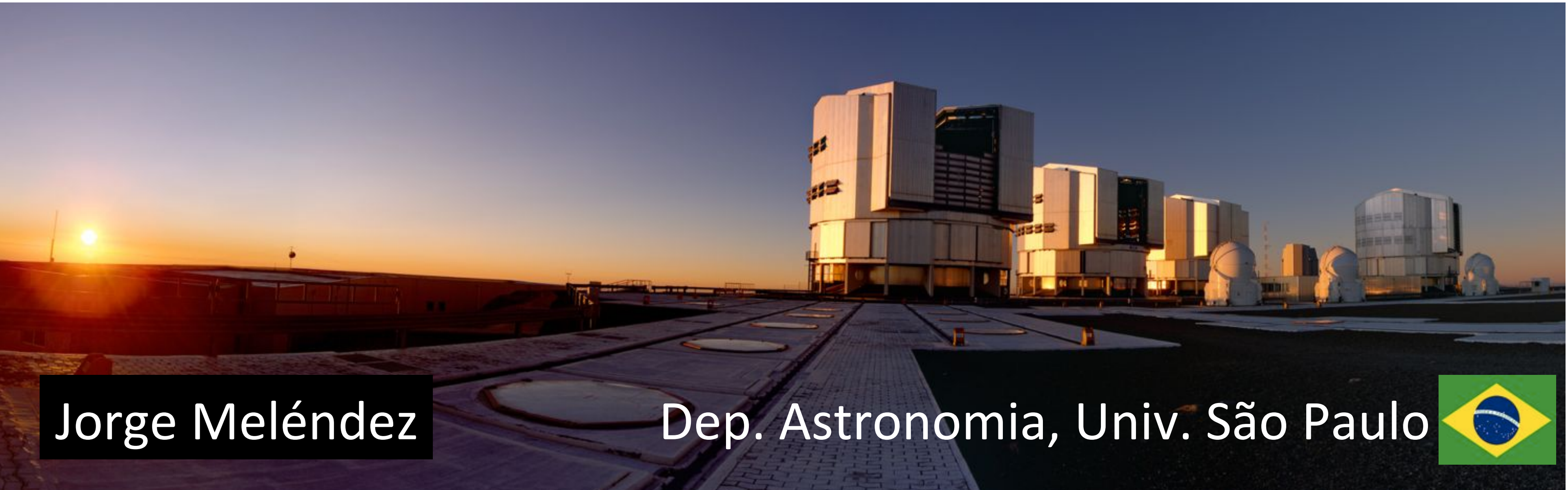
The Cosmological and Solar Lithium Problems

And the need for models of non-standard transport mechanisms inside stars

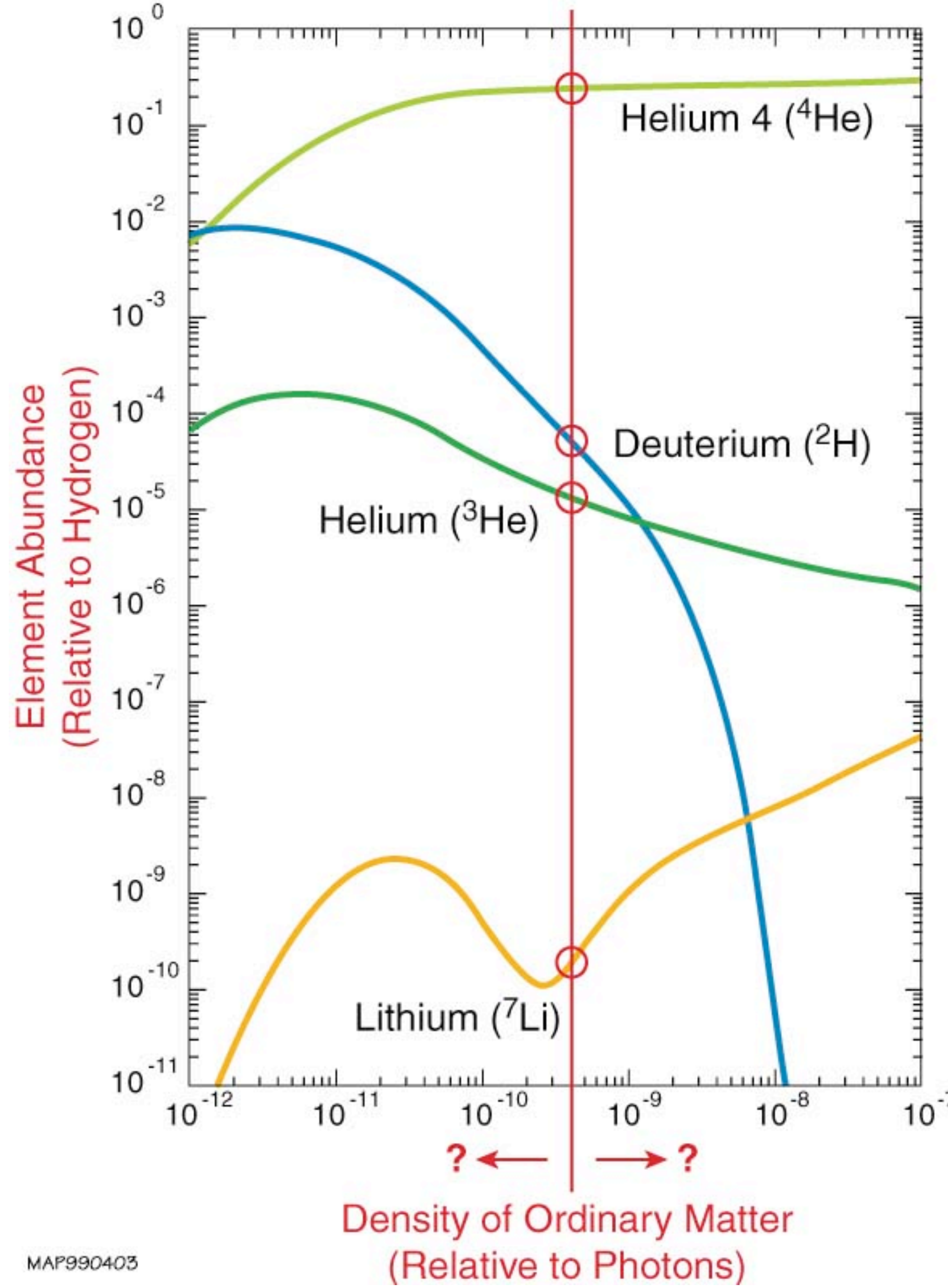


Jorge Meléndez

Dep. Astronomia, Univ. São Paulo

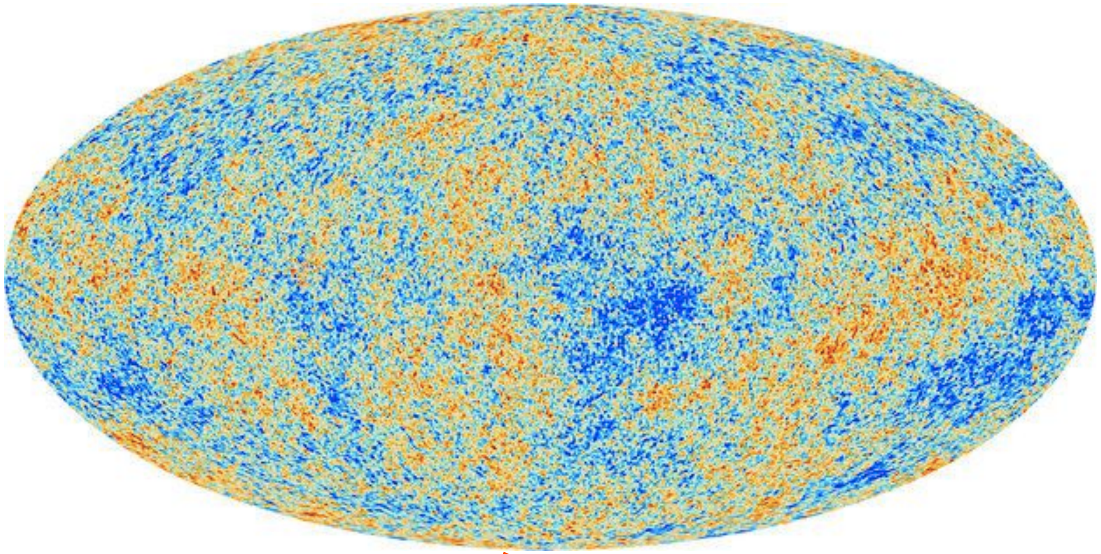
The nuclei of the light elements were synthetized in the first minutes after the *Big Bang*

Final abundances depend on baryon density η_{10}



Cosmic Microwave Background

Planck (previously WMAP)



Baryon density $\eta_{10} = 6.10 \pm 0.04$

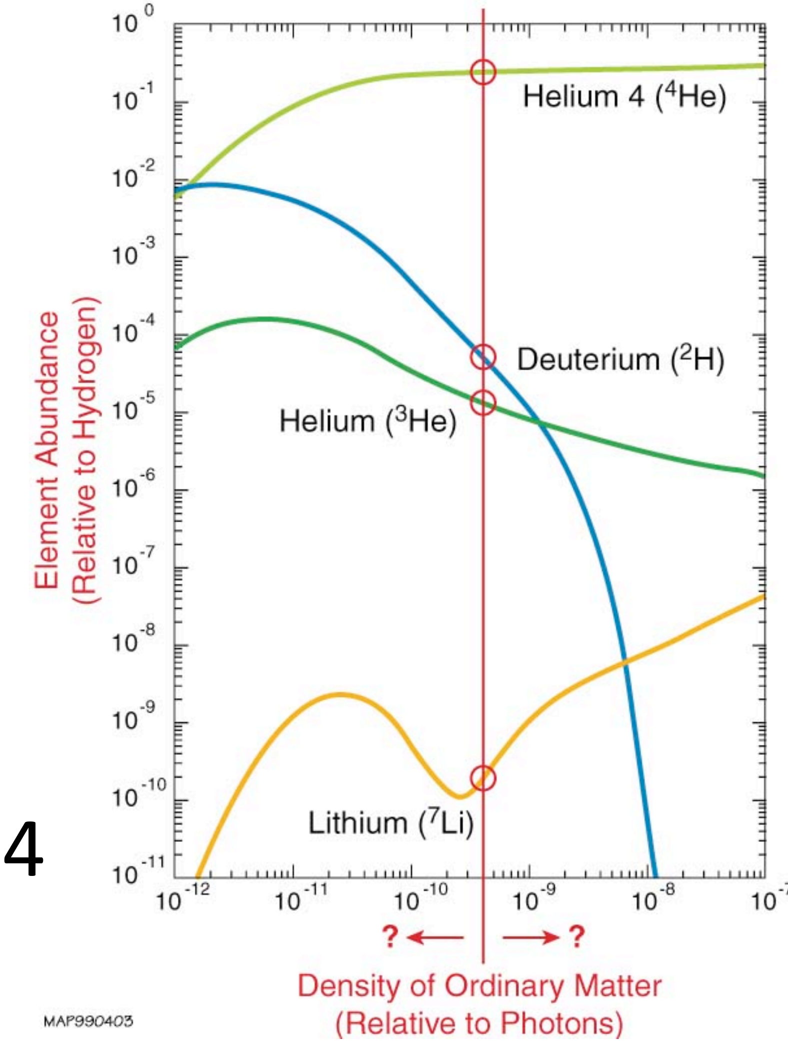
(Planck 2015)

Predicted primordial Li abundance:

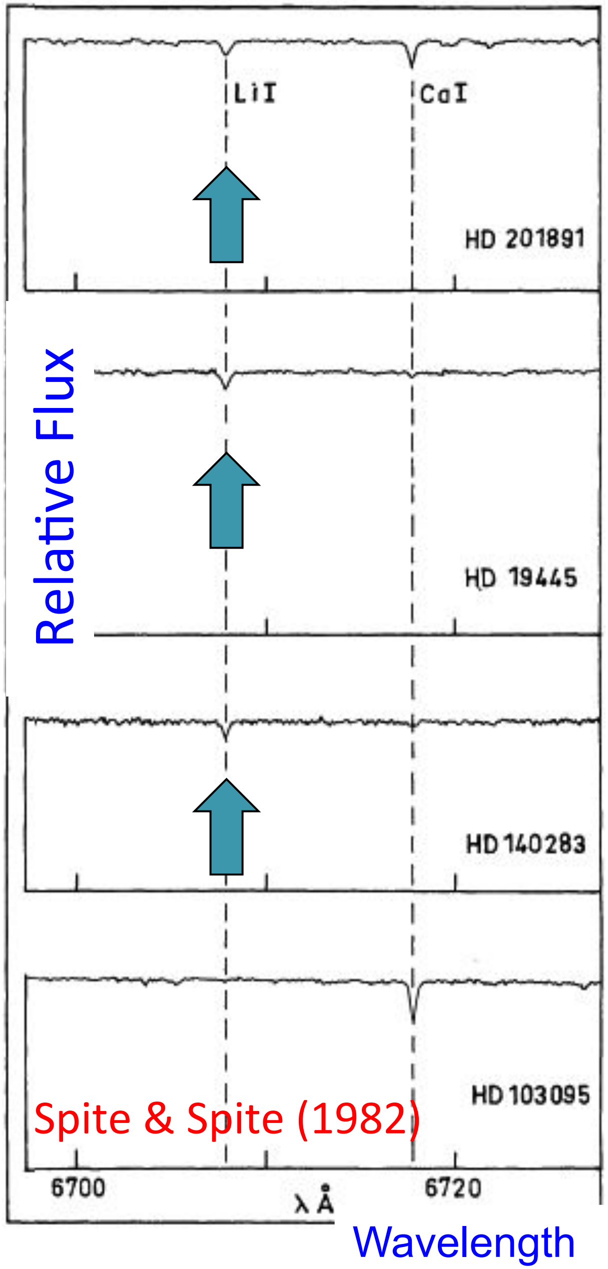
A(Li) = 2.67 dex

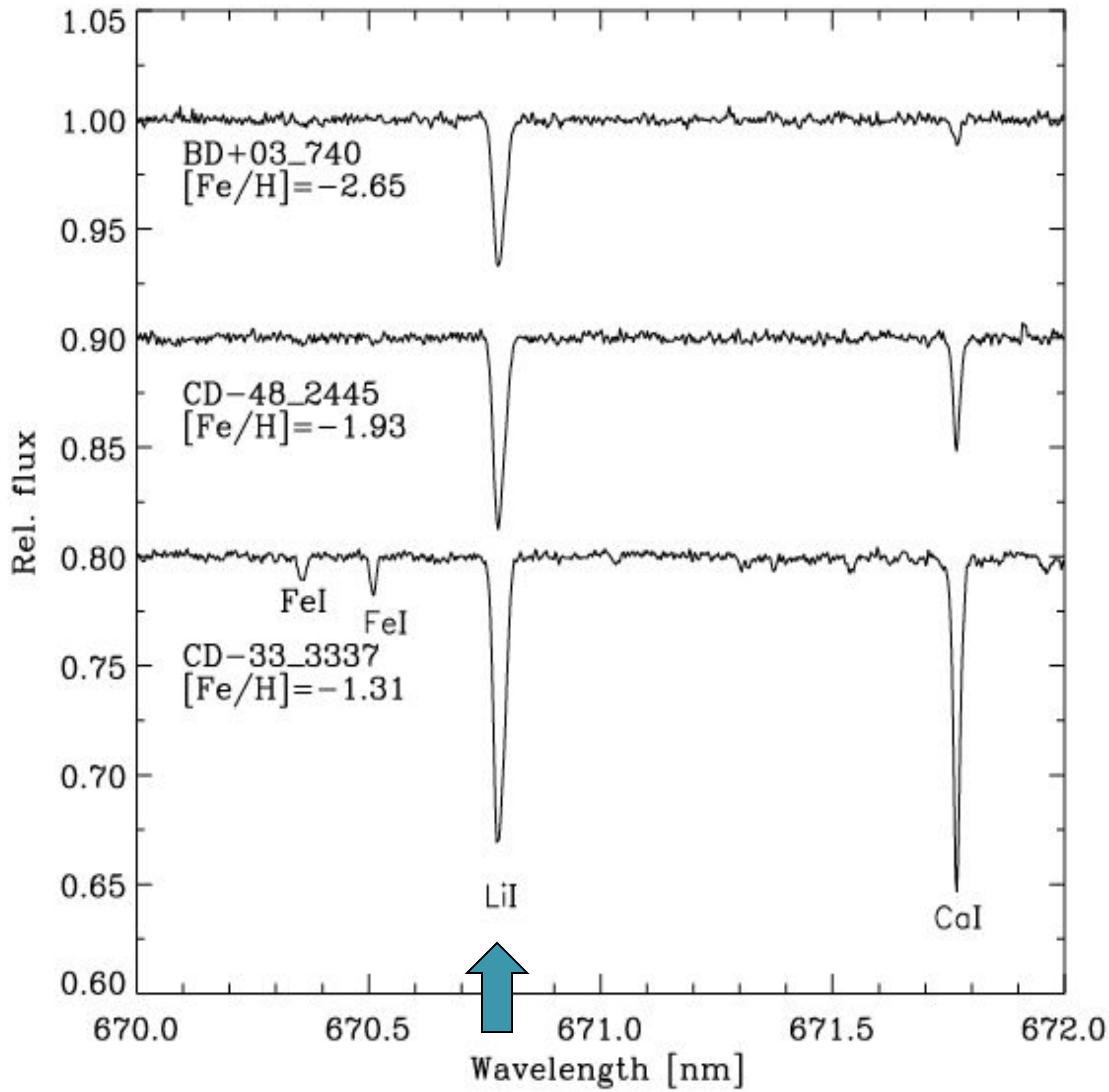
(Li/H = $4.65\ 10^{-10}$)

Cyburt et al. 2016



Relic Li observed in metal-poor stars ([Fe/H] < -1)





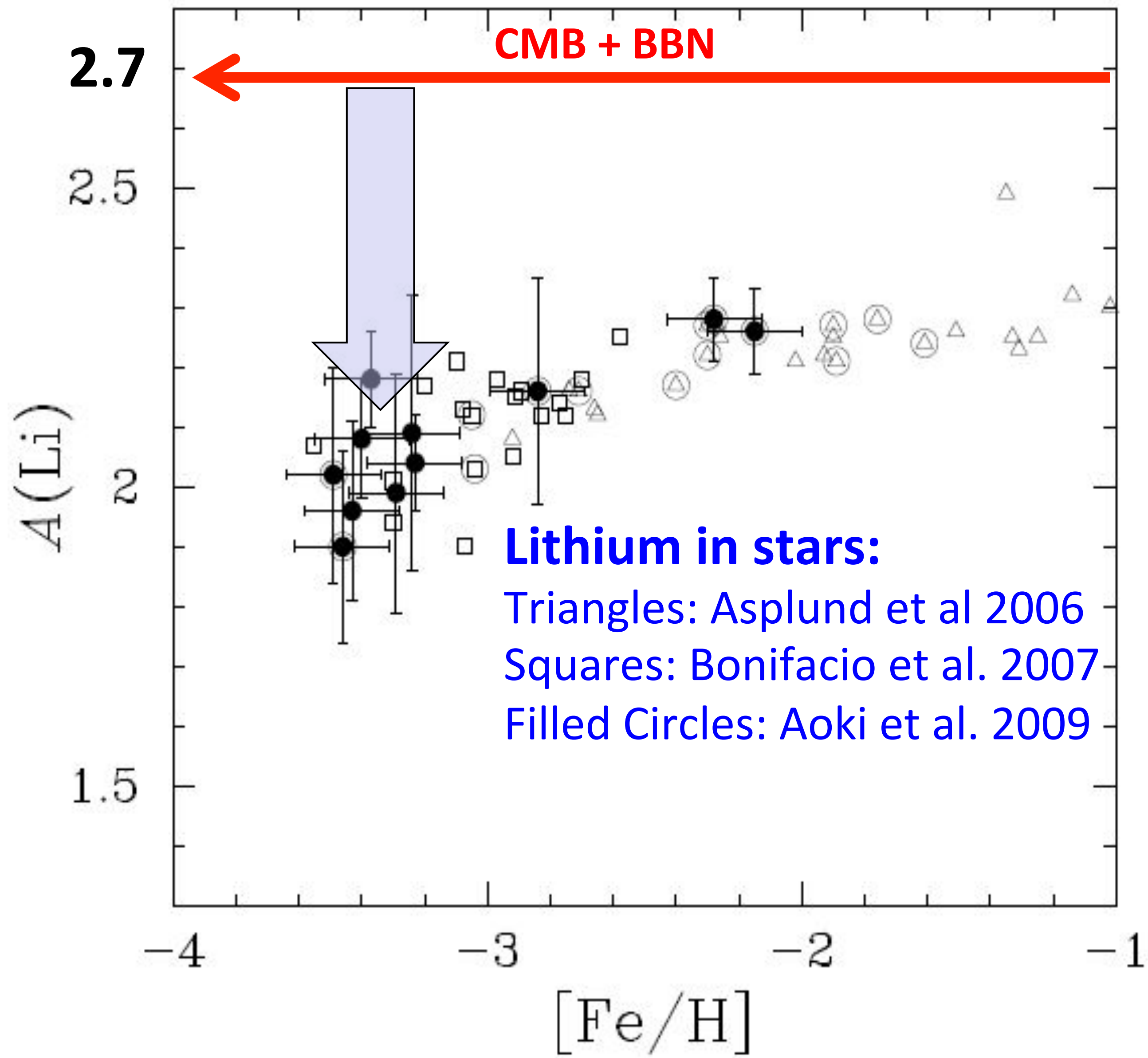
Asplund et al. (2006)

Cosmological Li problem

Planck + BBN
(Li = 2.67)

Stars
(Li = 2.0 – 2.25)

Discrepancy of about 0.5 dex (factor of 3)!



Aoki et al. (2009)

Solution : new physics/cosmology?

- Feng et al. (2003): *superweakly interacting massive particle dark matter signals from the early Universe*
- Jedamzik et al. (2004): *Did something decay, evaporate, or annihilate during big bang nucleosynthesis?*
- Coc et al. (2007): *Coupled variations of fundamental couplings and primordial nucleosynthesis*
- Erken et al. (2012): *Axion Dark Matter and Cosmological Parameters*
- Mosquera & Civitarese (2014): *Sterile neutrinos and Big Bang Nucleosynthesis in the 3 + 1 scheme*
- Sato et al. (2017) *A solution to Li problem by long-lived stau*

New physics could solve the Li problem

Asplund et al. (2006) paper has ~350 citations

Stellar solution: Atomic diffusion?

A&A 376, 955–965 (2001)
DOI: 10.1051/0004-6361:20010982

Astronomy & Astrophysics

Pre WMAP !

Atomic diffusion in metal-poor stars

II. Predictions for the Spite plateau

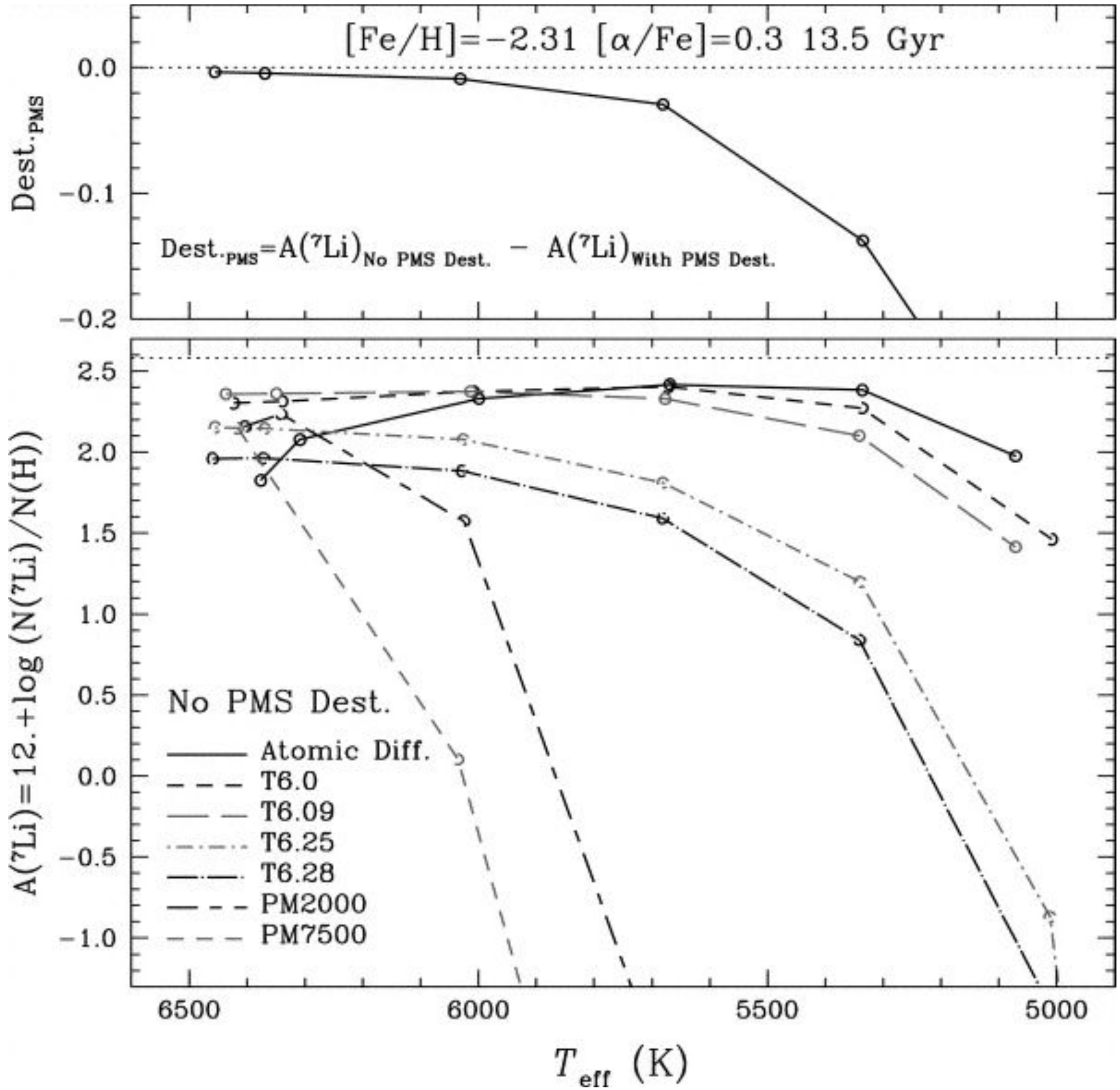
M. Salaris[1,2] and A. Weiss[2,3,4]

[1] Astrophysics Research Institute, Liverpool John Moores University, Twelve Quays House, Egerton Wharf, Birkenhead CH41 1LD, UK
[2] Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85748 Garching, Germany
[3] Institute for Advanced Study, Olden Lane, Princeton, USA
[4] Princeton University Observatory, Peyton Hall, Princeton, USA

From our models with diffusion we derive that the average Li abundance along the Spite plateau is about a factor of 2 lower than the primordial one. As a consequence, the derived primordial Li abundance would be consistent with a high He and low deuterium BBN; this implies a high cosmological baryon density as inferred from the analyses of the cosmic microwave background.

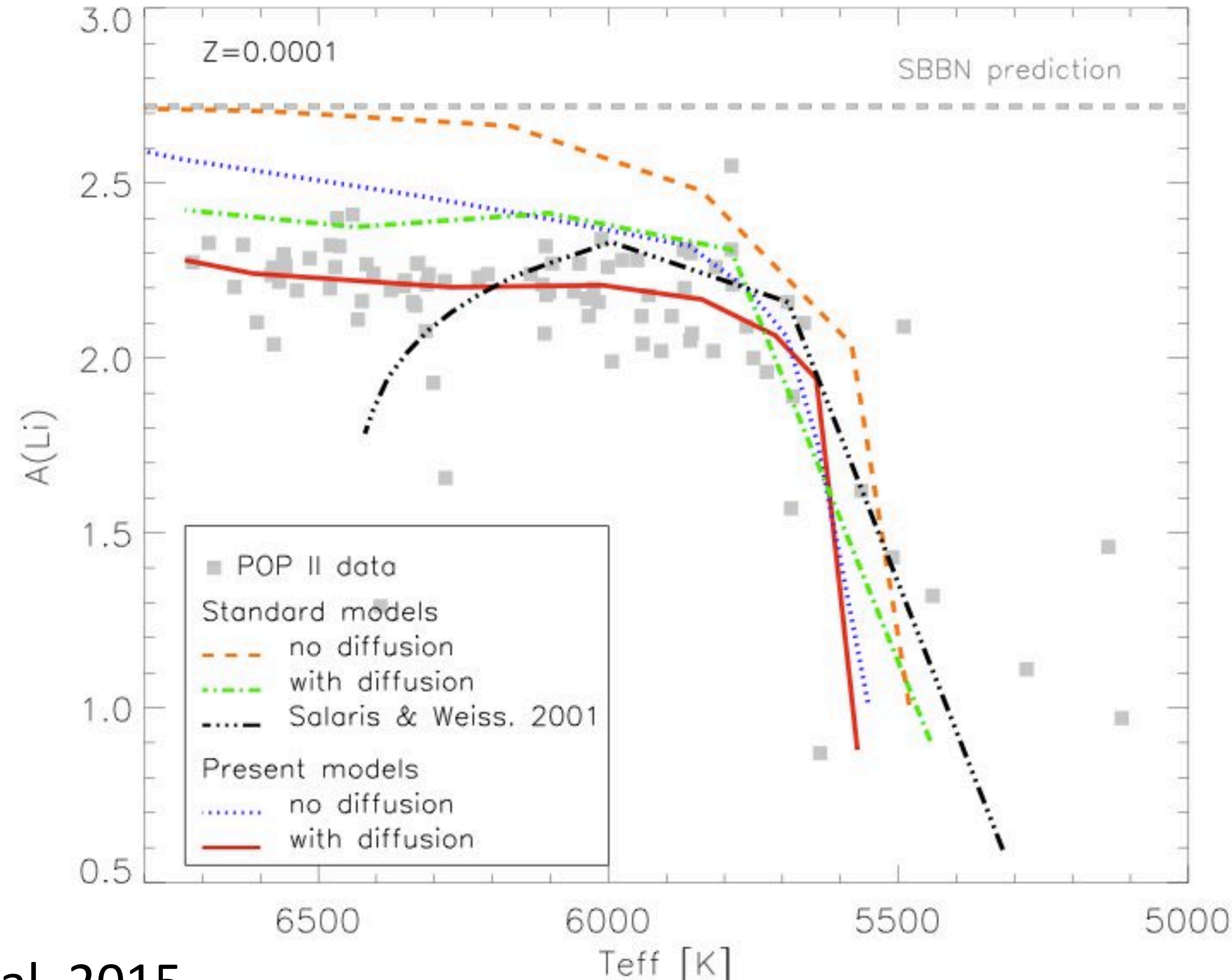
Stellar solution: Atomic diffusion + g_{rad} + turb

Richard et al. (2005) computed stellar models including diffusion + radiative acceleration + turbulence



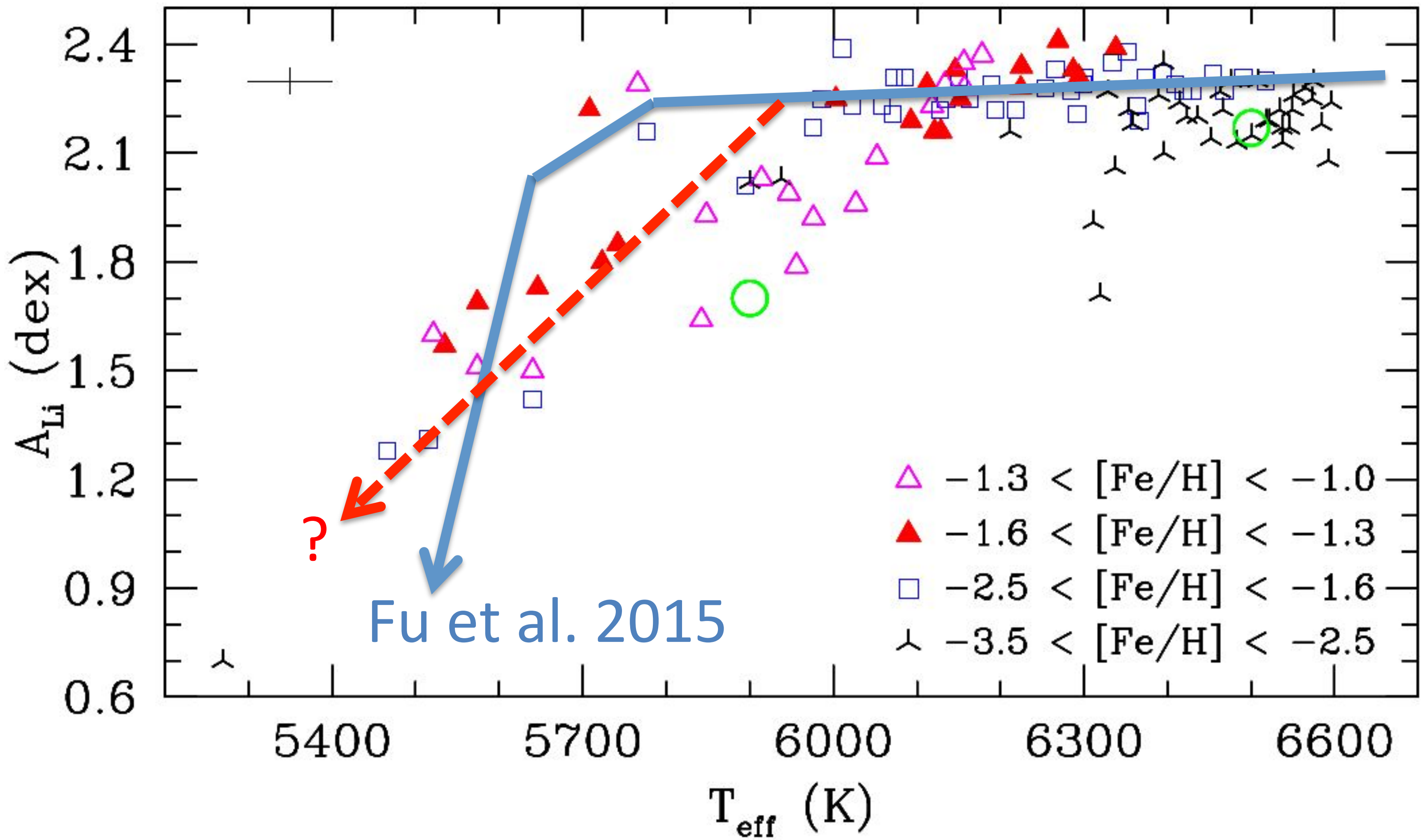
At least 0.2 dex reduction in stellar ^{7}Li

Stellar solution: Atomic diffusion + g_{rad} + overshooting + PMS treatment



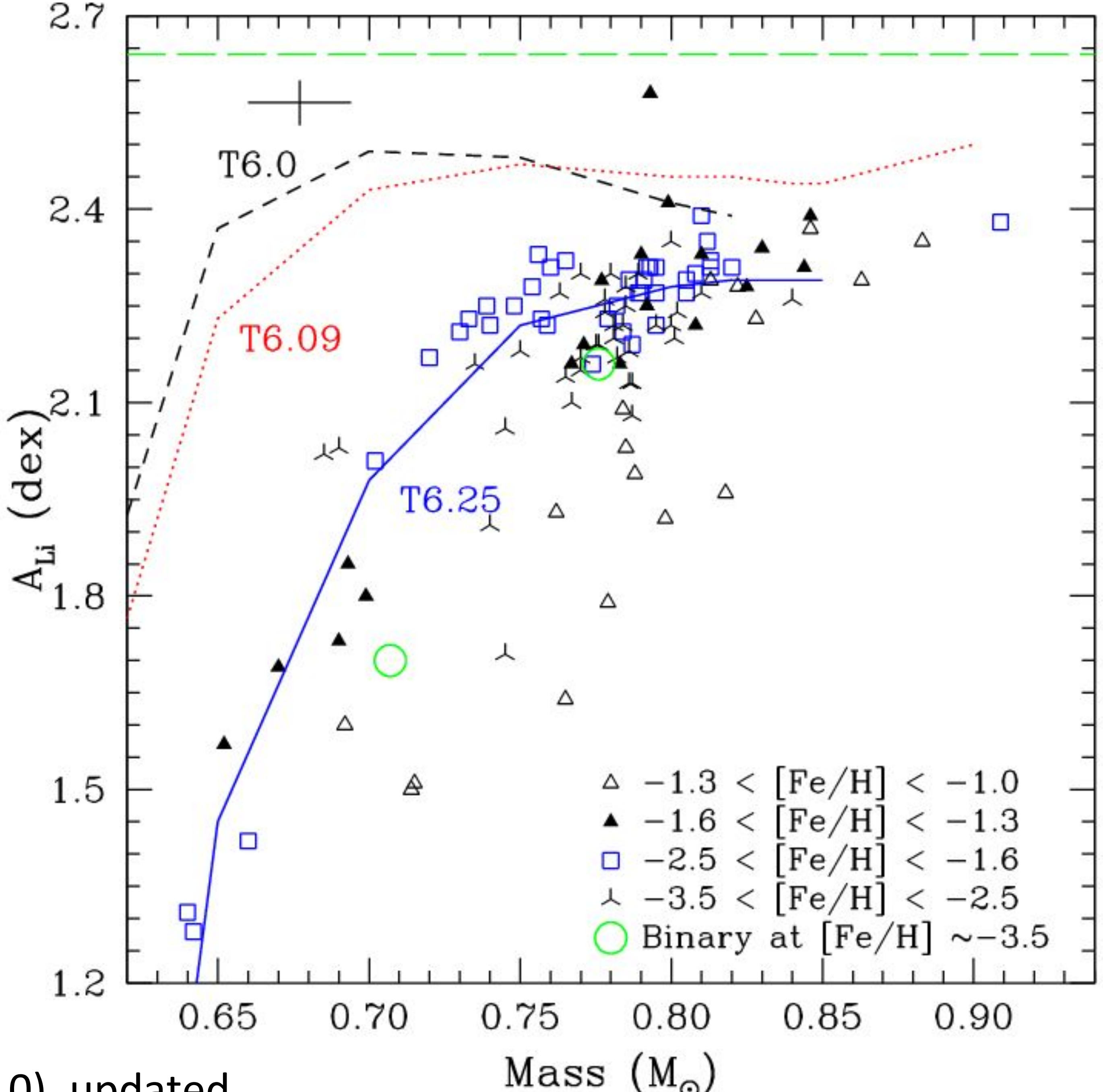
Fu et al. 2015

Field stars show that more models are needed



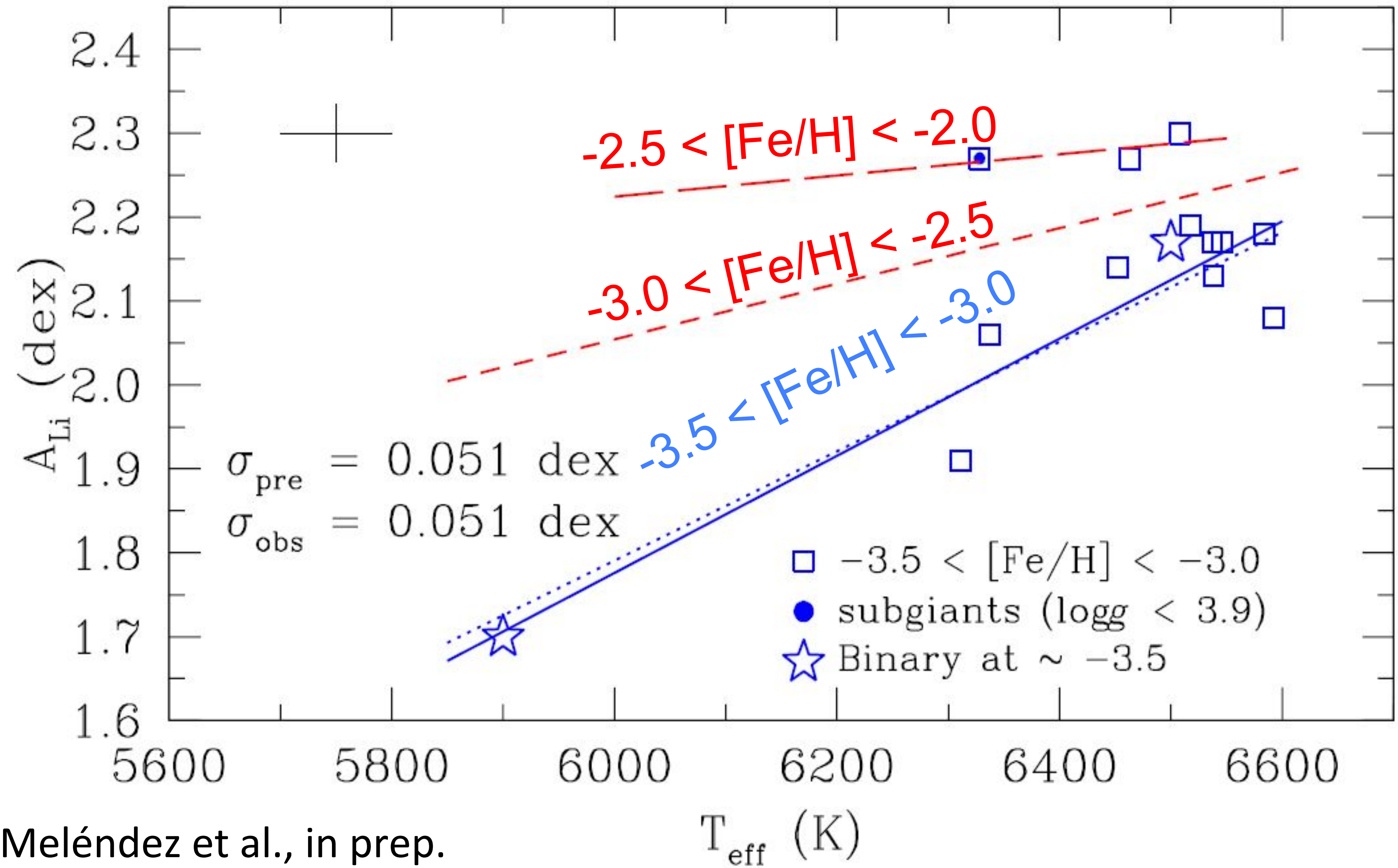
Meléndez et al. (2010), updated

Comparison of field halo stars with models by Richard et al. (2005)



Meléndez et al. (2010), updated

Li depletion in stars seems metallicity dependent

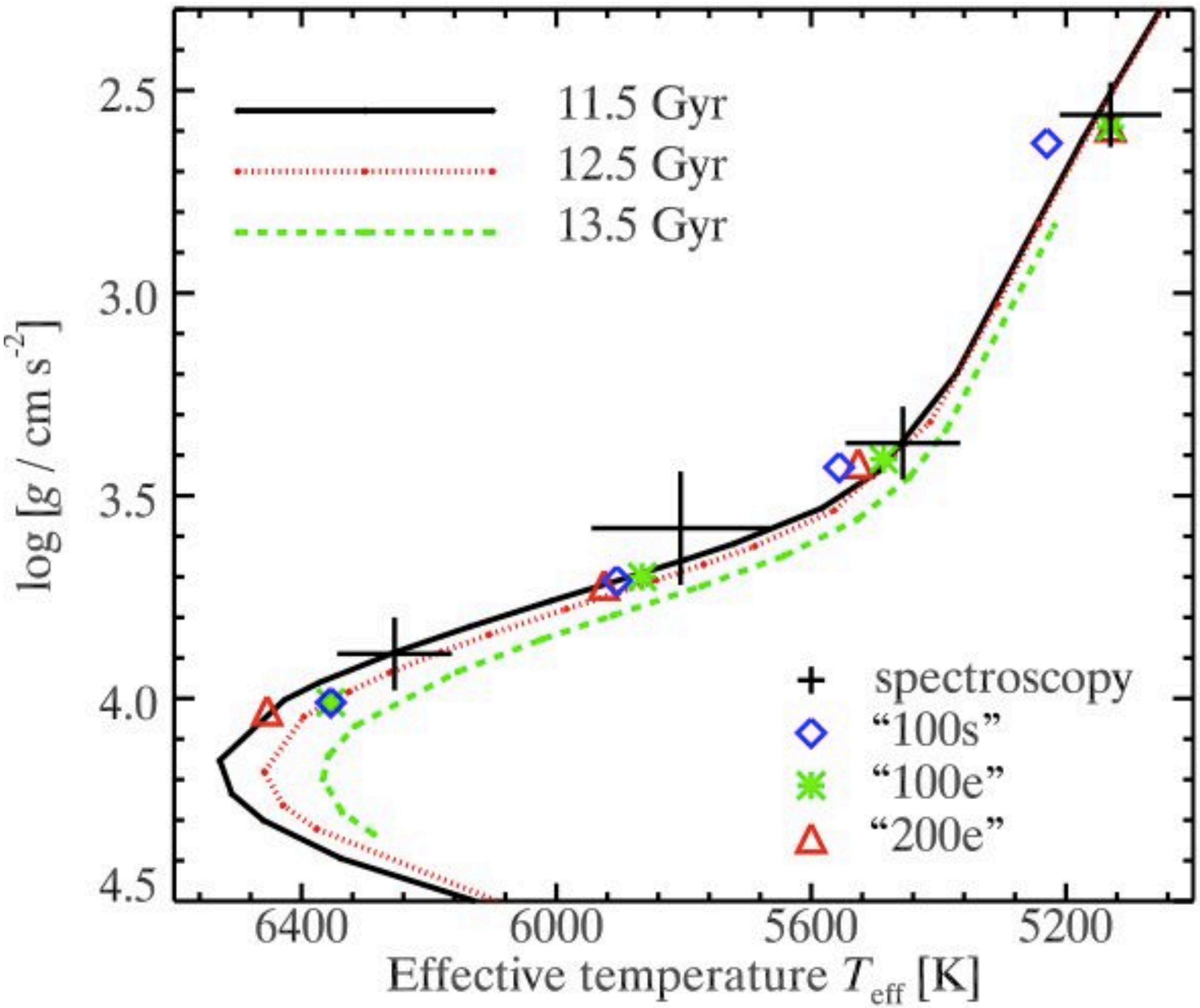


Meléndez et al., in prep.

More models are needed !

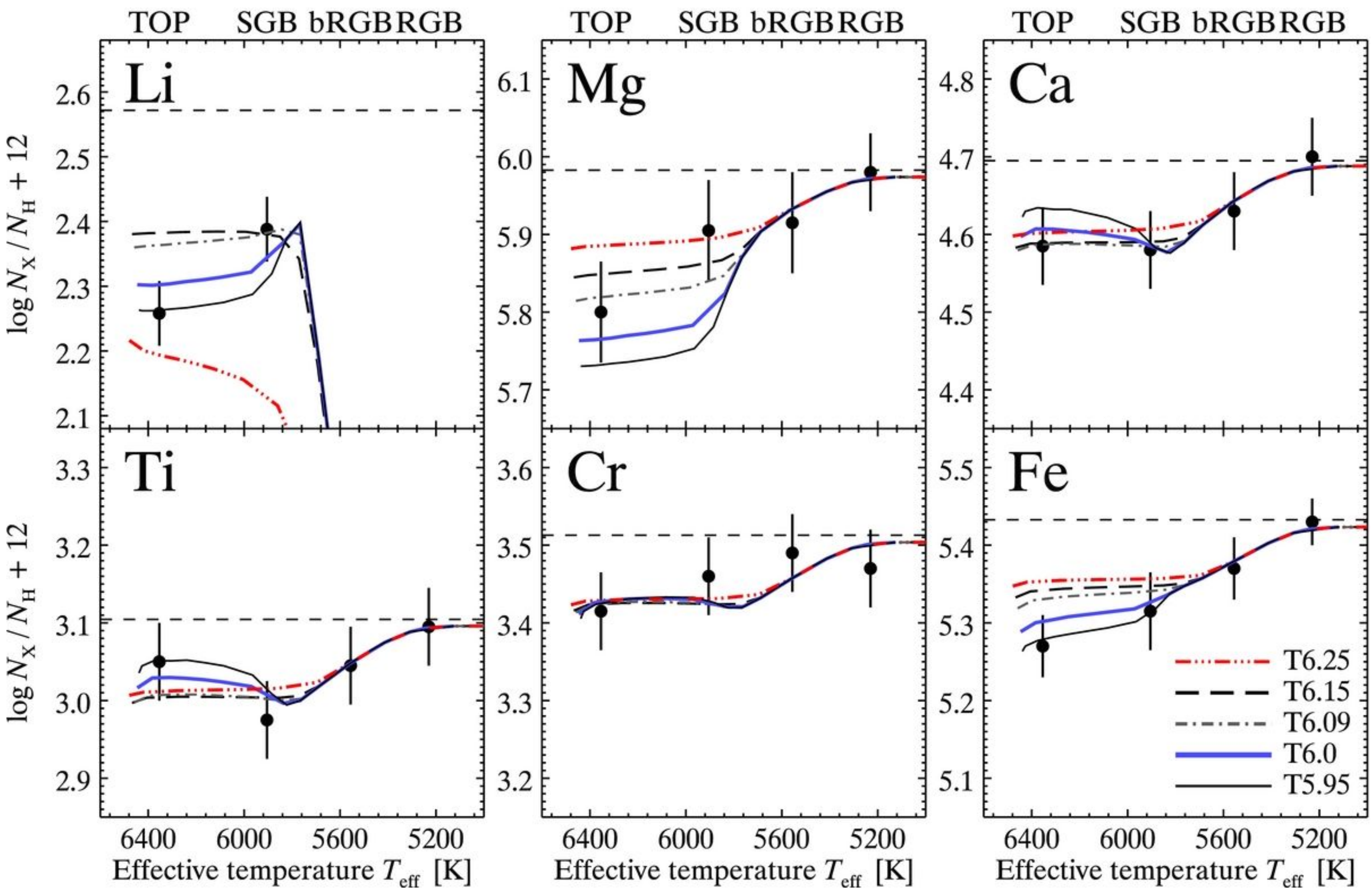
ATOMIC DIFFUSION AND MIXING IN OLD STARS. III. ANALYSIS OF NGC 6397 STARS UNDER NEW CONSTRAINTS

T. NORDLANDER[1], A. J. KORN[1], O. RICHARD[2], AND K. LIND[3] ApJ 2012



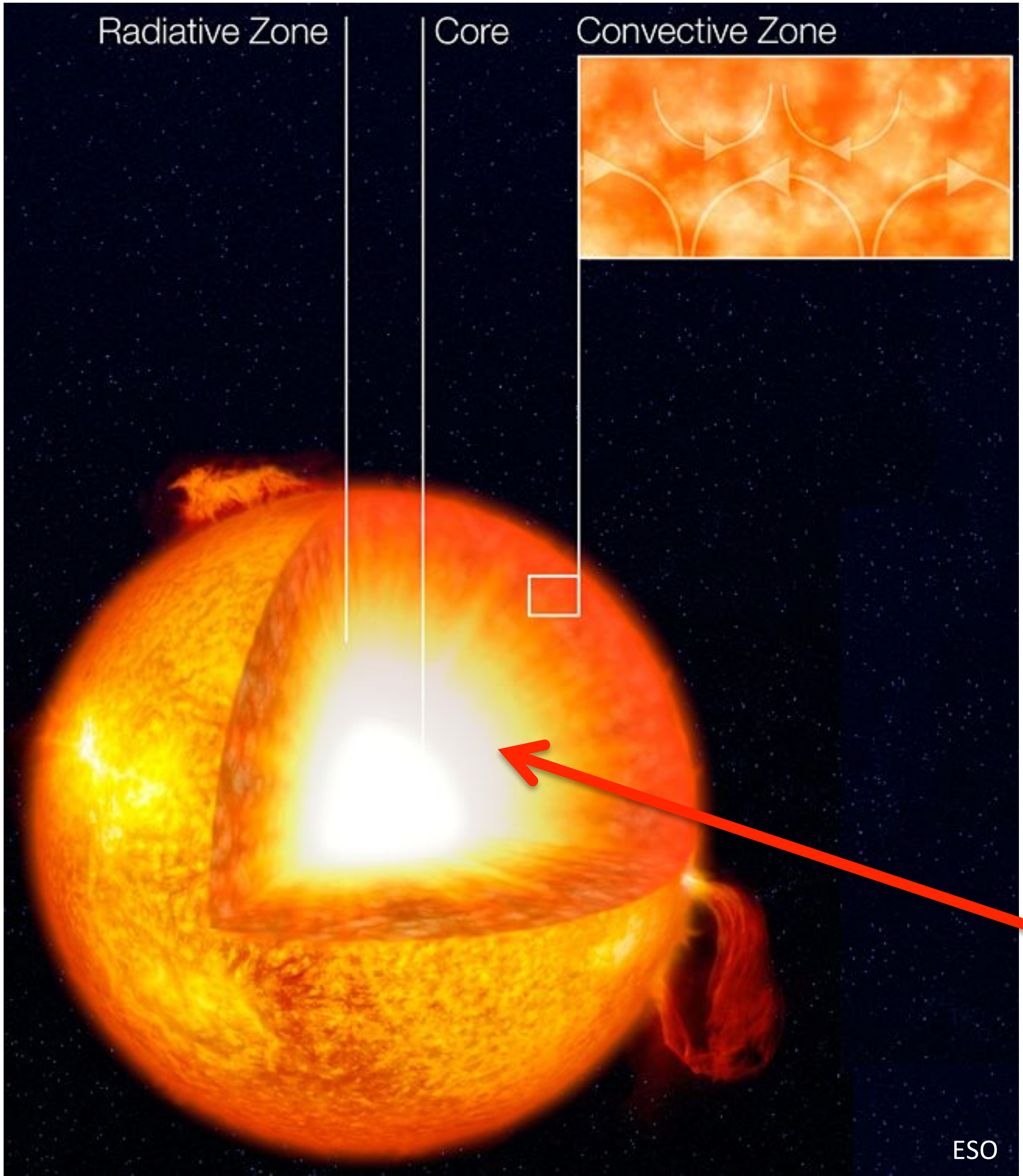
NGC 6397
[Fe/H] = -2.1

Signatures of atomic diffusion in the globular cluster NGC 6397



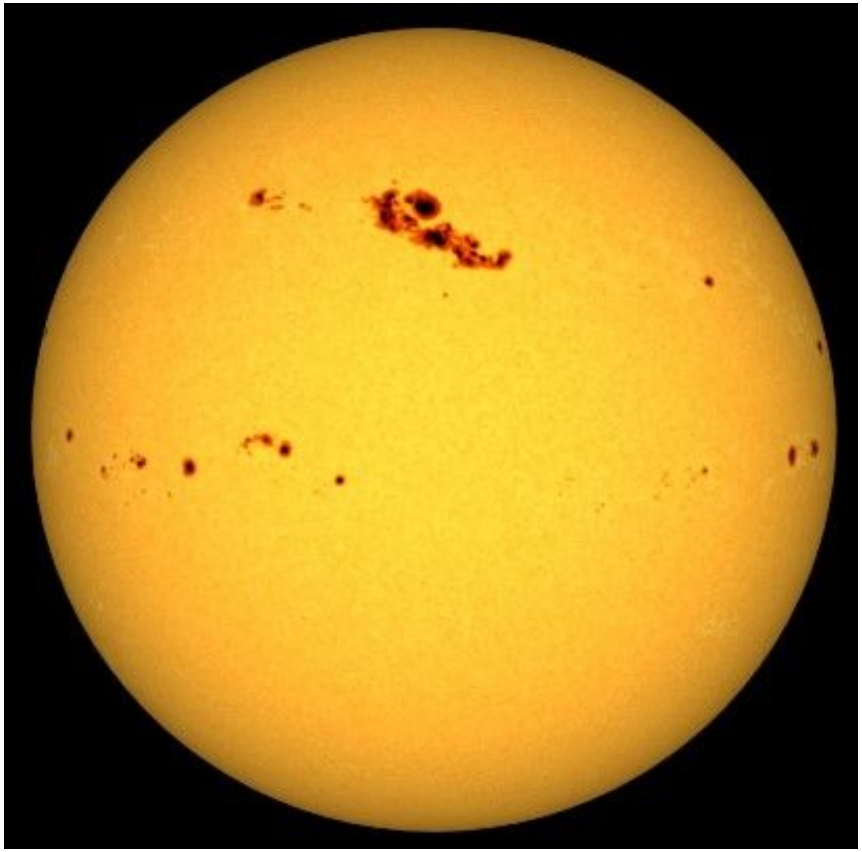
Nordlander et al. 2012

The solar lithium problem



- The solar Li is about 160 times lower than in meteorites.
- *Li burns at 2.5 10^6 K; **below** the convection zone: no depletion in the photosphere!*

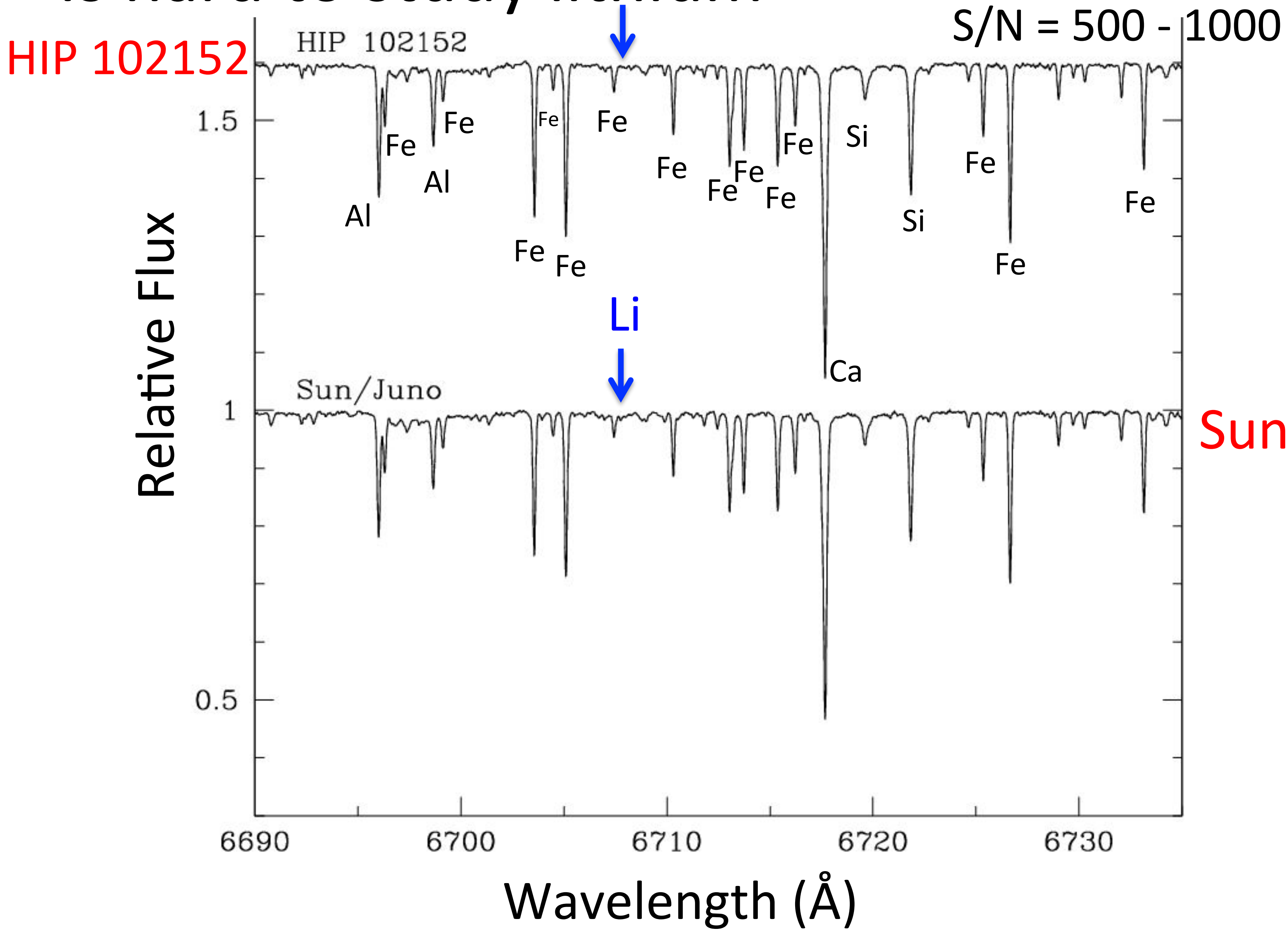
Solar twins: Stars like the Sun within 100 K in effective temperature, and within 0.1 dex in luminosity and [Fe/H]
→ mass as the Sun → similar stellar evolution



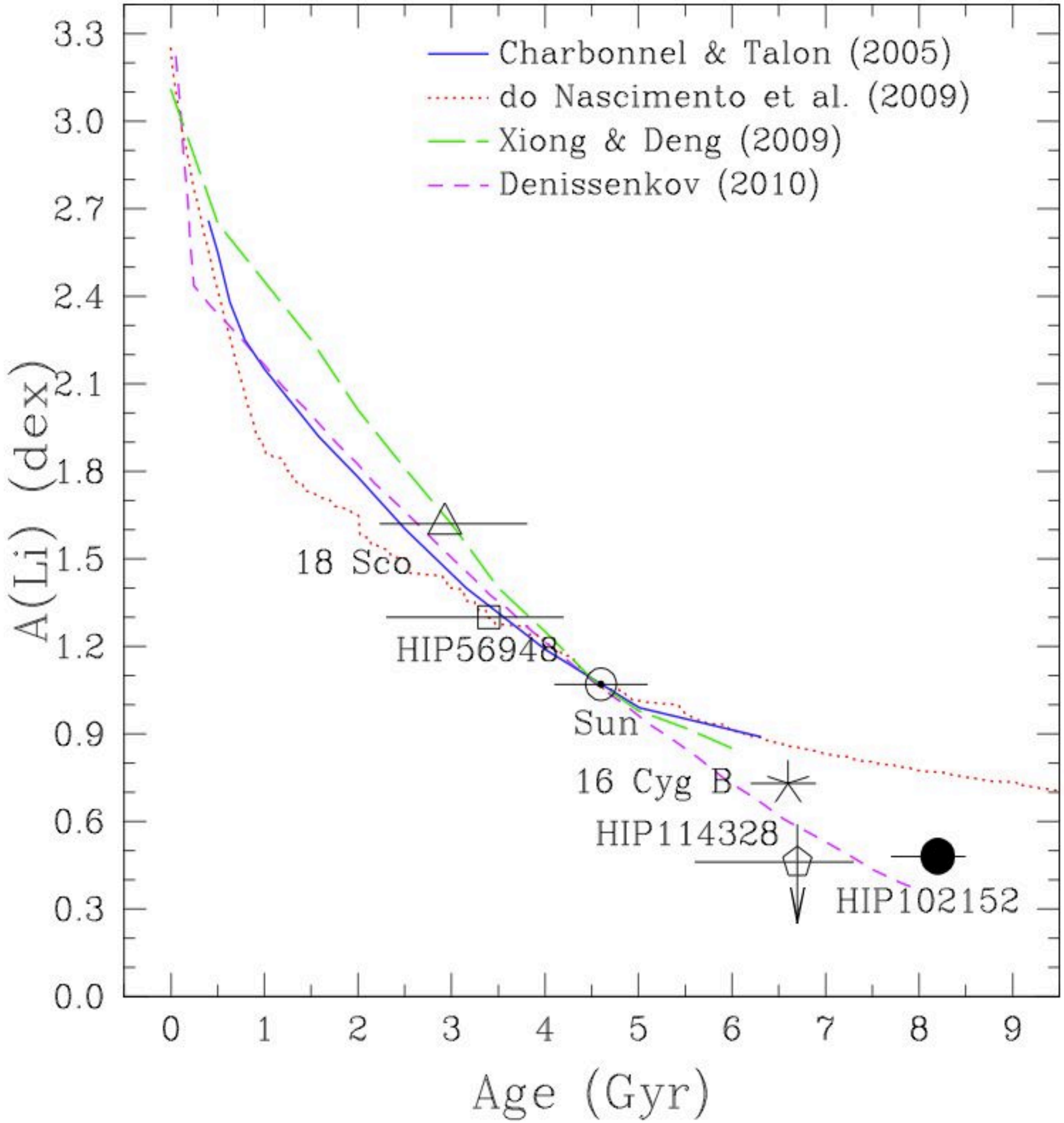
Is hard to study lithium

R = 110 000

S/N = 500 - 1000



Lithium decreases for older solar twins



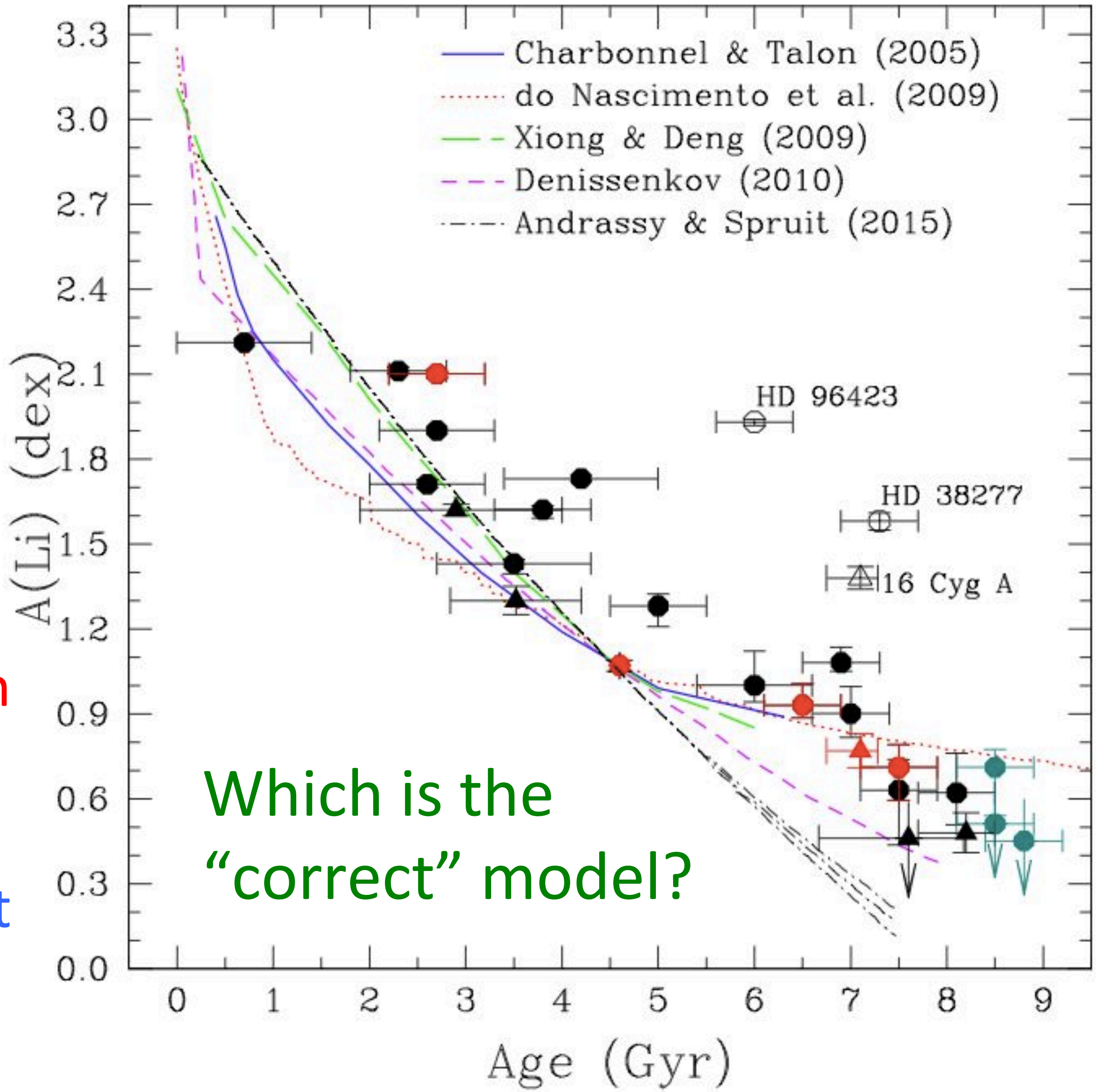
A&A 567, L3 (2014)
DOI: 10.1051/0004-6361/201424172

HIP 114328: a new refractory-poor and Li-poor solar twin★,★★

Jorge Meléndez[1], Lucas Schirbel[1], TalaWanda R. Monroe[1], David Yong[2], Iván Ramírez[3], and Martin Asplund[2]

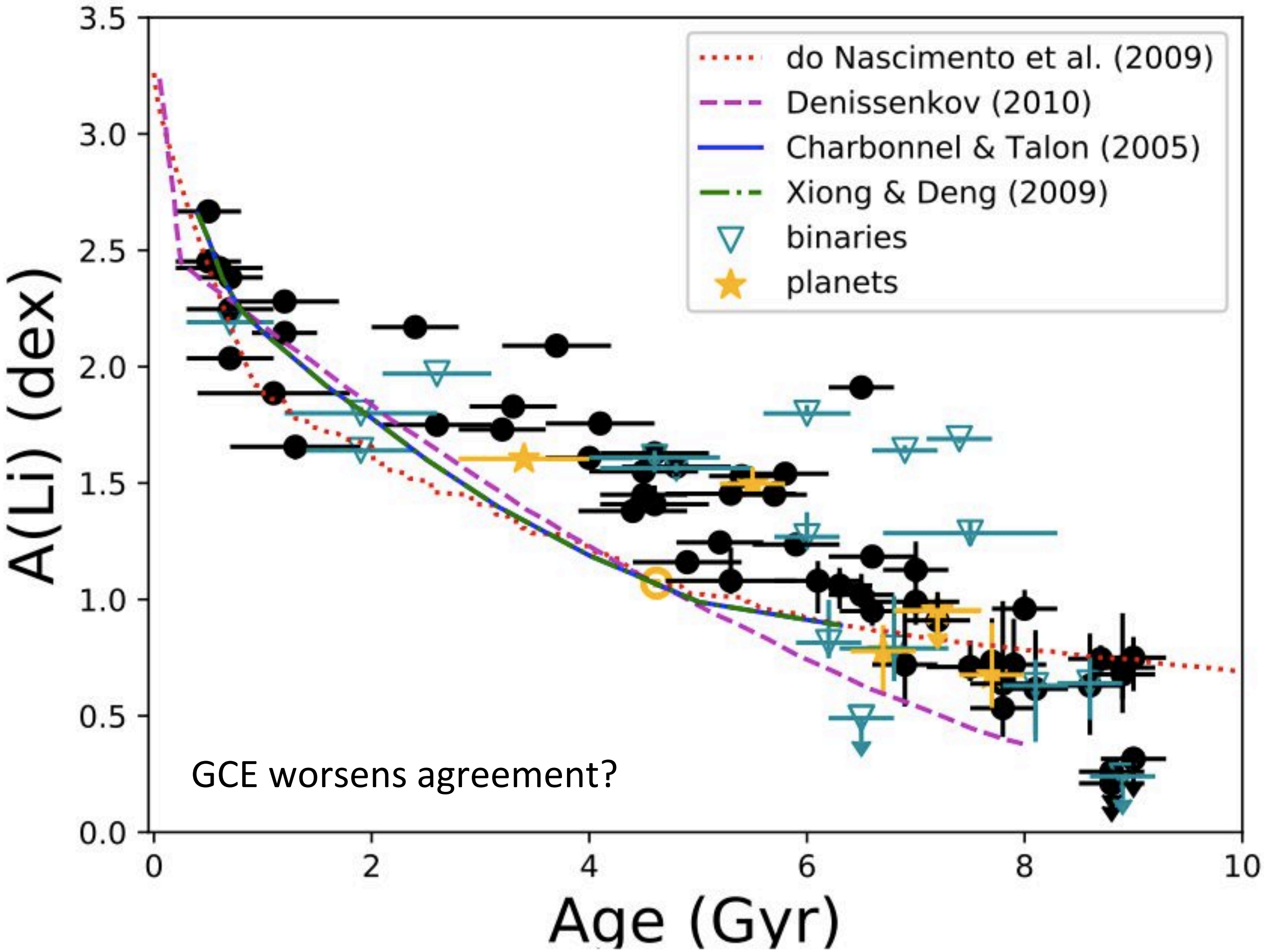
Most stars follow a lithium – age correlation, including stars with planets

16 Cyg B (planet host) is normal in Li. Perhaps 16 Cyg A accreted a planet



Carlos, Nissen & Melendez (2016)

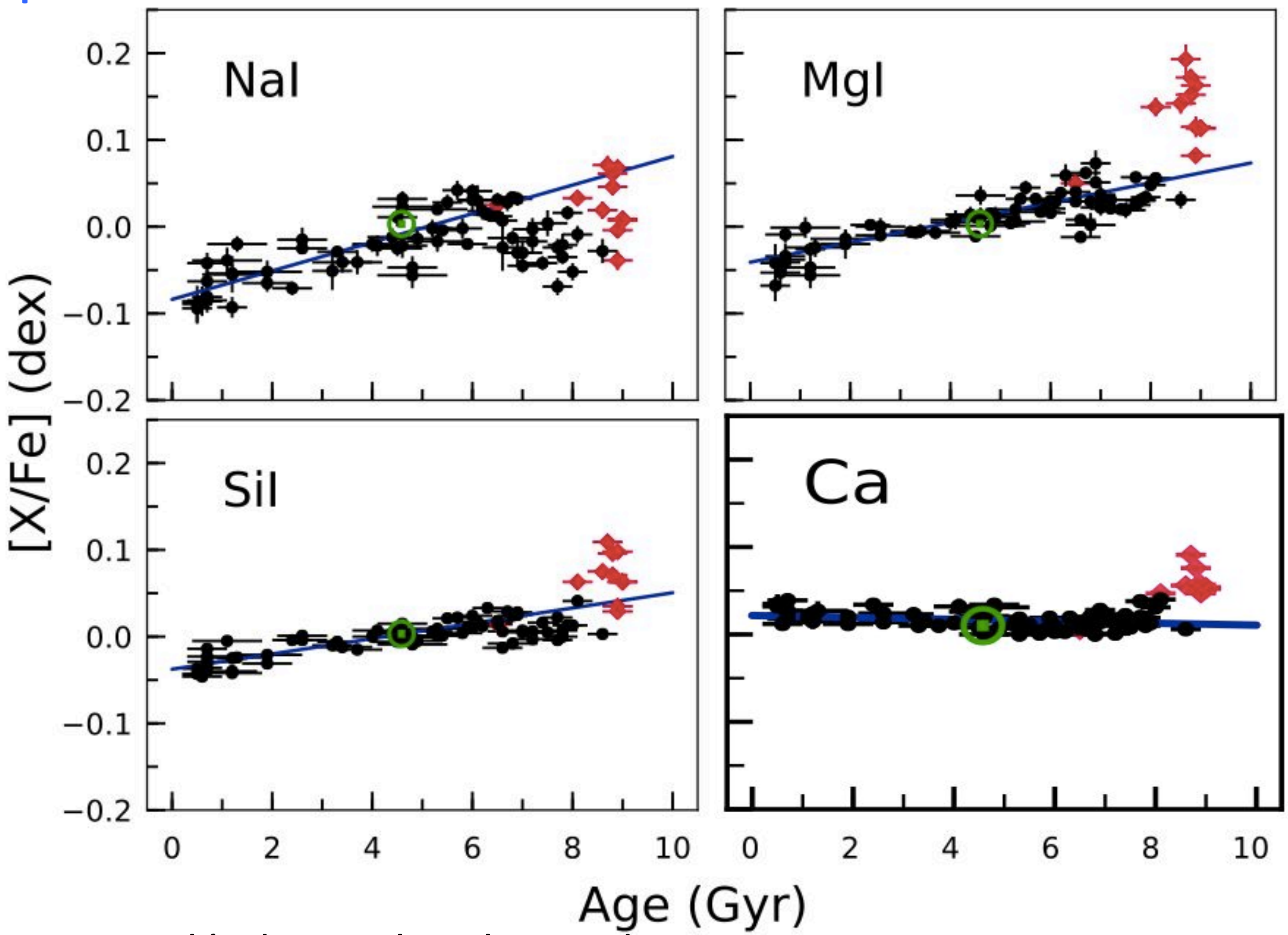
As we add more data and improve the ages, it seems that none of the models reproduce the solar twins



Carlos, Meléndez, Spina et al., in prep.

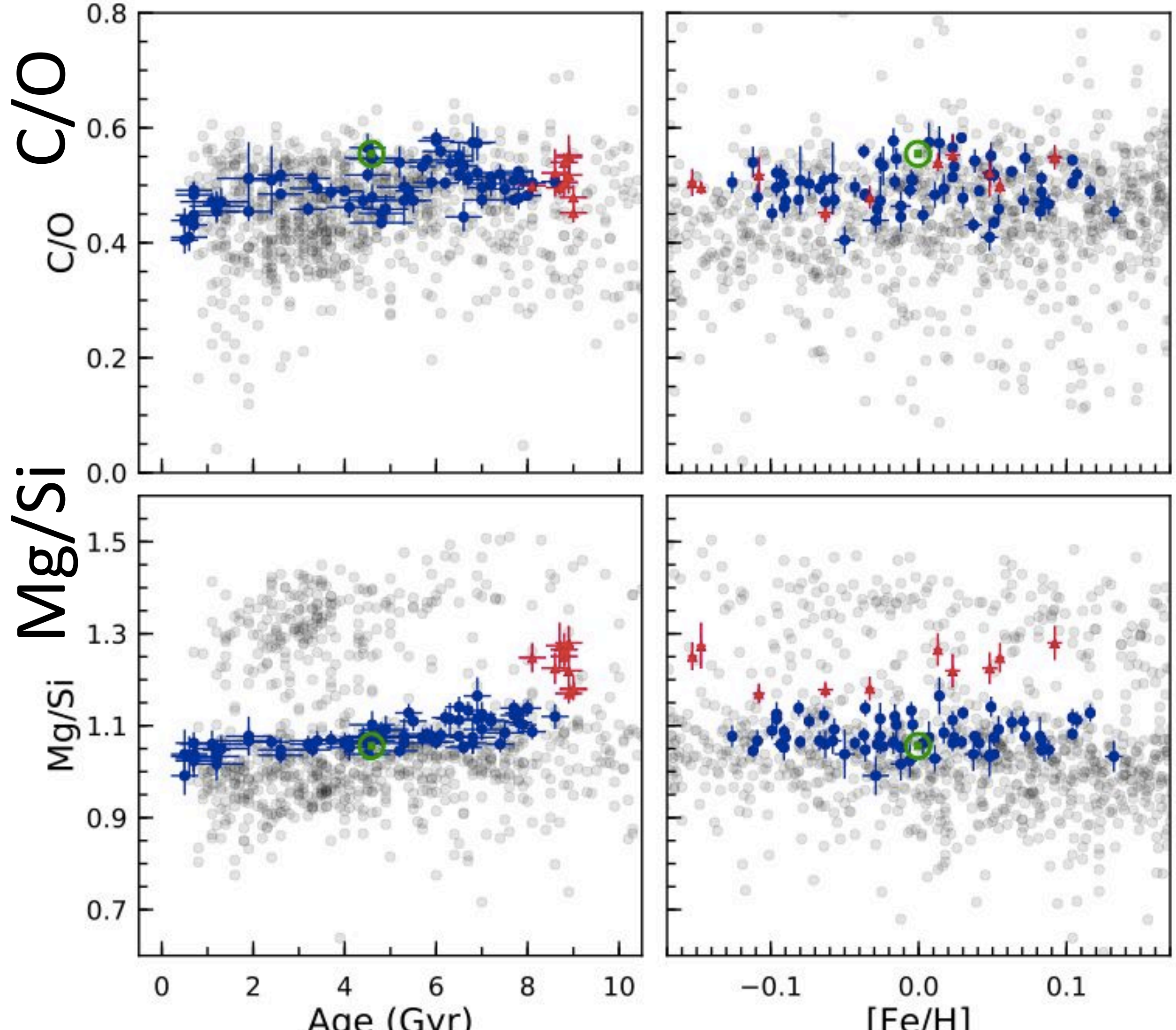
Galactic archaeology using solar twins from HARPS

Are these trends only due to different enrichment channels of supernova Ia & II? Or also differential atomic diffusion?



Bedell, Bean, Meléndez et al., submitted

Are the abundance ratios relevant for building exoplanets independent of age?

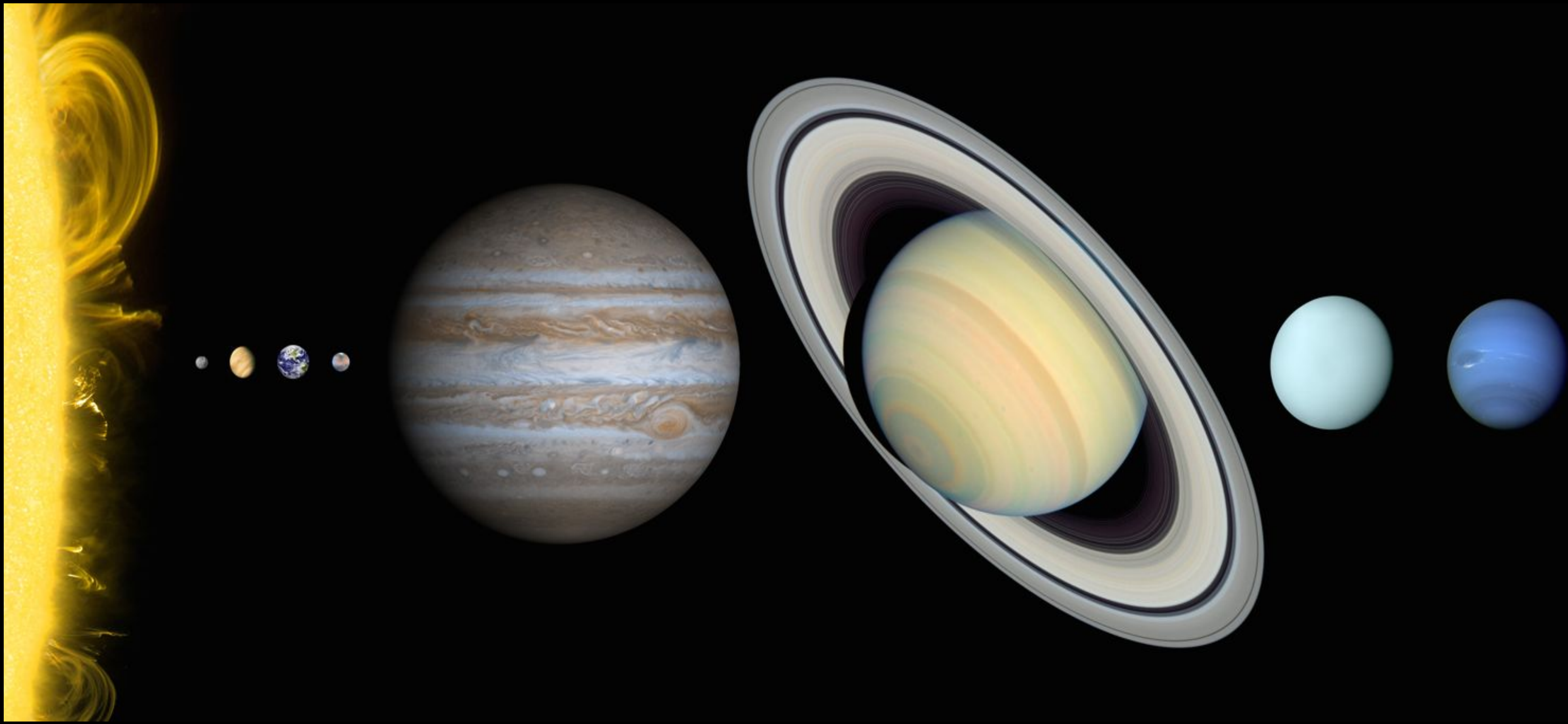


Bedell, Bean, Meléndez et al., submitted

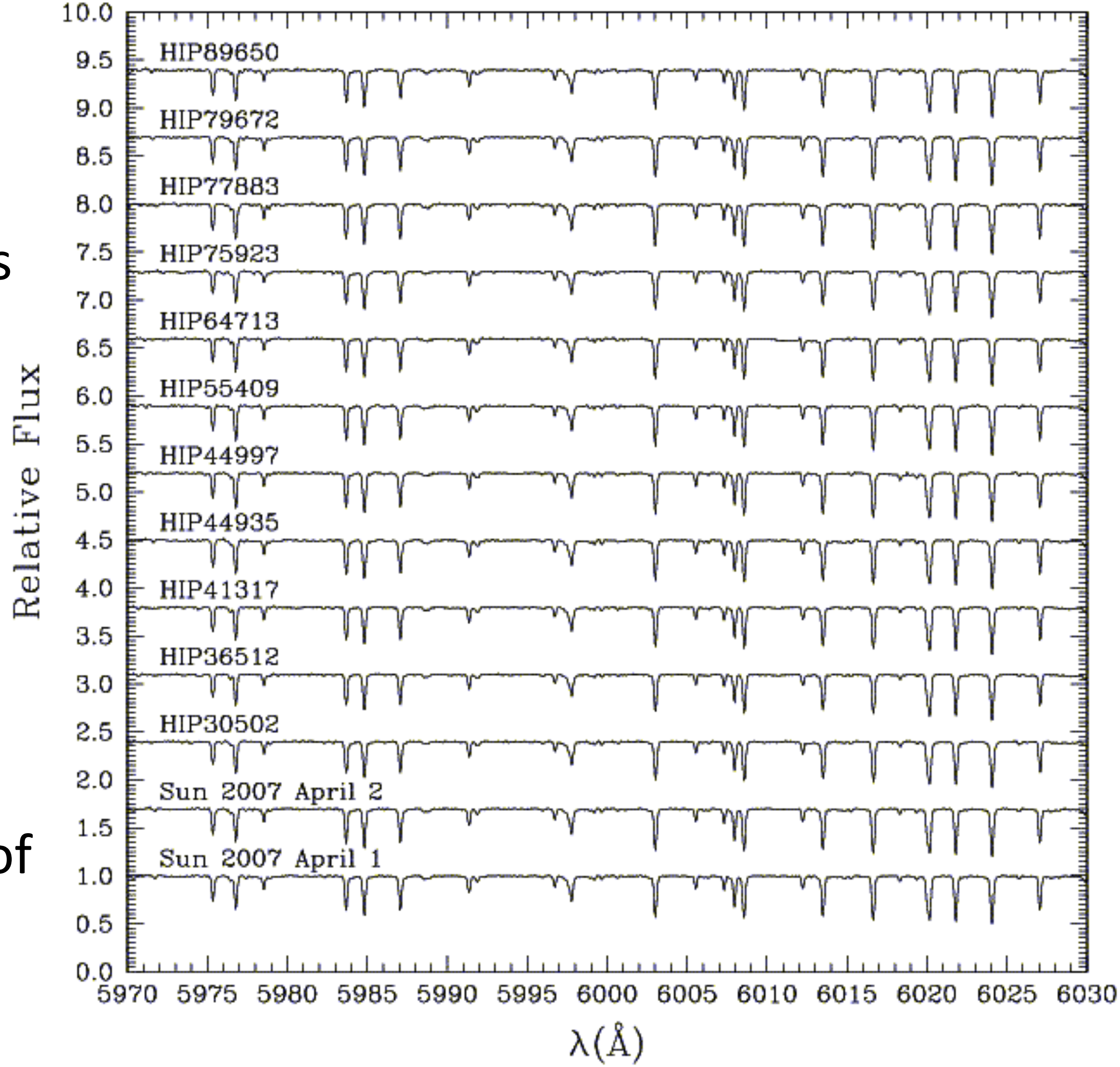
Solar twins (blue points) suggest high chemical homogeneity in C/O & Mg/Si.

How are the ratios affected by atomic diffusion?

How special is our planetary system?



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

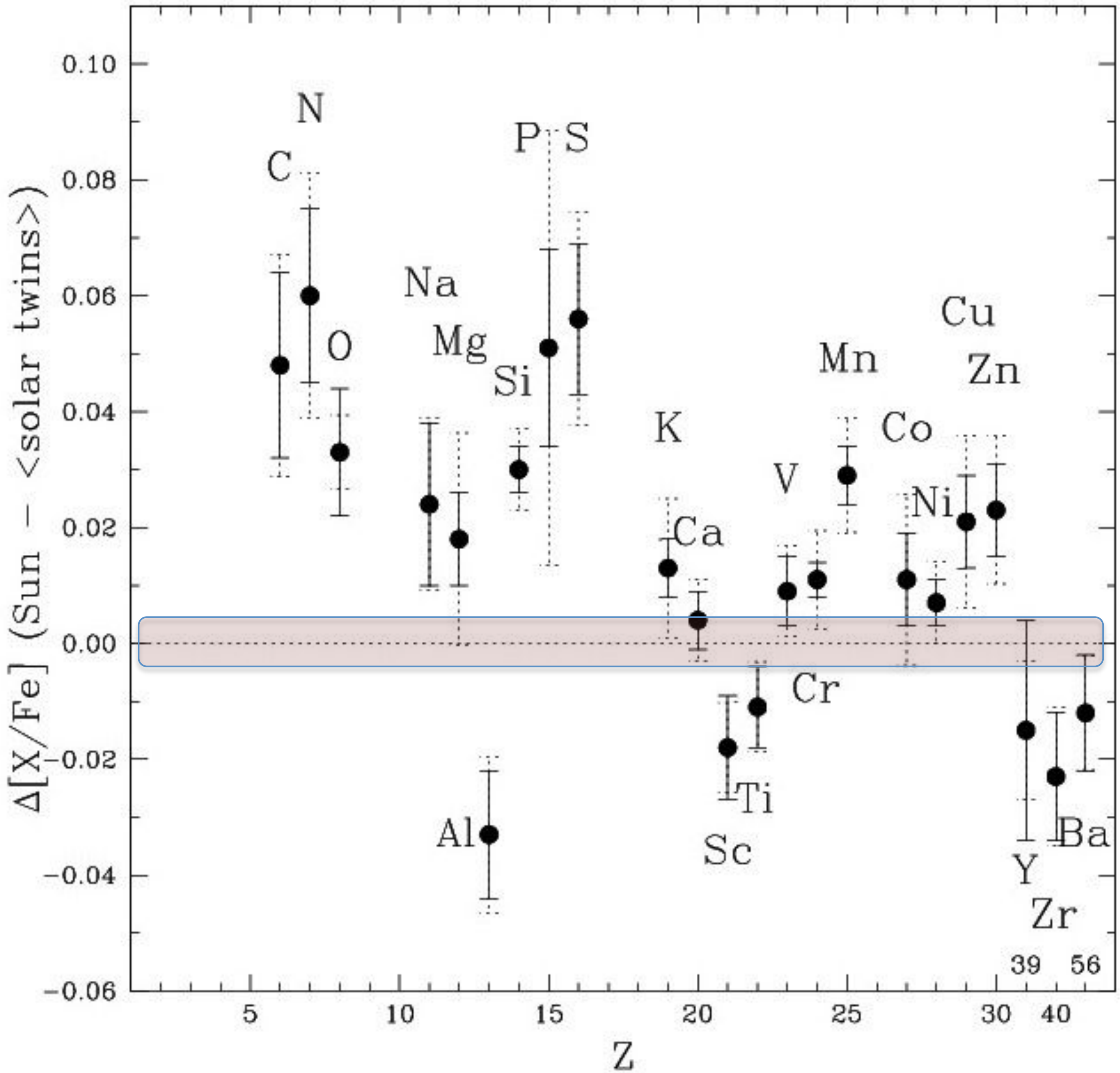
Meléndez et al. 2009, ApJ, 704, L66

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'

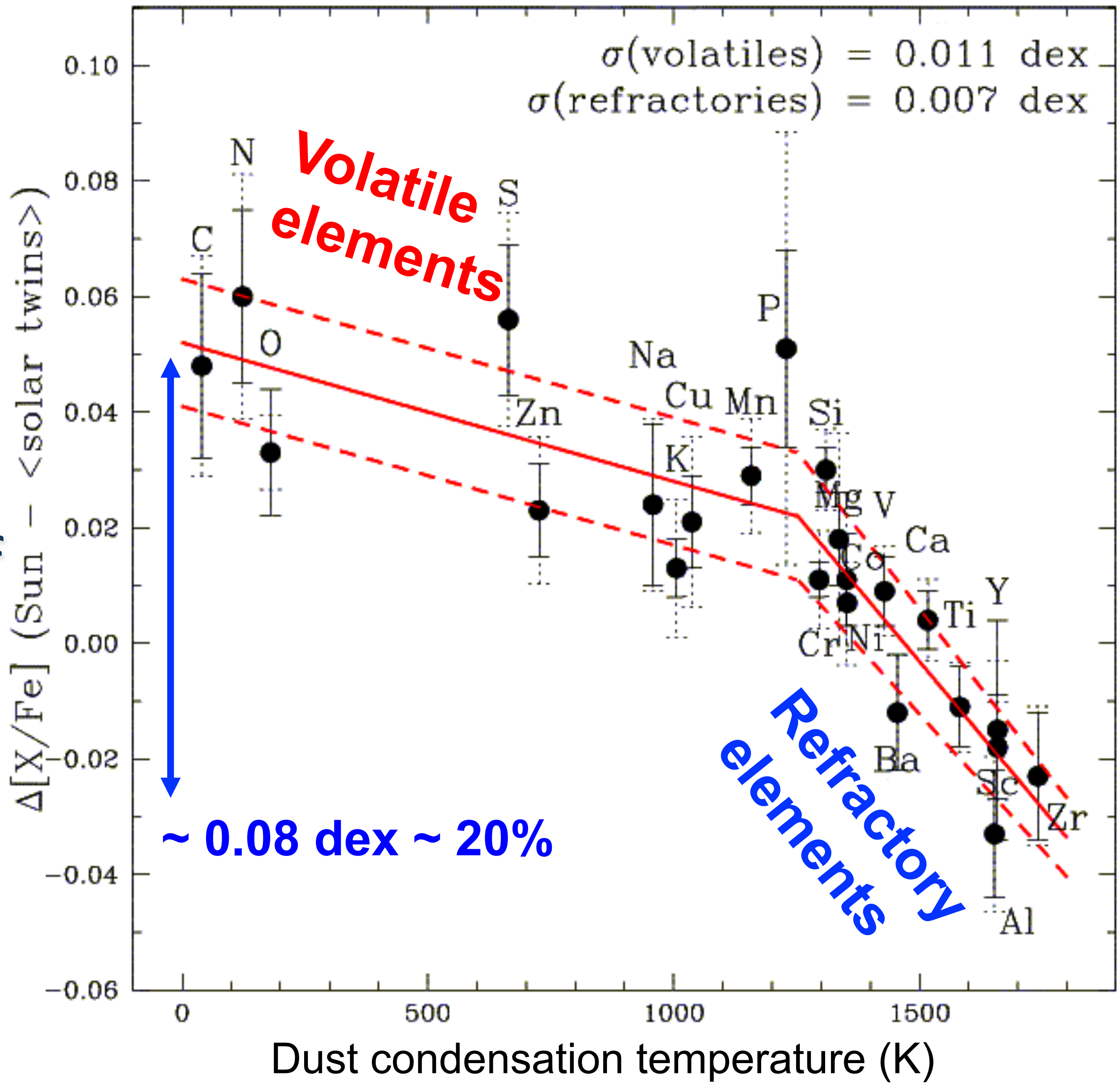


Meléndez et al. 2009

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

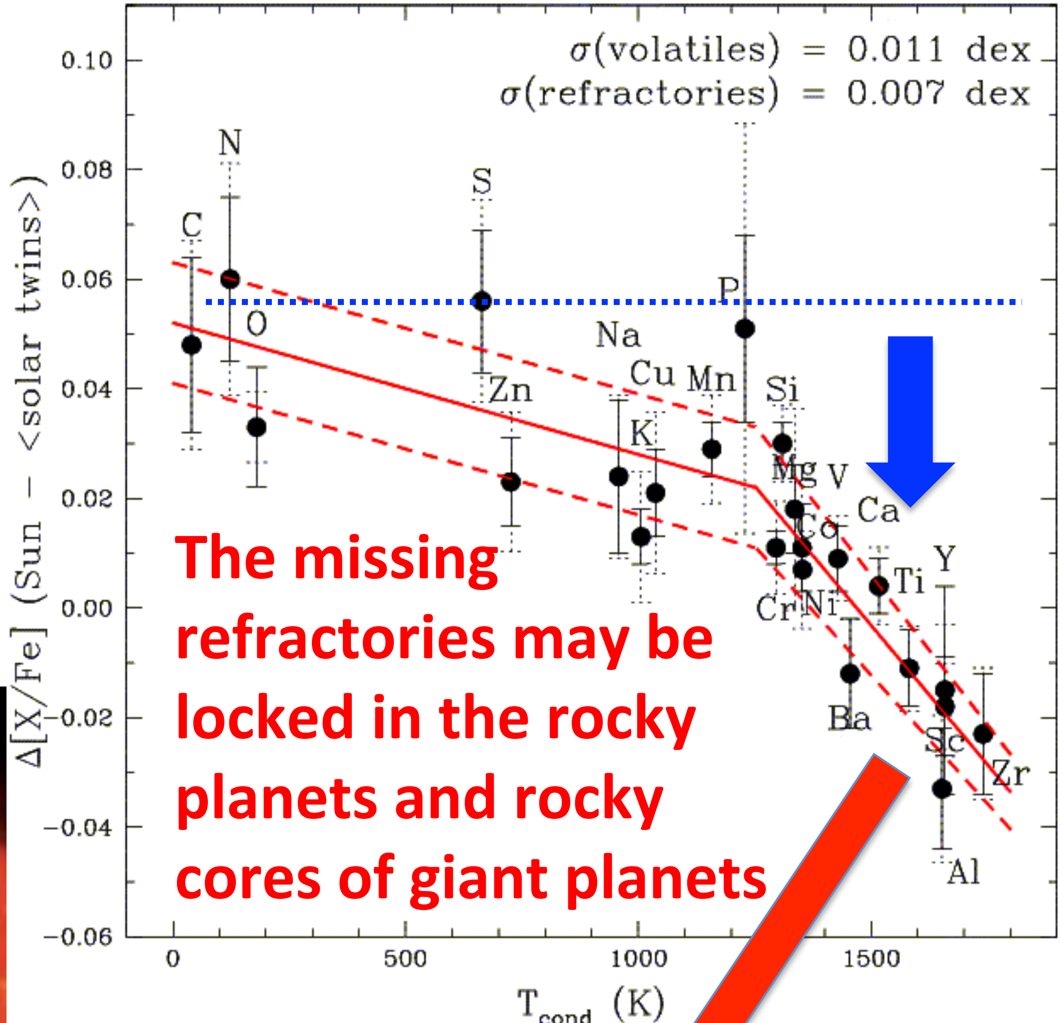
Correlation is highly significant probability ~**10^{-9}** to happen by chance

It's most likely to win the lottery



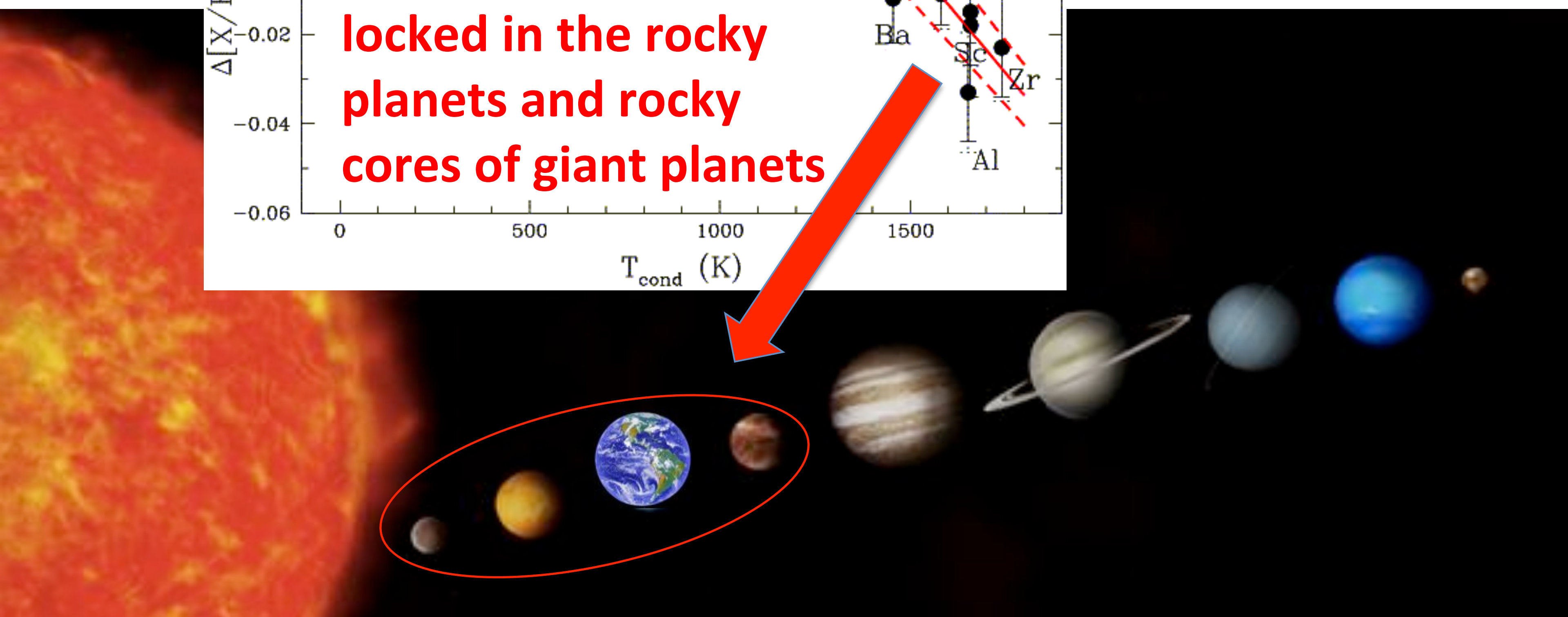
Meléndez, Asplund, Gustafsson, Yong 2009, ApJ Letters

Meléndez et al. 2009



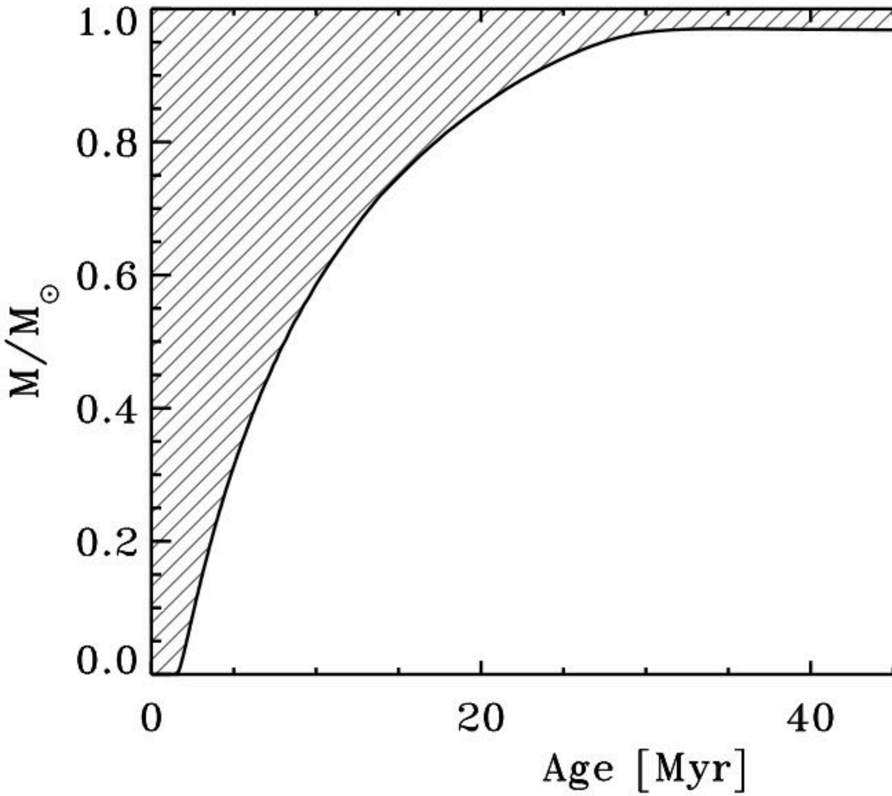
The missing refractories may be locked in the rocky planets and rocky cores of giant planets

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

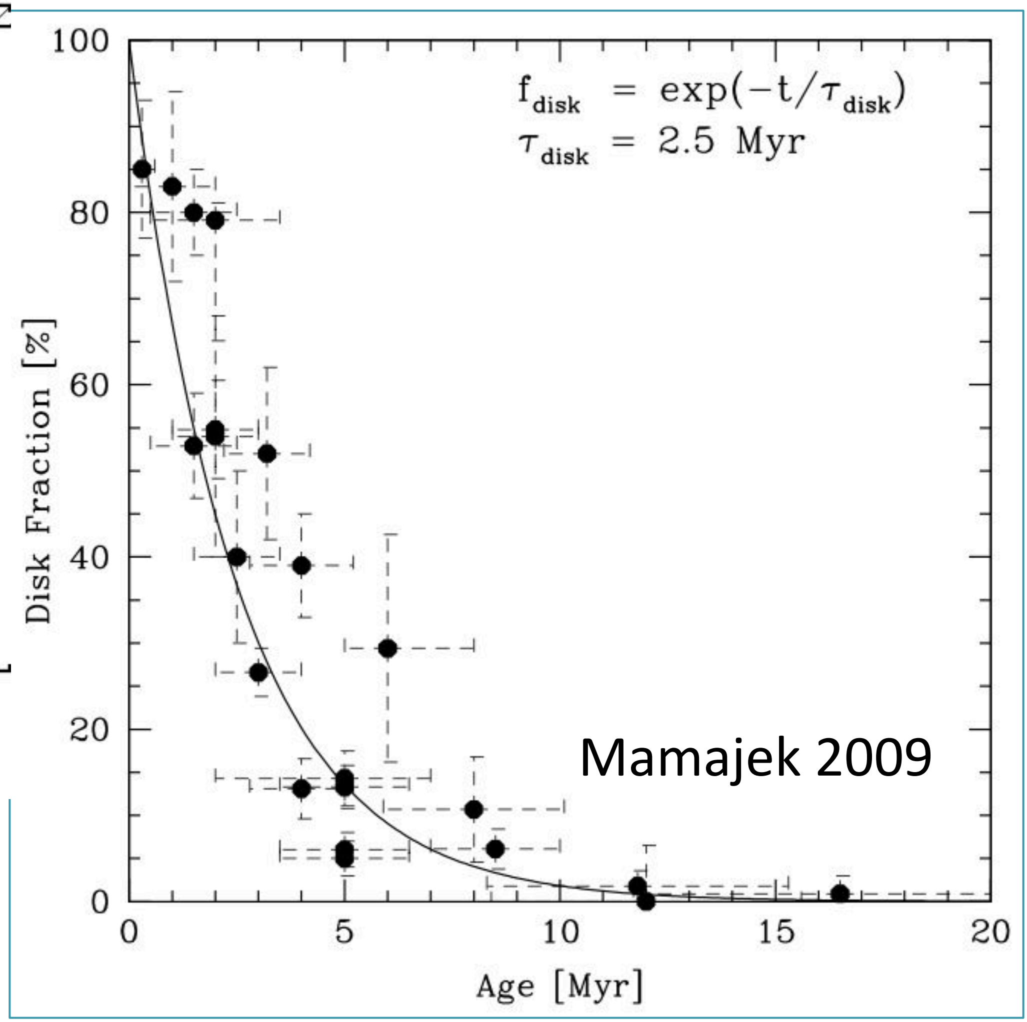


Timescale problem for planet signatures?

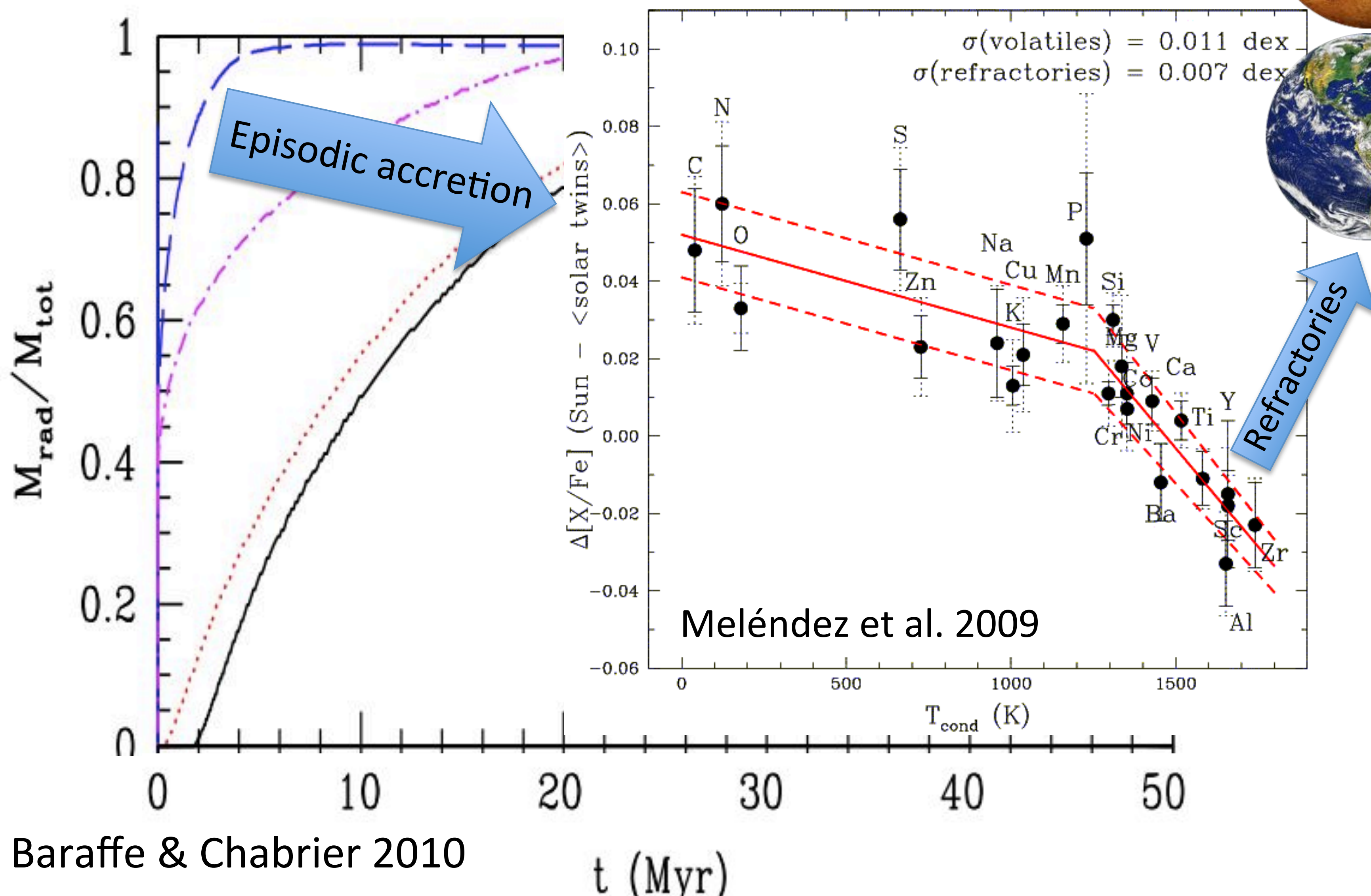
In the standard solar model the convection zone shrinks to current value after disk is gone

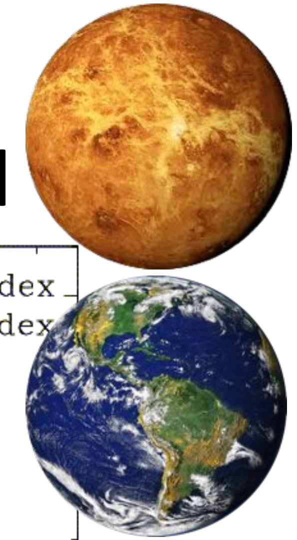


Standard solar model
Serenelli 2011



More work needed on accretion history of the early Sun and composition of accreted material





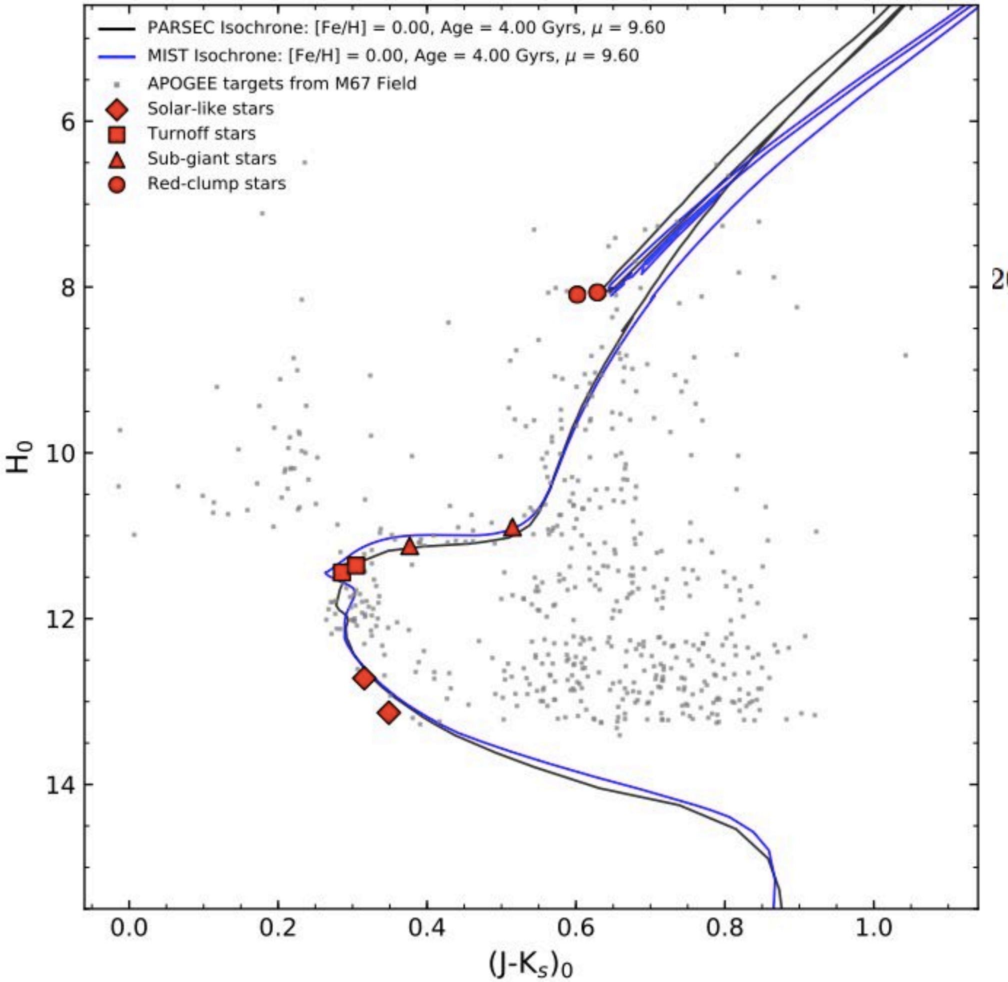
Are open clusters chemically homogeneous?

CHEMICAL ABUNDANCES OF MAIN-SEQUENCE, TURN-OFF, SUBGIANT AND RED GIANT STARS FROM APOGEE SPECTRA I: SIGNATURES OF DIFFUSION IN THE OPEN CLUSTER M67

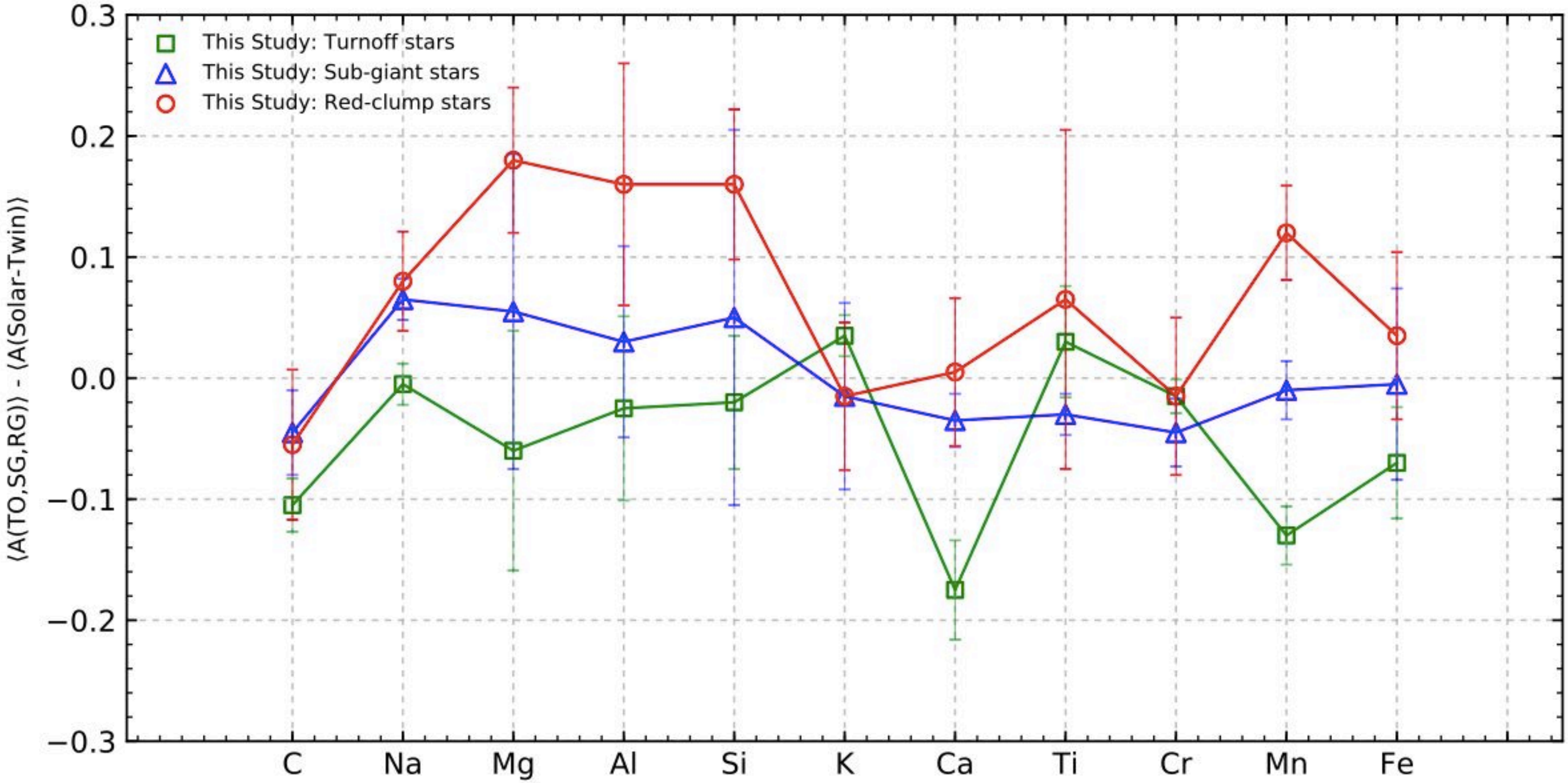
Diogo Souto,[1] Katia Cunha,[2,1]
D. A. García-Hernández,[4,5] Marc Pinso
Jon Holtzman,[9] J. A. Johnson,[6] I
Matthew Shetrone,[12] Jennifer Sobe
Olga Zamora,[4,5] Gail Zasowski,
J. G. Fernandez-Trincado,[17,18] Sandro Vi

arXiv:1803.04461v1

M67: about solar age and solar metallicity

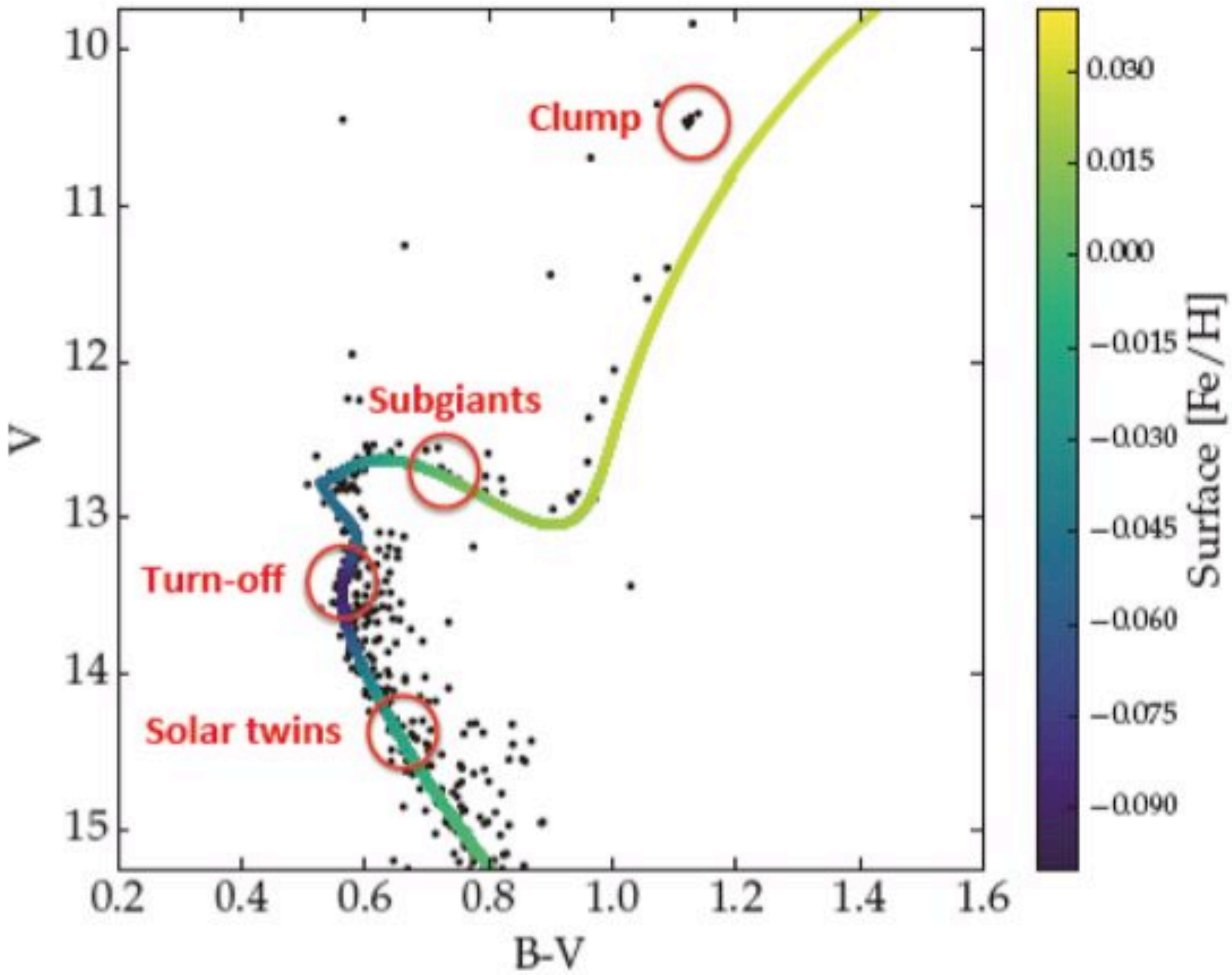


Signatures of atomic diffusion in M67



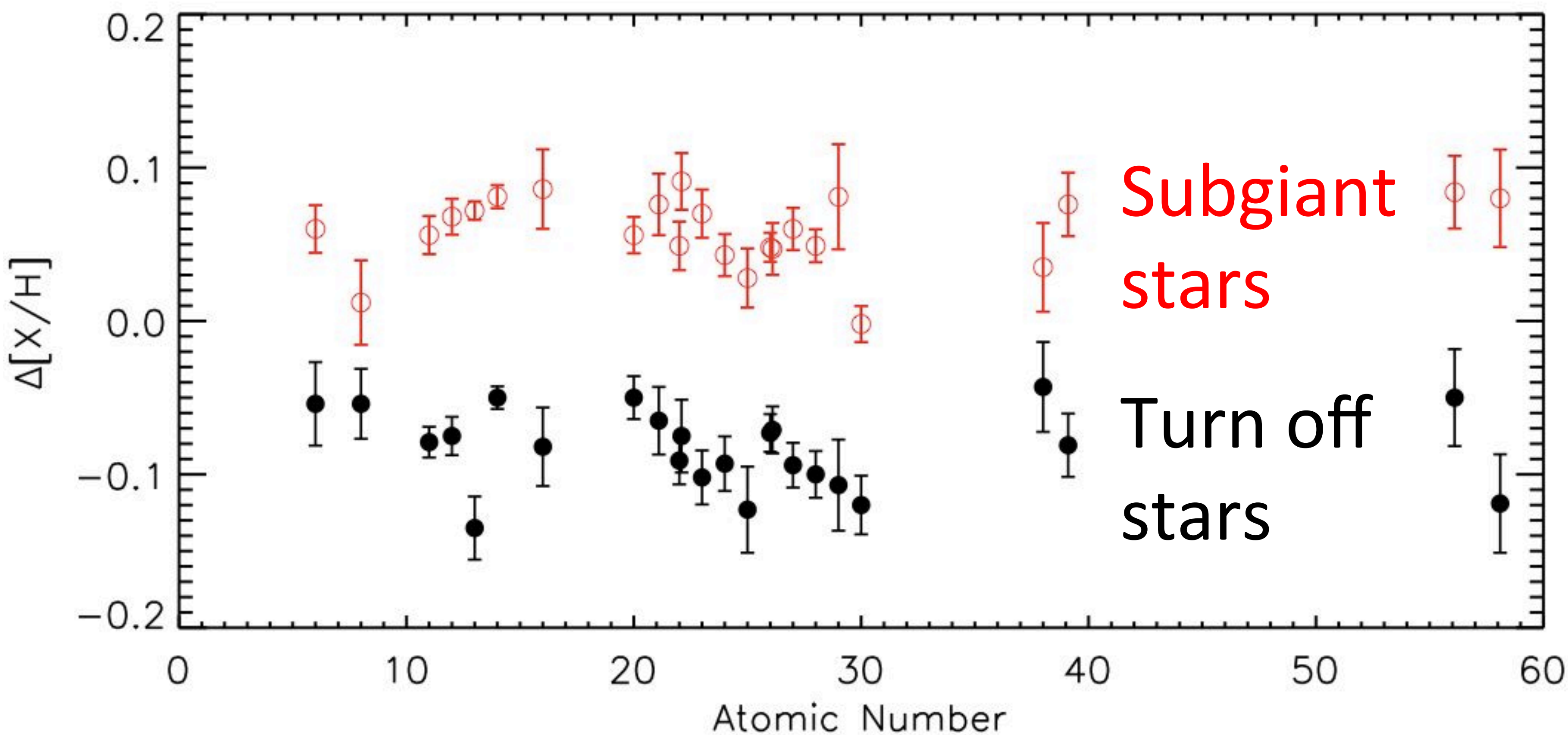
Souto et al. arXiv:1803.04461v1

More evidences of atomic diffusion in M67



Liu, Asplund, Yong et al., in prep.

More evidences of atomic diffusion in M67

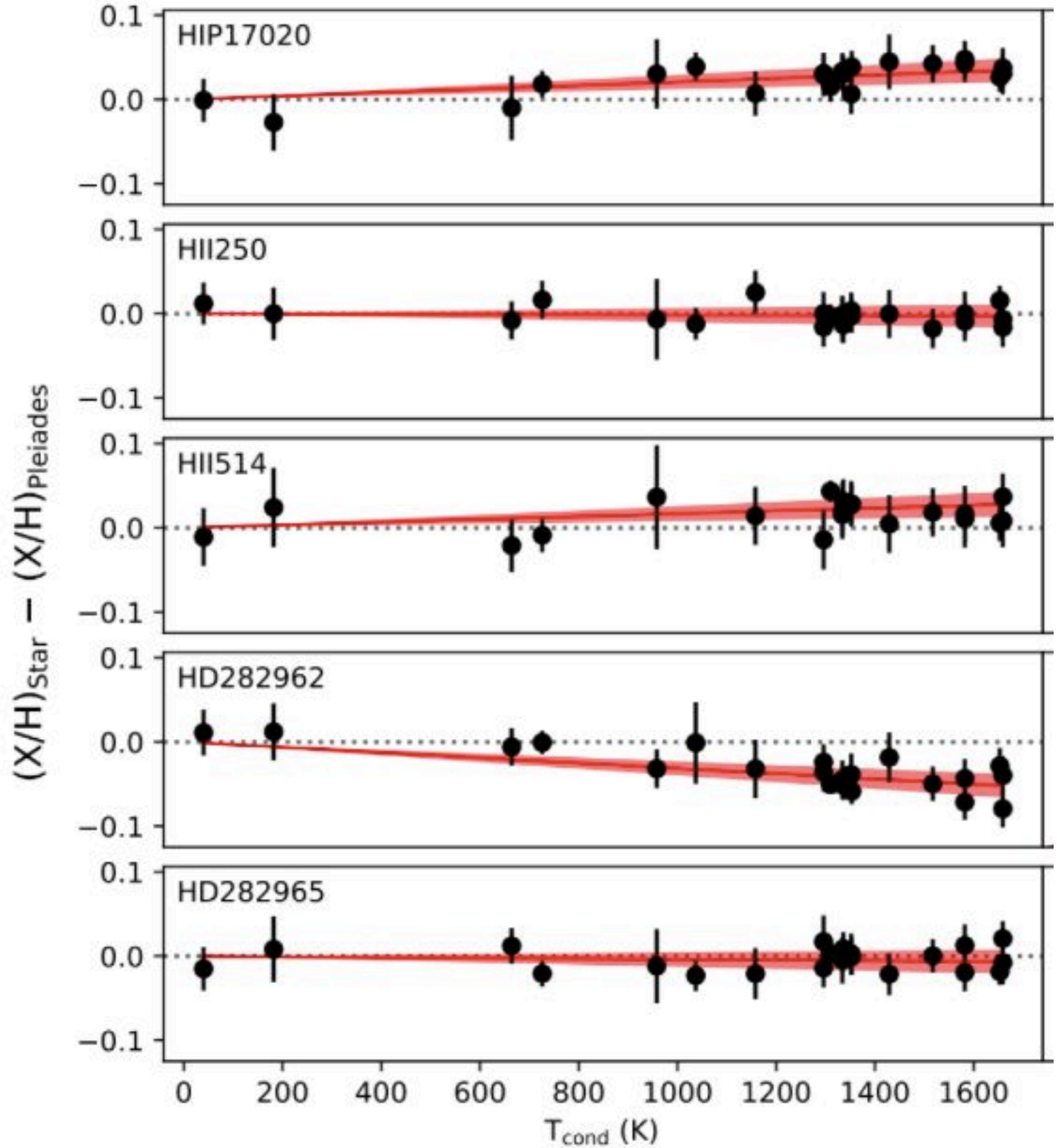


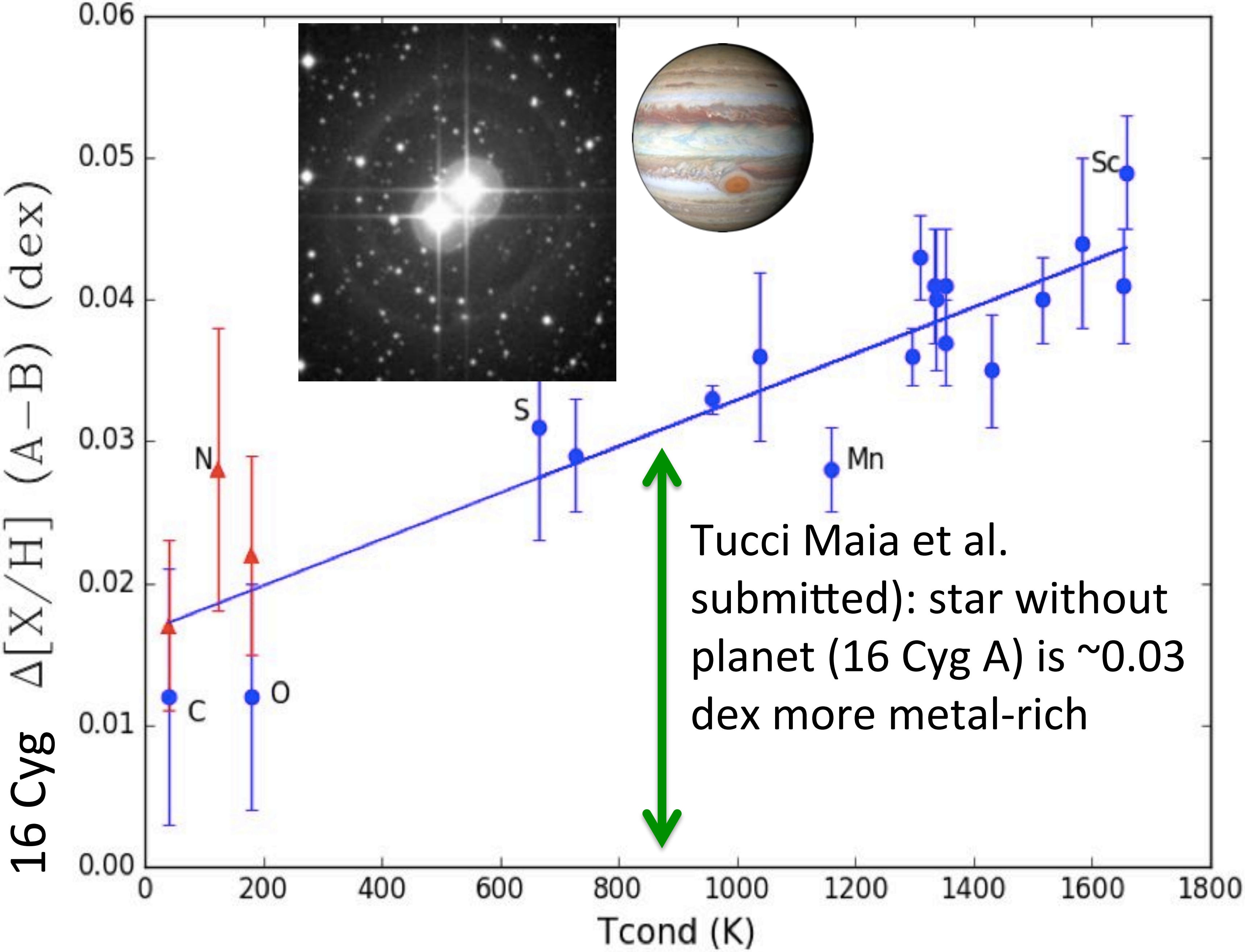
Liu, Asplund, Yong et al., in prep.

More on chemical homogeneity of open clusters: Pleiades.

Analysis of 5 twins stars show chemical anomalies. Planet signatures? When?

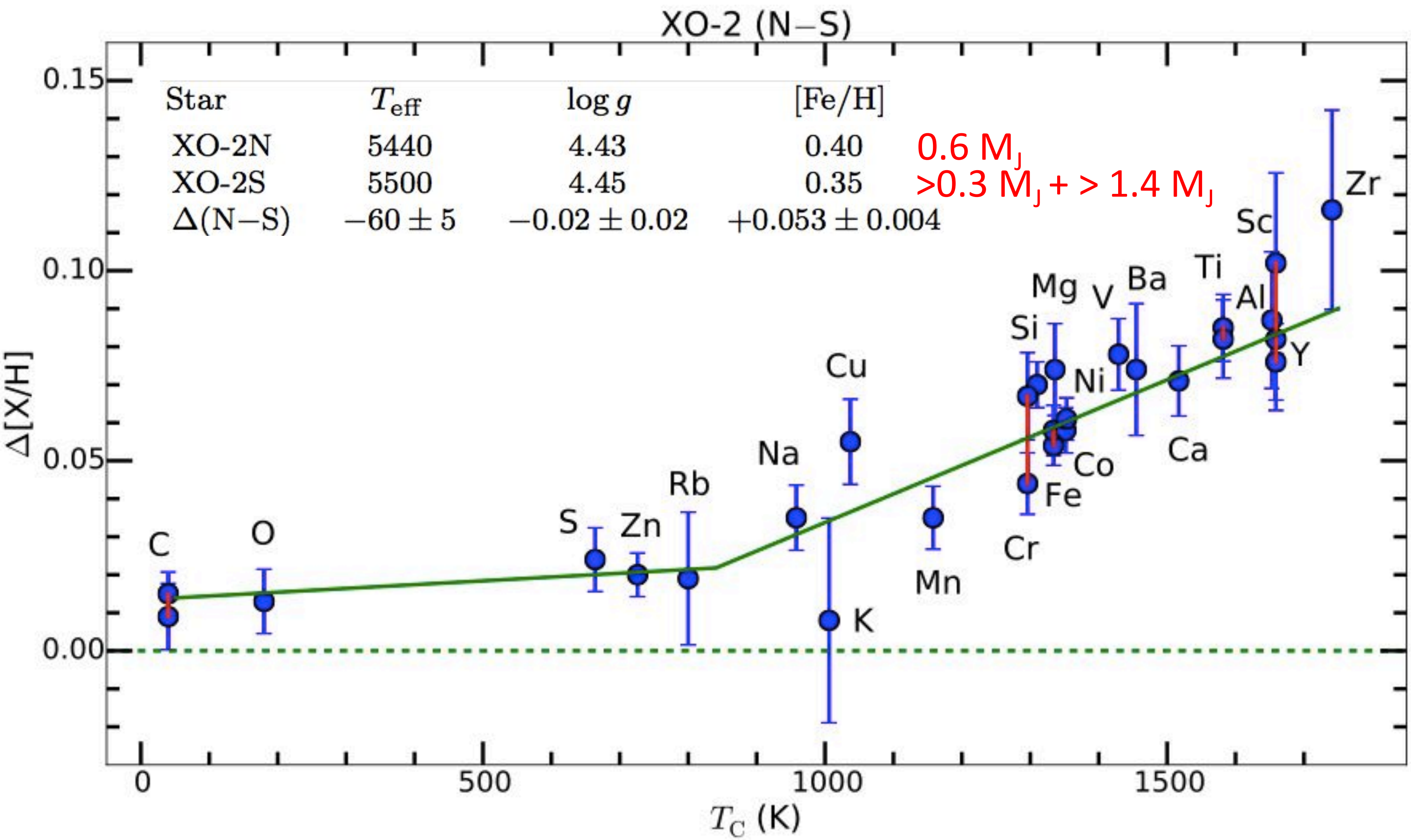
Spina et al., submitted





Twin stars in binaries can also be chemical homogeneous due to planets

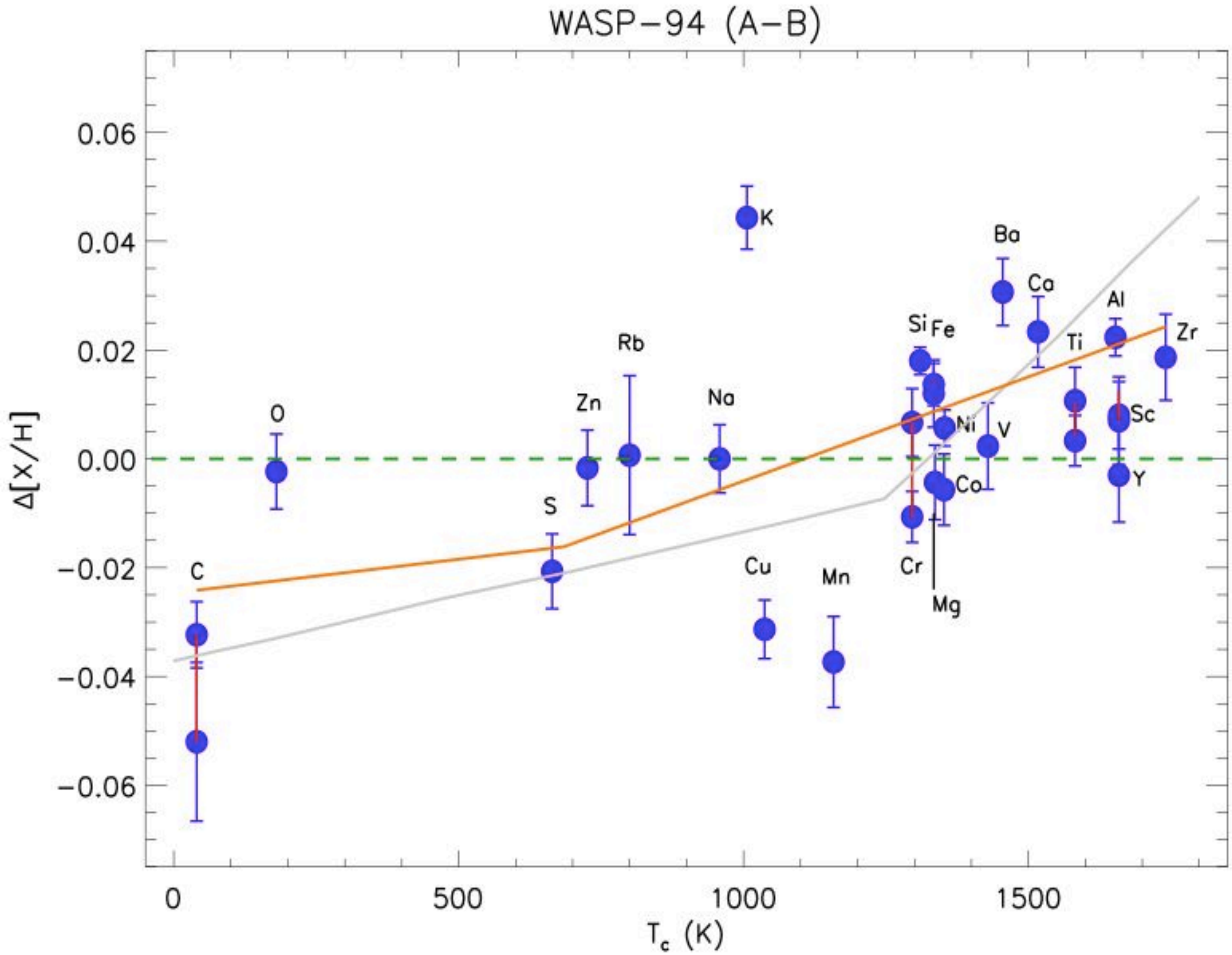
Another binary system with abundance differences: XO-2. Both stars host planets



Ramírez et al. 2015. See also Teske et al. 2015; Biazzo et al. 2015

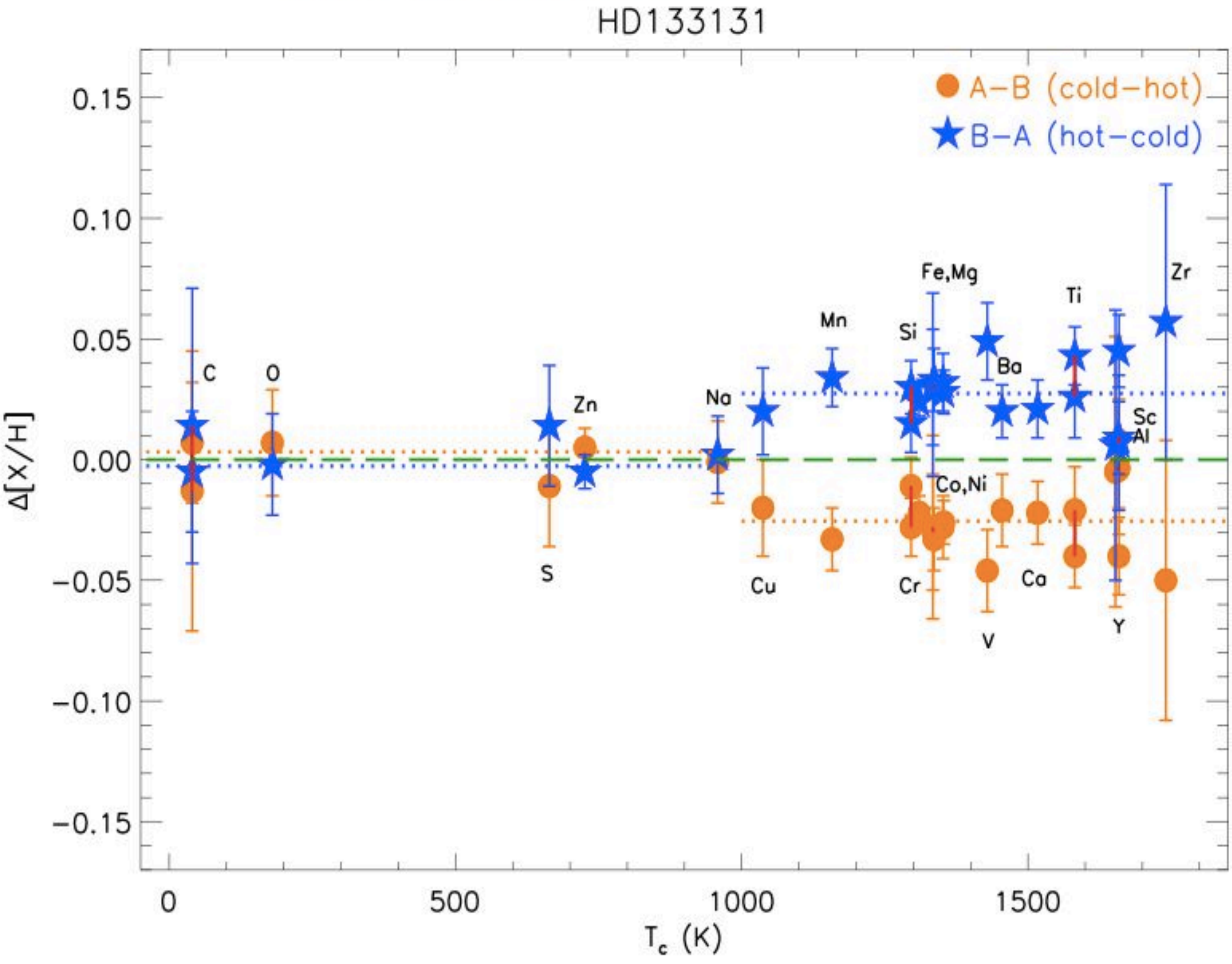
The Curious Case of Elemental Abundance Differences in the Dual Hot Jupiter Hosts WASP-94AB*

Johanna K. Teske[1,+], Sandhya Khanal[2], Ivan Ramírez[2]

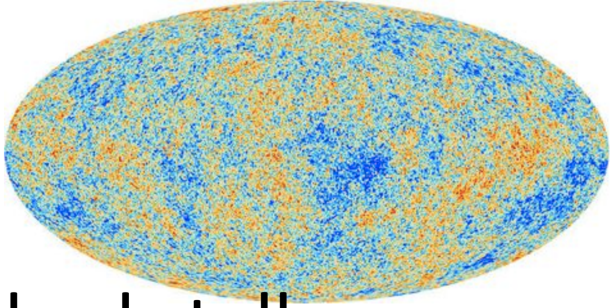


The Magellan PFS Planet Search Program: Radial Velocity and Stellar Abundance Analyses of the 360 AU, Metal-Poor Binary "Twins" HD 133131A & B[†]

Teske et al. 2016



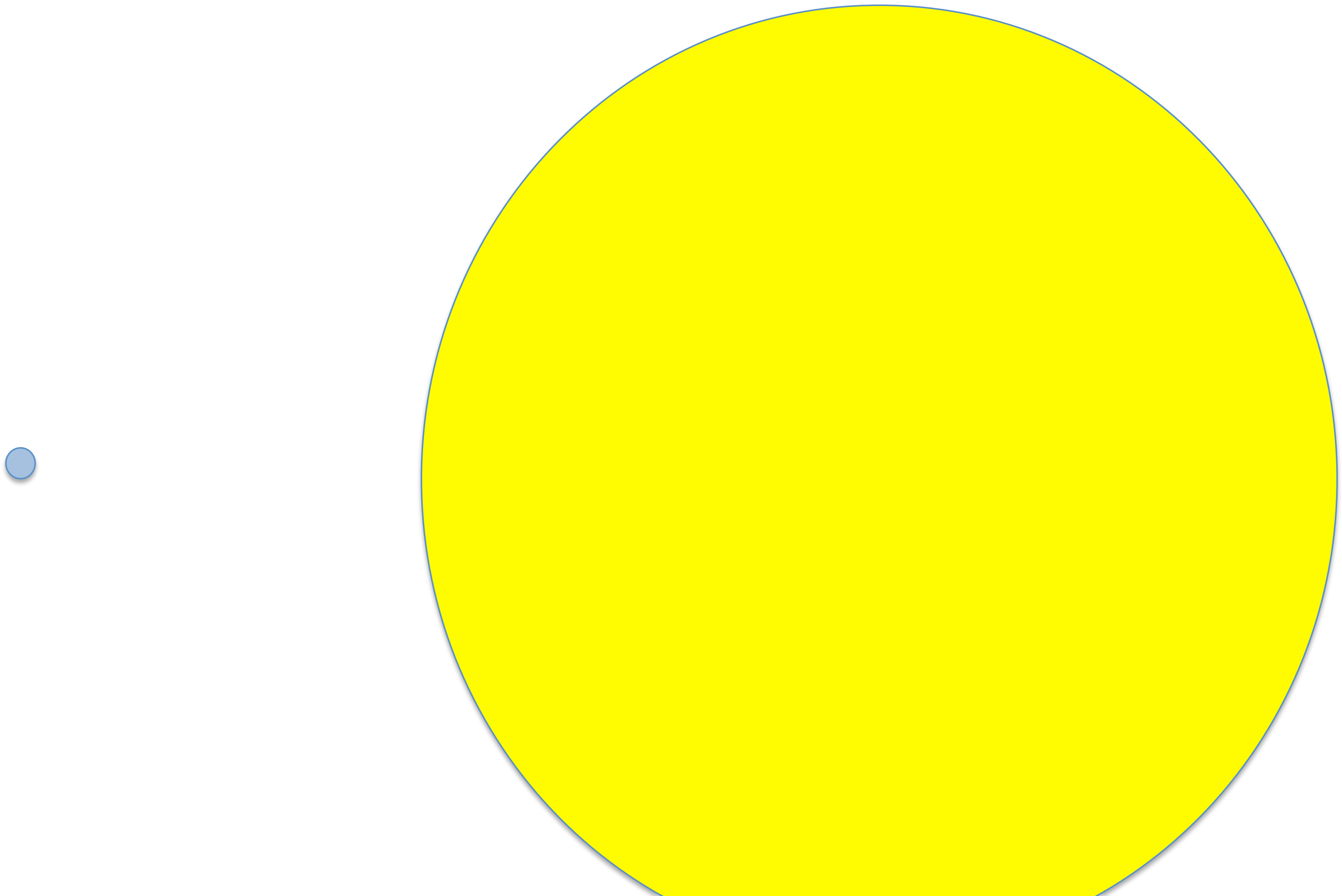
Conclusions



- Extensive calculations of non-standard stellar models are urgently needed for different applications, such as the cosmological and solar lithium problems, Galactic chemical evolution, asteroseismology, and the planet-star connection
- The notion of chemical homogeneity adopted by chemical tagging is challenged by the effects of atomic diffusion and planets

Extra slides

Suns with white dwarf companions

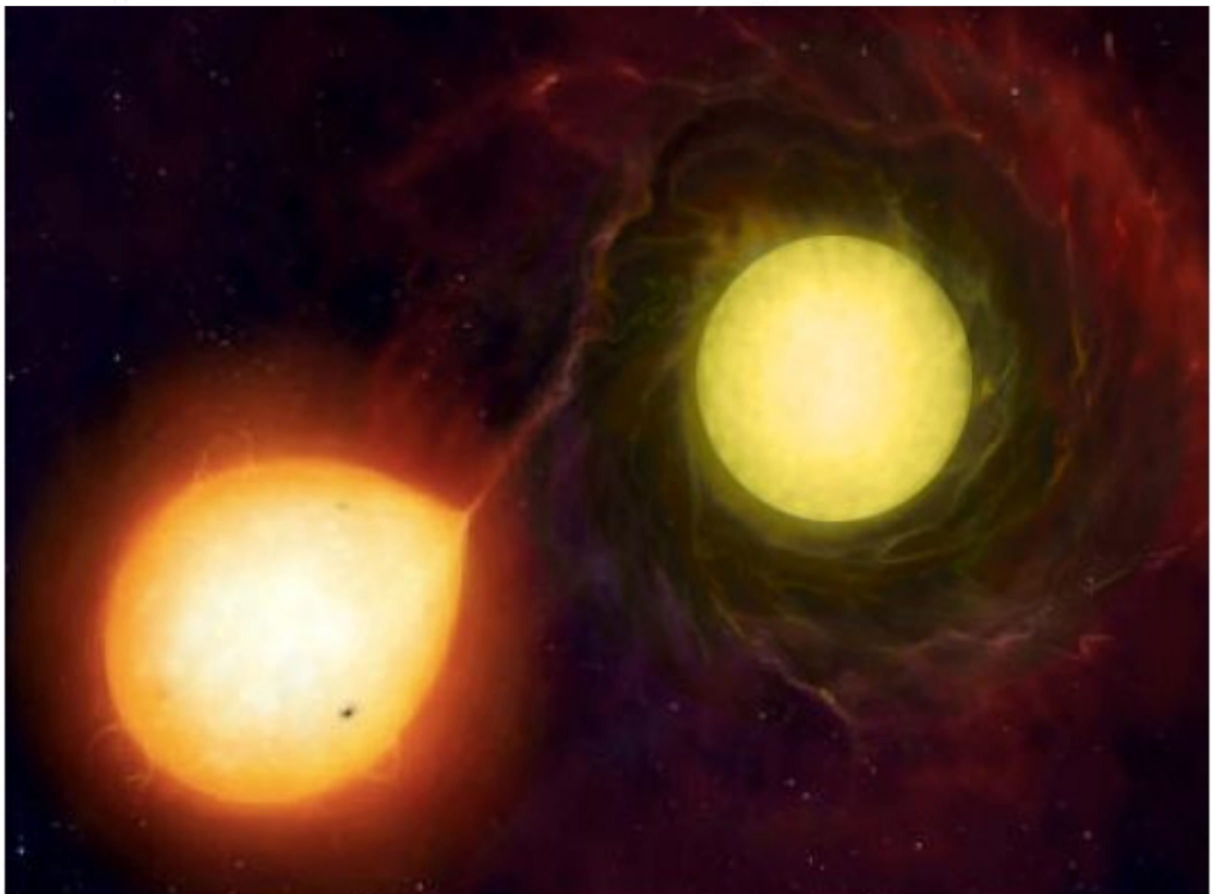


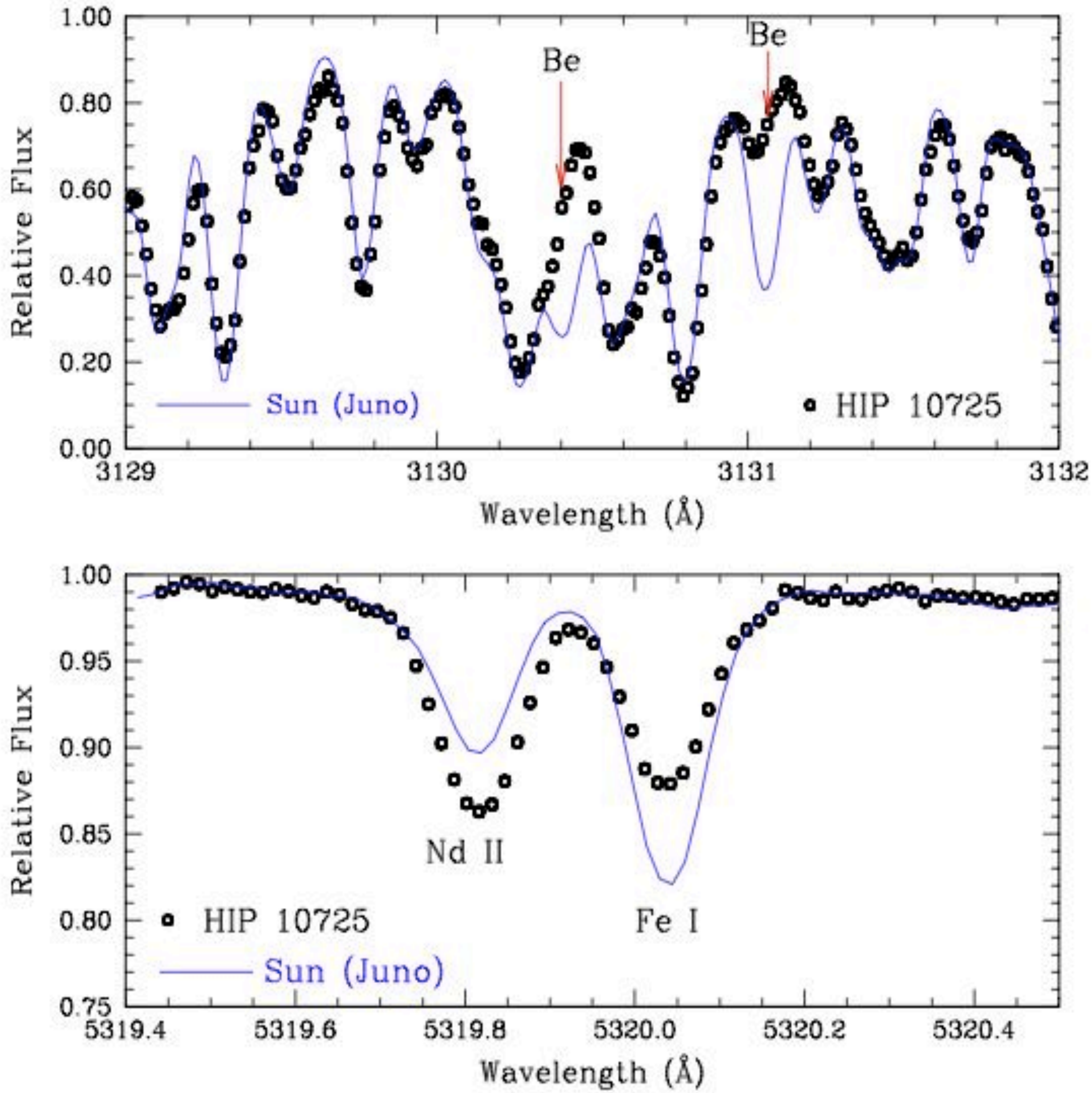
A&A 584, A116 (2015)
DOI: 10.1051/0004-6361/201527303

Astronomy & Astrophysics

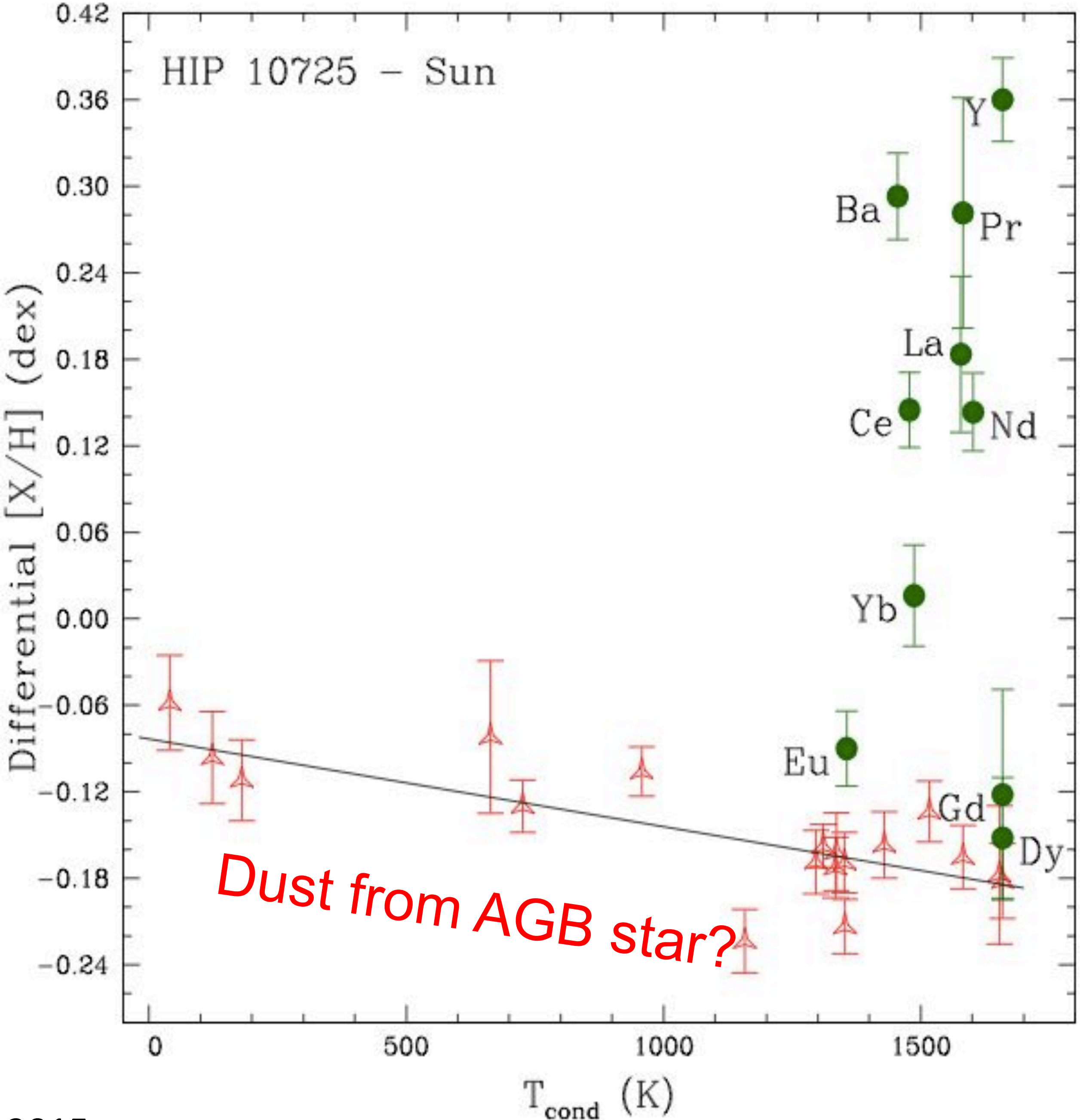
HIP 10725: The first solar twin/analogue field blue straggler⋆,⋆⋆

Lucas Schirbel[1], Jorge Meléndez[1], Amanda I. Karakas[2], Iván Ramírez[3], Matthieu Castro[4], Marcos A. Faria[5], Maria Lugaro[6], Martin Asplund[2], Marcelo Tucci Maia[1], David Yong[2], Louise Howes[2], and José D. do Nascimento Jr.[4,7]



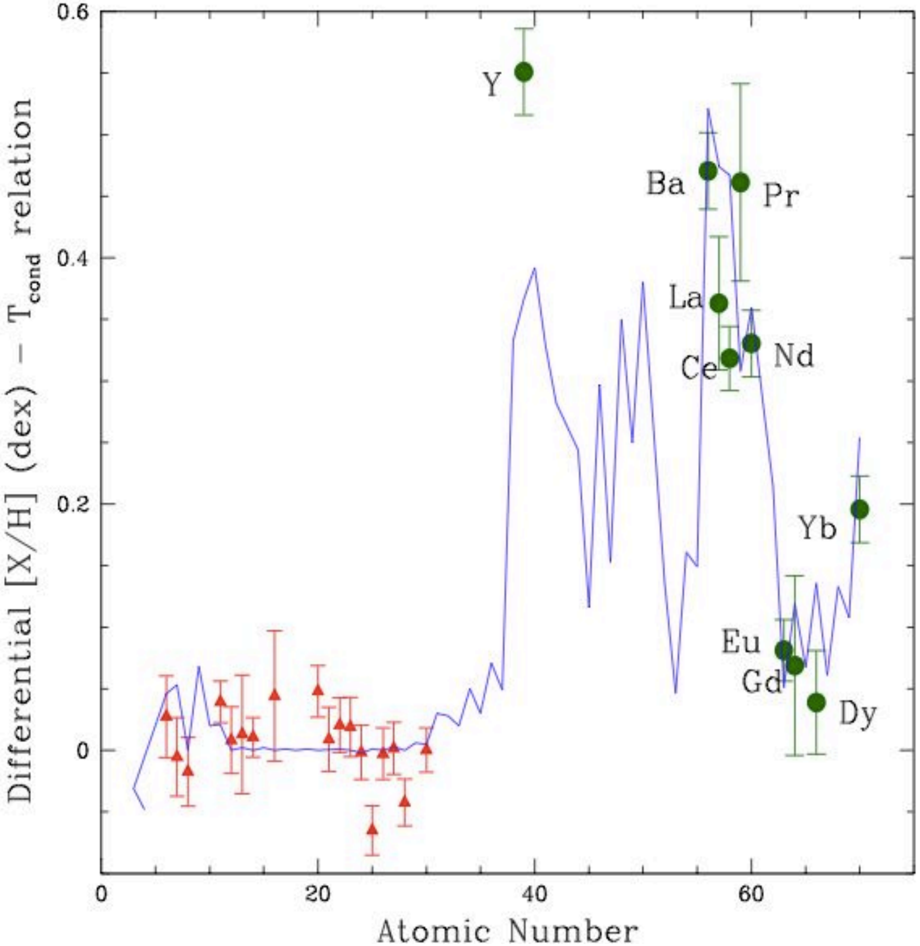


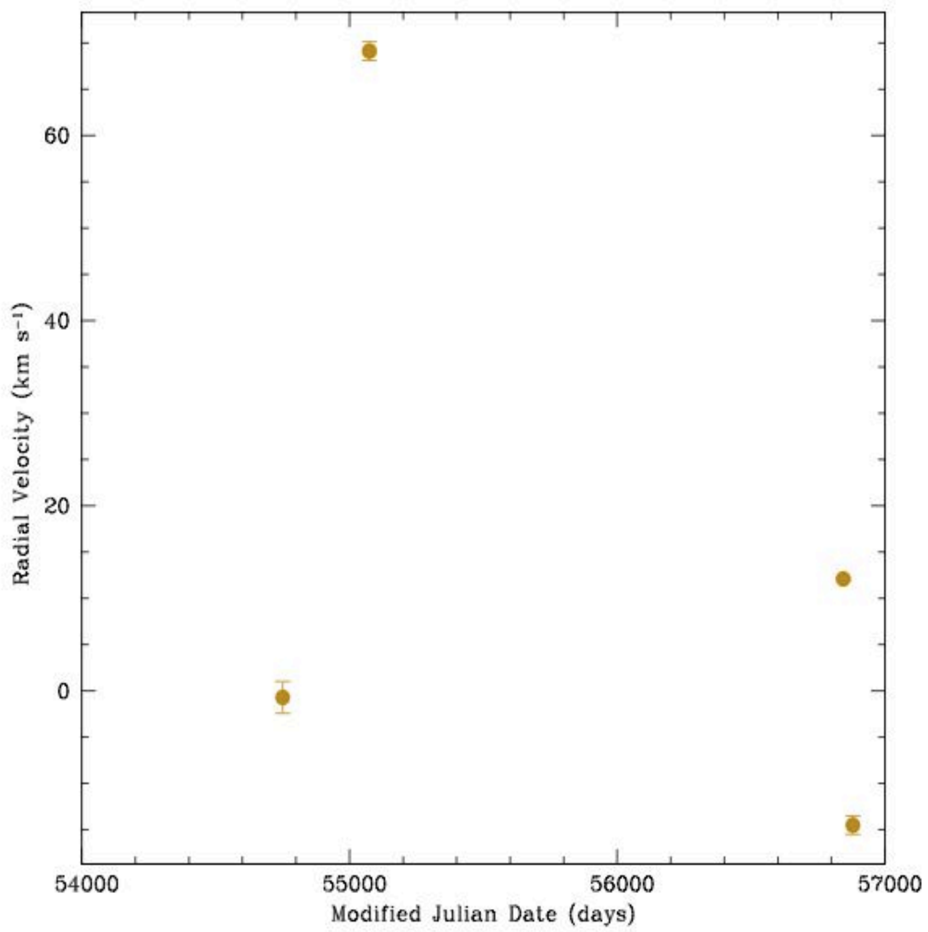
Schirbel et al. 2015



Schirbel et al. 2015

Signatures of former AGB star



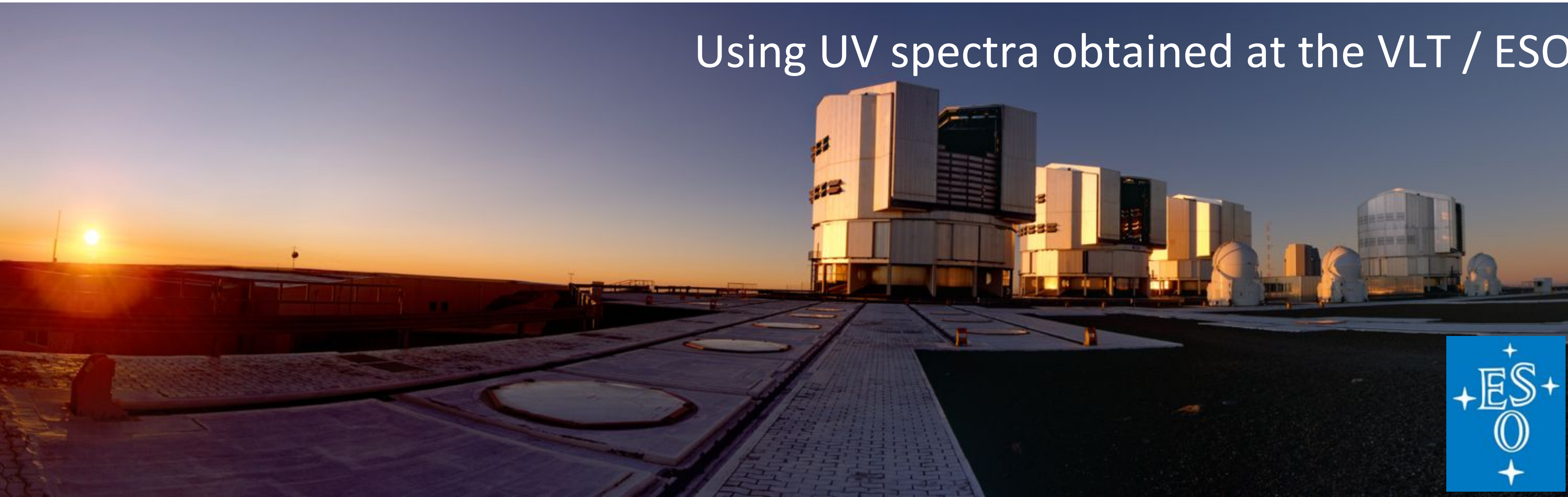


Y is not well-reproduced by the AGB models

Schirbel et al. 2015

Diverse abundance signatures unveiled in the solar twin 18 Sco

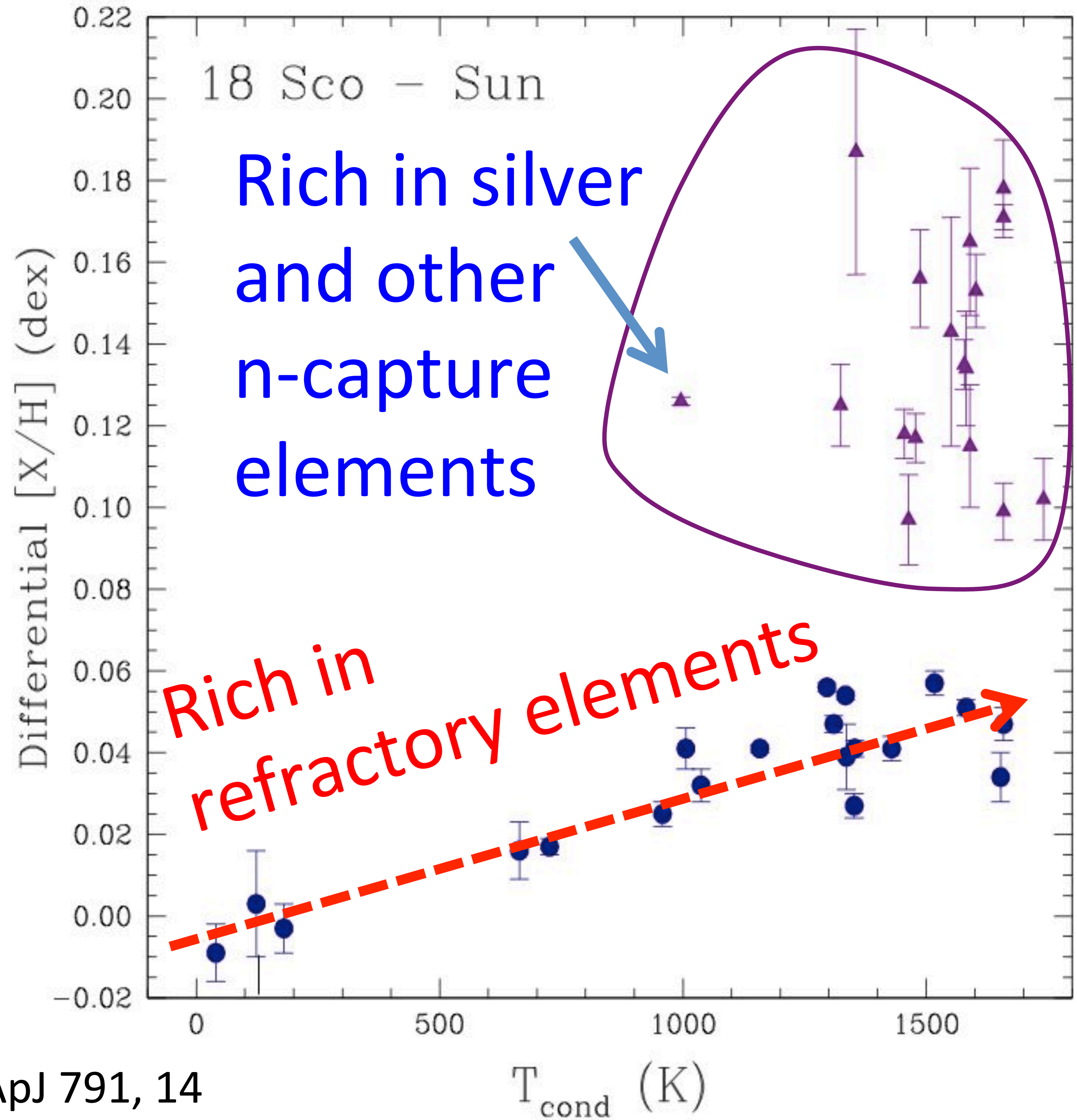
a solar twin younger than the Sun and rich in refractories, s-process and r-process elements



18 Sco

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

Age = 2.9 Gyr

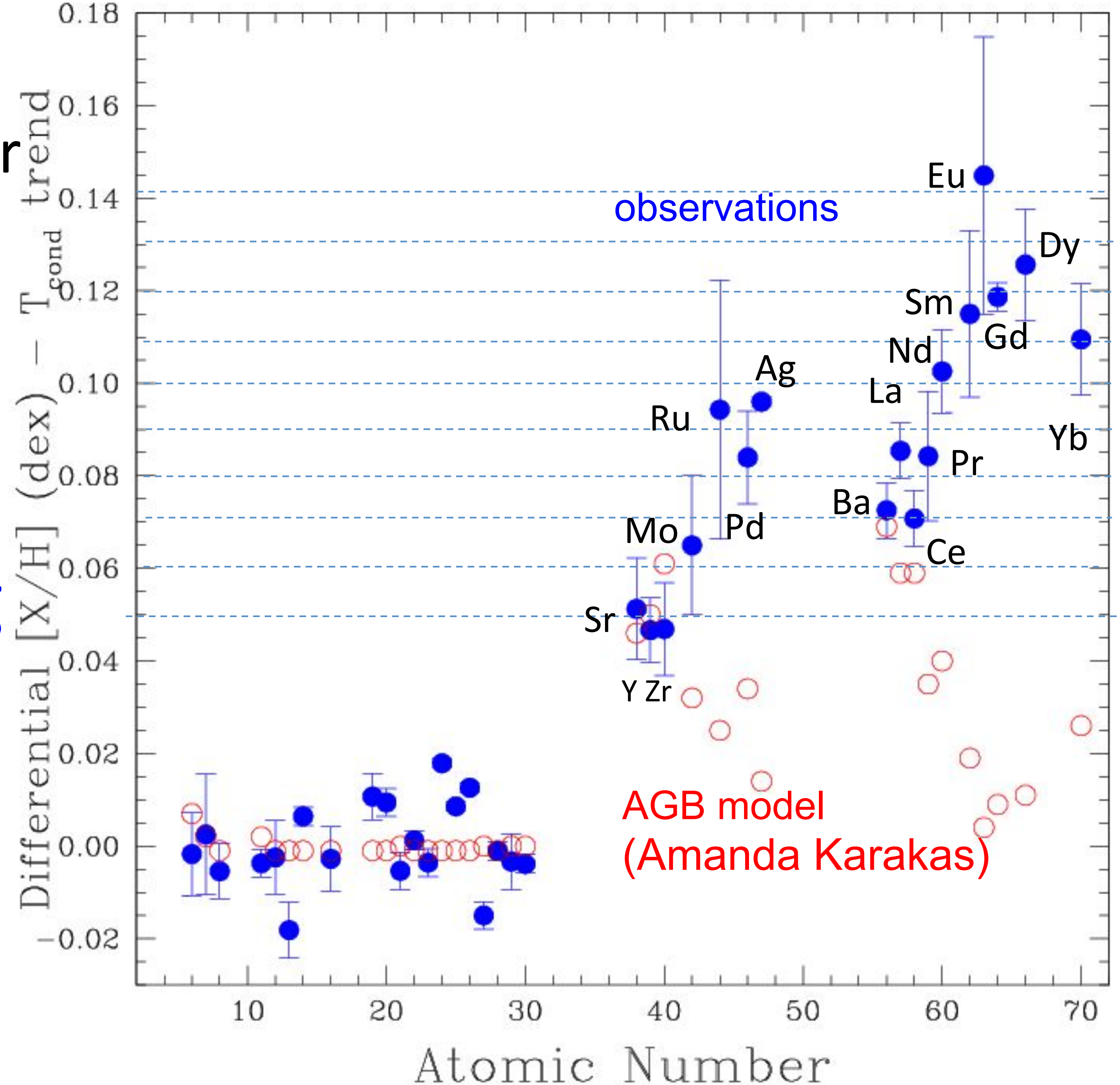


Meléndez et al. 2014, ApJ 791, 14
August 10, 2014

18 Sco

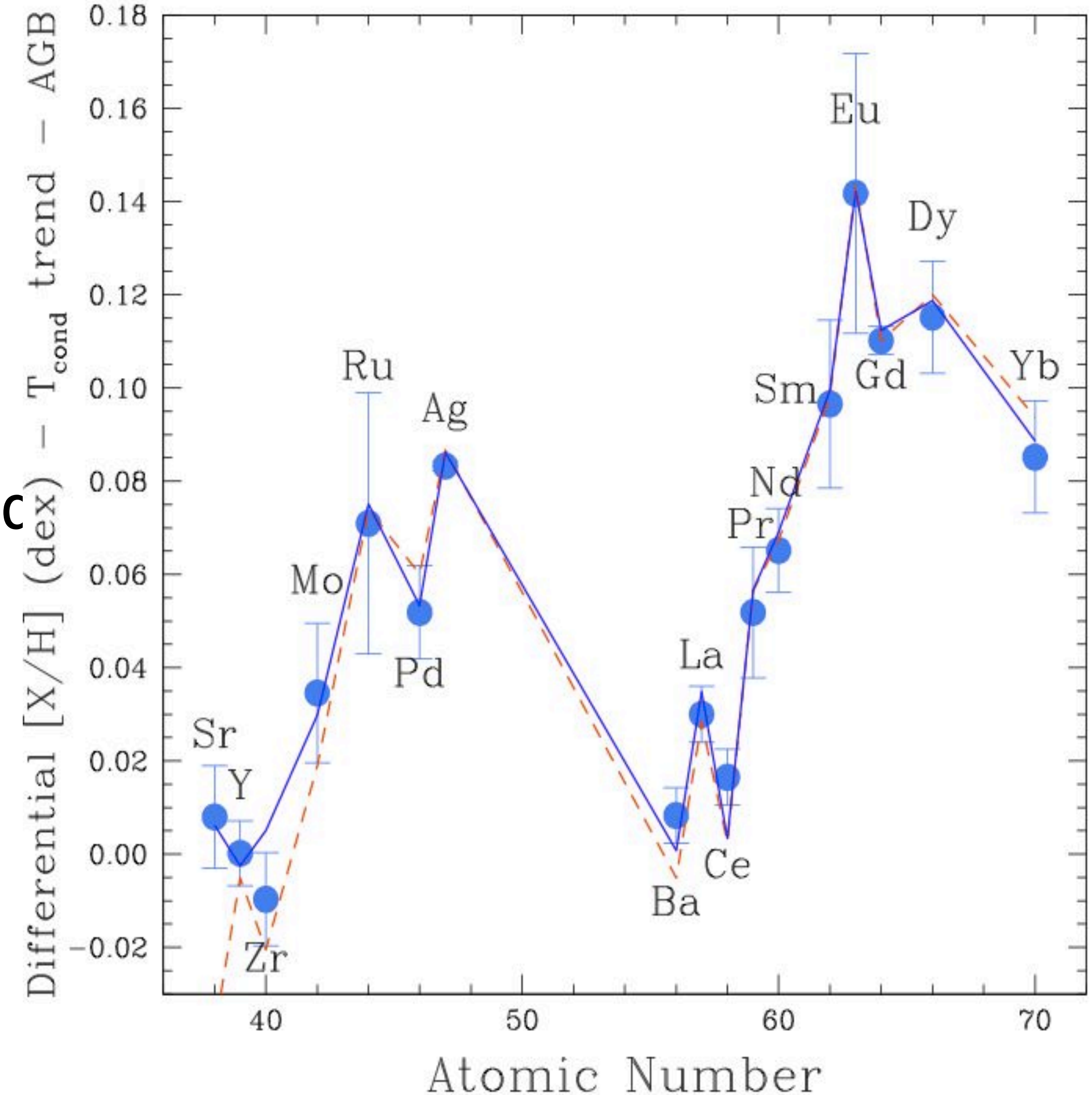
(brightest solar twin, V = 5.5)
UVES+VLT
R = 110 000
S/N = 800

Subtracting T_{cond} trend



Meléndez et al. 2014, ApJ

Perfect agreement between residual abundances anc predictions from the SS r-process fractions

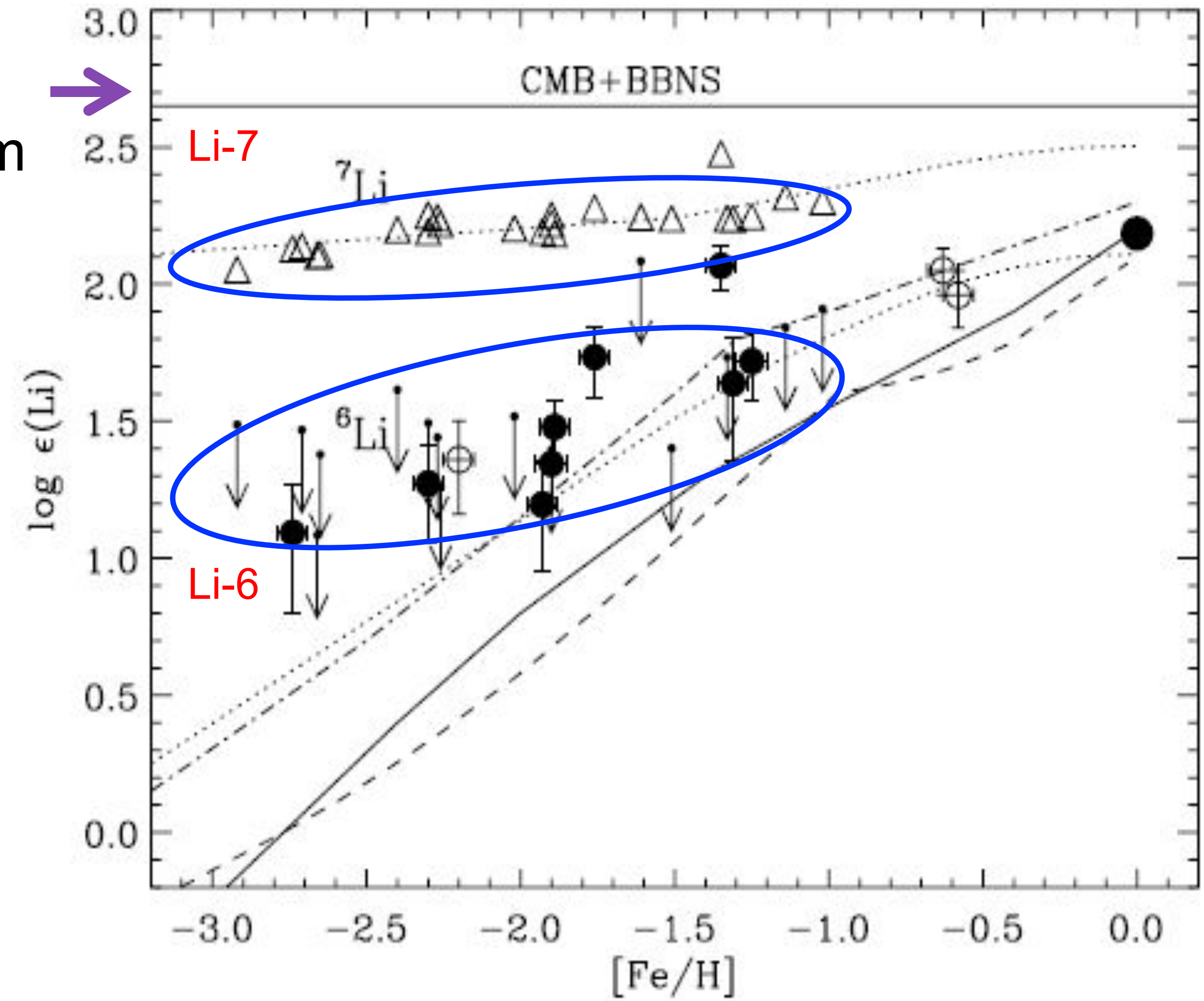


Meléndez et al. 2014, ApJ

Figure 10. Filled circles represent the [X/H] ratios in 18 Sco after they have been subtracted from the condensation temperature trend (Figure 8) and from the AGB contribution (Figure 9). The residual enhancement, $[X/H]_r$ (filled circles), is in extraordinary agreement with the predicted *r*-process enhancement based on the solar system *r*-process fractions by Simmerer et al. (2004) and Bisterzo et al. (2011, 2013), represented by dashed and solid lines, respectively.

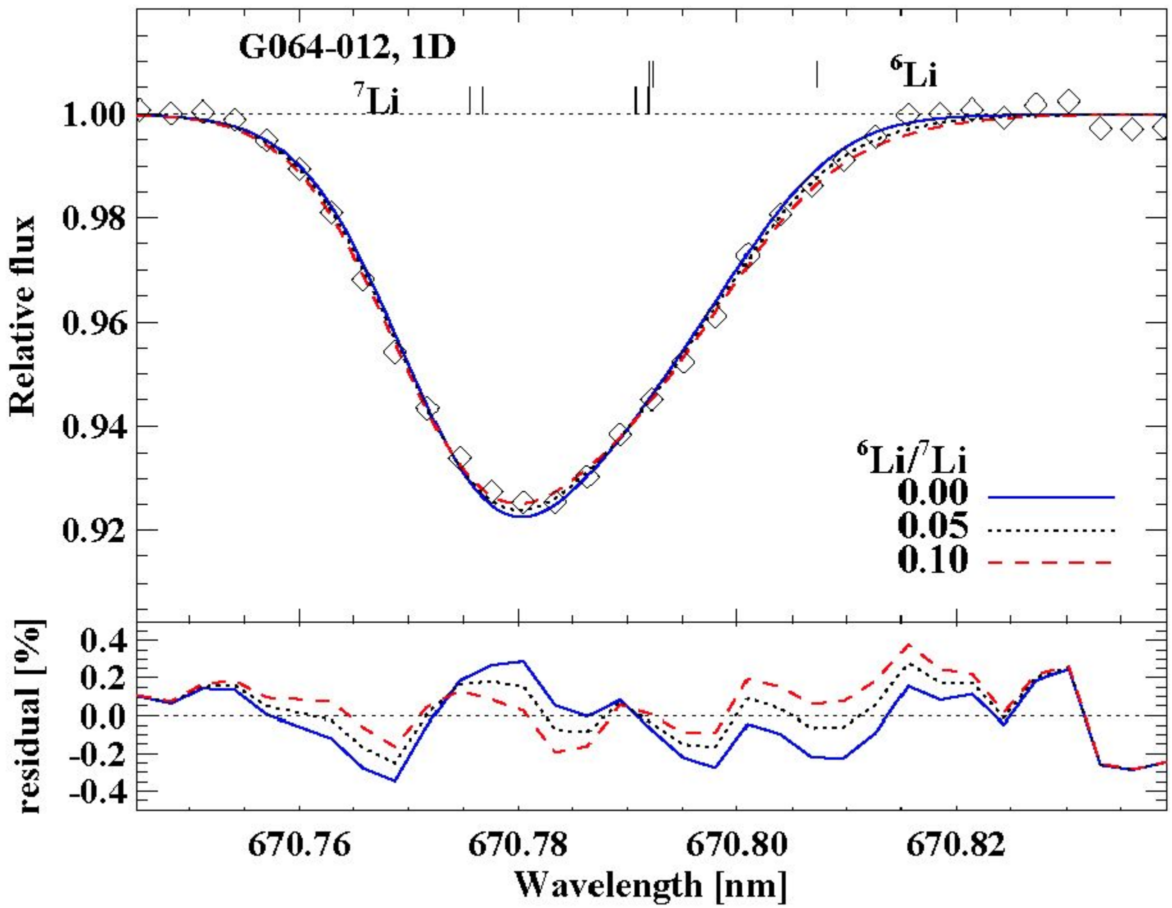
Actually TWO lithium problems (Asplund et al. 2006): too much Li-6, too little Li-7

Expected primordial lithium



Asplund et al. (2006)

Lithium in extremely metal-poor stars using HIRES at Keck (10 meter)



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The lithium isotopic ratio in very metal-poor stars

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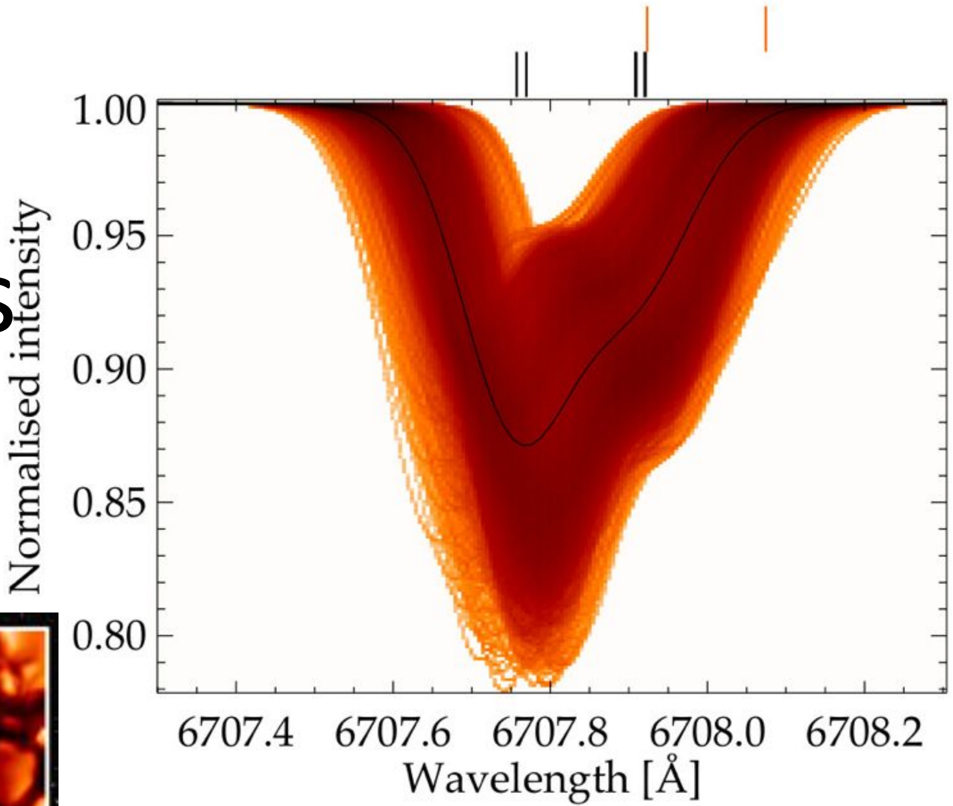
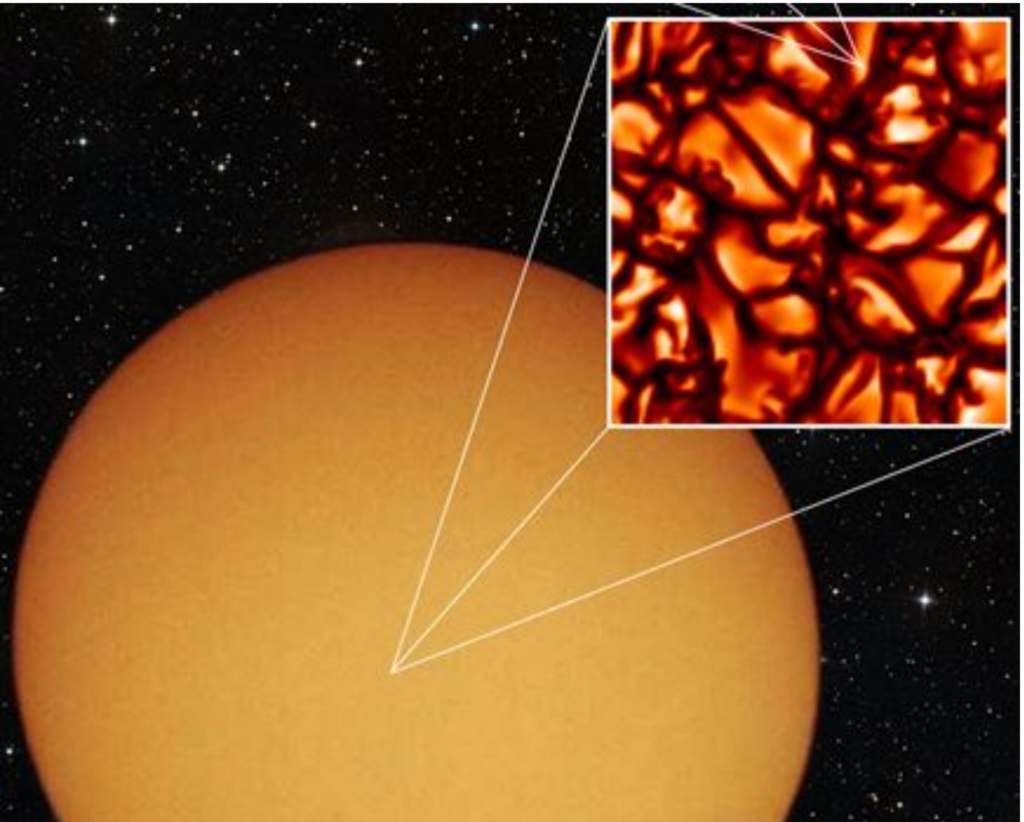
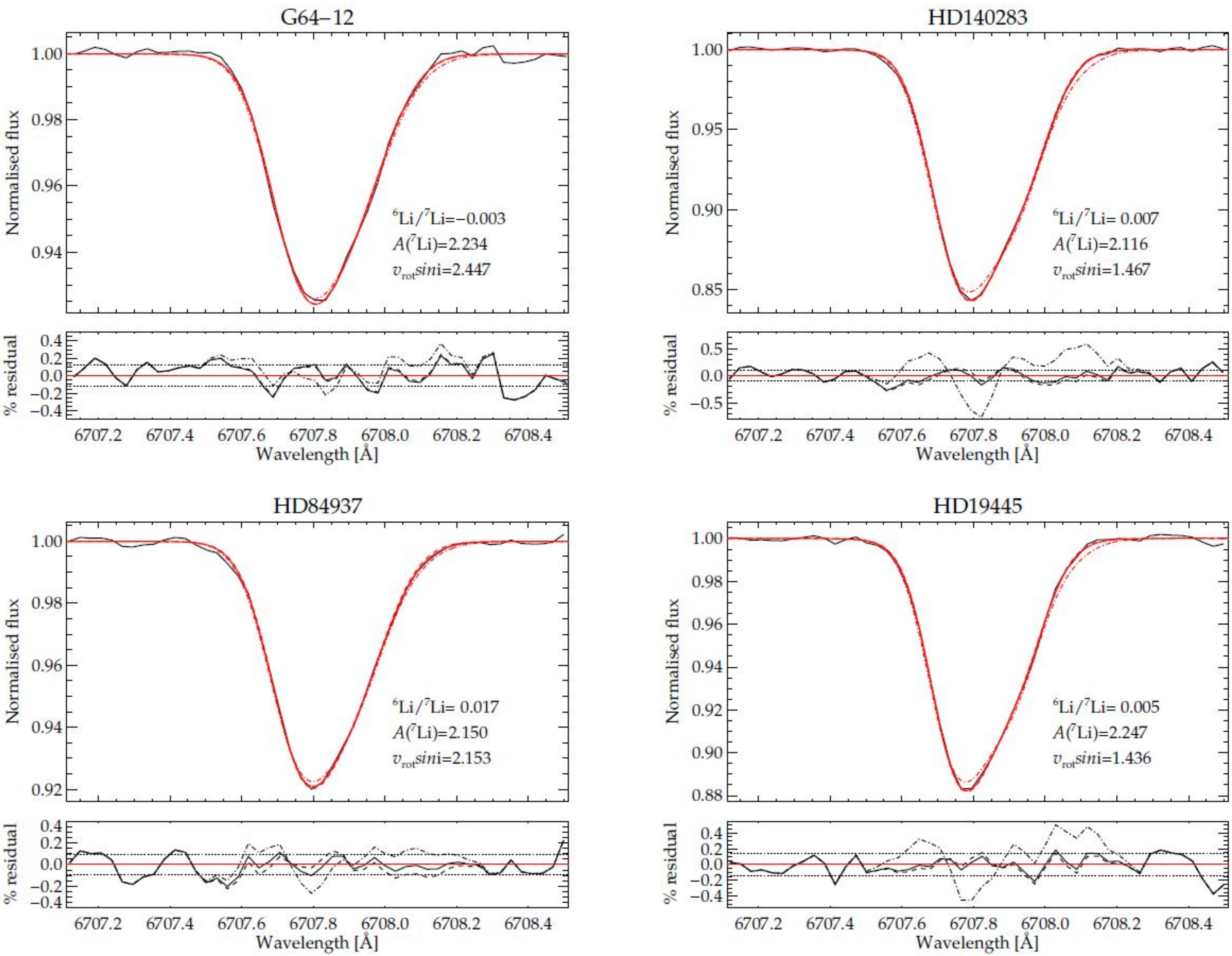
3D + NLTE for Li and other elements







G64−12
Normalised flux
1.00
0.98
0.96
0.94
6Li/7Li=−0.003
A(7Li)=2.234
vrotsini=2.447
% residual
0.4
0.2
0.0
-0.2
-0.4
6707.2 6707.4 6707.6 6707.8 6708.0 6708.2 6708.4
Wavelength [Å]
HD140283
Normalised flux
1.00
0.95
0.90
0.85
6Li/7Li= 0.007
A(7Li)=2.116
vrotsini=1.467
% residual
0.5
0.0
-0.5
6707.2 6707.4 6707.6 6707.8 6708.0 6708.2 6708.4
Wavelength [Å]
HD84937
Normalised flux
1.00
0.98
0.96
0.94
0.92
6Li/7Li= 0.017
A(7Li)=2.150
vrotsini=2.153
% residual
0.4
0.2
0.0
-0.2
-0.4
6707.2 6707.4 6707.6 6707.8 6708.0 6708.2 6708.4
Wavelength [Å]
HD19445
Normalised flux
1.00
0.98
0.96
0.94
0.92
0.90
0.88
6Li/7Li= 0.005
A(7Li)=2.247
vrotsini=1.436
% residual
0.4
0.2
0.0
-0.2
-0.4
6707.2 6707.4 6707.6 6707.8 6708.0 6708.2 6708.4
Wavelength [Å]