The Stellar Actinide Boost and its Implications for the r-Process

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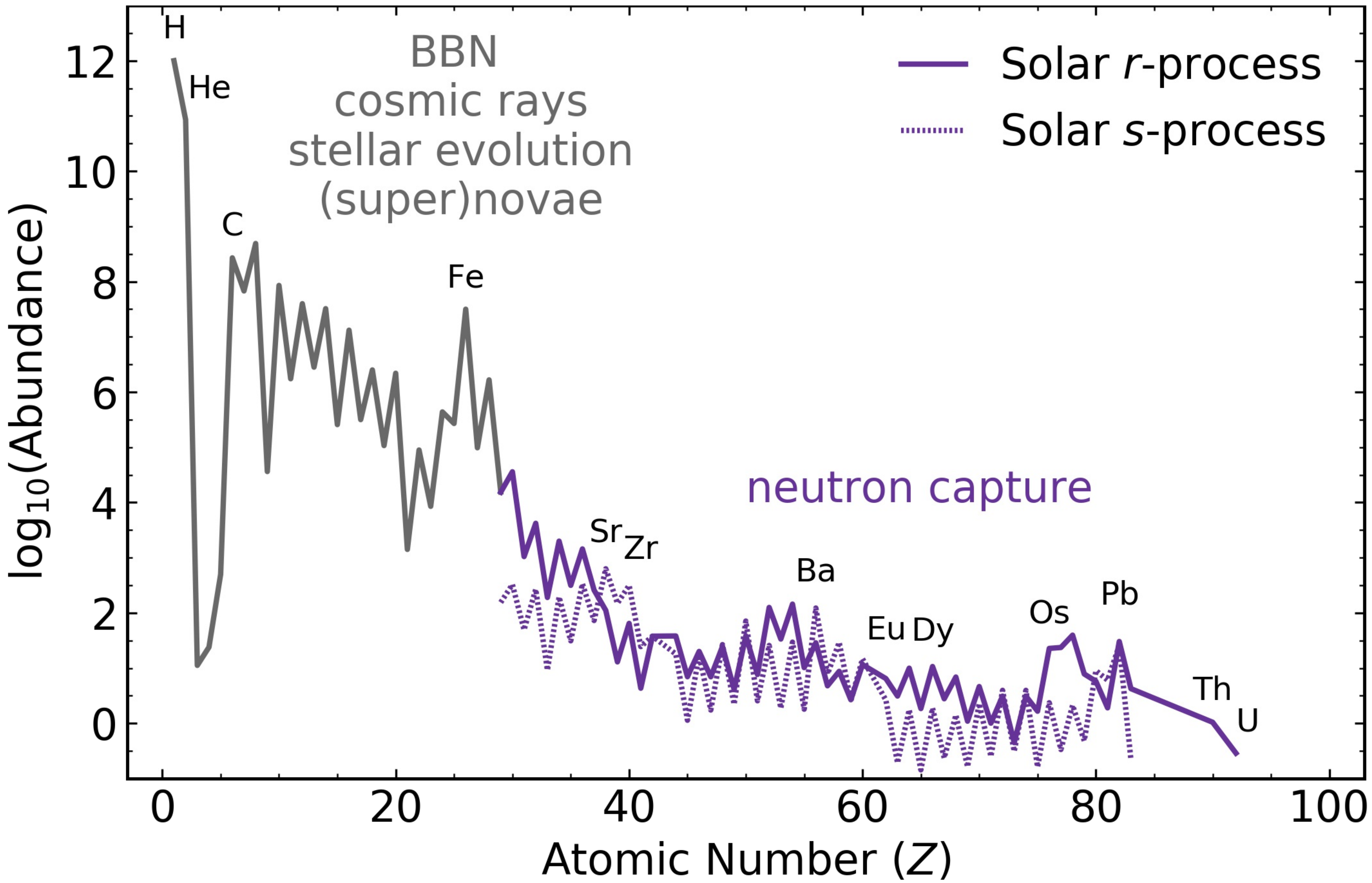
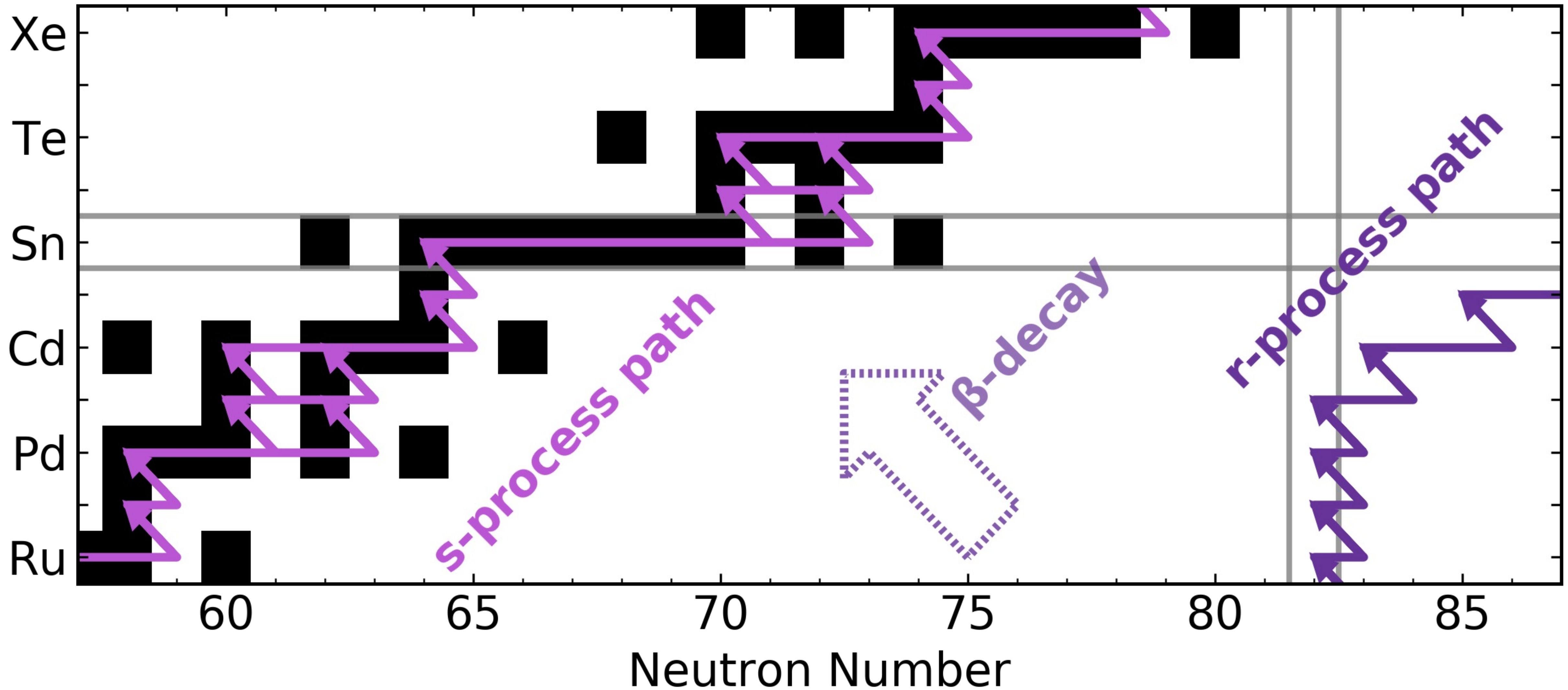
15 February 2019

Elements in the Universe

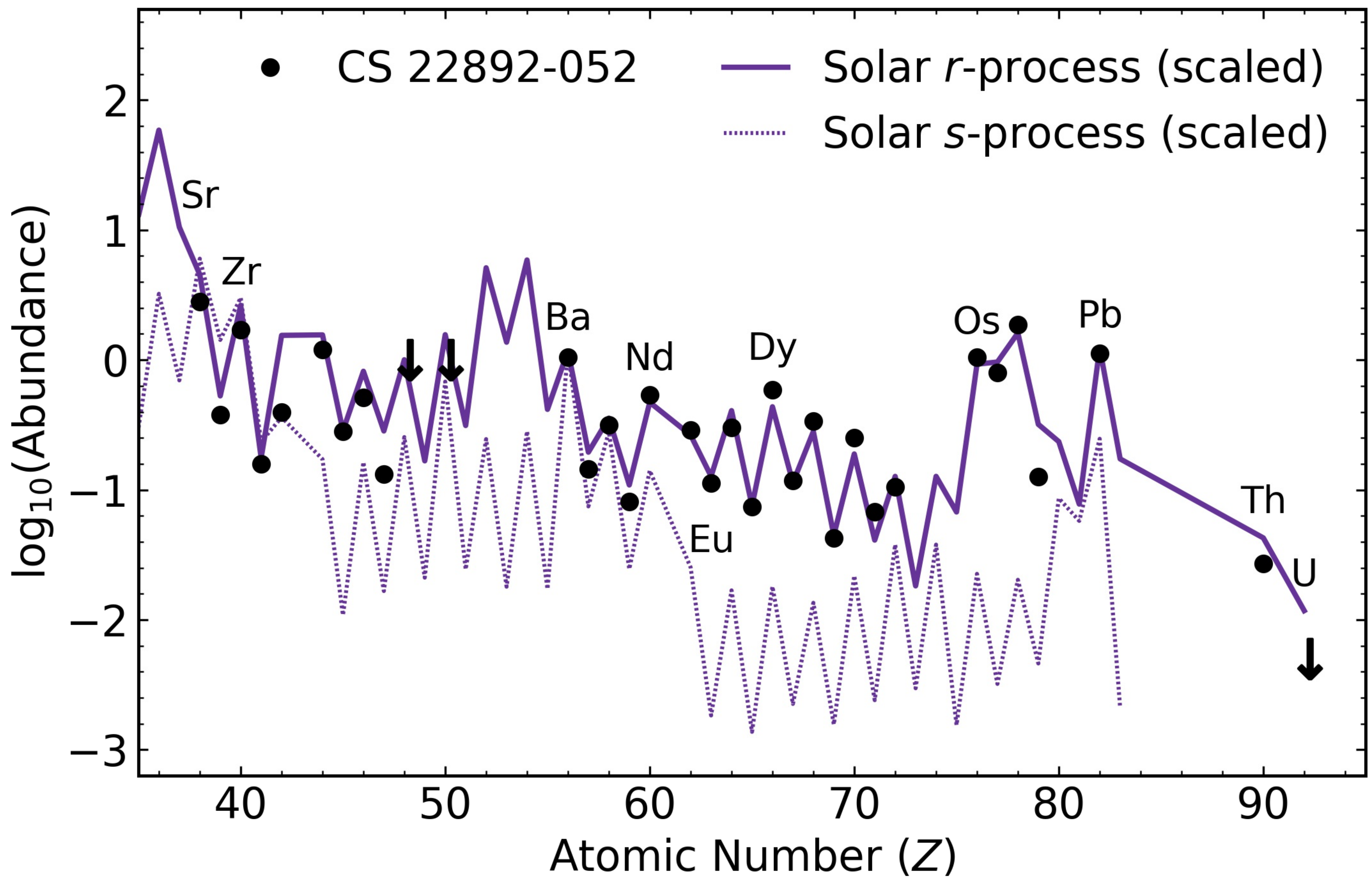


from data in Sneden+ (2008)

Neutron capture



r-II stars



from data in McWilliam+ (1995), Sneden+ (2003)

Site of the r-process?

Core-collapse supernovae

MHD-jet supernovae

Collapsars

Neutron-star mergers

???

R-Process Alliance est. Fall 2017

Phase I: Identify Bright, Very Metal-Poor Targets

Phase II: Obtain Snapshot High-Res Spectra

Phase III: Obtain Portrait High-Res Spectra

Phase IV: Galactic Chemical Evolution / Modeling

Phase V: Lab Measurements / Theory

Identify 75–100 new r-II stars

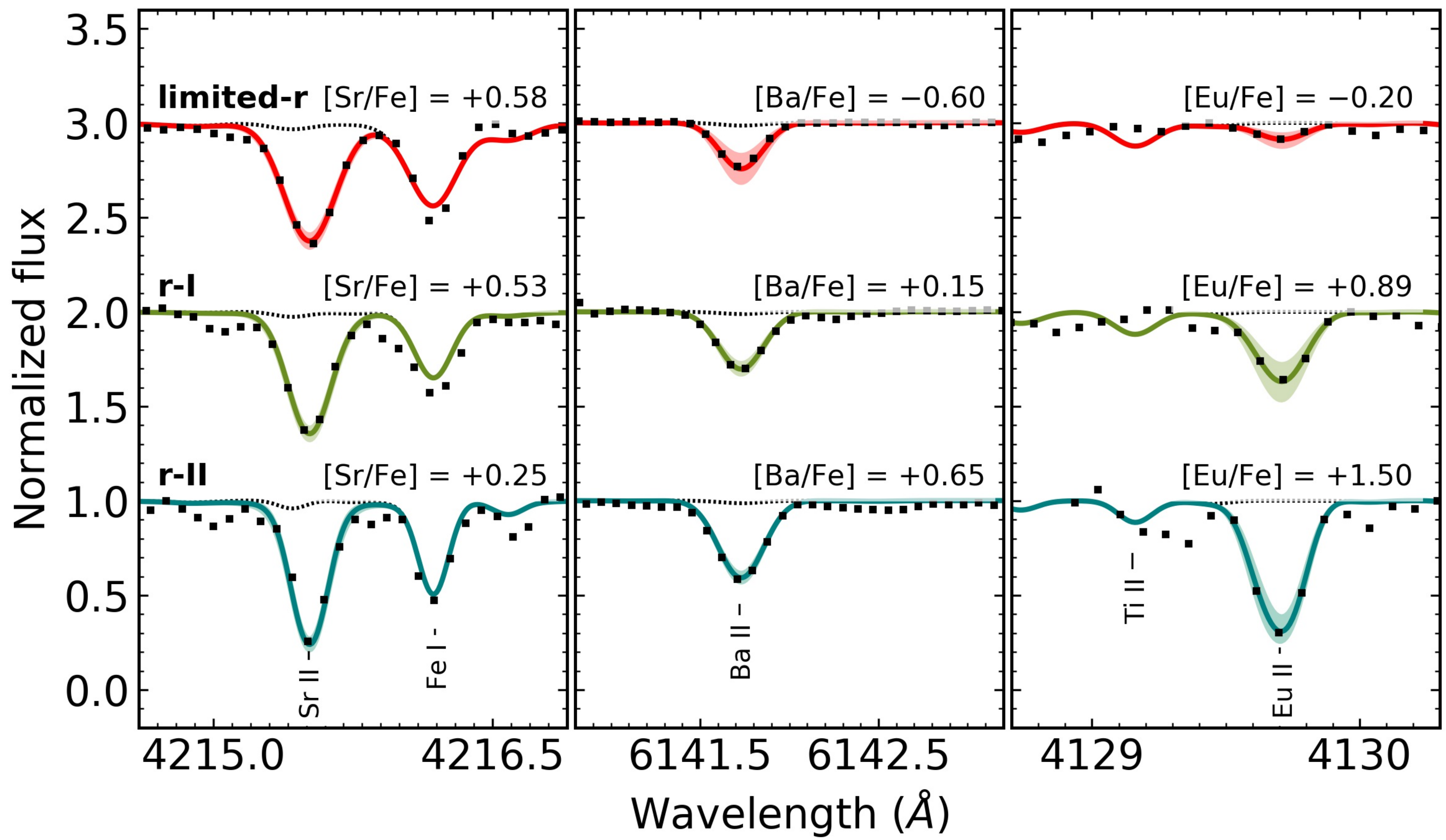
RPA status

Snapshot high-resolution data obtained for ~1350 (of target 2500) stars

Expect 3-5% to be *r*-II stars

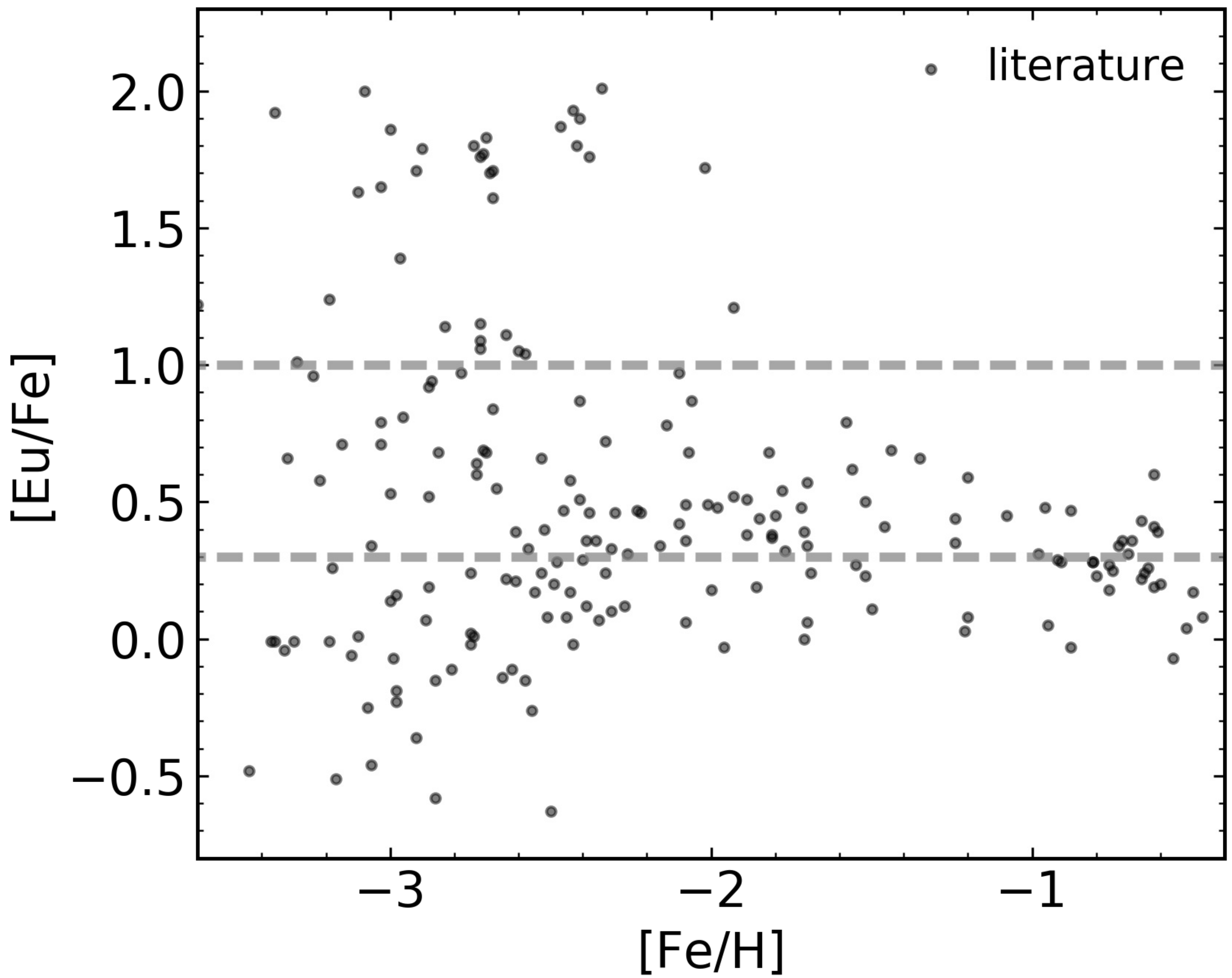
Identified over 30 new r-II stars (of ~500 analyzed)

High-resolution spectroscopy



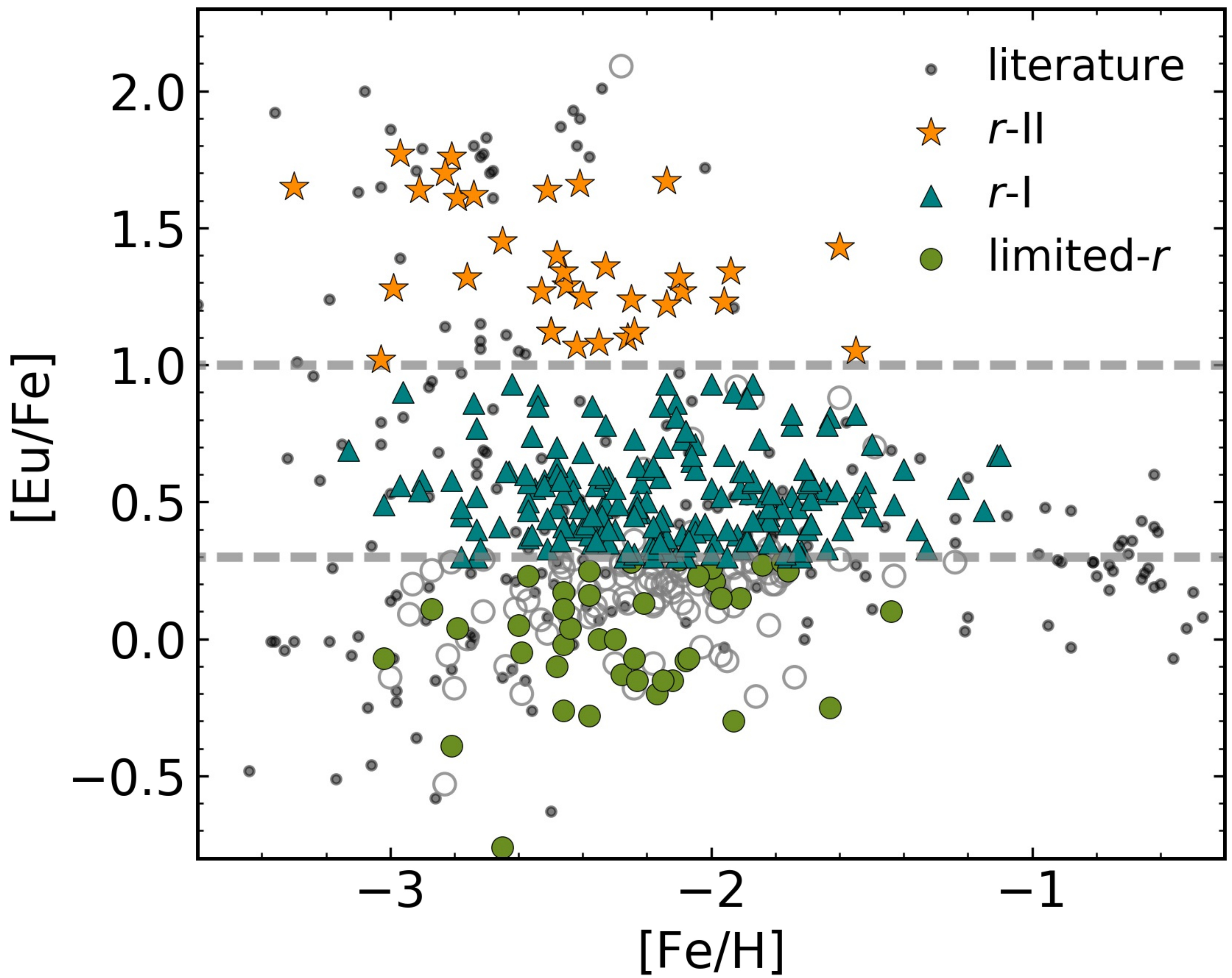
Hansen, Holmbeck+ (2018)

[Eu/Fe] before the RPA



from data in Abohalima & Frebel (2018)

[Eu/Fe] after the RPA



from RPA data (2017-2019)

The R-Process Alliance

Gull, M., Frebel, A., Cain, M. G., et al. 2018, ApJ, 862, 174

Hansen, T. T., Holmbeck, E. M., Beers, T. C., et al. 2018, ApJ, 858, 92

Holmbeck, E. M., Beers, T. C., Roederer, I. U., et al. 2018, ApJL, 859, L24

Holmbeck, E. M., Sprouse, T. M., Mumpower, M. R., et al. 2019, ApJ, 870, 23

Placco, V. M., Holmbeck, E. M., Frebel, A., et al. 2017, ApJ, 844, 18

Placco, V. M., Beers, T. C., Santucci, R. M., et al. 2018, AJ, 155, 256

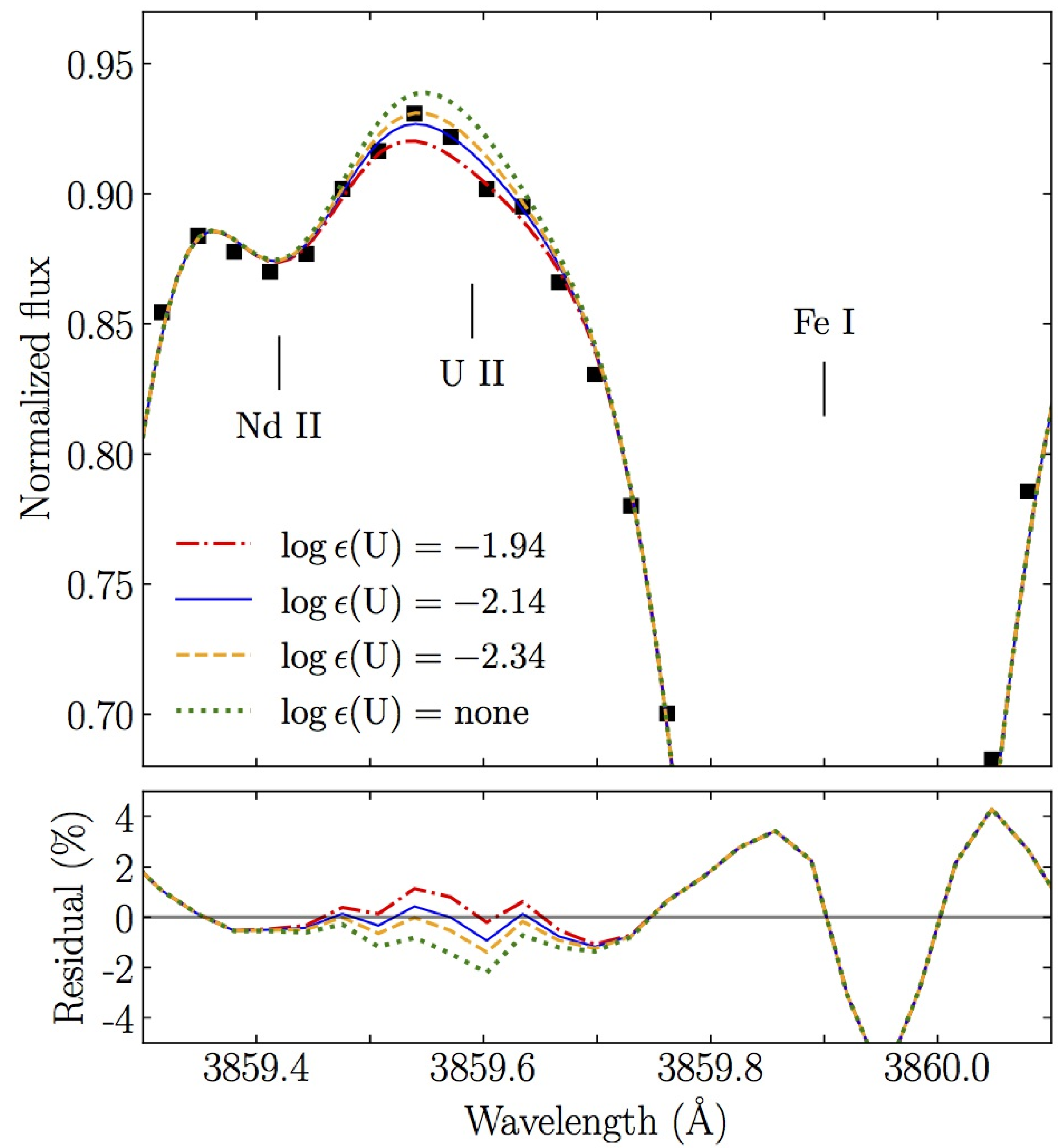
Roederer, I. U., Sakari, C. M., Placco, V. M., et al. 2018, ApJ, 865, 129

Roederer, I. U., Hattori, K., & Valluri, M. 2018, AJ, 156, 179

Sakari, C. M., Placco, V. M., Farrell, E. M., et al. 2018, ApJ, 868, 110

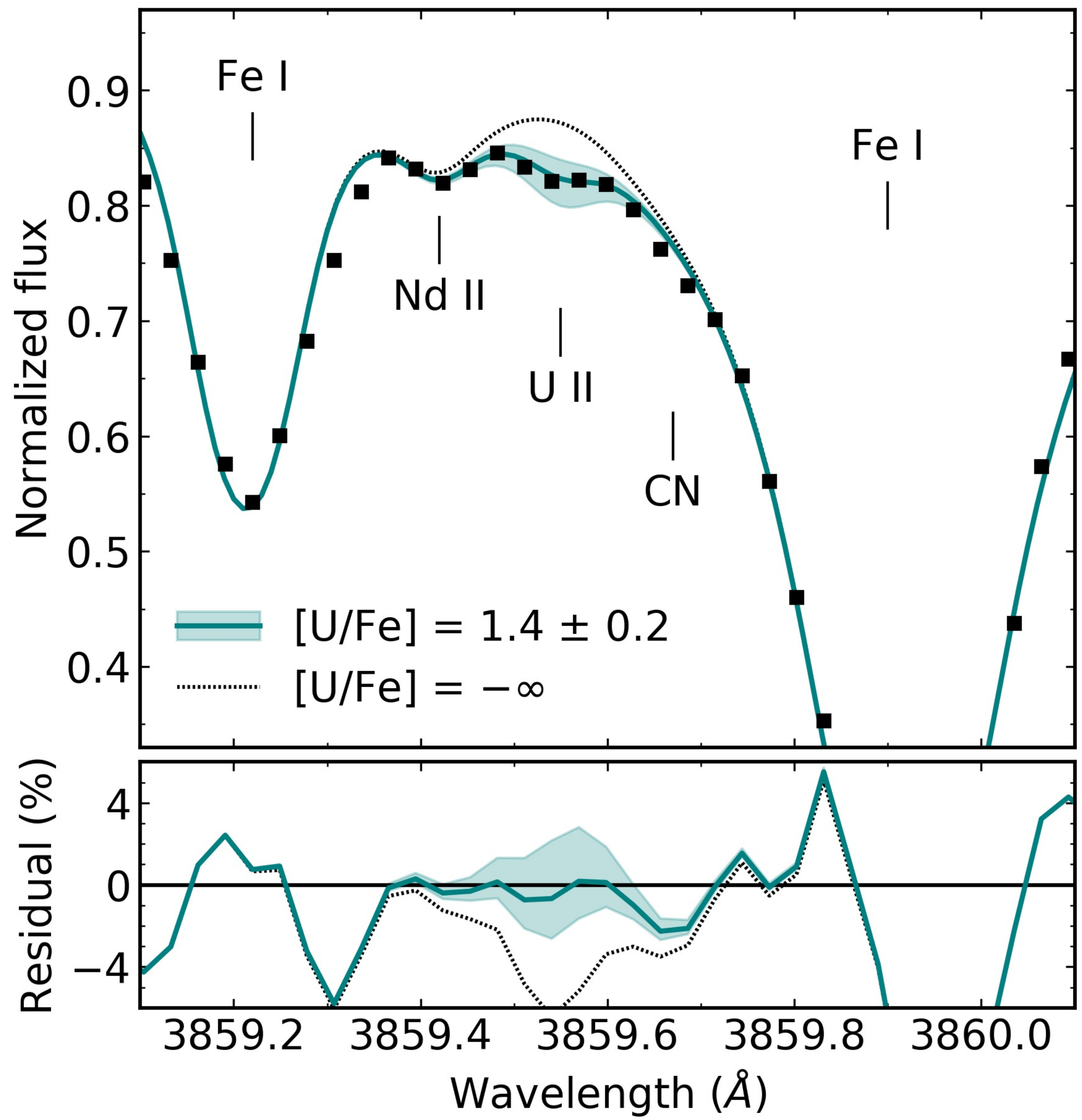
Sakari, C. M., Placco, V. M., Hansen, T., et al. 2018, ApJL, 854, L20

Uranium in RAVE J203843.2-002333



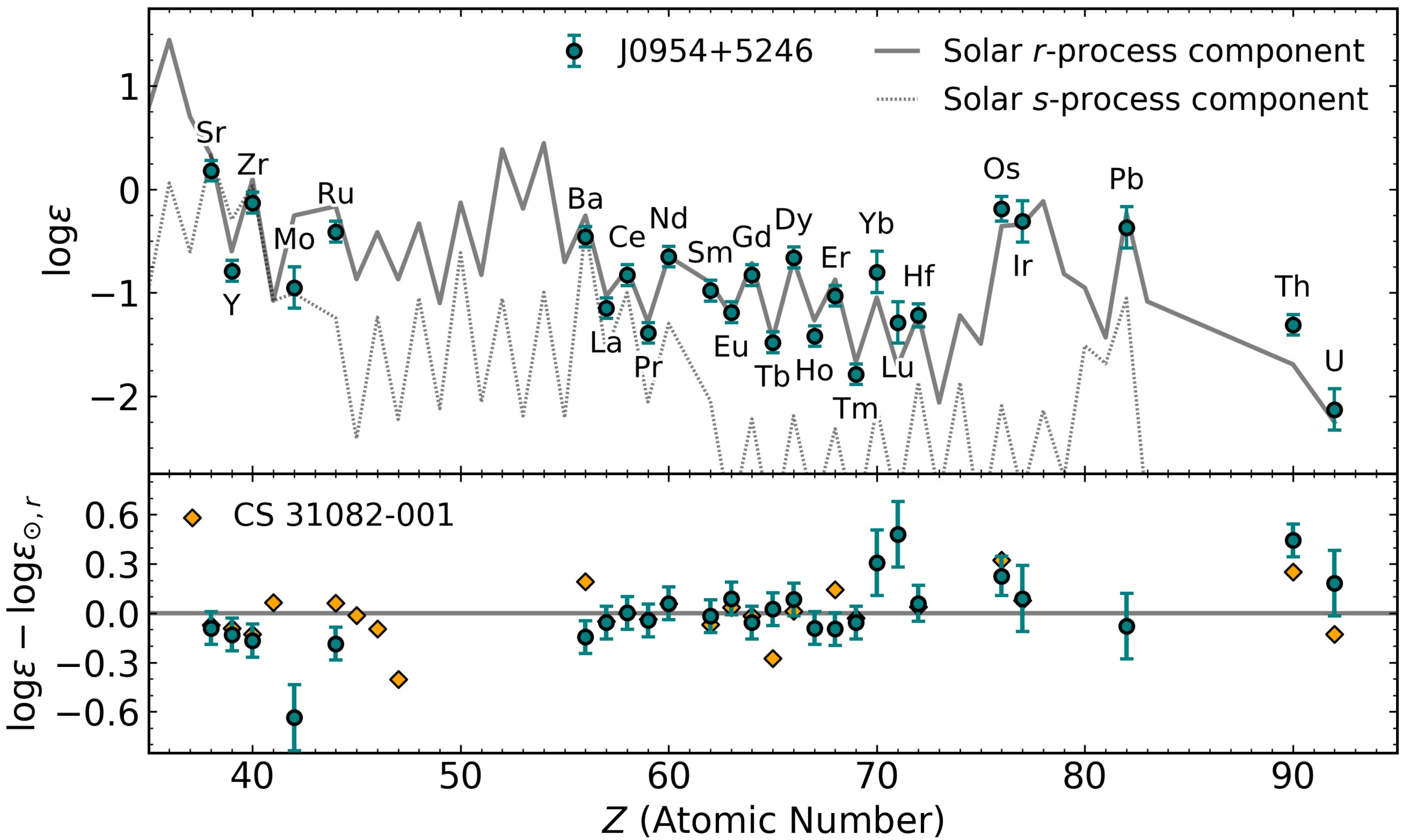
Placco, Holmbeck+ (2017)

Uranium in J0954+5246



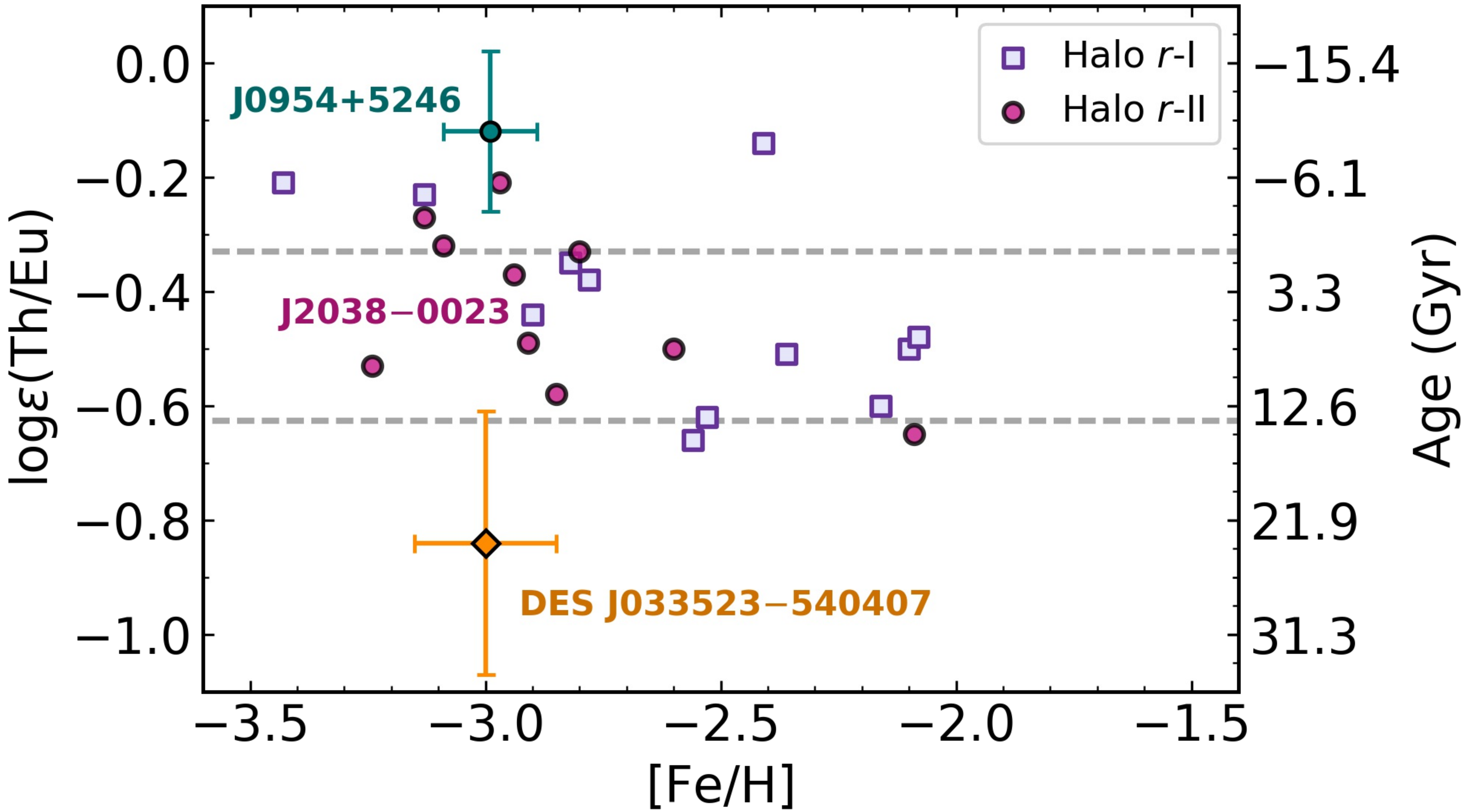
Holmbeck+ (2018)

The actinide boost and J0954+5246



Holmbeck+ (2018)

Ages and cosmochronometry



Holmbeck+ (2018)

Ages and cosmochronometry

232-Th and 238-U are radioactive

Allows radioactive decay dating

$$t = 46.67\ \mathrm{Gyr}\,[\log\epsilon(\mathrm{Th/Eu})_0 - \log\epsilon(\mathrm{Th/Eu})_{\mathrm{obs}}]$$

$$t = 14.84\ \mathrm{Gyr}\,[\log\epsilon(\mathrm{U/Eu})_0 - \log\epsilon(\mathrm{U/Eu})_{\mathrm{obs}}]$$

$$t = 21.80\ \mathrm{Gyr}\,[\log\epsilon(\mathrm{U/Th})_0 - \log\epsilon(\mathrm{U/Th})_{\mathrm{obs}}]$$

Actinides and the r-process

Can varying levels of neutron richness
in a NSM account for the actinide boost?

PRISM

T. Sprouse and M. Mumpower

Low-entropy dynamical (tidal) ejecta of a NSM
(Korobkin+ 2012; Rosswog+ 2013)

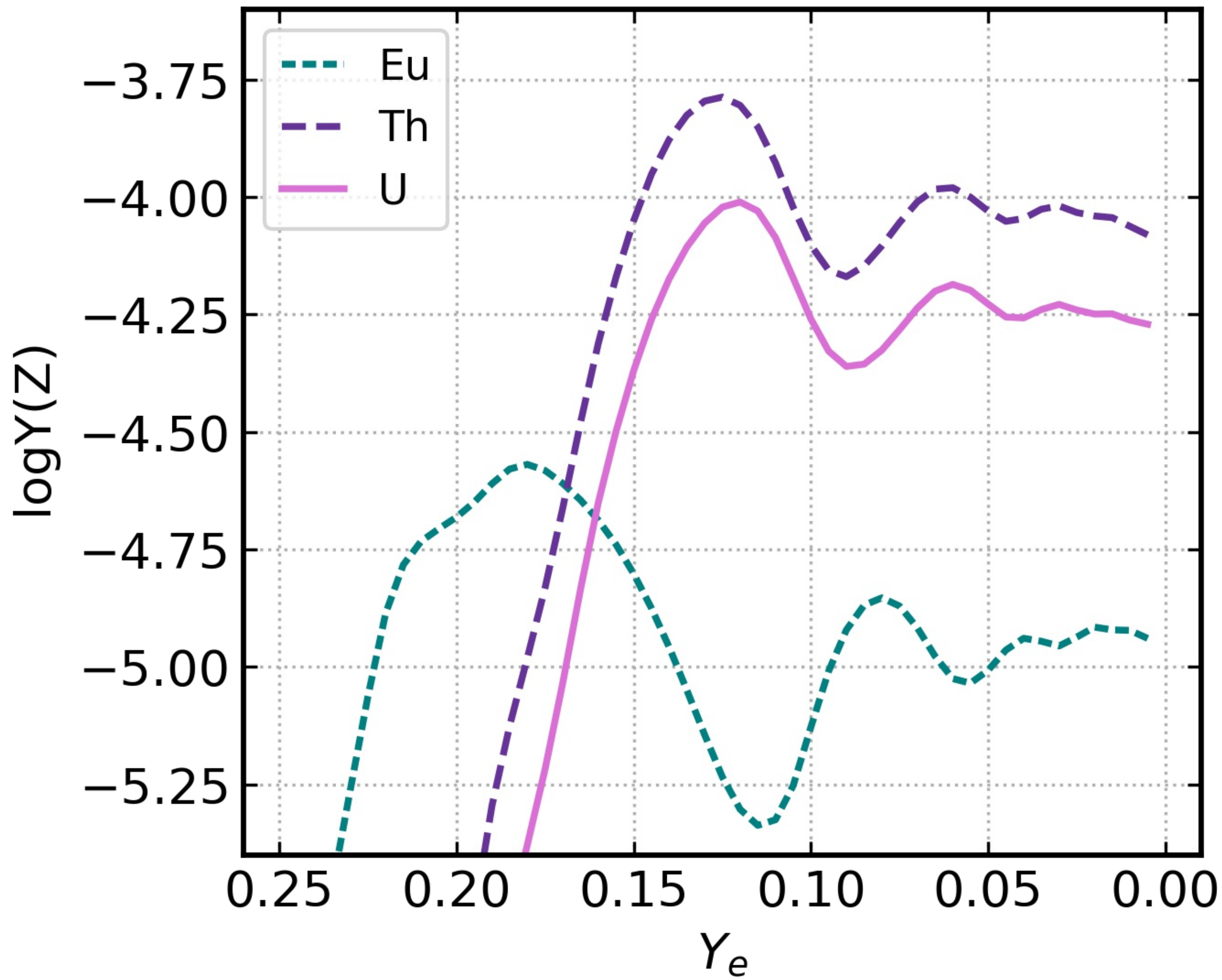
Vary the initial electron fraction: $Y_e = 0.005 - 0.250$

$$Y_e = \frac{1}{1+(n_n/n_p)}$$

Actinide and lanthanide production

Holmbeck with PRISM (T. Sprouse and M. Mumpower)

Actinide and lanthanide production



Holmbeck+ (2019)

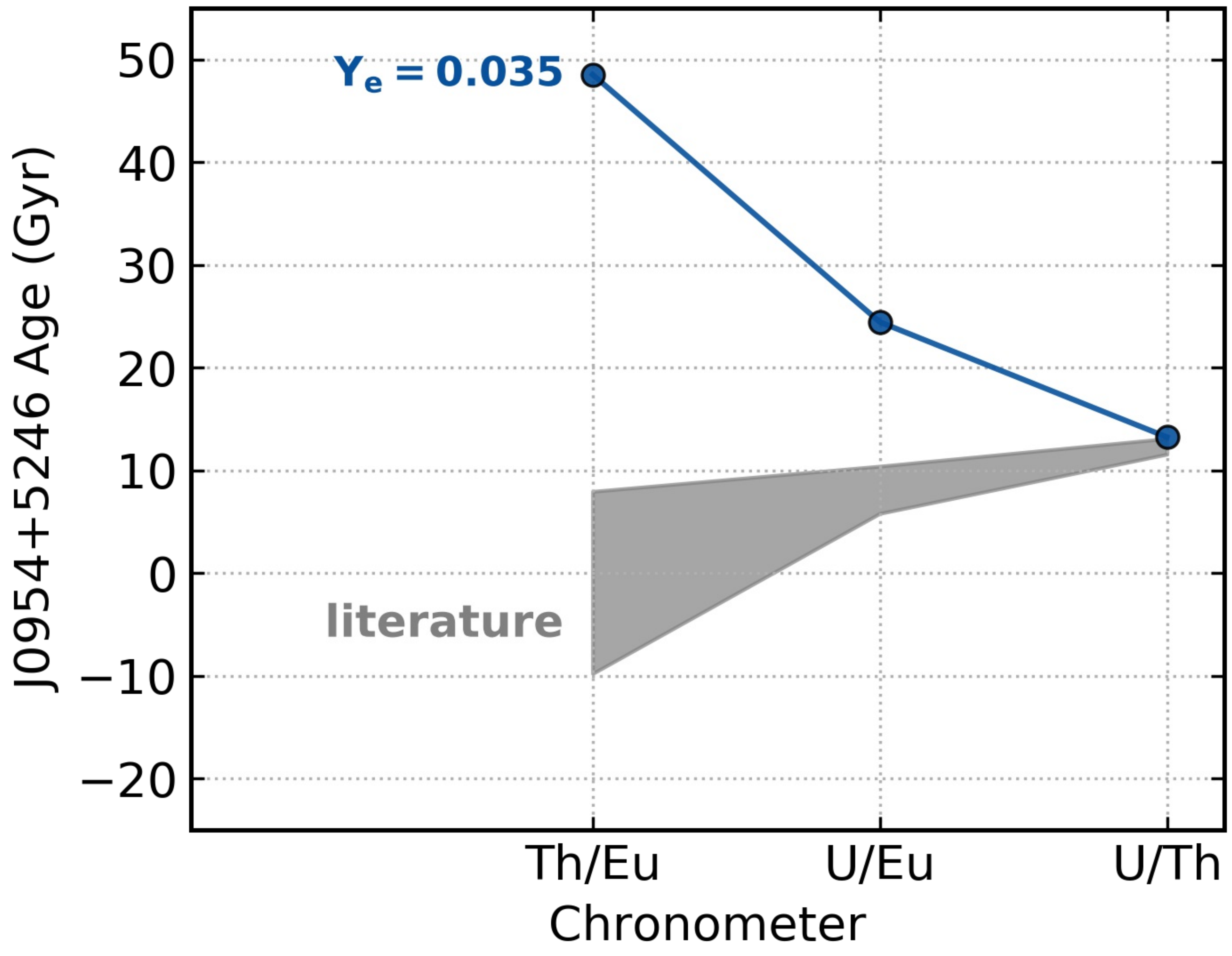
Ages and cosmochronometry

$$t = 46.67\ \text{Gyr}\left[\log\epsilon(\text{Th}/\text{Eu})_0 - \log\epsilon(\text{Th}/\text{Eu})_{\text{obs}}\right]$$

$$t = 14.84\ \text{Gyr}\left[\log\epsilon(\text{U}/\text{Eu})_0 - \log\epsilon(\text{U}/\text{Eu})_{\text{obs}}\right]$$

$$t = 21.80\ \text{Gyr}\left[\log\epsilon(\text{U}/\text{Th})_0 - \log\epsilon(\text{U}/\text{Th})_{\text{obs}}\right]$$

The age of J0954+5246



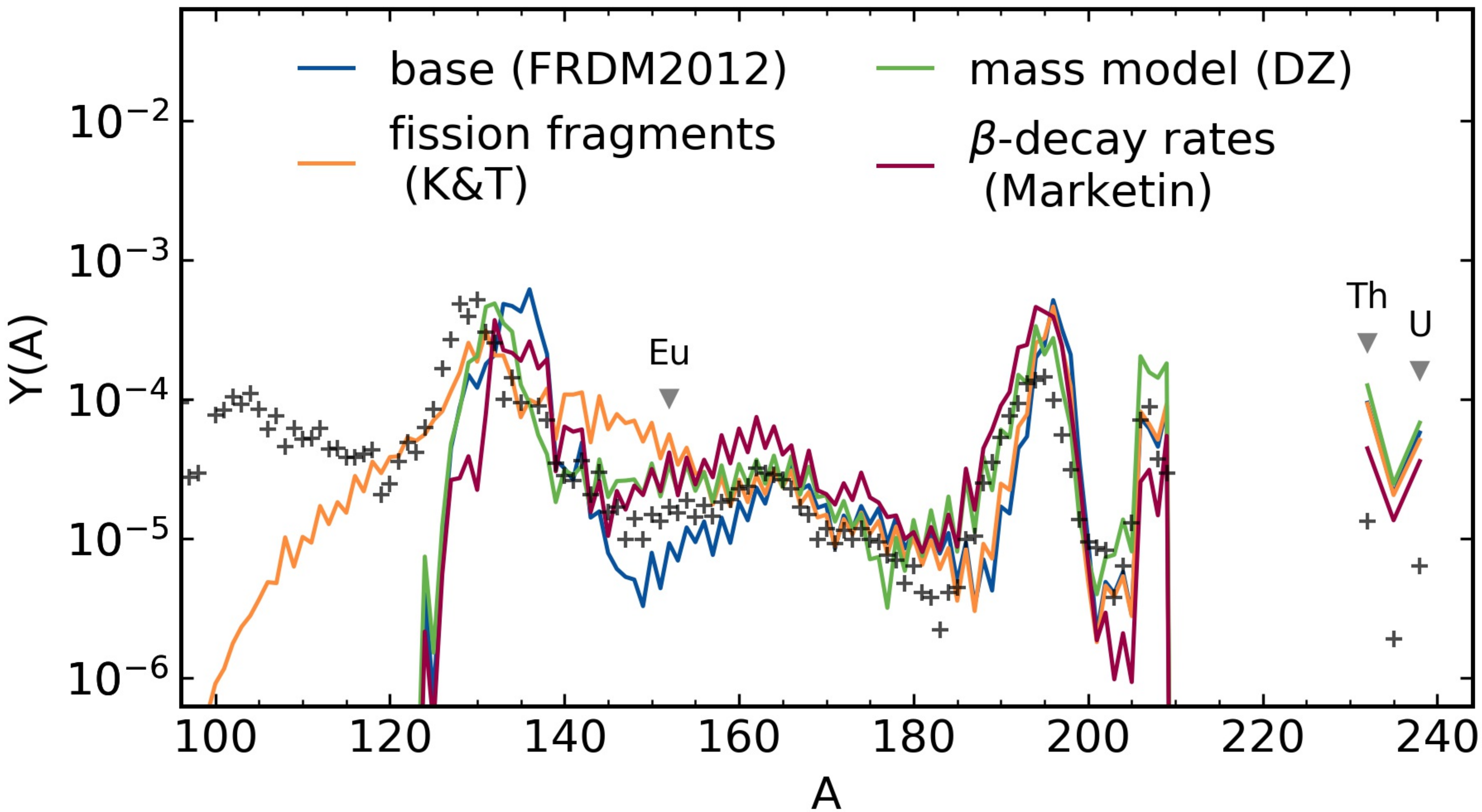
Holmbeck+ (2019)

The age of J0954+5246

Ye

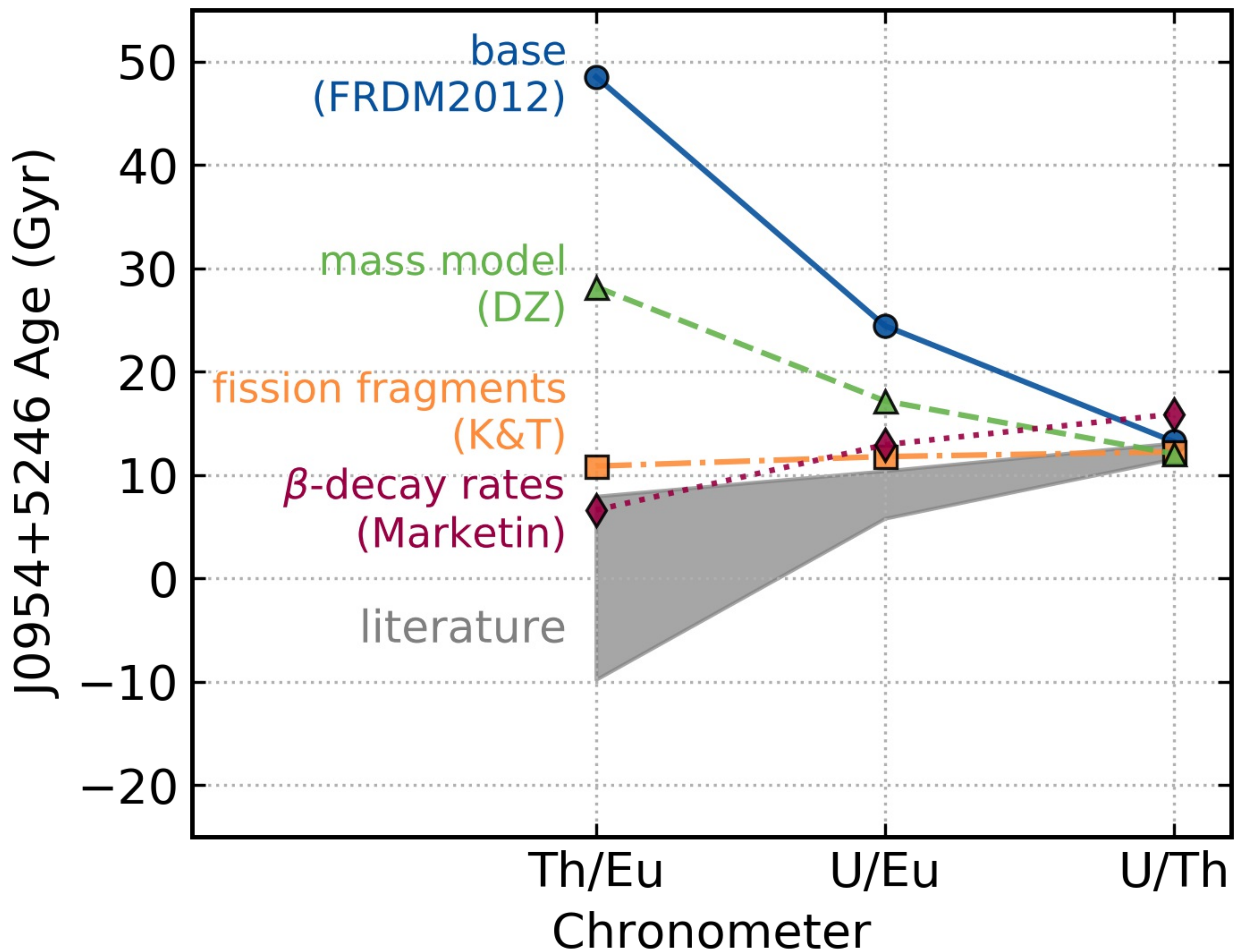
Holmbeck+ (2019)

Nuclear physics variations



from data in Holmbeck+ (2019)

The age of J0954+5246



Holmbeck+ (2019)

Actinides are currently not observed at such high levels

Need a method to dilute the actinides to reduce the Th/Eu production ratio

Actinide-Dilution model

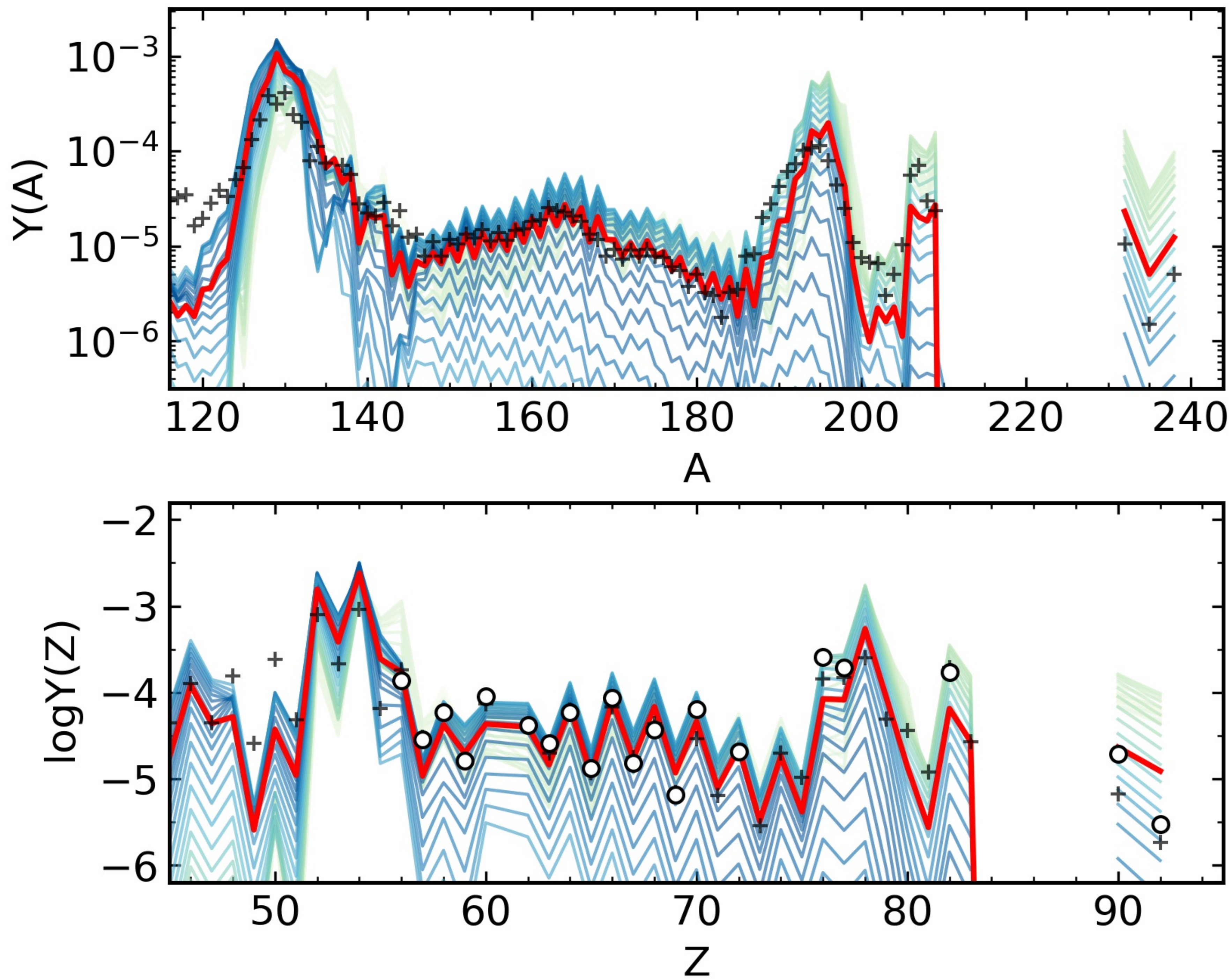
Distribution of Y_e

Tidal ejecta centered at $Y_e = 0.16$
(Bovard+ 2017)

Wind centered at $Y_e = 0.22$
(Lippuner+ 2017)

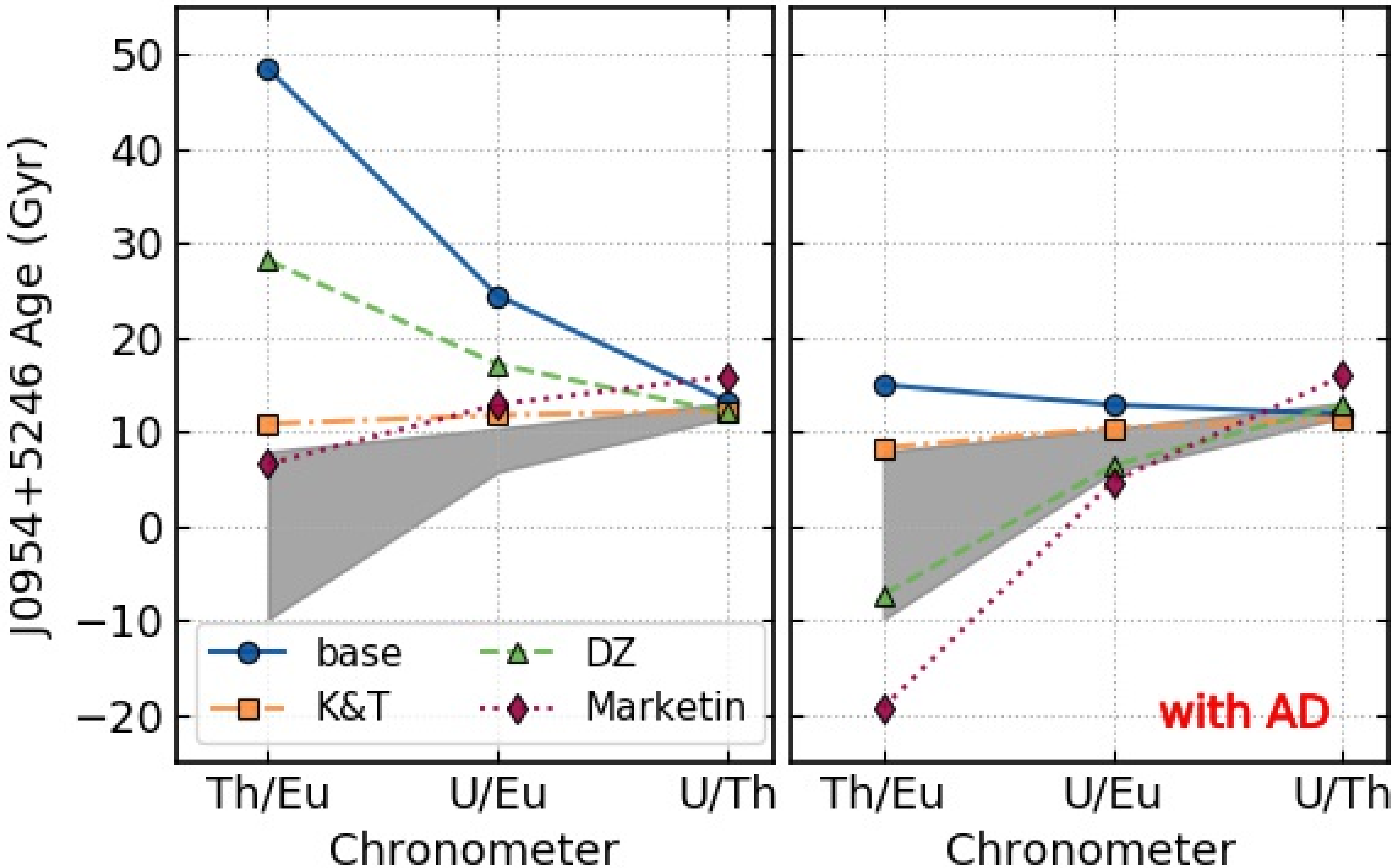
$m_{\rm wind}/m_{\rm dyn} = 3$
GW170817
(Rosswog+ 2017; Tanaka+ 2017)

Actinide-Dilution model



Holmbeck+ (2019)

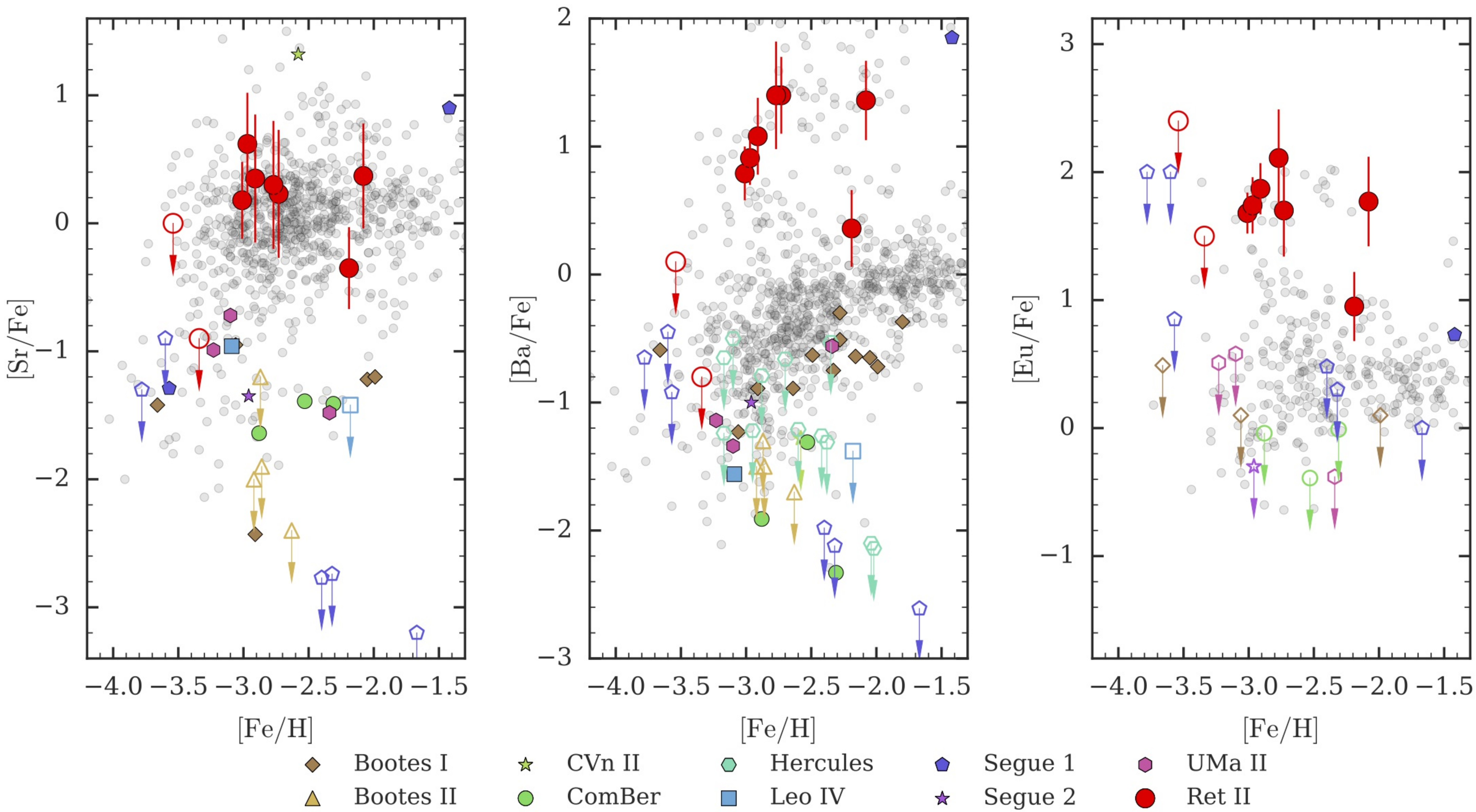
Ages



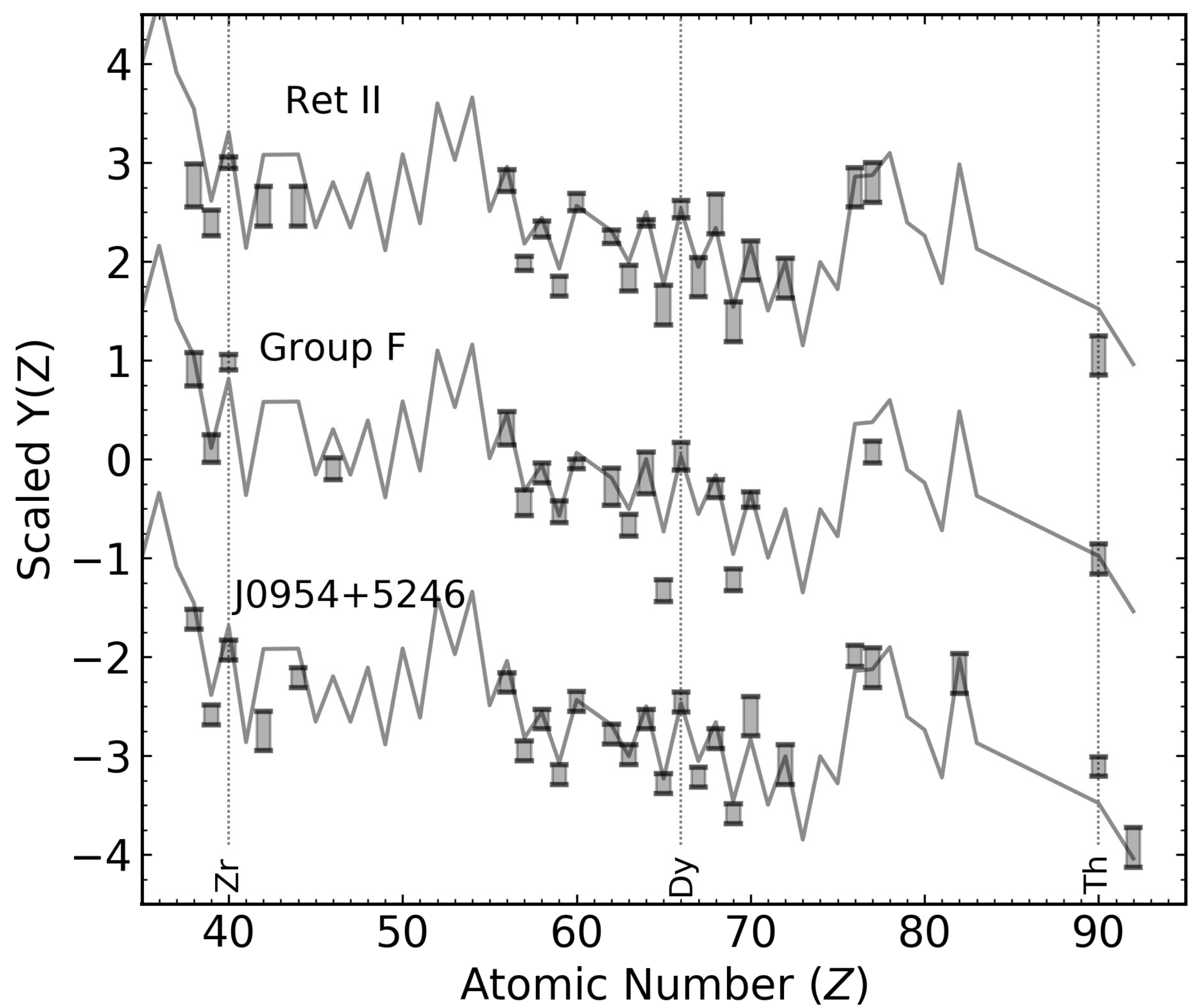
Holmbeck+ (2019)

Can NSMs accommodate a range of actinide production?

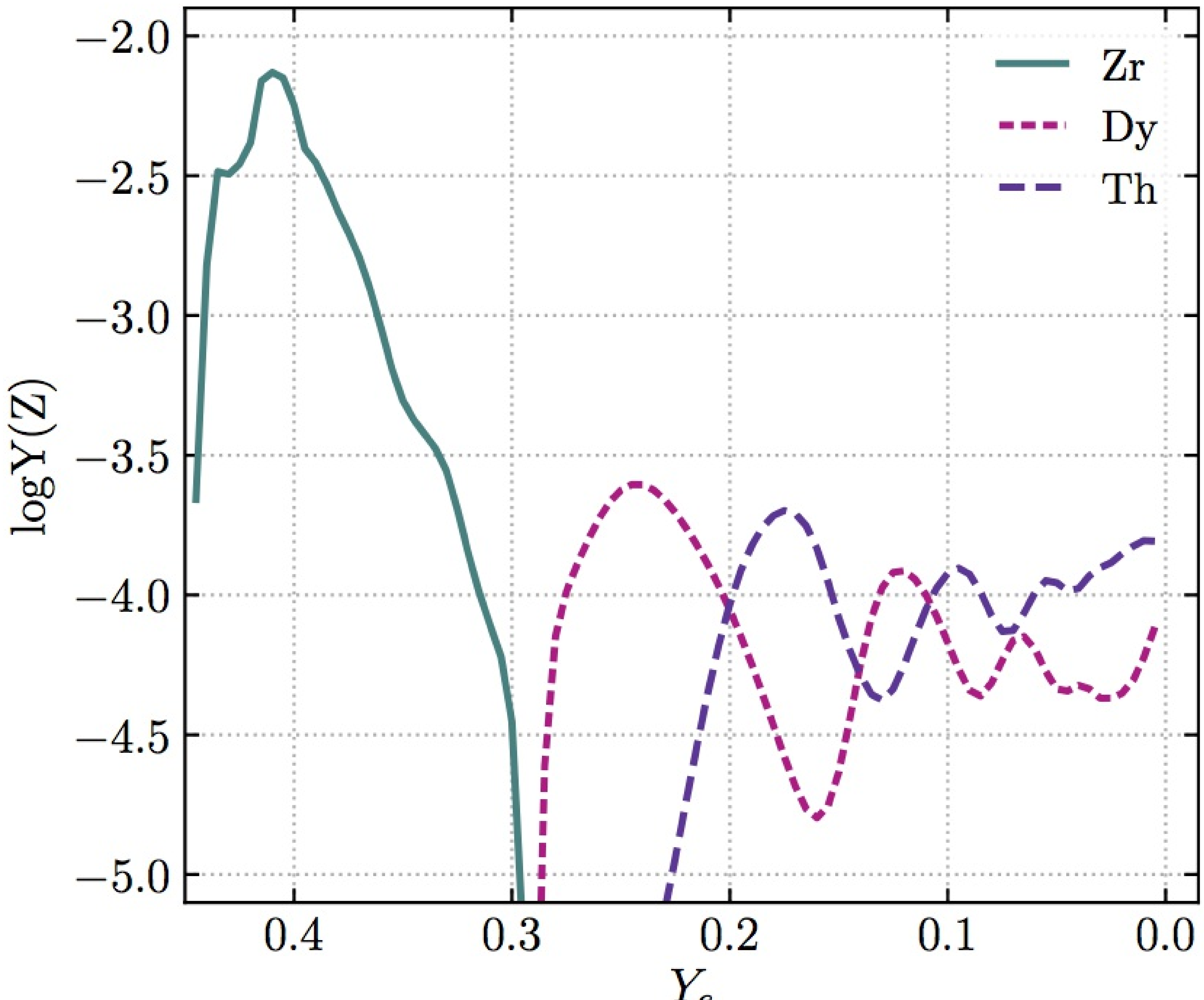
Reticulum II



Groups of r-process enhanced stars



Zr, Dy, Th production

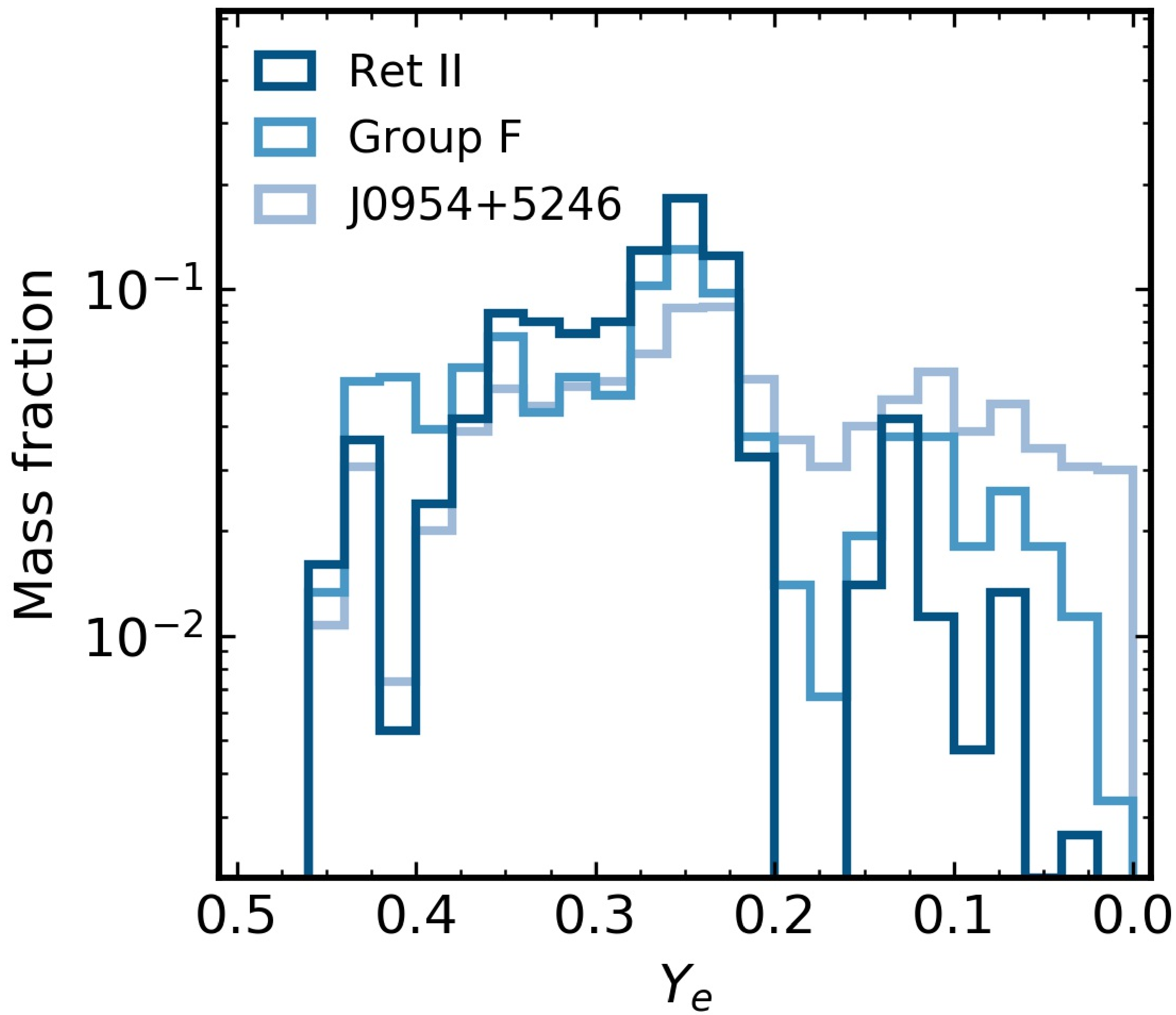


Actinide-Dilution with Matching model

Uses a Monte-Carlo method with constraints from observed abundances

Builds empircal mass ejecta distributions as a function of Y_e between 0.005 and 0.450

Preliminary AD+M results



Future work

Continue *R*PA observations of metal-poor stars

Use *R*PA data as AD+M input

Extend AD+M to different astrophysical parameters/sites

Test AD+M with mass model variations

Publication Timeline