An Inconvenient Truth? The low r-process fraction in the metal-poor subgiant star HD 140283

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The r-/s-process controversy

My research

- The isotopic fraction – implications of the result
- Abundances calculated in the analysis
- Shortcomings of 1D LTE codes – asymmetries in absorption lines

The r-/s-process Controversy

Truran (1981) hypothesised that neutron capture elements in older populations of stars should be dominated by r-process material.

As metallicity decreases, heavier elemental abundances should be the result of the r-process not the s-process due to neutron capture timescales.

e.g. barium & europium can all be formed by both processes but should be dominated by r-process as there is a lack of iron seeds in primordial stars.

Work by Magain (1995) on barium isotopes in HD 140283 found it to be an s-process star. Lambert et al. (2002) and Collet et al. (2009) found the star to be r-process rich.

Barium Isotopes

There are 5 stable isotopes of barium, some of which are pure s-process and others a combination of r- and s-process

Isotope	Wavelength (Å)	
^{134}Ba:	4554.0314	← s
^{135}Ba:	4554.0003	
	4554.0015	
	4554.0019	← r & s
	4554.0473	
	4554.0500	
	4554.0512	
^{136}Ba:	4554.0317	← s
^{137}Ba:	4553.9975	
	4553.9986	
	4553.9988	← r & s
	4554.0498	
	4554.0531	
	4554.0542	
^{138}Ba:	4554.0330	← r & s

Table from Collet et al. arXiv:0811.4586v1

The even isotopes (except 138) are pure s-process nuclei and the odd isotopes are a mixture of both processes.

This means that barium isotopes are a good indication of whether a star is dominated by r- or s-processes

Barium Isotopes

Only 2 barium lines with significant isotope differences in optical spectrum range, 4554.03 Å (shown) & 4934 Å.

Affected by hyperfine splitting.

- The spin of the electron and nucleus affects the energy of odd isotopes.

Changing the isotope ratio the appearance of the line changes.

f_{odd} represents the ratio of odd to even isotopes

$$f_{odd} = [N(^{135}Ba) + N(^{137}Ba)] / N(Ba)$$

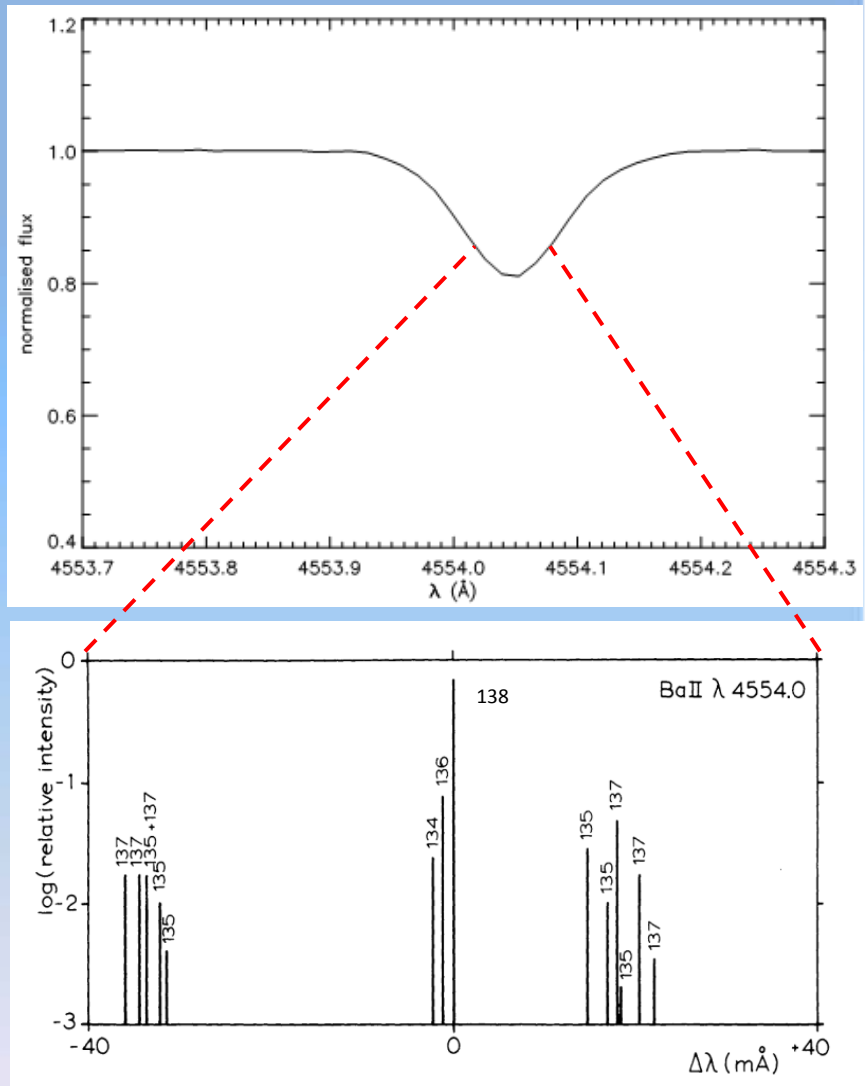


Image from Rutten 1978SoPh...56..237R

Analysis of HD 140283

Observations

Data from high resolution spectrograph on the Subaru Telescope.

High S/N ~ 1100 per 12 mÅ wide pixel around 4554 Å
High resolution ~ 95,000
Ba II 4554Å - EqW 20.1 mÅ

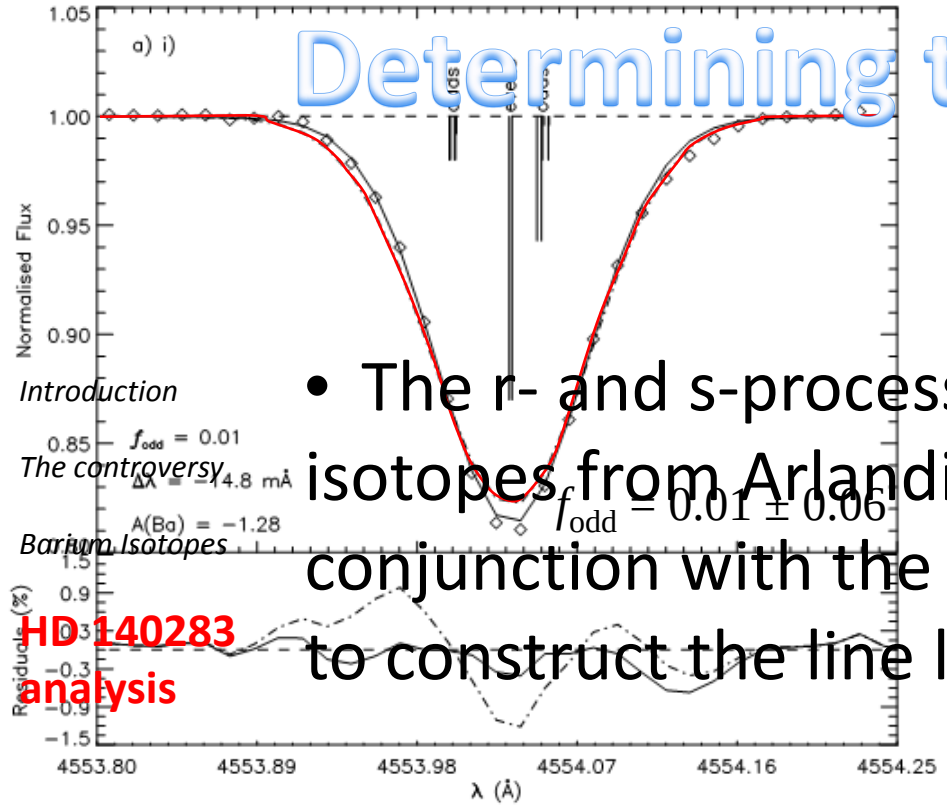
Macroturbulence

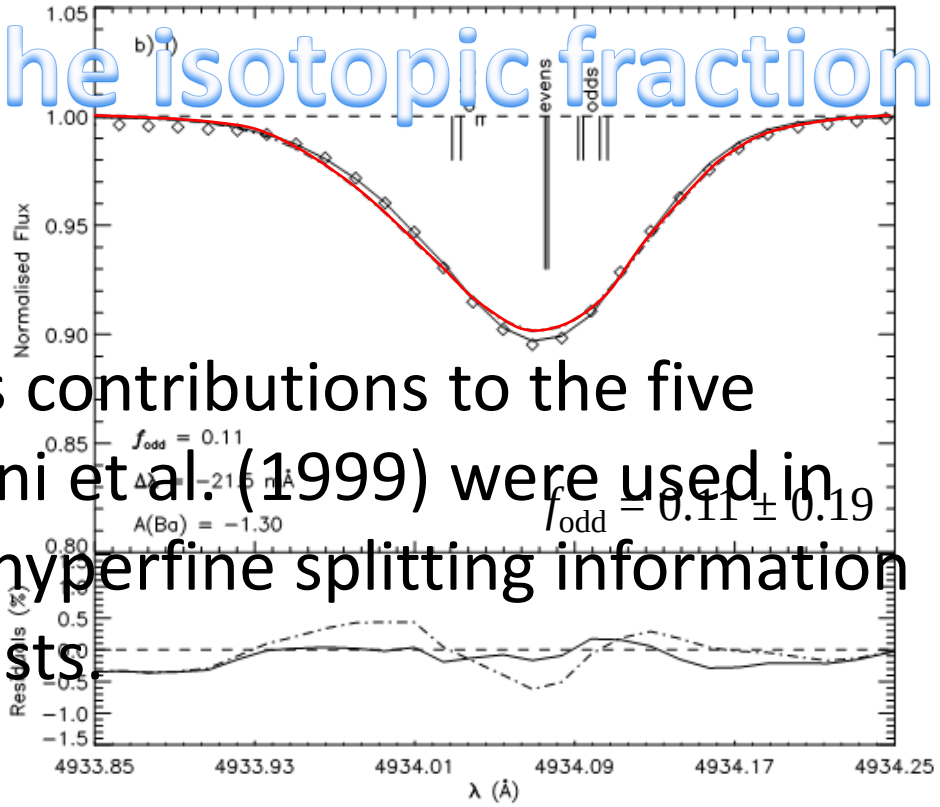
Constrained using 93 apparently unblended Fe lines by a χ^2 test. Renormalizes A(Fe), Δλ and macroturbulence for every line. Used three broadening techniques:

Gaussian – Γ = **4.70 km s^{-1}** – 32 lines best fit
Radial Tangential – ζ = **4.37 km s^{-1}** – 58 lines best
Rotation – ***v*sin*i* = 3.89 km s^{-1}** – 3 lines best fit

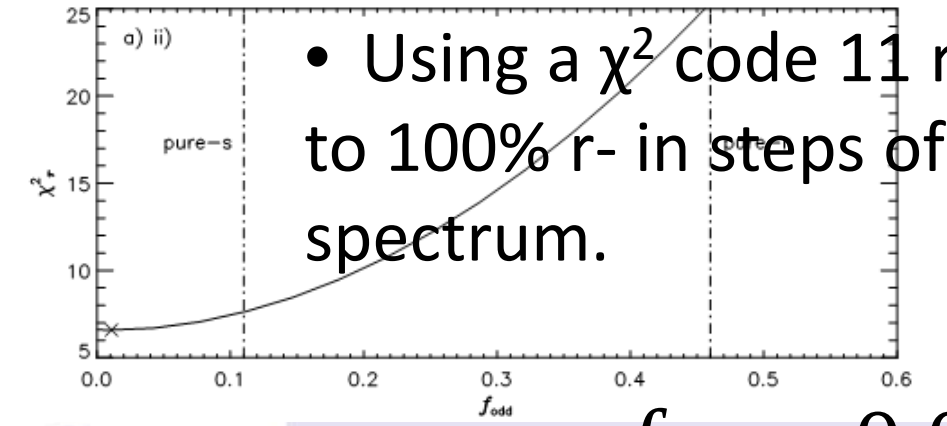
New upper limit on rotation set at 3.89±0.02 km s^{-1}.

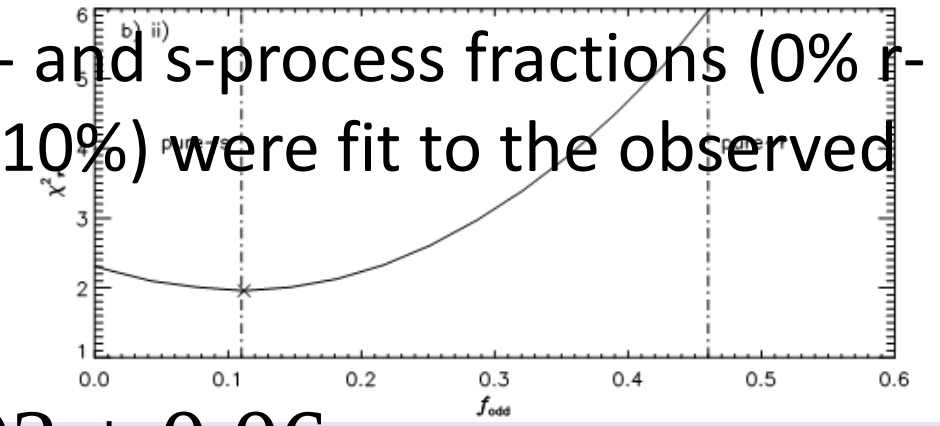
Determining the isotopic fraction





- The r- and s-process contributions to the five isotopes from Arlandini et al. (1999) were used in conjunction with the hyperfine splitting information to construct the line lists.





- Using a χ^2 code 11 r- and s-process fractions (0% r- to 100% r- in steps of 10%) were fit to the observed spectrum.

$$f_{odd} = 0.02 \pm 0.06$$

Europium Work

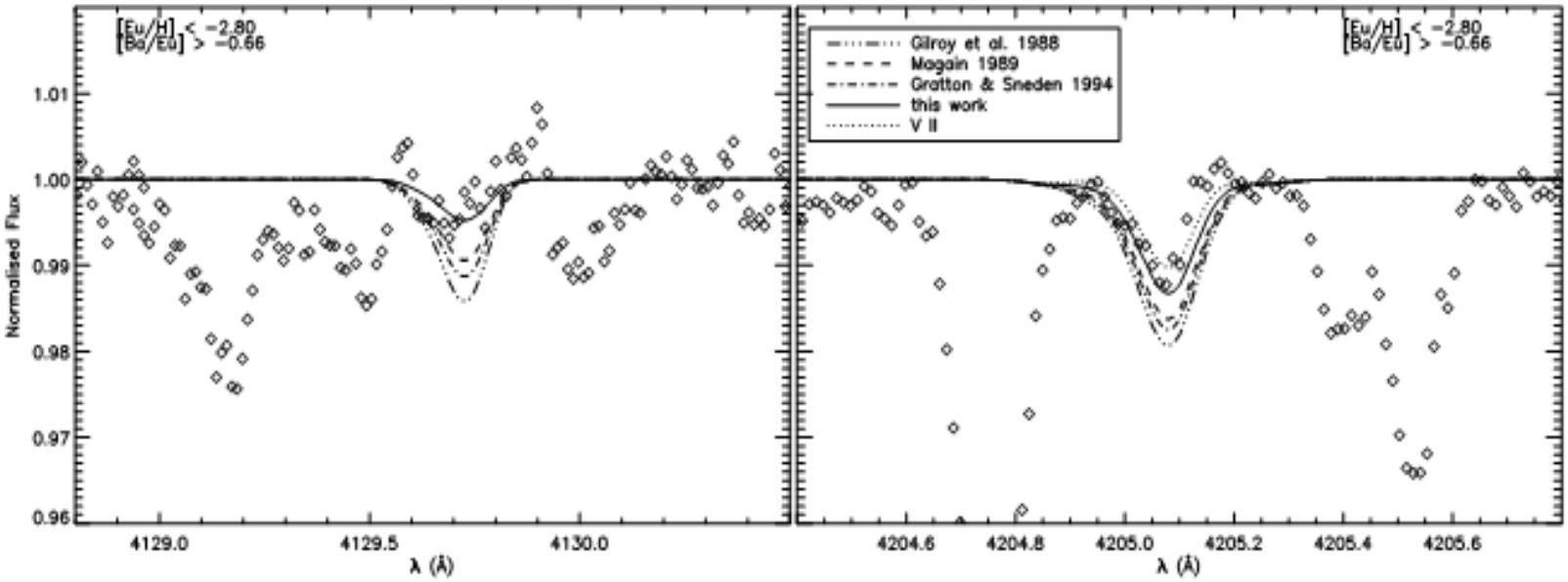
Europium was also analysed. Due to the weakness of the two lines in our spectrum (4129 Å and 4205 Å) we find an upper limit rather than a real detection:

[Eu/H] < -2.80

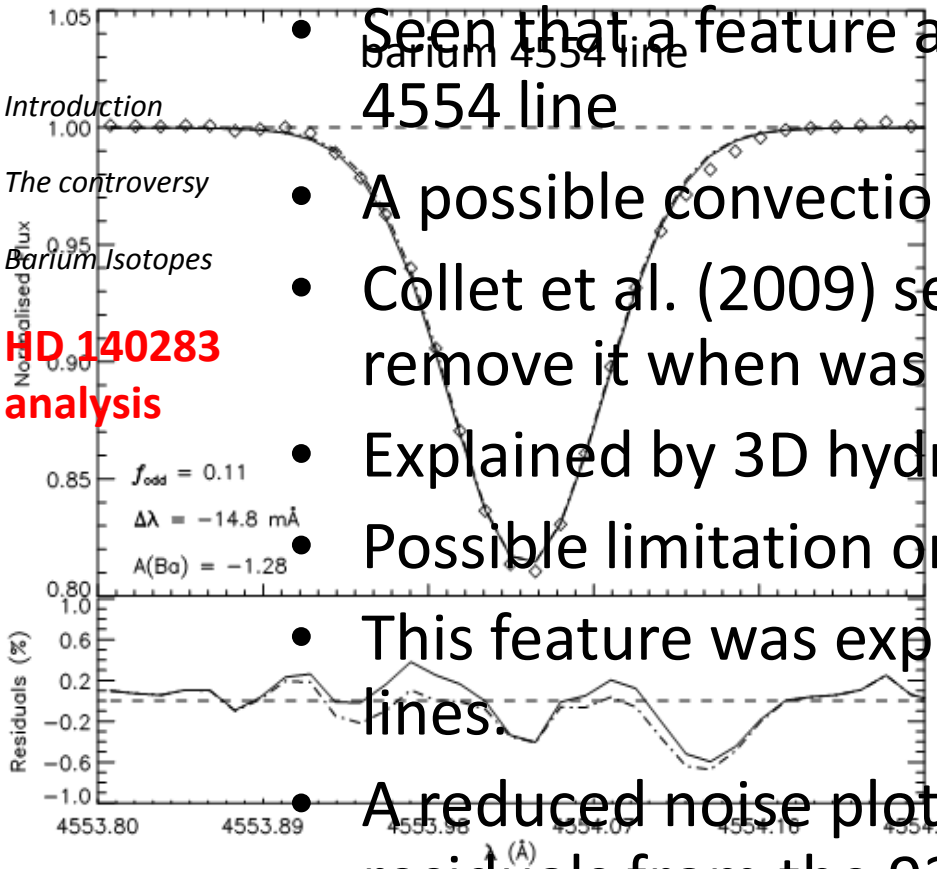
Meaning that:

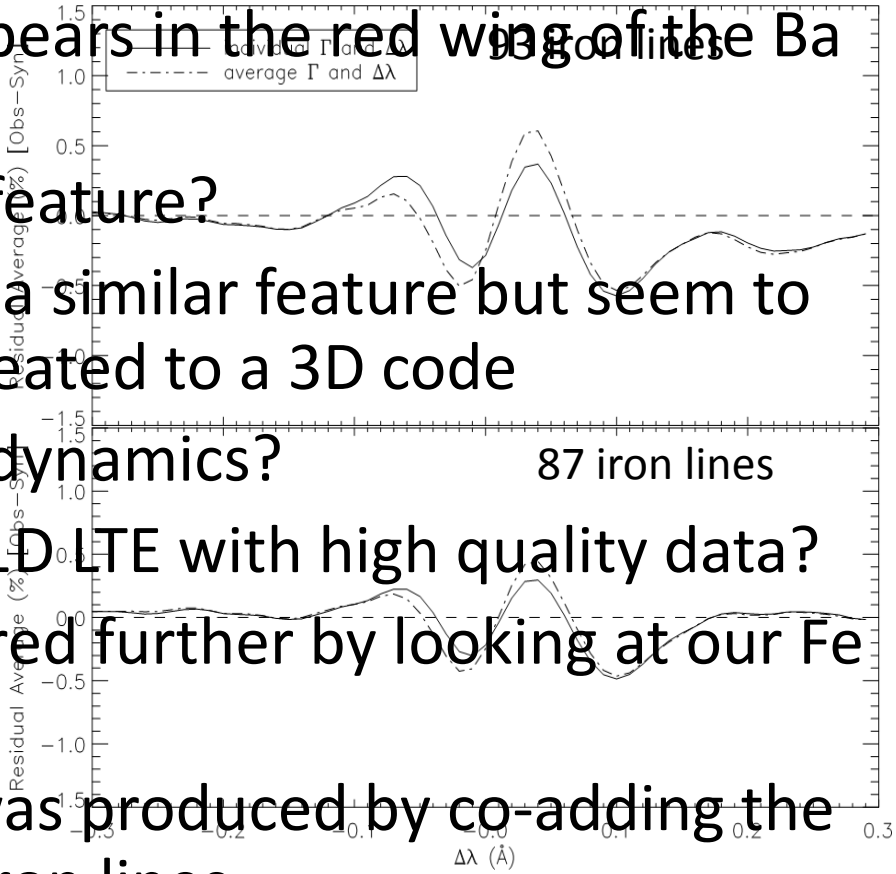
[Ba/Eu] > -0.66

According to Burris et al. (2000) (or Arlandini et al. 1999) a pure r-process ratio, -0.81 (-0.69), is marginally ruled out but a pure s-process, +1.45 (+1.13) or an s- and r-process regime is most likely.



Asymmetries in Fe lines





- Seen that a feature appears in the red wing of the Ba 4554 line
- A possible convection feature?
- Collet et al. (2009) see a similar feature but seem to remove it when was treated to a 3D code
- Explained by 3D hydrodynamics?
- Possible limitation on 1D LTE with high quality data?
- This feature was explored further by looking at our Fe lines.
- A reduced noise plot was produced by co-adding the residuals from the 93 iron lines.

Conclusions

- We have carried out a thorough investigation of the uncertainties and explored all avenues for error
- We have shown that HD 140283 is not r-process enhanced like other papers have claimed it to be. Has large implications on current theory
- In the paper we have shown possible limitations of 1D LTE synthesis codes when dealing with high quality data
- We have set new [Ba/H] and [Fe/H] ratios and have placed a lower limit on [Ba/Eu] and new upper limits on [Eu/H] and rotation
- Details on all of this can be found in A. Gallagher et al. (2010) *submitted*