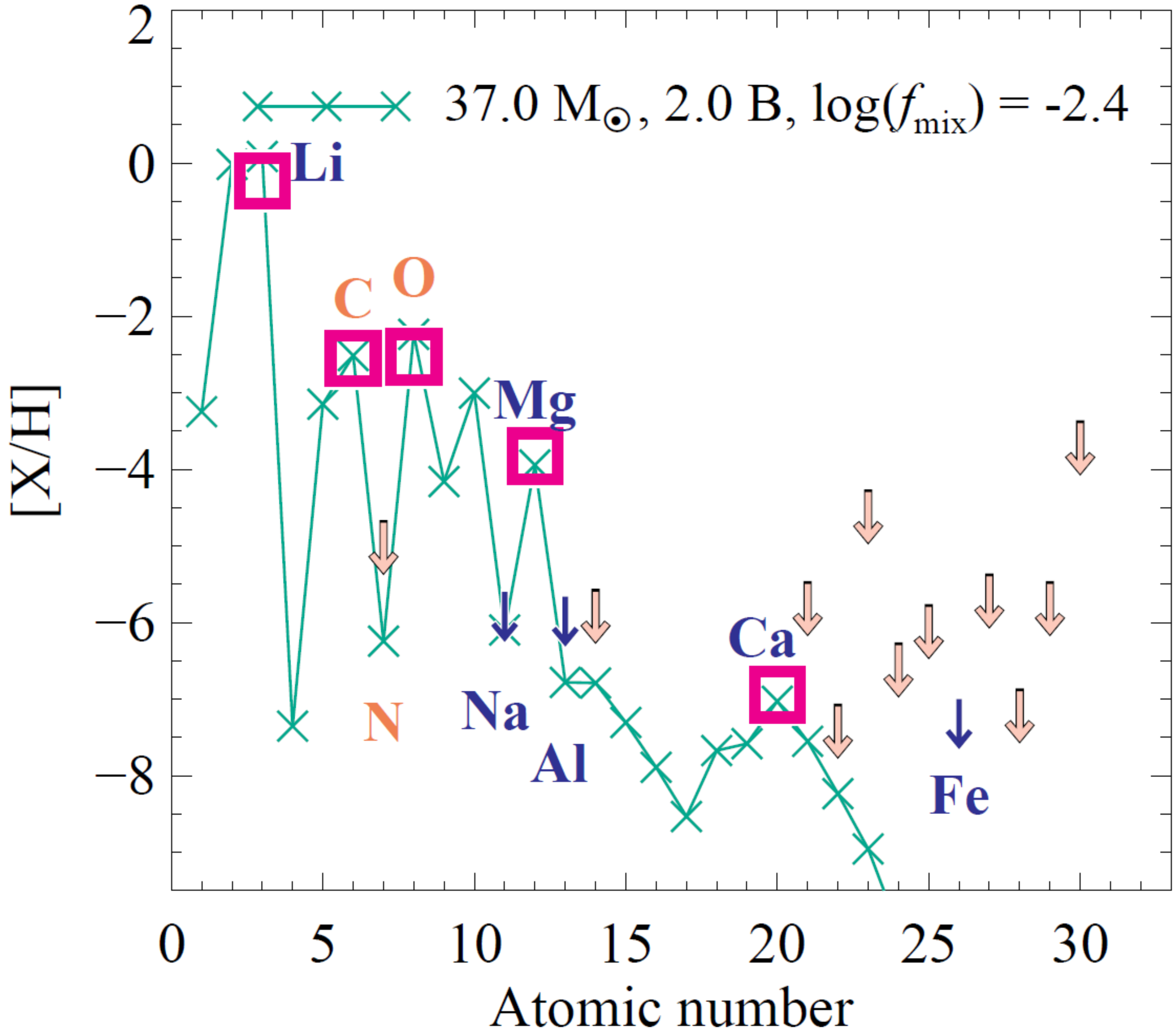
(Keller et al. 2014, Nature 506, 463)

SMSS 0313–6708: Abundance pattern



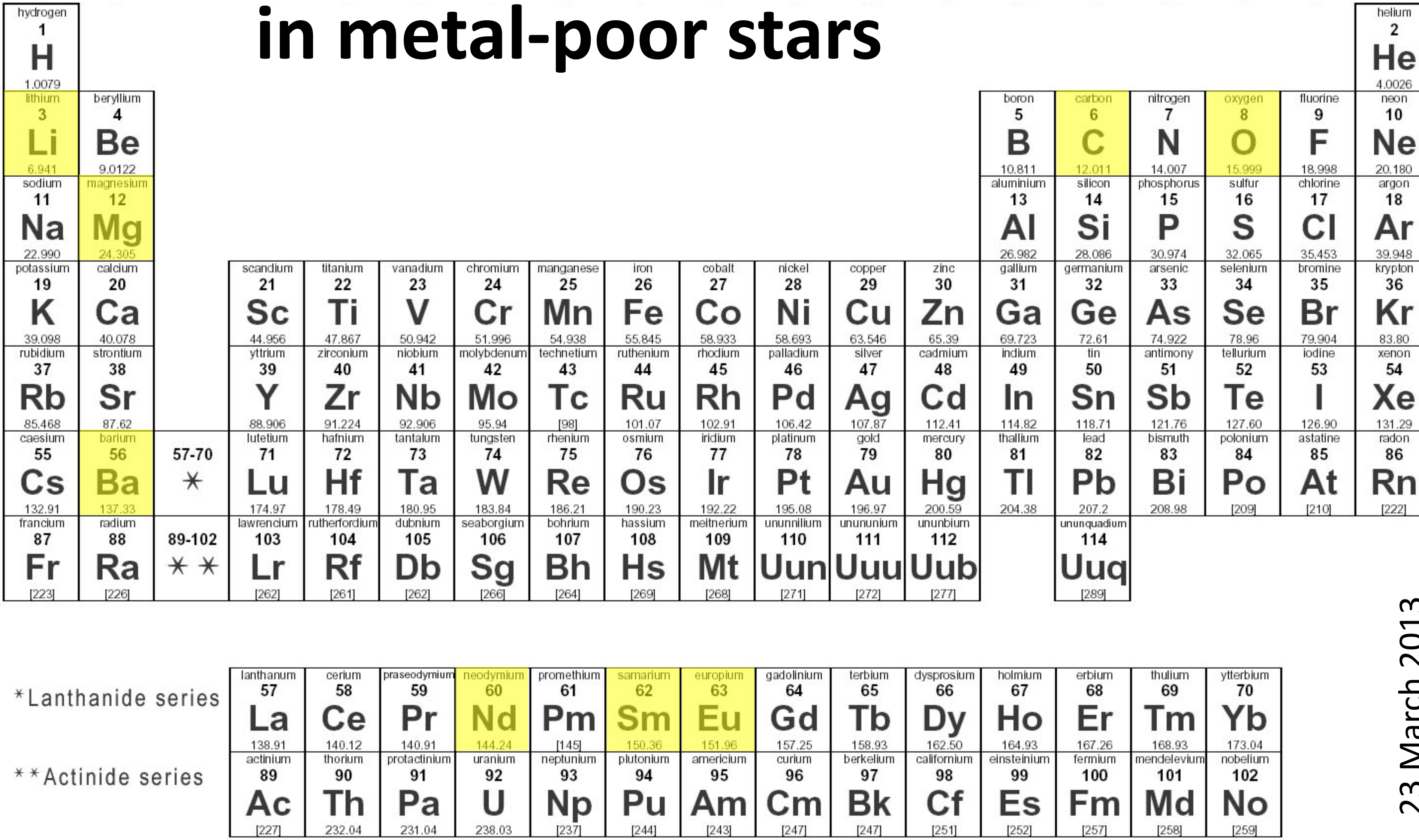
(Bessell et al. 2015, ApJ 806, L16)

SMSS 0313–6708: 3D NLTE abundance pattern



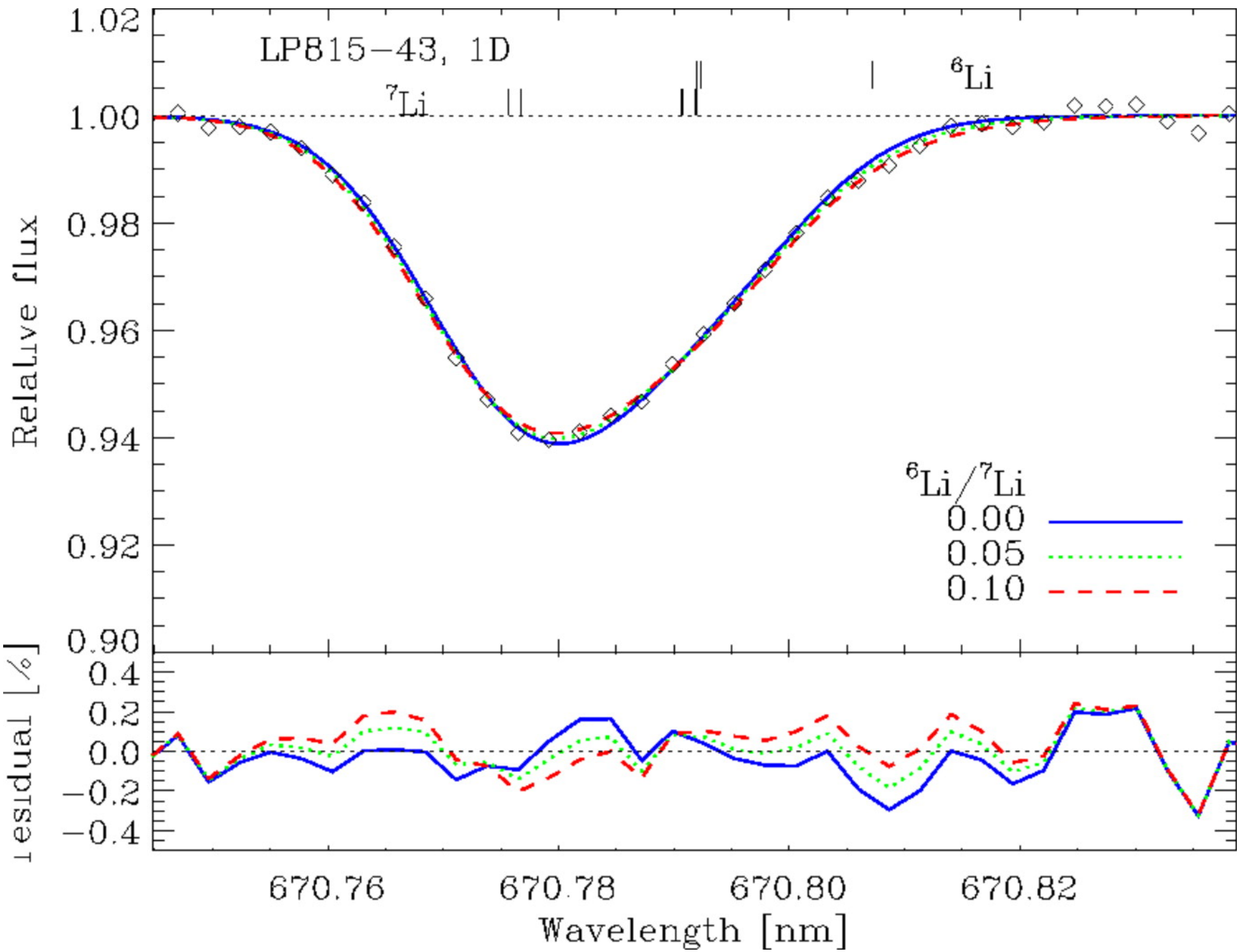
(Nordlander et al. 2016, arXiv 1609.0741)

Isotopic ratios measured in metal-poor stars



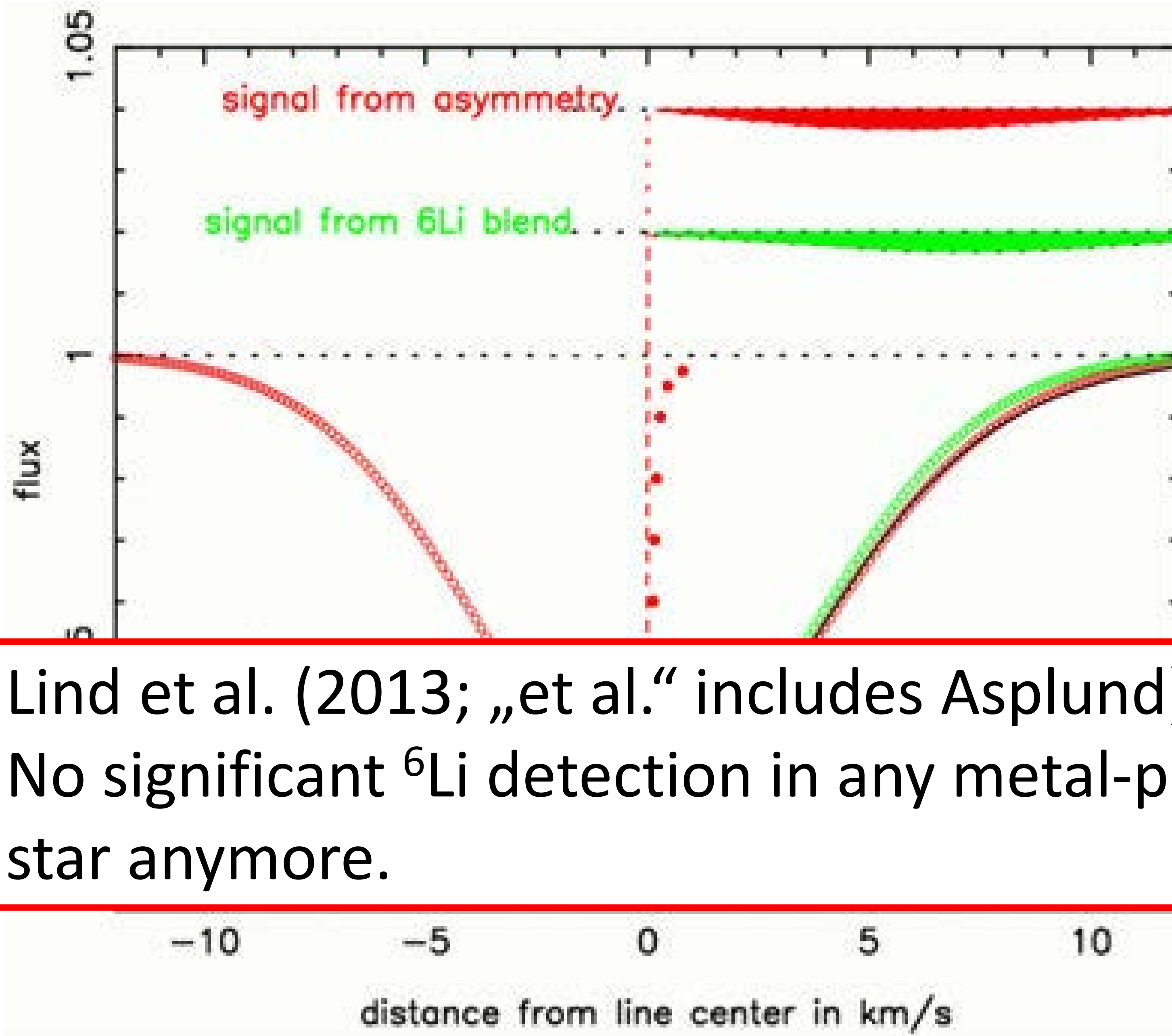
23 March 2013

Lithium isotopic ratio



(Asplund et al. 2006, ApJ 644, 229)

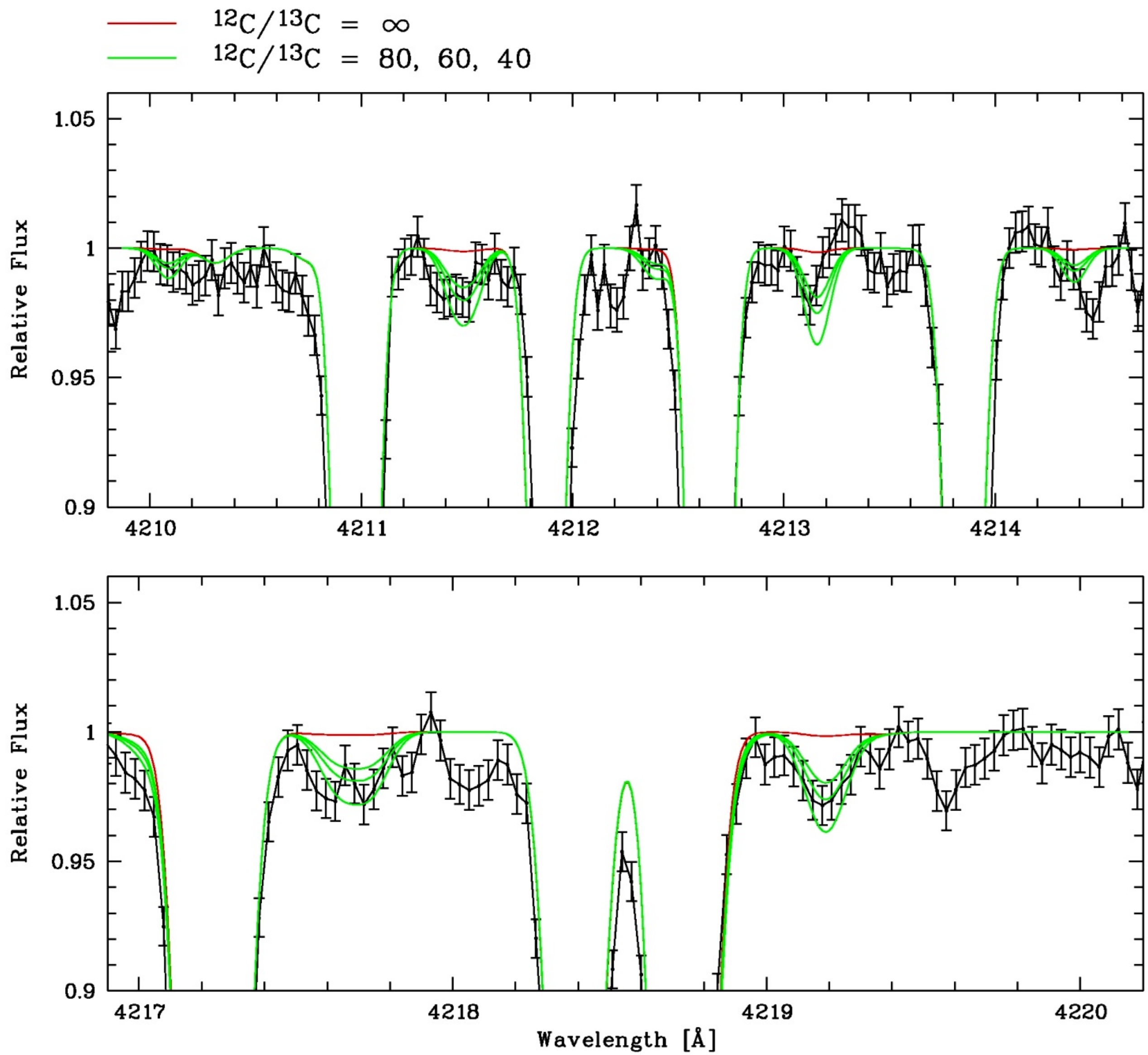
But…



(Cayrel et al. 2007, A&A 473, L37)

Lind et al. (2013; „et al.“ includes Asplund): No significant ^{6}Li detection in any metal-poor star anymore.

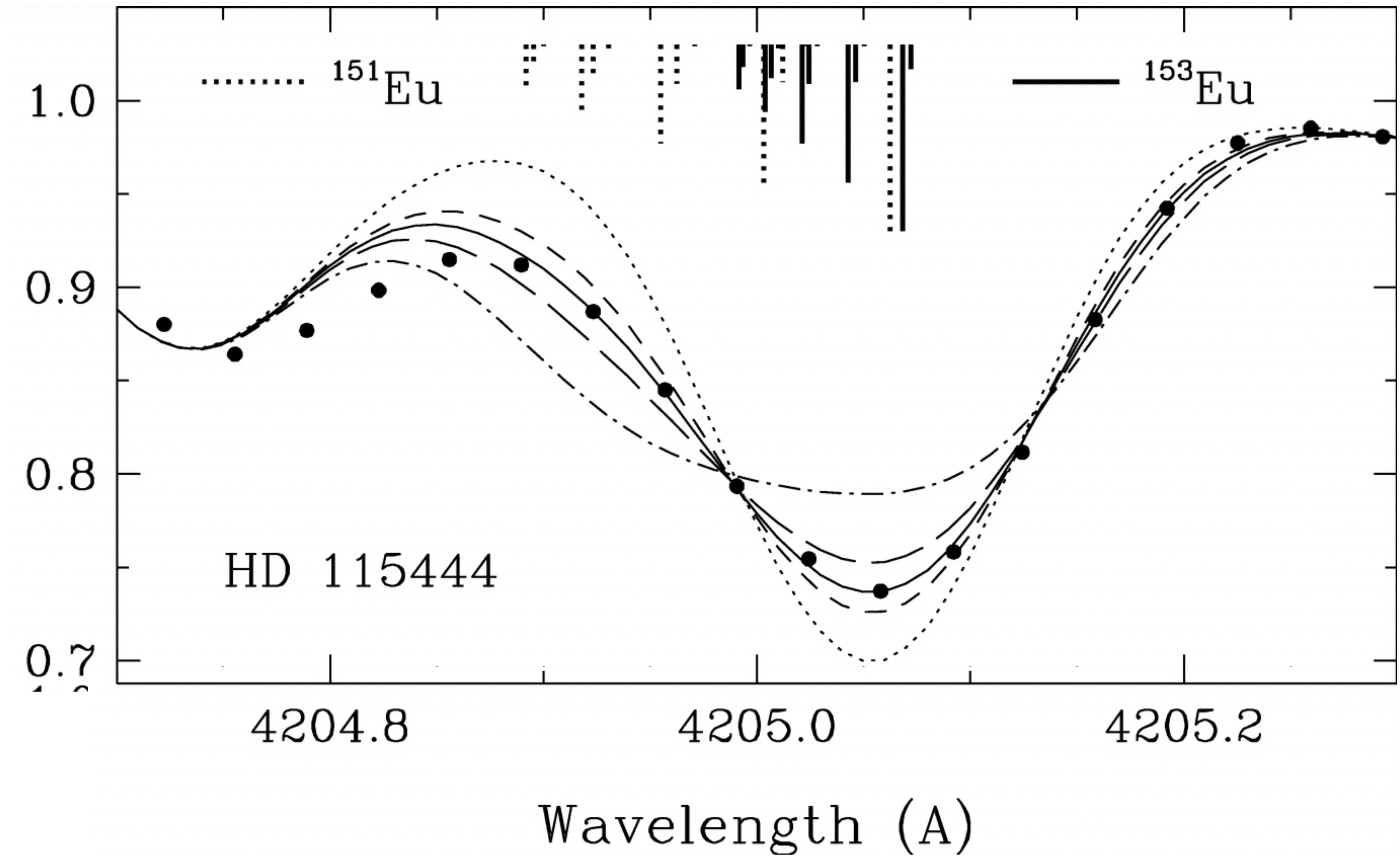
^{13}C in HE 0107–5240



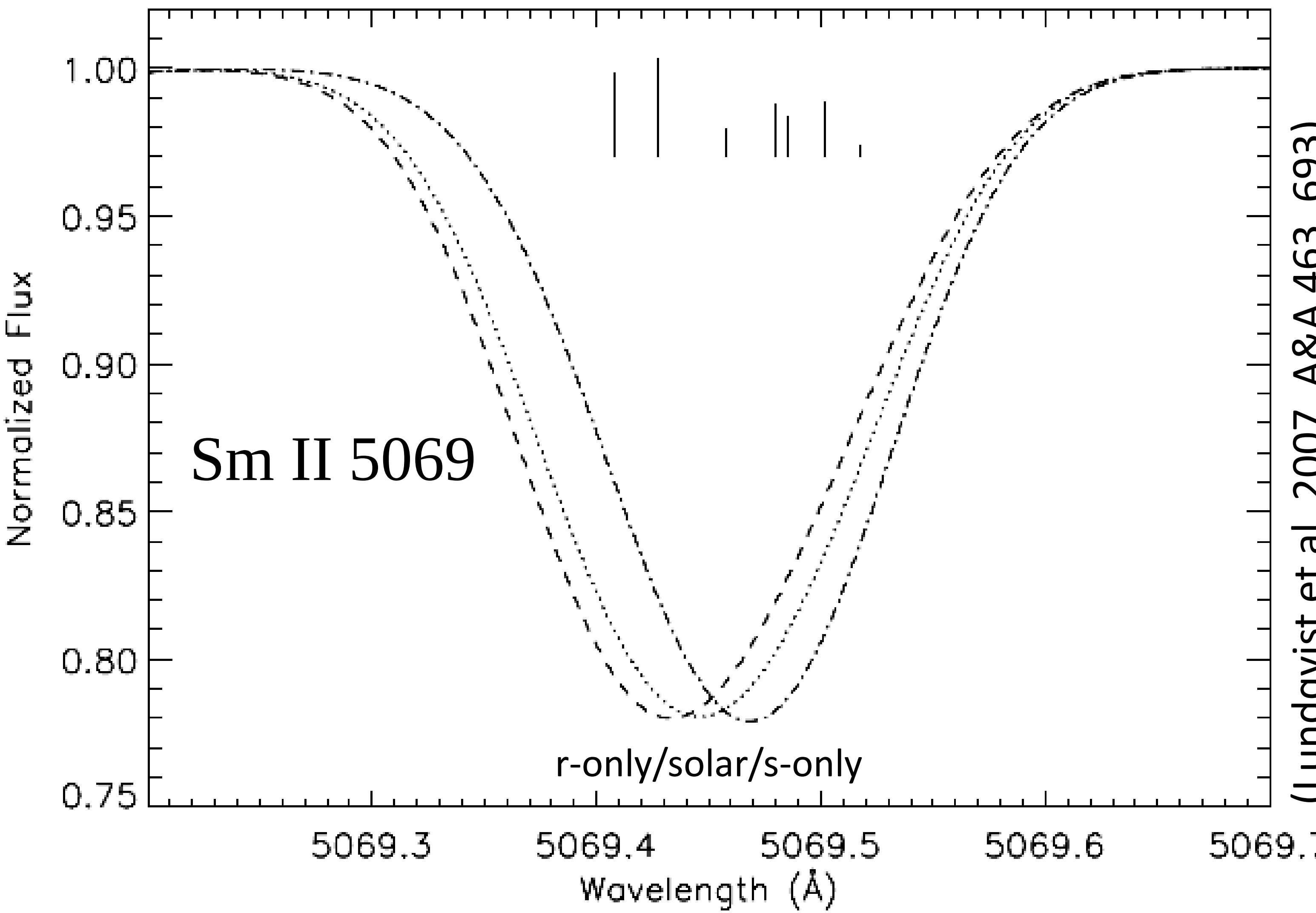
(Christlieb et al. 2099, in preparation)

Europium isotopic ratio

(Sneden et al. 2002, ApJ 566, L25)



Isotopic ratio of samarium

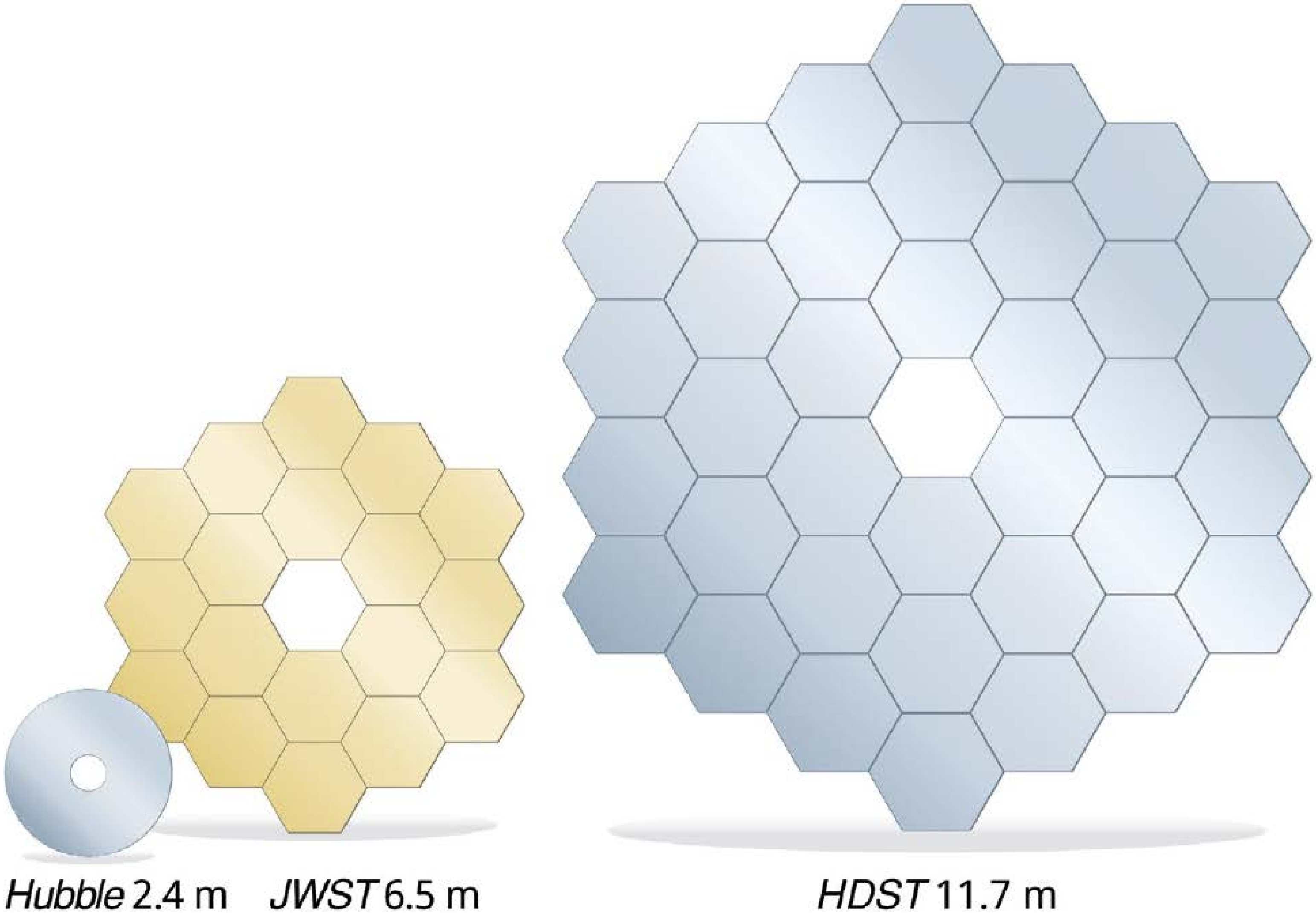


(Lundqvist et al. 2007, A&A 463, 693)

Outlook: Expected progress

- **3D models; NLTE calculations**
  => more accurate abundances and isotopic ratios
- **Multi-object spectrographs** at 4-8m telescopes; e.g., 4MOST/VISTA, WEAVE/WHT, ngCFHT.
  => larger samples of stars; lower [Fe/H]
- **CUBES**: a joint ESO-Brazil high-resolution UV spectrograph for the VLT. => more light in the UV
- **E-ELT HIRES**: Crossed-dispersed optical/IR Èchelle spectrograph. => More photons
- **High-Definition Space Telescope (HDST):**
  => UV observations from space after HST

High-Definition Space Telescope (HDST)

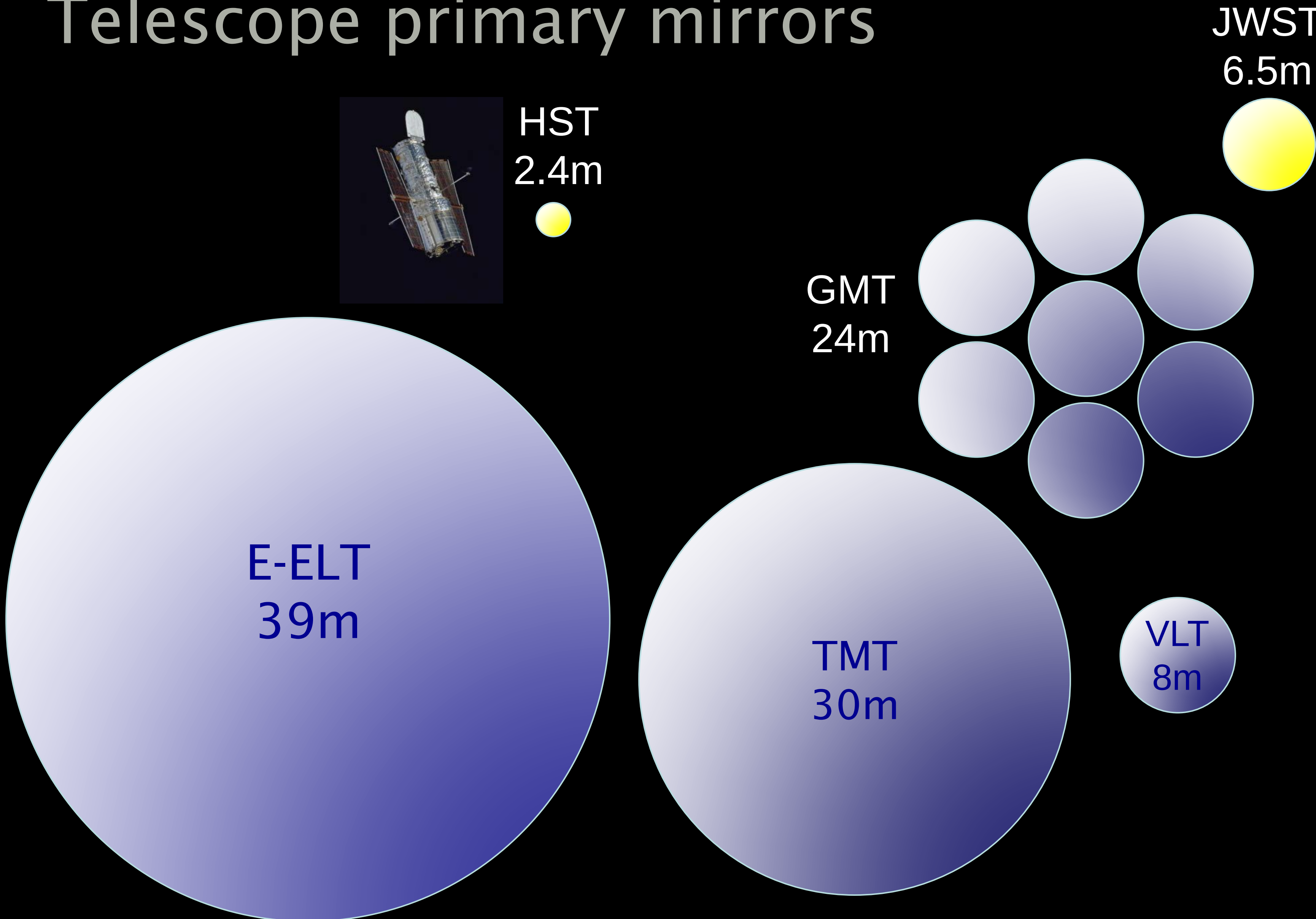


(Dalcanton et al. 2015, AURA report)

30m-class telescope projects

- **European Extremely Large Telescope (E-ELT)** **`www.eso.org/sci/facilities/eelt/`**
  - ESO
  - 798 hexagonal primary mirror segments of 1.4 m <=> *D* = 39 m
  - Site: Cerro Armazones, Chile
  - First Light: “mid-2020ies”
- **Thirty Meter Telescope (TMT; `www.tmt.org`)**
  - USA + Canada + China + Japan
  - 492 hexagonal primary mirror segments of 1.4 m <=> *D* = 30 m
  - Site: Mauna Kea, Hawai’I
  - First Light: 2022?
- **Giant Magellan Telescope (GMT; `www.gmto.org`)**
  - USA + Australia + Korea
  - 7 round mirrors of 8.4 m <=> *D* = 22 m
  - Site: Las Campanas, Chile
  - First Light: “2022”

Telescope primary mirrors



Summary

- Elemental abundances of old, metal-poor stars in our Galaxy provide observational constraints on nucleosynthesis processes in the early Universe, and their sites.
- Outlook:
  (a) 3D NLTE
  (b) larger samples of stars
  (c) more light in the UV from ground and space
  (d) higher quality spectra quality for more stars.