Nuclear & Chemical Sciences

Nature’s Fission Fragment Distribution

Erika M. Holmbeck

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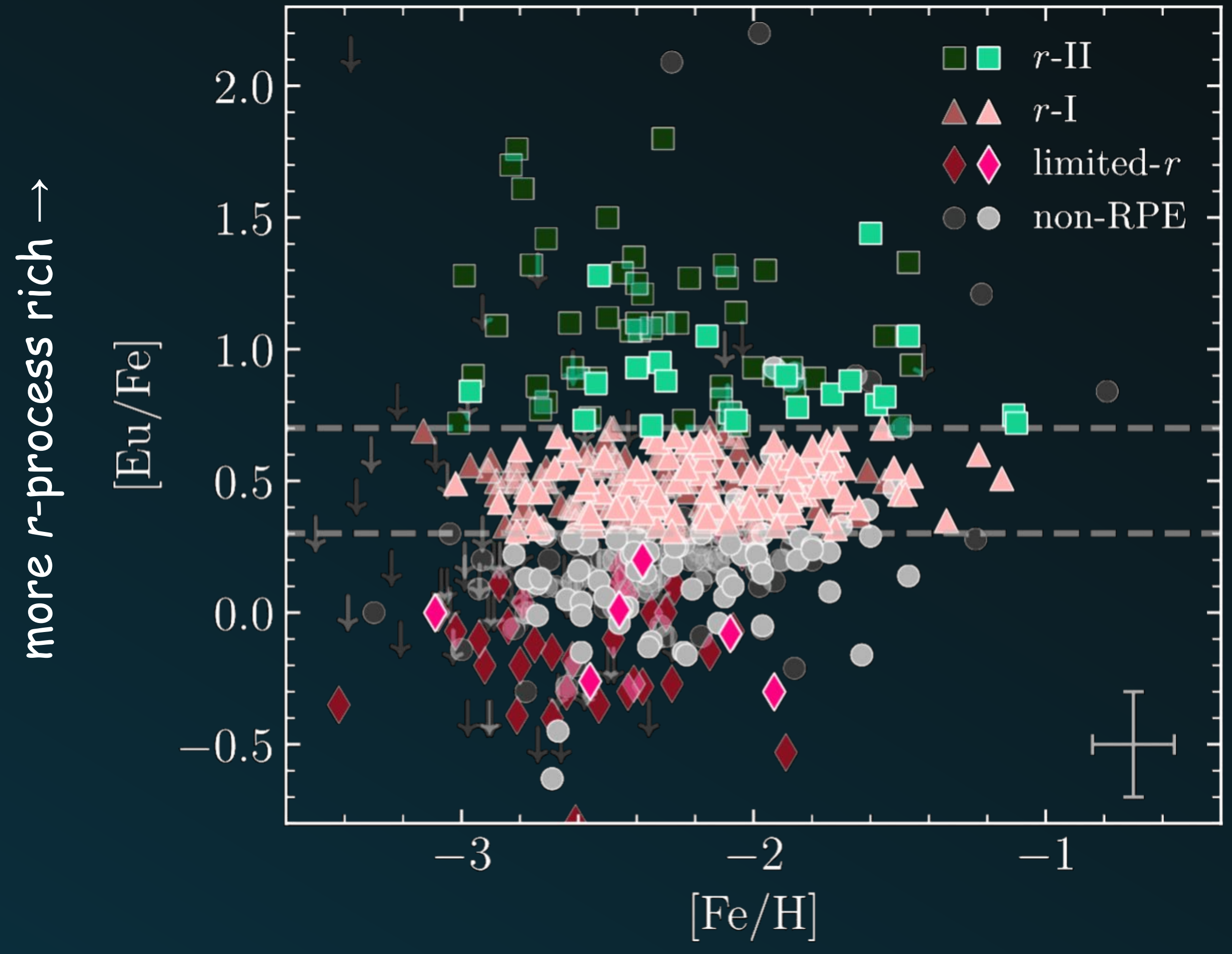
The oldest, most *r*-process enhanced ("*r*-II") stars are considered "single-origin" in their neutron-capture elements



* See talks by Miho Ishigaki, Ruizjeng Jiang, and Mila Racca

R-Process Alliance

DR4: **Holmbeck+** (2020)

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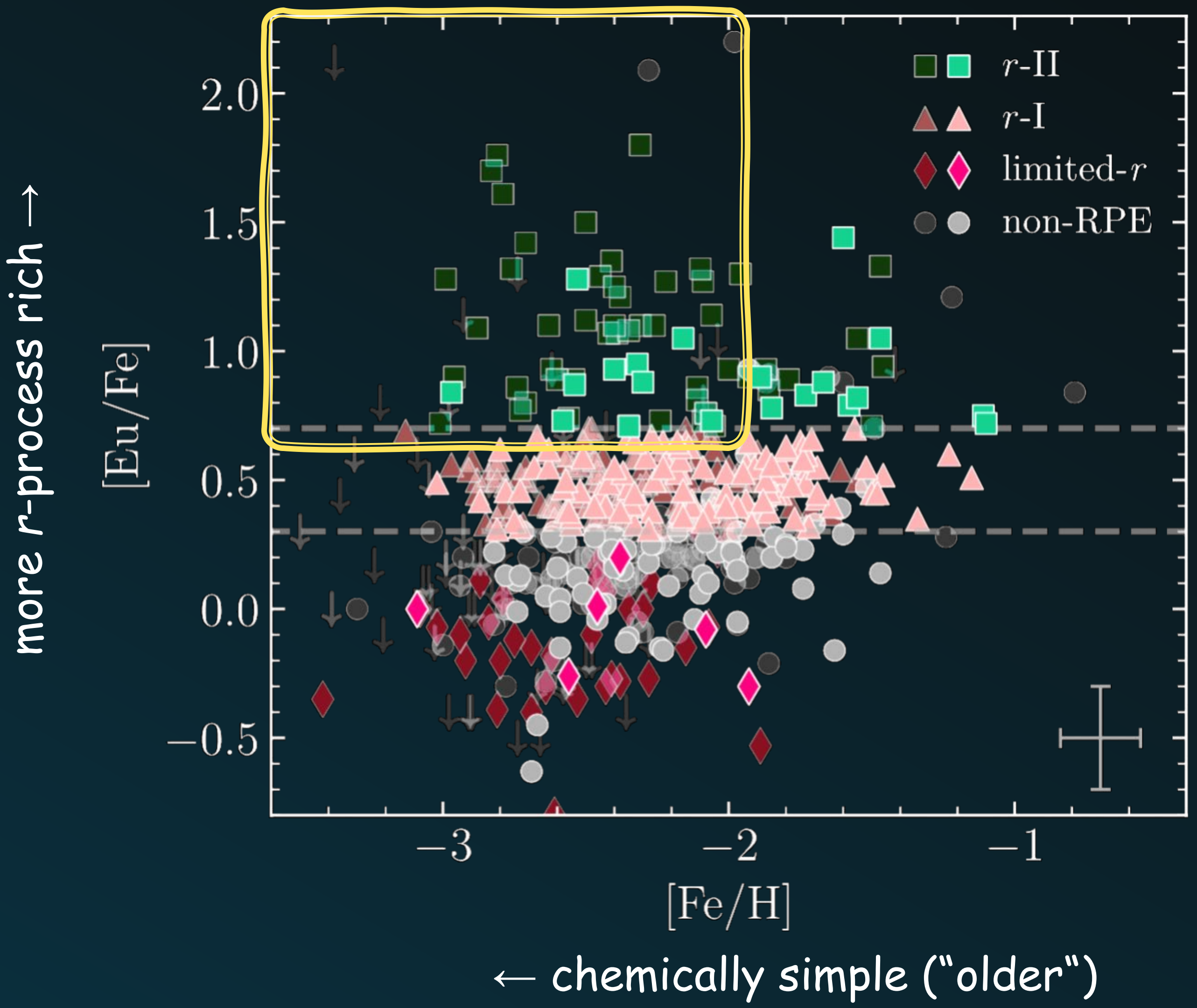

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R-Process Alliance

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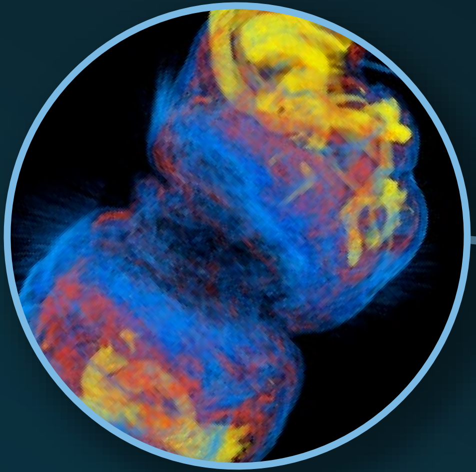
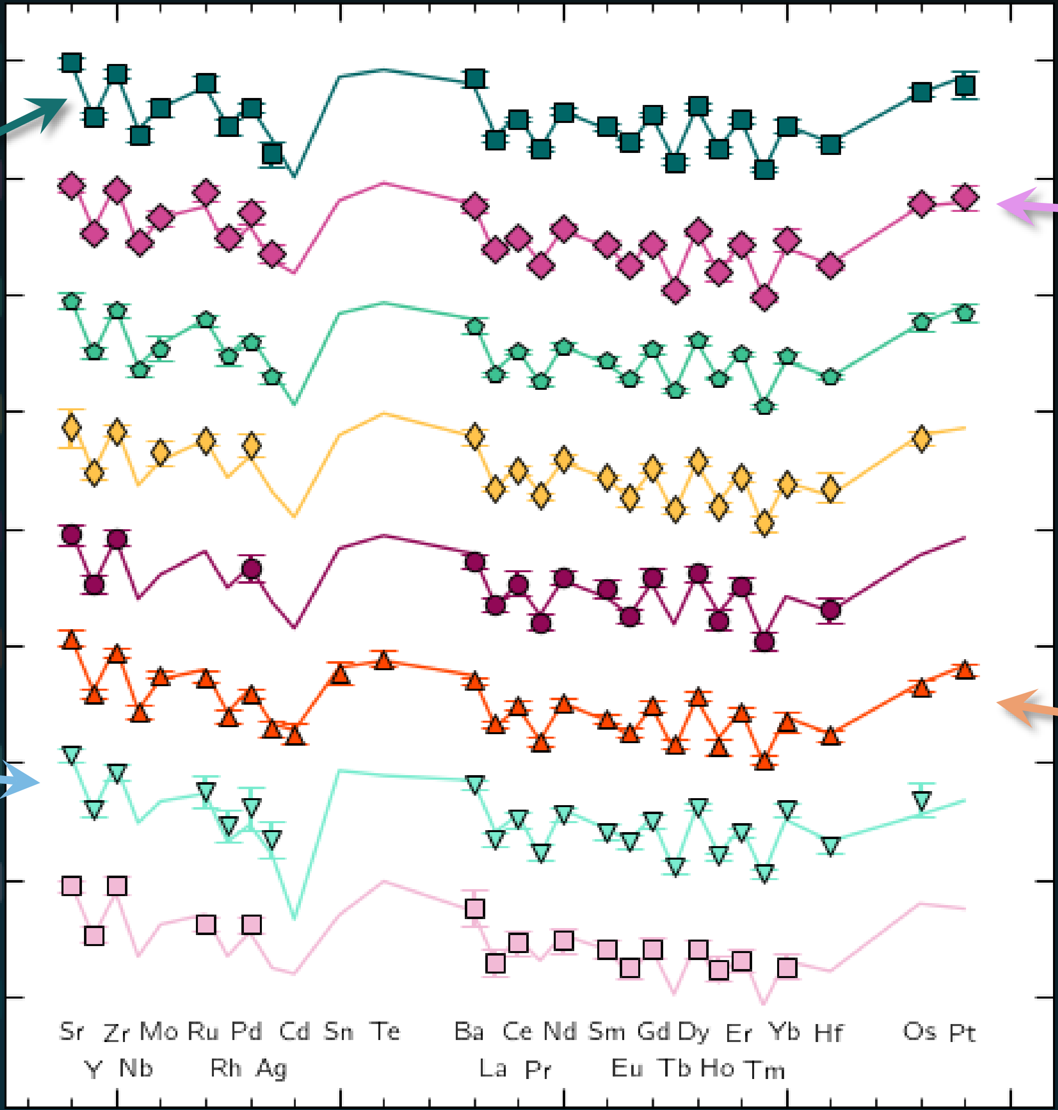
"It can clearly be seen that the abundance pattern for this star is reproduced by my favorite r-process site"





Holmbeck+ (*in prep.*)

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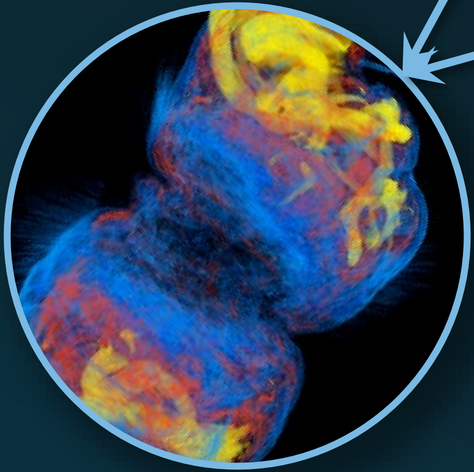
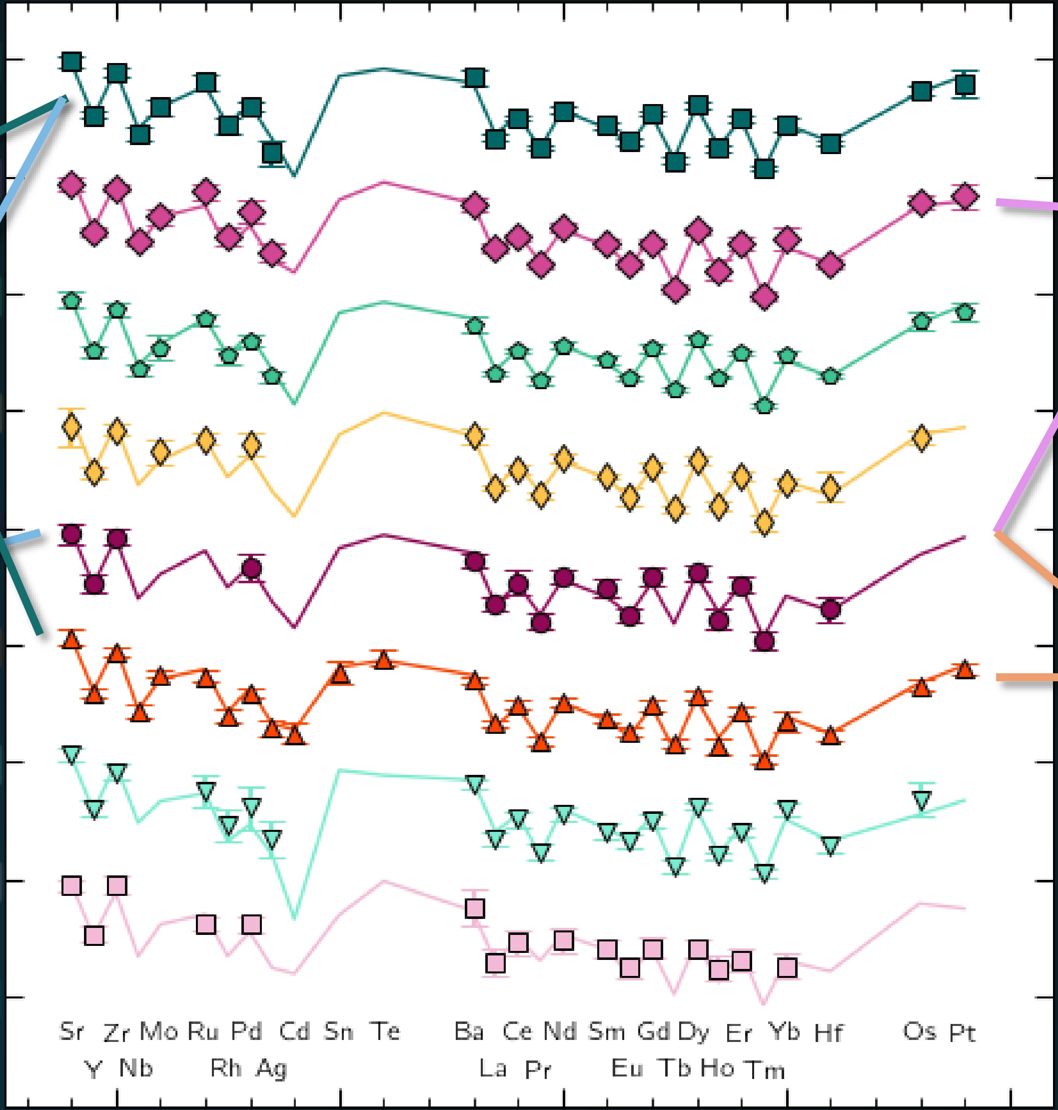
The inconvenient truth: stars were likely enriched from multiple *r*-process sites…yes, even the metal-poor ones





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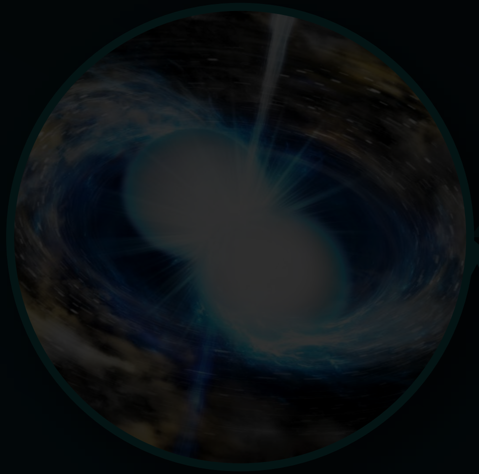
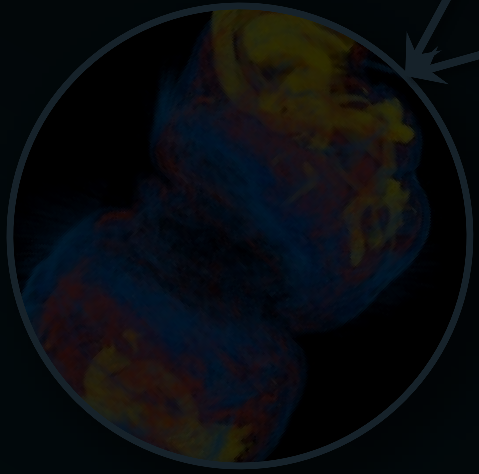
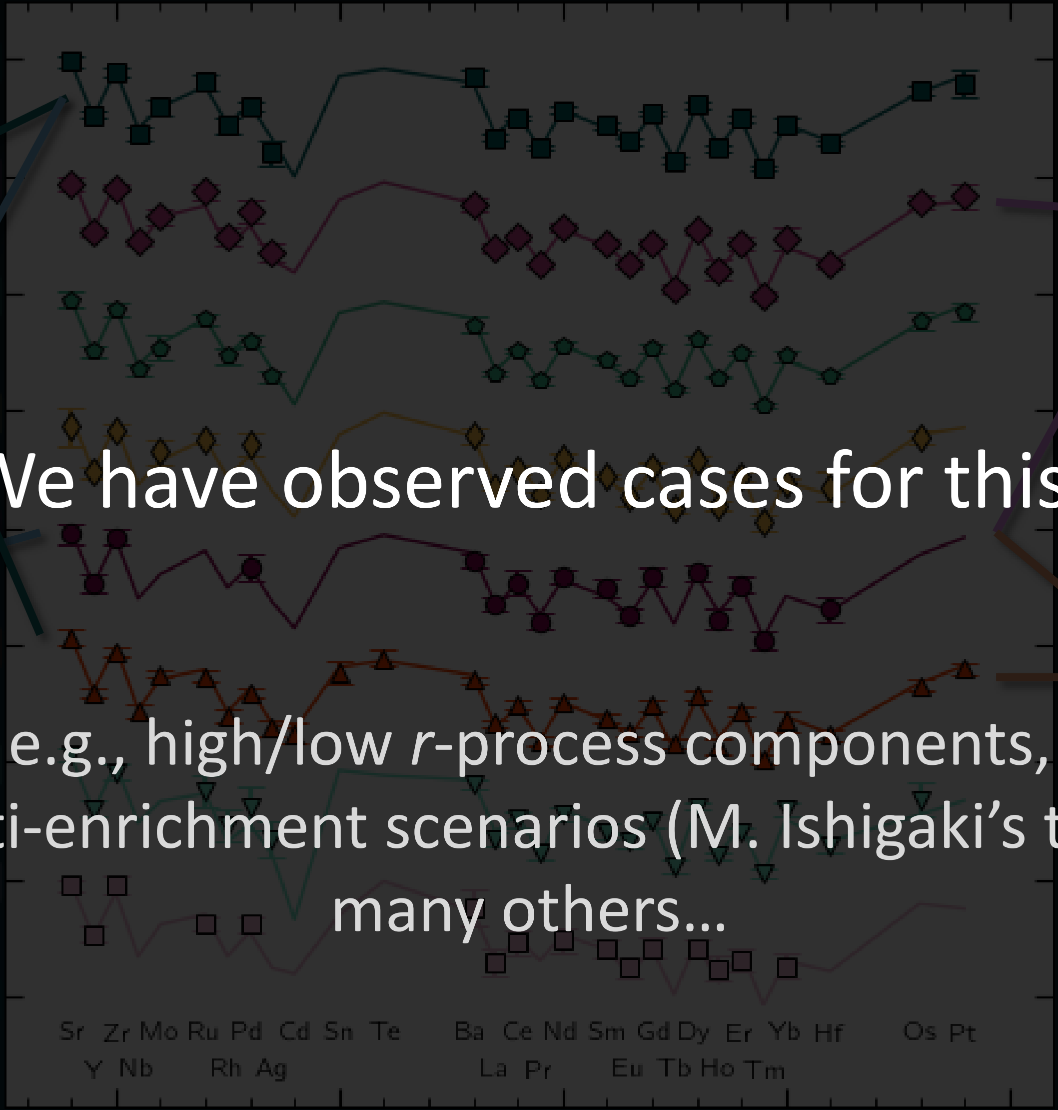
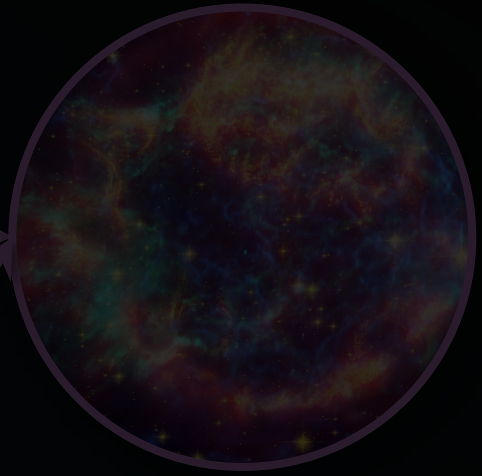
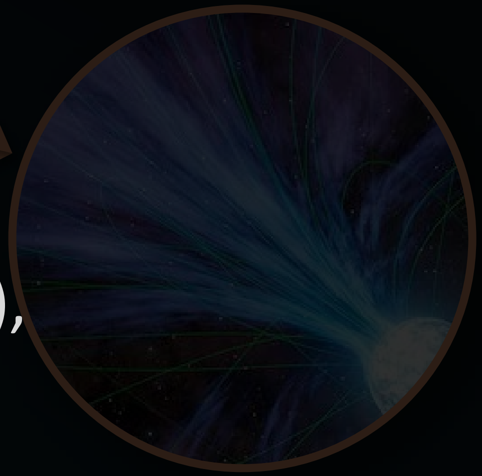








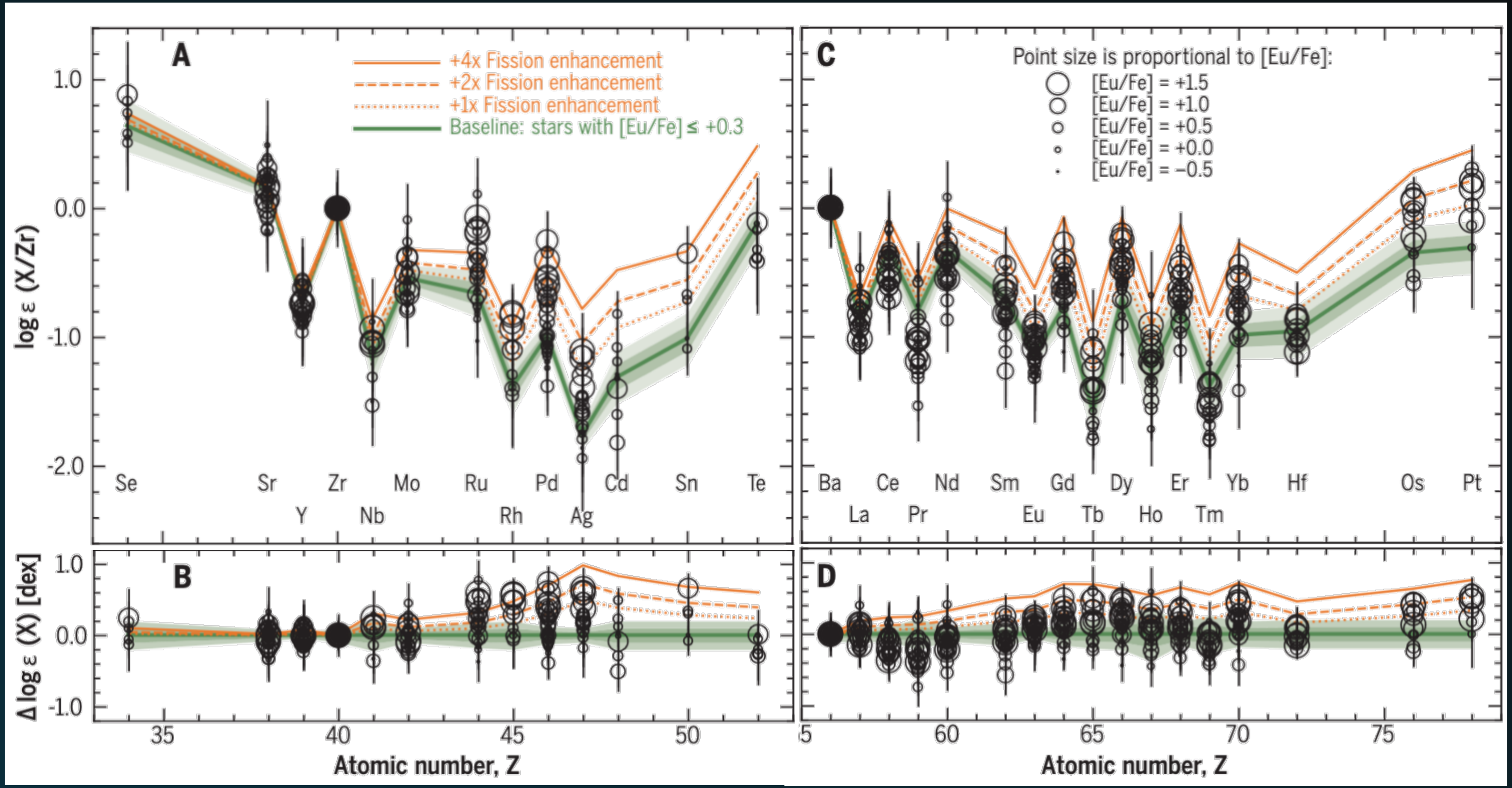


We have observed cases for this!

e.g., high/low *r*-process components,
multi-enrichment scenarios (M. Ishigaki's talk),
many others…

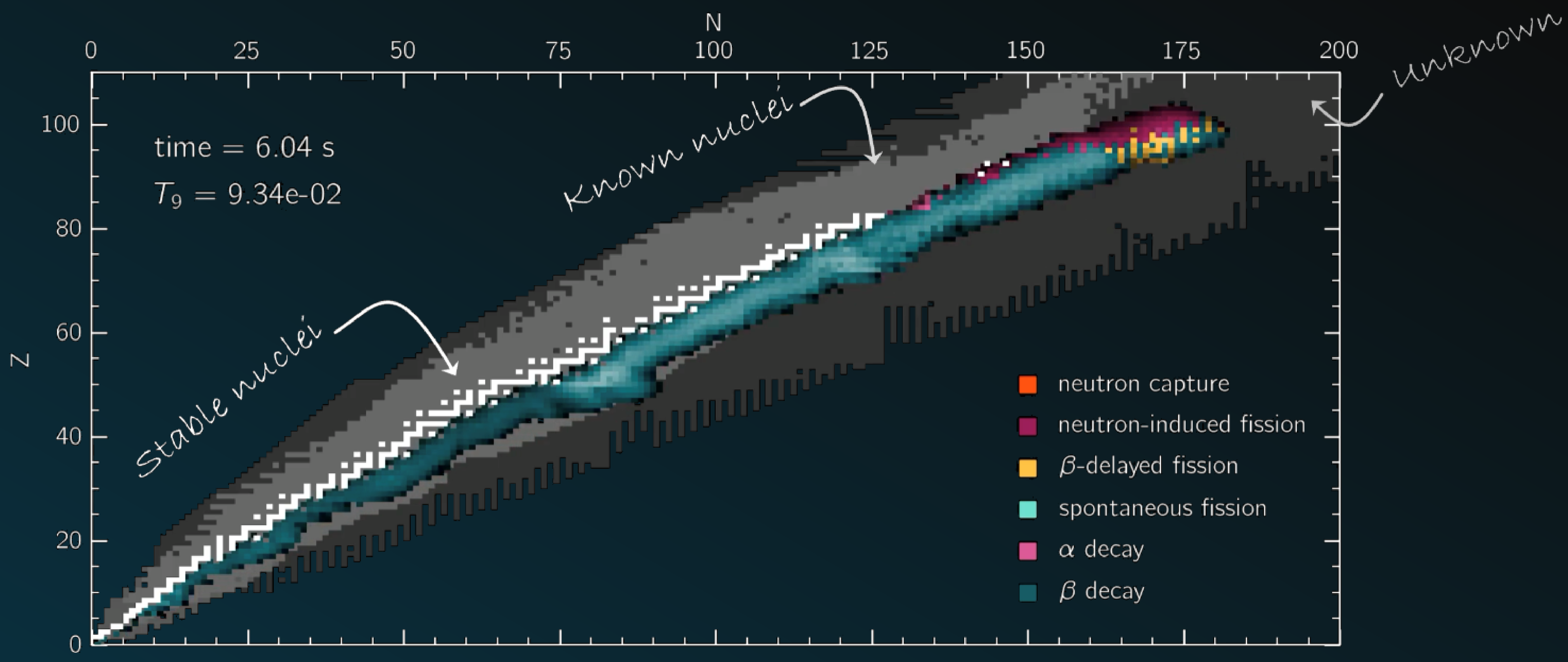
Holmbeck+ (*in prep.*)

We have a sample of 42 stars with *r*-process patterns that appear to be described by a baseline component plus a fission component



Roederer+ (2023)

In favorable site conditions, nuclei **fission** and deposit material at lower masses, producing an abundance excess



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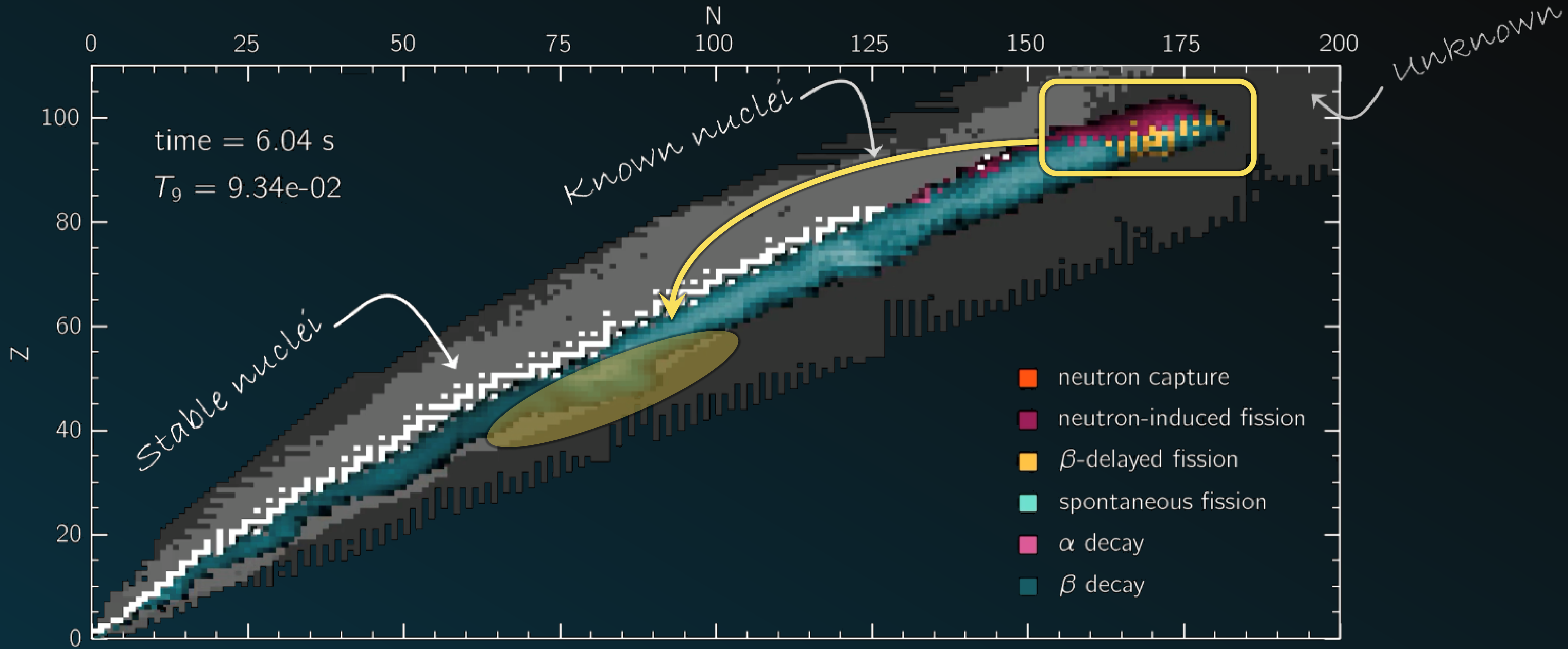
In some conditions, nuclei **fission** and deposit material at lower masses, producing an abundance excess



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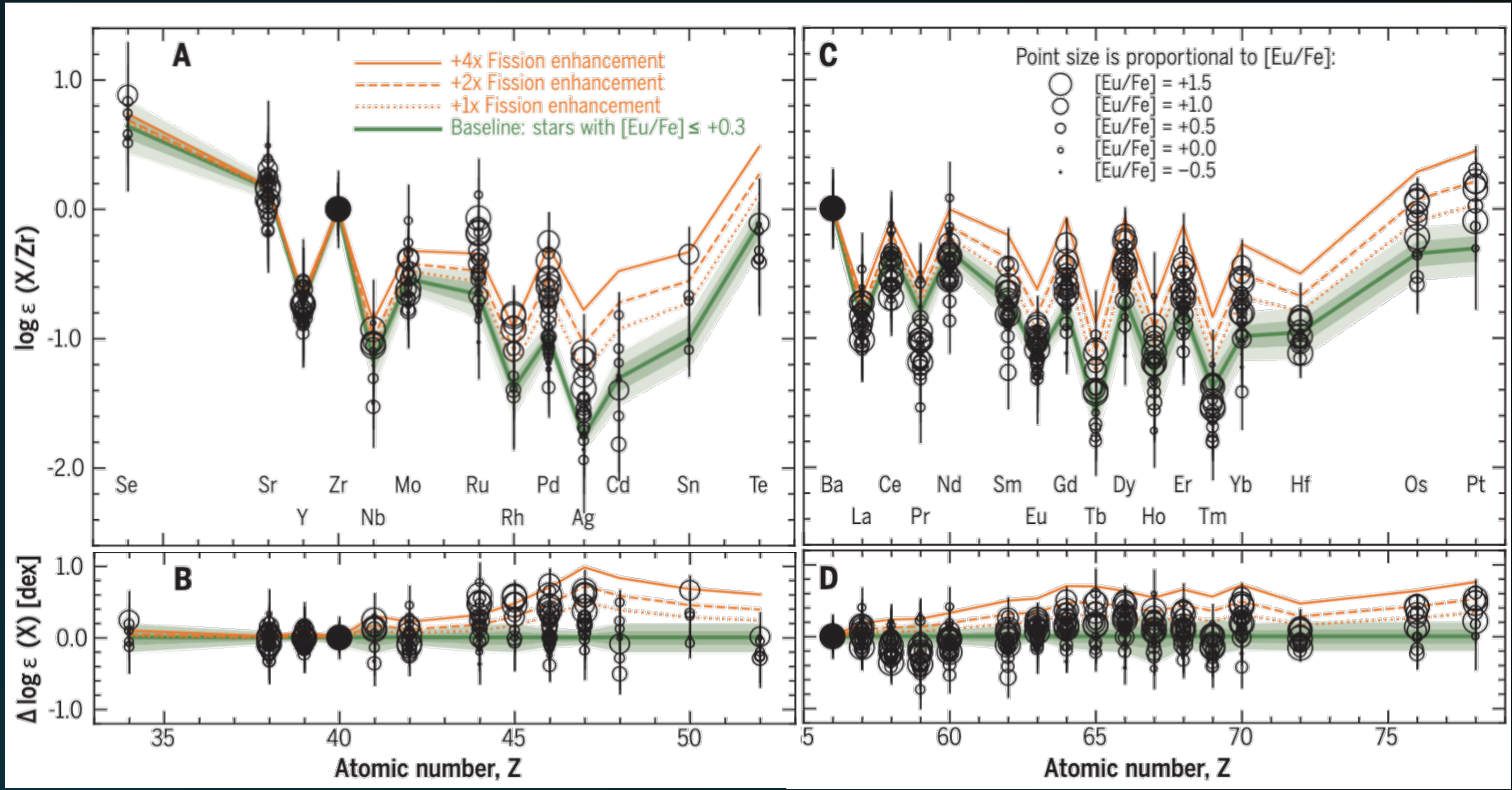
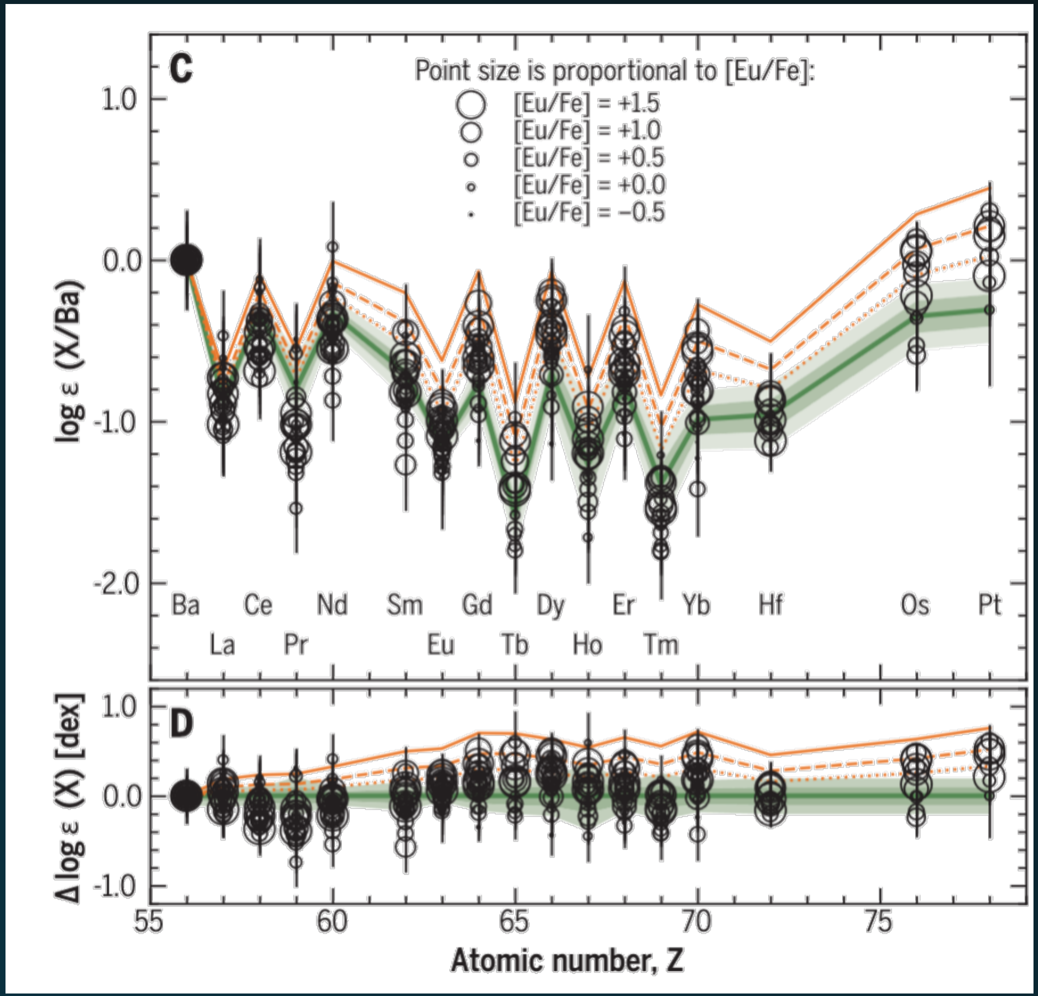
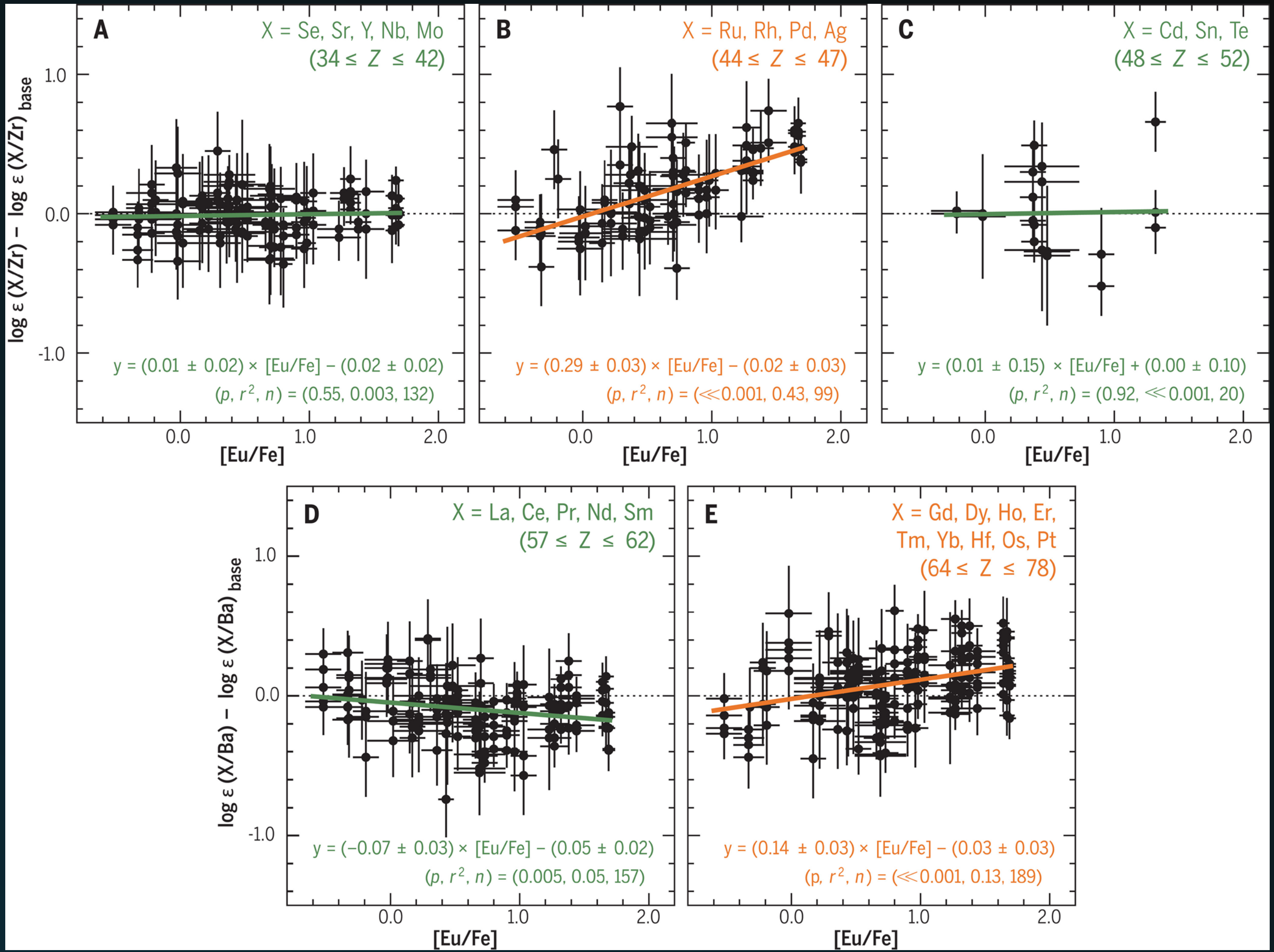


Roederer+ (2023)

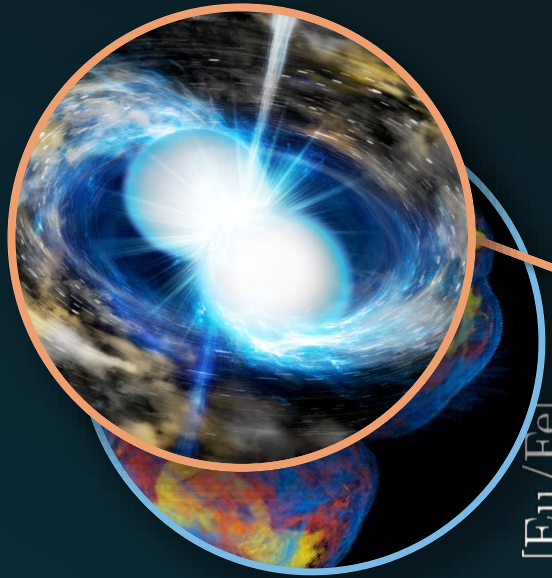
The abundance excess increases with [Eu/Fe] (*r*-process enrichment)

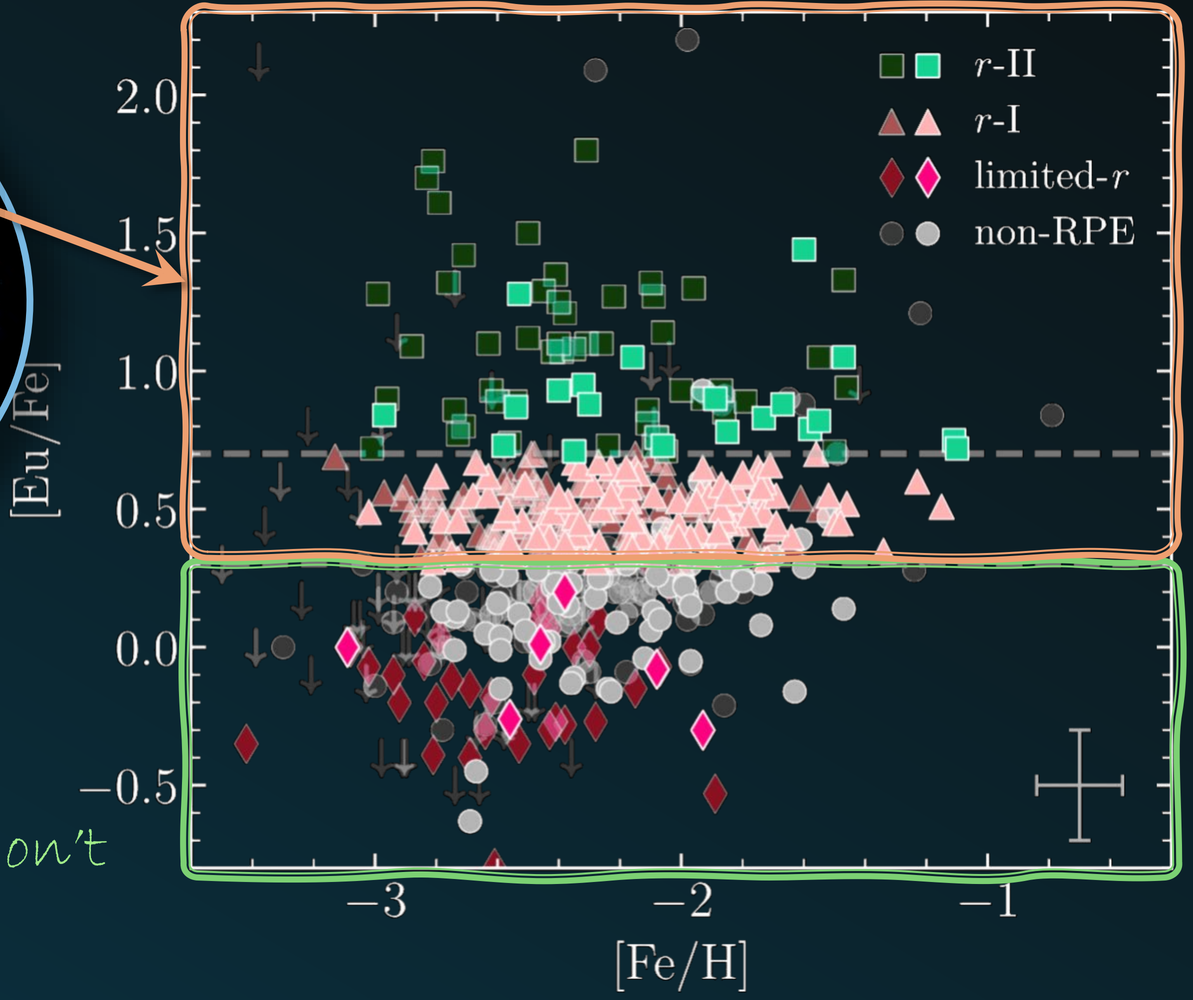


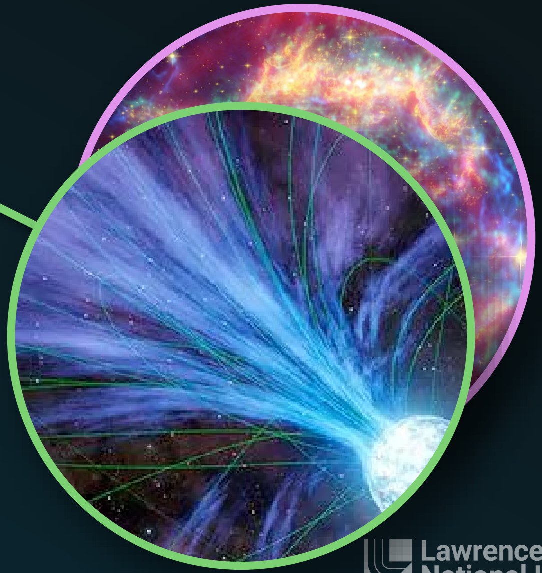


Roederer+ (2023)

Does this equate to each star being a combination of fission-capable *r*-processes and non-fission achieving sites?







RPA DR4: **Holmbeck+** (2020)

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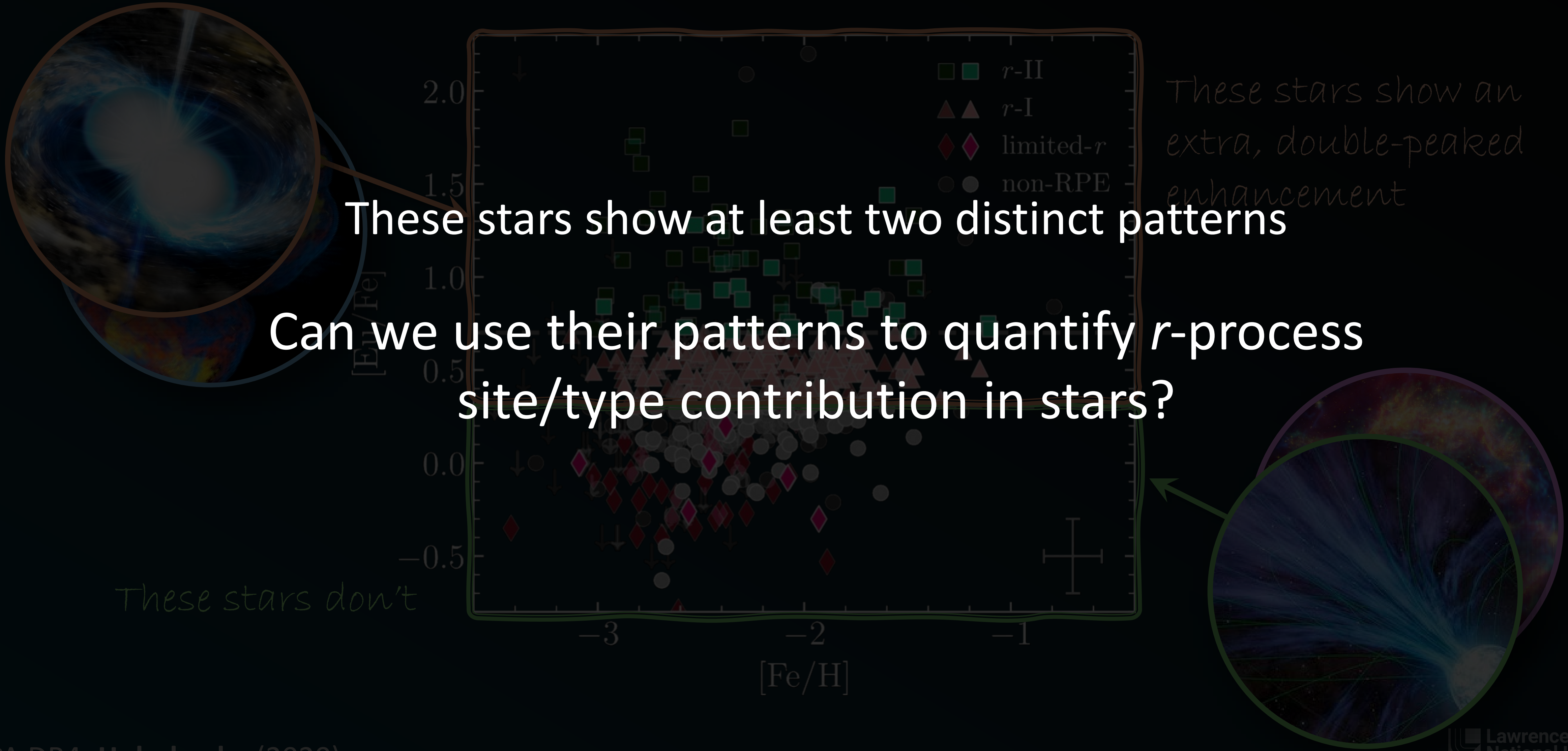
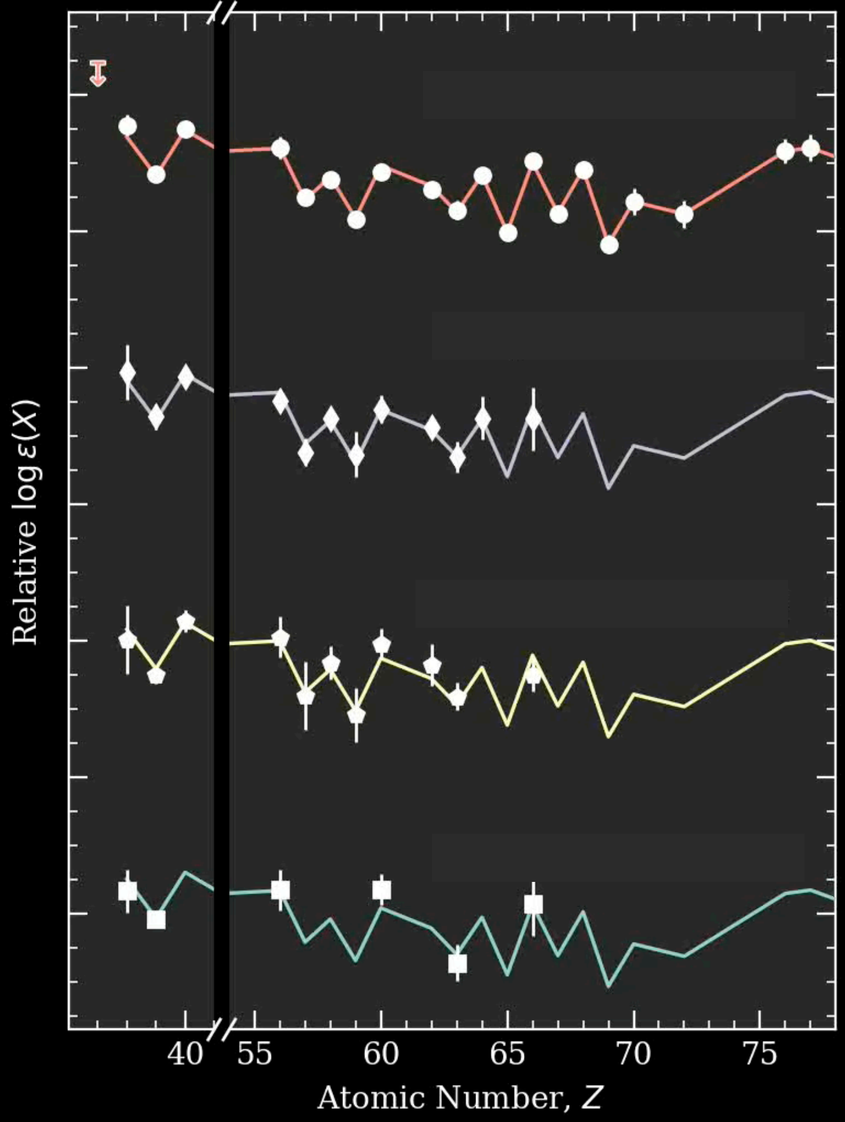


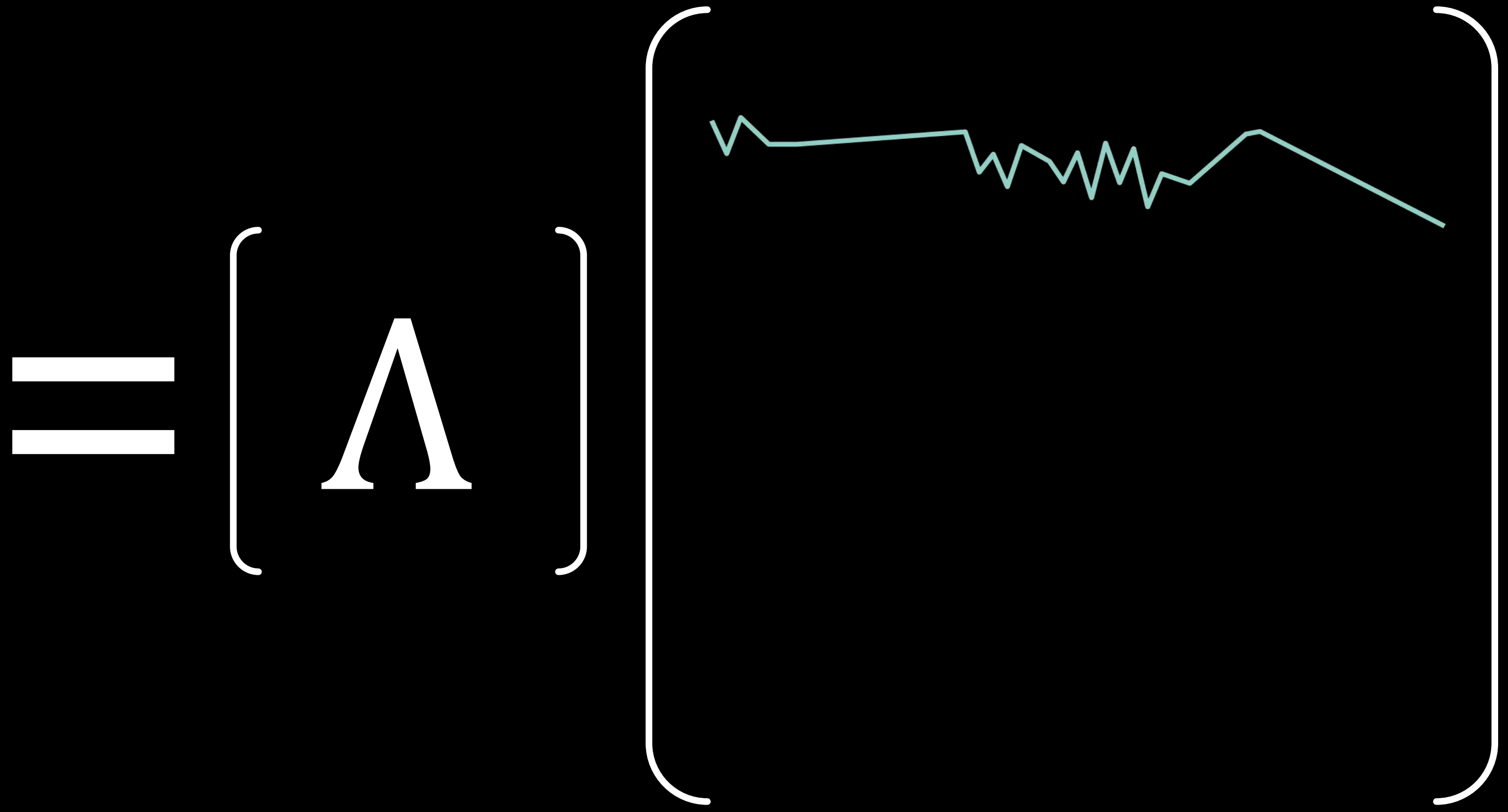
These stars show at least two distinct patterns

Can we use their patterns to quantify *r*-process site/type contribution in stars?

RPA DR4: **Holmbeck+** (2020)

The method: treat each of the 42 abundance patterns as a linear combination of a basis set of abundance patterns and **iterate**





See also:
Hansen+ (2012); Hansen, Montes, & Arcones (2014); Griffith+ (2022)

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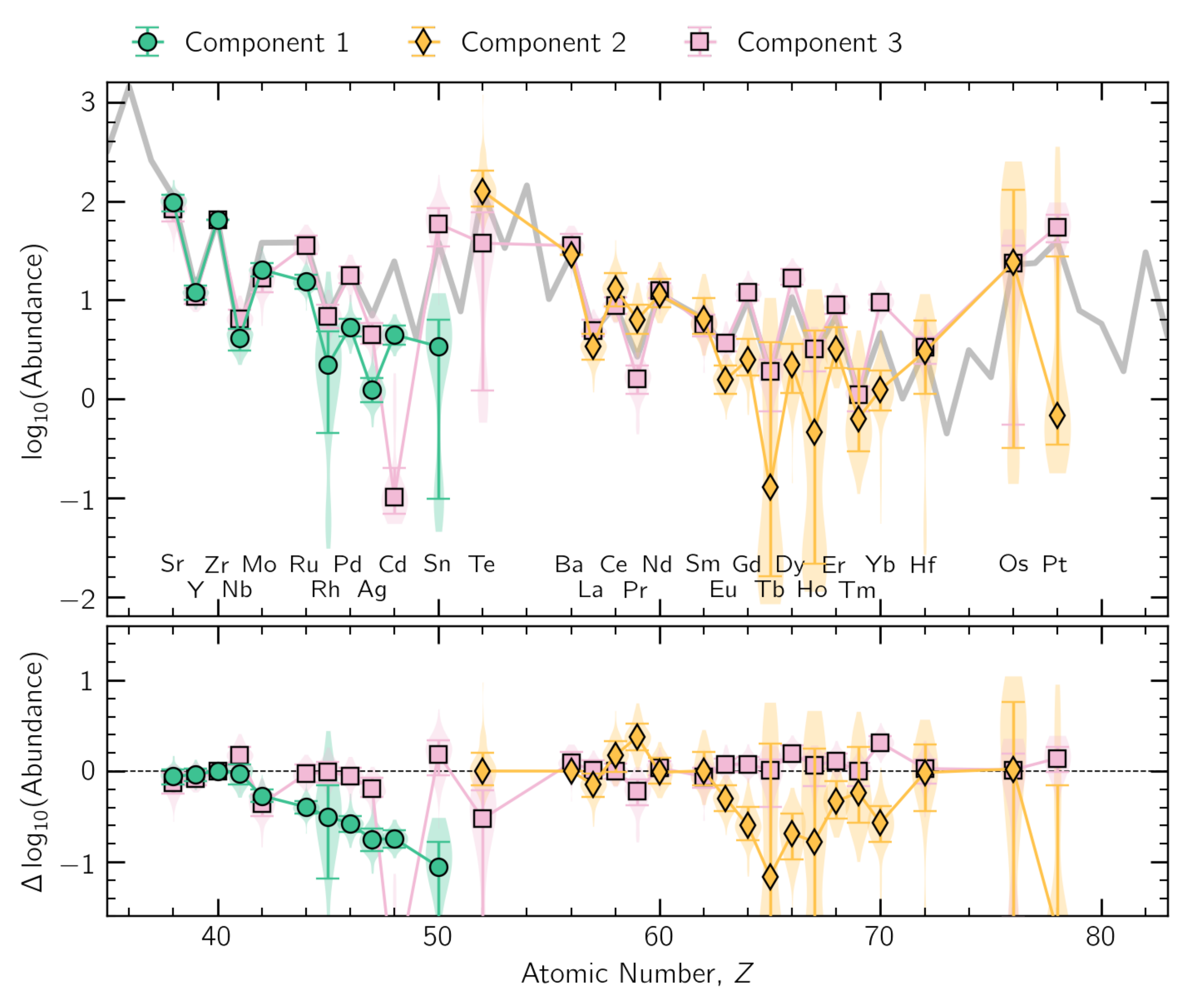
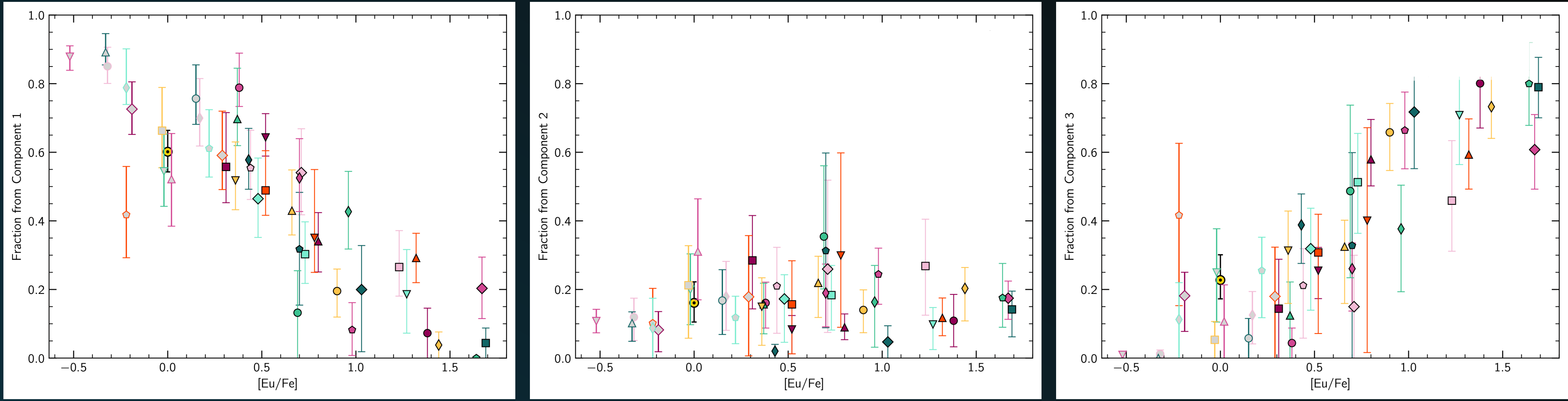
Three components optimally fits all 42 patterns: one each for the light (Z=38–50) and heavy (Z≥52) neutron-capture elements and one for the whole range (Z=38–78)



Holmbeck+ (*in prep.*)

How much each component contributes to each star as a function of its [Eu/Fe]



Component 1:

Light/limited *r*-process that decreases with [Eu/Fe]—agrees with observation

Component 2:

A main *r*-process that is constant(?) over [Eu/Fe]

Component 3:

A full *r*-process pattern that increases with [Eu/Fe] —agrees with observations

Holmbeck+ (*in prep.*)

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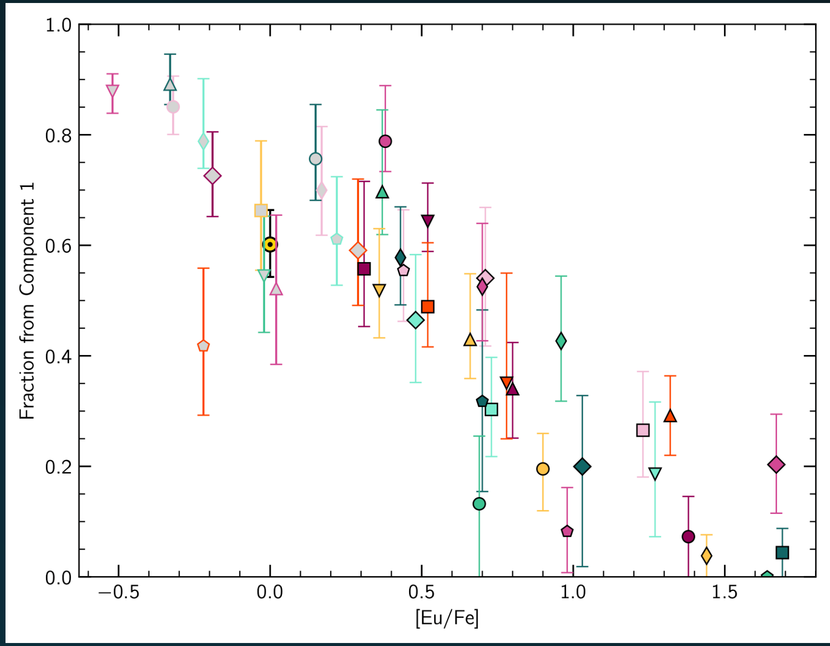

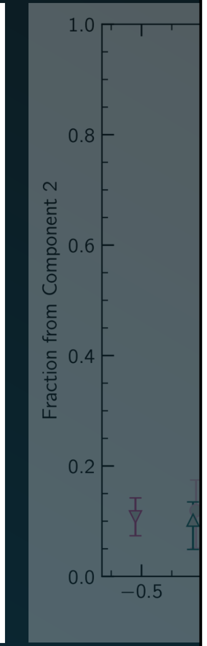

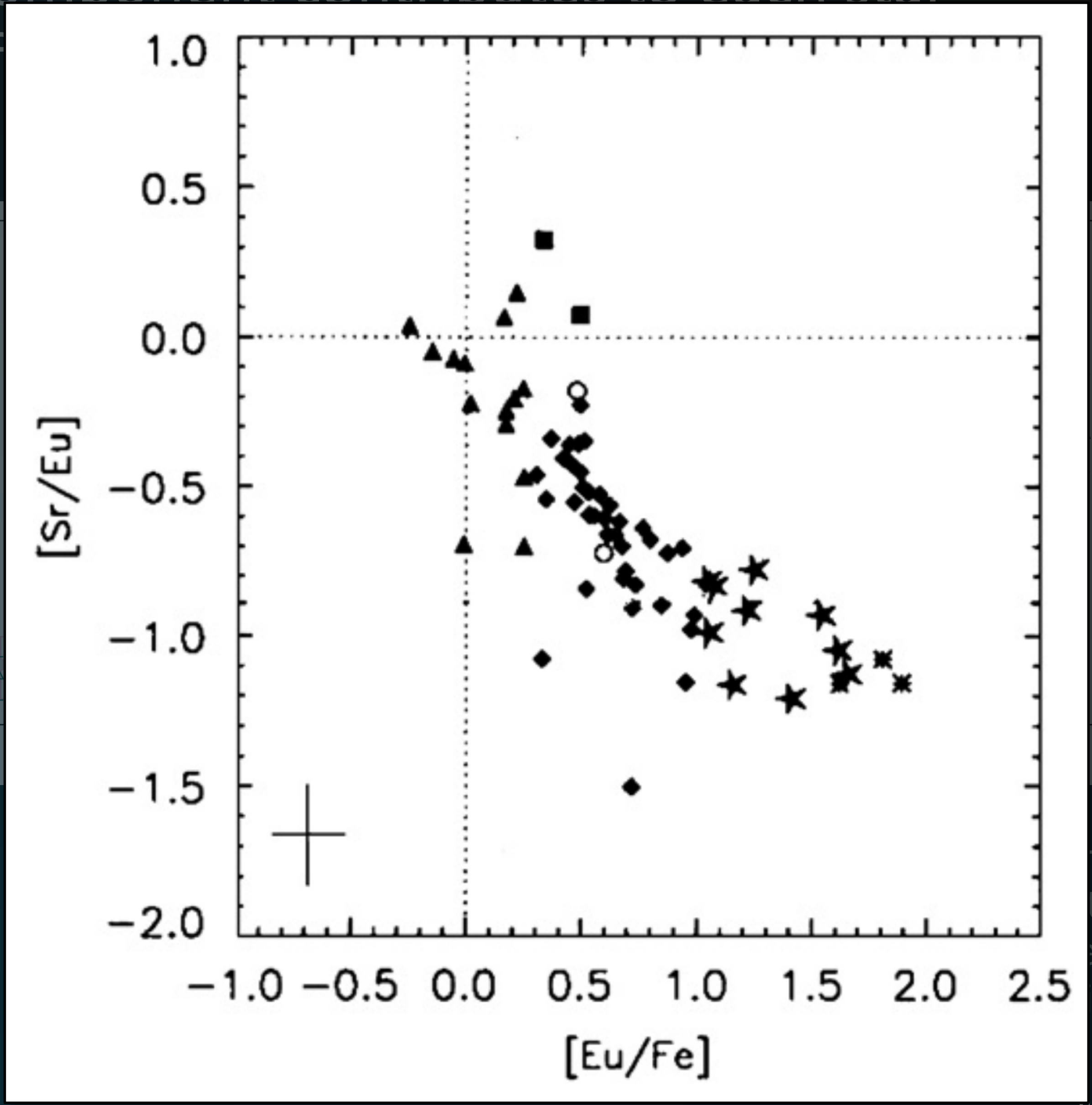

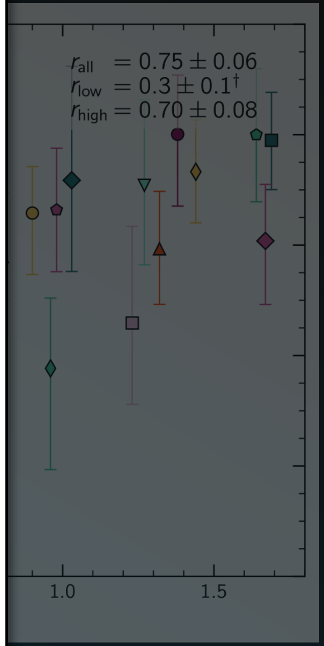

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Arnould+ (2007)

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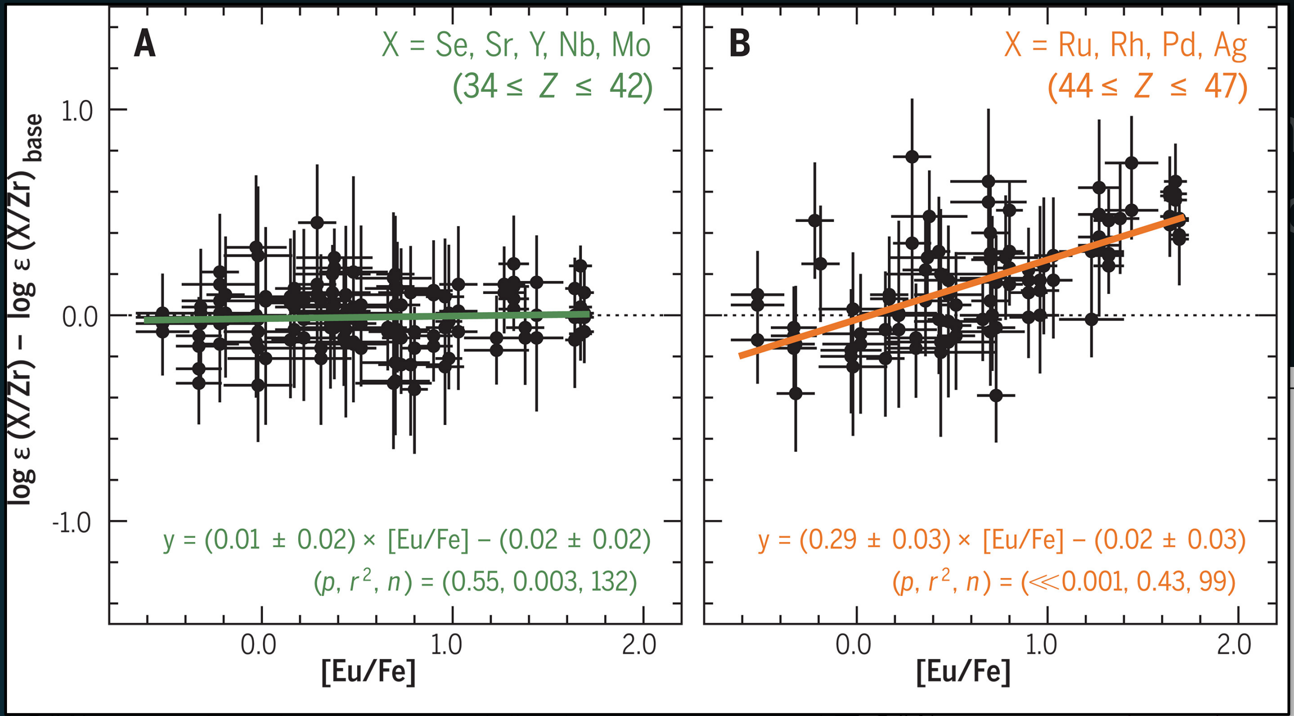

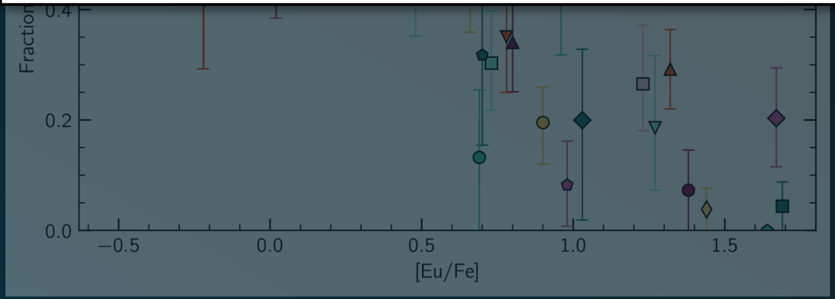

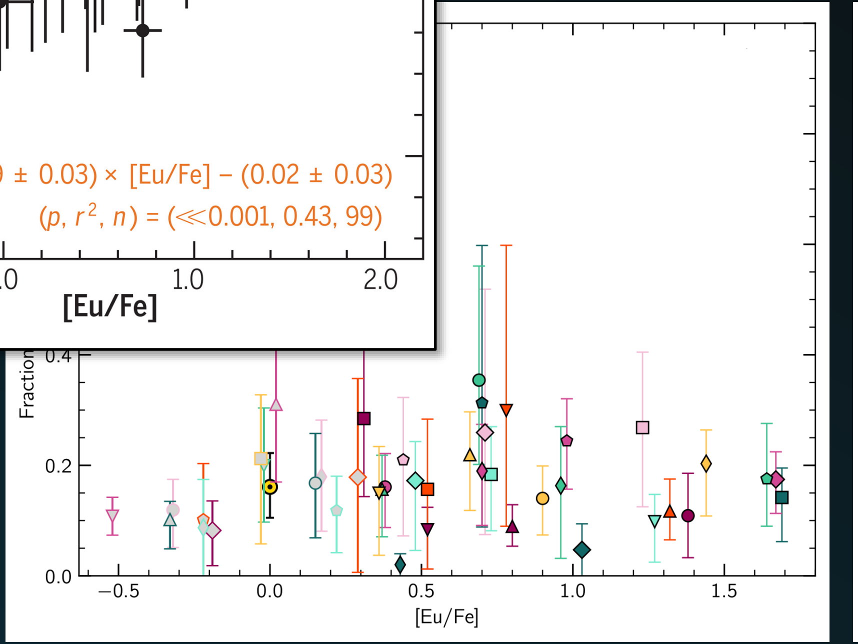

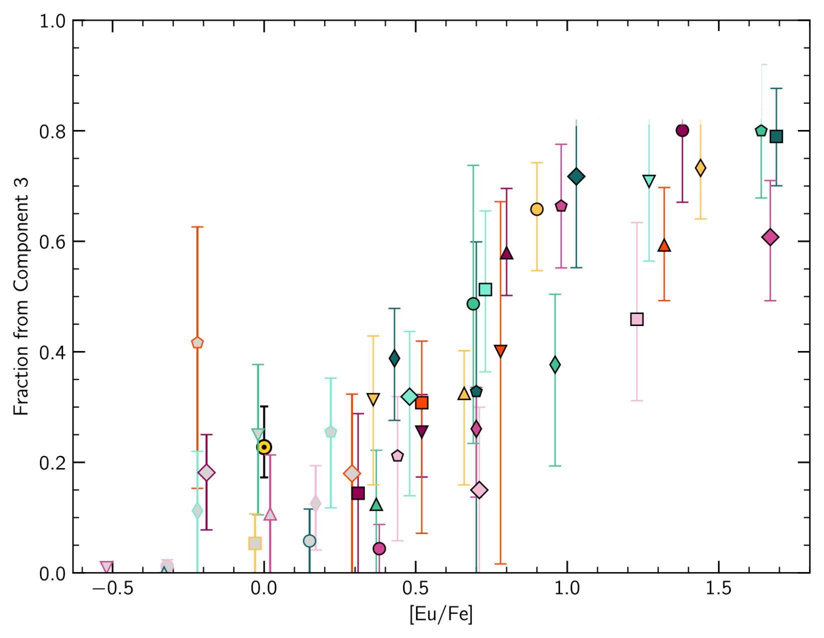

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<u>Component 3:</u>

A full *r*-process pattern that increases with [Eu/Fe] —agrees with observations

Roederer+ (2023)

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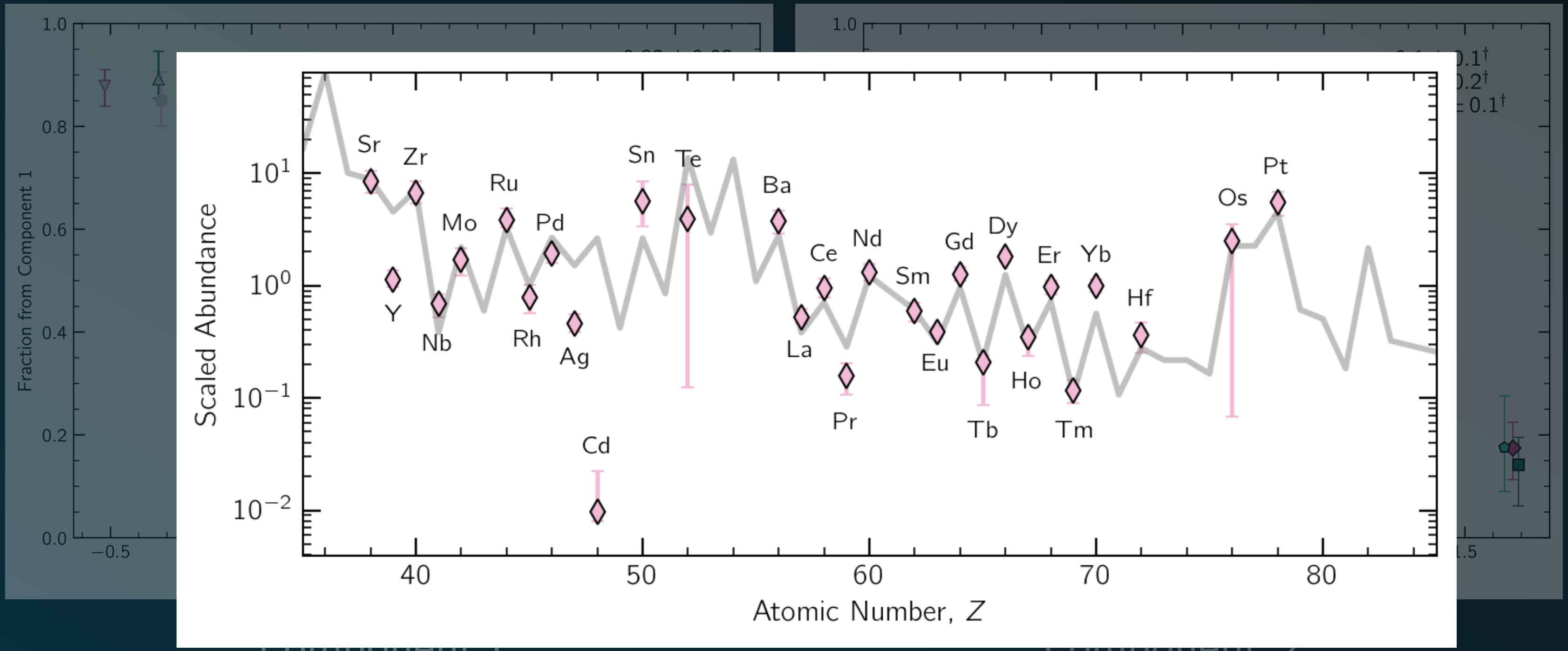
The third component appears to agree with the enhancement seen by Roederer+ (2023)…a pure fission-cycling *r*-process?



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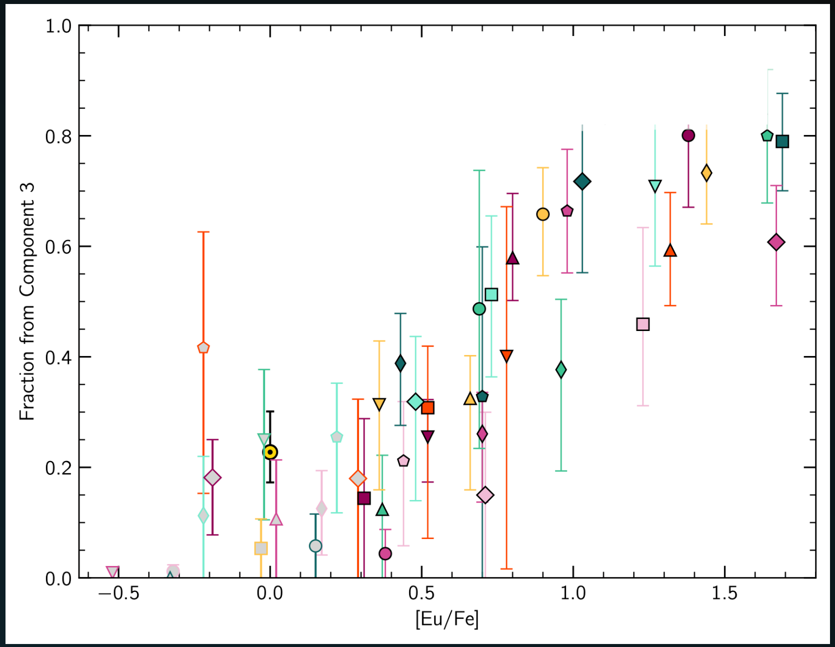

Component 3:

A full *r*-process pattern that increases with [Eu/Fe] —agrees with observations

Holmbeck+ (*in prep.*)

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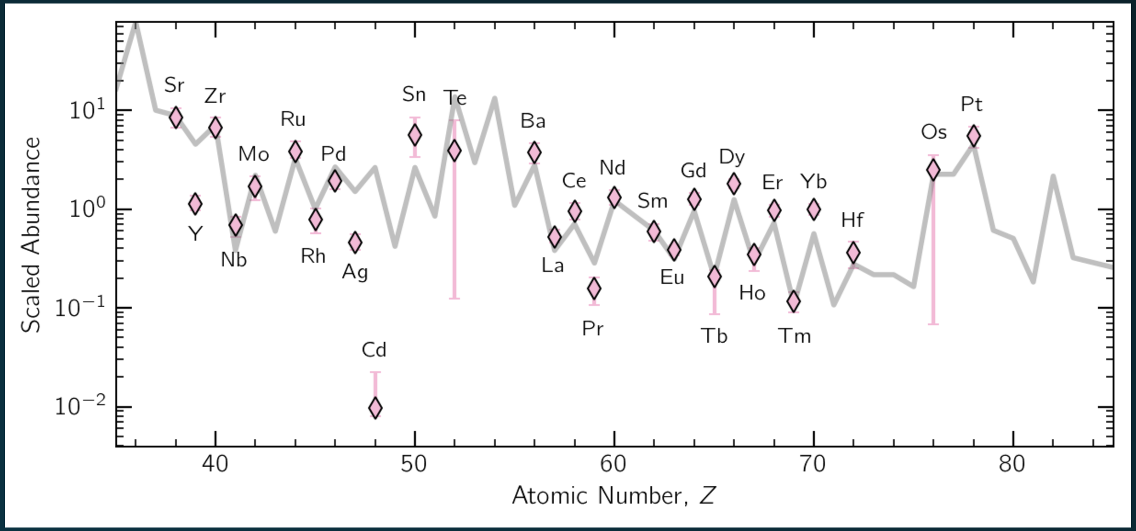
In Summary

It is convenient to treat the *r*-process abundance patterns of very metal-poor stars as the individual children of single *r*-process-hosting events

This work shows an attempt to answer the question posed by Hasen, Montes, and Arcones (2014): *"How many nucleosynthesis processes exist at low metallicity?"*

Our answer: as few as three, one of which could be the "pure" fission cycling *r*-process, which **can/should be used to compare to neutron-rich *r*-process models**



This method can be applied to other populations to quantify *r*-process site contribution over time/metallicity, constrain unknown nuclear physics (e.g., fission), probe astrophysical conditions, …

Bonus: see Erin Huntzinger's poster (#146)!

Thanks!

Collaborators & Students

Jessica Agnos (SFSU)
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Avrajit Bandyopadhyay (UFlorida)
John Cowan (Oklahoma)
Elizabeth Den Hartog (Wisconsin)
Peter Haramis (SFSU)
Dimitrii Gudin (Notre Dame)
Kohei Hattori (NAOJ, Japan)
Yutaka Hirai (Notre Dame/Tohoku U, Japan)
Alexander Ji (UChicago)
James Lawler (Wisconsin)
Young Sun Lee (Chungnam Natl U, Korea)
Mohammad Mardini (Zarqa U, Jordan)
Jennifer Marshall (Texas A&M)
Mila Racca (Stockholm U, Sweden)
Shivani Shah (UFlorida)
Derek Shank (Notre Dame)
Chris Sneden (UTexas)
Nicole Vassh (TRIUMF, Canada)
Teodora Xylakis-Dornbusch (Heidelberg, Germany)

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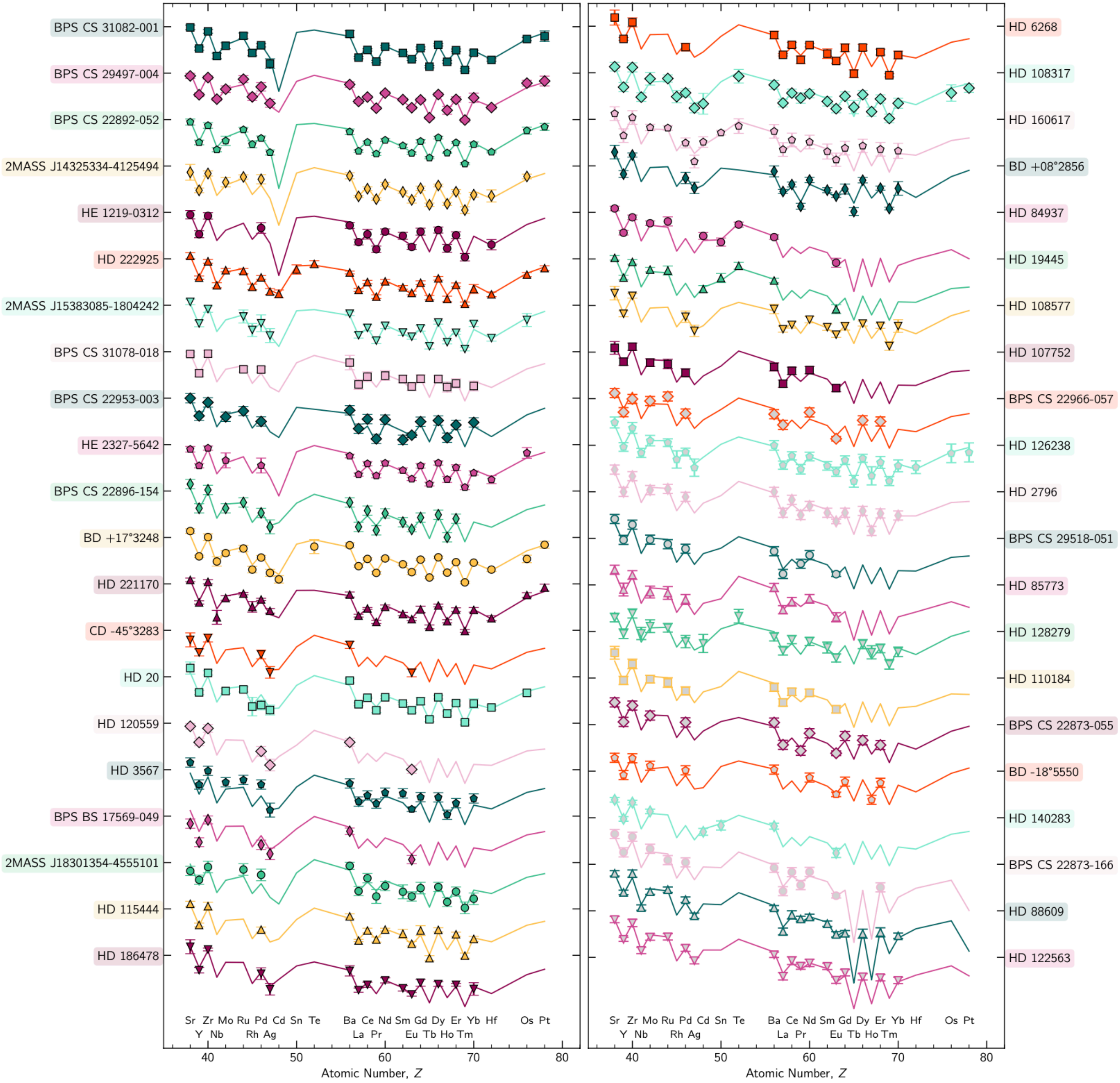
NASA Astrophysics Data Analysis Program grant 80NSSC21K0627
DOE Contract DE-AC52-07NA27344
Swedish Research Council: VR 2021-05556

s-process contamination?

Holmbeck+ (*in prep.*)



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