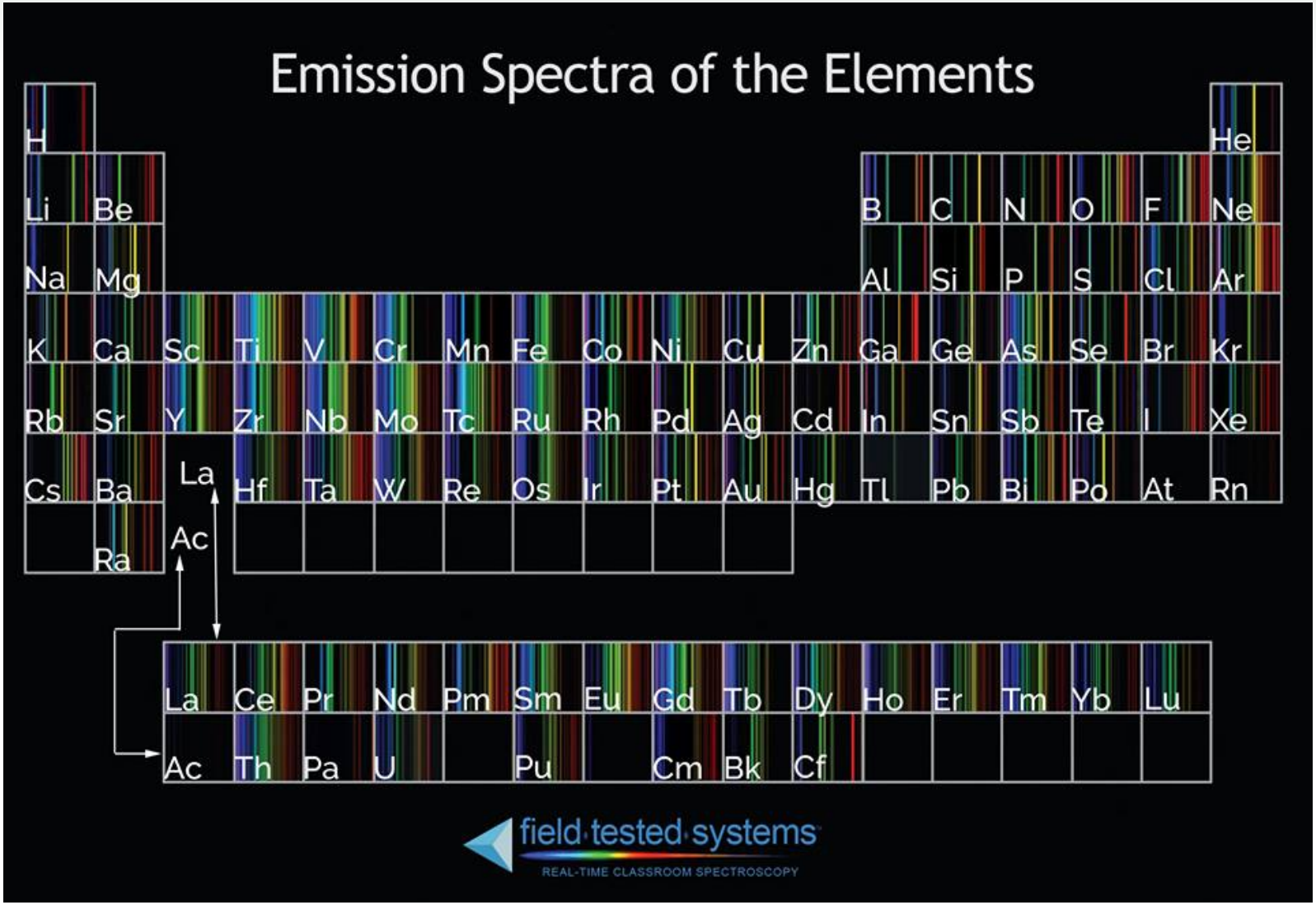
A dear child has many names
- production of the light neutron-capture elements.

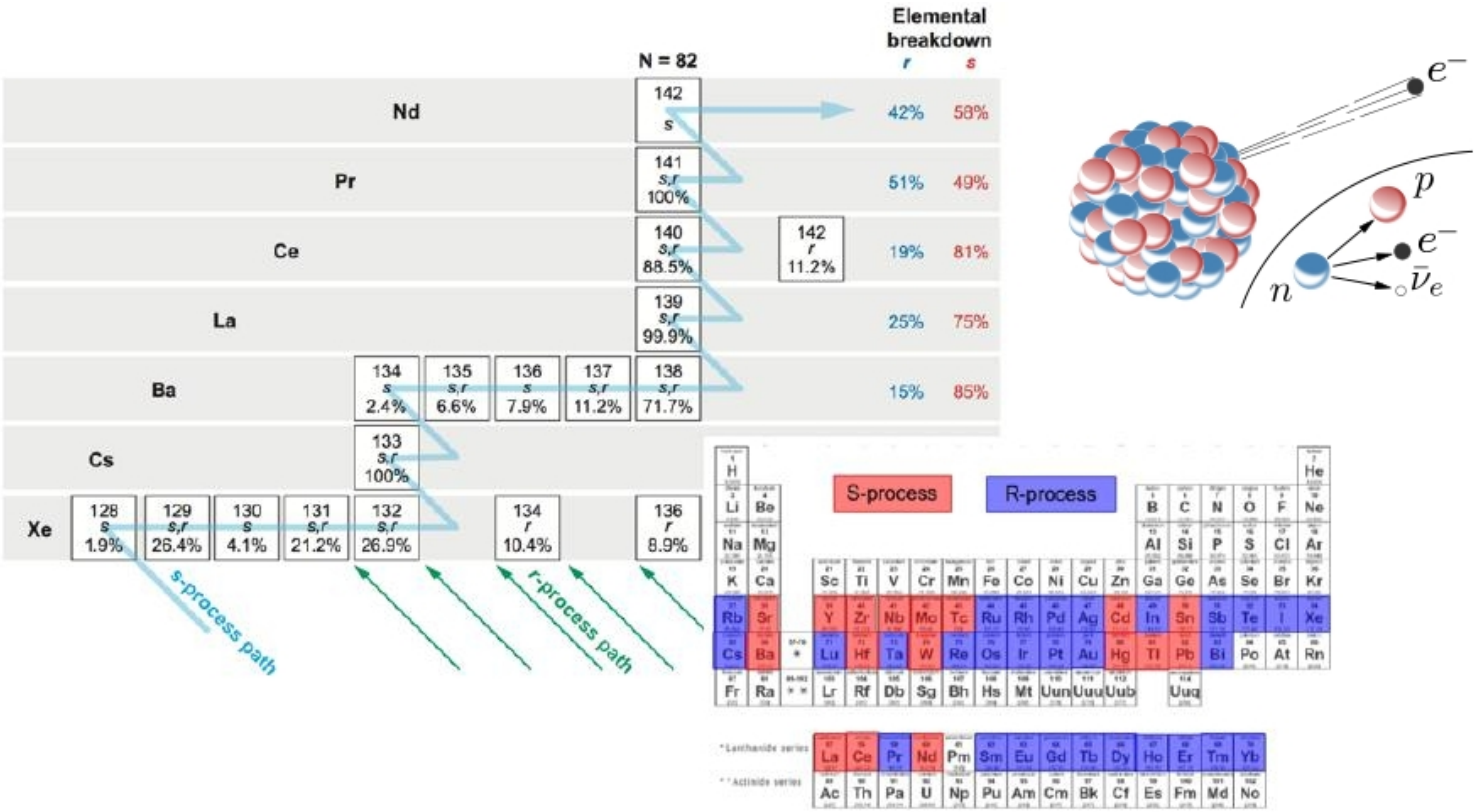
Terese T. Hansen

Astronomy Seminar
Uppsala University
September 2022

Origin of the elements



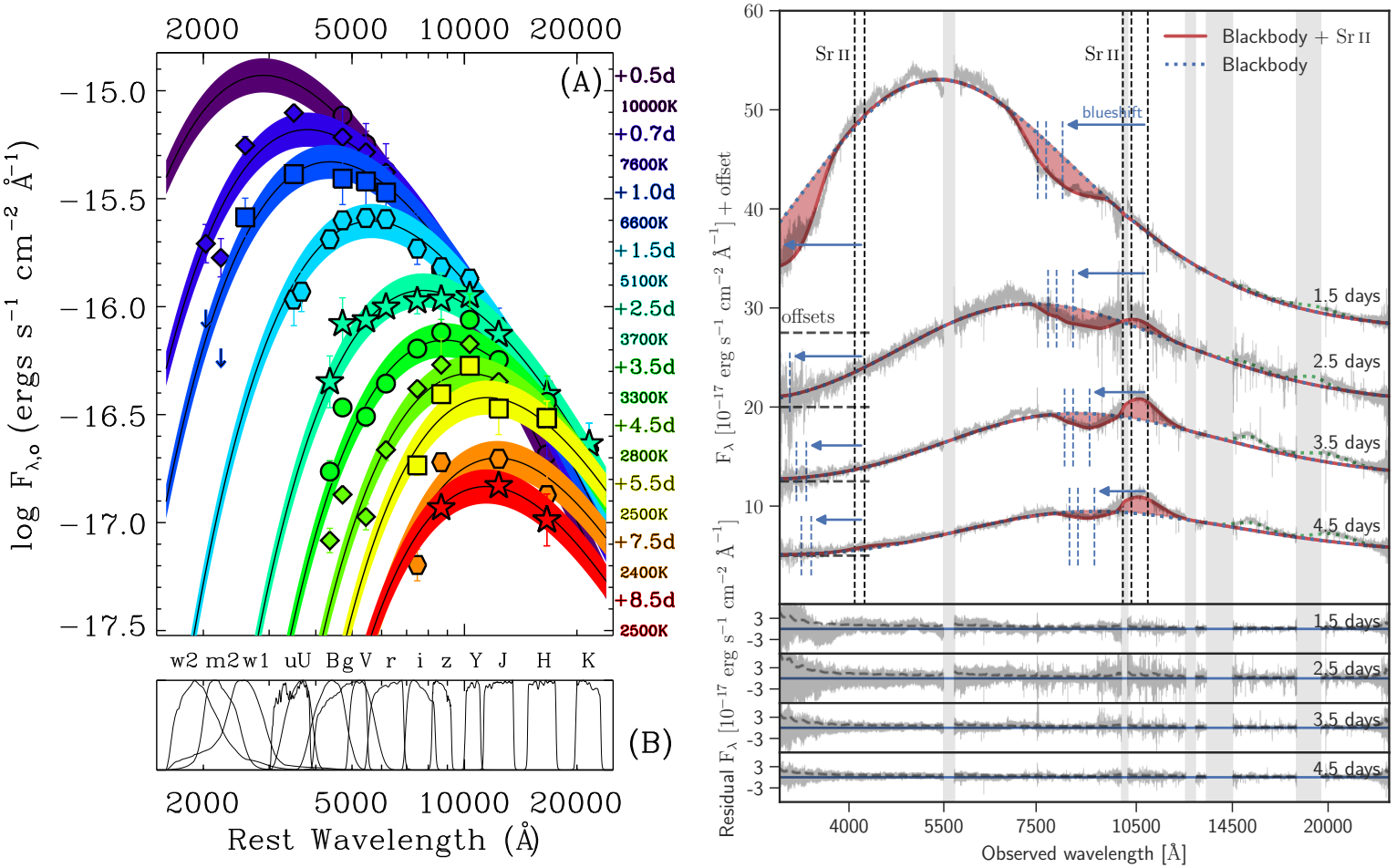
Neutron capture



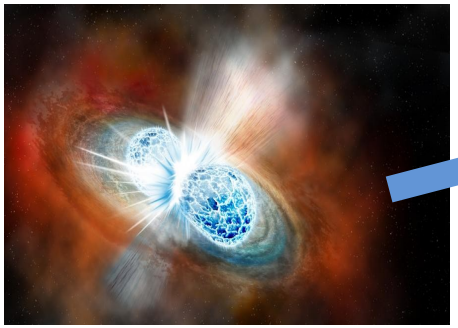
Neutron-capture processes

- main s-process $\rightarrow$ asymptotic giant branch stars (Ba)
- weak s-process $\rightarrow$ massive stars, boosted by rotation (Sr)
- main r-process $\rightarrow$ neutron star mergers and ? (Eu)
- weak r-process / limited r-process / Light Element Primary Process $\rightarrow$ core collapse supernovae? (?)

GW170817 - The neutron-star merger



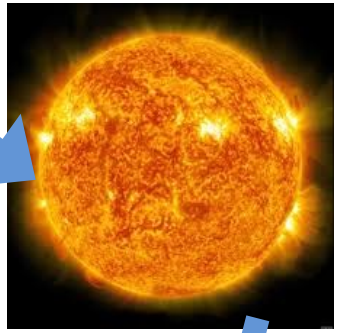
Drout+ 2017, Watson+ 2019

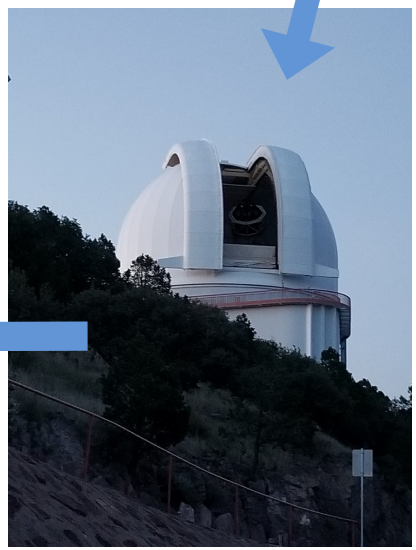


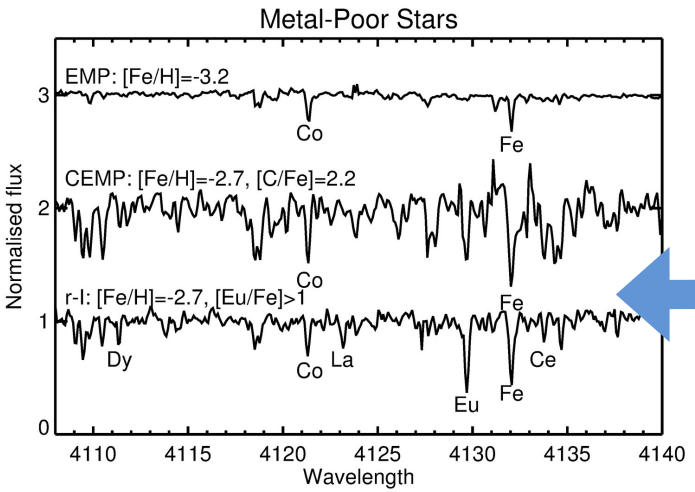
Nucleosynthesis event

Enriching interstellar medium

Low mass star we can observe today



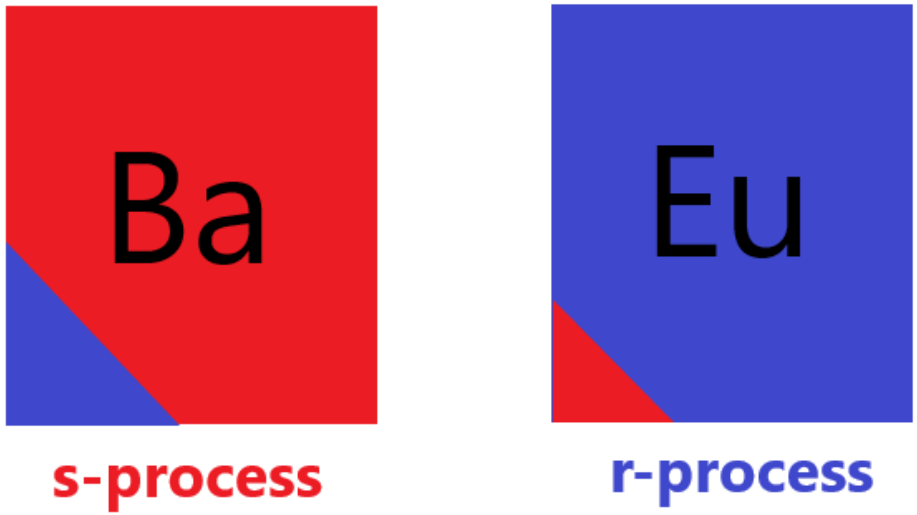




Measure stellar abundance of Eu <-> Eu produced in the nucleosynthesis event.

R-Process Alliance

Ba and Eu as s-process vs r-process enrichment diagnostics



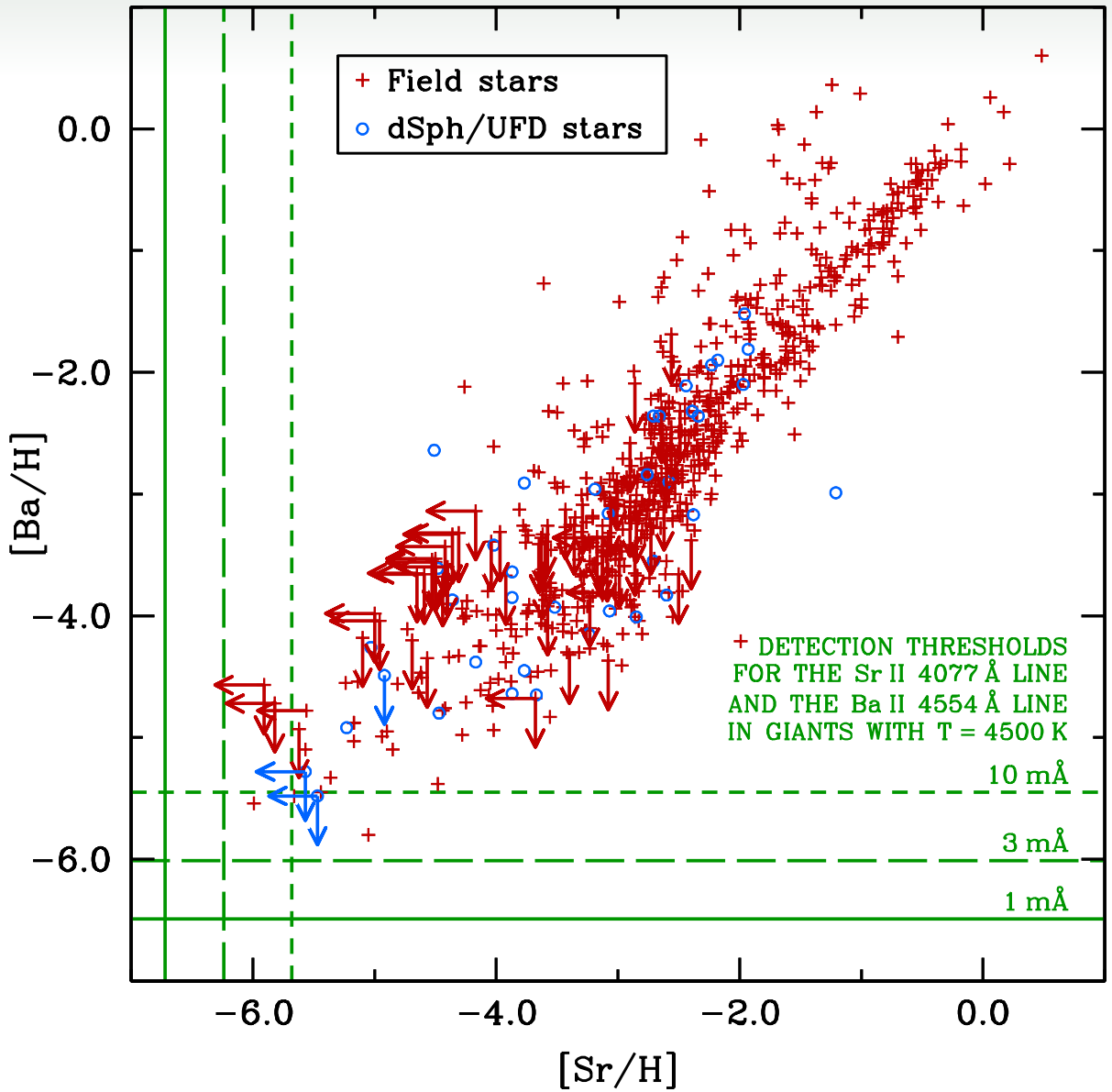
"pure" r-process $[\mathrm{Ba/Eu}] \sim -0.9$
"pure" s-process $[\mathrm{Ba/Eu}] \sim +1.3$

Prantzos+ 2020

Three lines of investigation

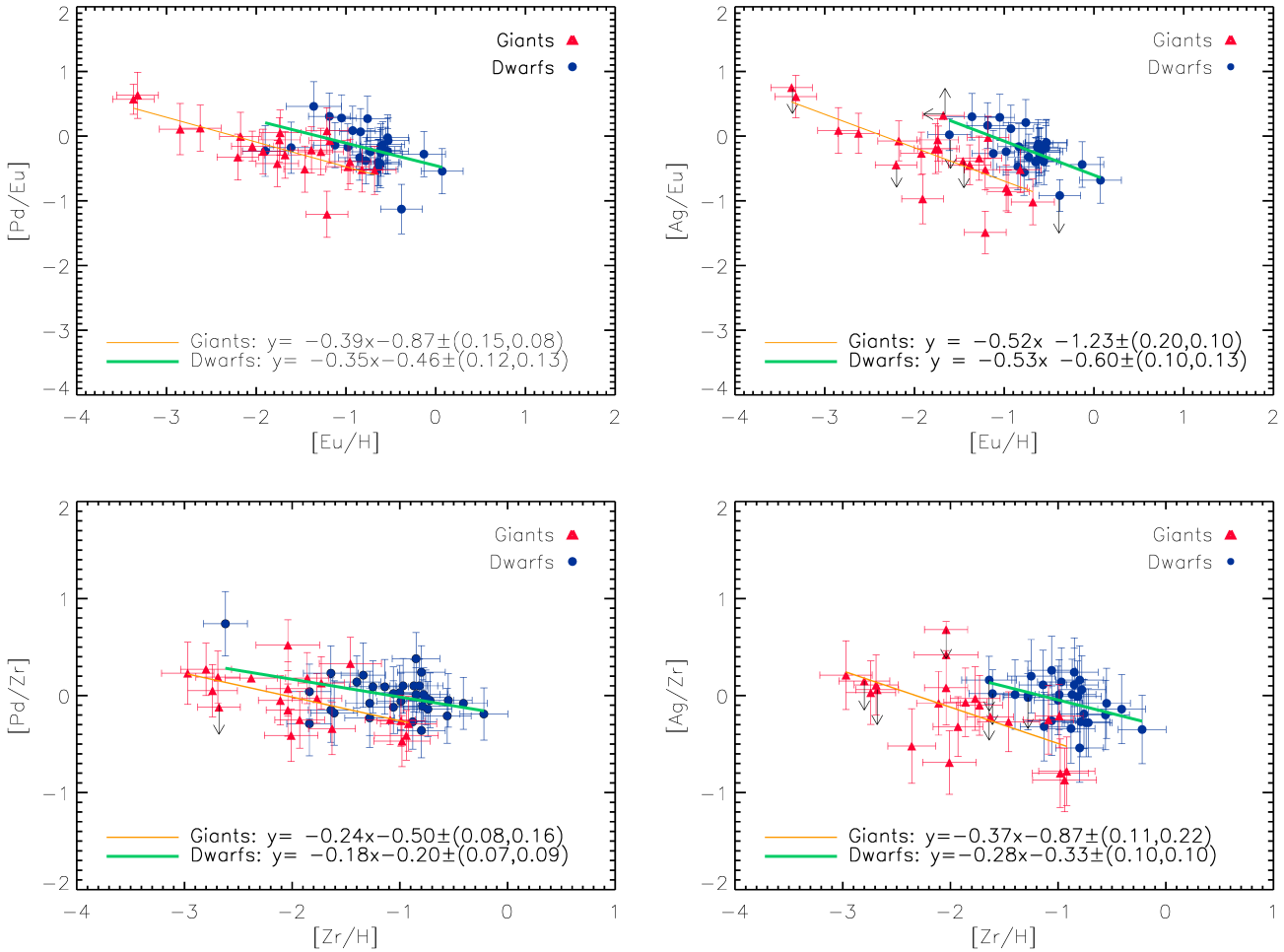
- (1) Neutron-capture element abundances in metal-poor stars
- (2) Neutron-capture element abundances in r-process enhanced stars ($[\mathrm{Eu/Fe}] > 0.3$)
- (3) Neutron-capture element abundances in r-process poor stars ($[\mathrm{Eu/Fe}] < 0.3$)

(1) Sr and Ba detected in "all" stars



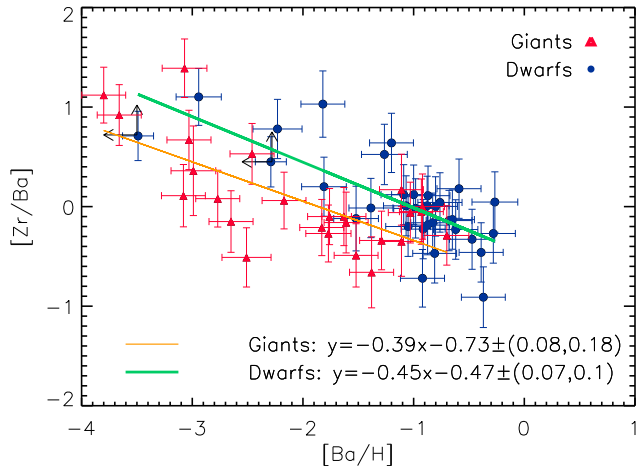
Roederer 2013

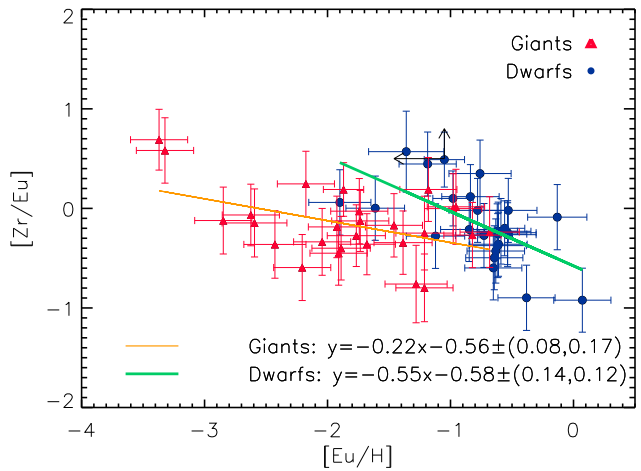
(1) Abundance anti-correlations between light and heavy elements



Hansen+ 2012

(1) Abundance anti-correlations between light and heavy elements

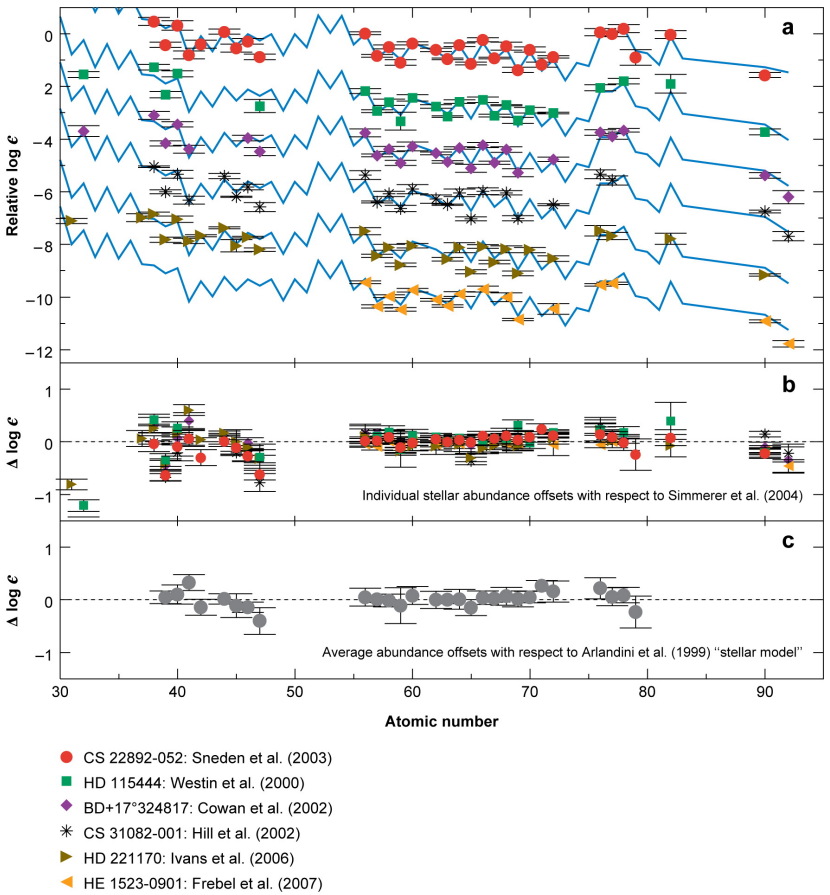




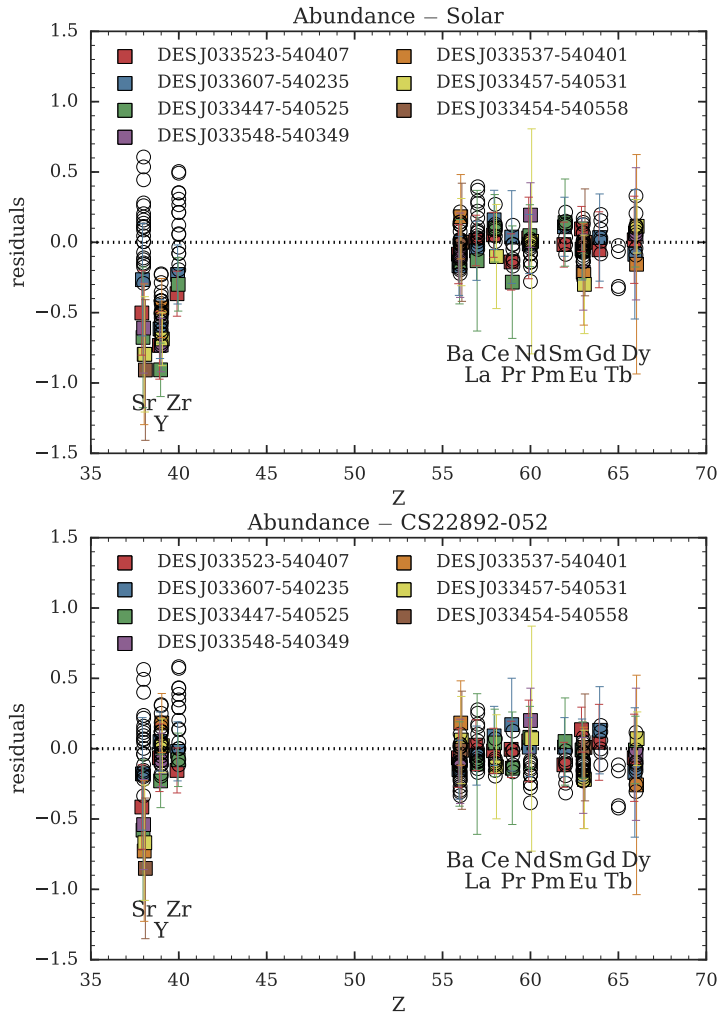
Hansen+ 2012

See also Travaglio+ 2004 GCE and Light Element Primary Process.

(2) The (almost) universal pattern for stars with [Eu/Fe] > 0.3



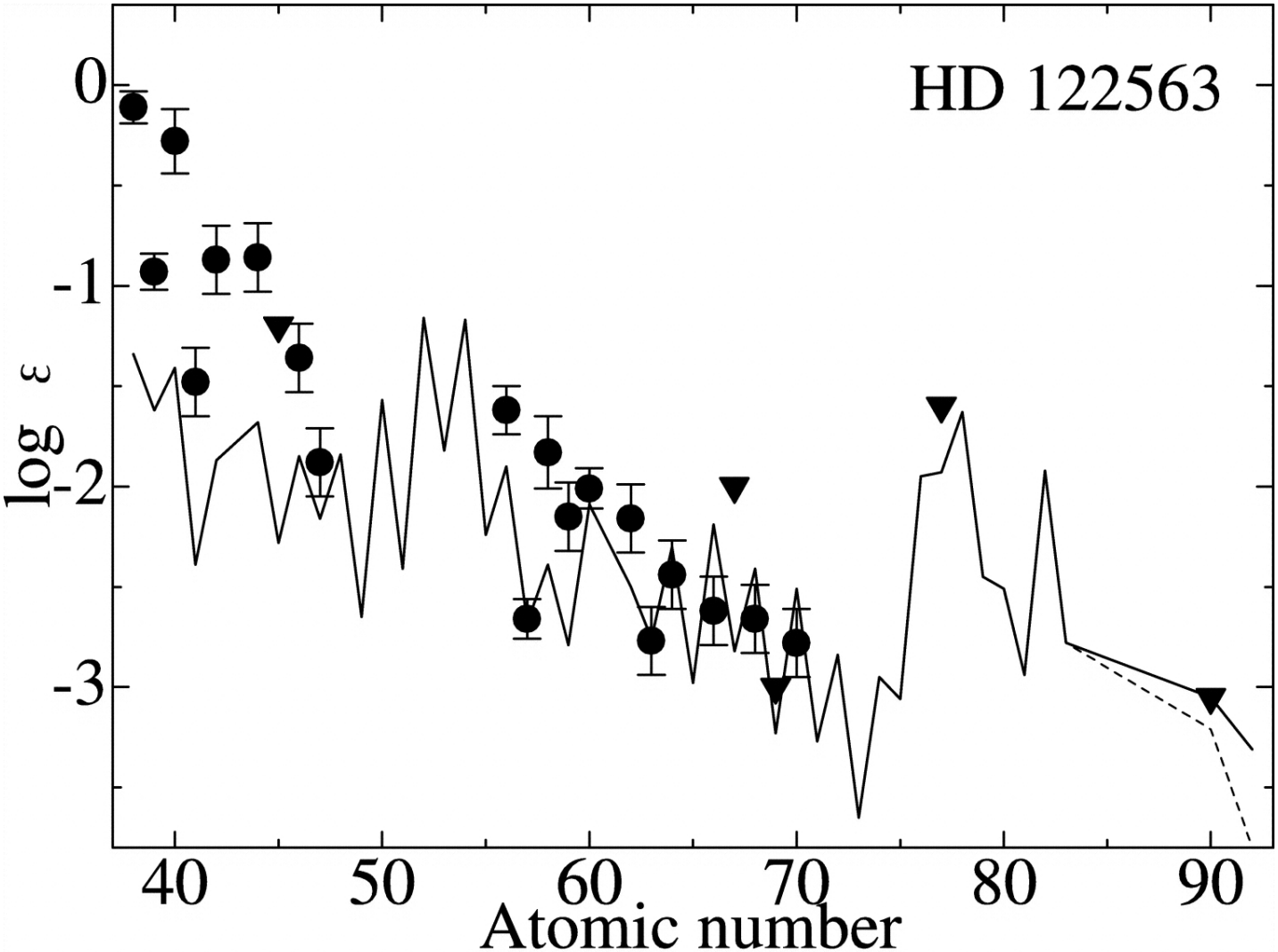
Sneden C, et al. 2008.
Annu. Rev. Astron. Astrophys. 46:241–88



Sneden 2008, Ji+ 2016

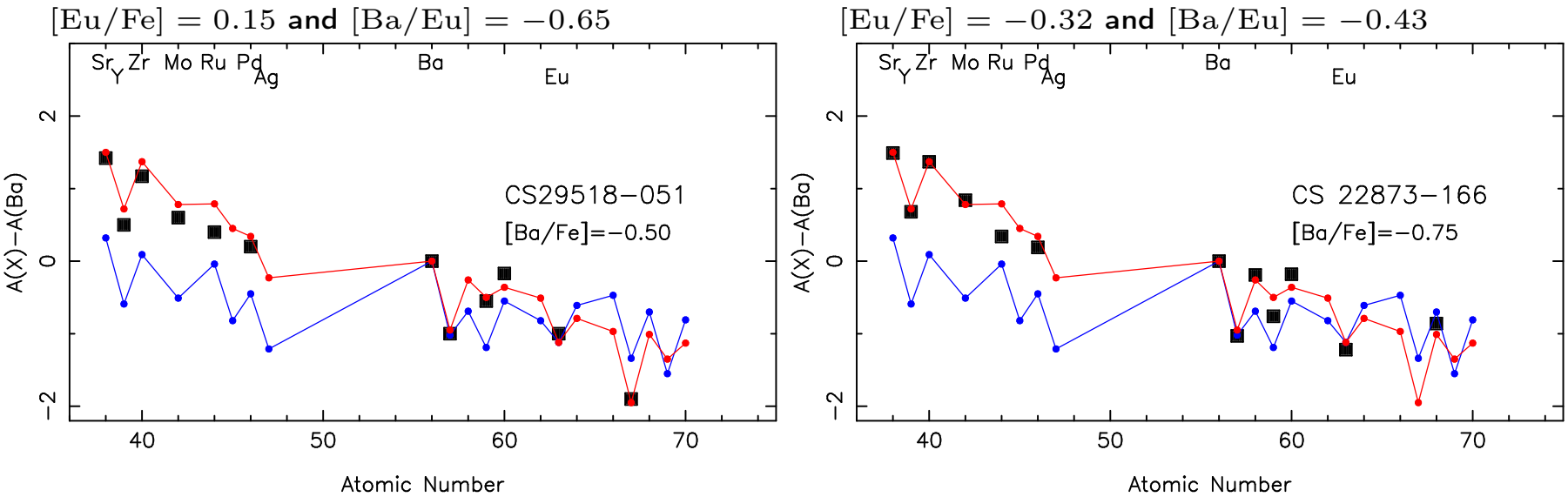
(3) r-process poor star HD122563

$[\mathrm{Eu/Fe}] = -0.47$, but $[\mathrm{Ba/Eu}] = -0.50 \rightarrow$ r-process



Honda+ 2006

(3) More r-process poor stars



Spite+ 2018

Red= HD122563, Blue = CS31082-001

Three lines of investigation

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- (2) Neutron-capture element abundances in r-process enhanced stars ($[\mathrm{Eu/Fe}] > 0.3$)
- (3) Neutron-capture element abundances in r-process poor stars ($[\mathrm{Eu/Fe}] < 0.3$)

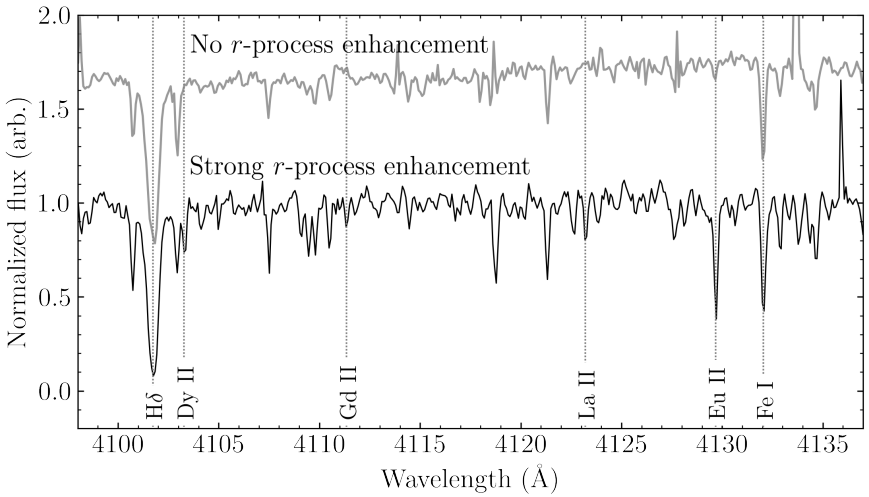
$\rightarrow$ The second r-process exists but where?

R-Process Alliance

Core members: Tim Beers (University of Notre Dame), Anna Frebel (Massachusetts Institute of Technology), Vini Placco (NOIRLab), Ian Roederer (University of Michigan), Charli Sakari (San Francisco State University), Rana Ezzeddine (University of Florida), Erika Holmbeck (Carnegie Observatories), and Terese Hansen (Stockholm University).

RPA - Target selection

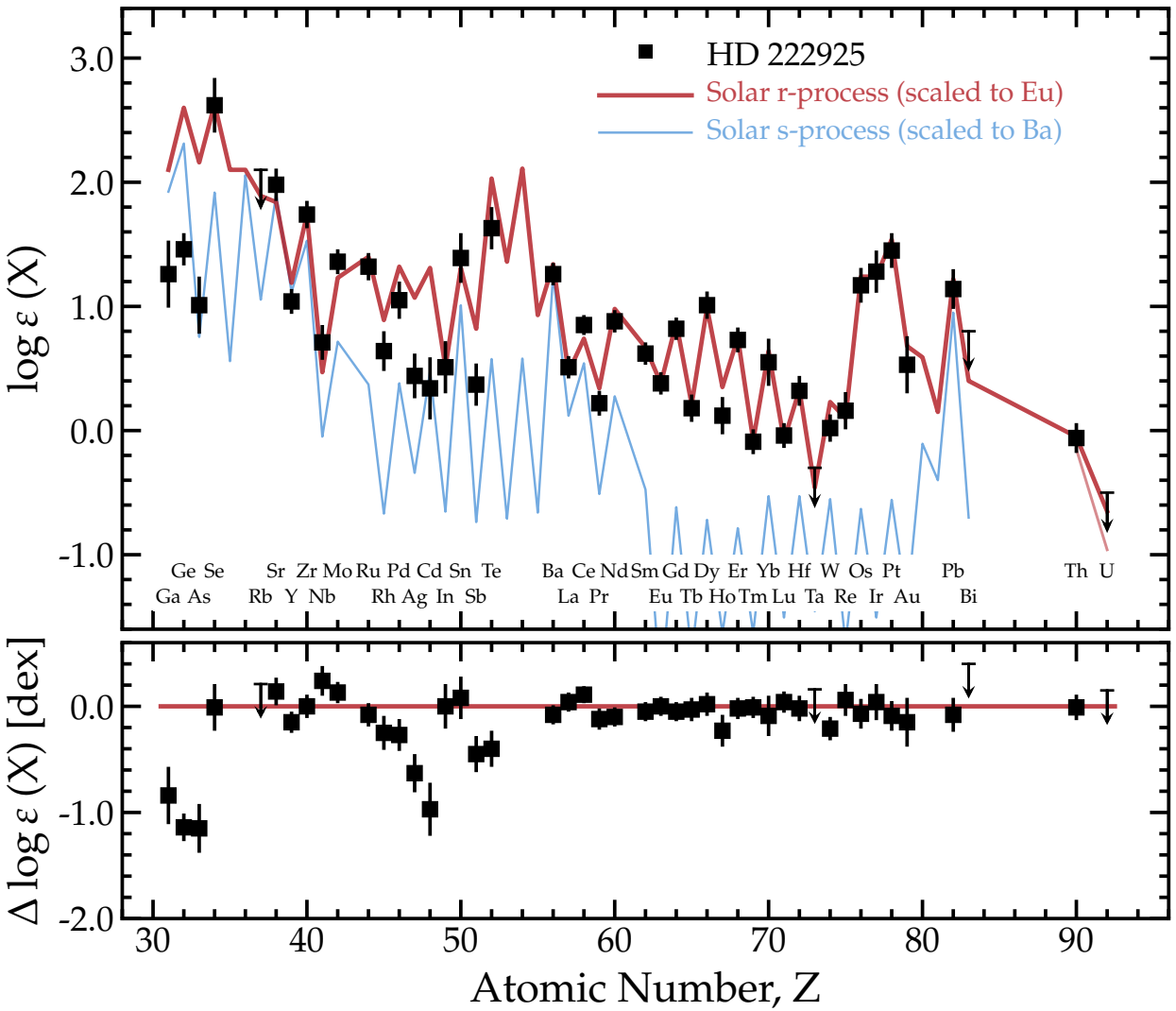
- **Bright**, $V < 13.5 \rightarrow$ can observe many stars in short time
- **Cold**, $4000 < \mathrm{T_{eff}} < 5500 \rightarrow$ Get Eu abundance or good upper limits
- **Metal poor**, $[\mathrm{Fe/H}] < -2 \rightarrow$ Only few nucleosynthesis events



RPA - HD222925 - The golden standard

$V = 9.02$, [Fe/H]=-1.46, [Eu/Fe]=1.32

42 n-cap elements, 63 elements in total

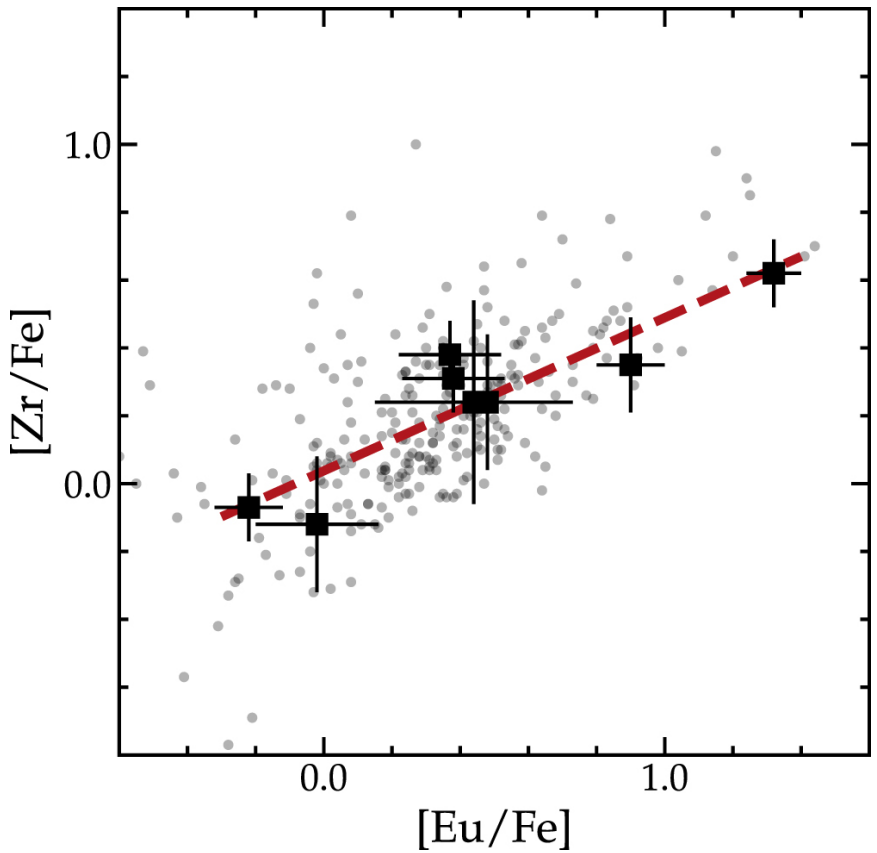


Roederer, RPA+ 2022a

RPA - Light element universality

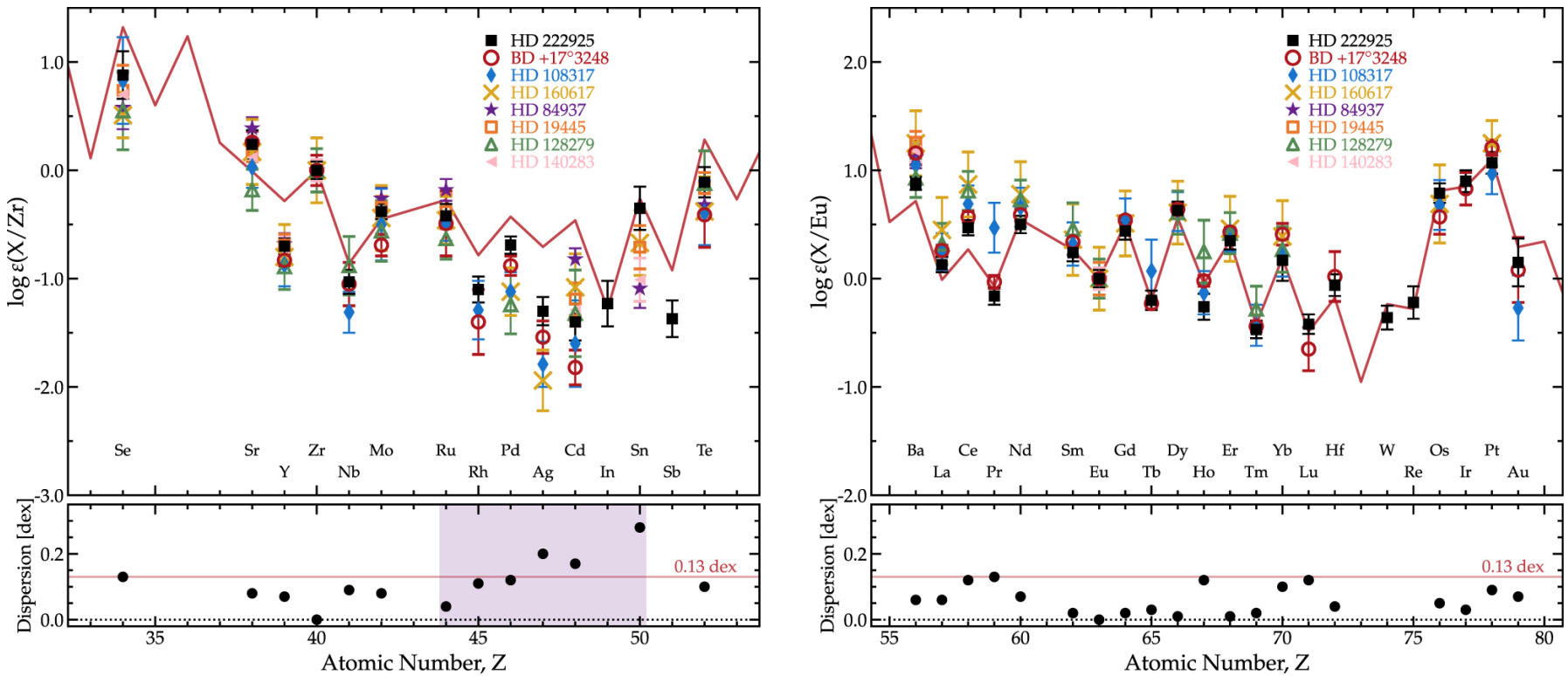
Stars with -0.22 < [Eu/Fe] < 1.32

Heavy elements match pattern



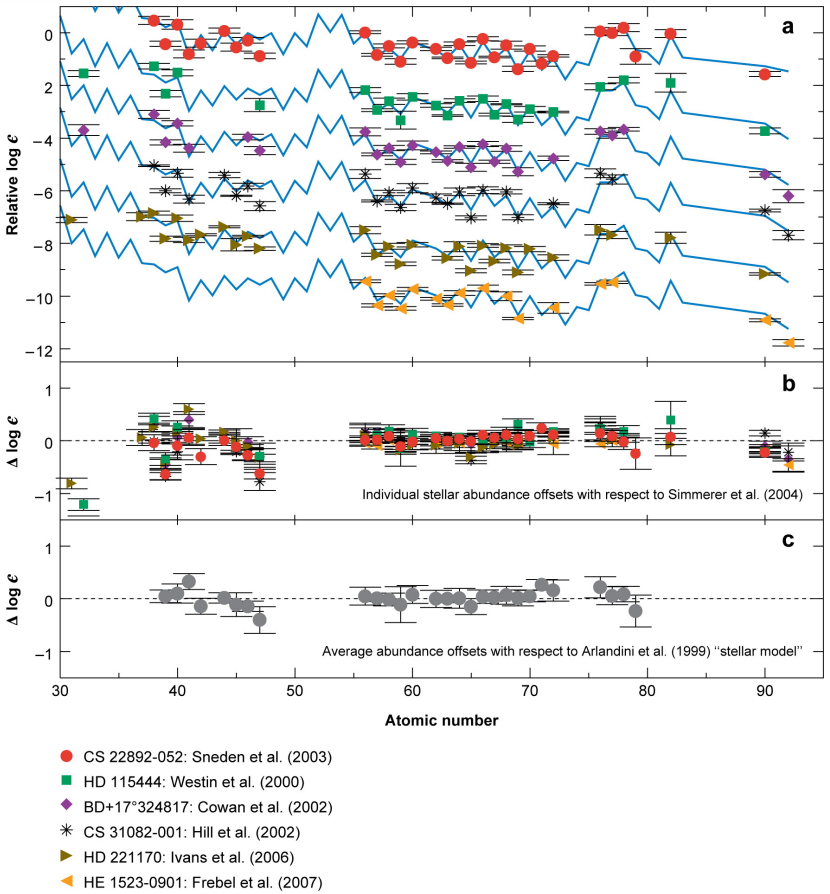
Roederer, RPA+ 2022b

RPA - Light element universality



Roederer, RPA+ 2022b

(2) The universal pattern



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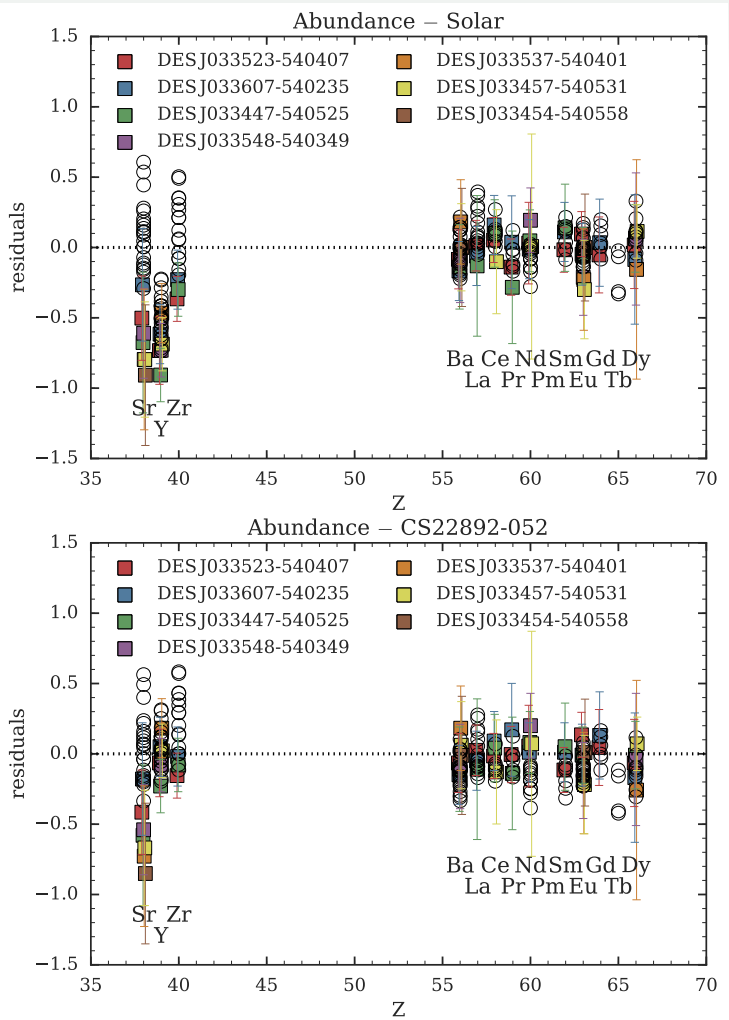
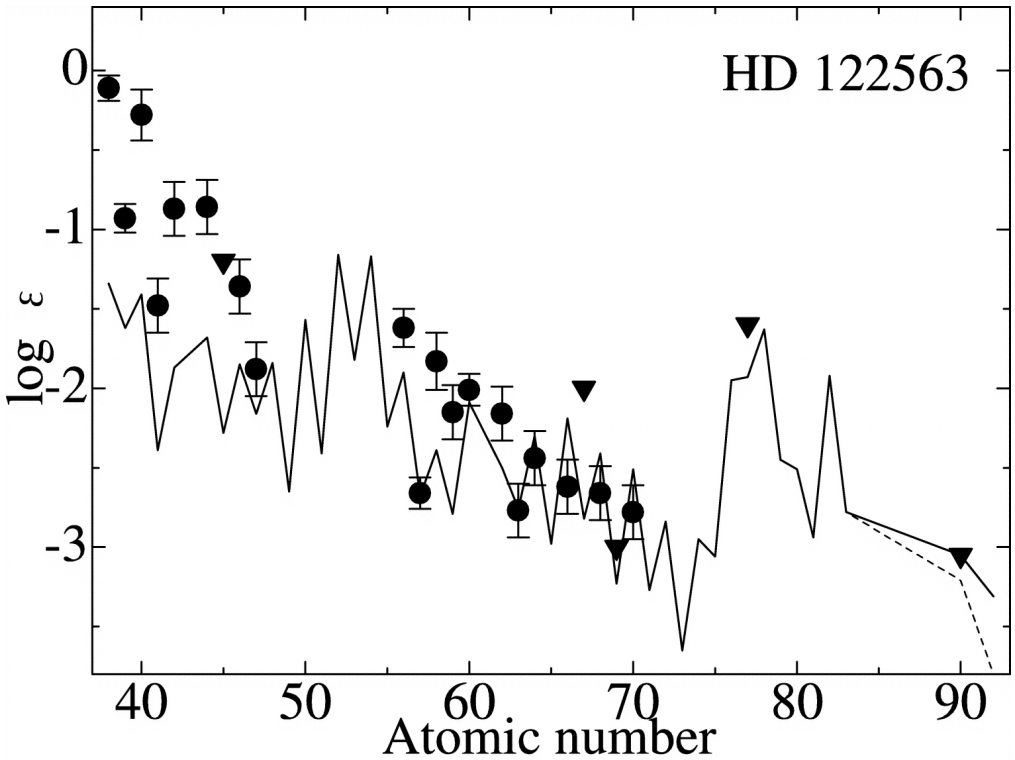


Sneden 2008, Ji+ 2016

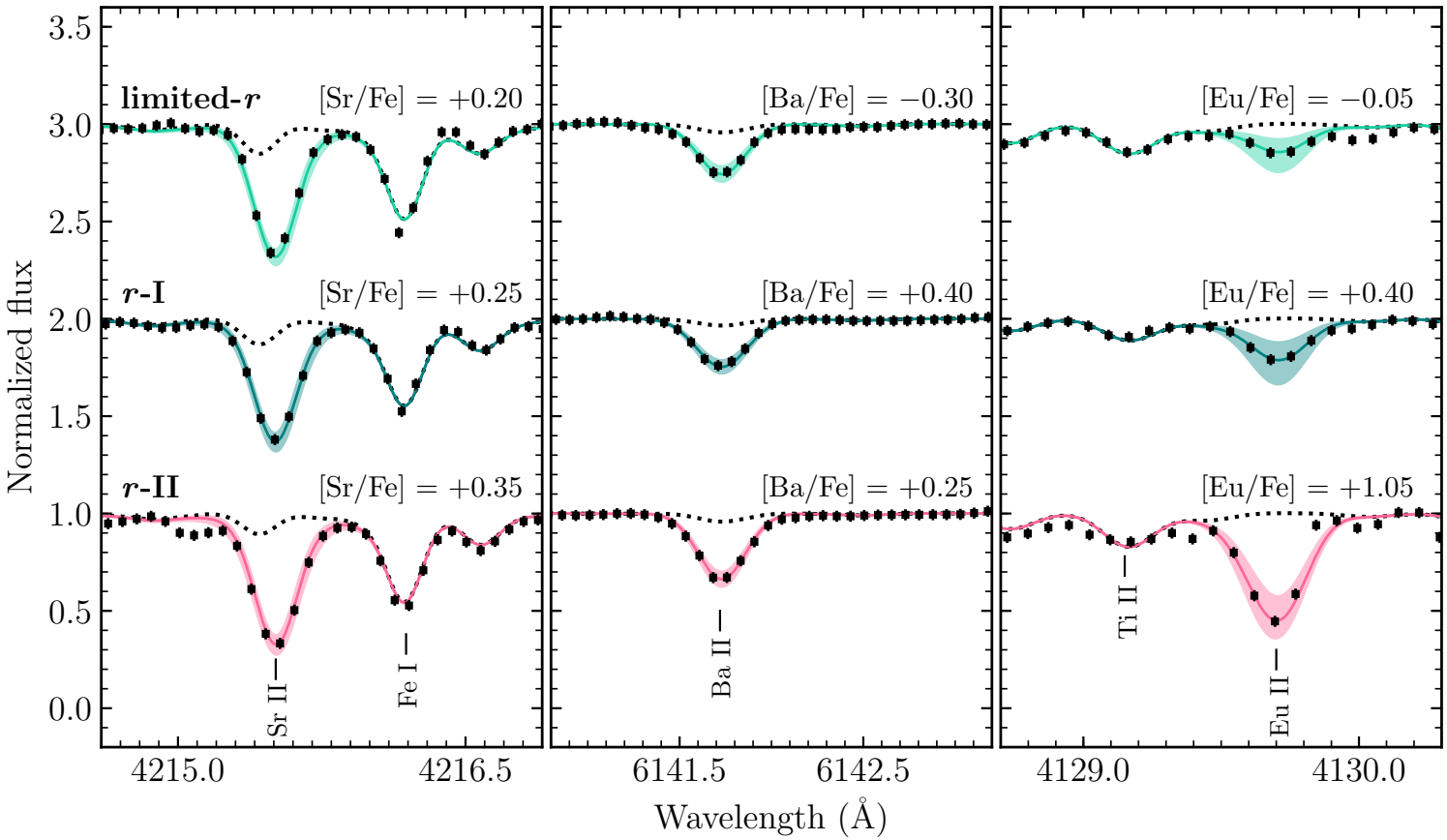
(3) Neutron-capture element abundances in r-process poor stars ($[\mathrm{Eu/Fe}] < 0.3$) whose pattern doesn't follow the main r-process patten.



Honda+ 2006

RPA - Classification

r_{lim}: [Sr/Ba] > +0.5, [Sr/Eu] > +0.0, [Eu/Fe] < +0.3



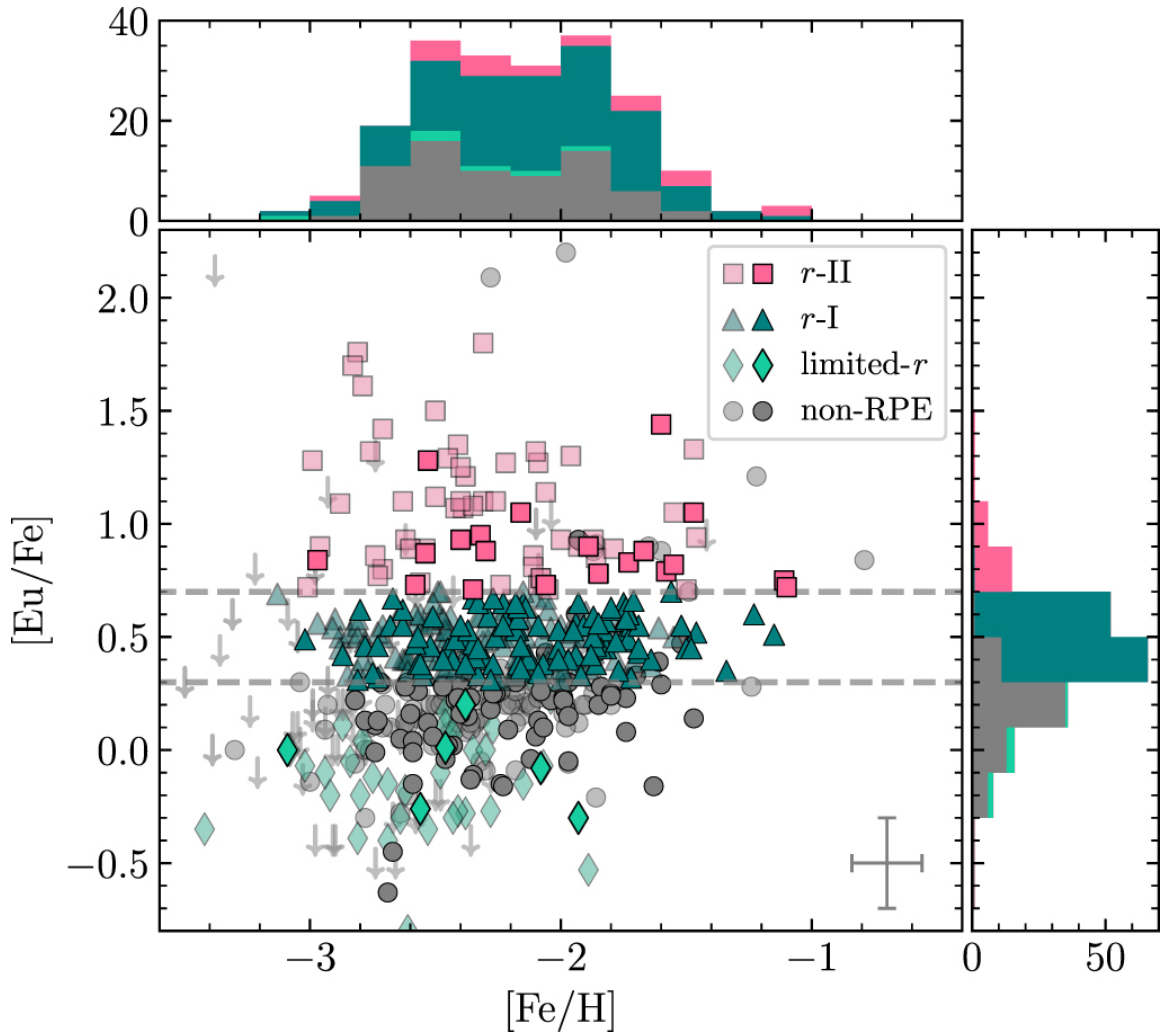
Holmbeck+ 2020

RPA - Current results - 600 stars

72 r-II

232 r-I

42 r_{lim}



Hansen+ 2018, Sakari+ 2018, Ezzeddine+ 2020, Holmbeck+ 2020

RPA Limited-r stars

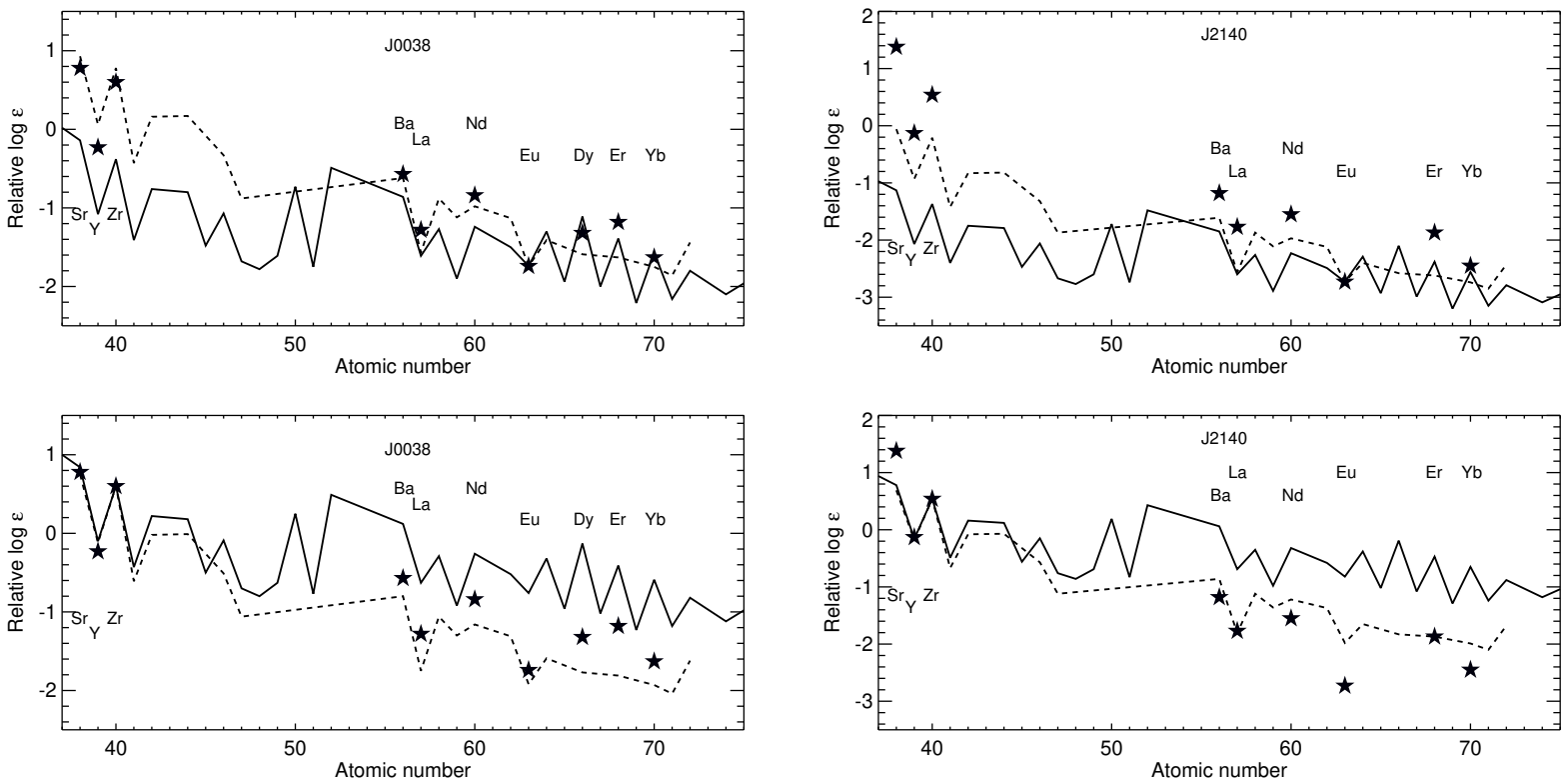
J0038:
$[\mathrm{Sr/Ba}] = 0.66$, $[\mathrm{Sr/Eu}] = 0.18$, $[\mathrm{Eu/Fe}] = 0.10$,
$[\mathrm{Ba/Eu}] = -0.48$

J2140:
$[\mathrm{Sr/Ba}] = 1.60$, $[\mathrm{Sr/Eu}] = 1.49$, $[\mathrm{Eu/Fe}] = -0.22$,
$[\mathrm{Ba/Eu}] = -0.11$

Xylakis-Dornbusch+ in prep.

RPA Limited-r stars

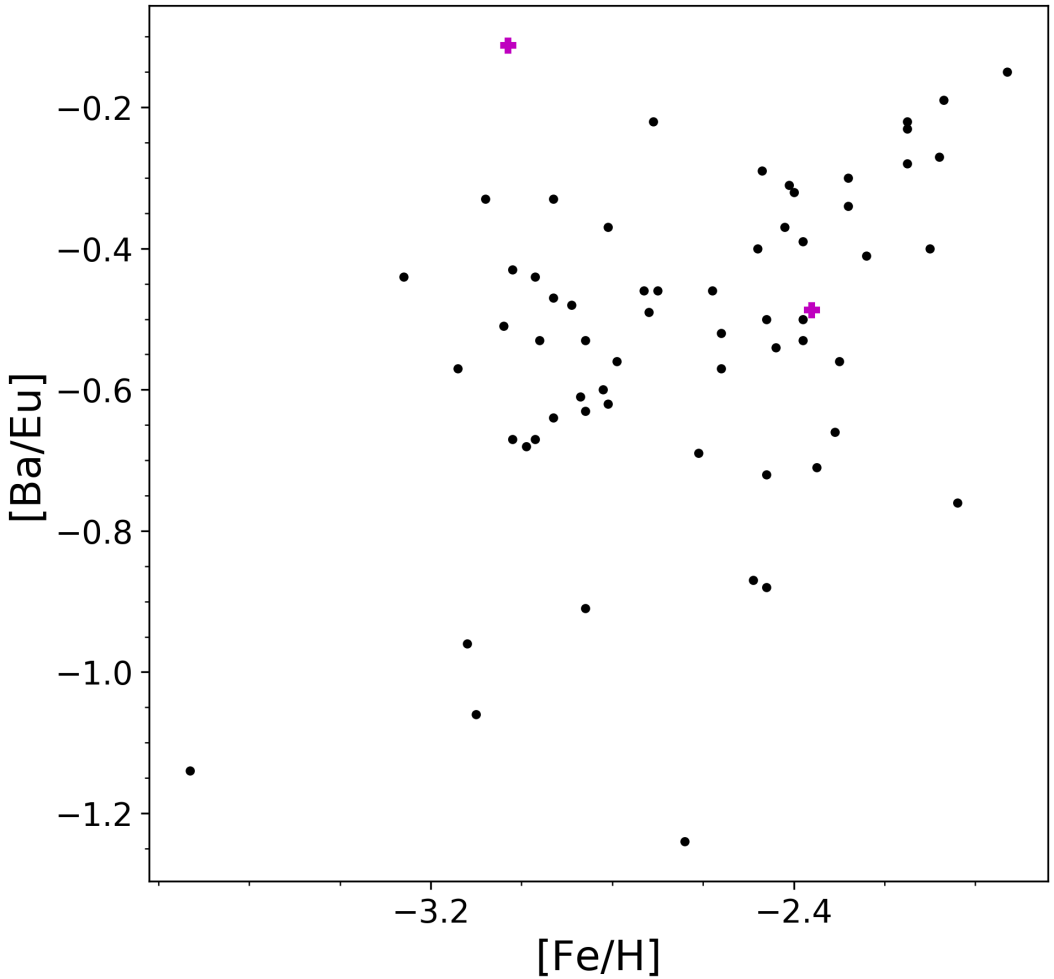
Comparred to HD122563 (dashed) and HD222529 (solid) scaled Eu(top) and Zr (bottom)



Xylakis-Dornbusch+ in prep.

RPA Limited-r stars - [Ba/Eu]

Wide range but all have $[\mathrm{Ba/Eu}] < 0$, this is not a selection criteria.



Xylakis-Dornbusch+ in prep.

Summary

- Universality of light neutron-capture elements pattern for stars with universal main r-process pattern
- Maybe light neutron-capture element universality extends further.
- RPA survey - focus on stars with excess of light neutron-capture elements - 42 new stars discovered
- RPA survey - homogeneous derived abundances for a large sample of stars with excess of light neutron-capture elements.

$\rightarrow$`sites.google.com/view/rprocessalliance`