John Cowan and the low metallicity galaxy

Silver, palladium and the 'second' r-process

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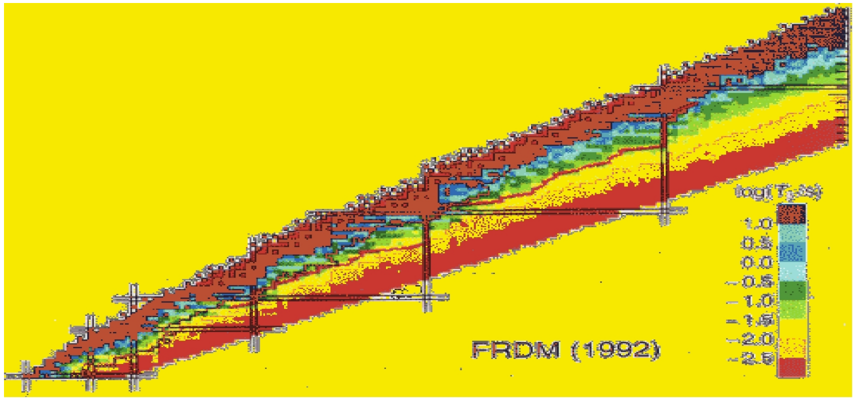


Some of John's contributions

R-process predictions/simulations

- 2 regimes or sites

Near-UV observations

- Metal-poor stars
- BD+17 3248

Zr, Pd and Ag compared to recent observations

BD +17 3248

BD +17 3248

Gold (Au) was first detected in this star

Age: 13.8 ± 4 Gyr

Since Cowan et al 2002 (Right hand side table) 6 more n-capture elements have been detected making BD +17 3248 the record holding star with the most (32) derived n-capture elemental abundances

TABLE 3
NEUTRON CAPTURE ELEMENT ABUNDANCES FOR BD +17°3248

			McDonald, Keck				*HST*/STIS			
Species	Z	$\log \epsilon_{\odot}$[a]	$\log \epsilon$	σ[b]	Number	[M/Fe]	$\log \epsilon$	σ[b]	Number	[M/Fe]
Ge I	32	3.41	...	...	...	...	0.60	(0.15)	1	−0.72
Sr I	38	2.90	0.90	(0.15)	1	0.09	...	...	...	...
Sr II	38	2.90	1.10	(0.10)	2	0.29	...	...	...	...
Y II	39	2.24	0.04	0.05	11	−0.11	...	...	...	...
Zr II	40	2.60	0.76	0.14	19	0.25	0.65	0.13	5	0.14
Nb II	41	1.42	−0.18	(0.15)	1	0.49	...	...	...	...
Pd I	46	1.69	0.24	0.09	3	0.64	...	...	...	...
Ag I	47	1.24	−0.28	0.11	2	0.57	...	...	...	...
Ba II	56	2.13	0.44	0.11	6	0.40	...	...	...	...
La II	57	1.22	−0.42	0.05	15	0.45	...	...	...	...
Ce II	58	1.55	−0.18	0.06	22	0.36	...	...	...	...
Pr II	59	0.71	−0.71	(0.05)	9	0.67	...	...	...	...
Nd II	60	1.50	−0.07	0.17	40	0.52	...	...	...	...
Sm II	62	1.00	−0.42	0.14	17	0.67	...	...	...	...
Eu II	63	0.51	−0.67	0.05	9	0.91	...	...	...	...
Gd II	64	1.12	−0.26	0.09	15	0.71	...	...	...	...
Tb II	65	0.33	−0.91	(0.05)	5	0.85	...	...	...	...
Dy II	66	1.10	−0.03	0.07	19	0.96	...	...	...	...
Ho II	67	0.50	−0.70	0.17	3	0.89	...	...	...	...
Er II	68	0.93	−0.20	0.06	7	0.96	...	...	...	...
Tm II	69	0.13	−1.07	(0.10)	2	0.89	...	...	...	...
Os I	76	1.45	0.45	(0.10)	2	1.1:	0.47	(0.05)	3	1.11
Ir I	77	1.30	0.30	0.13	3	1.09	...	...	...	...
Pt I	78	1.80	...	...	...	...	0.67	0.07	5	0.96
Au I	79	0.83	...	...	...	...	−0.3:	(0.30)	1	0.8:
Pb I	82	1.85	...	...	...	...	<0.3	0.25	2	<0.5
Th II	90	0.12	−1.18	(0.10)	2	0.79	...	...	...	...
U II	92	−0.07	−2.0:	(0.30)	1	0.0:	...	...	...	...

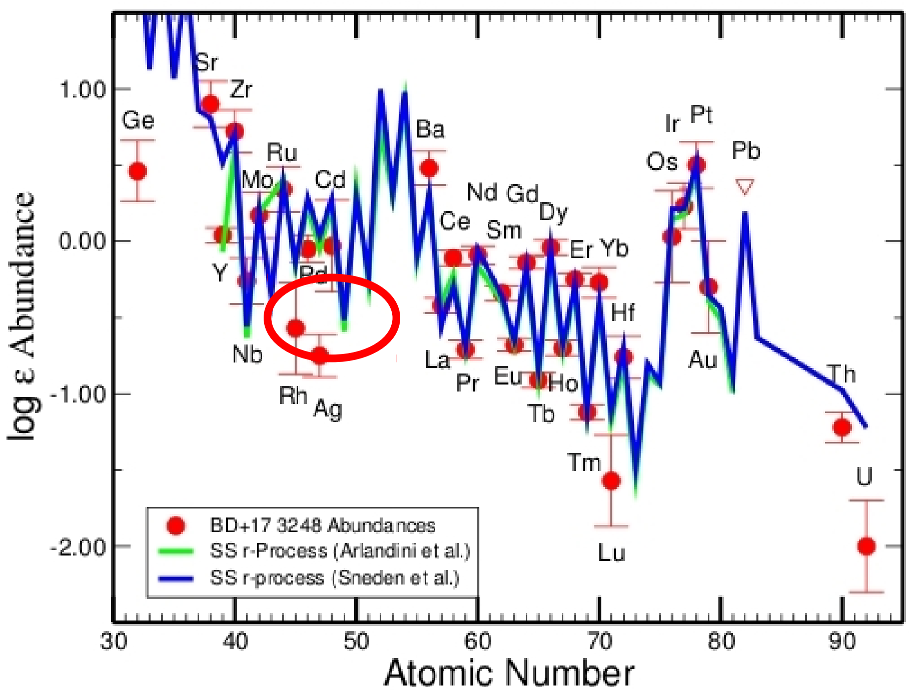
[a] Taken from Grevesse & Sauval 1998.

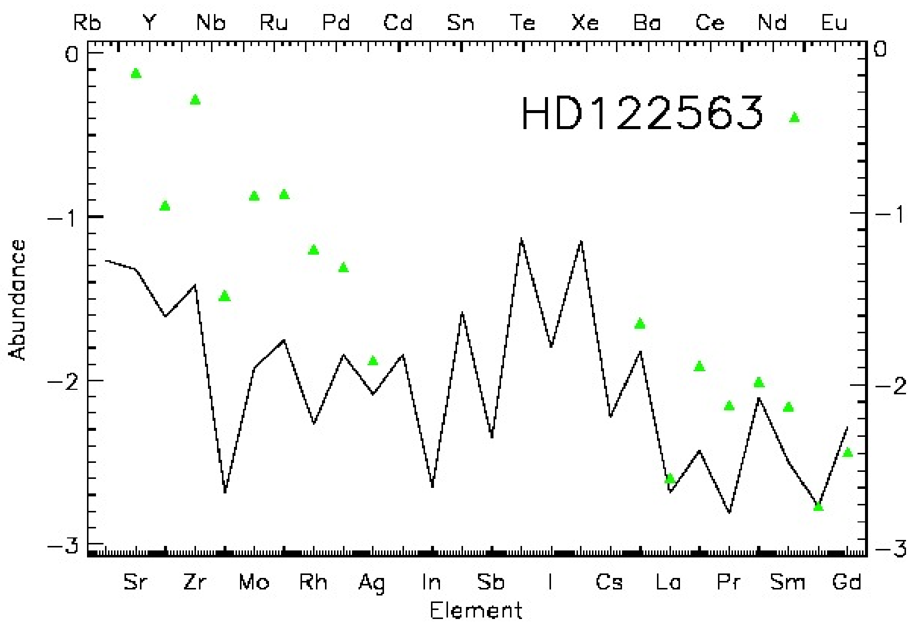
[b] For a species with three or more lines, the σ entry is the maximum of the measured sample standard deviations or 0.05. If there are two lines, the entry is the greater of the true σ or 0.10, and if only one line has been used, the entry is the greater of the true σ or 0.15. For any of these cases, if an arbitrary minimum value of 0.05, 0.10, or 0.15 is entered, then it is enclosed in parentheses.

Indications of 2 r-processes in metal-poor stars

BD+17 3248 r-rich
Solar scaled r-process

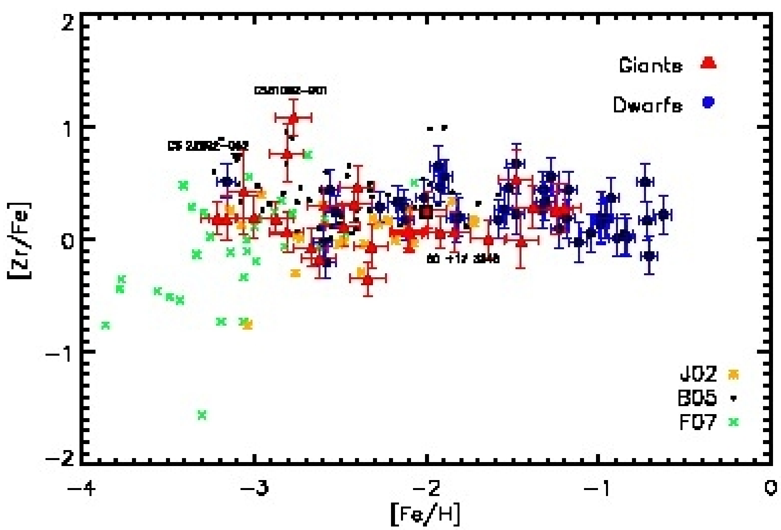
HD122563 – r-poor
'LEPP' prototype

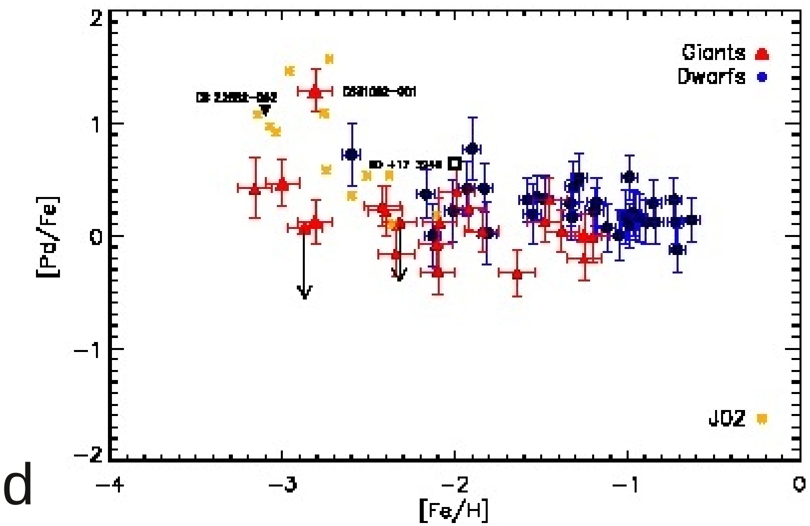




Cowan et al 2011

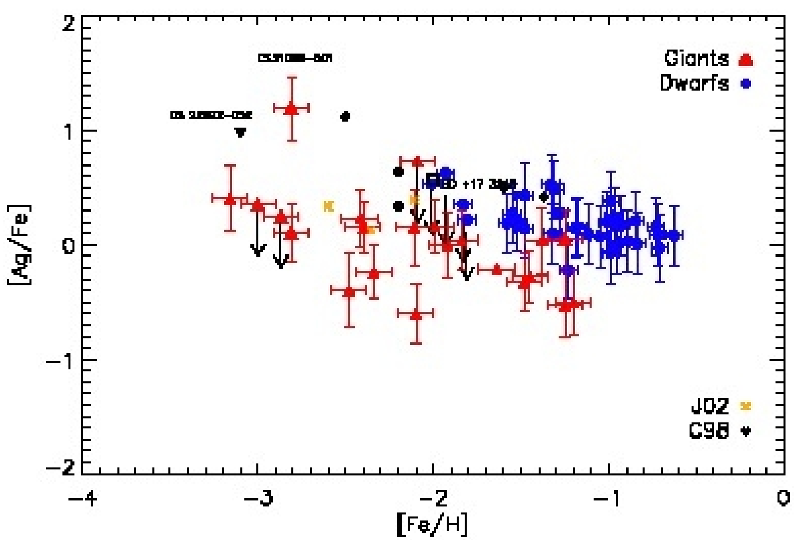
Large star-to-star scatter

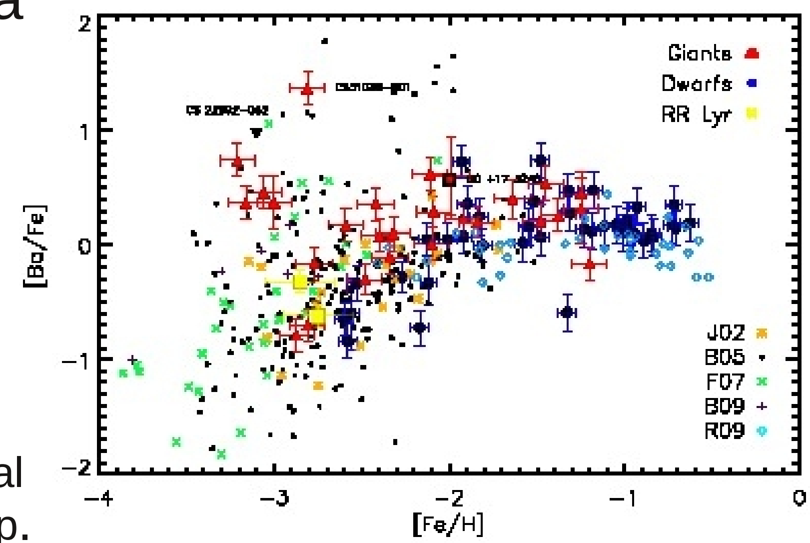




Zr Pd

Ag Ba

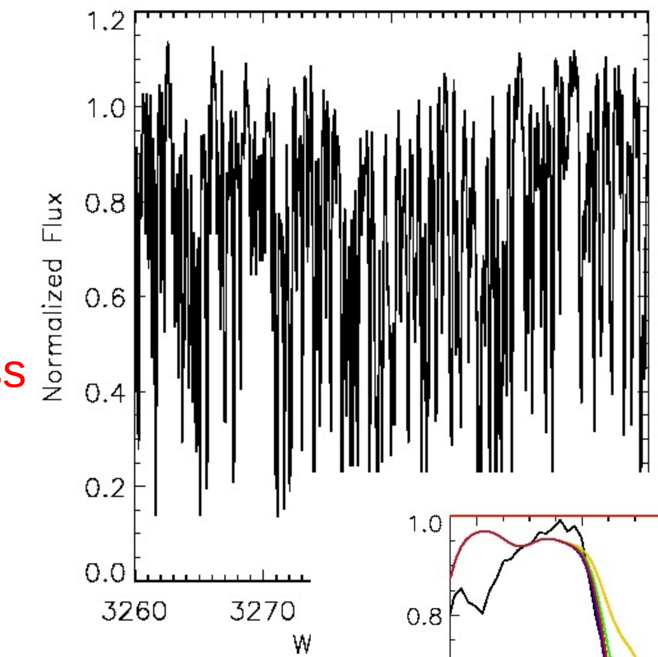


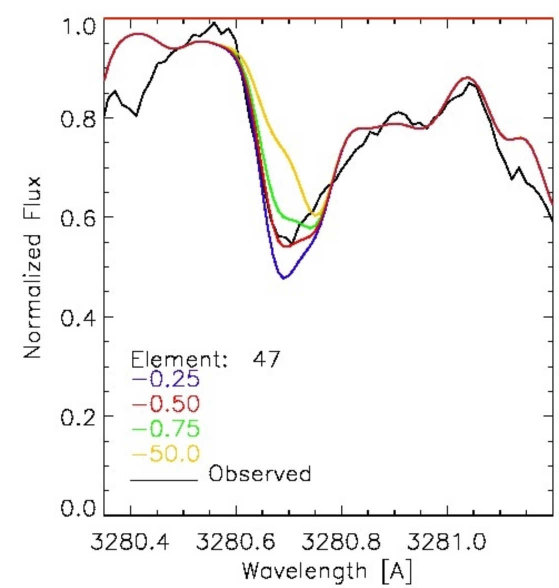


Hansen et al 2011 in prep.

What can we learn from Pd and Ag?

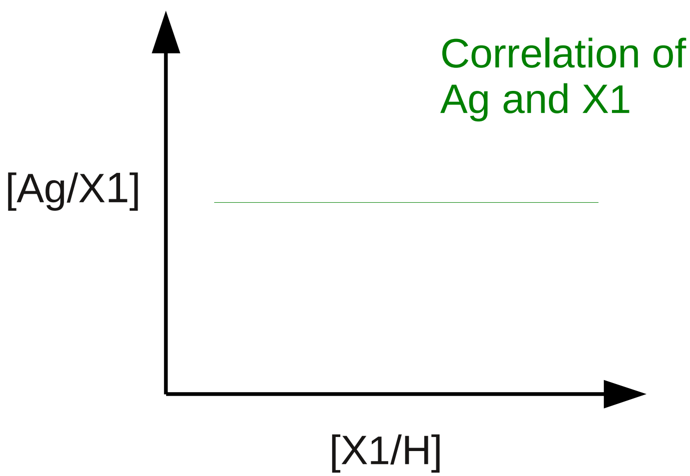
- Are there two r-processes?
- Large abundance scatter and/or correlations/anti-correlations
- Silver is a good tracer of the second r-process
- Ag and Pd: 328.0, 338.2, 340.4 nm
- But... Ag and Pd are difficult to derive abundances of since their lines are blended

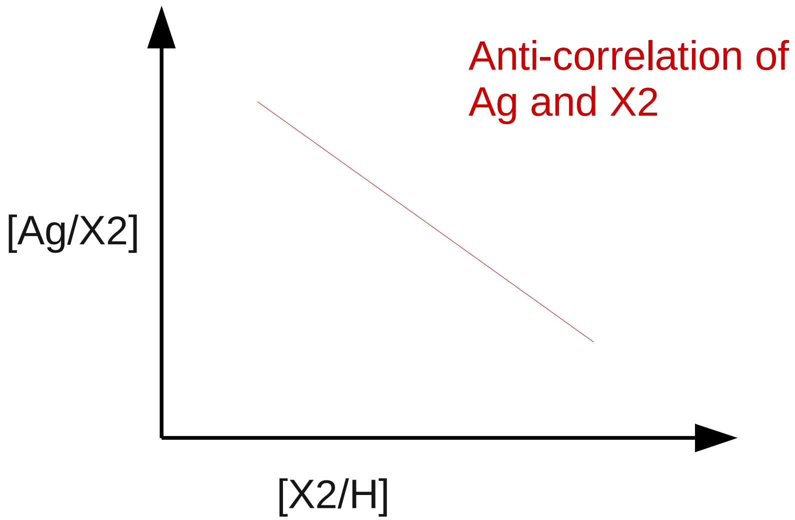




Correlations?

- If two elements are produced in the same way they will most likely grow in the same way, hence their abundances are said to correlate if their trend is flat (left) and they anti-correlate if they grow in very different ways, which will be expressed by a trend with a negative slope (right)

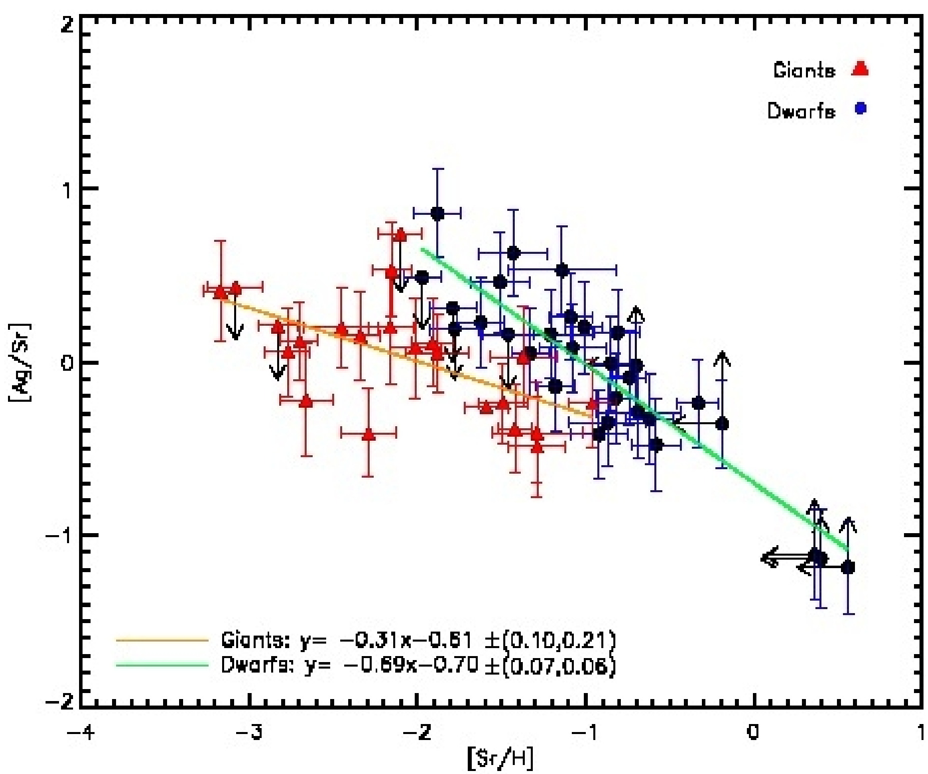


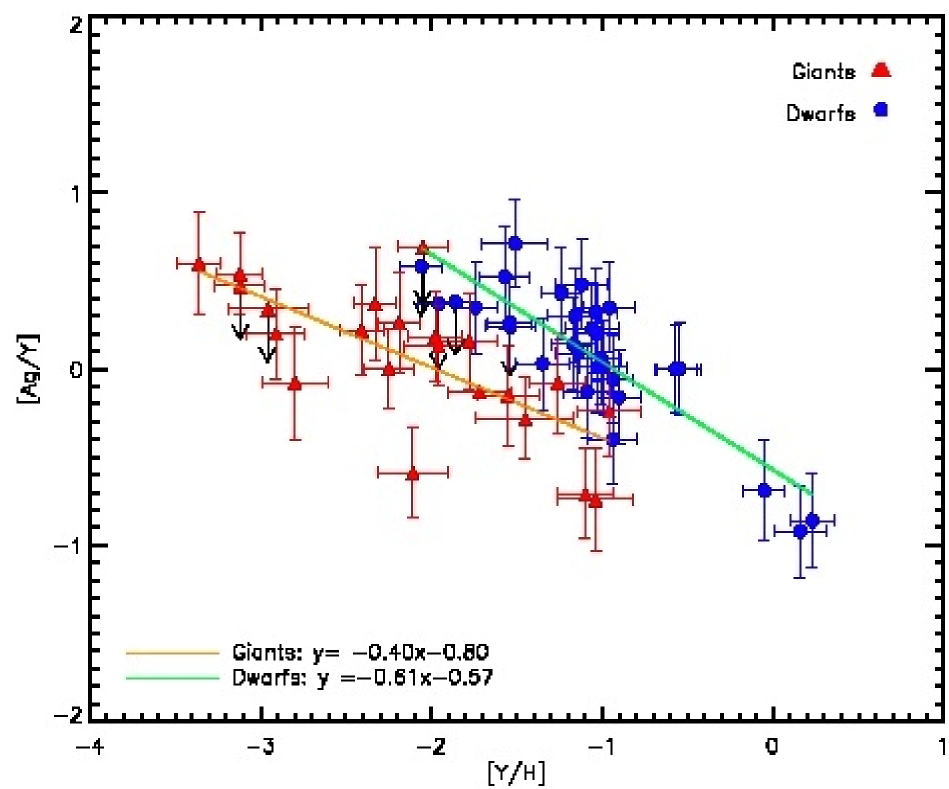


- Elements (~38 < Z < 50) are generally found to anti-correlate with elements in the range: Z > 56 (Burris et al, 2000, Montes et al, 2007, Francois et al 2007)

Correlations of Ag with Sr or Y?

Weak s-process tracers: Sr (85%), Y (92%), (Arlandini et al. 1999)

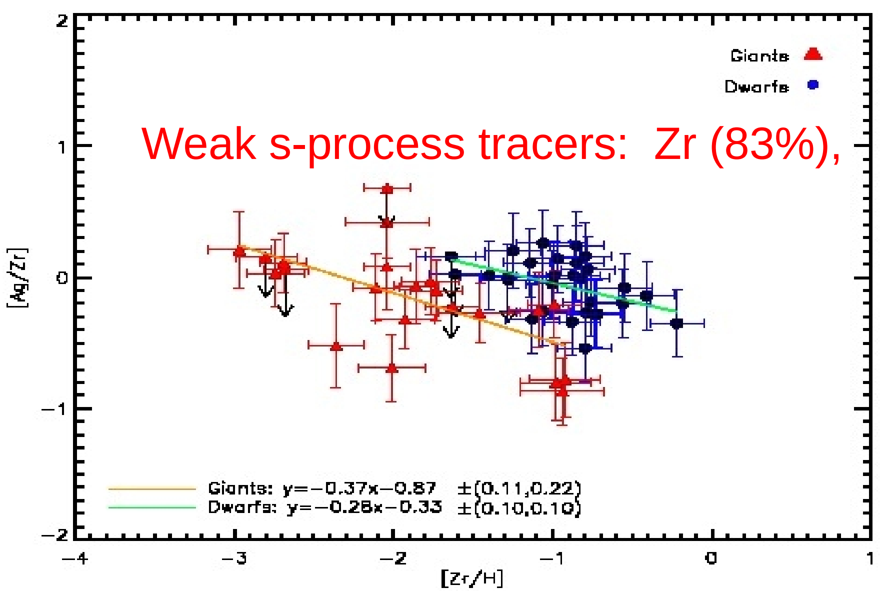




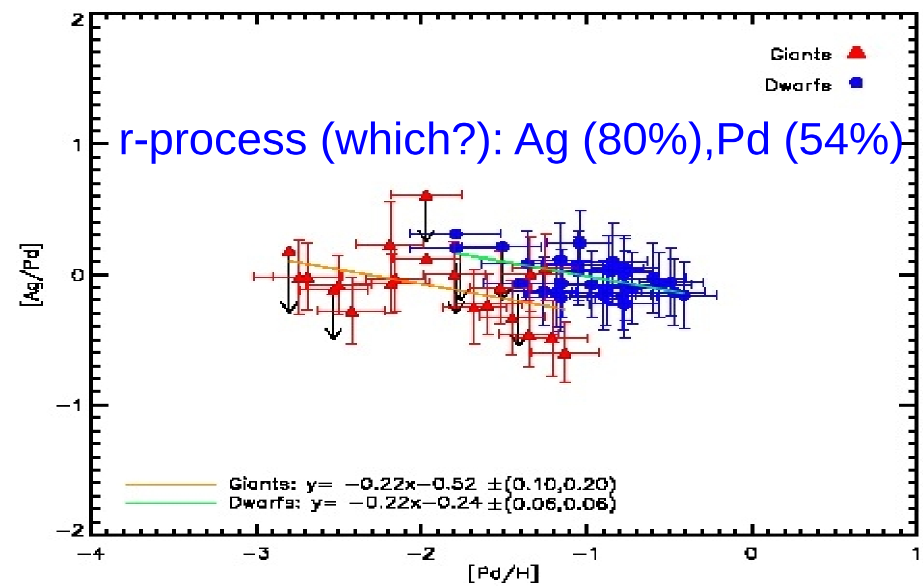
Hansen et al 2011 in prep.

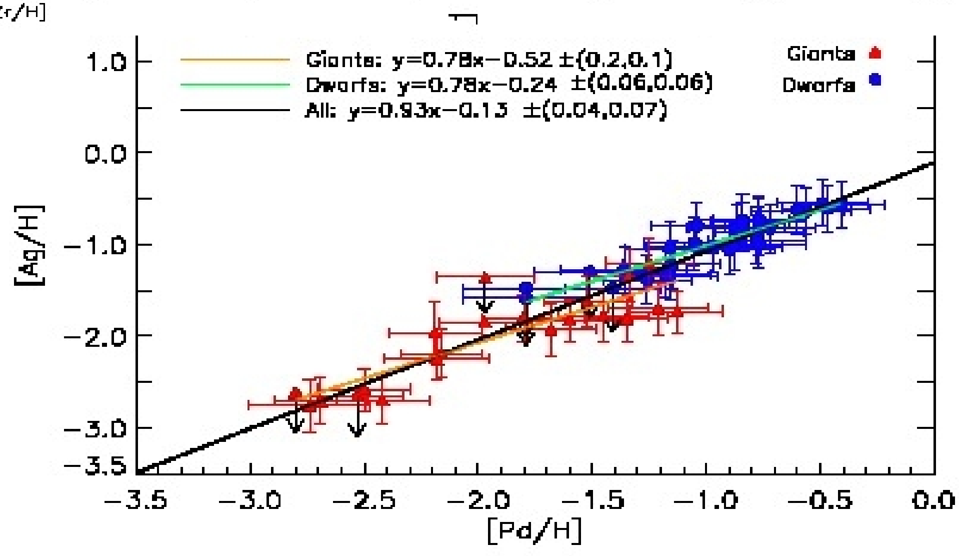
Correlations of Ag with Zr and Pd?

Weak s-process tracers: Zr (83%),



r-process (which?): Ag (80%),Pd (54%)





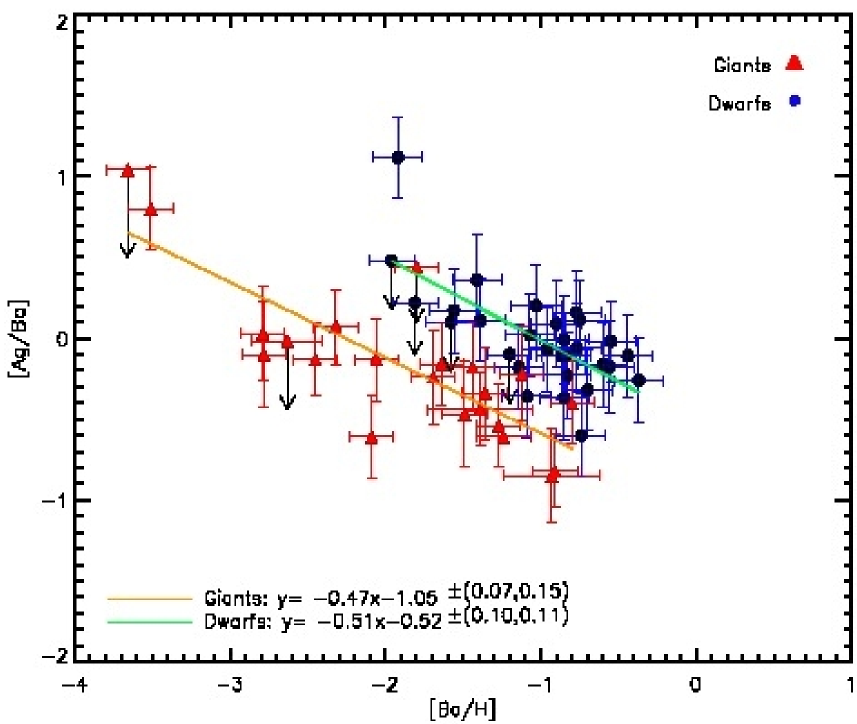
NOTE:
Different y-axis – CORRELATION of Ag and Pd

Hansen et al 2011

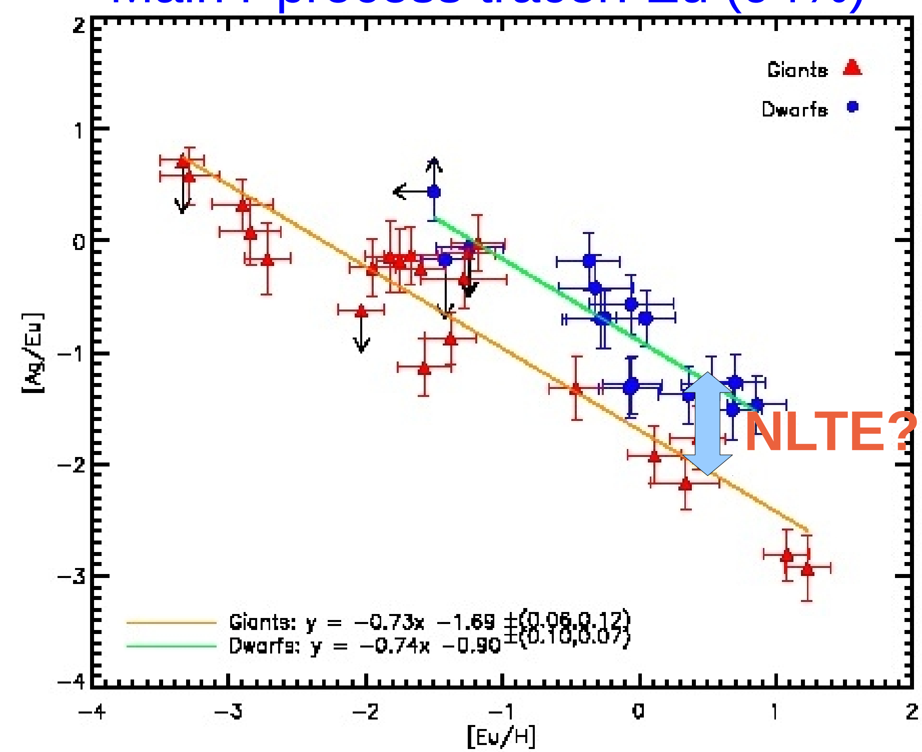
Correlations of Ag with Ba or Eu?

- Ag: not main s-process & not main r-process

Main s-process tracer: Ba (81%)



Main r-process tracer: Eu (94%)

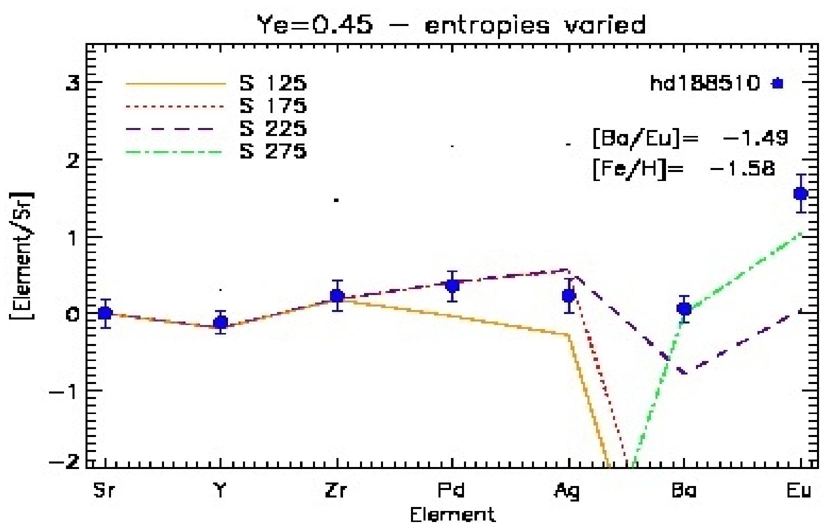


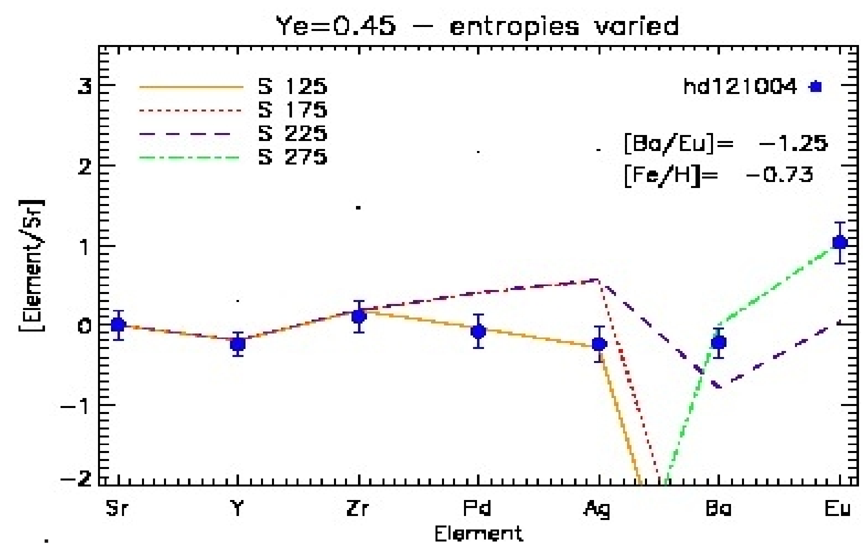
- Note dwarfs and giants show the same trend!
- However, the offset could be due to NLTE and/or 3D effects

Exploring different r-process sites

Two different processes/regimes seem necessary – are these related to different sites?

We compare to HEW (Farouqi et al 2009,2010) as well as ECSN (Wanajo et al 2010)



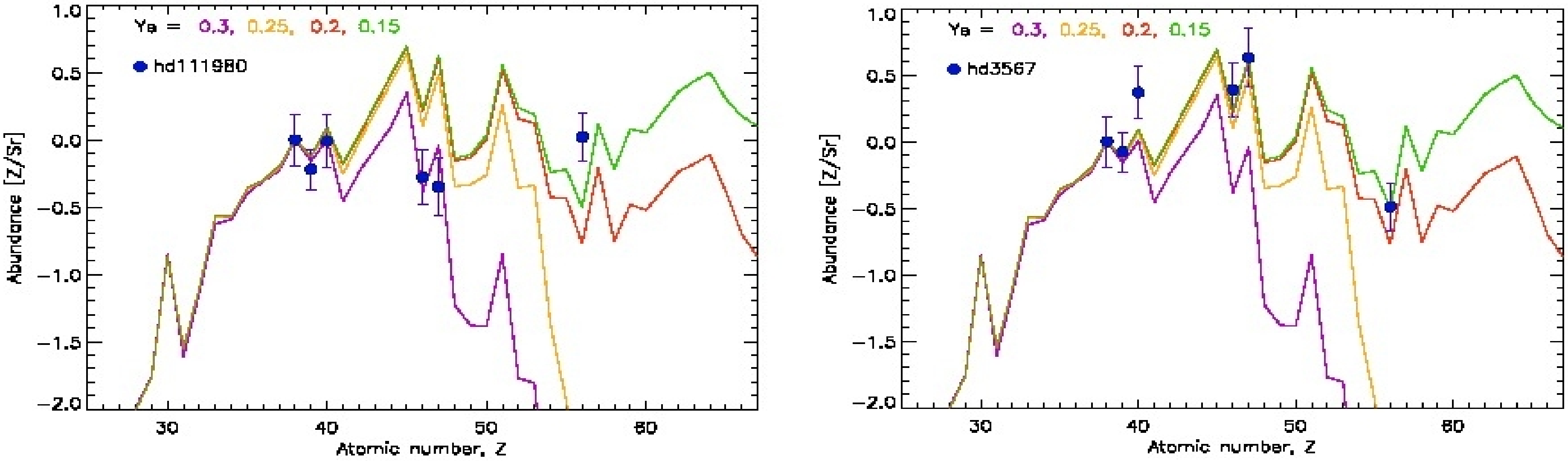


K.-L. Kratz priv. com.

Pure r-process dwarf stars compared to HEW predictions

Another possible site – ECSN/O-Ne-Mg SN

Comparison of dwarfs to yield predictions from Wanajo et al. 2010, 2D, low entropy, varied Y_e



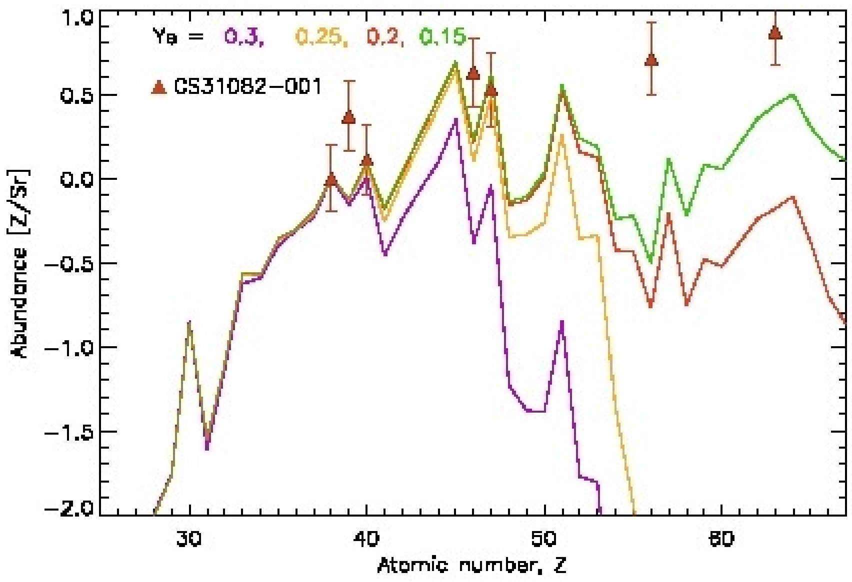
S. Wanajo priv. com.

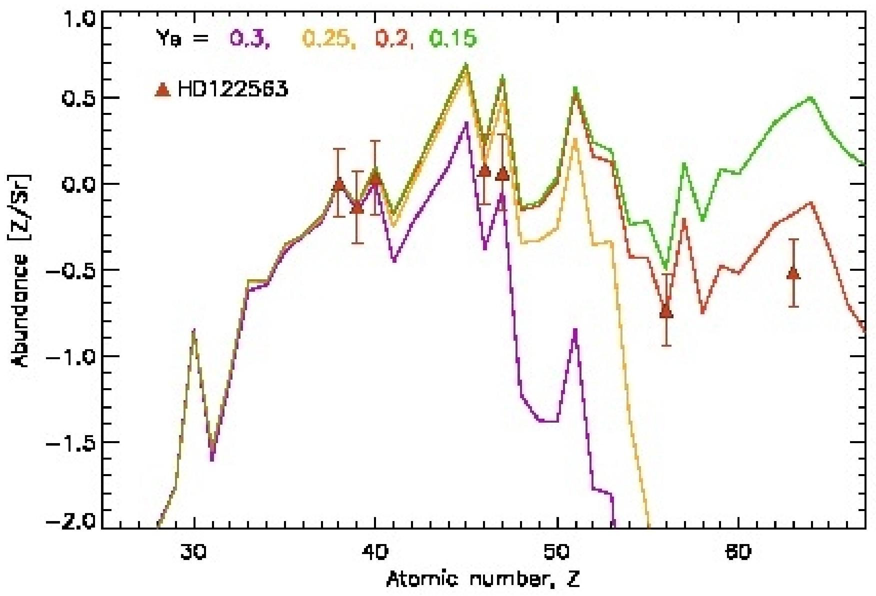
Their 1D models do not yield Pd or Ag!

ECSN predictions

CS31082-001: r-rich

HD122563: r-poor





The ECSN are not energetic or n-rich enough to produce heavy r-process elements like Eu

Summary

- Elements Z < 40 could be created by the weak s-process, but Zr also receives contributions from the weak r-process
- Elements from Zr to Ag possibly up to Z~ 50 or more may be produced by the weak r-process
- Depending on metallicity Ba receives contributions from the r-process
- Eu is produced by the main r-process which has very different characteristics compared to the weak r-process
- The weak r-process is due to its lower neutron environment closer to stability and may therefore share some features with the s-process
- Two different regimes needed to explain r-poor and r-rich stars such as HD122563 and e.g. BD+17 3248 or CS31082-001

Summary II

A possible site for the r-poor stars could be the faint ECSN (Wanajo et al)

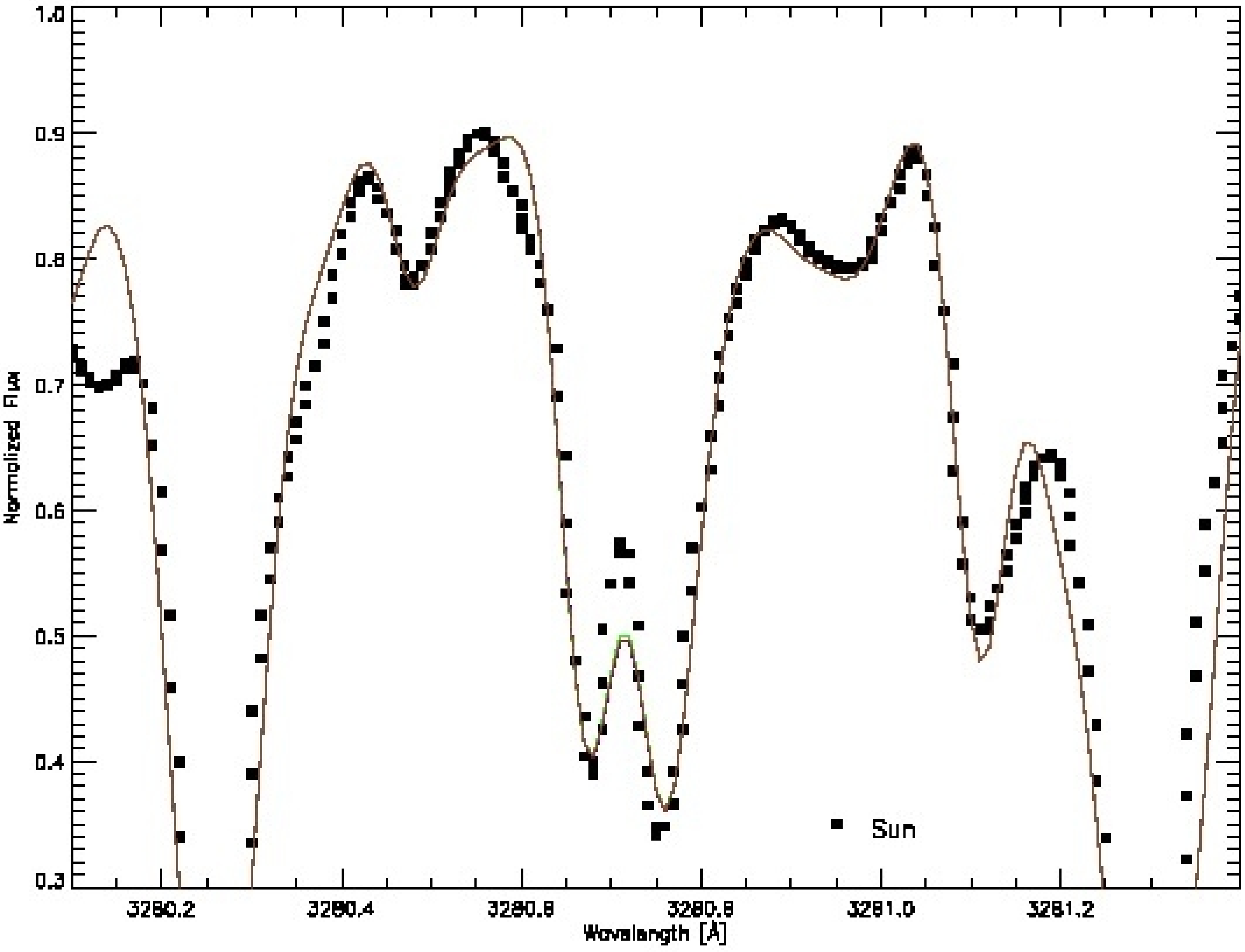
The HEW could be the site that explains the abundances of r-rich stars

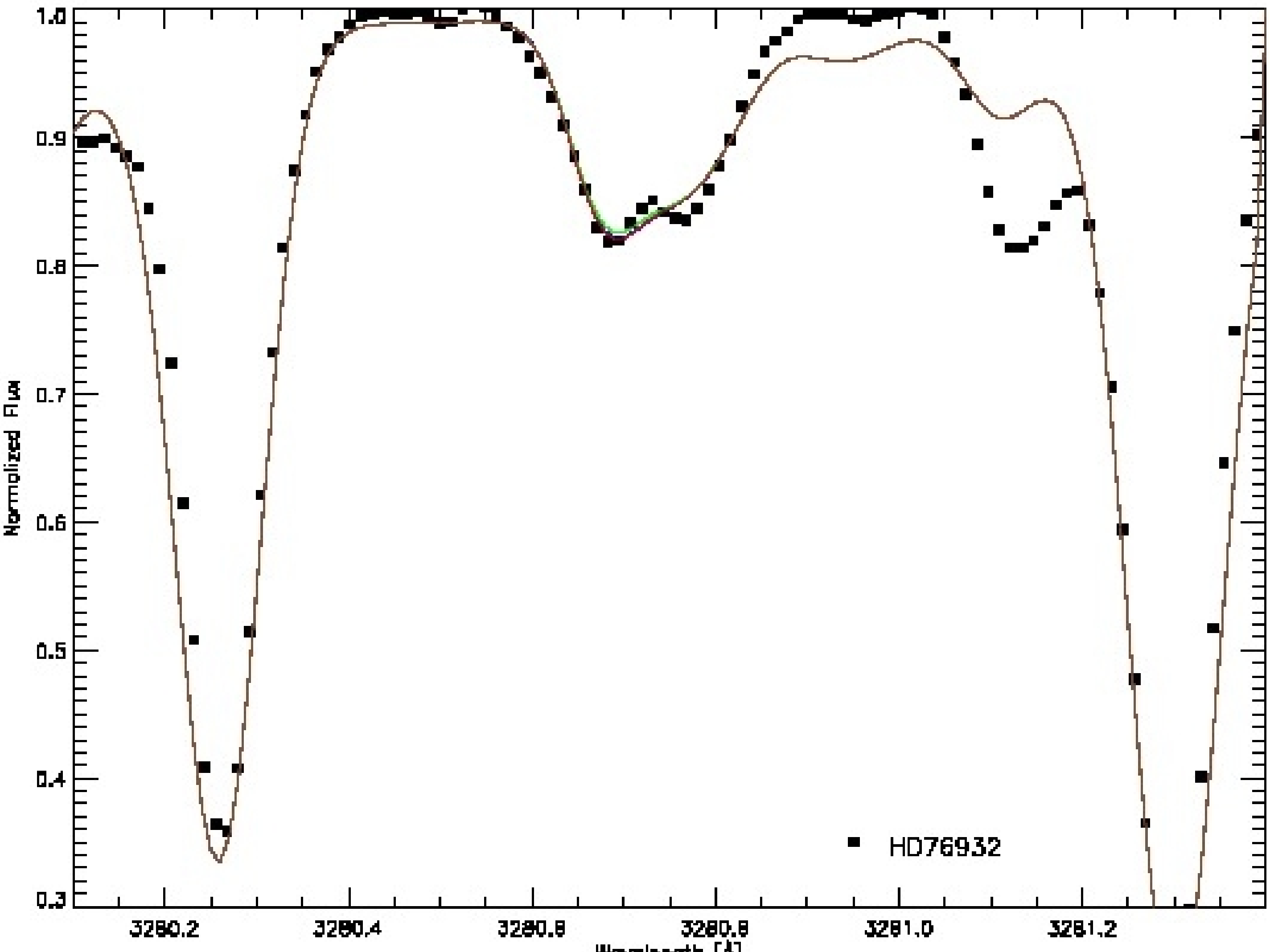
Still, these and other sites need investigation (e.g. neutron star mergers etc)

More near-UV/HST observations are needed to fully map the heavy elements and the various n-capture processes as well as gaining more complete information of also r-poor stars

Thank you

Isotopic 'Bonus' Slide





1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Normalized Flux
3280.2
3280.4
3280.6
3280.8
3281.0
3281.2
Wavelength [Å]
HD76932