Disentangling the signature of planets and neutron-capture enrichment using UV/optical spectroscopy

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Ni Si Fe O Cr Eu Mg Ca C V Ti Dy K Cr S Al N Sm Ag Nd Gd La Ru Yb Mo Pr Ba Pd Sr Ce Zr Y

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How to achieve a precision of 0.01 dex in elemental abundances?

- Very high S/N: *reduces errors in* W_λ
- High spectral resolution: *reduces errors in* W_λ
- Careful selection of lines: *reduces blends*
- Strictly differential approach: *reduces model errors*

How to achieve a precision of 0.01 dex in elemental abundances?

- Very high S/N
- High spectral resolution
- Careful selection of lines
- *Strictly differential approach using stars similar to the Sun (**solar twins**):*

  - "star-like" Sun (asteroids: Vesta, Ceres, ...)

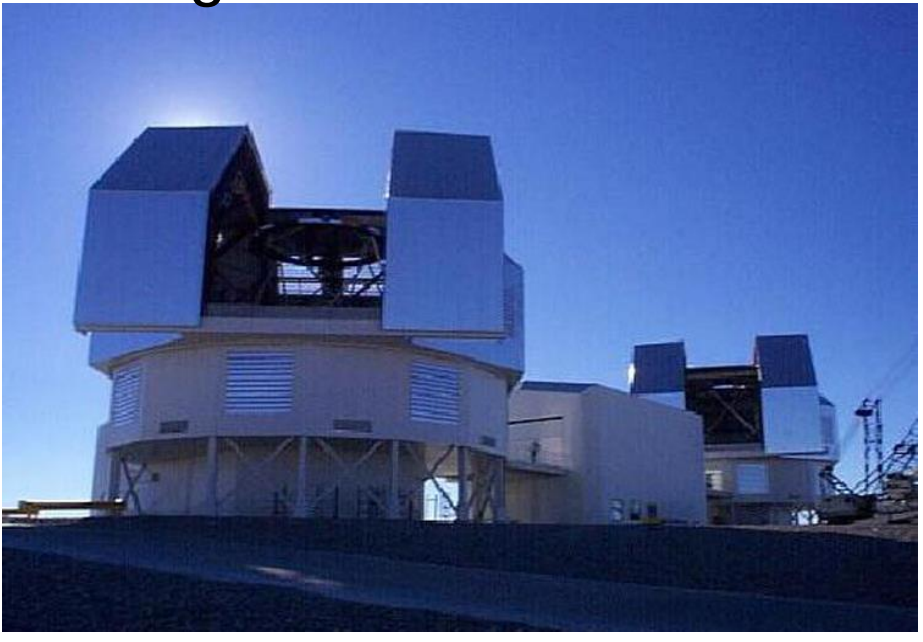
  - accuracy in T_{eff} - scale

  - line-by-line cancel errors in gf-values

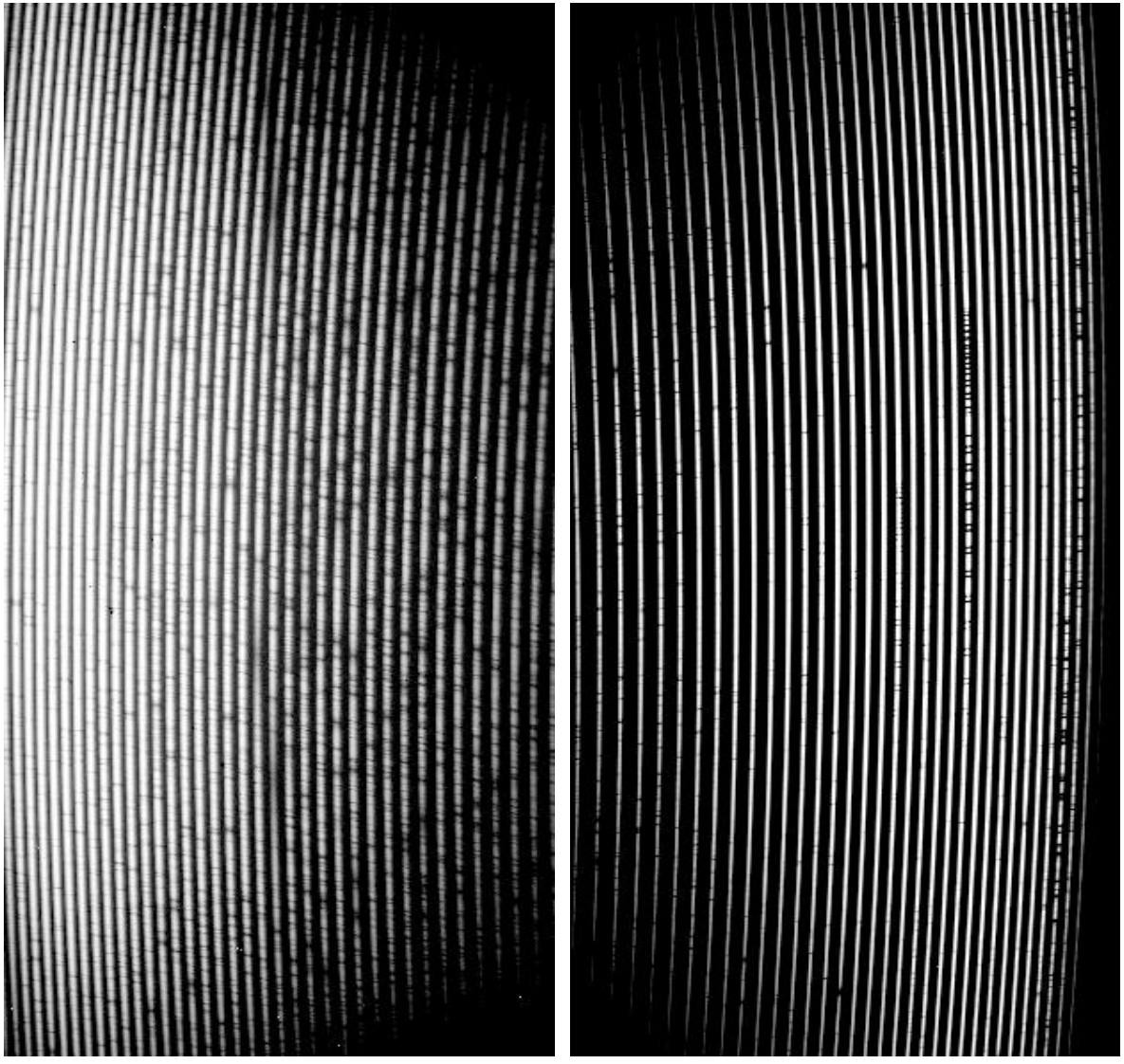
  - weak dependence on model atmospheres

Magellan ultra high precision study of solar twins

- Magellan 6.5m Clay Telescope & Mike spectrometer
- R = 65,000
- S/N = 450 per pixel
- coverage 340 – 1000 nm
- Solar spectrum: Vesta
- 3 nights of observations

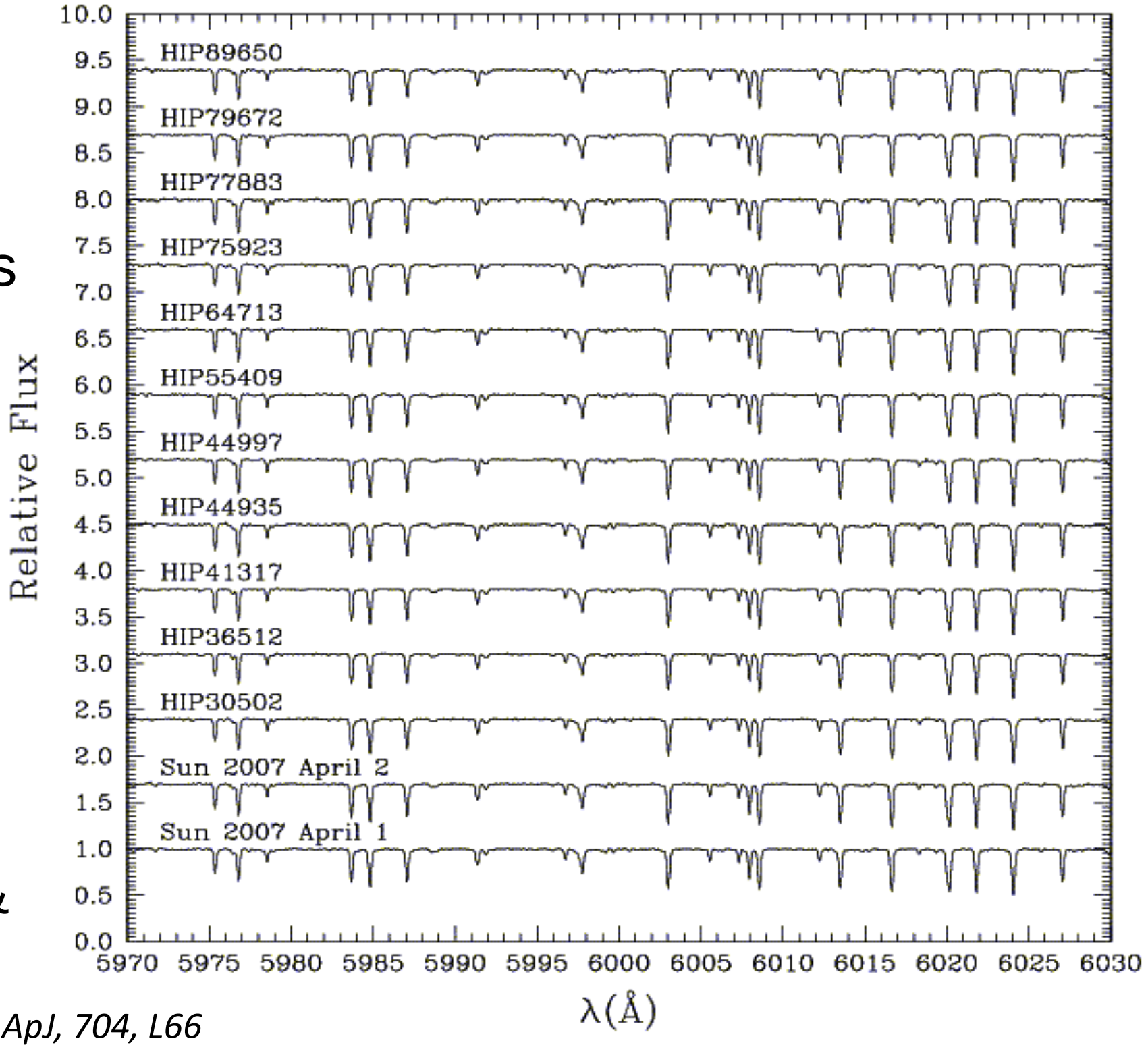


Observations of the solar twin 18 Sco



BLUE frame **RED frame**

Example of Magellan spectra of 11 solar twins and the Sun *(total spectral coverage 3350 A -1μm)*

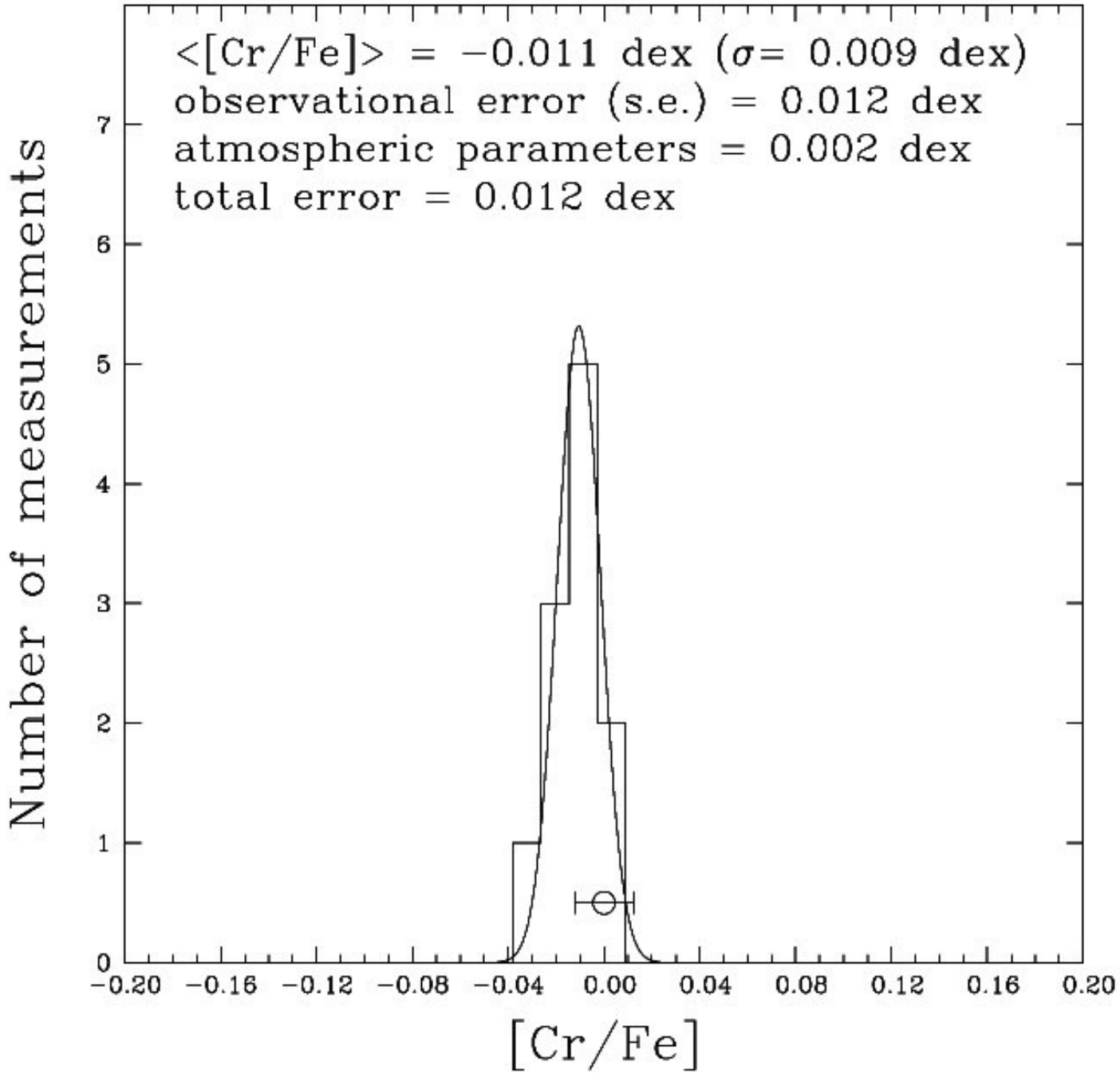


Small part (597-603nm) of solar twin & Sun's spectra

Meléndez et al. 2009, ApJ, 704, L66

[Cr/Fe] distribution in 11 solar twins

Star-to-star scatter of only **0.009 dex**

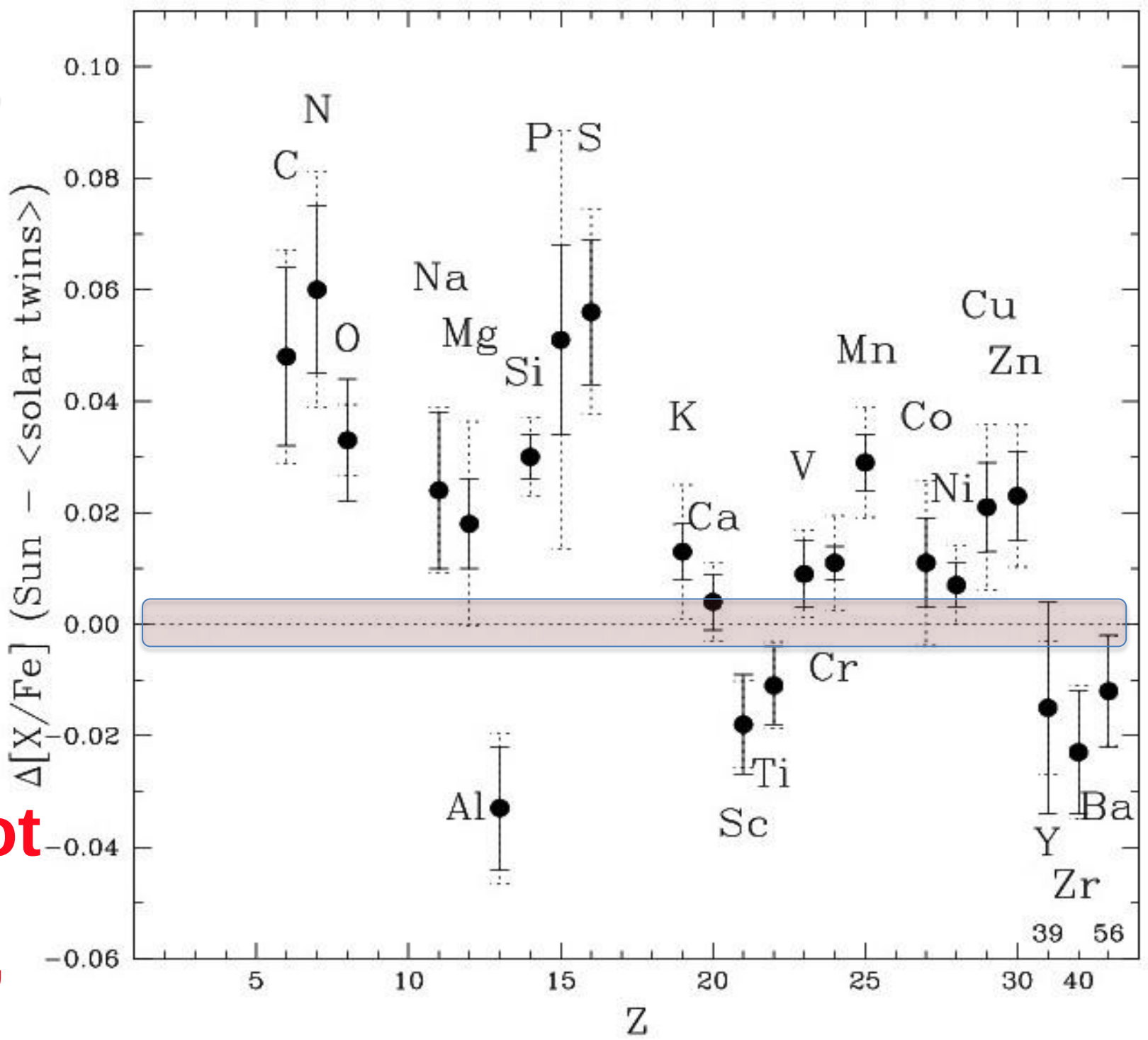


Δ abundance: Sun - <twins> vs. atomic number Z

Sun typical : Δ = 0

Sun weird : Δ ≠ 0

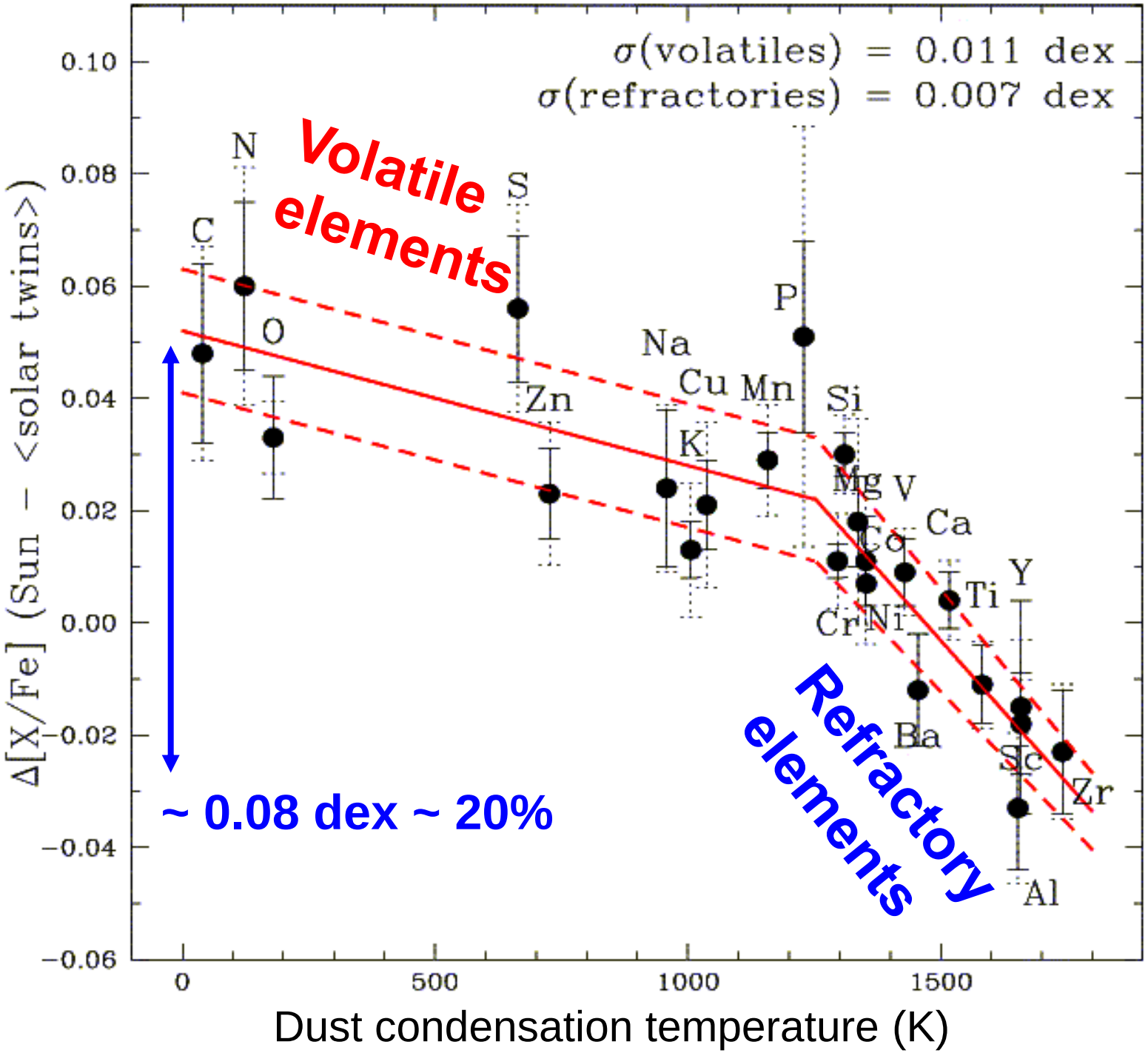
Our solar system is not host by a typical 'Sun'



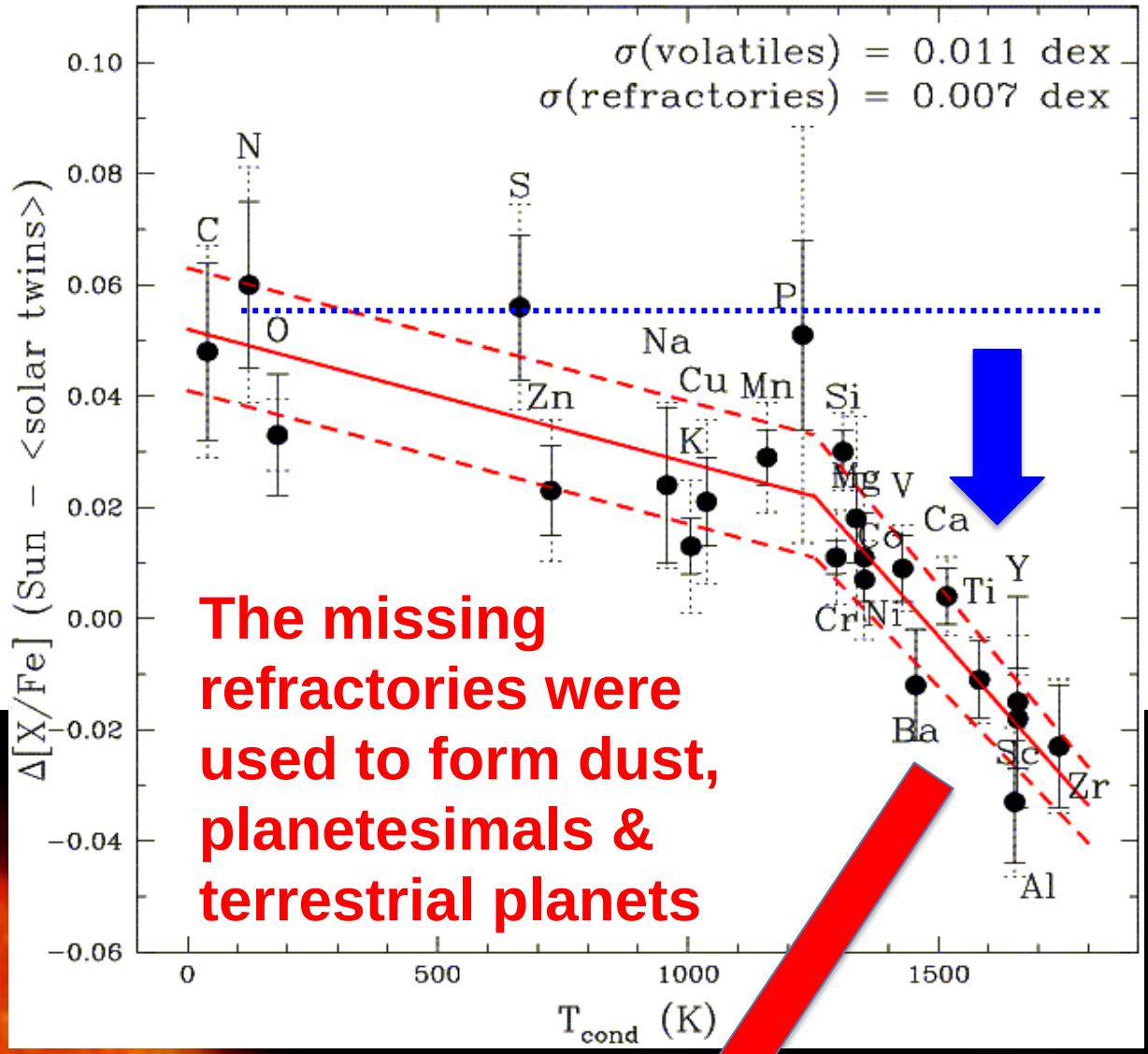
Sun's anomalies are strongly correlated to the dust condensation temperature of the elements!

Correlation is highly significant probability ~10^{-9} to happen by chance

It's most likely to win the lottery

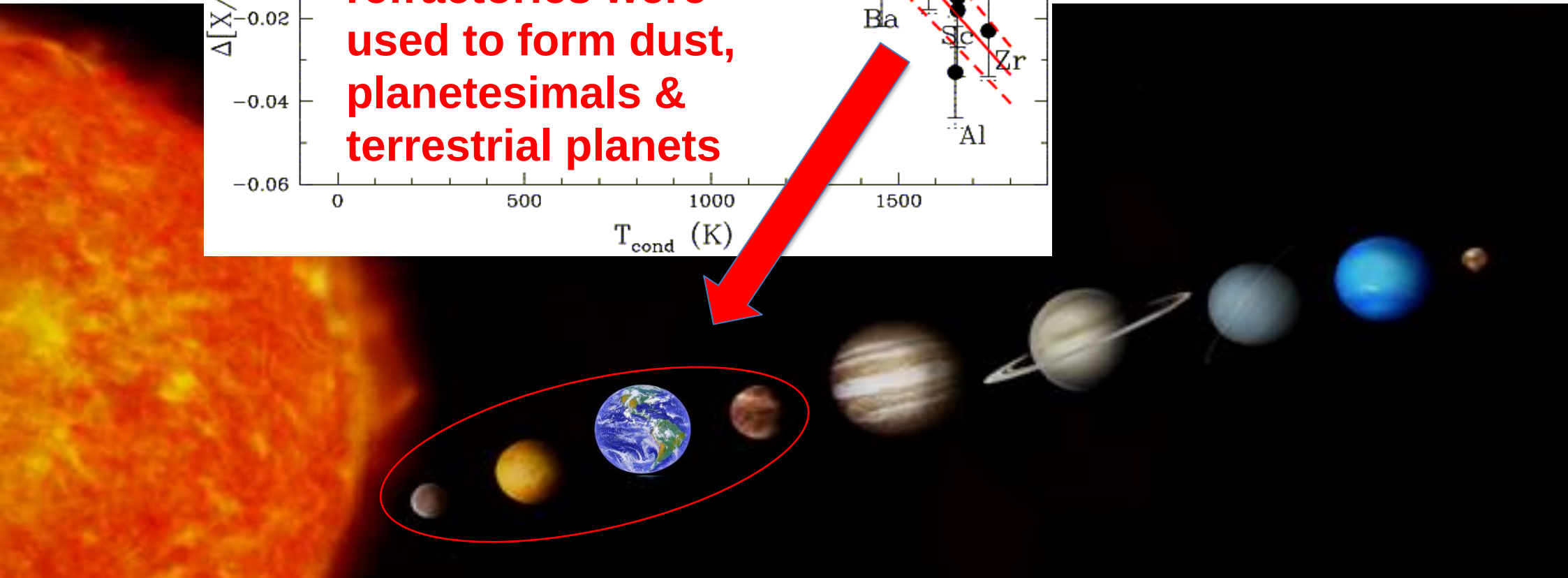


Meléndez, Asplund, Gustafsson, Yong 2009, ApJ Letters



The missing refractories were used to form dust, planetesimals & terrestrial planets

The late accreted gas in the convection zone was deficient in refractories

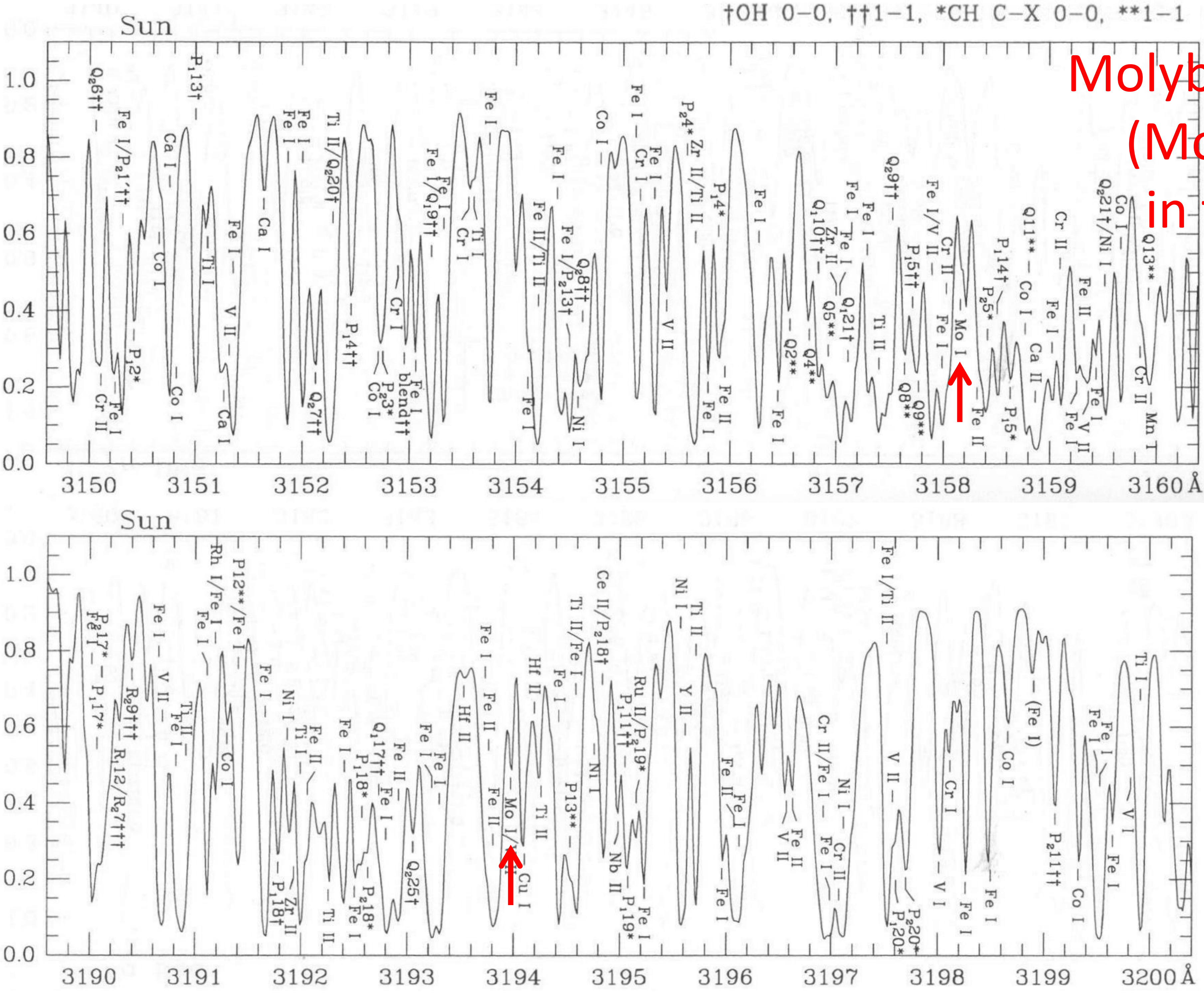


Beyond planet effects

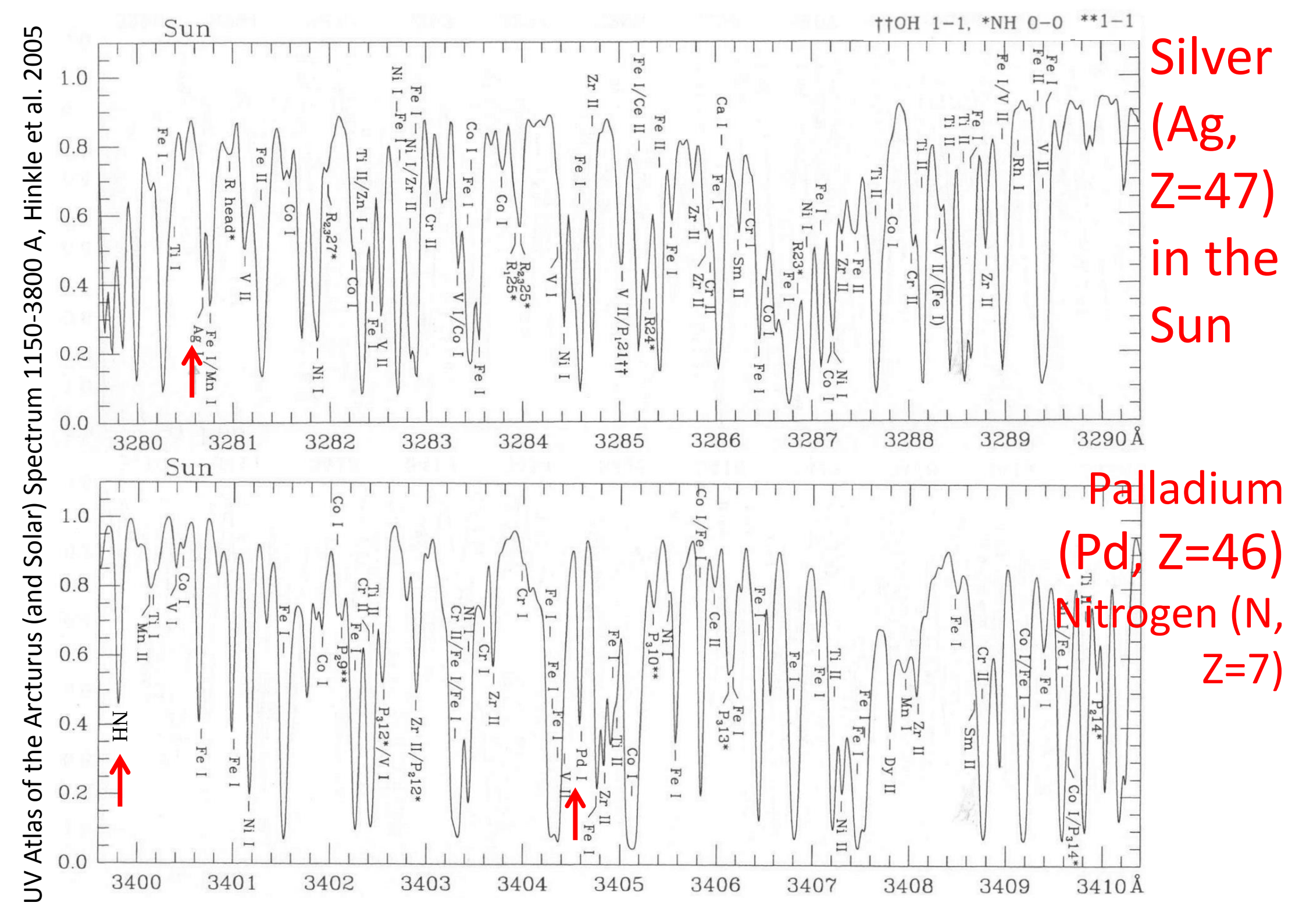
High precision abundances in 18 Sco:

a solar twin rich in refractories and neutron-capture elements

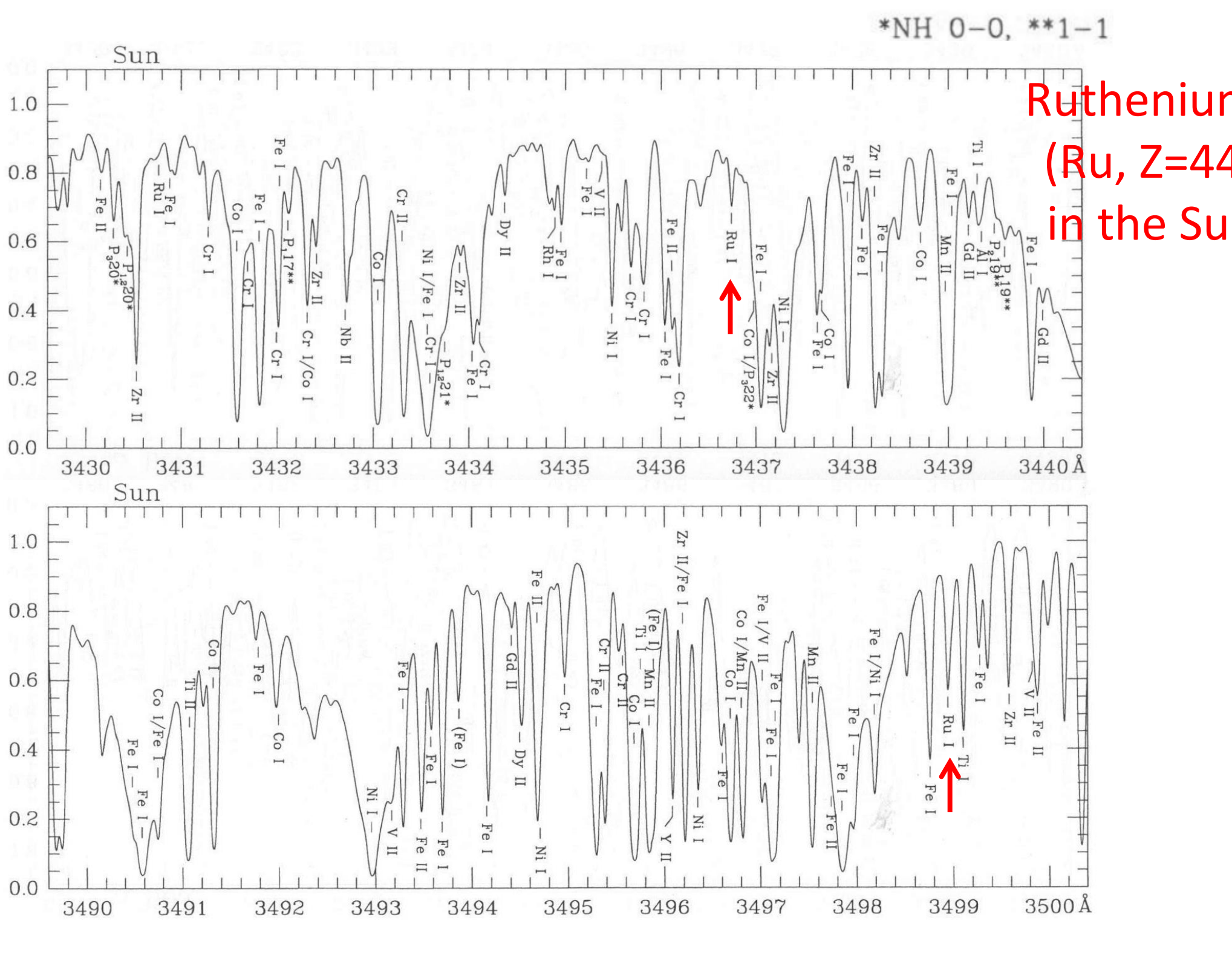
Molybdenum (Mo, Z=42) in the Sun



UV Atlas of the Arcturus (and Solar) Spectrum 1150-3800 A, Hinkle et al. 2005

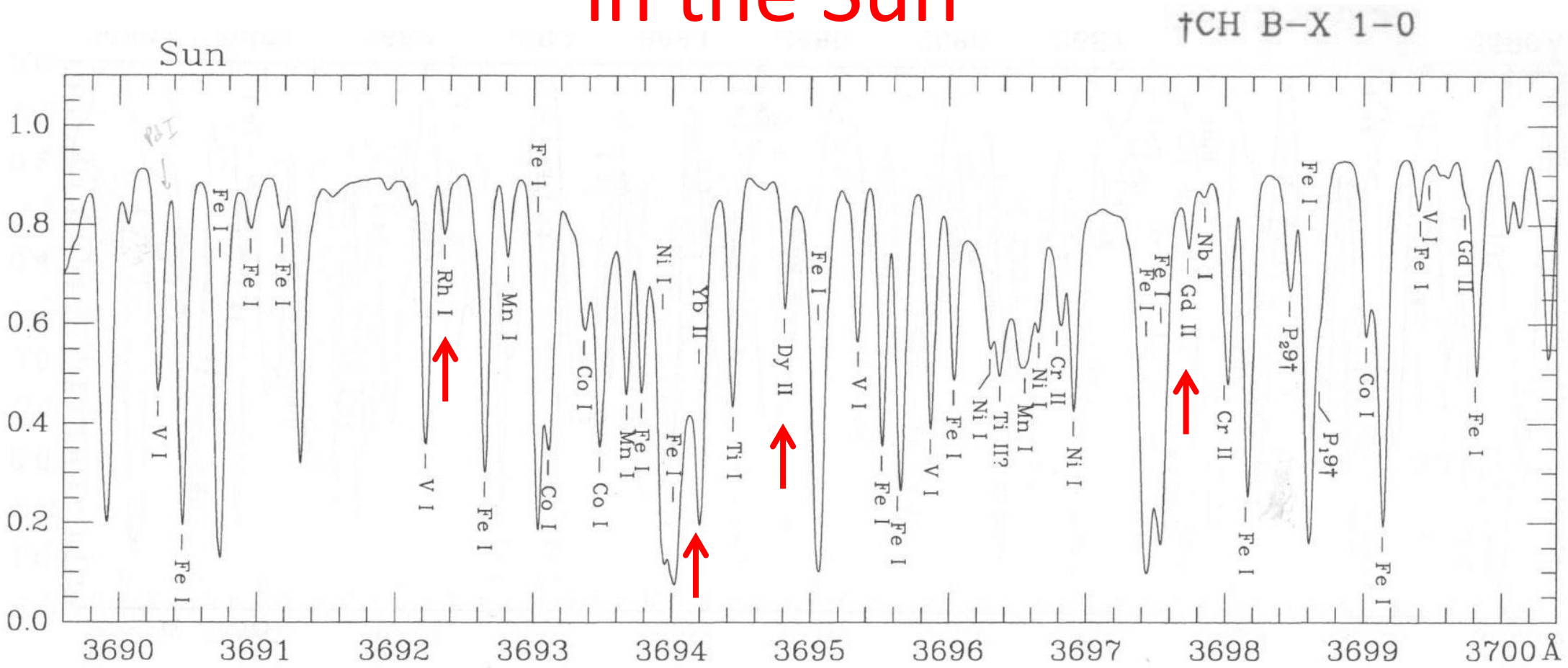

UV Atlas of the Arcturus (and Solar) Spectrum 1150-3800 A, Hinkle et al. 2005
Sun
††OH 1-1, *NH 0-0 **1-1
Fe I – Ti I – Fe I/Mn I Ag I – R head* – V II – Fe II – Co I – Ni I – R2,327* – Co I – Ti II/Zn I – V II Fe I – Ni I/Zr II – Cr II – Fe I Ni I – Fe I – Co I – Fe I – V I/Co I – Co I – R2,325* R1,125* – V I – Ni I – Zr II – Fe I – V II/P1,21†† – R24* – Fe II – Fe I – Zr II Cr II Zr II – Ca I – Fe I – Cr I – Sm II – Co I – Fe I – Fe I – R23* Fe I – Ni I Co I – Fe II – Zr II – Ni I Co I – Ti II – Co I – Cr II – V II/(Fe I) Ti II – Ti II – Fe I Ti II – Zr II – Fe I/V II – Rh I – Fe II – V II – Fe I
3280 3281 3282 3283 3284 3285 3286 3287 3288 3289 3290 Å
Sun
HN – Ti I Mn II – Co I V I – Fe I – Fe I – Ni I – Co I – Co I – P29** – Ti II Cr II Fe I – P3,12*/V I – Zr II/P2,12* – Ni I Cr II/Fe I/Fe I – Cr I – Zr II – Cr I – Fe I Fe I – Pd I – V II – Zr II Fe I – Co I Fe I – Ti II – Ni I P310** – Co I/Fe I – Ce II – Fe I P313* – Fe I – Fe I – Ti II – Fe I – Ni II – Fe I Fe I – Zr II Mn I – Dy II – Fe I – Sm II – Cr II – Co I/Fe I – Fe I – Co I/Fe I – Ti II – P214* – Co I/P314*
3400 3401 3402 3403 3404 3405 3406 3407 3408 3409 3410 Å
Silver (Ag, Z=47) in the Sun
Palladium (Pd, Z=46)
Nitrogen (N, Z=7)

UV Atlas of the Arcturus (and Solar) Spectrum 1150-3800 A, Hinkle et al. 2005



Ruthenium (Ru, Z=44) in the Sun

Rhodium (Z=45), Ytterbium (Z=70), Dysprosium (Z=66), Gadolinium (Z=64) in the Sun



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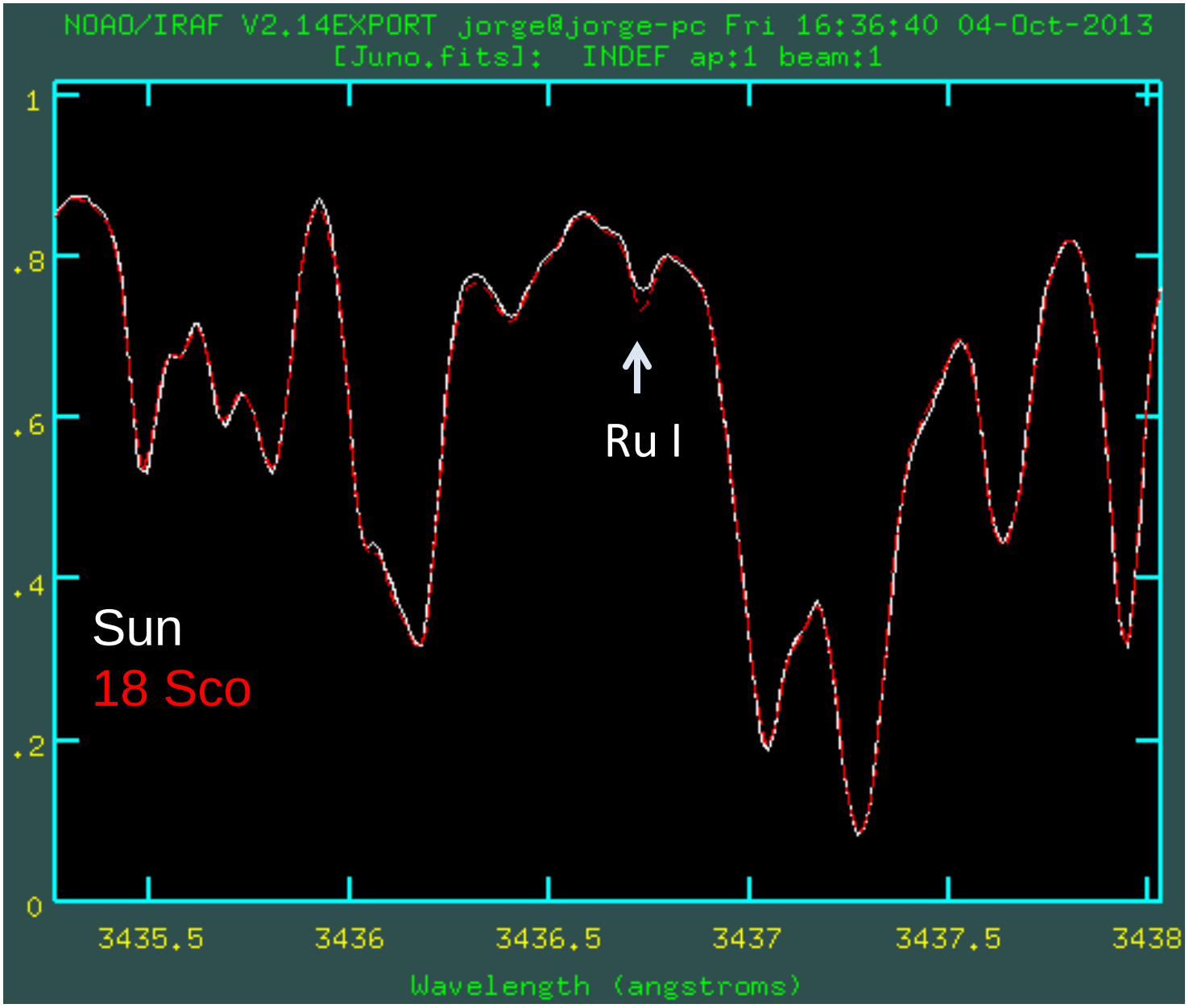
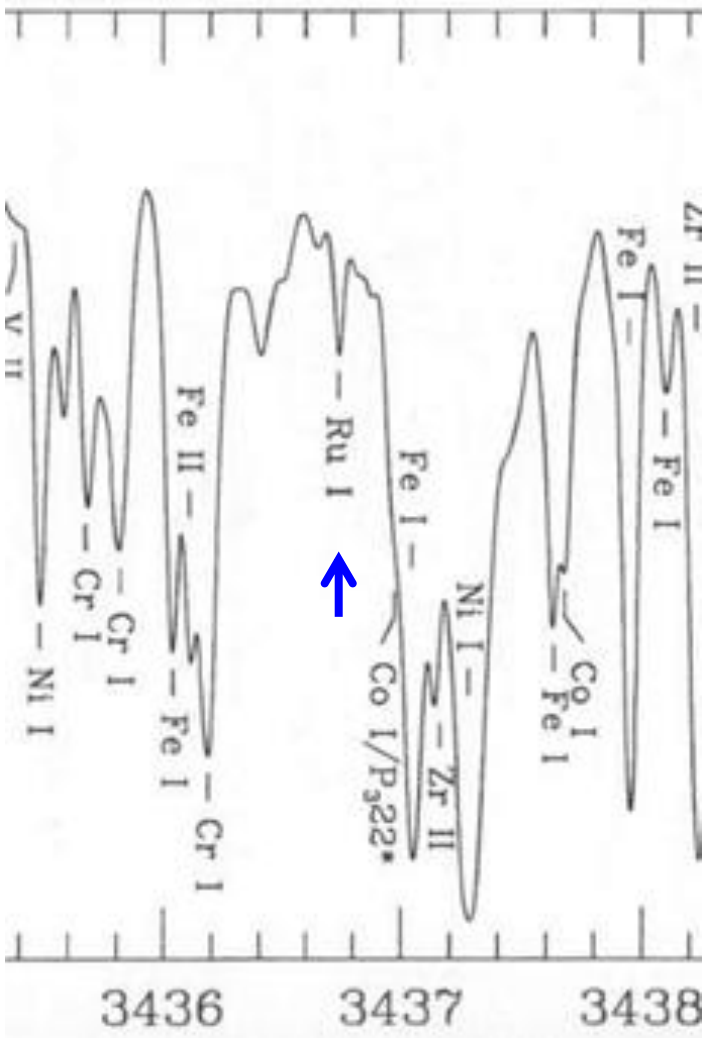
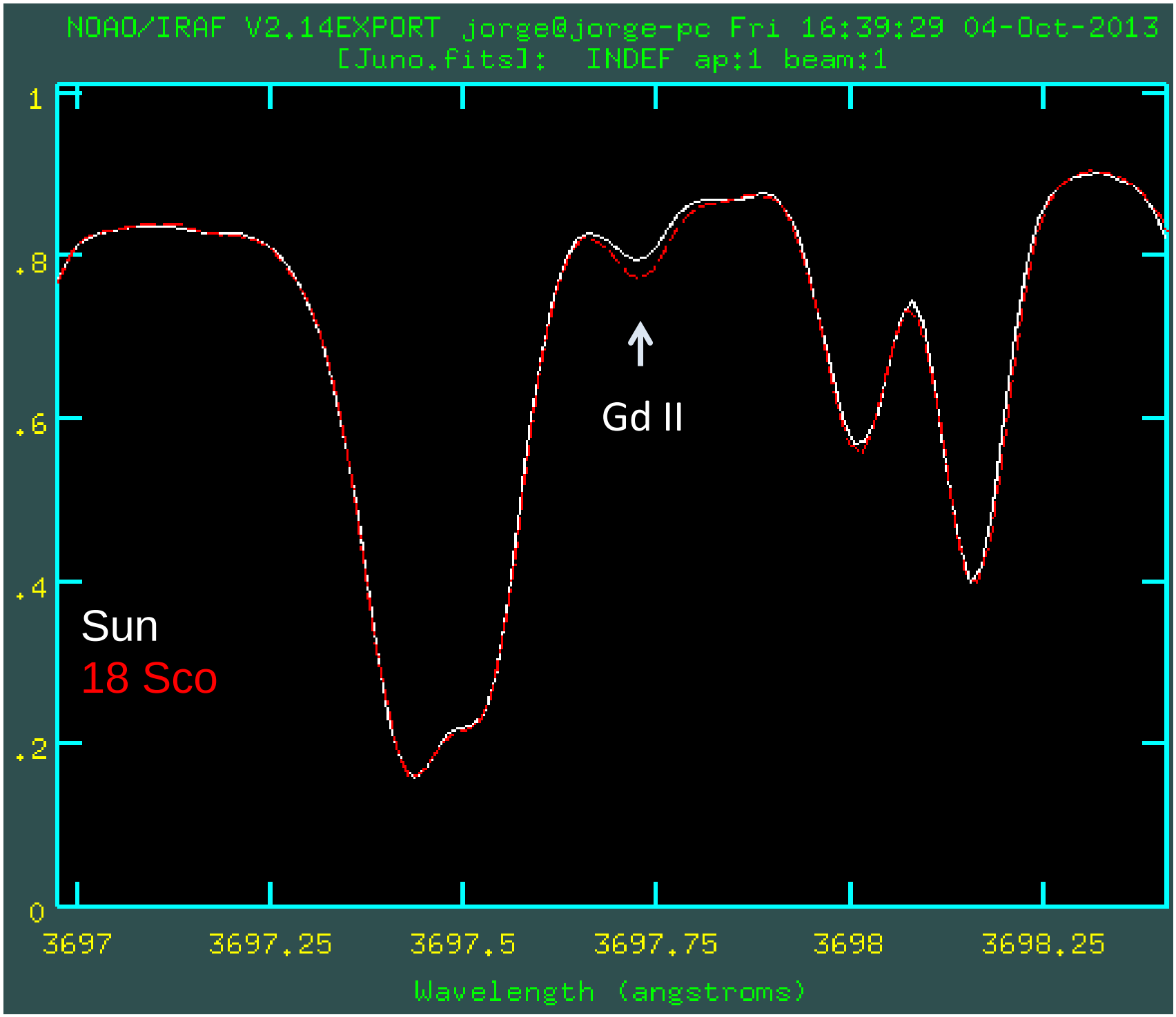


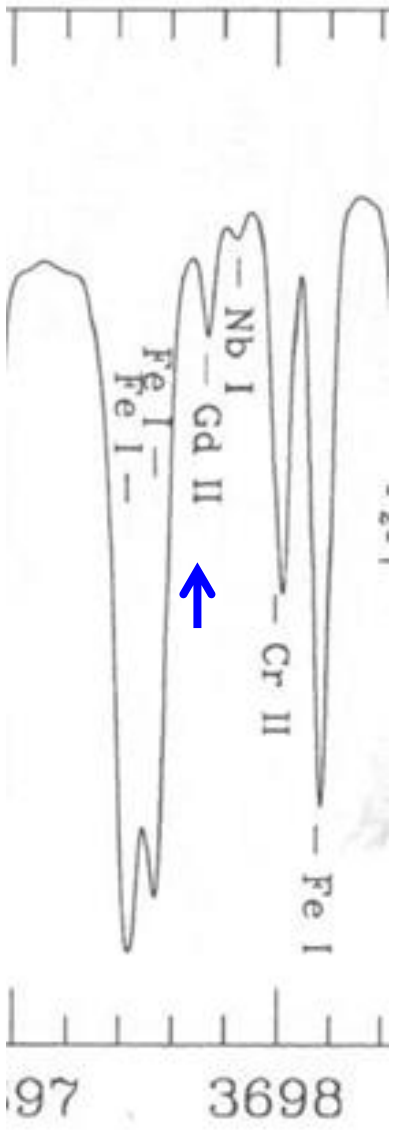
R=65 000, UVES/VLT



R=348 000, FTS/NSO



R=65 000, UVES/VLT

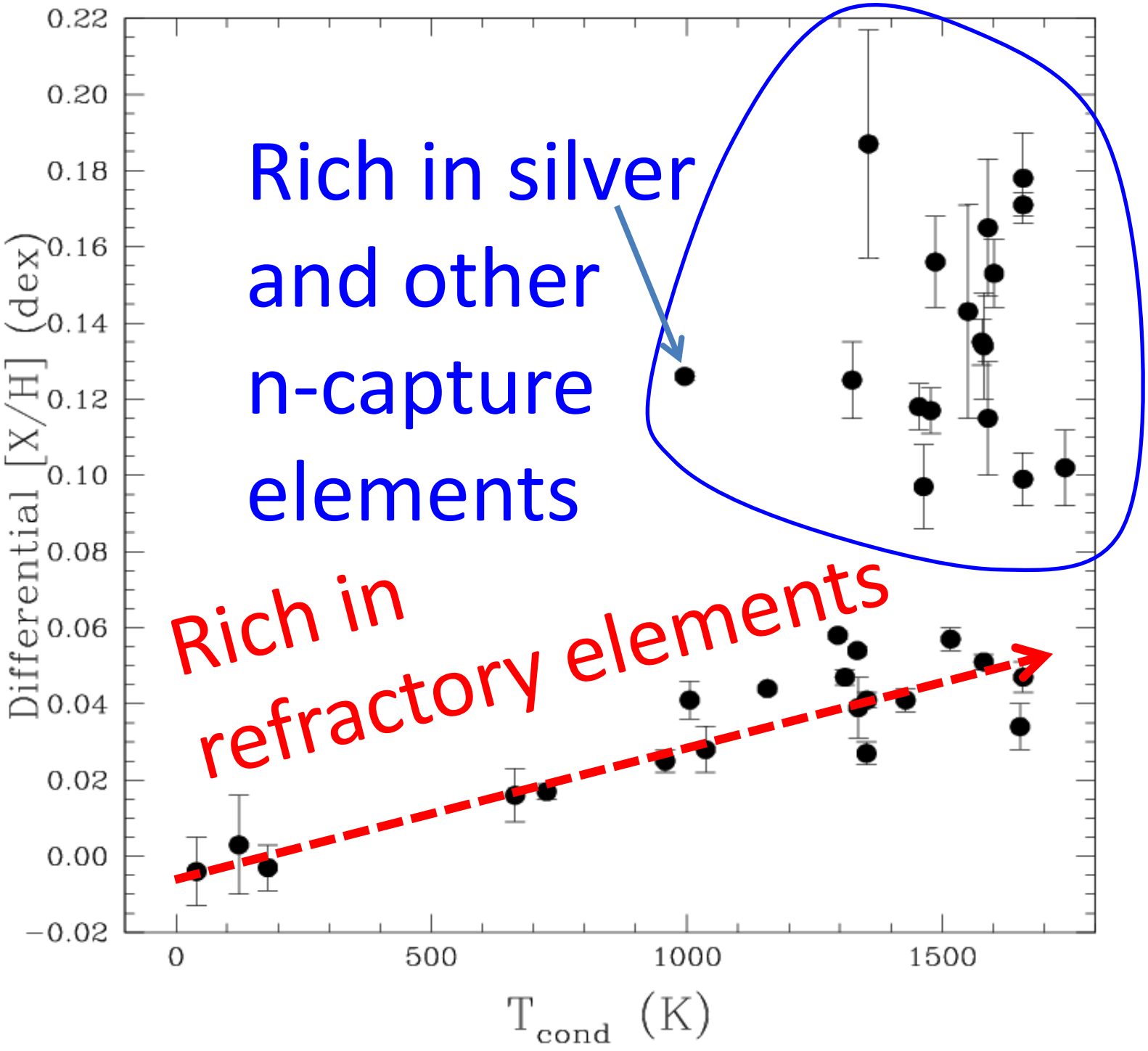


R=348 000,
FTS/NSO

18 Sco

(brightest solar twin, V = 5.5)
UVES+VLT
R = 110 000 (red)
R = 65 000 (blue)

Age = 2.9 Gyr

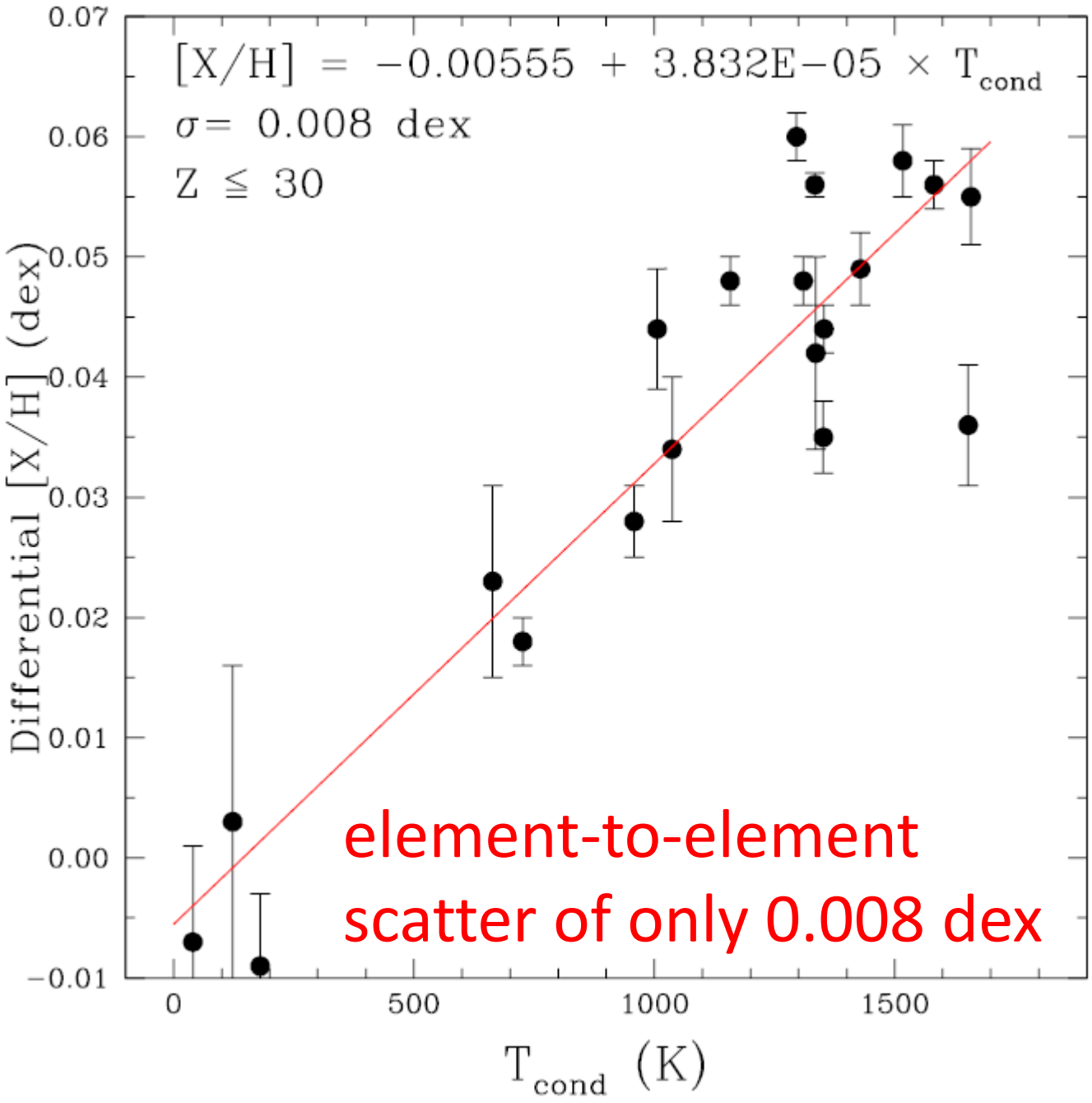


Meléndez et al. 2013, in preparation

18 Sco

(brightest solar twin, V = 5.5)
UVES+VLT
R = 110 000
S/N = 800

Elements with Z <= 30: trend with T_{cond}



Meléndez et al. 2013, in preparation

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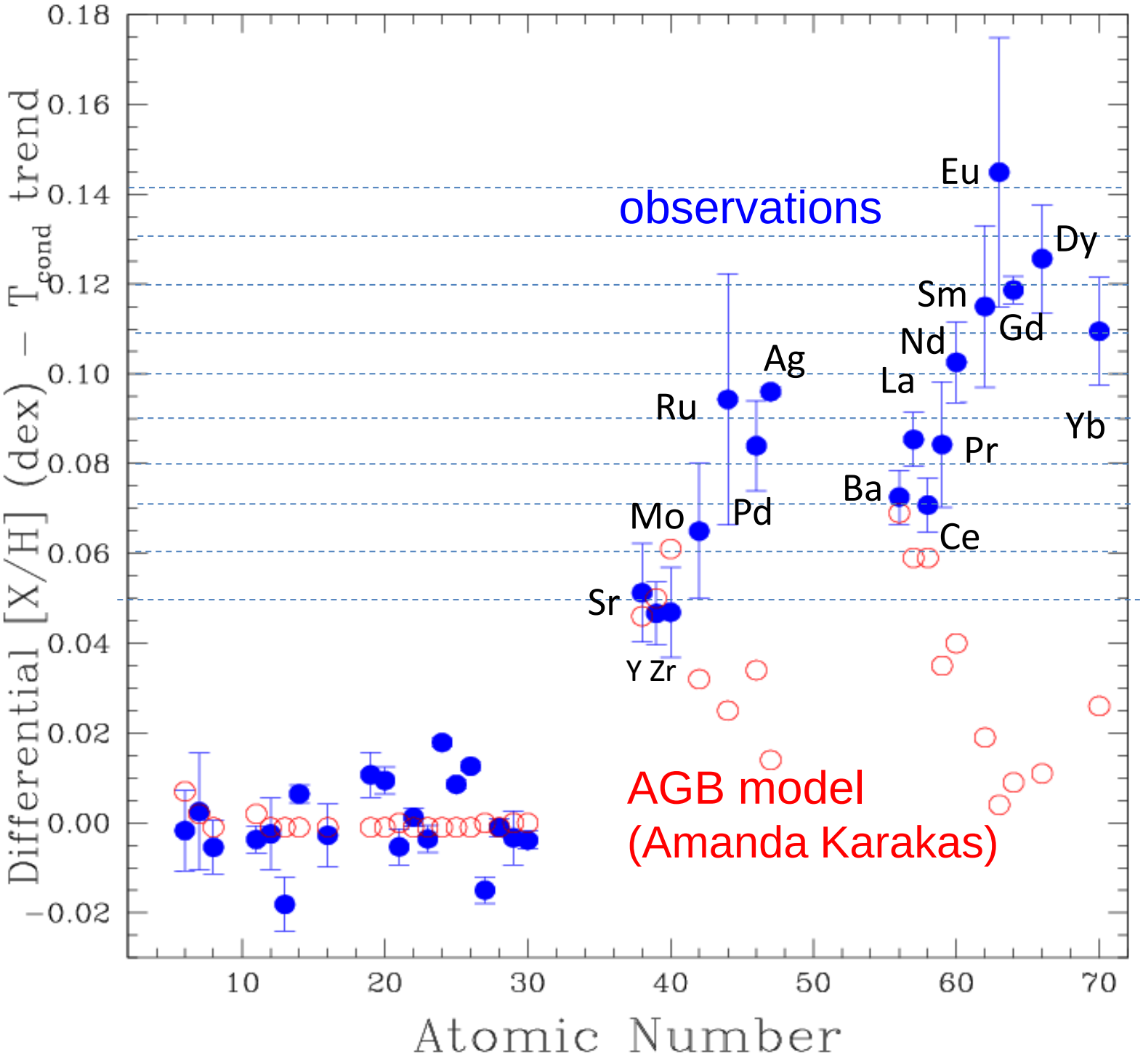
UVES+VLT
R = 110 000
S/N = 800

Subtracting T_{cond} trend



Meléndez et al. 2013, in preparation

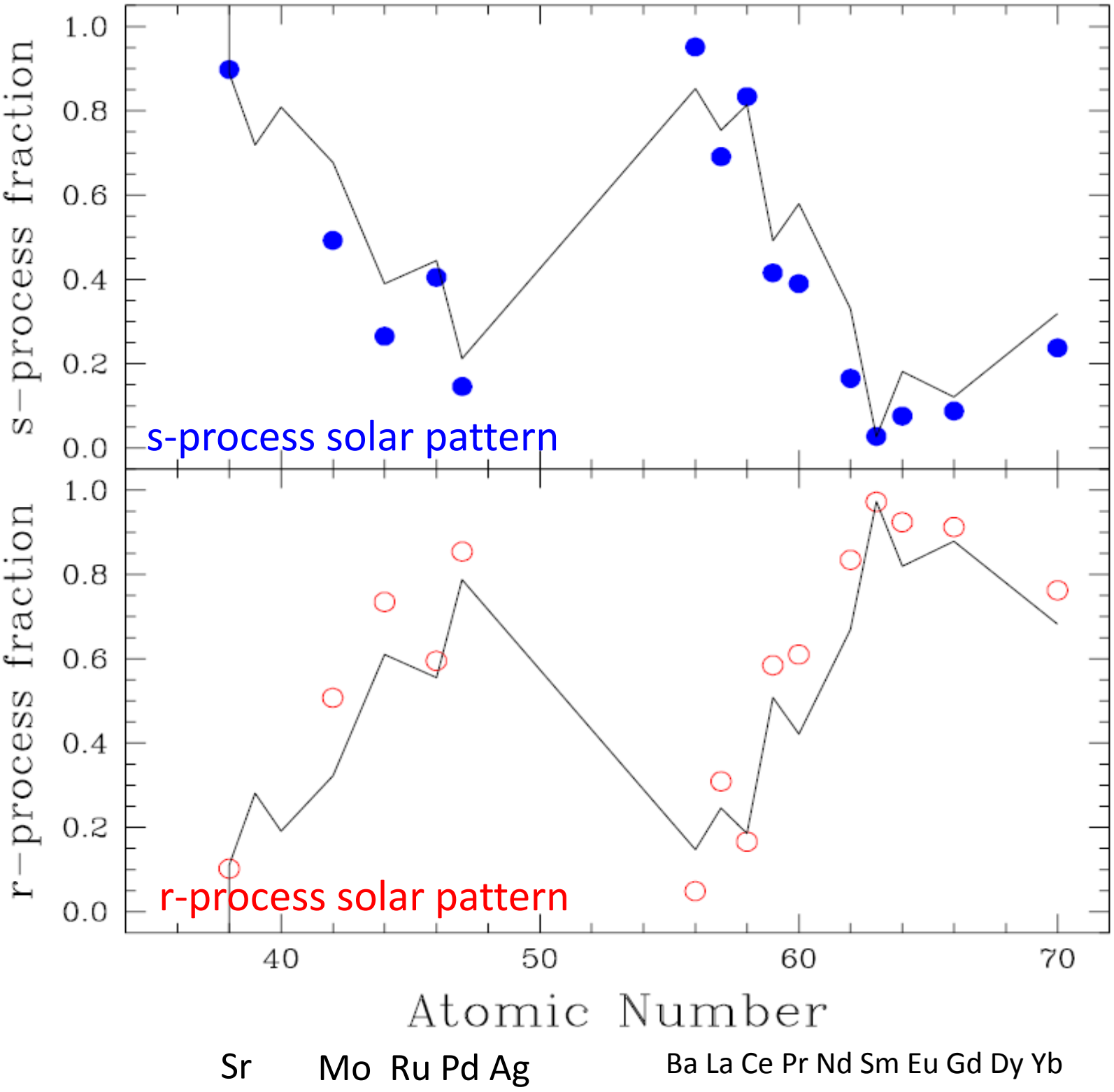
18 Sco

(brightest solar twin, V = 5.5)

Subtracting AGB model

Excellent agreement with s- and r-process in the solar system!

Meléndez et al. 2013, in preparation



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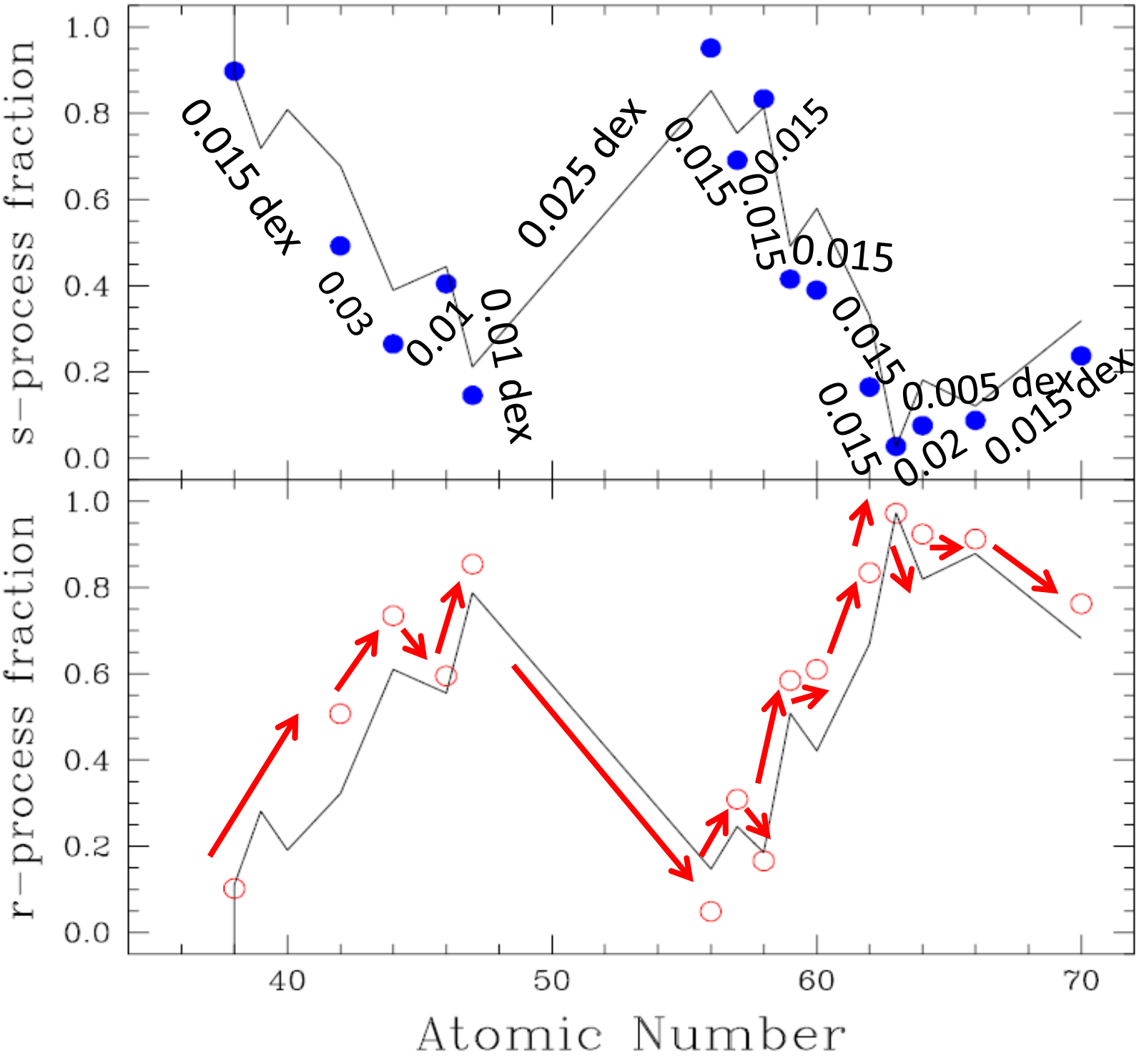
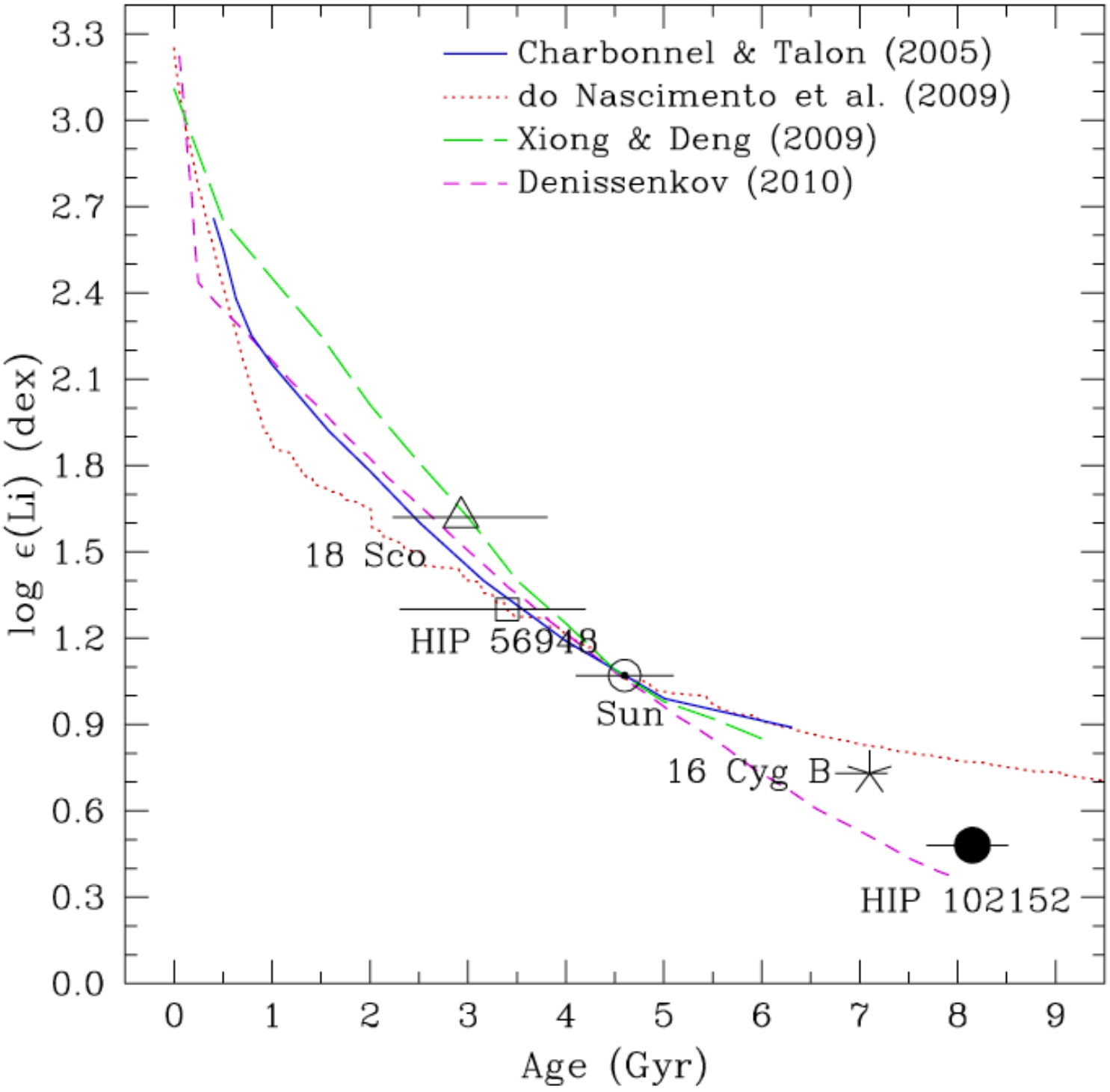


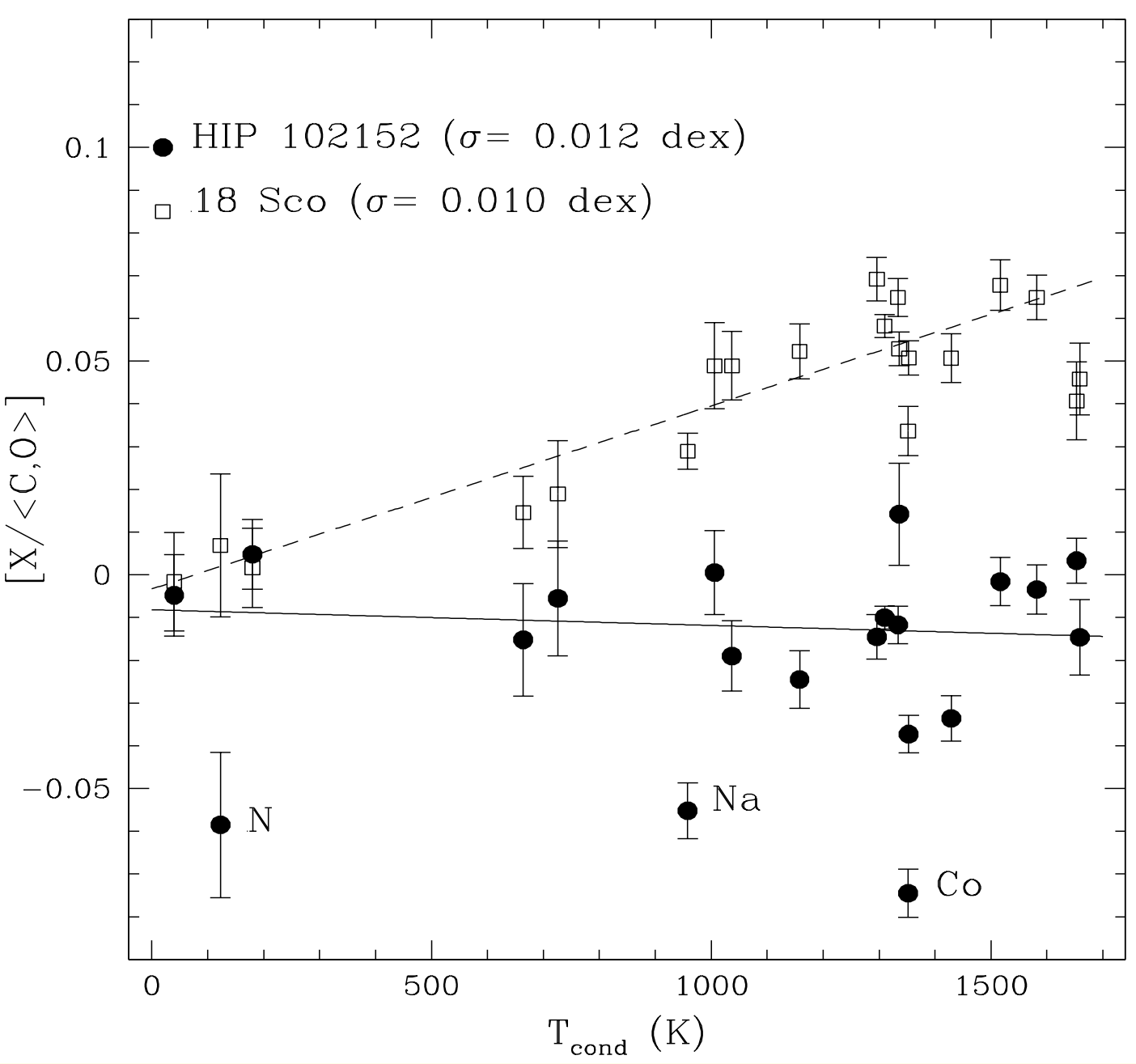
Only possible to see detailed n-capture pattern **if errors ≤ 0,01 dex**

n-capture elements in solar twins of different ages



HIP 102152: Most "solar-like" abundance pattern

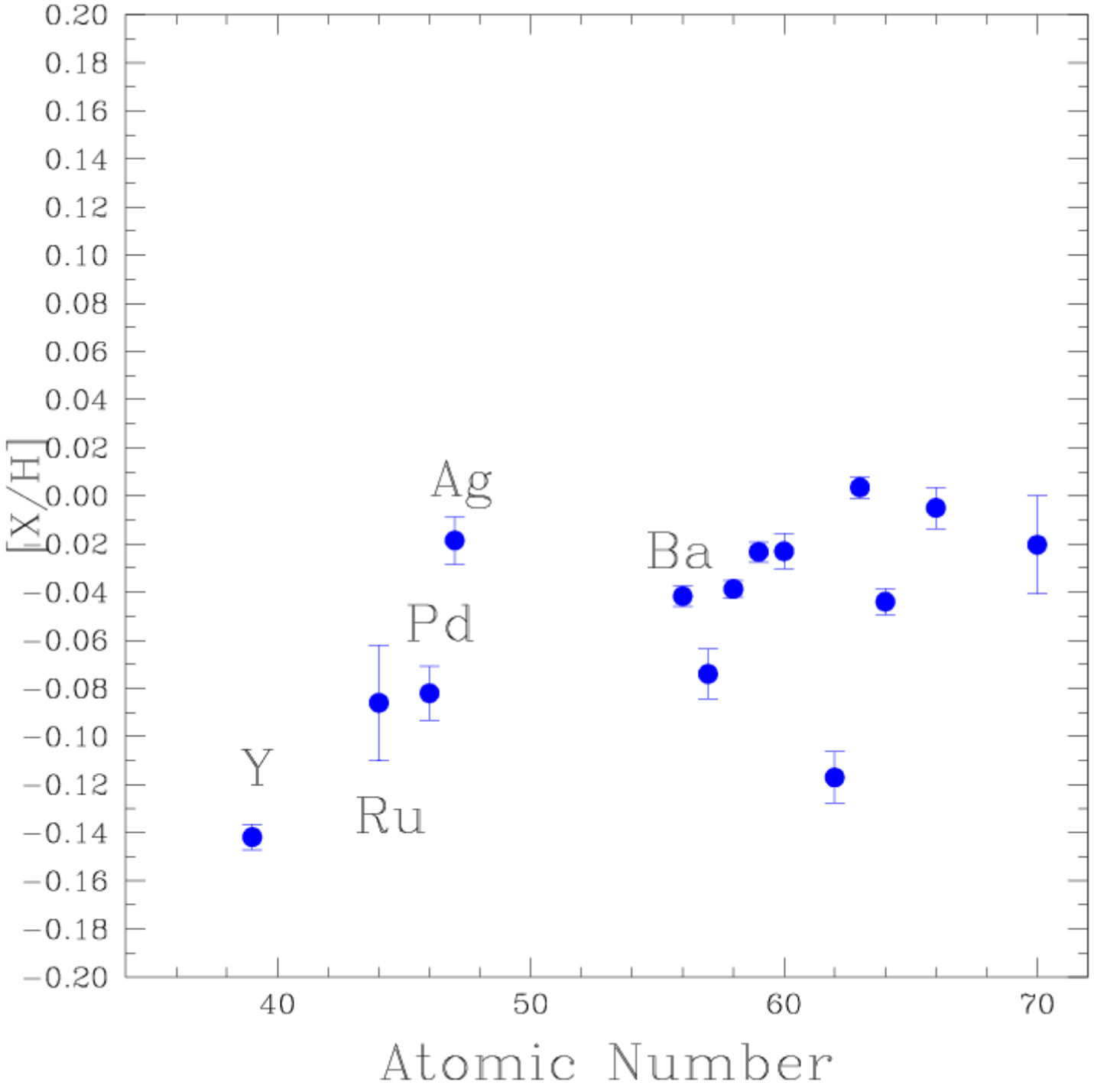
- 8.2 Gyr
- 3% fewer metals than Sun
- HIP 102152 has a solar abundance pattern
- Refractory elements depleted compared to other solar twins
- ΔTeff = -54K, Δlog g = -0.09 dex, Δv_t =0.00 km s^{-1}



Monroe, Meléndez, Ramírez et al. (2013)

n-capture elements in HIP102152

age = 8.2 Gyr



Preliminary results

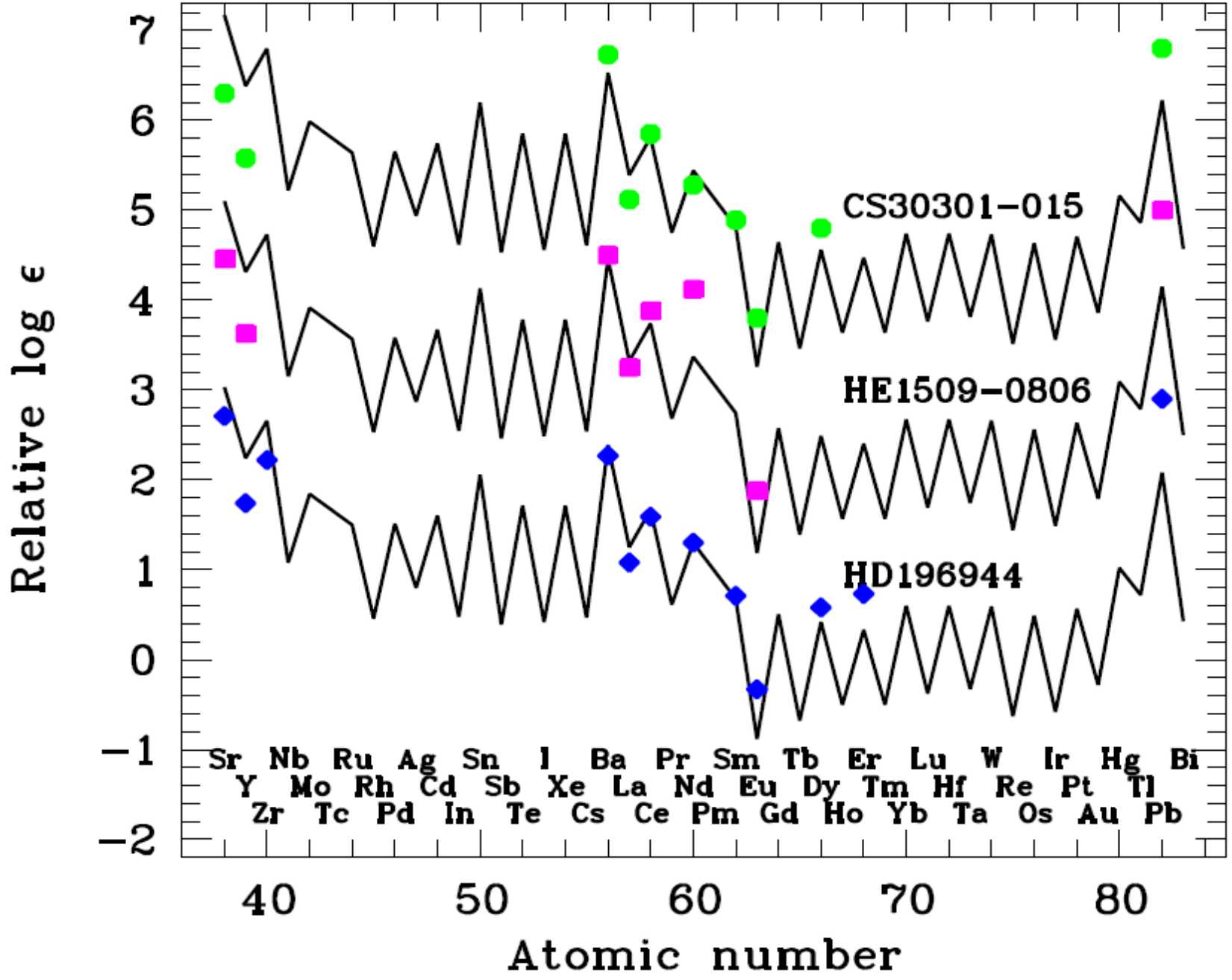
Conclusions

- Abundances at the 0,01 dex level can give us important information on planets and on the chemical evolution of the neutron-capture elements in solar type stars.

- **Access to the UV region at high resolution (ideally R ≥ 40 000 but R=20 000 is OK) is needed to perform this work**

r-processs in metal-poor stars is “easy” (~ 0.5 – 1.0 dex)

r-process in solar twin 18 Sco: ~ 0.015 dex



Frebel & Norris 2012