These slides are not very informative without the accompanying text, which may be found at:

http://users.obs.carnegiescience.edu/iur/talks/nic2012-rpro.pdf

New UV Observations of Exotic Heavy Elements in Metal-Poor Stars

Ian U. Roederer
Carnegie Observatories

with collaborators:
Jim Lawler (Wisconsin), Jen Sobeck (Obs. Cote d'Azur; Chicago),
John Cowan (Oklahoma),Tim Beers (NOAO), Anna Frebel (MIT),
Inese Ivans (Utah), Hendrik Schatz (Michigan State), Chris Sneden (Texas)

r-process nucleosynthesis

r-process nucleosynthesis

rapid addition of neutrons

r-process nucleosynthesis

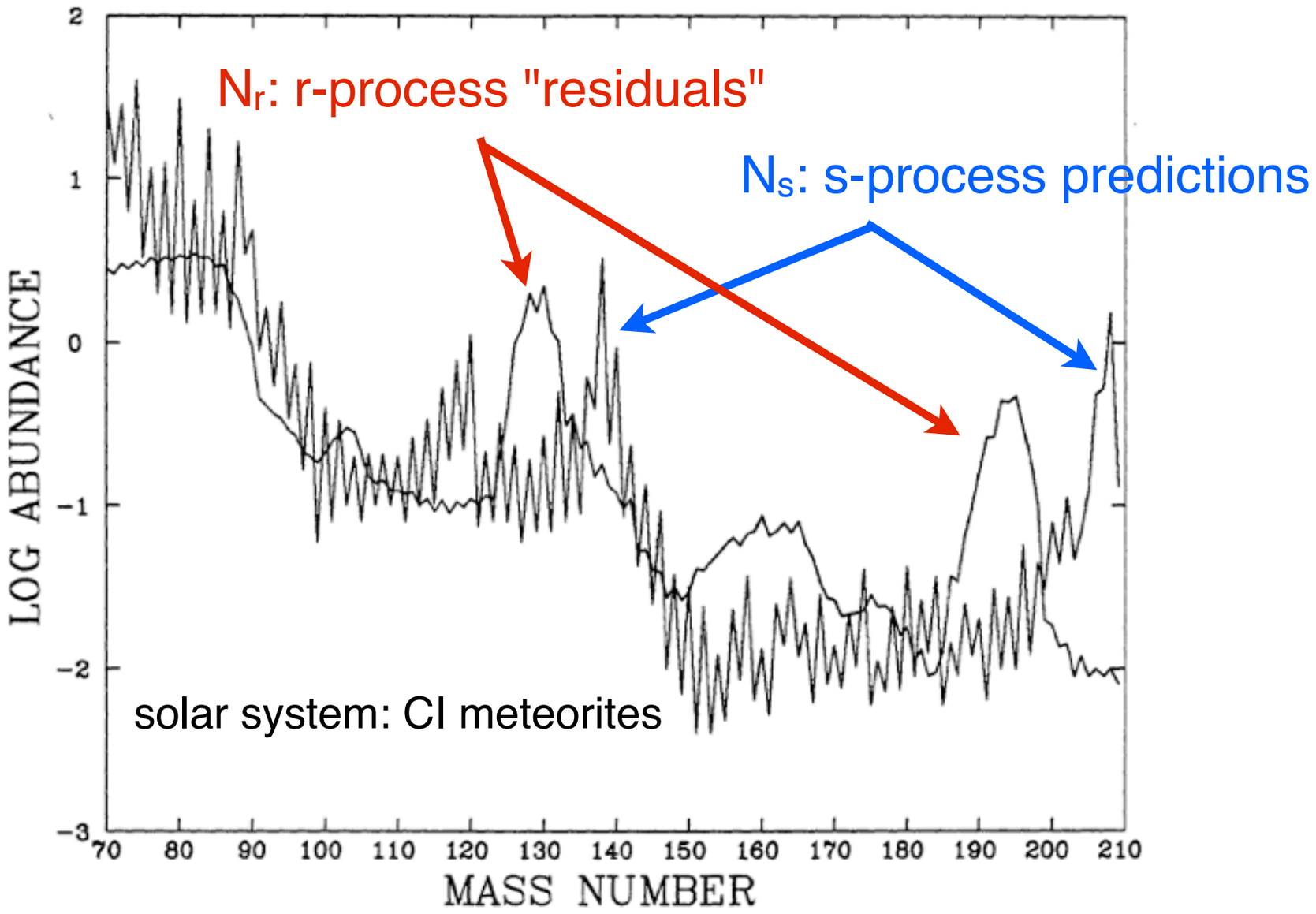
most heavy elements in the oldest stars

r-process nucleosynthesis

half the heavy elements in the Sun

$$N_r = N_{total} - N_s$$

$$N_r = N_{total} - N_s$$



Cameron (1982, Astrophys. Space Sci. 82, 123)

CAUTION

Stellar abundance distributions are derived!

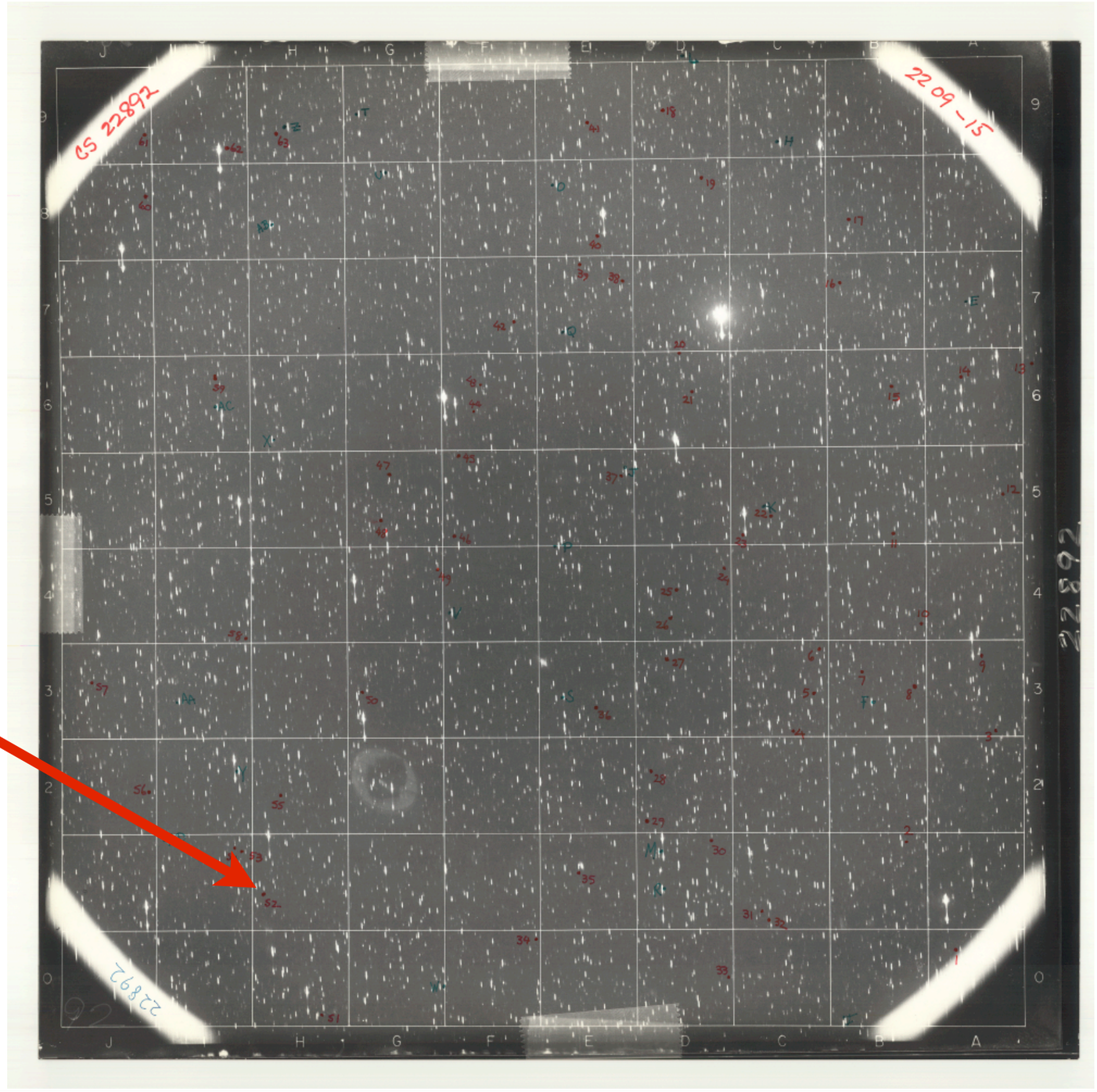
"The site of the r-process is unknown,
but core-collapse supernovae and neutron star mergers
are thought to be likely candidates."

Ways to improve the state of observations:

(1) environments where r-process material is found

(2) r-process yield patterns

CS 22892–052



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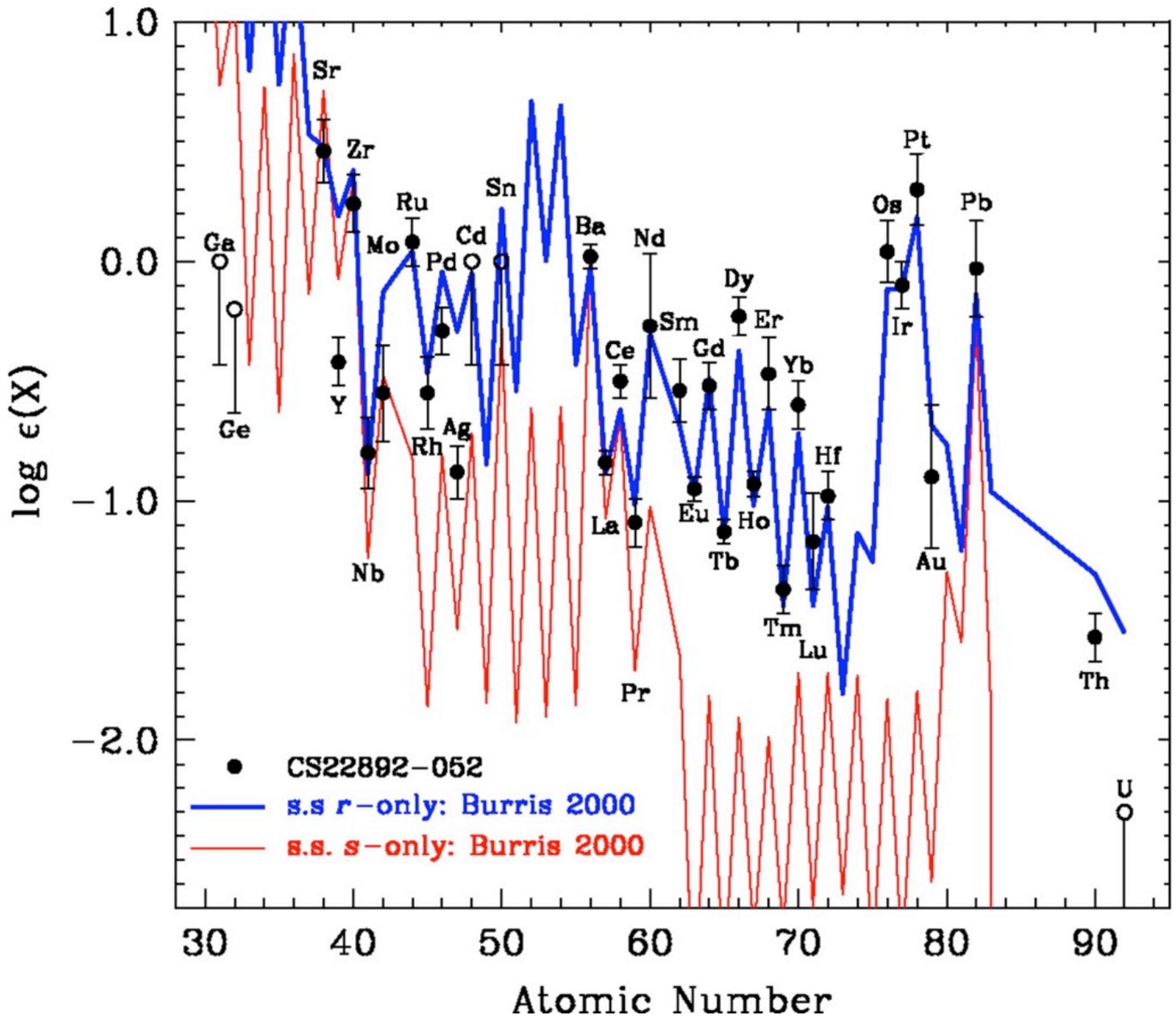
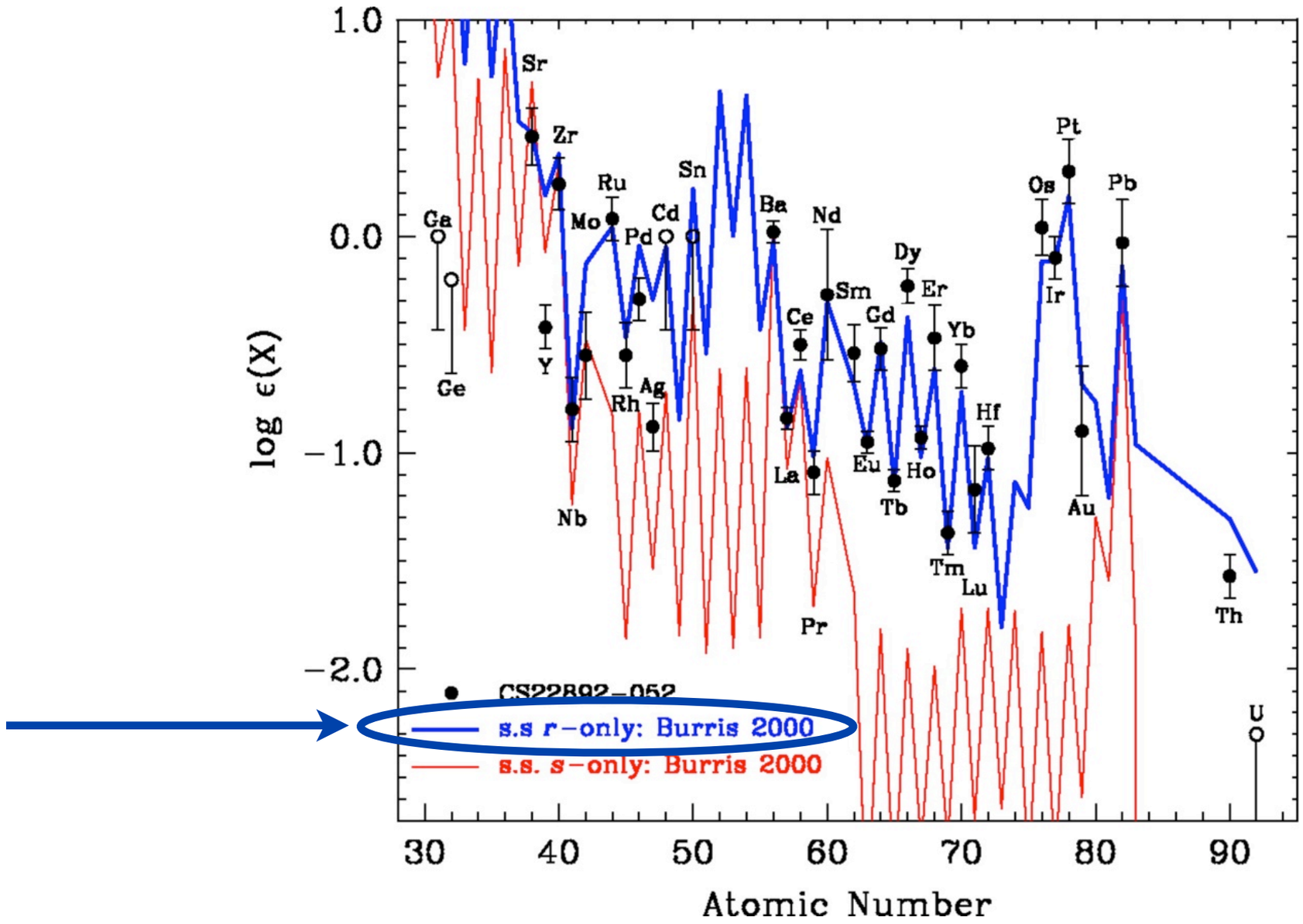
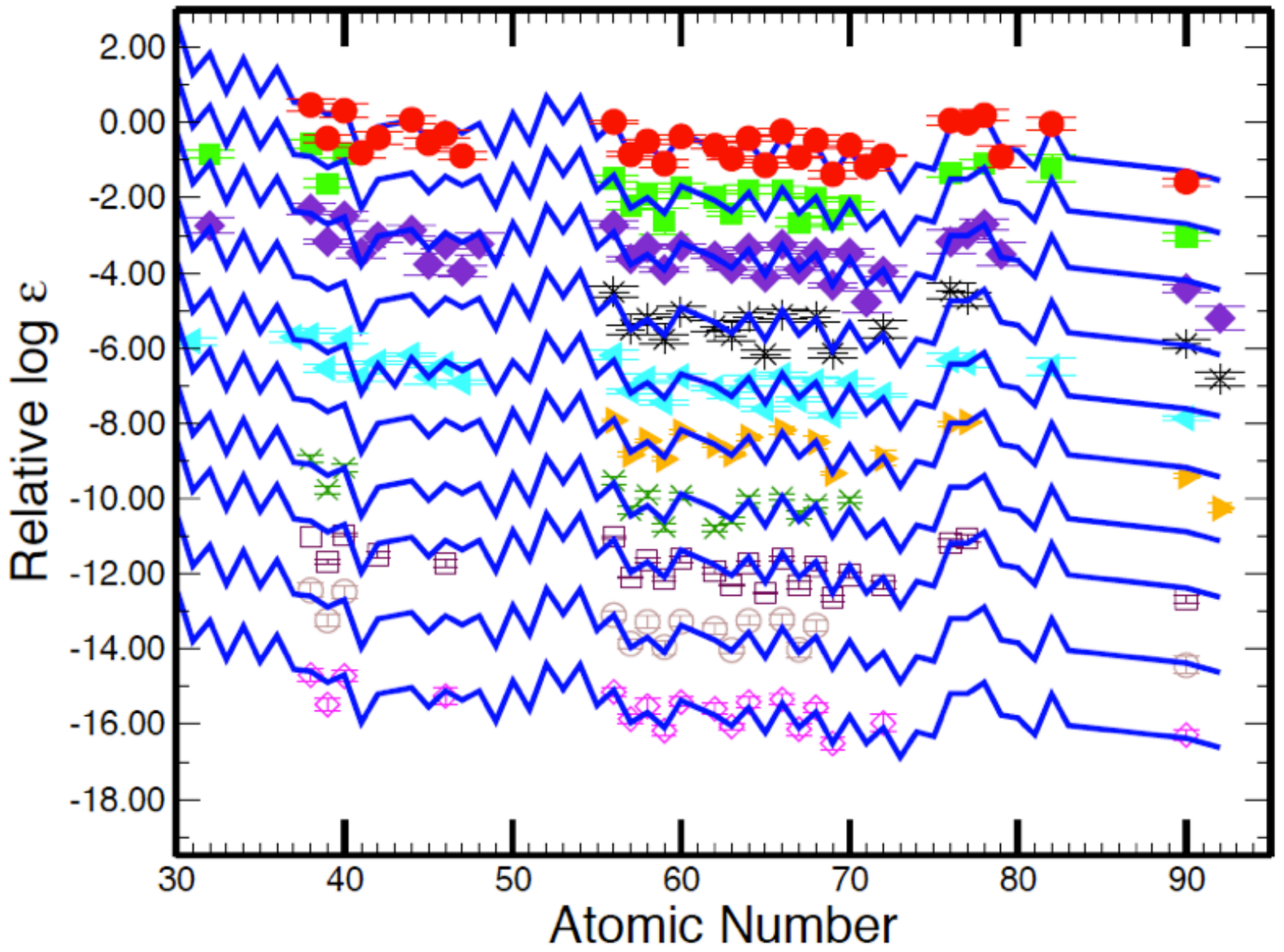


Sneden et al. (2003, ApJ, 591, 936)

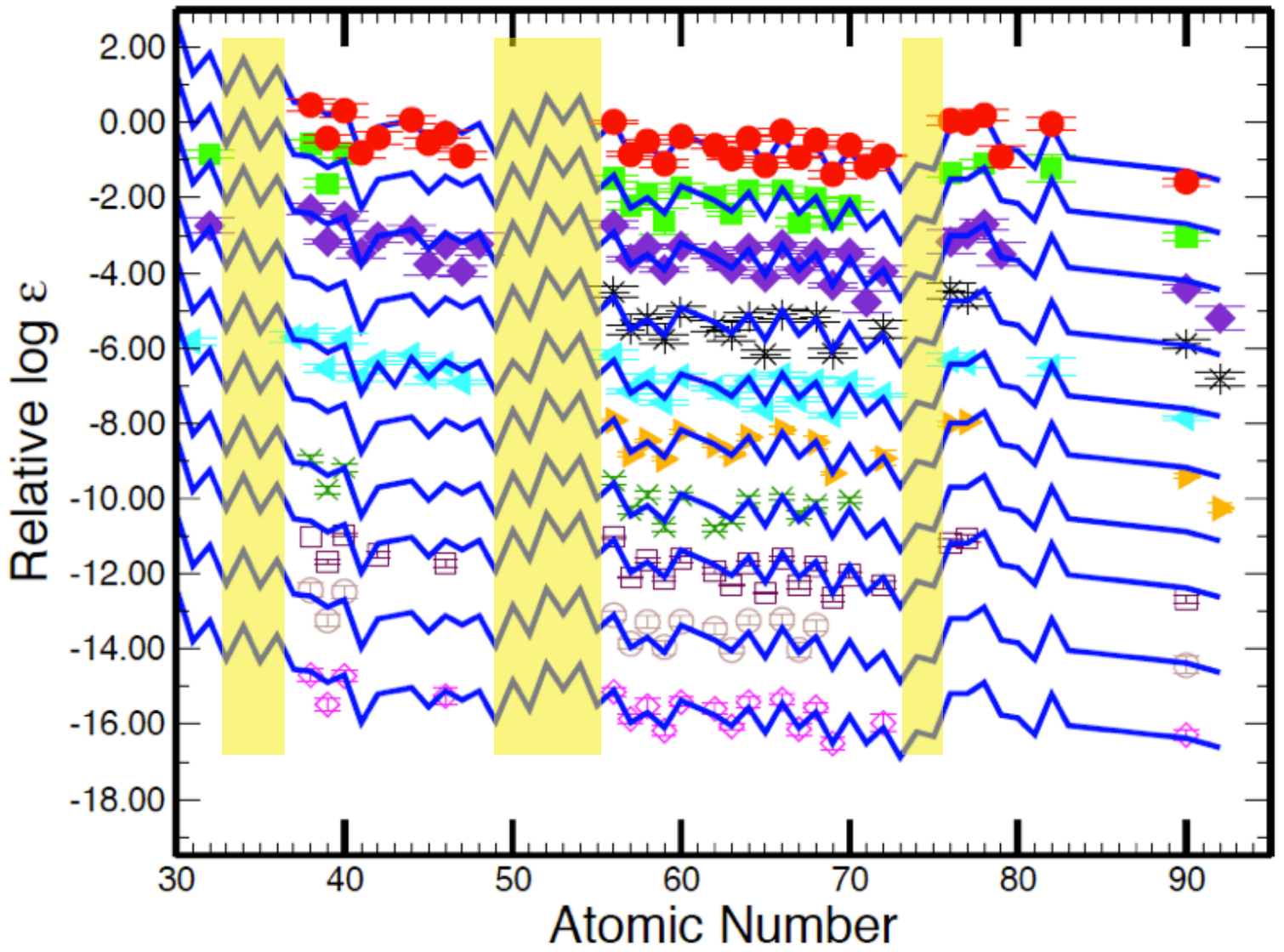
CS 22892–052



Sneden et al. (2003, ApJ, 591, 936)

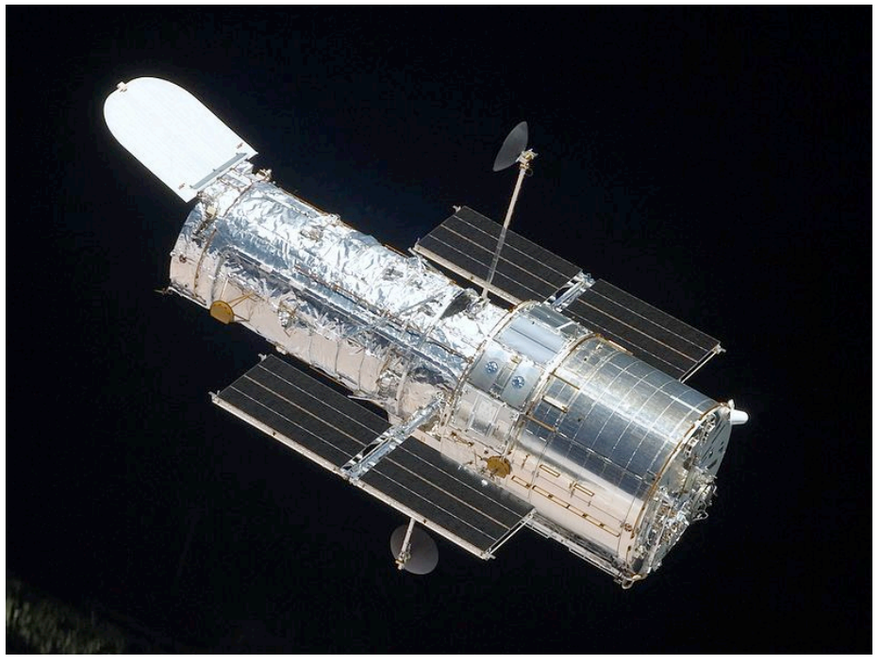


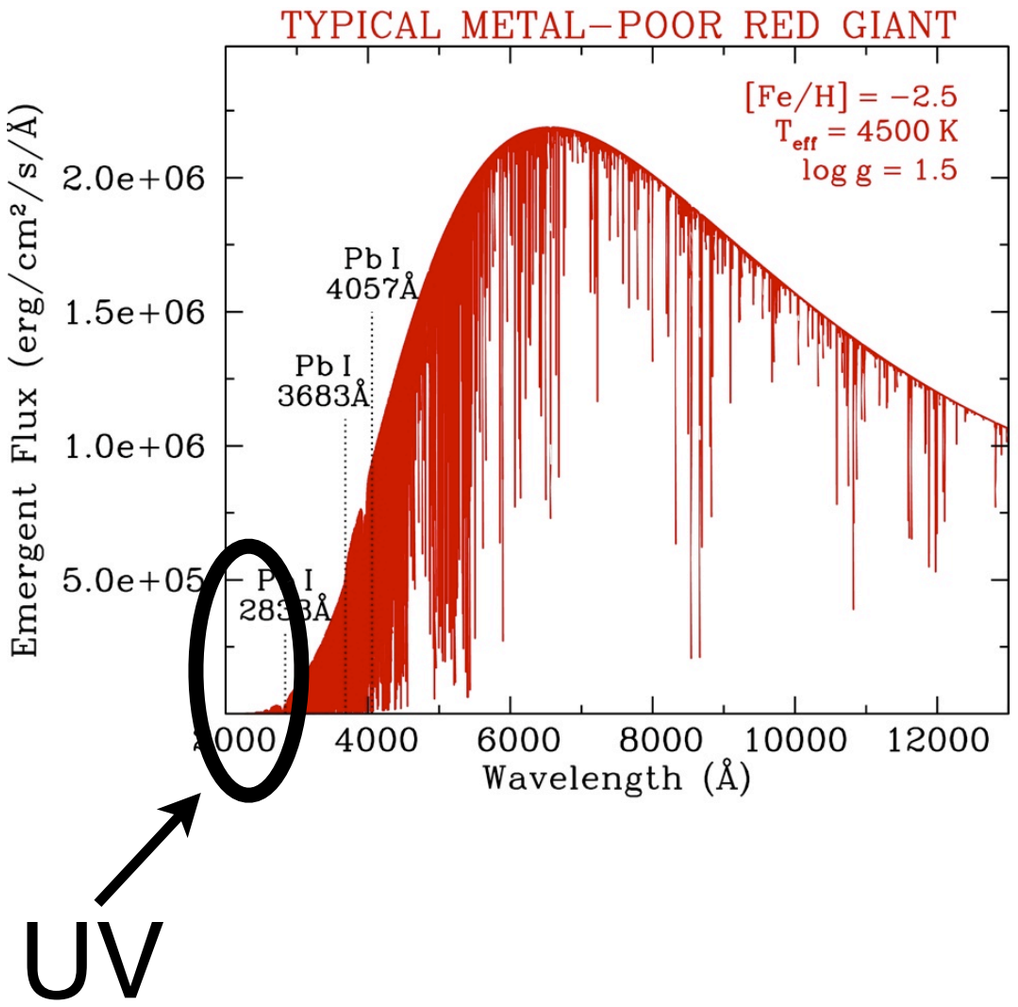
Cowan et al. (2011, Carnegie Obs. Astrophys. Series, 5, 223)



Cowan et al. (2011, Carnegie Obs. Astrophys. Series, 5, 223)

STIS

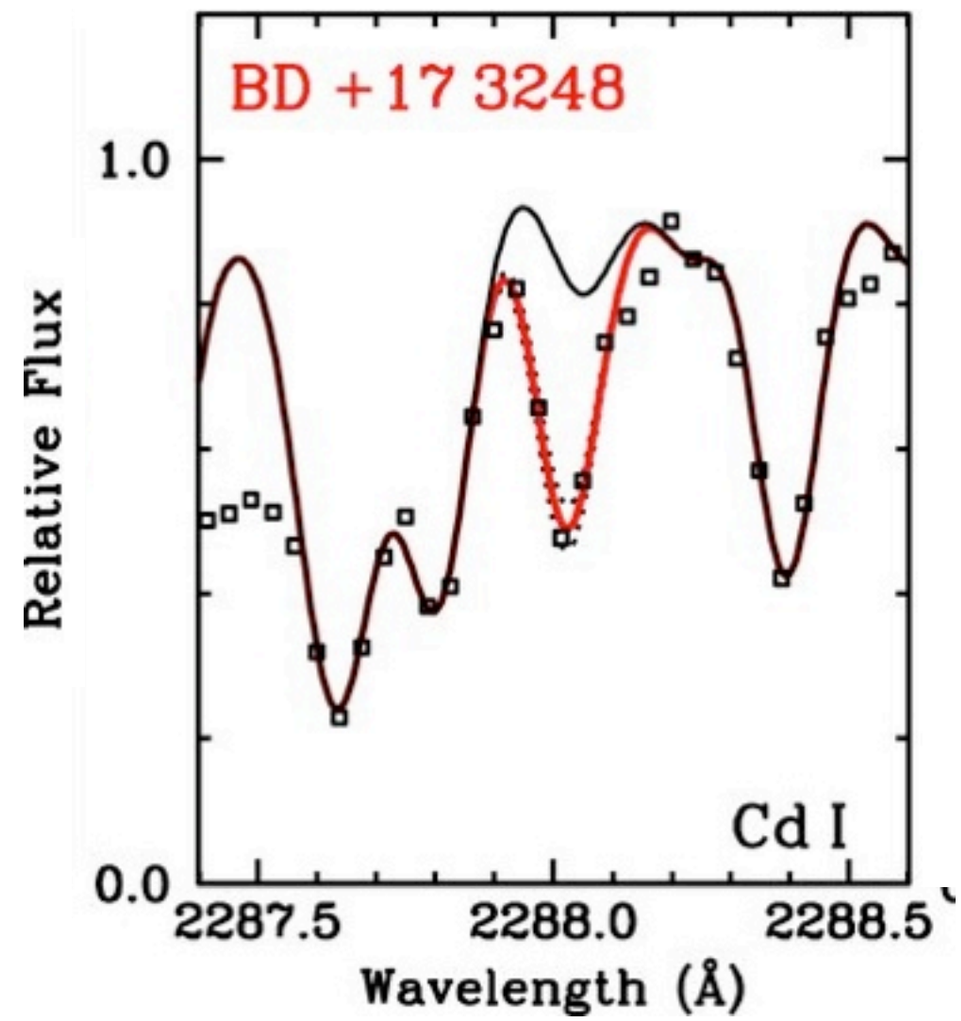



TYPICAL METAL−POOR RED GIANT
[Fe/H] = −2.5
T_eff = 4500 K
log g = 1.5
Emergent Flux (erg/cm²/s/Å)
2.0e+06
1.5e+06
1.0e+06
5.0e+05
Pb I
4057Å
Pb I
3683Å
Pb I
2833Å
4000
6000
8000
10000
12000
Wavelength (Å)
UV

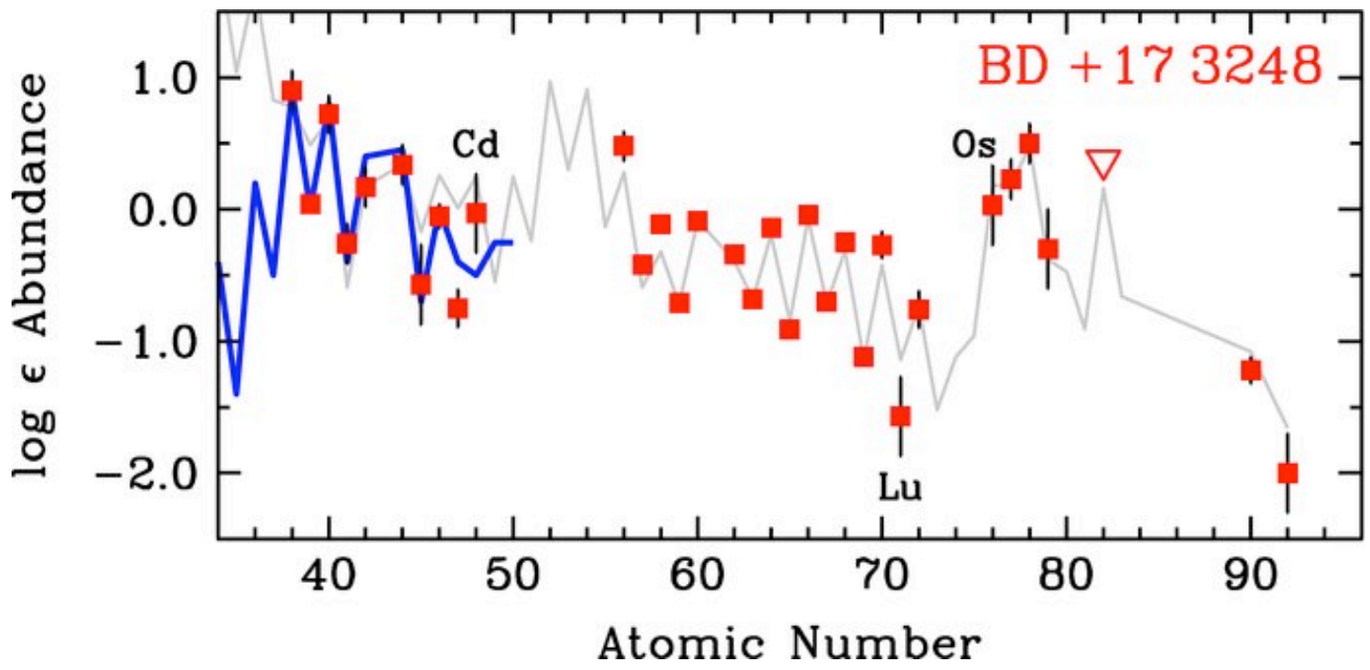
THE ASTROPHYSICAL JOURNAL, 460:L115–L118, 1996 April 1

FIRST DETECTION OF PLATINUM, OSMIUM, AND LEAD IN A METAL-POOR HALO STAR: HD 126238

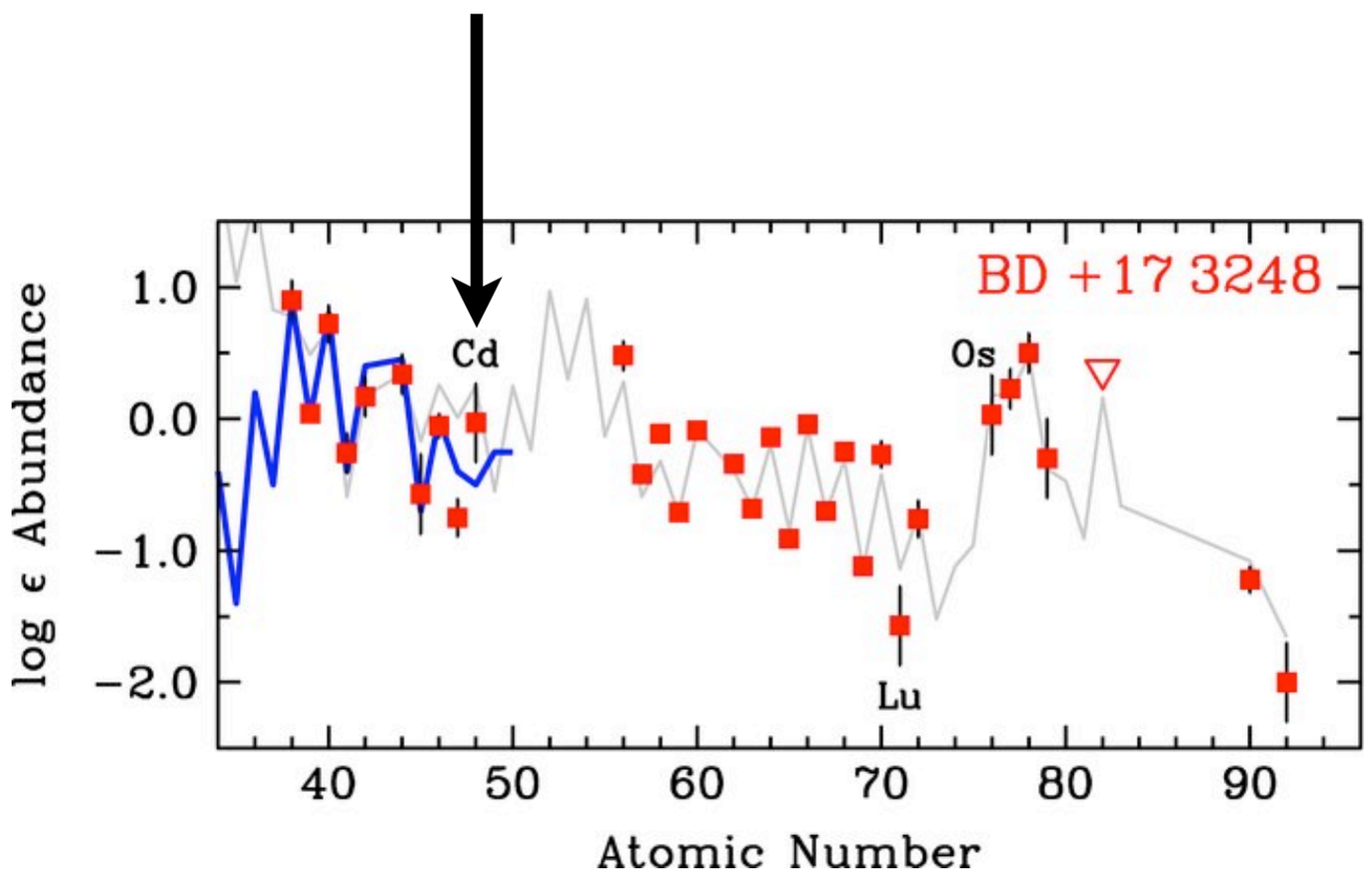
JOHN J. COWAN,[1] CHRISTOPHER SNEDEN,[2,3] JAMES W. TRURAN,[4] AND DEBRA L. BURRIS[1]



Roederer et al. (2010, ApJ, 714, L123)



Roederer et al. (2010, ApJ, 714, L123)



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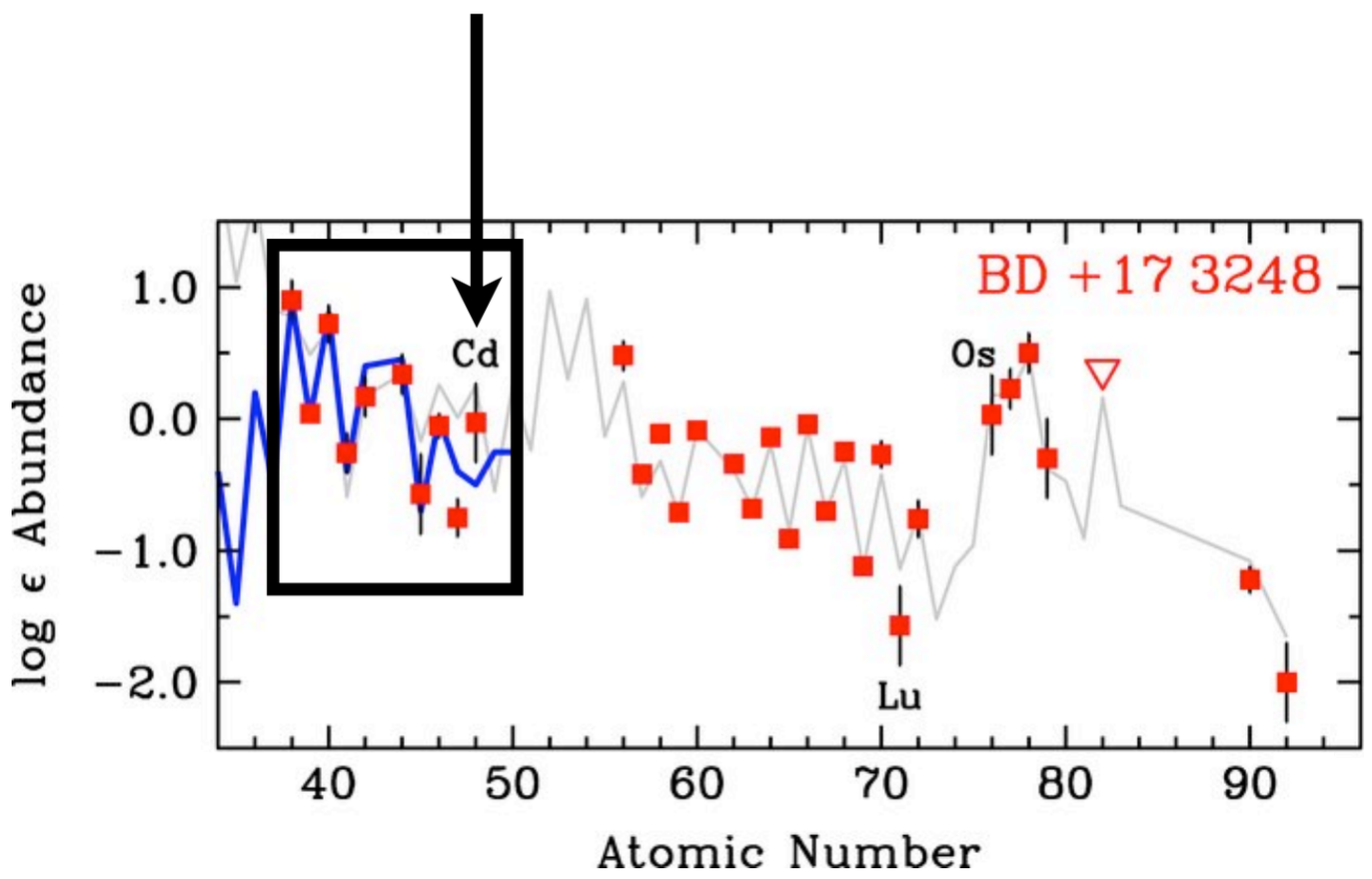
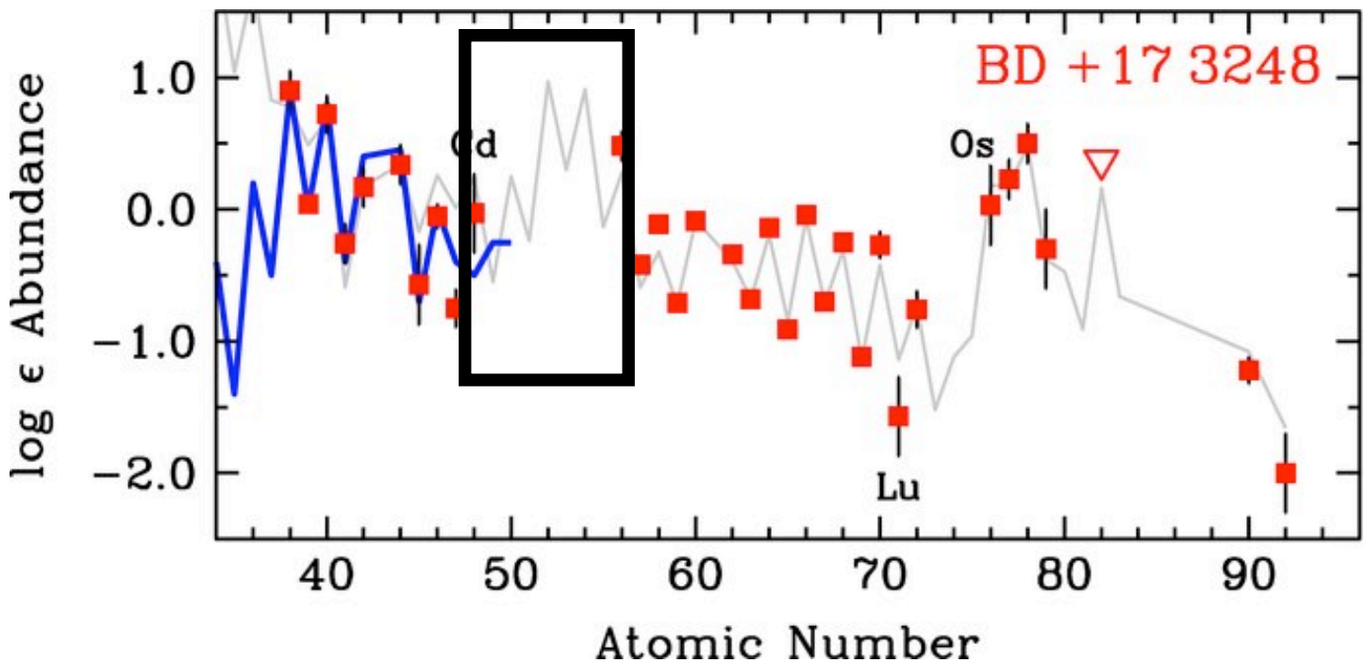
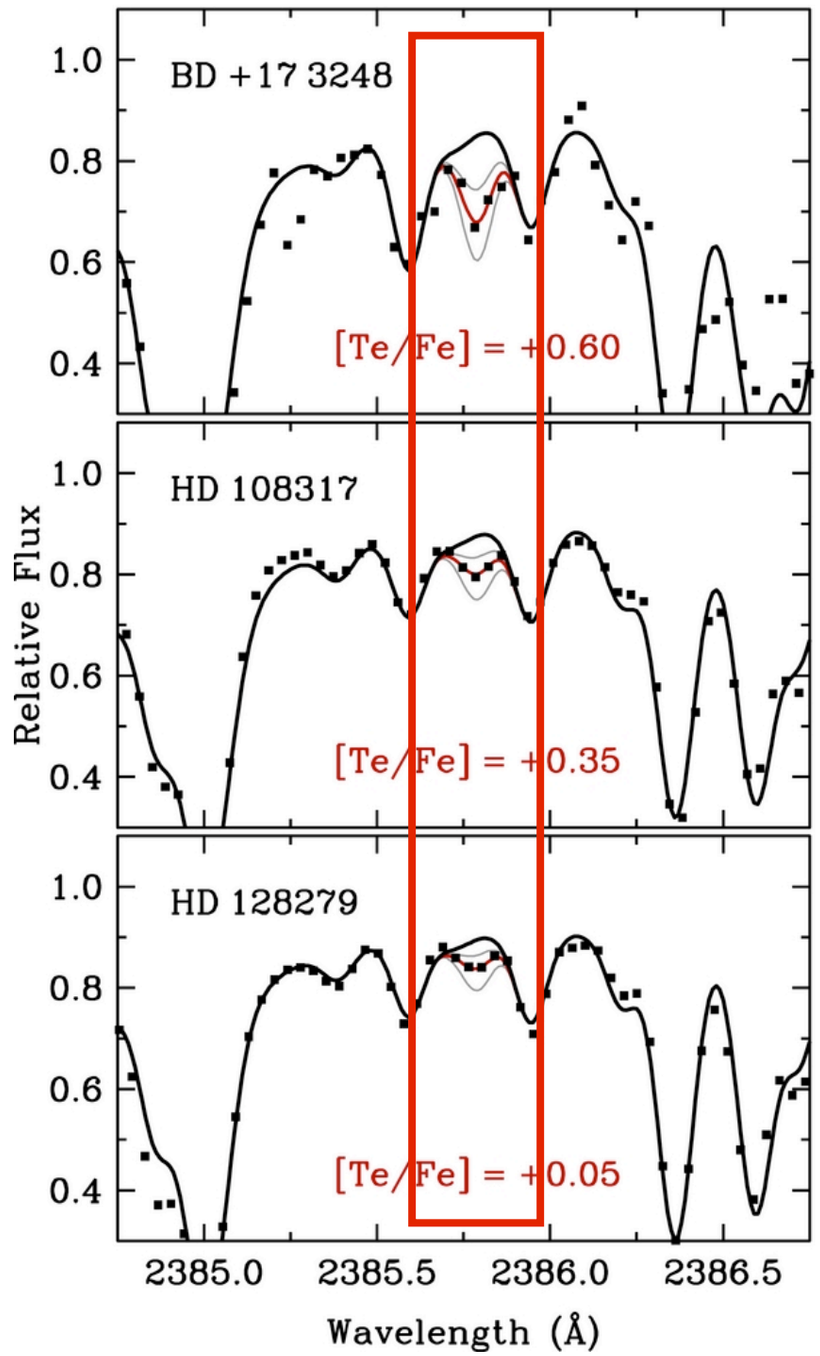


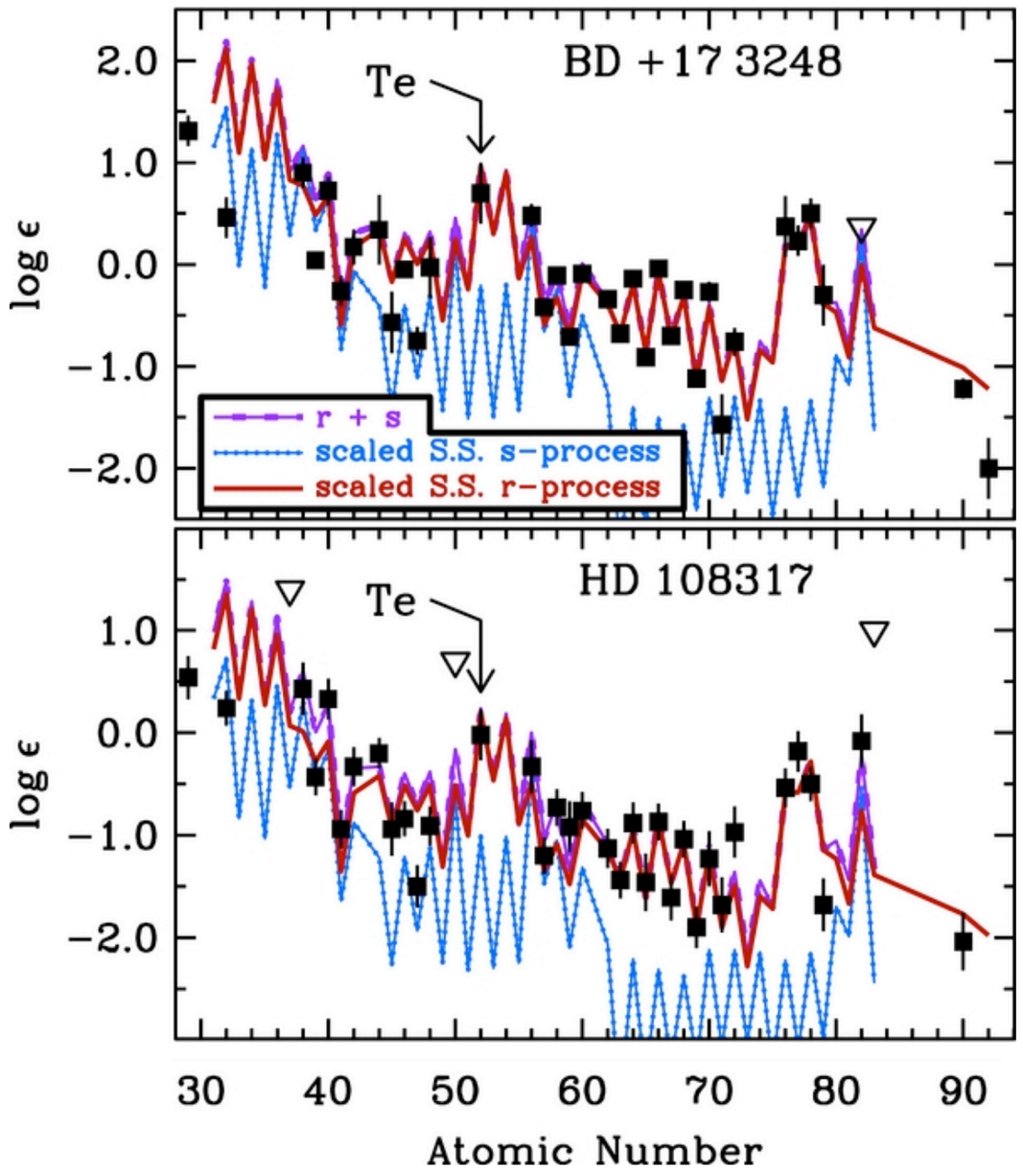
Roederer et al. (2010, ApJ, 714, L123)



Roederer et al. (2010, ApJ, 714, L123)



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



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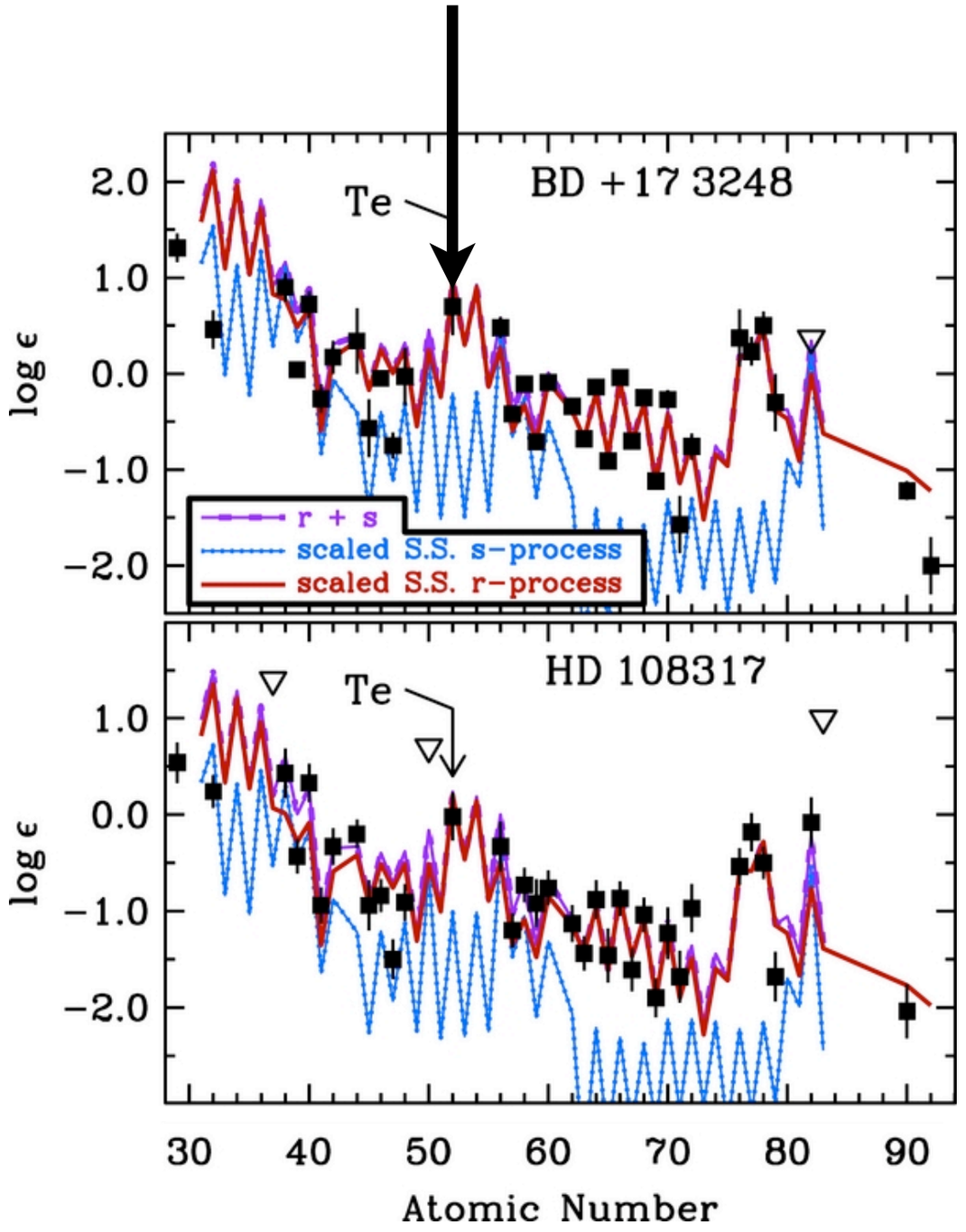

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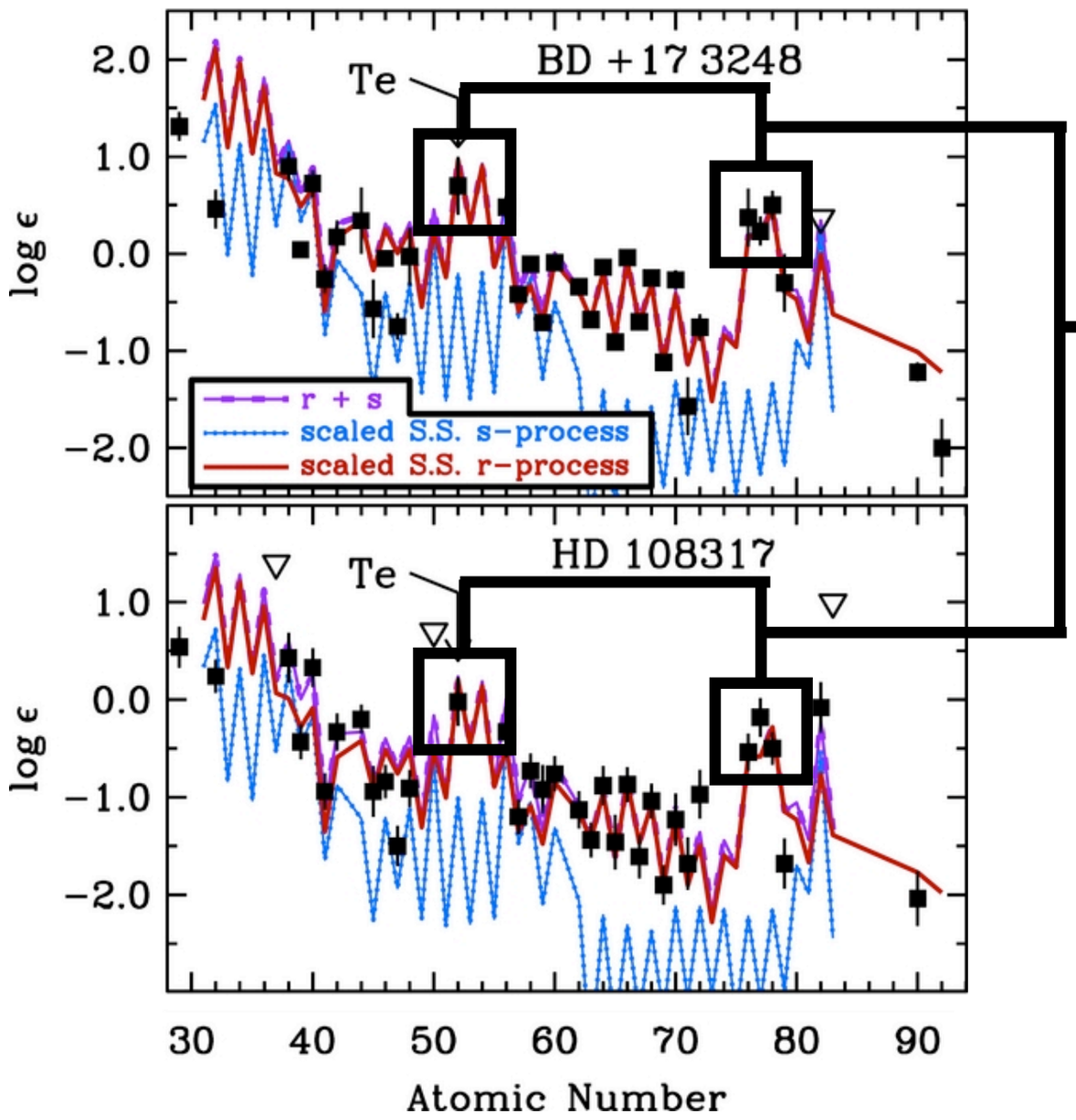


2nd and 3rd r-process peaks

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

Tellurium

Tellurium is produced along with the heavier r-process elements.

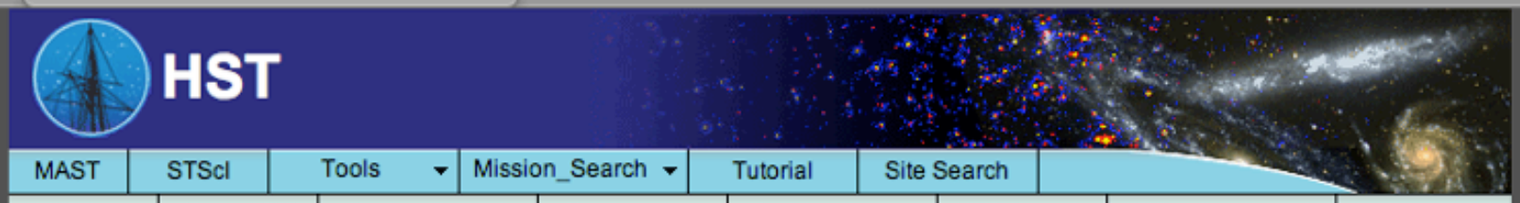
The r-process that was operating in the early Universe

The r-process that was operating in the early Universe was the same as later r-process events

The r-process that was operating in the early Universe was the same as later r-process events that produced about half

The r-process that was operating in the early Universe was the same as later r-process events that produced about half of the heavy elements

The r-process that was operating in the early Universe was the same as later r-process events that produced about half of the heavy elements found on Earth.



MAST | STScI | Tools | Mission_Search | Tutorial | Site Search

HST Home | About HST | Getting Started | Registration | Archive Status | HST Search | HSTonline Search

Archive Status

HST Search Form

(Help)
Field Descriptions

Standard Form

File Upload Form

Search | Reset | Clear Form

Target Name

Resolver: NED

Radius (arcmin): 3.0

Right Ascension

Declination

Equinox: J2000

Imagers: ALL NONE
- STIS
- NICMOS
- WFPC2
- WF/PC
- FOC
- ACS
- WFC3
- COS

Spectrographs: ALL NONE
- STIS
- NICMOS
- GHRS
- FOS
- FOC
- ACS
- WFC3
- COS

Other: ALL NONE
- FGS
- HSP

Start Time | Exp Time | Proposal ID | Release Date

Dataset | Filters/Gratings | Obset ID | Archive Date

Target Descrip | Apertures | Observations: [x] Science [ ] Calibration

PI Last Name

User-specified field 1 | Field Descriptions

User-specified field 2 | Field Descriptions

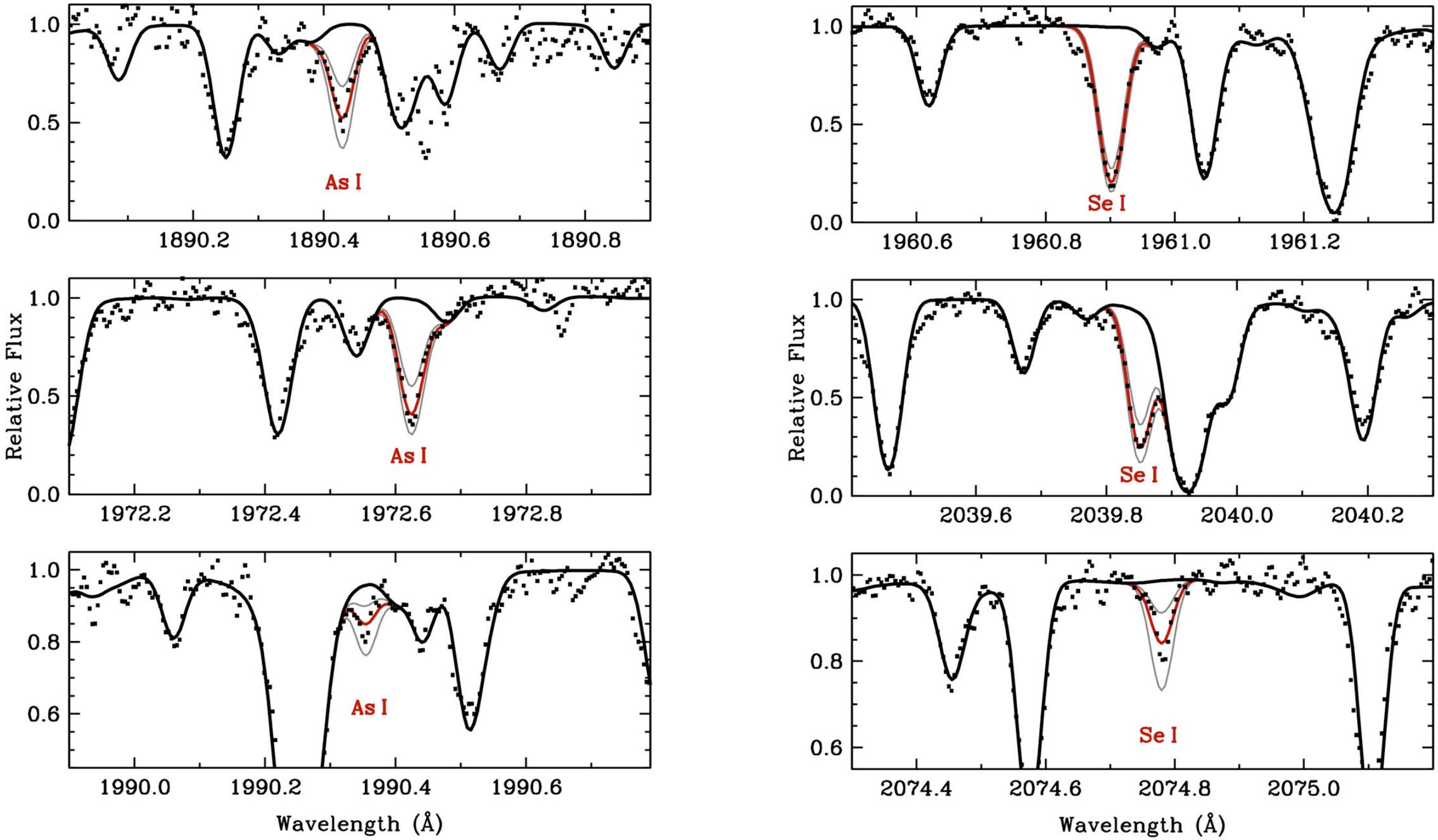
7 stars

< 2000 Å

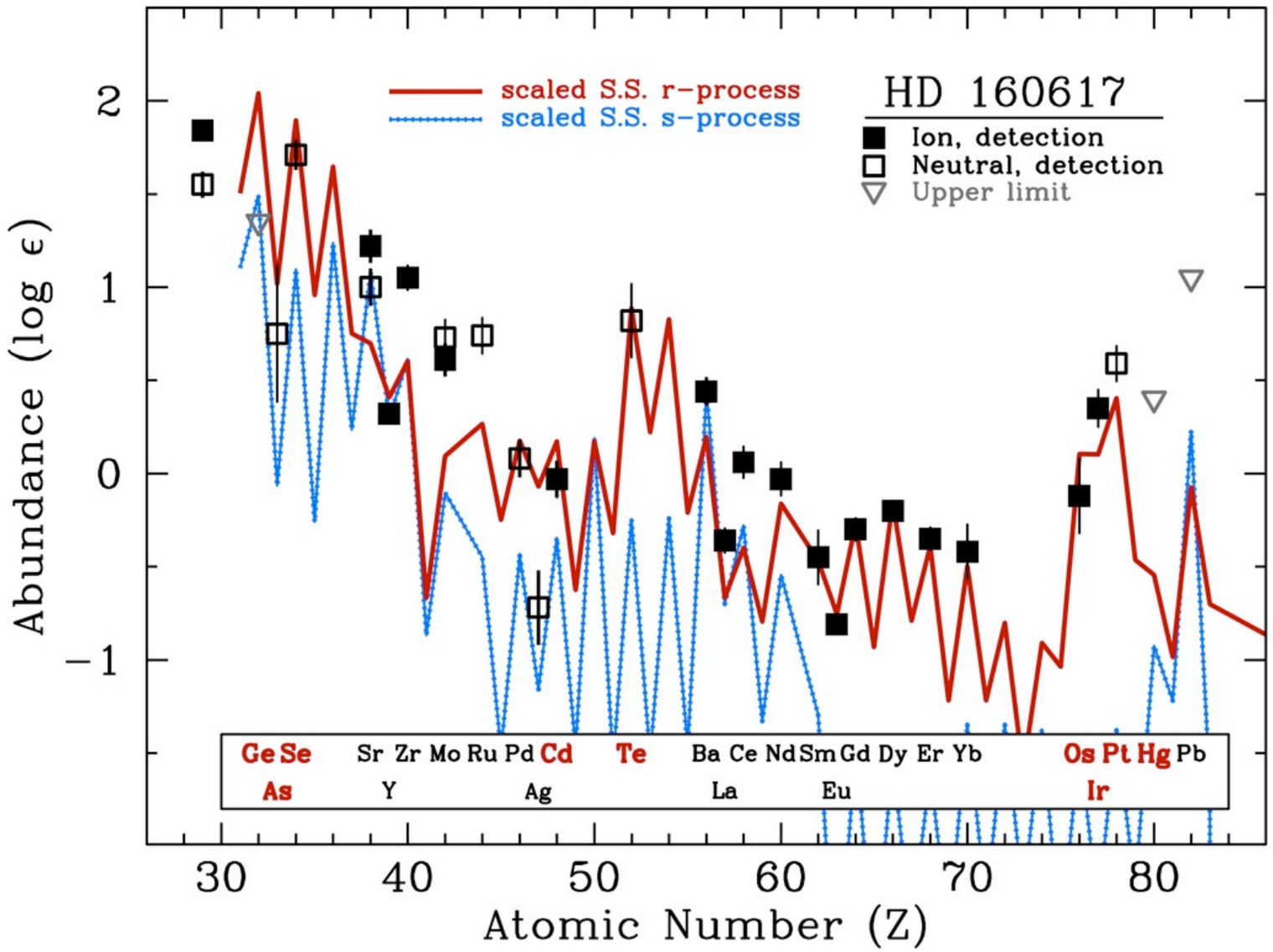
hydrogen 1 H 1.0079																	helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminium 13 Al 26.982	silicon 14 Si	phosphorus 15 P	sulfur 16 S	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	ununnium 111 Uuu [272]	unubium 112 Uub [277]		ununquadium 114 Uuq [289]				

*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
**Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

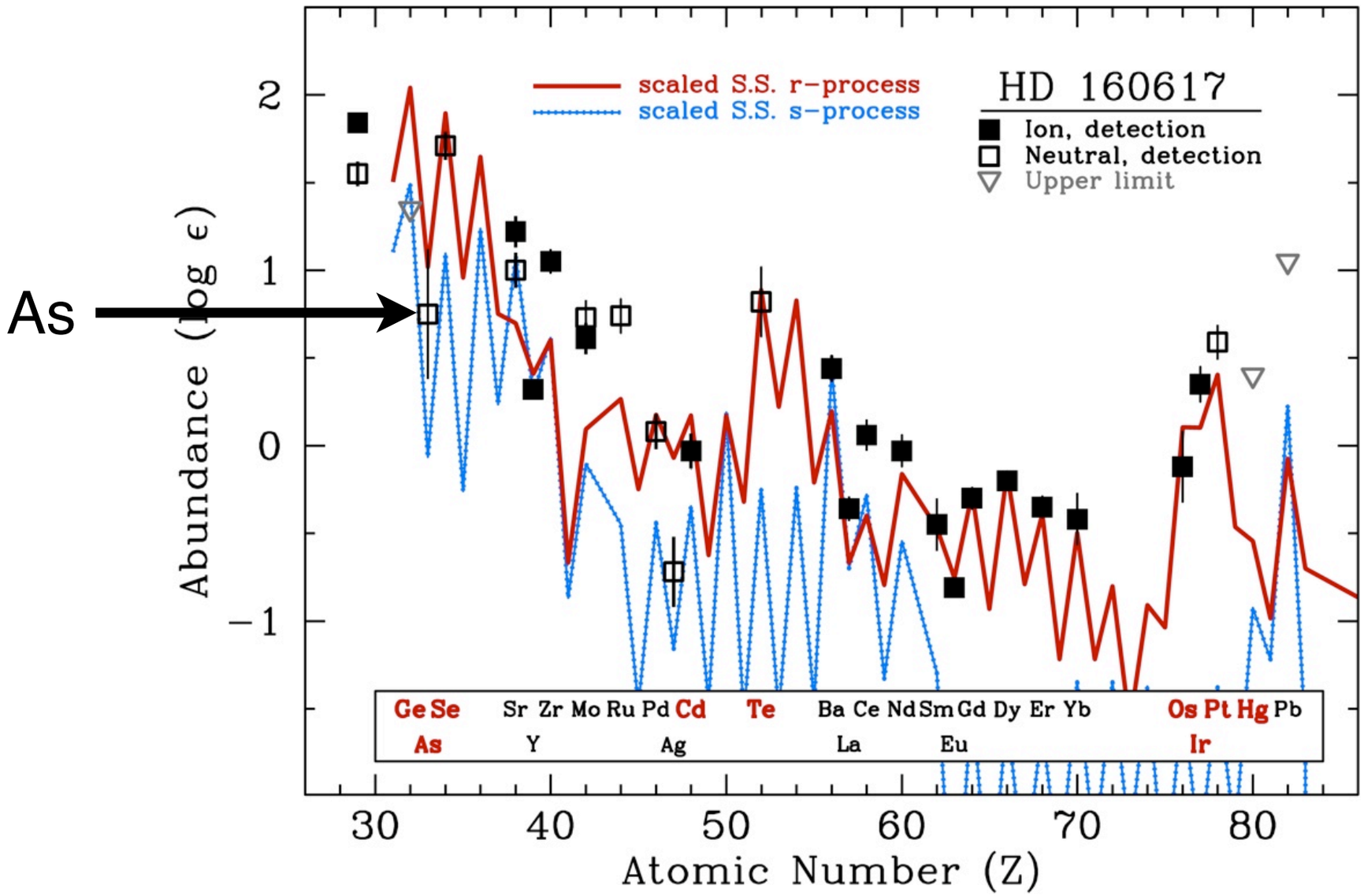
observed spectrum of HD 160617 from HST/STIS



Roederer & Lawler (2012, ApJ, 750, 76)



Roederer & Lawler (2012, ApJ, 750, 76)



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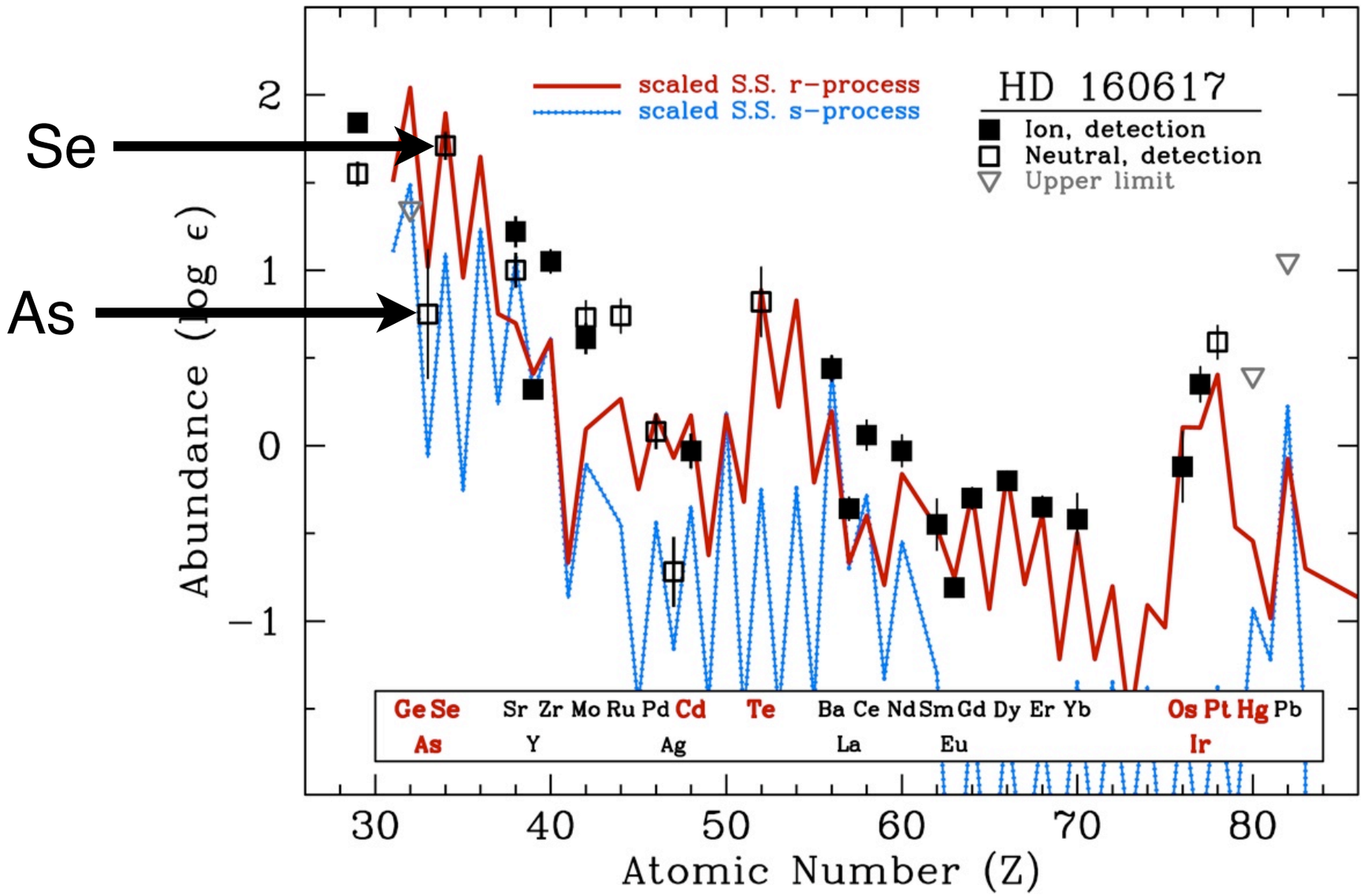

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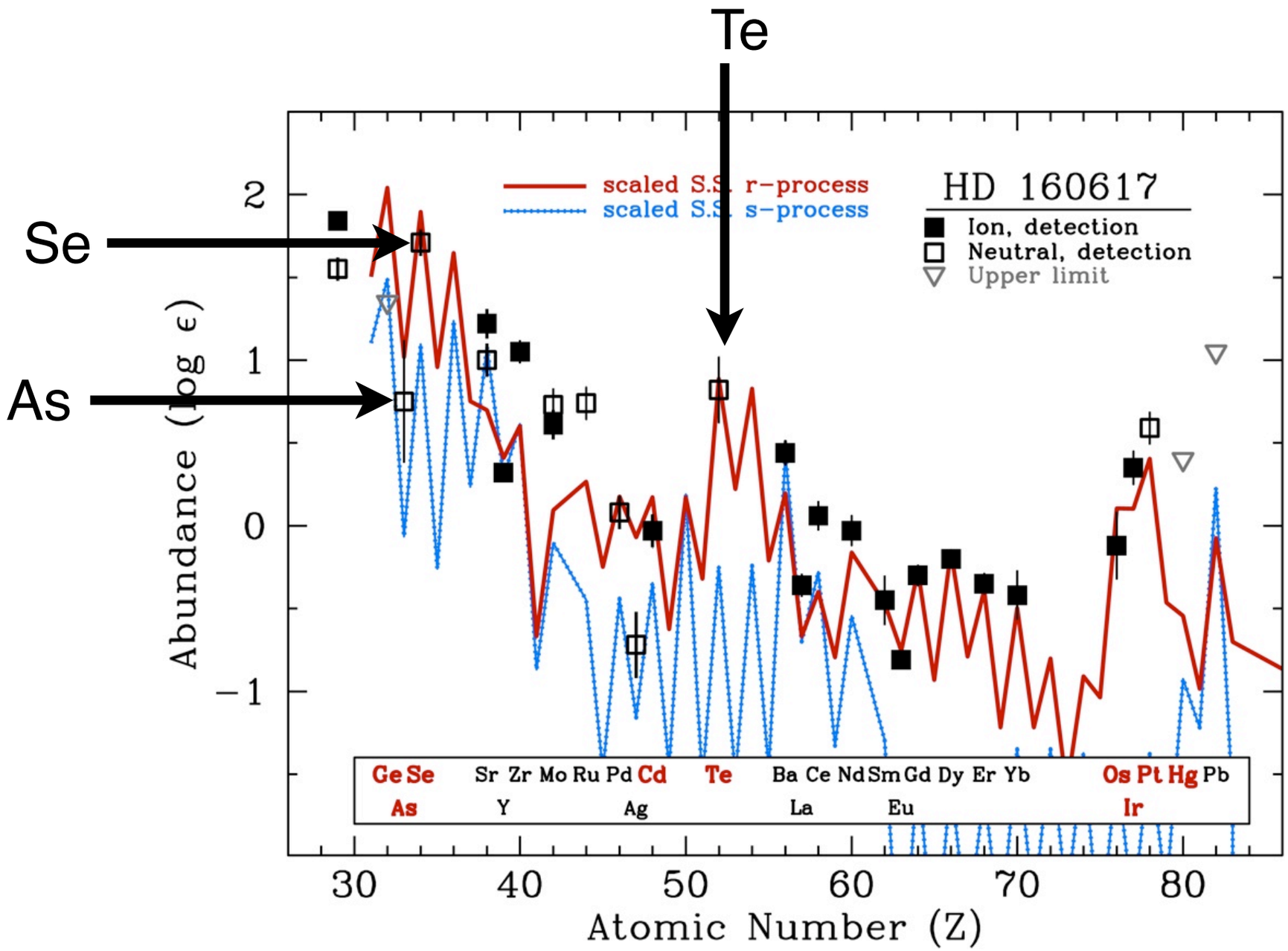

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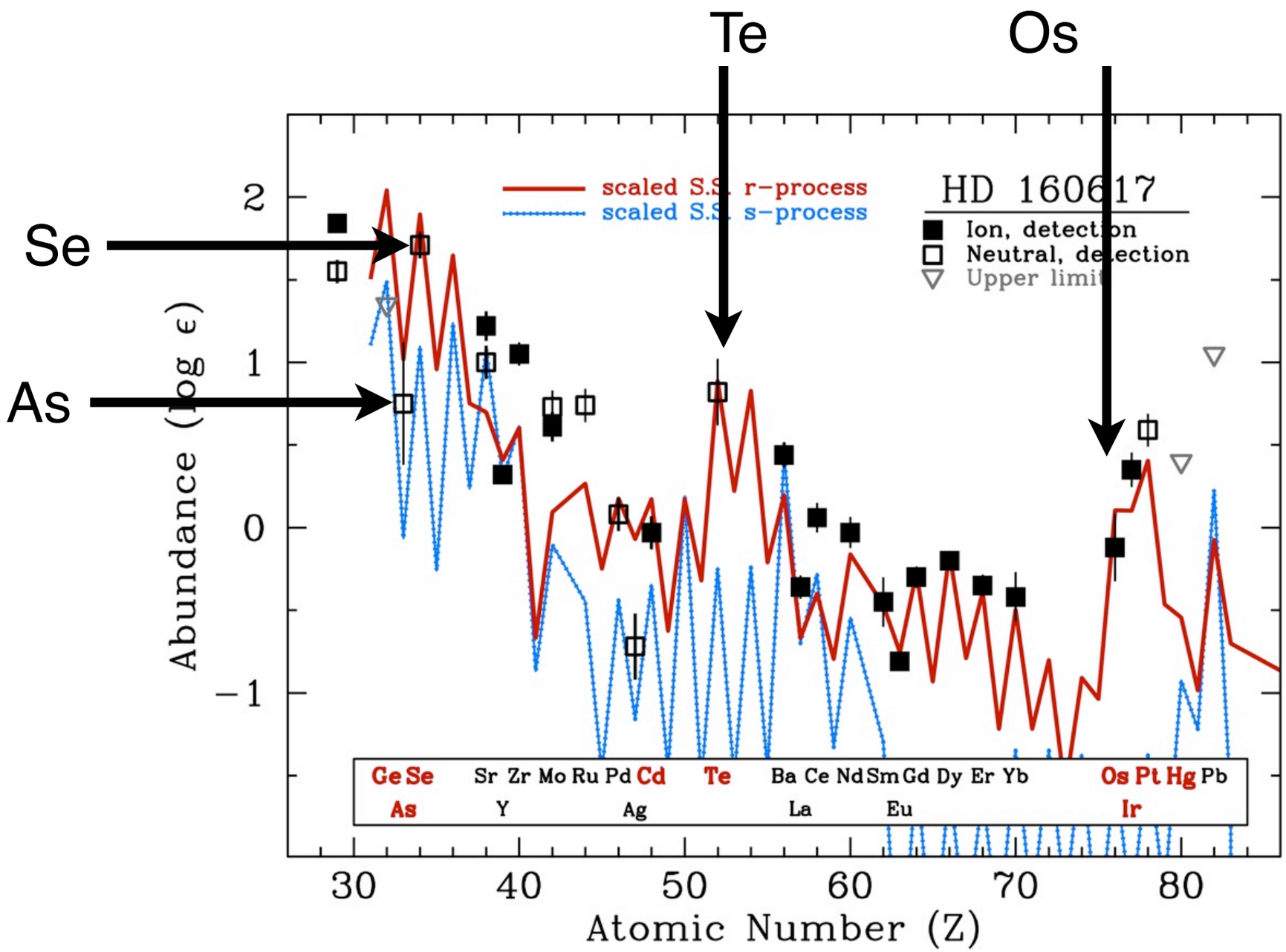

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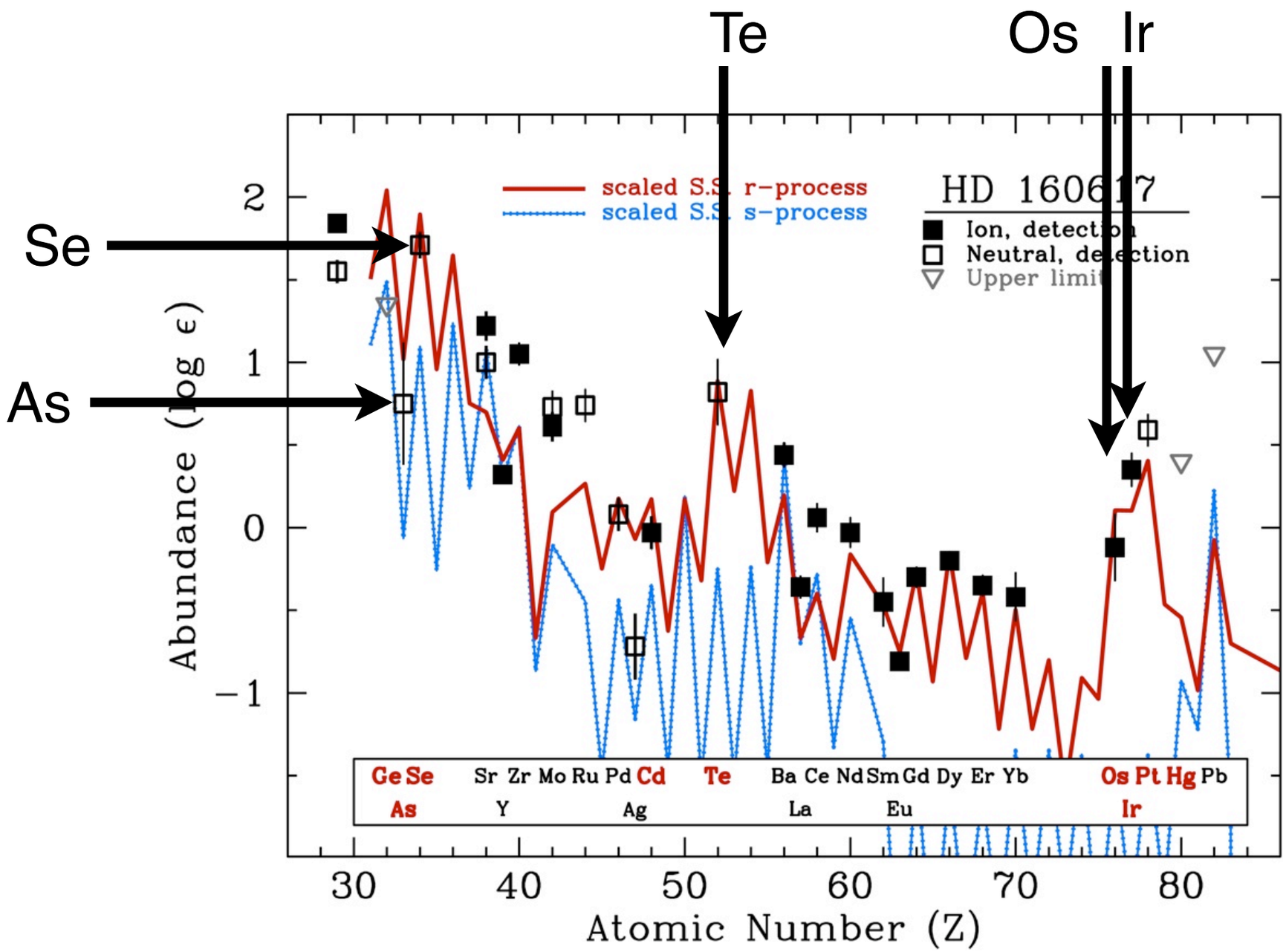

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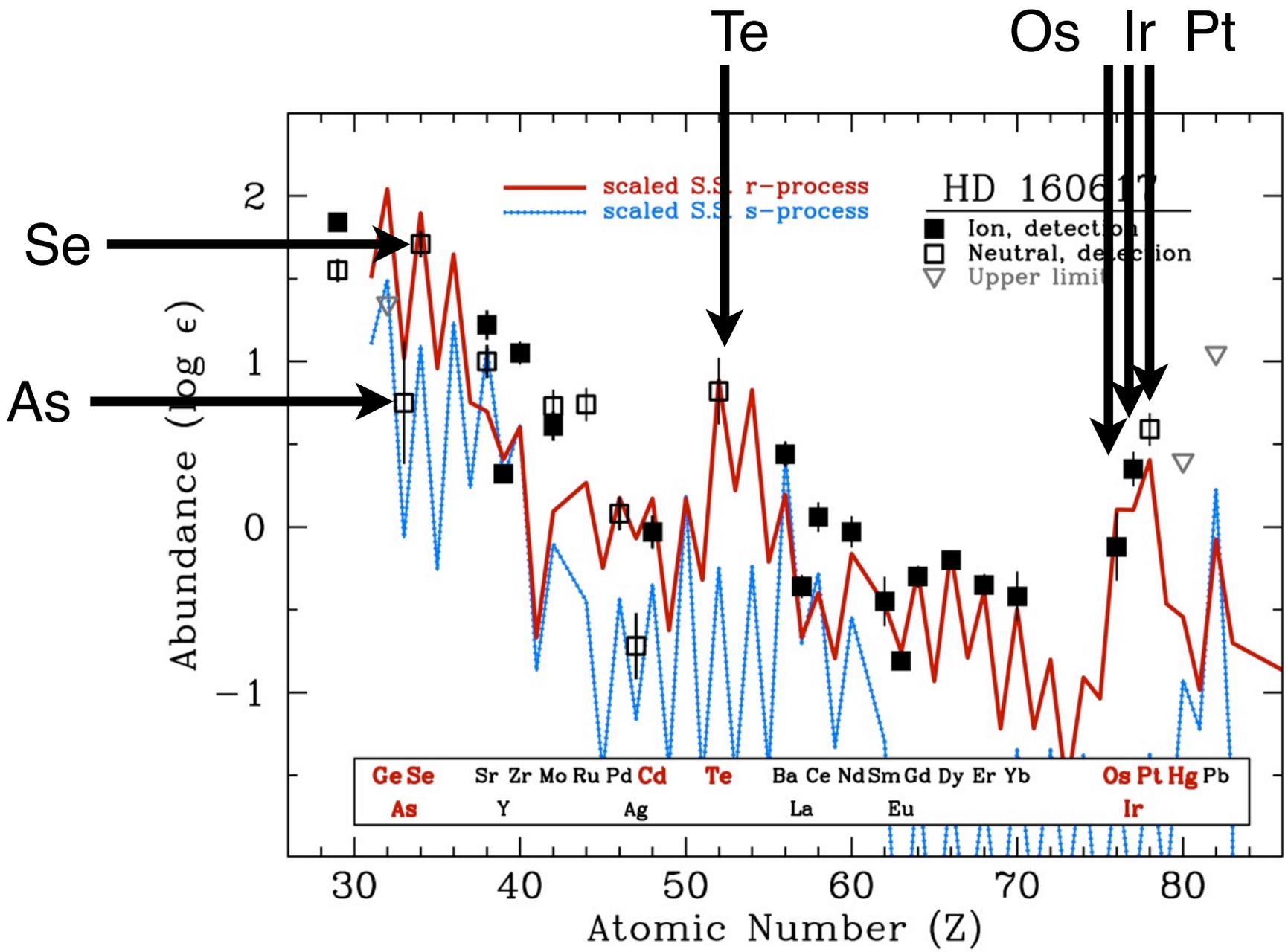
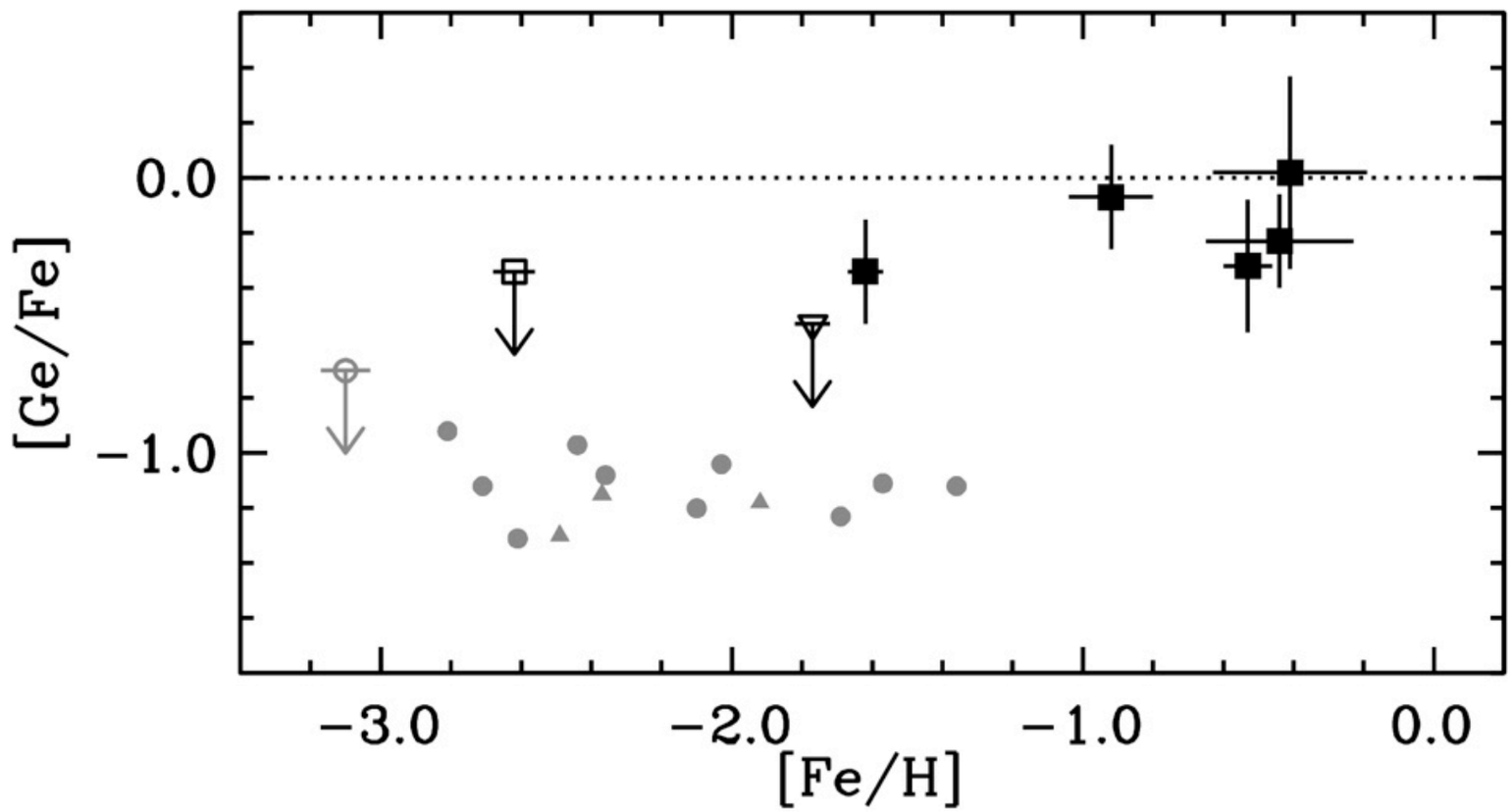


Roederer & Lawler (2012, ApJ, 750, 76)

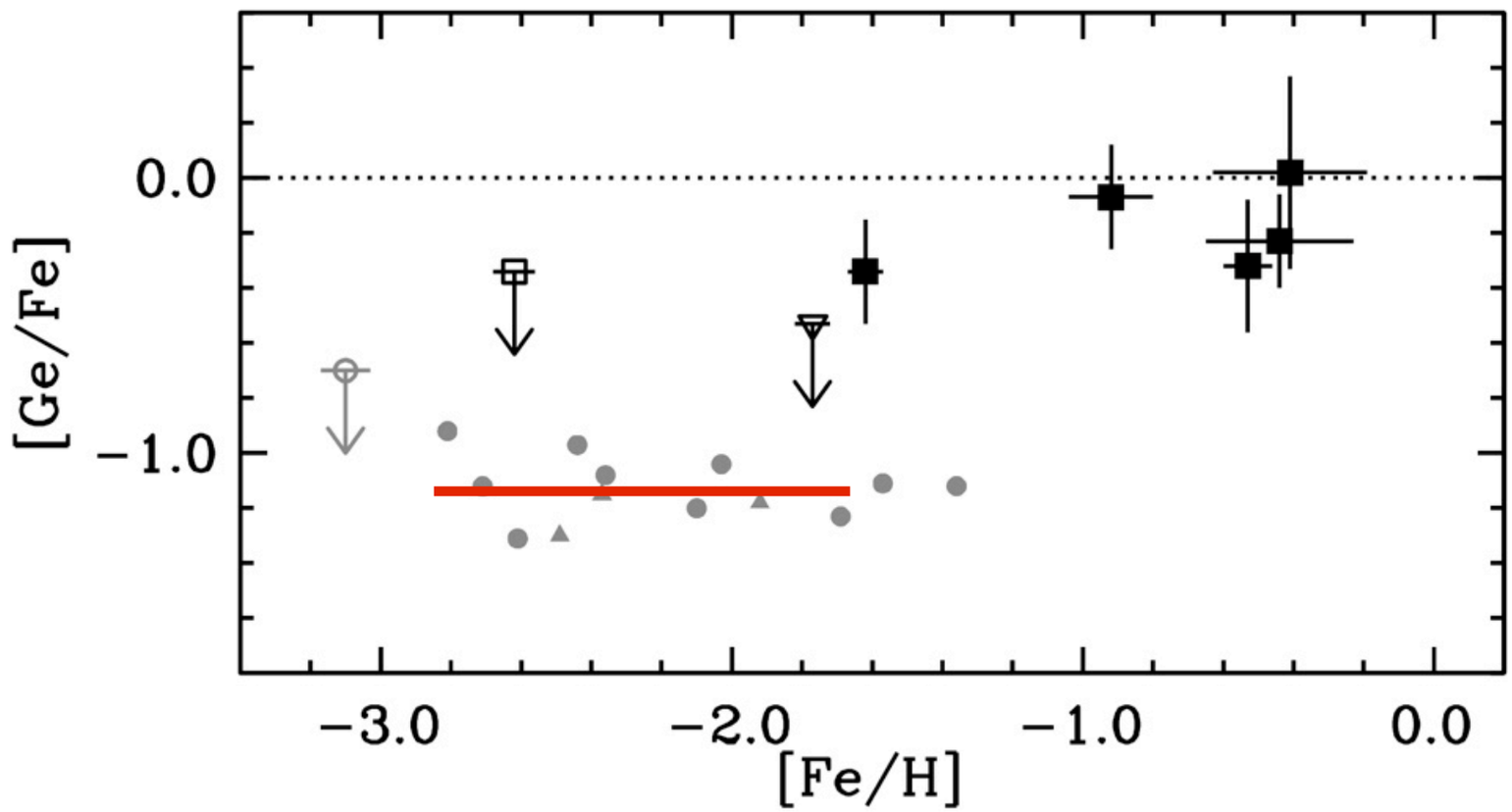


Roederer (ApJ, 2012, in press, arXiv:1207.0518)

additional data from:

Cowan et al.
(ApJ, 2005, 627, 238)

Roederer et al.
(ApJS, 2012, submitted)



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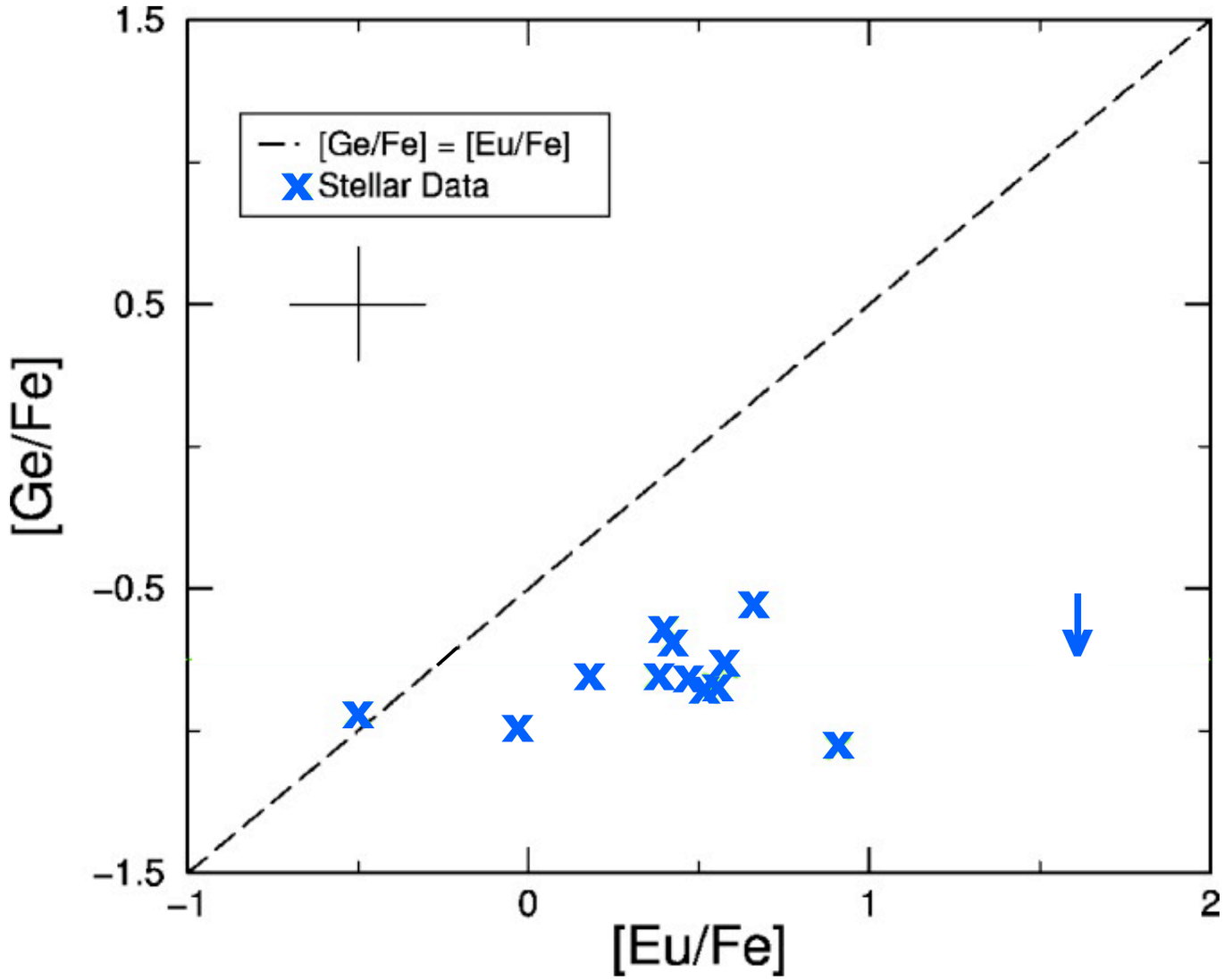
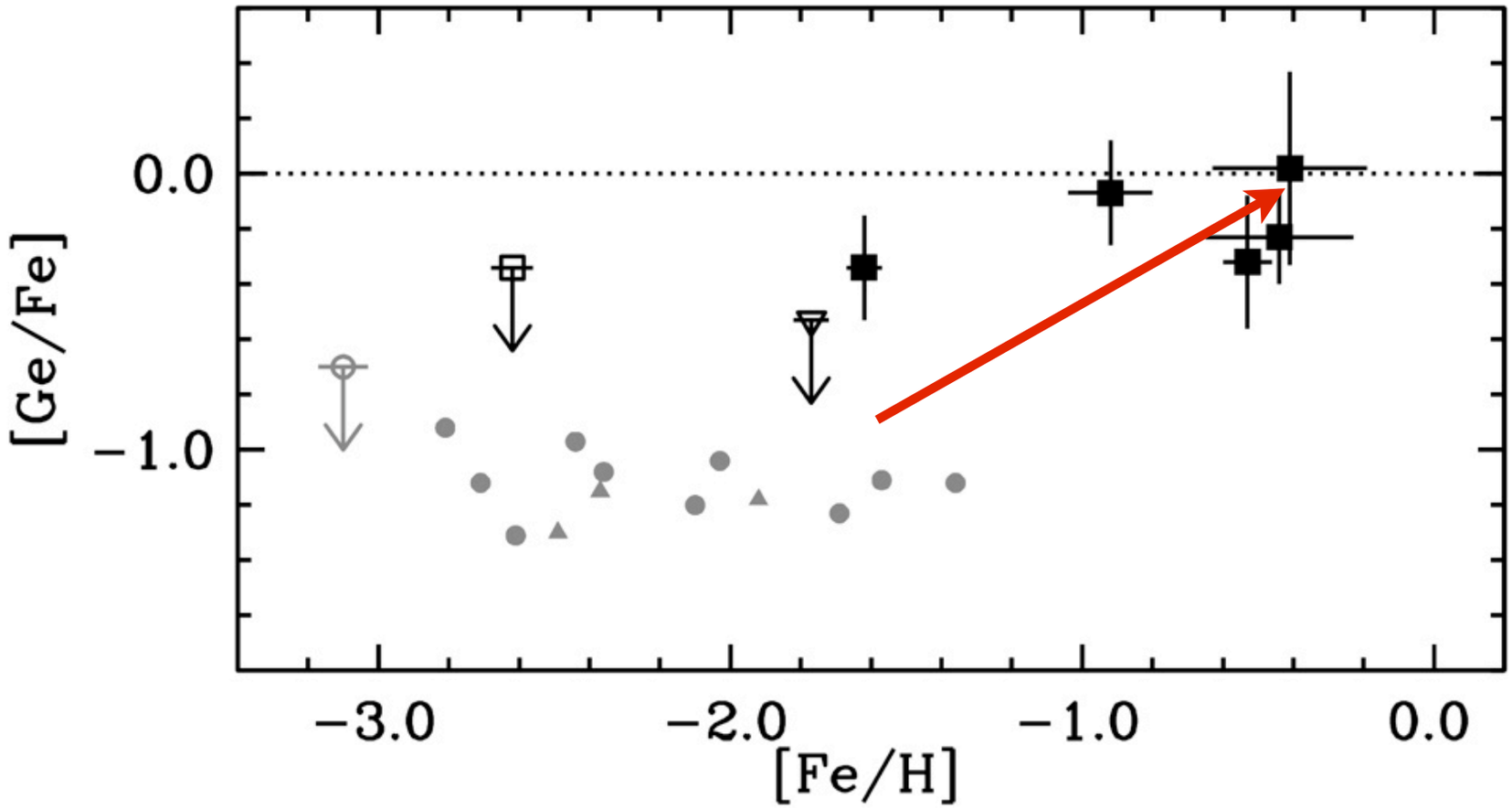


updated from Cowan et al. (2005, ApJ, 627, 238)



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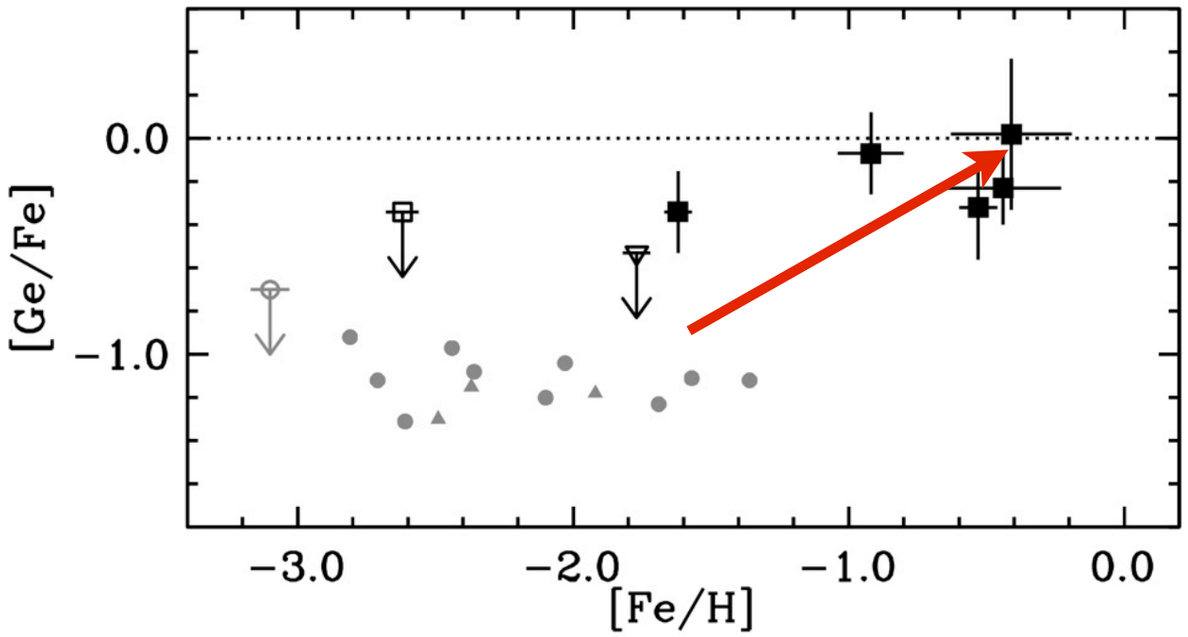

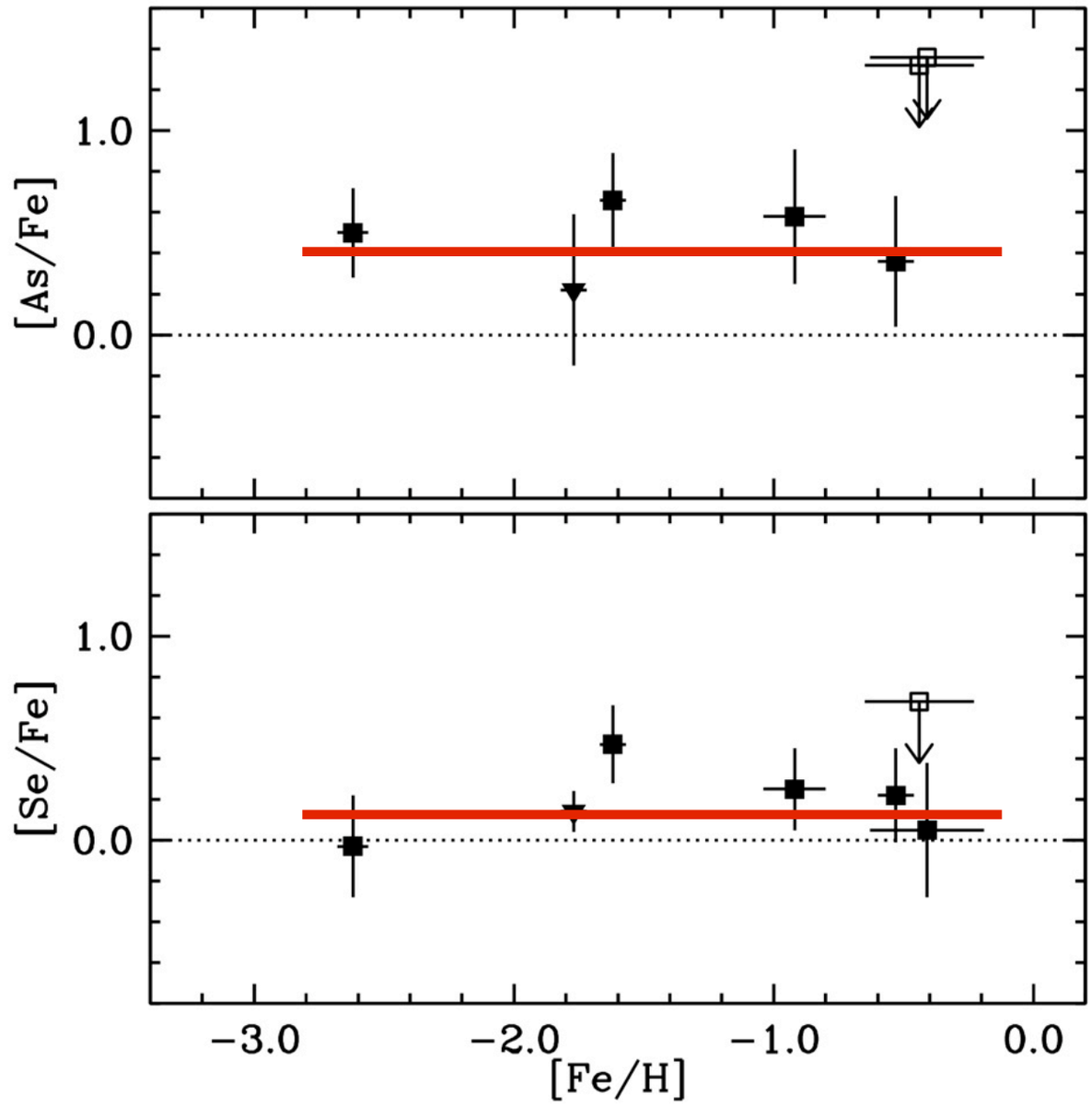

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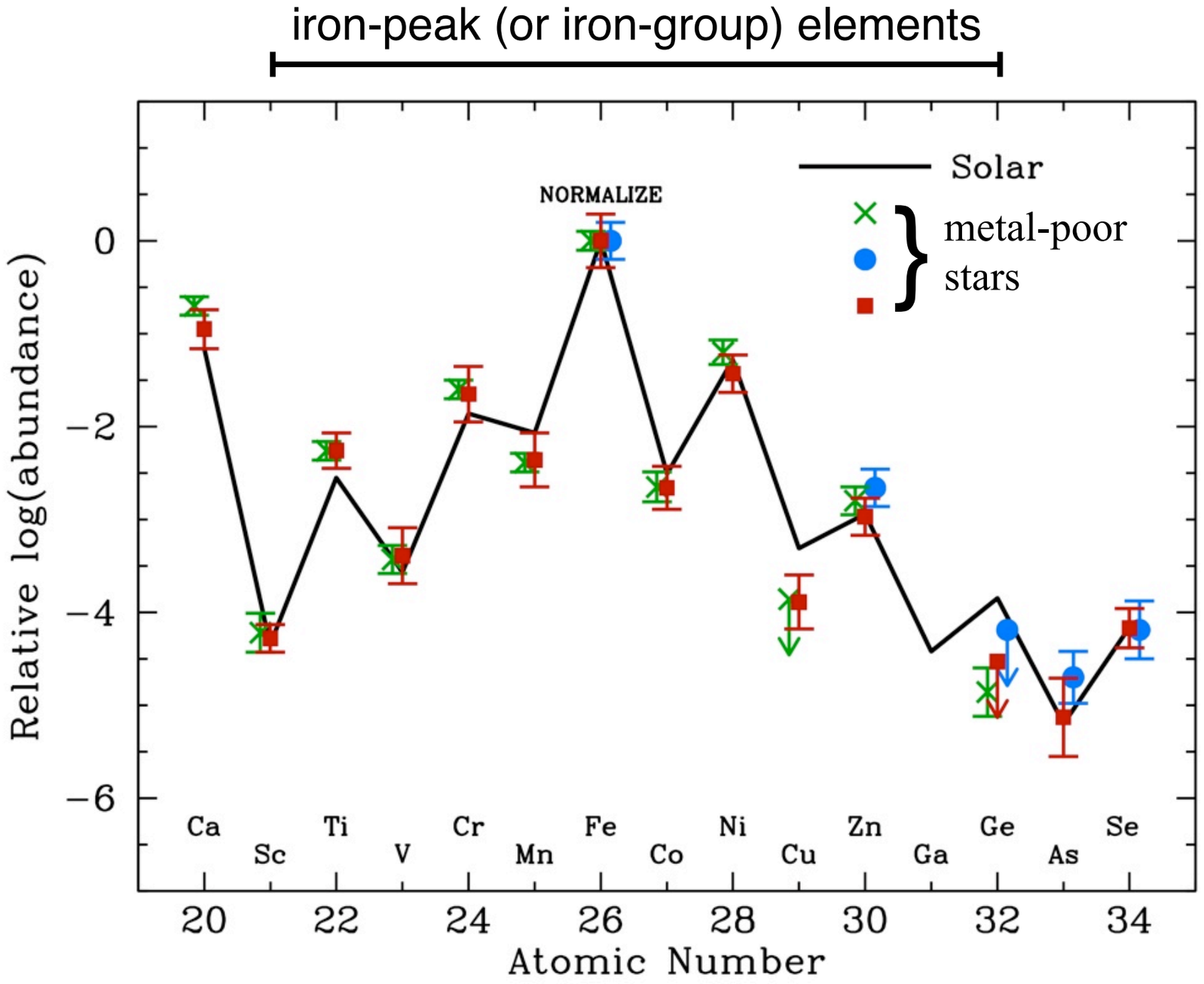
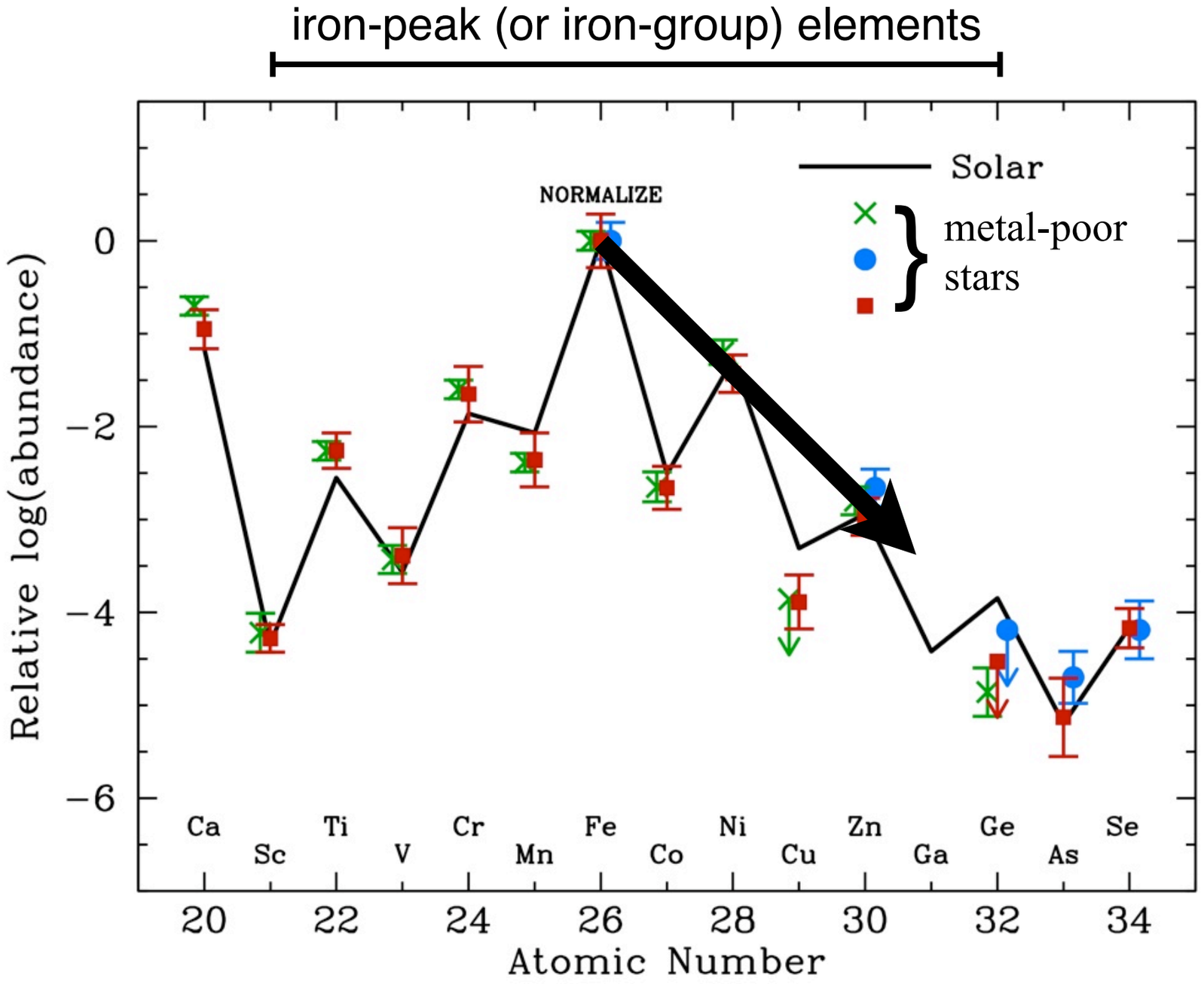

iron-peak (or iron-group) elements
Solar
NORMALIZE
metal-poor
stars
Relative log(abundance)
0
−2
−4
−6
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
20
22
24
26
28
30
32
34
Atomic Number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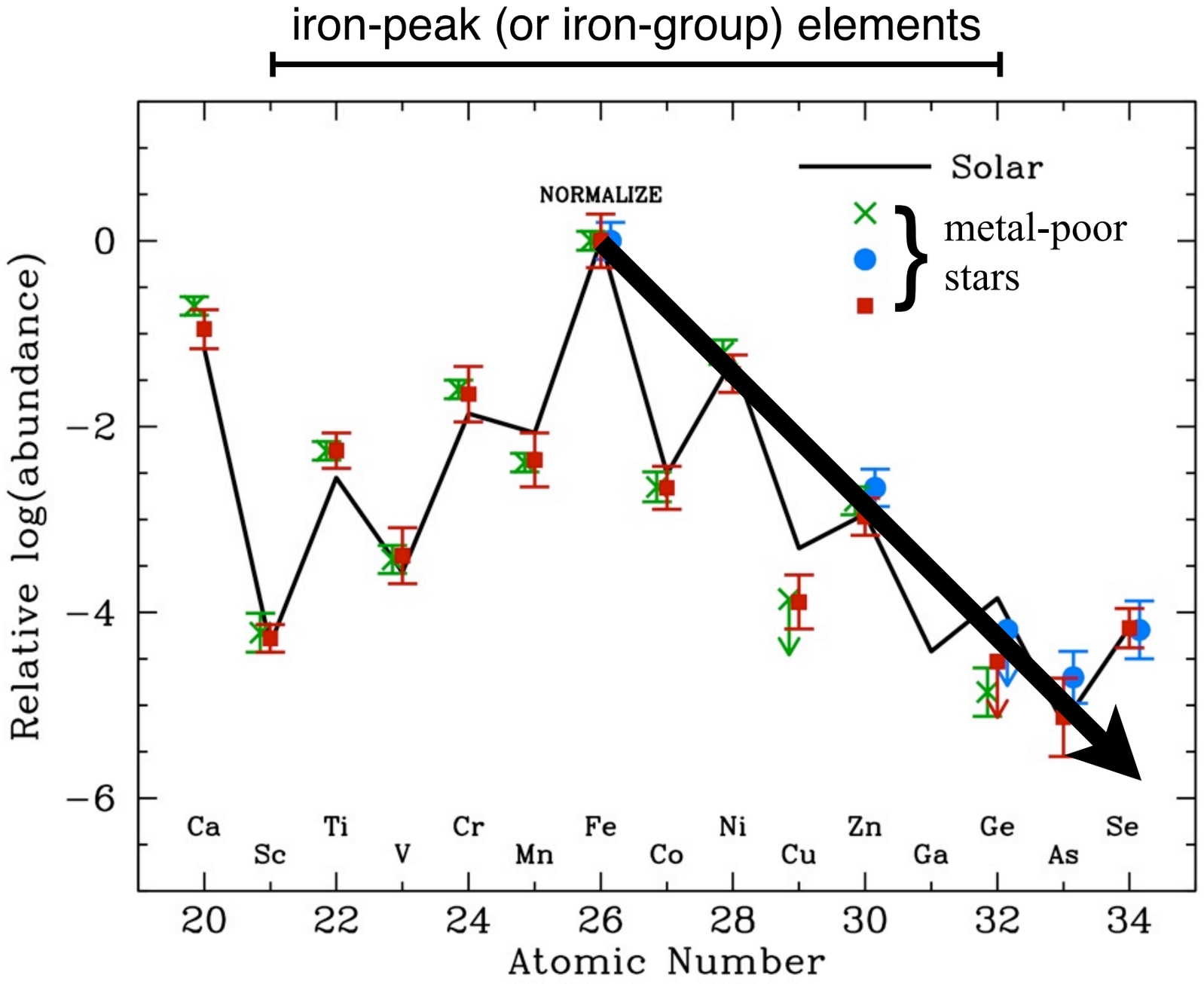
32
34
Atomic Number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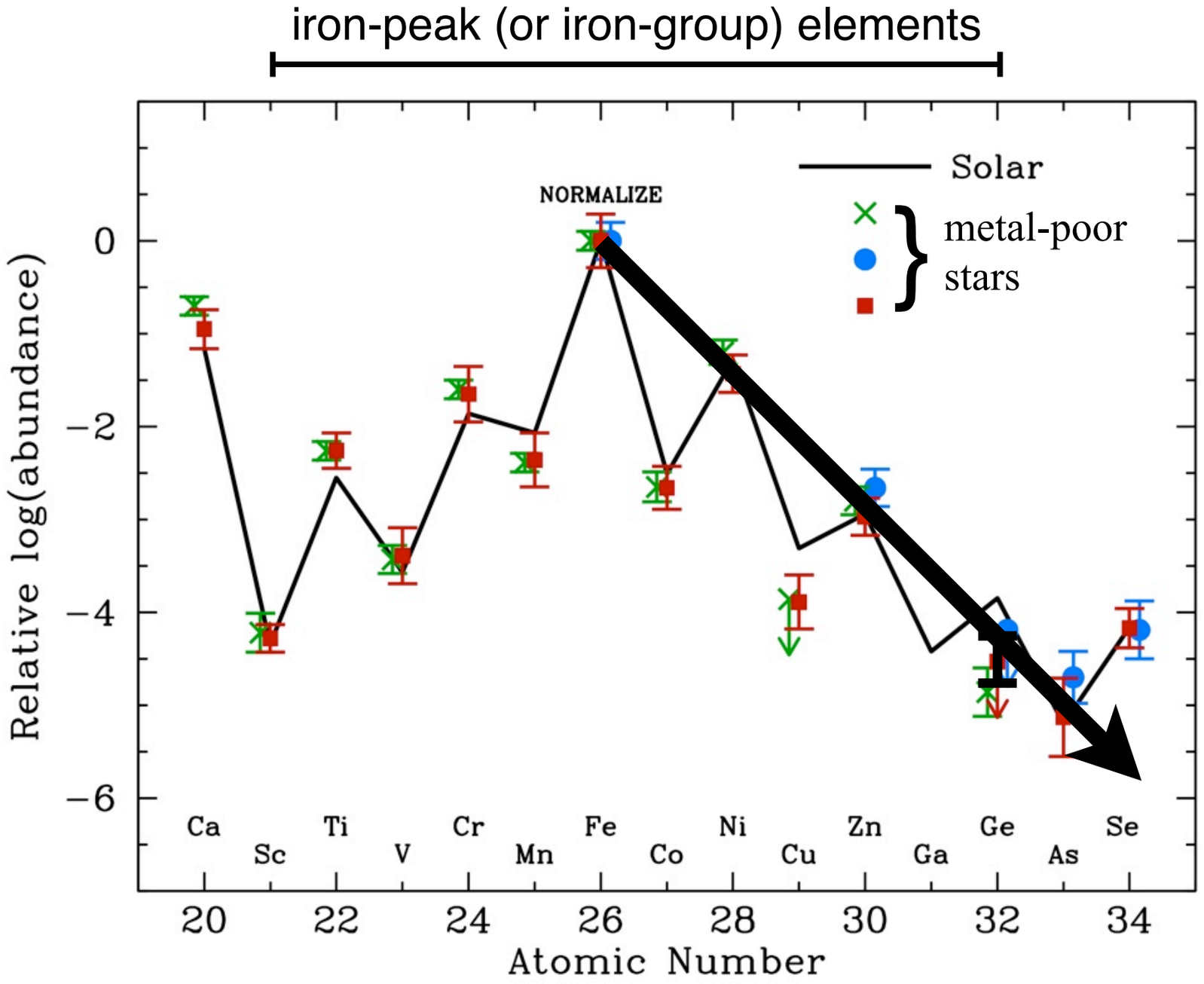
32
34
Atomic Number


iron-peak (or iron-group) elements
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Se
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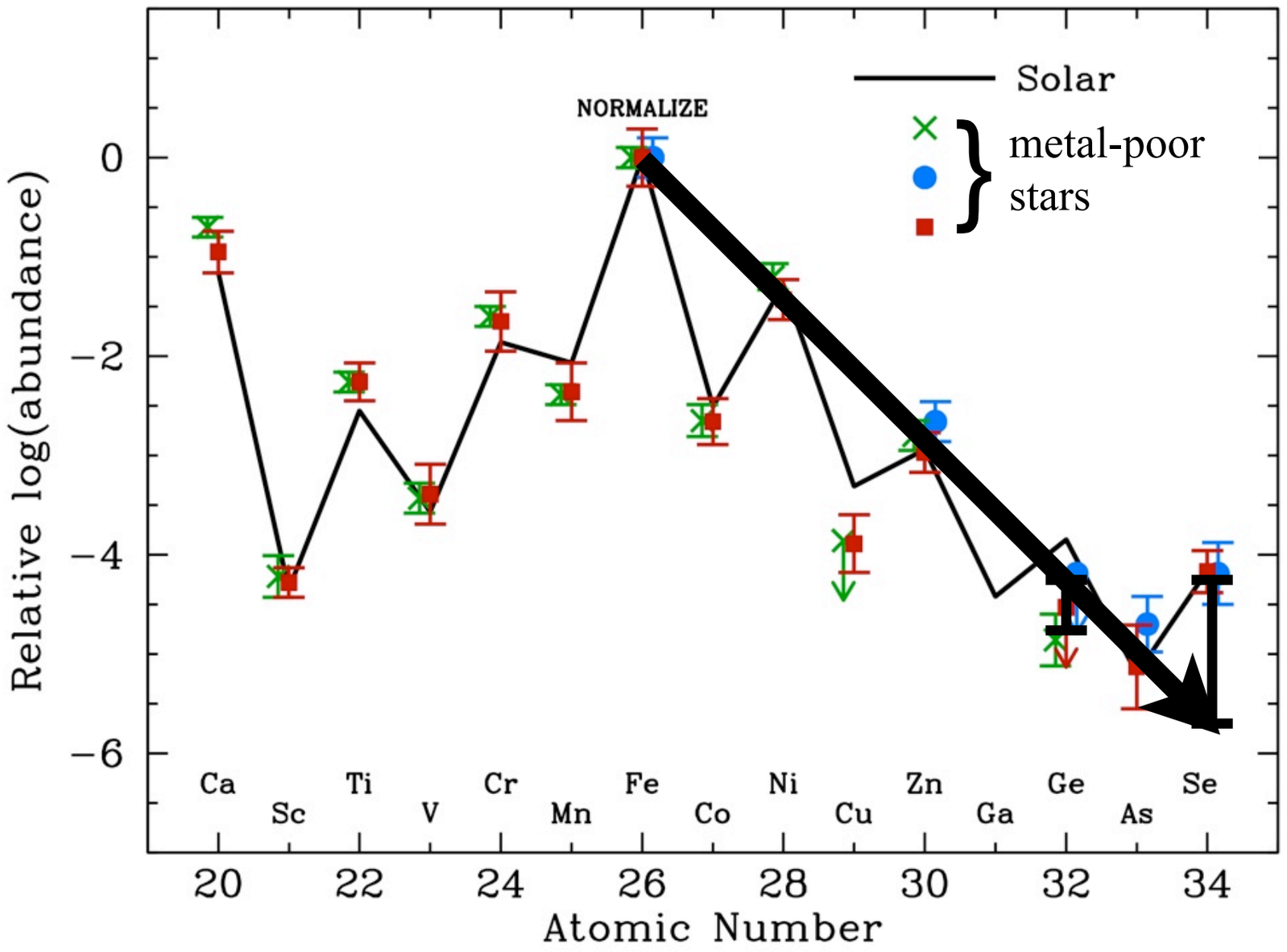
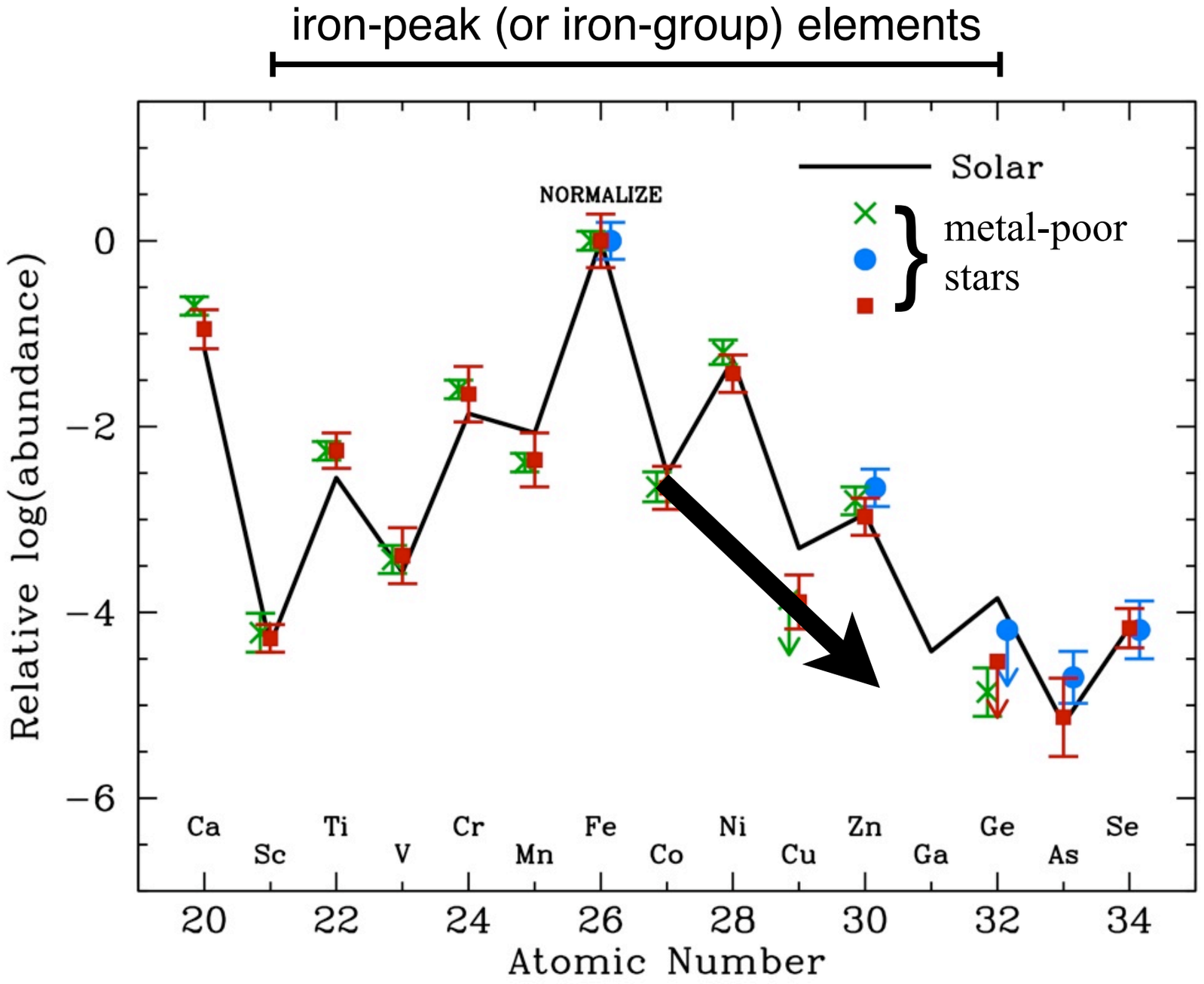
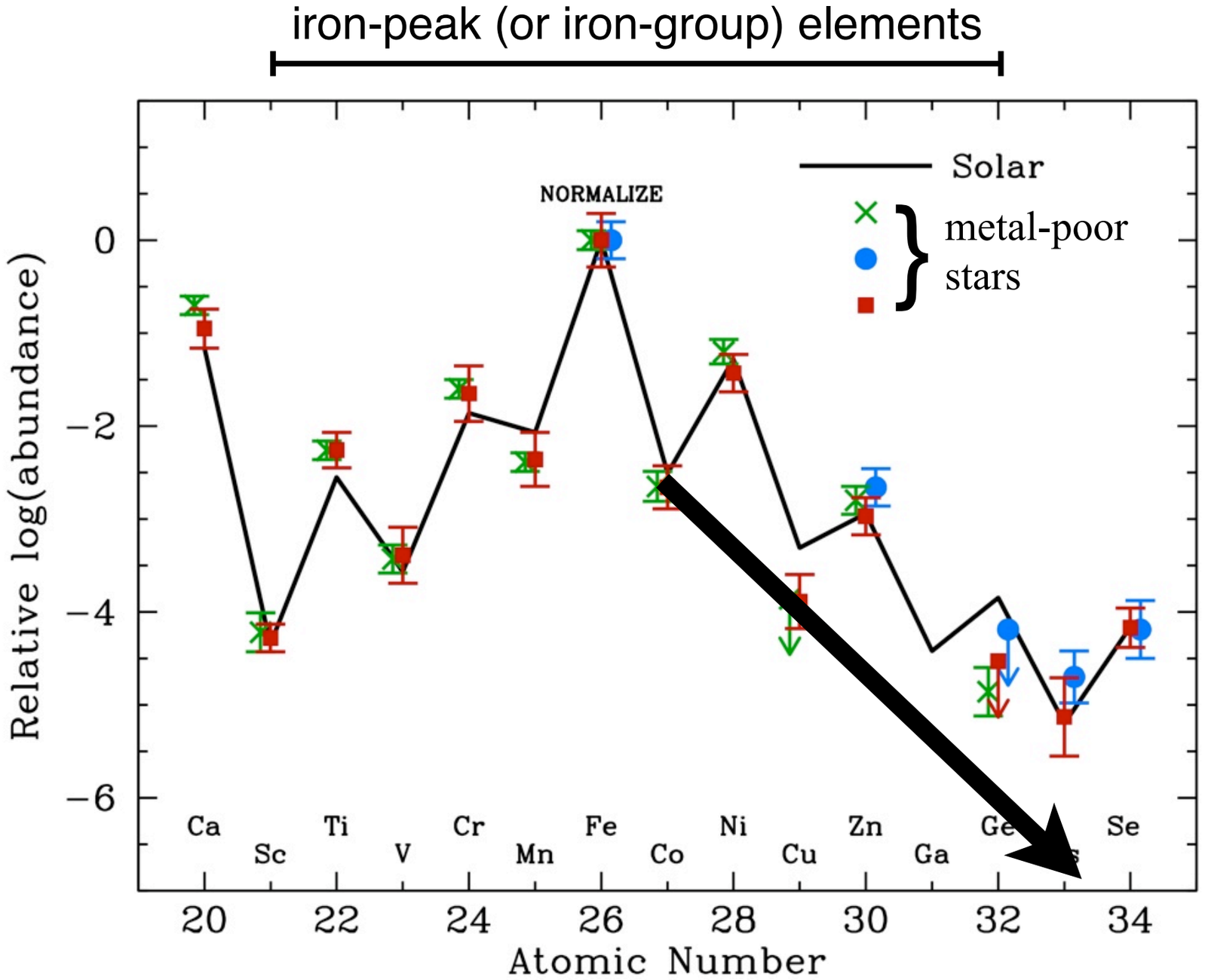
30
32
34
Atomic Number

iron-peak (or iron-group) elements




iron-peak (or iron-group) elements
Solar
NORMALIZE
metal-poor
stars
Relative log(abundance)
0
−2
−4
−6
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
20
22
24
26
28
30
32
34
Atomic Number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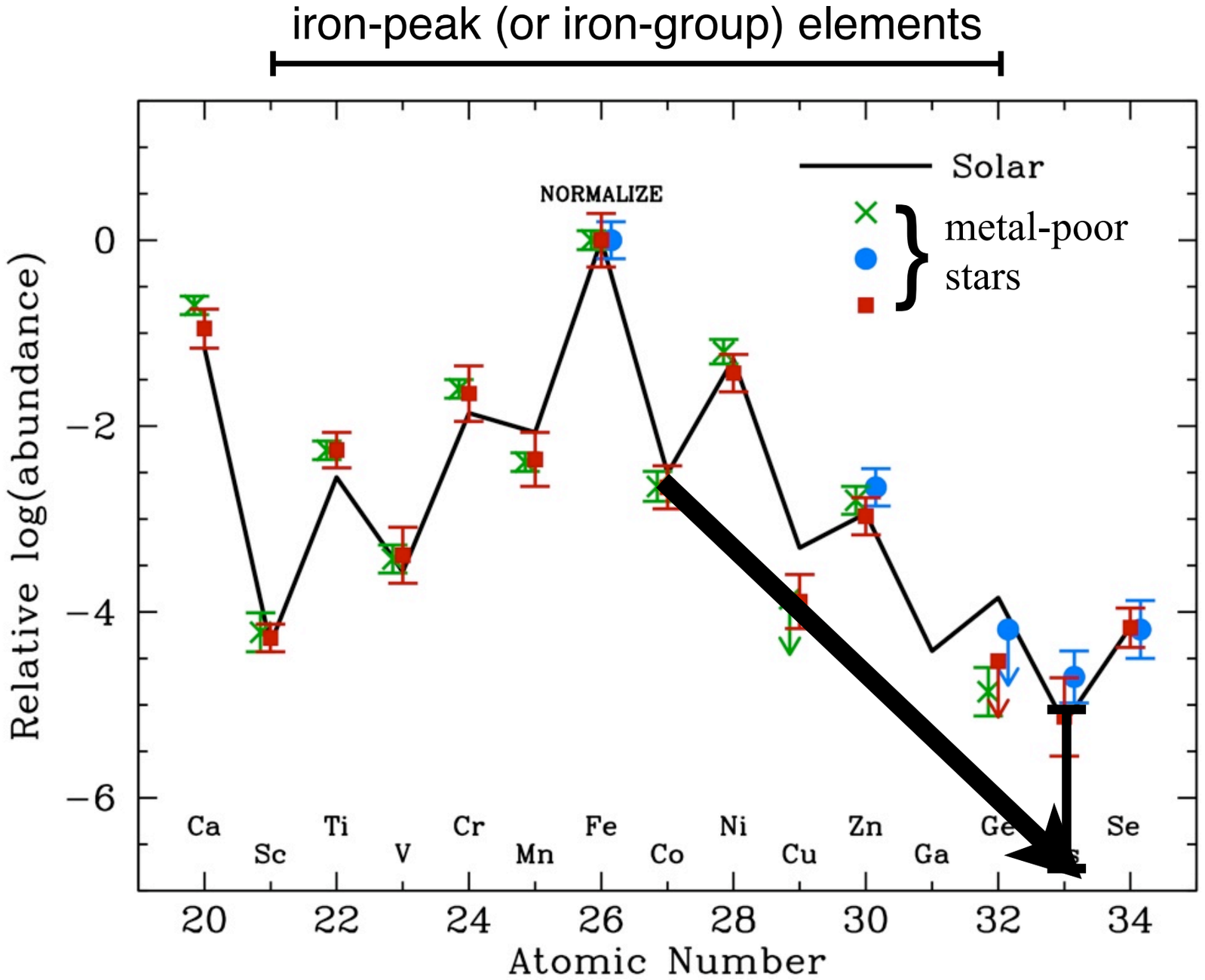
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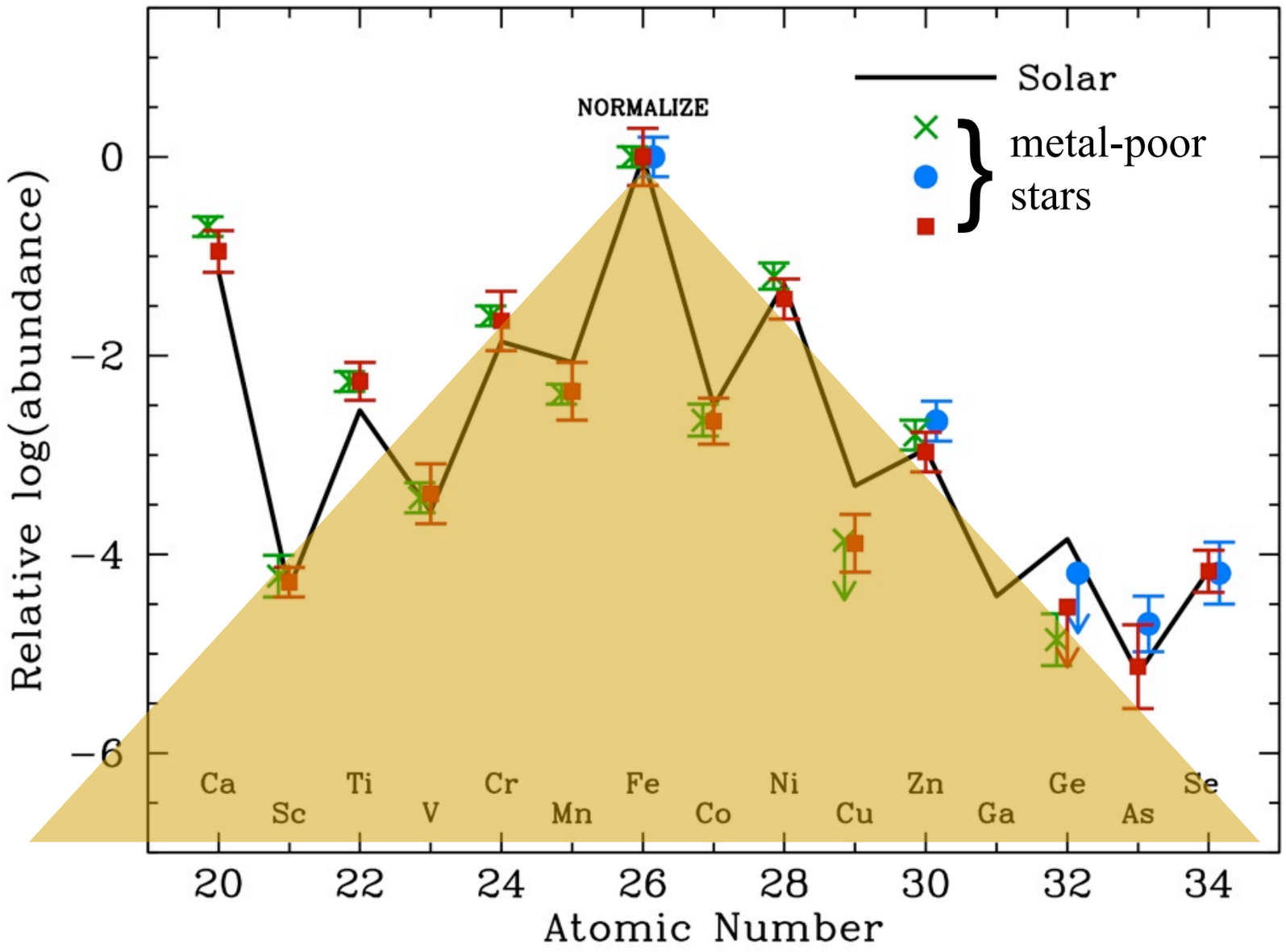
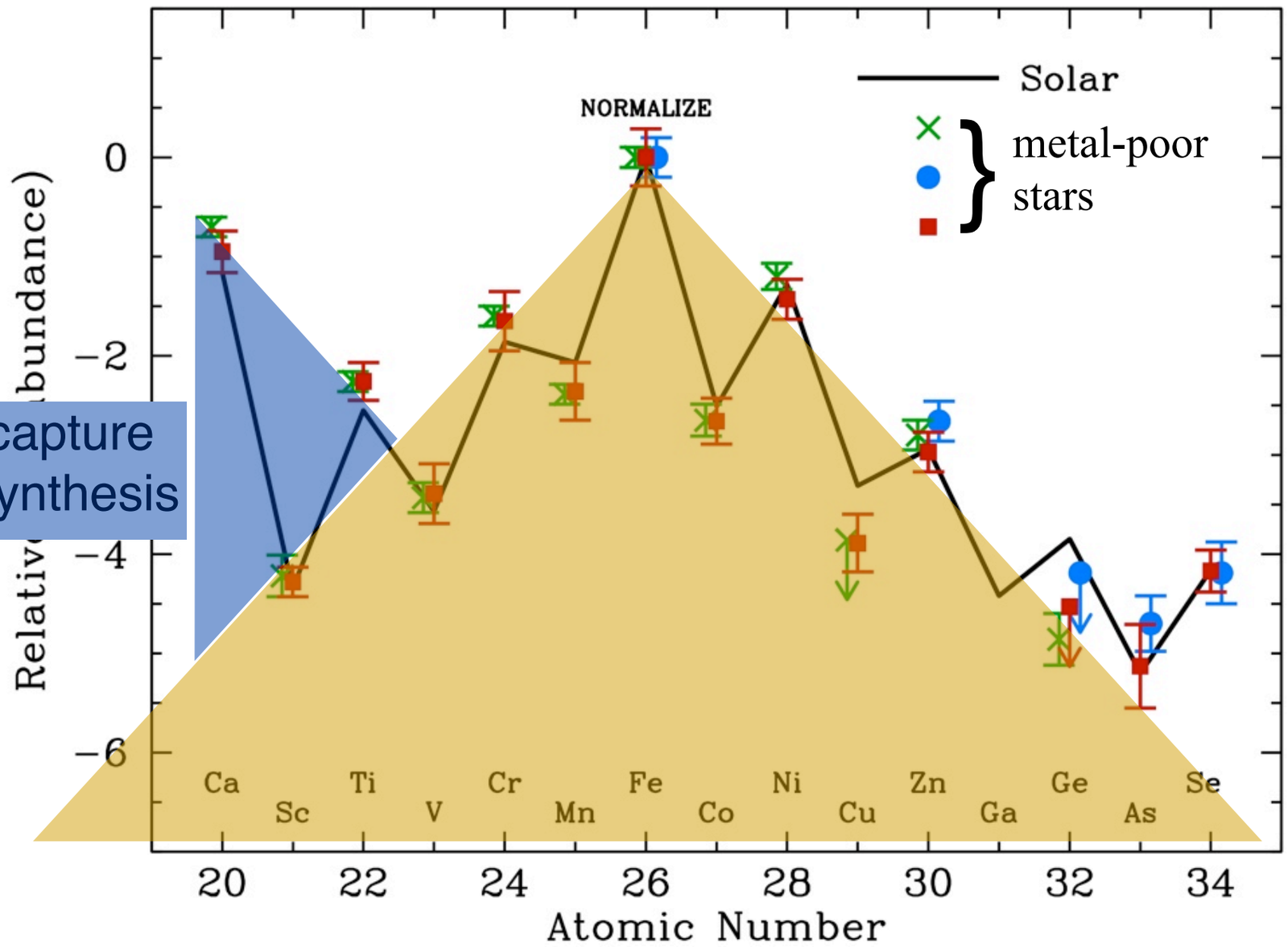


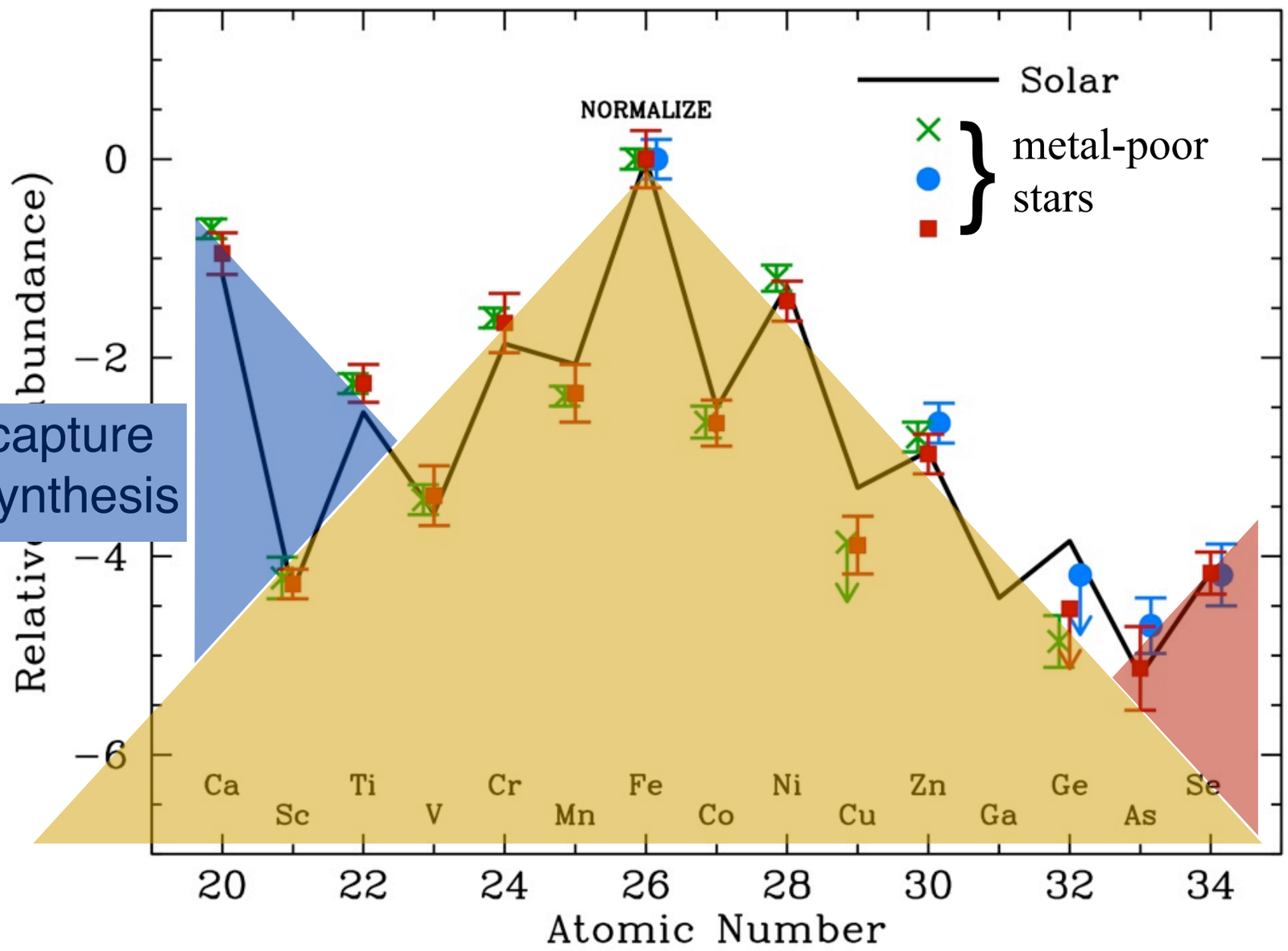
iron-peak (or iron-group) elements

alpha-capture nucleosynthesis



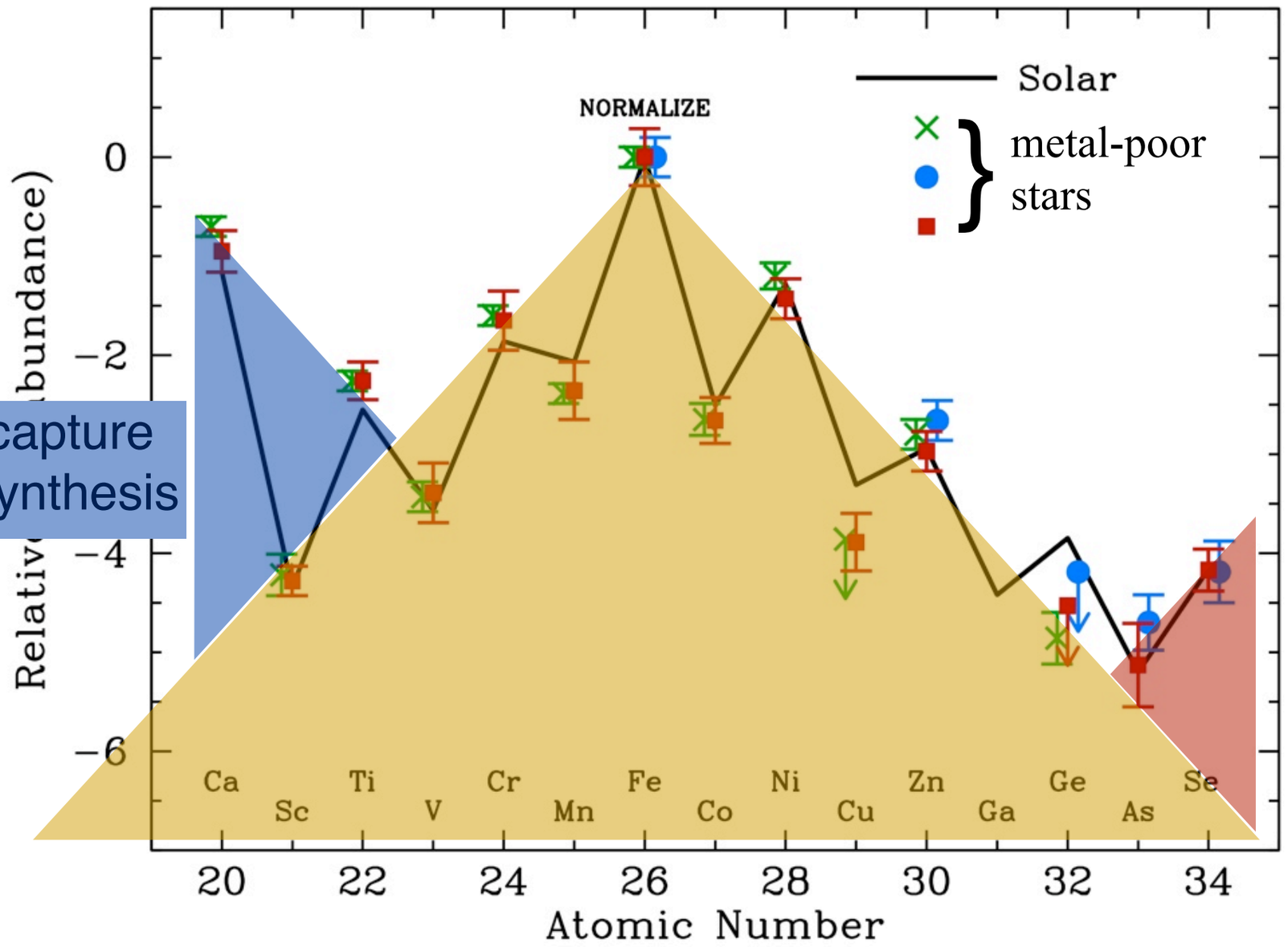
iron-peak (or iron-group) elements

alpha-capture nucleosynthesis

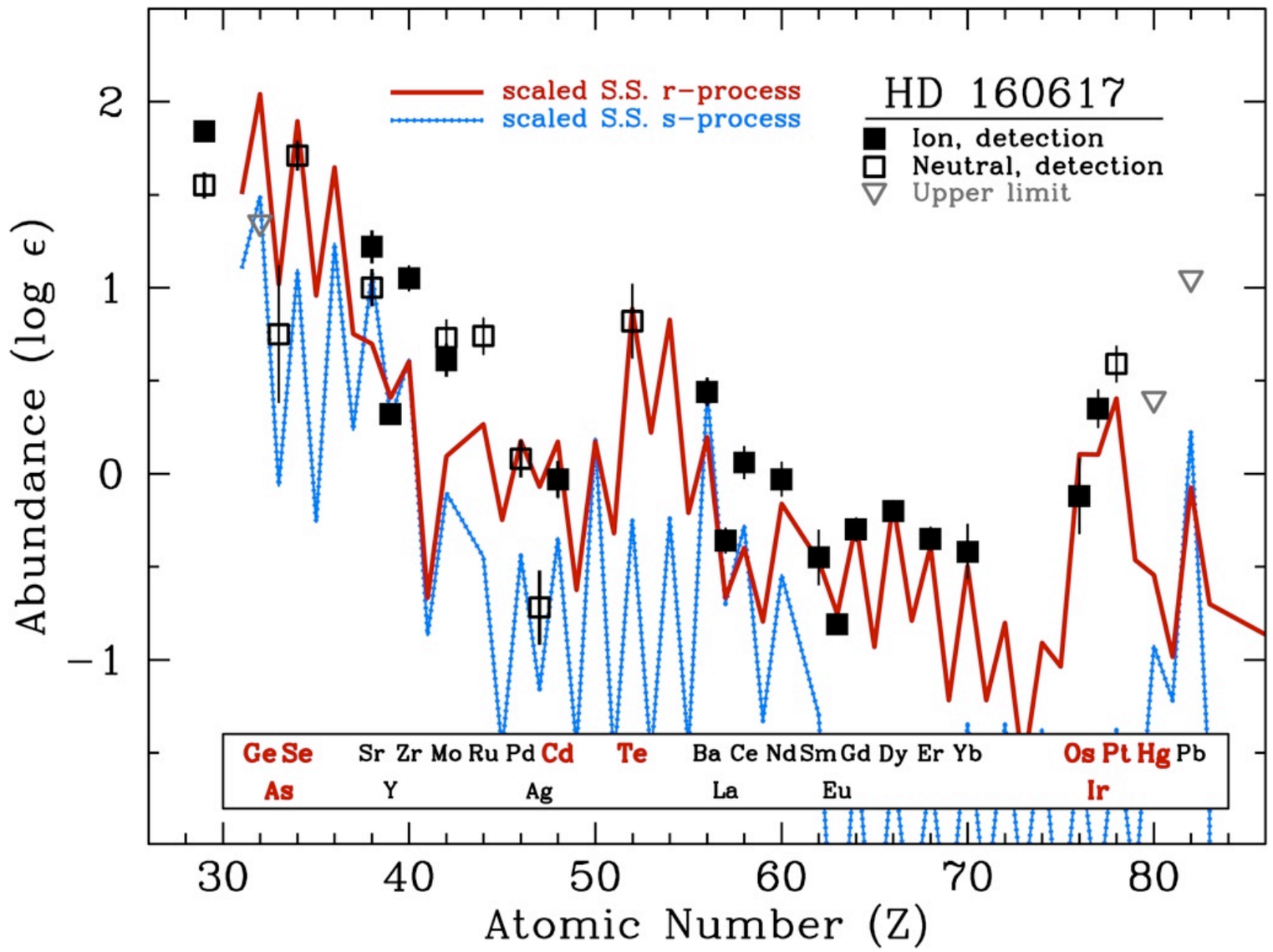


iron-peak (or iron-group) elements

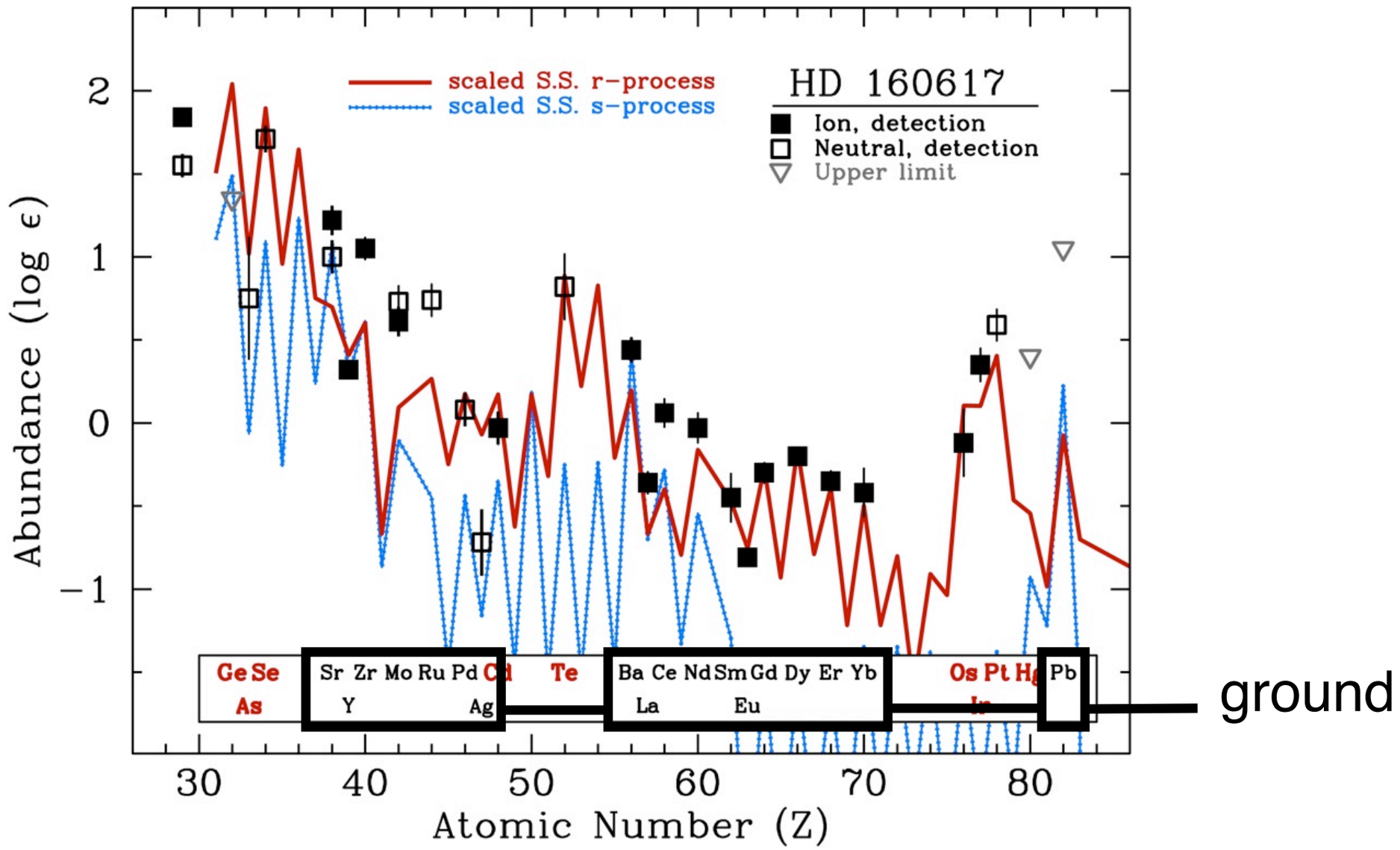
alpha-capture nucleosynthesis



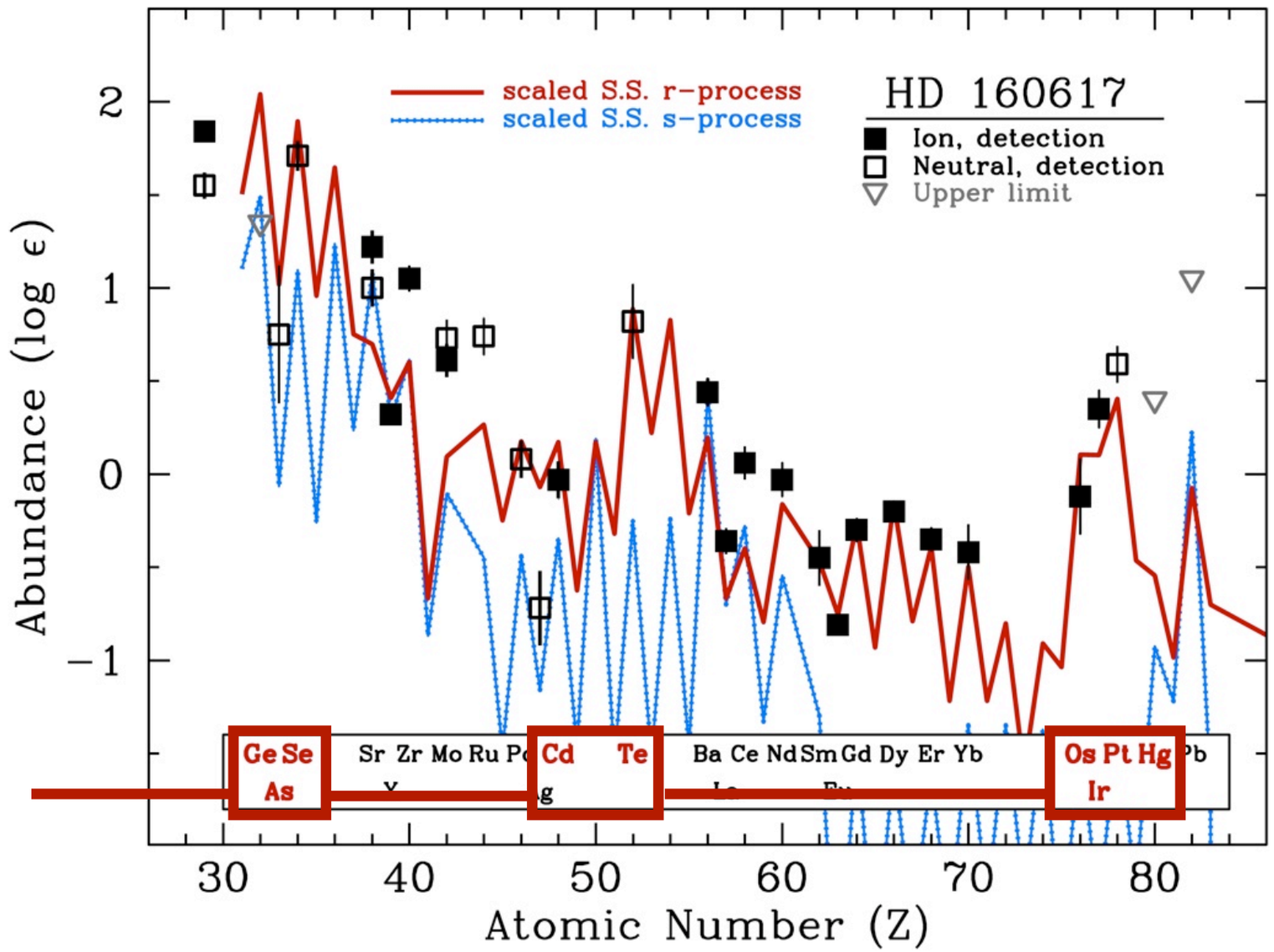
Is this the start of heavy element nucleosynthesis?



Roederer & Lawler (2012, ApJ, 750, 76)



Roederer & Lawler (2012, ApJ, 750, 76)

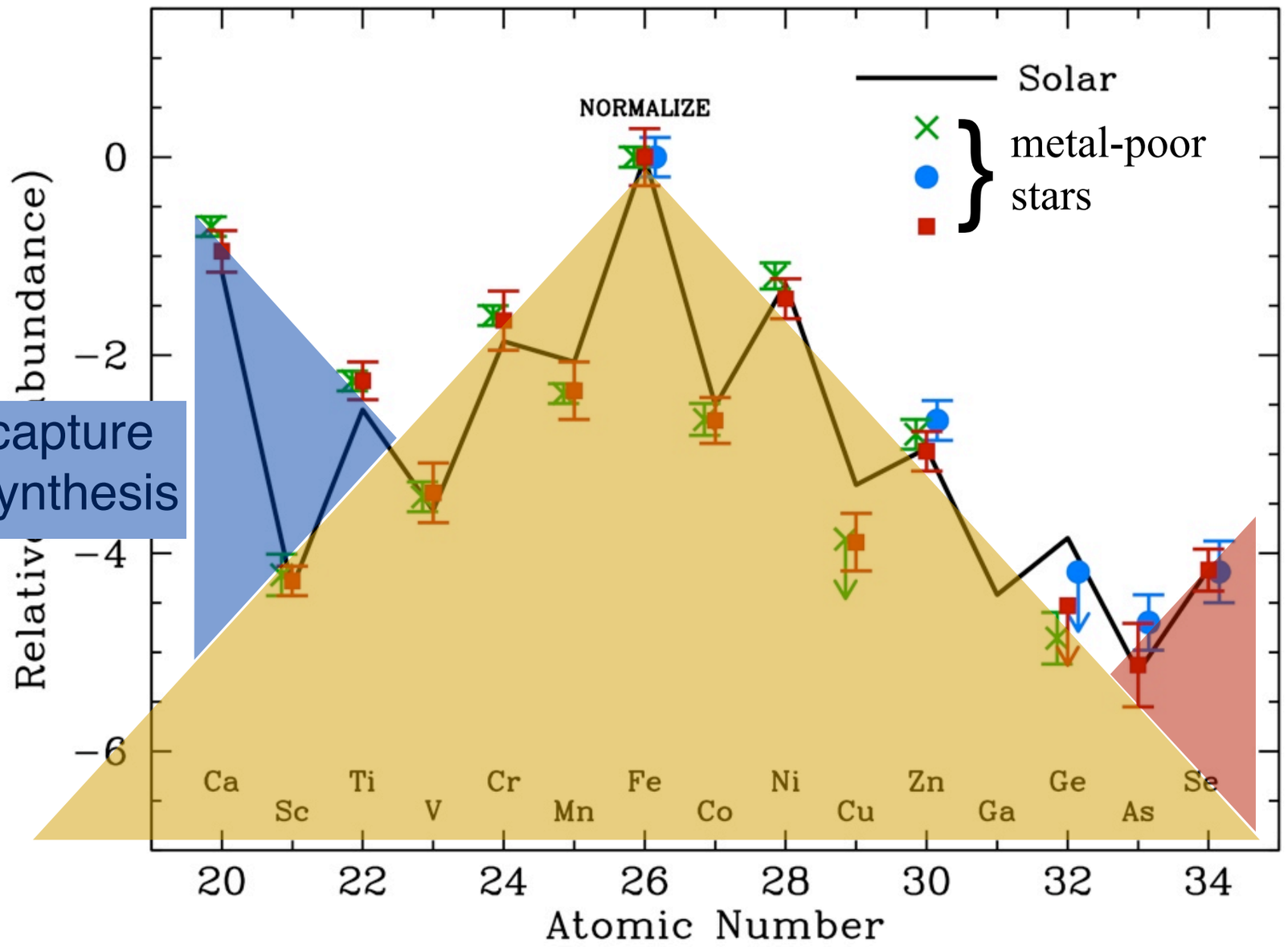


HST only!

Roederer & Lawler (2012, ApJ, 750, 76)

iron-peak (or iron-group) elements

alpha-capture nucleosynthesis



Is this the start of heavy element nucleosynthesis?