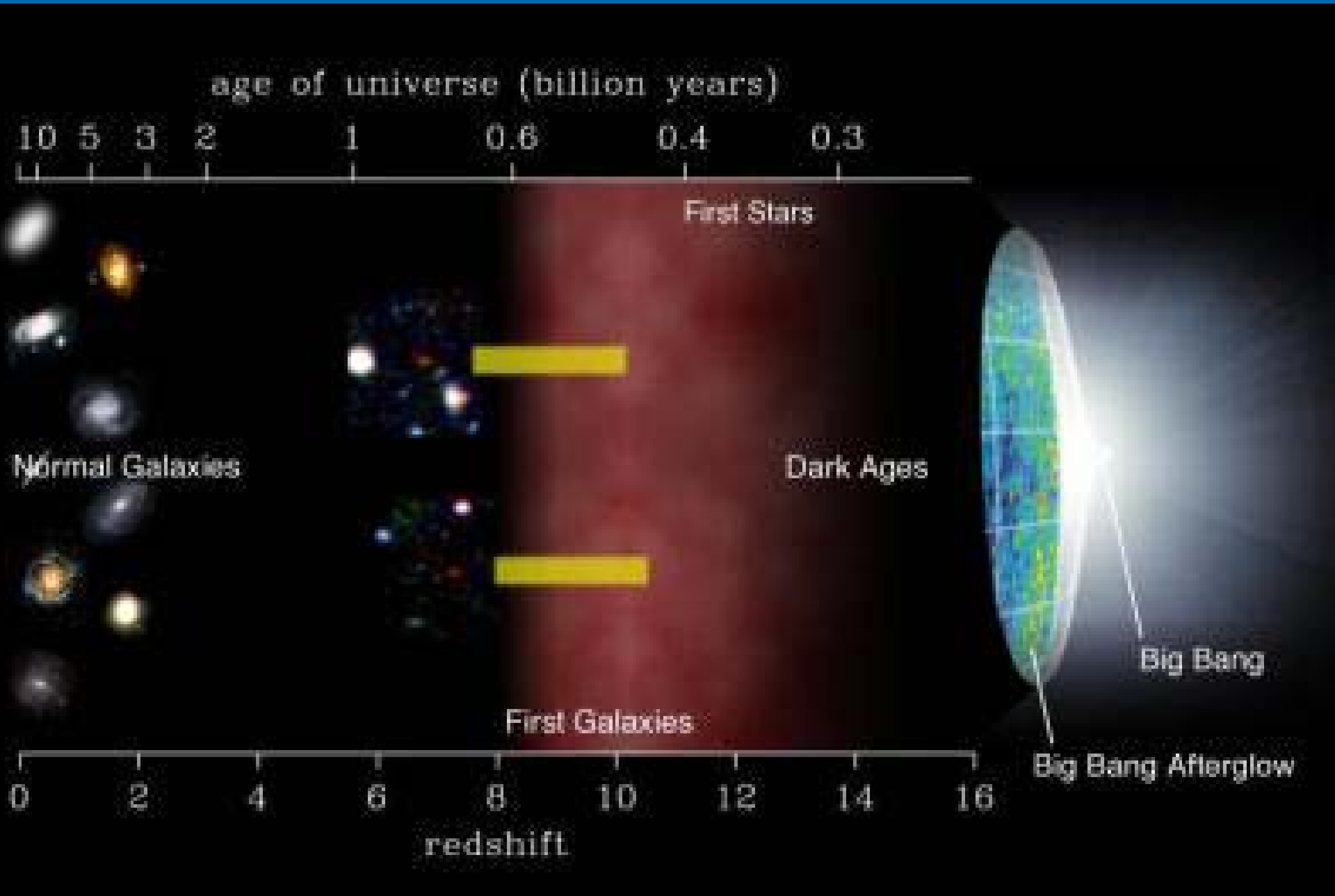
THE FIRST STARS:

Uranium-rich metal-poor star

CS 31082-001

- HST – STIS 45 orbits – 43 completed
- PI: Roger Cayrel (2001 – 2004)
- Useful range: 250-310nm, R~30,000
- B. Barbuy, M. Spite, V. Hill, F. Primas, B. Plez, C. Sneden, F. Spite, T.C. Beers, J. Andersen, B. Nordstrom, P. Bonifacio, P. François, P. Molaro, C. Siqueira-Mello

Evolution of Universe vs. redshift



The first generation of stars was never observed but should be detected in two ways:

- High mass stars explode as supernovae and produce an intense γ-ray peak (z ~ 15 ?)

-First generations of low mass stars should be still evolving, identified by a very low metallicity (z ~ 5 to 15)

Beers & Christlieb 2005, ARA&A

TABLE 2 Definition of subclasses of metal-poor stars

Neutron-capture-rich stars	
r-I	$0.3 \leq$ [Eu/Fe] $\leq +1.0$ and [Ba/Eu] < 0
r-II	[Eu/Fe] $> +1.0$ and [Ba/Eu] < 0
s	[Ba/Fe] $> +1.0$ and [Ba/Eu] $> +0.5$
r/s	$0.0 <$ [Ba/Eu] $< +0.5$
Carbon-enhanced metal-poor stars	
CEMP	[C/Fe] $> +1.0$
CEMP-r	[C/Fe] $> +1.0$ and [Eu/Fe] $> +1.0$
CEMP-s	[C/Fe] $> +1.0$, [Ba/Fe] $> +1.0$, and [Ba/Eu] $> +0.5$
CEMP-r/s	[C/Fe] $> +1.0$ and $0.0 <$ [Ba/Eu] $< +0.5$
CEMP-no	[C/Fe] $> +1.0$ and [Ba/Fe] < 0

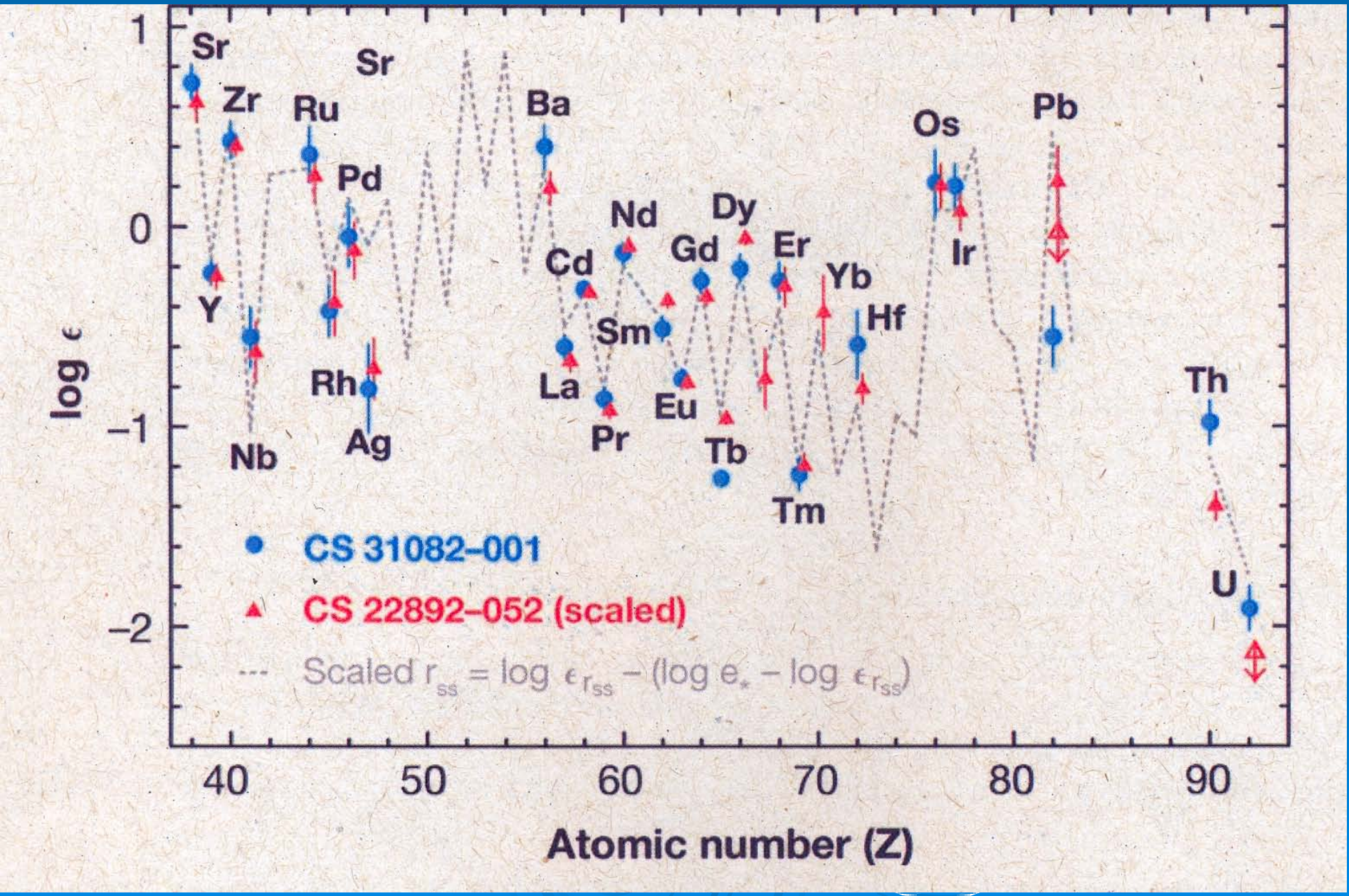
So far, 12 r-II stars (Hayek et al. 2009)

6 with well-detected Thorium

3 stars with Uranium detected:

- CS 31082-001 (Cayrel et al. 2001; Hill et al. 2002)
- HE 1523-0901 (Frebel et al. 2007)
- BD+17º3248 (Cowan et al. 2002)

Beers & Christlieb 2005, ARA&A



There are 3 types of chronometers involving U, Th (Cayrel et al. 2001, Nature, 409, 691):

$$\Delta t = 46.7[\log(\mathrm{Th}/r)_0 - \log(\mathrm{Th}/r)_{\mathrm{obs}}]$$

$$\Delta t = 14.8[\log(\mathrm{U}/r)_0 - \log(\mathrm{U}/r)_{\mathrm{obs}}]$$

$$\Delta t = 21.8[\log(\mathrm{U}/\mathrm{Th})_0 - \log(\mathrm{U}/\mathrm{Th})_{\mathrm{obs}}]$$

expressed in Gyr, r is a stable third-peak

MAIN AIM:
TO REDUCE ERROR ON AGES FROM:

- LINE MEASUREMENTS – BLENDS, S/N, NUMBER OF RELIABLE LINES
- ATOMIC PARAMETERS – LOG GF, C6
- STELLAR PARAMETERS: TEFF, LOGG, [FE/H],VT
- PRODUCTION RATIO (PR)

Frebel Et al. 2007

Age± 2.7Gyr

TABLE 1

AGES DERIVED FROM DIFFERENT ABUNDANCE RATIOS

X/Y	log (PR)[a]	Ref.	log $\epsilon(X/Y)_{obs}$	Age (Gyr)	Uncertainties[b] (Gyr)
Th/Eu	−0.377	1	−0.58	9.5	3.3/3.4/0.6/0.6/5.6
	−0.33	2	−0.58	11.7	3.3/3.3/0.5/0.5/5.6
	−0.295	3	−0.58	13.3	3.3/3.0/0.2/0.2/5.6
Th/Os	−1.15	2	−1.38	10.7	3.3/2.8/5.6/0.0/5.6
Th/Ir	−1.18	2	−1.44	12.1	3.3/1.9/2.8/1.4/5.6
	−1.058	1	−1.44	17.8	3.3/2.0/2.9/1.5/5.6
U/Eu	−0.55	2	−1.44	13.2	1.9/0.6/0.4/0.2/1.6
U/Os	−1.37	2	−2.24	12.9	1.9/0.6/1.2/0.3/1.6
U/Ir	−1.40	2	−2.30	13.3	1.9/0.3/0.3/0.7/1.6
	−1.298	3	−2.30	14.8	1.9/0.3/0.3/0.8/1.6
U/Th	−0.301	4	−0.86	12.2	2.8/0.4/0.9/0.4/2.2
	−0.29	5	−0.86	12.4	2.8/0.4/0.9/0.4/2.2
	−0.256	3	−0.86	13.1	2.8/0.5/1.0/0.5/2.2
	−0.243	6	−0.86	13.4	2.8/0.4/0.8/0.4/2.2
	−0.22	2	−0.86	13.9	2.8/0.4/0.9/0.4/2.2

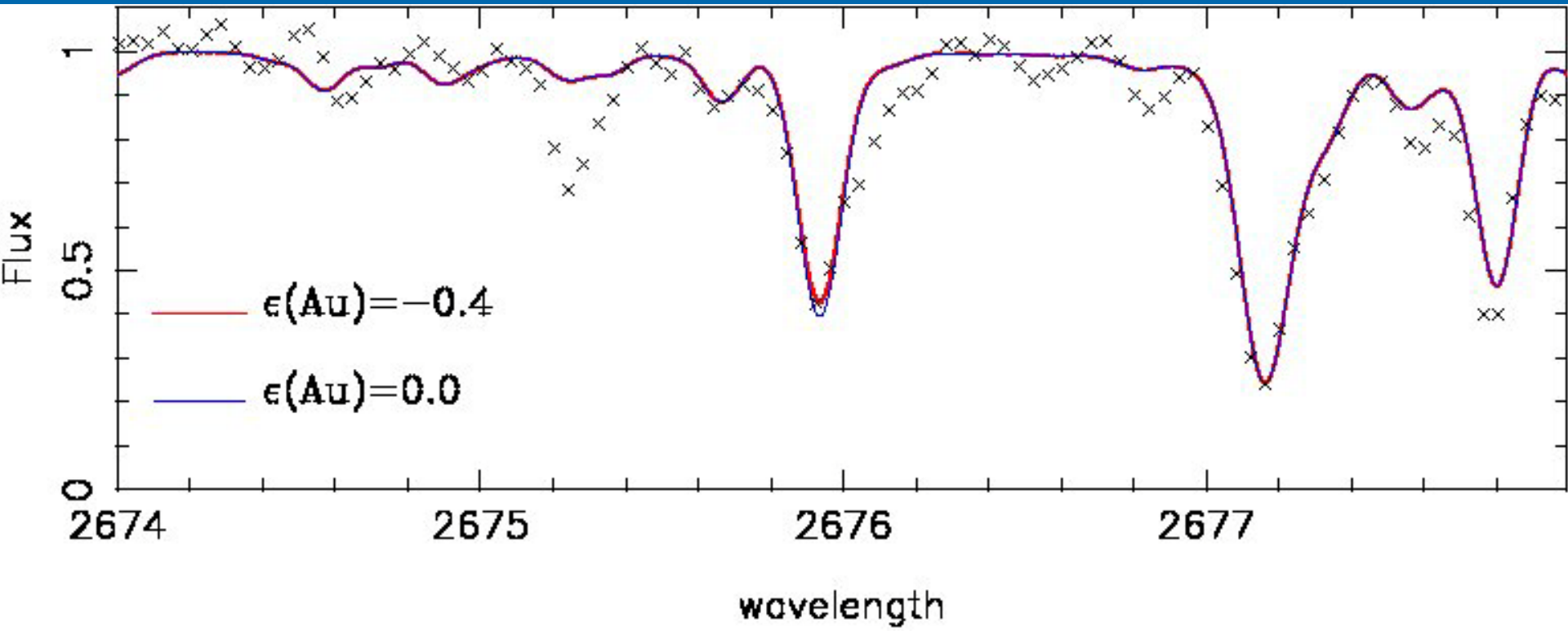
REFERENCES.—(1) Sneden et al. 2003; (2) Schatz et al. 2002; (3) Cowan et al. 2002; (4) Goriely & Arnould 2001; (5) Wanajo et al. 2002; (6) Dauphas 2005.

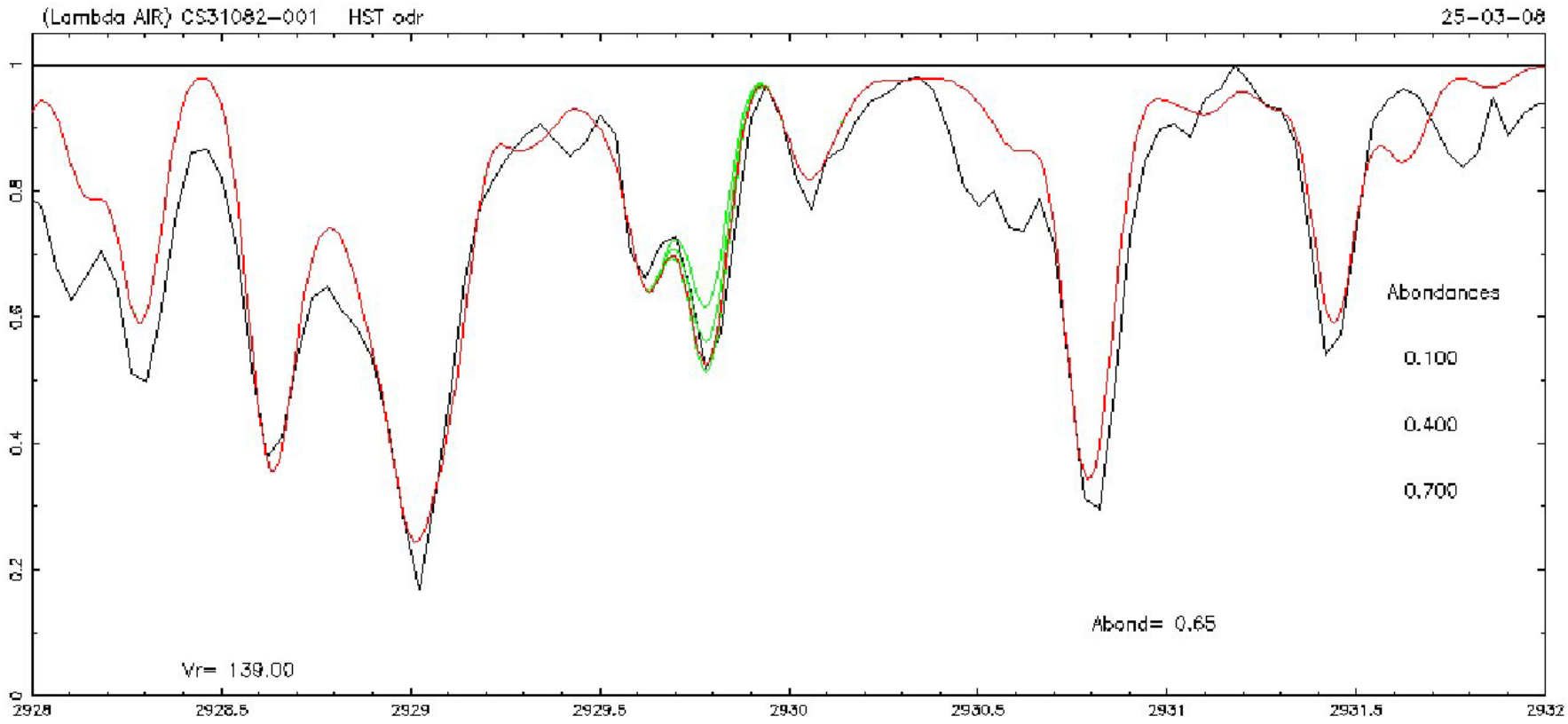
[a] Initial production ratio.

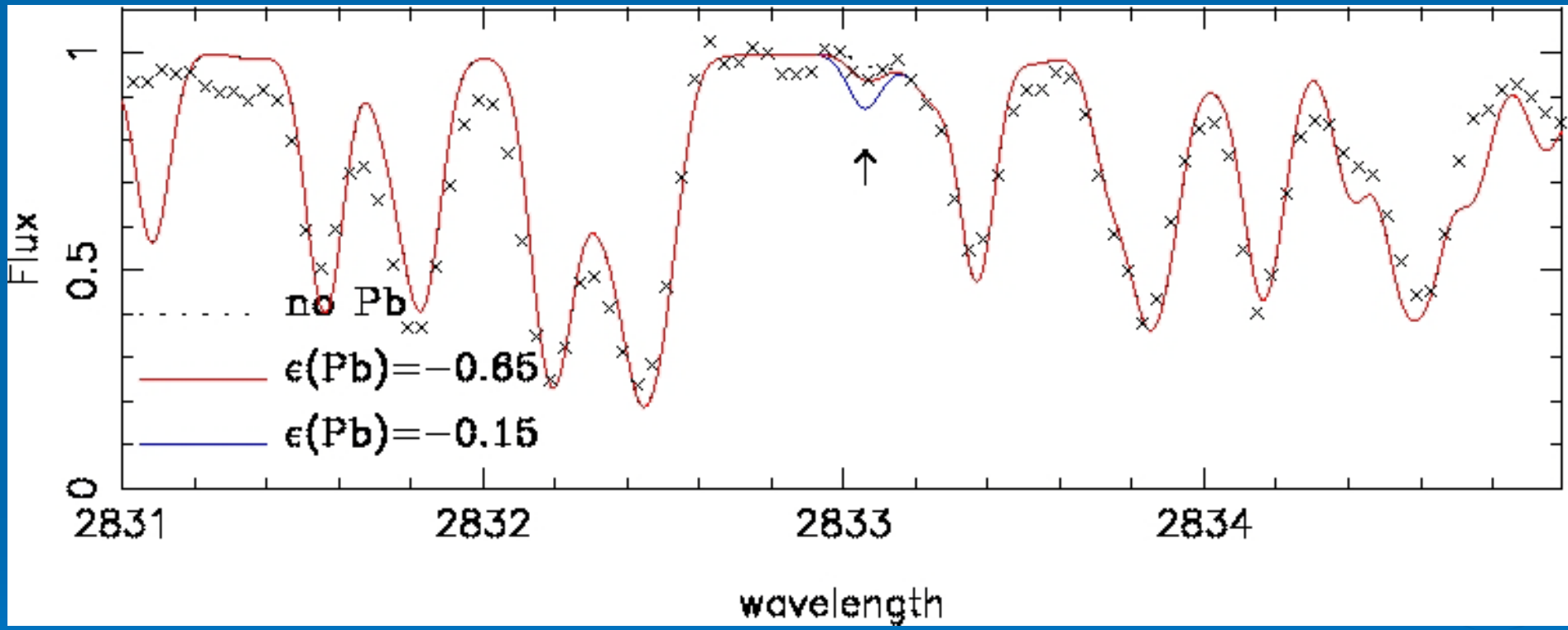
[b] Age uncertainties arising from uncertainties in observed measurements/ T_{eff}/log g/v_{micr}/PR.

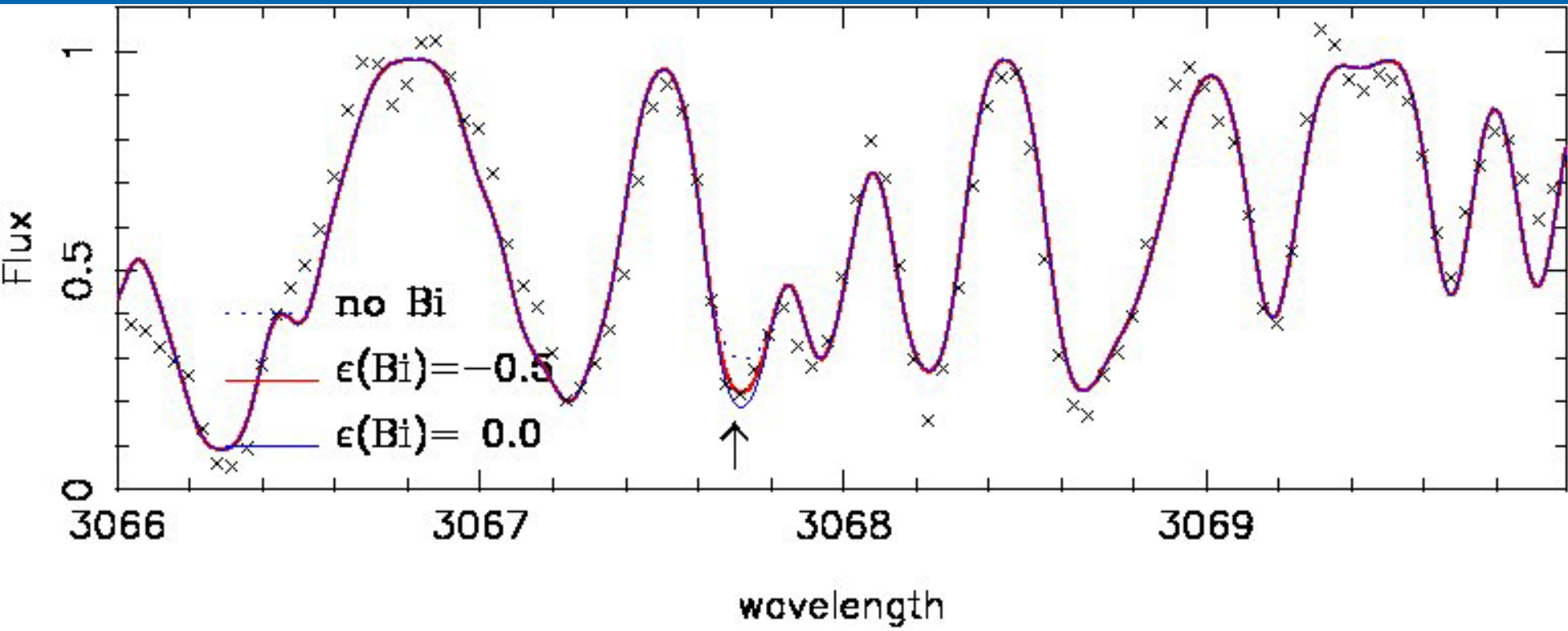
USE OF STIS SPECTRUM IN ORDER TO:

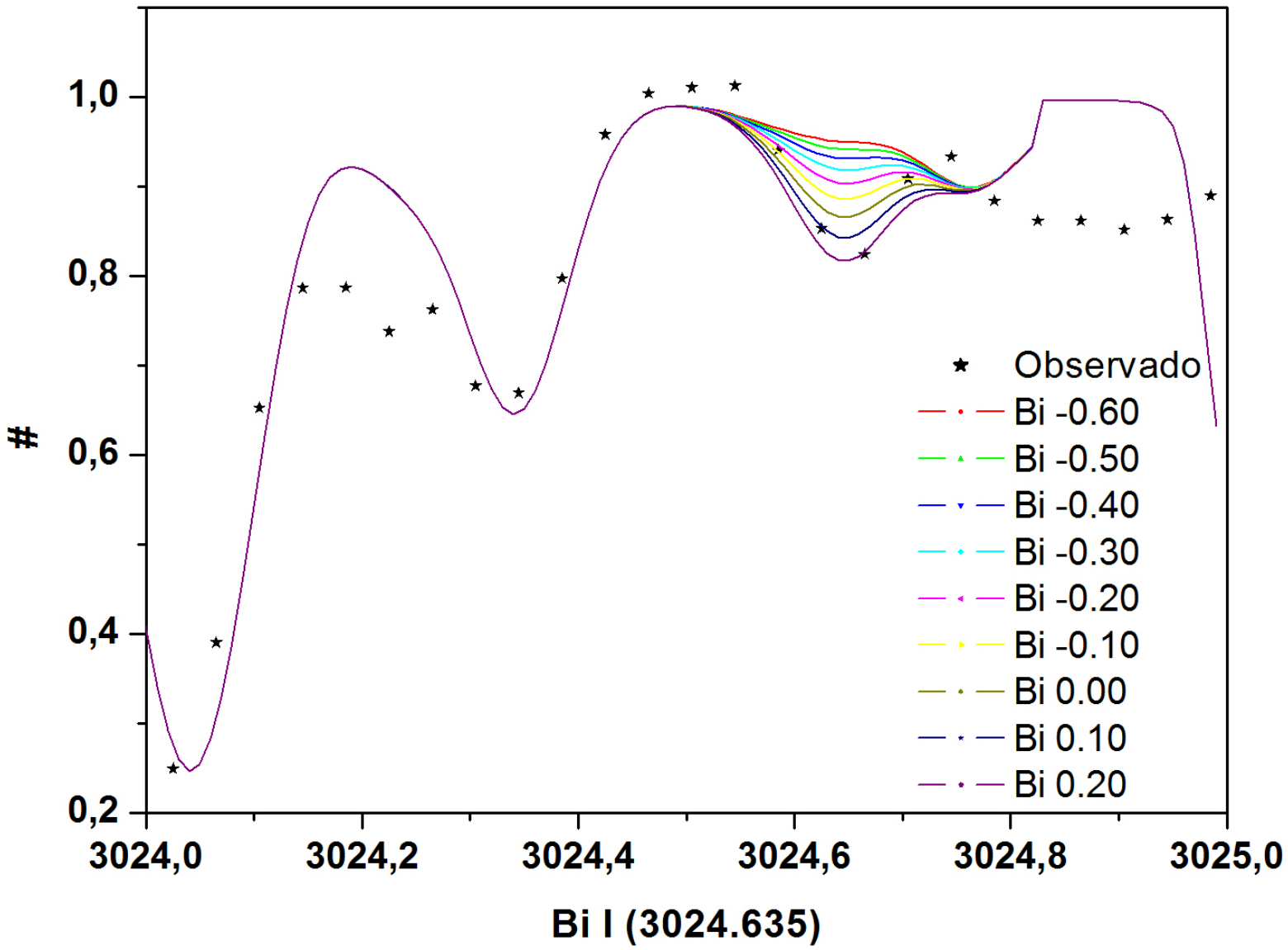
- Measurements of new elements, in particular the heaviest elements near the actinides: Bi, Pb
- Other dominantly r-elements: Eu, Os, Ir
- New lines of the elements: Th, U, Eu

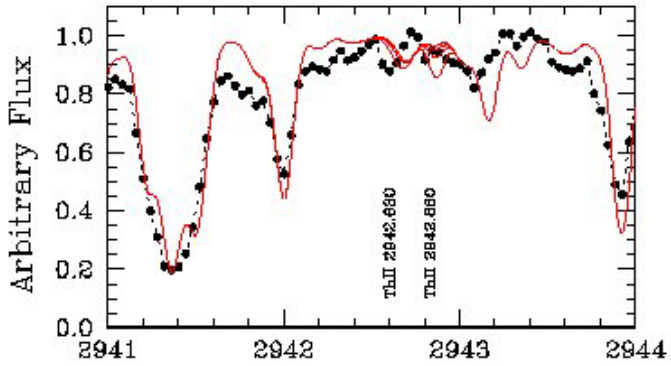

Flux
1
0.5
0
ϵ(Au)=−0.4
ϵ(Au)=0.0
2674
2675
2676
2677
wavelength


(Lambda AIR) CS31082-001 HST odr
25-03-08
Abondances
0.100
0.400
0.700
Abond= 0.65
Vr= 139.00
0
0.2
0.4
0.6
0.8
1
2928
2928.5
2929
2929.5
2930
2930.5
2931
2931.5
2932

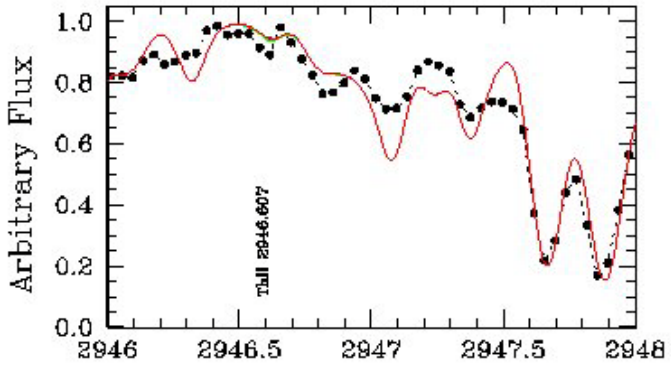

Flux
0
0.5
1
2831
2832
2833
2834
wavelength
no Pb
ϵ(Pb)=−0.65
ϵ(Pb)=−0.15


Flux
1
0.5
0
3066
3067
3068
3069
wavelength
no Bi
ϵ(Bi)=−0.5
ϵ(Bi)= 0.0


1,0
0,8
0,6
0,4
0,2
#
3024,0
3024,2
3024,4
3024,6
3024,8
3025,0
Bi I (3024.635)
Observado
Bi -0.60
Bi -0.50
Bi -0.40
Bi -0.30
Bi -0.20
Bi -0.10
Bi 0.00
Bi 0.10
Bi 0.20



logA(Th)=-1.48,-0.98(VLT),-0.48,none



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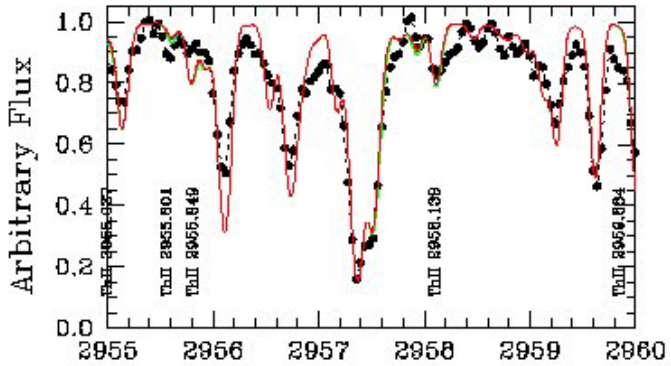

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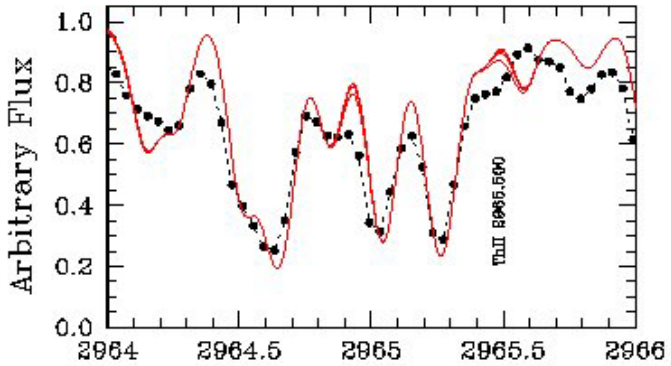

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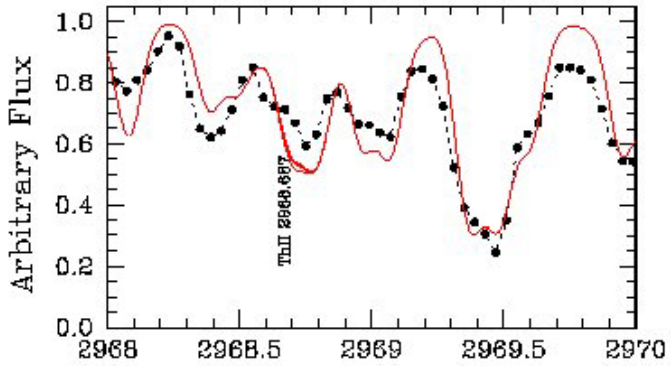

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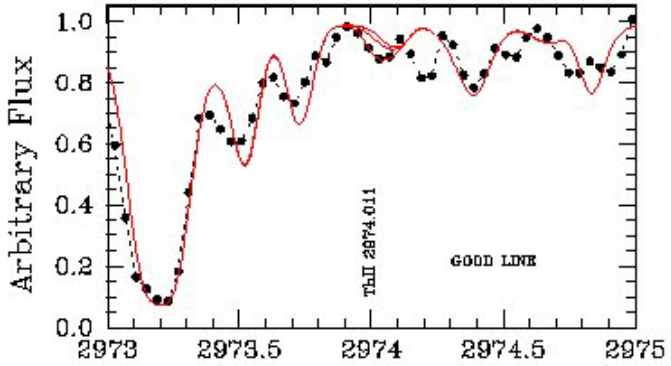
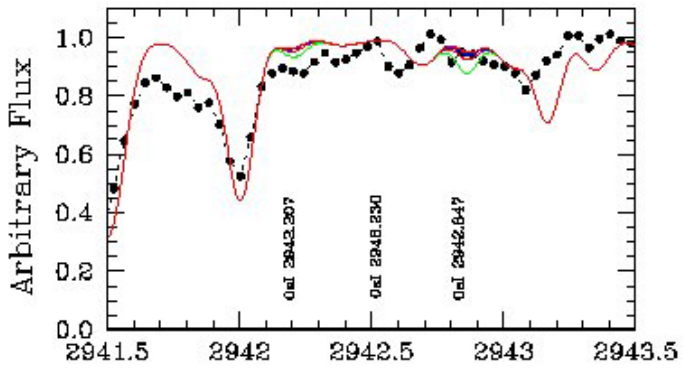
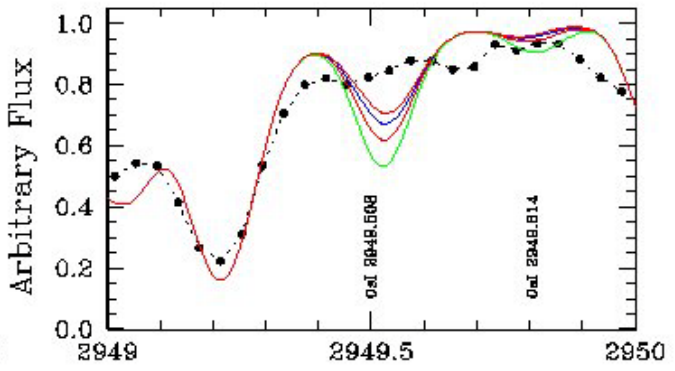


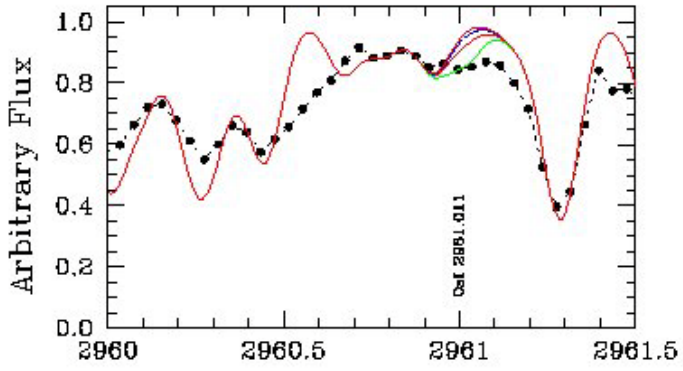
logA(Th)=-1.48,-0.98(VLT),-0.48,none



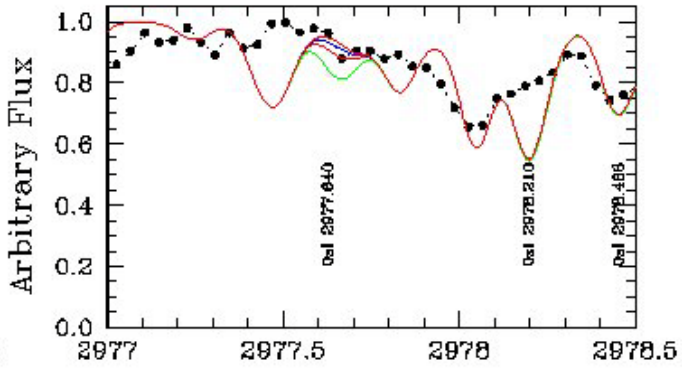
logA(Os)=-0.07,0.43(VLT),0.93,none



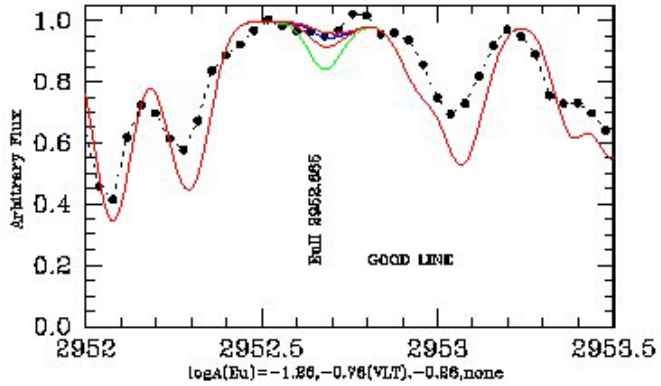
logA(Os)=-0.07,0.43(VLT),0.93,none

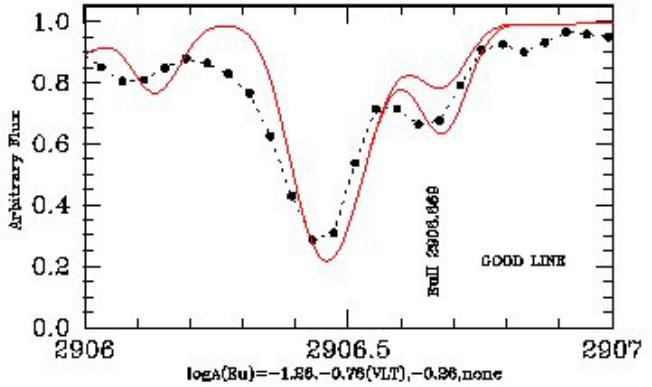


logA(Os)=-0.07,0.43(VLT),0.93,none



logA(Os)=-0.07,0.43(VLT),0.93,none





		LOG A(X)			
		Z	Sun	VLT	HST
OsI	2838.6	76	1.45	0.43	0.10
OsI	3058.6				0.30
PtI	2929.8	78	1.80	----	0.65
PtI	3064.7				0.40
AuI	2675.9	79	1.01	----	-0.90
PbI	2833.0	82	1.95	-0.55	-0.65
BiI	3067.7	83	0.68	----	-0.50
BiI	3024.6				0.10
ThII	2974.0	90	0.85	-0.98	-0.48

Pb is deficient (Plez et al. 2004 with VLT spectrum, confirmed with HST)

Os, Pt ehanced
together with U, Th

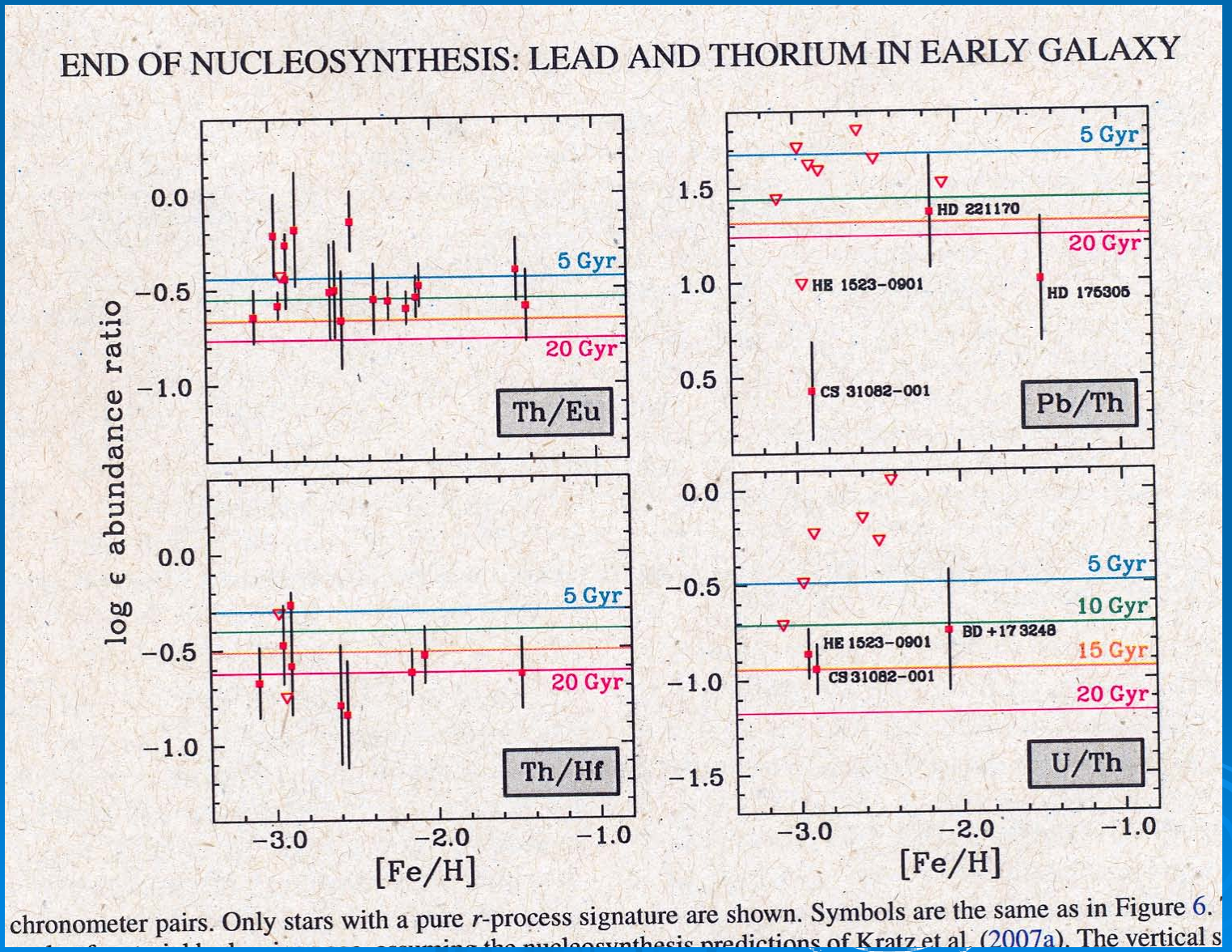
Bi, Au less enhanced

➔Better precision expected by including new lines (as for ThII)

Actinide chronometers:
232Th, 235U, 238U

	log(Th/U)	age(Kratz et al. 07)
CS	0.94	16.2 Gyr
BD	0.88	14.9
HE	0.86	idem

Roederer et al. 2009



chronometer pairs. Only stars with a pure *r*-process signature are shown. Symbols are the same as in Figure 6. ' nucleosynthesis predictions of Kratz et al. (2007a). The vertical s

Th/U ages should be better constrained by abundances of stable elements, such as Pb, Bi:

➔Pb is low: supposing a complete decay of 232Th → 208Pb

235U → 207Pb

238U → 206Pb

Log A(Pb) = 0.1, but measured is -0.65

→ Very low age for CS 31082-001

Roederer et al. 2009 :
universality of abundance pattern of heavy r-process elements applies to Ba to Pt.

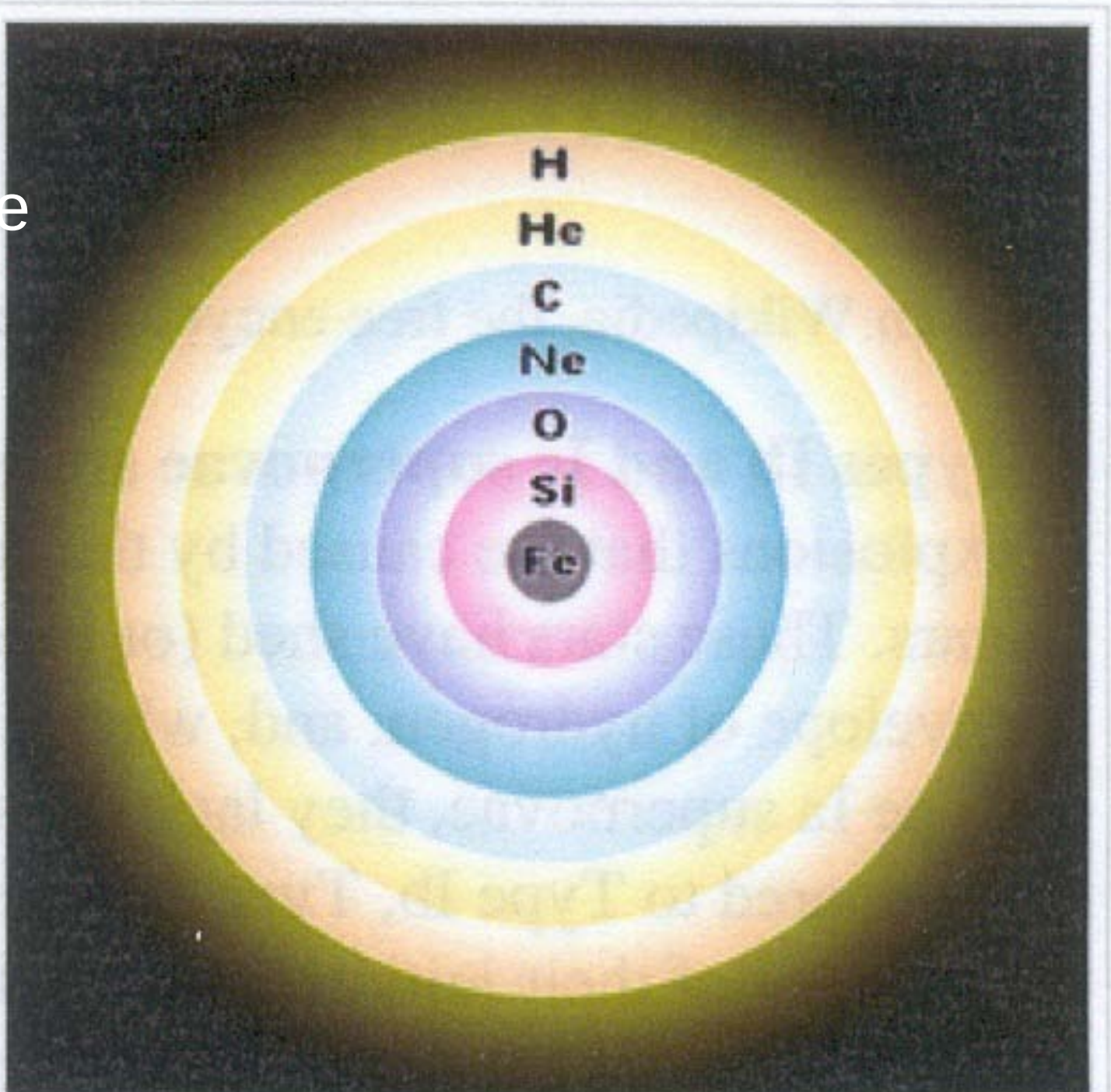
It seems not to extend to Pb and beyond.

4 stars were found to show actinides boost:
CS30306-132, [Fe/H]=-2.97 (Honda)
CS31078-018, [Fe/H]=-2.85 (Lai)
HE1219-018, [Fe/H]=-2.42 (Jonsell)
CS31082-001, [Fe/H]=-2.9 (Hill)
→ so far this is not understood

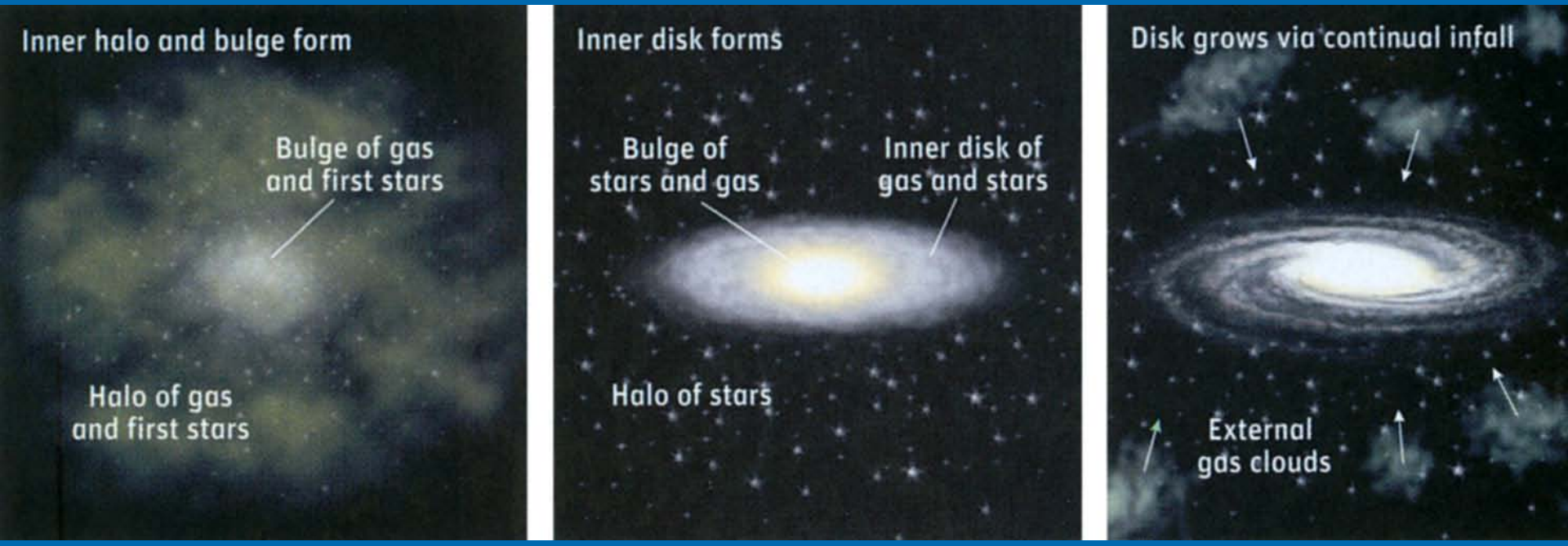
Conclusions:

- Lowest metallicity oldest stars = laboratories for insights into the r-process nucleosynthesis
- STIS UV spectrum:
  legacy for atomic physics in terms of lines of heavy elements and FeII
- Independent constraint on the age of the oldest stars

Supernovae enrich Universe In chemical elements



Formation of the Galaxy



First Detection of Uranium in an old star

Cayrel et al. 2001, Nature

CS31082-001
14 Gyr

Now: 3 such stars detected

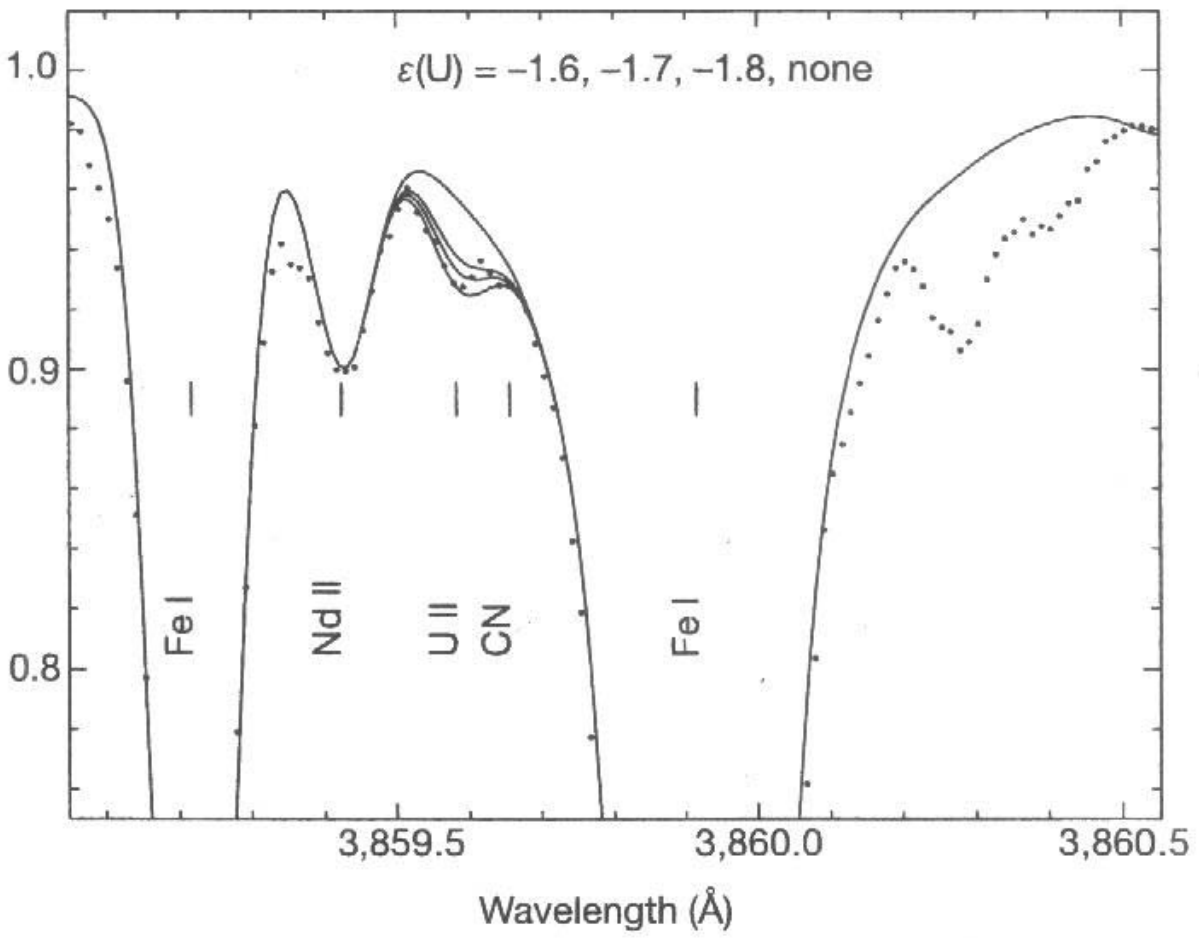


Figure 1 The spectrum of CS31082–001 around the U II line at 385.959 nm. The synthetic spectra (solid lines) were computed with the stellar atmospheric parameters given in the text, and for the three U abundances indicated, adopting an oscillator strength $f = 0.053$ for the line (ref. 13). The observed spectrum (data points) was obtained in four hours, for a total S/N ratio of 300.

The End