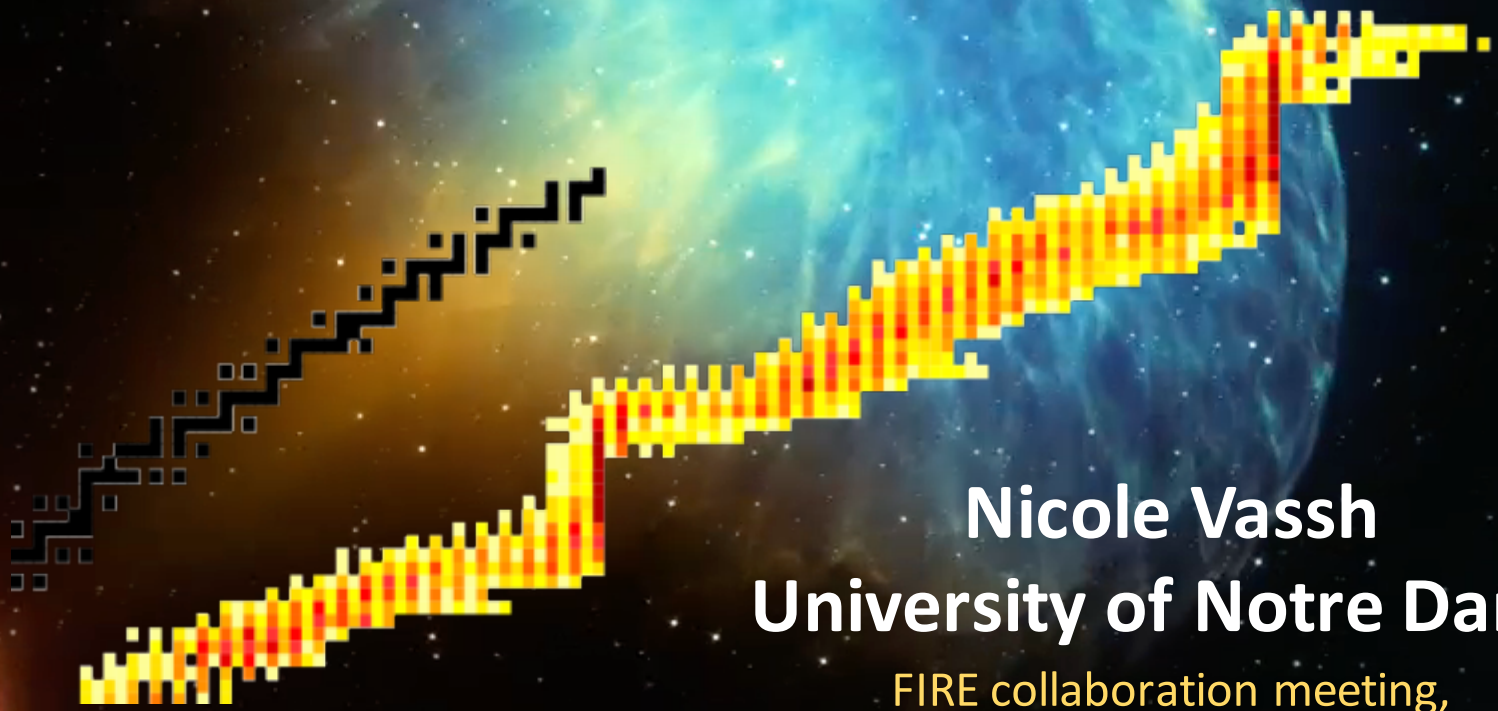
The impact of fissioning nuclei on *r*-process nucleosynthesis observables



FIRE

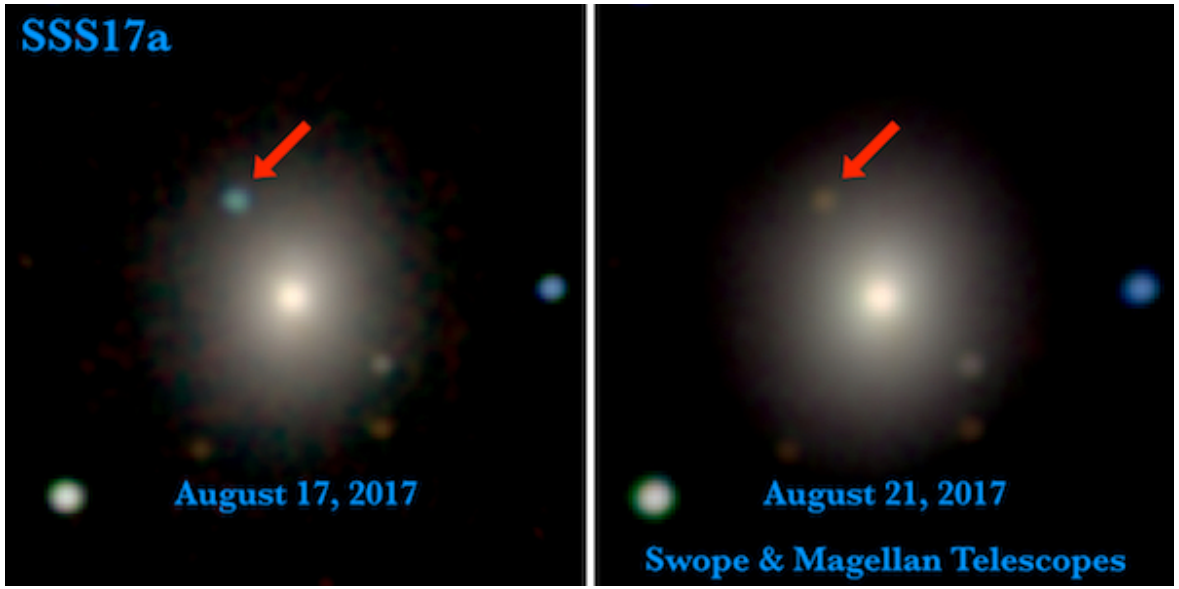
Fission In R-process Elements

JINA-CEE

Nicole Vassh
University of Notre Dame

FIRE collaboration meeting,
Live from home
July 1, 2020

r-process in mergers: GW identification along with electromagnetic follow-up



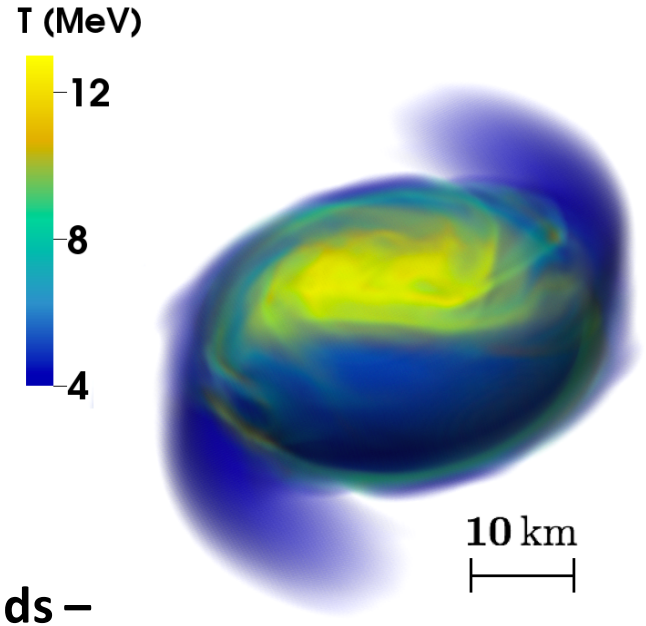
1M2H/UC Santa Cruz and Carnegie Observatories/Ryan Foley

Lanthanide and/or actinide mass fraction ↑ , opacity ↑, longer duration light curve shifted toward infrared

Dynamical ejecta

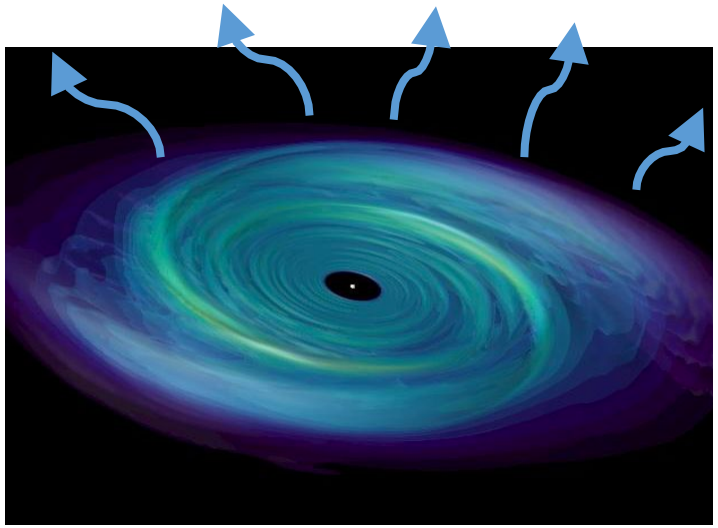
Hot, shocked ejecta

Very neutron-rich cold, tidal ejecta



Foucart *et al* (2016)

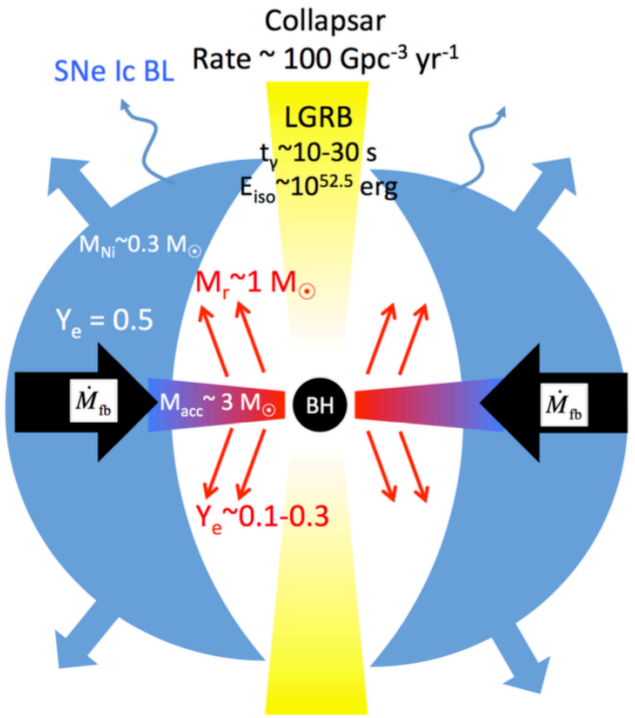
Accretion disk winds – exact driving mechanism and neutron richness varies



Owen and Blondin (2005)

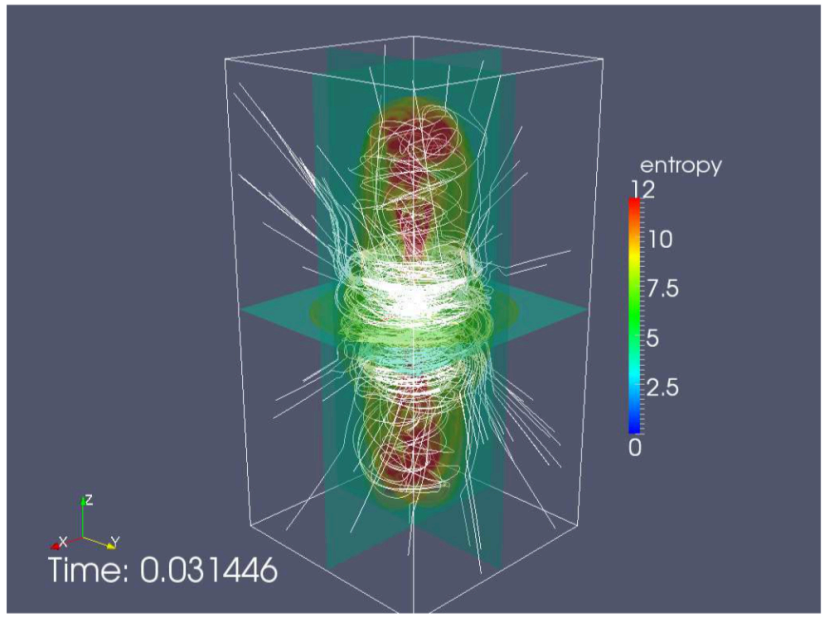
Additional possible sources of heavy *r*-process elements

Collapsar disk winds



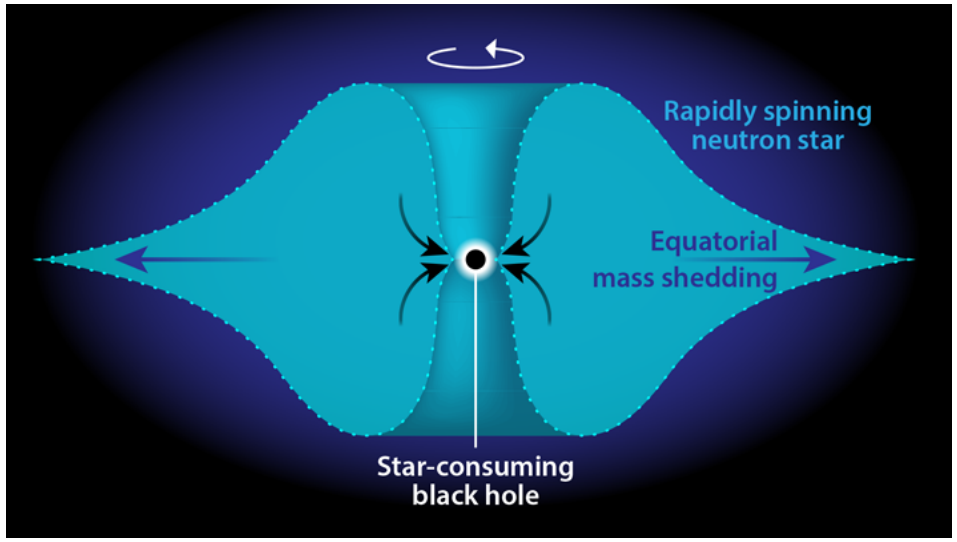
Siegel, Barnes, and Metzger (2018); also McLaughlin and Surman (2005), Miller *et al* (2019)

Magneto-rotationally driven (MHD) supernovae



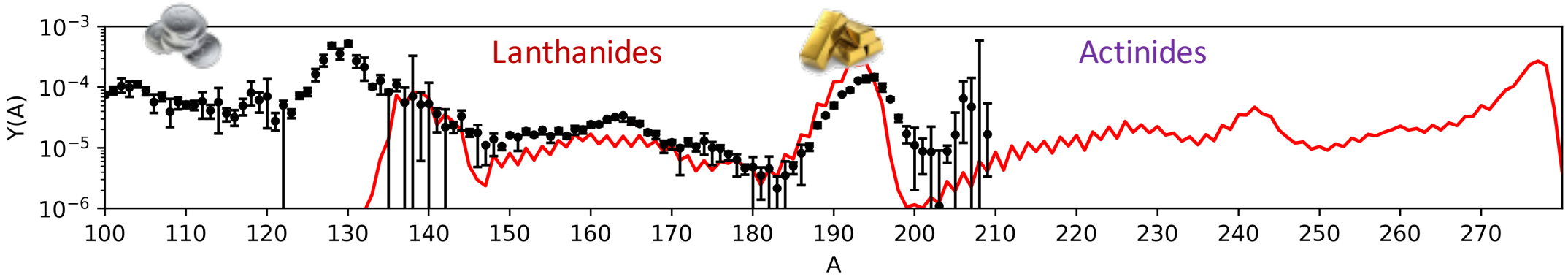
Winteler *et al* (2012); also Mosta *et al* (2017)

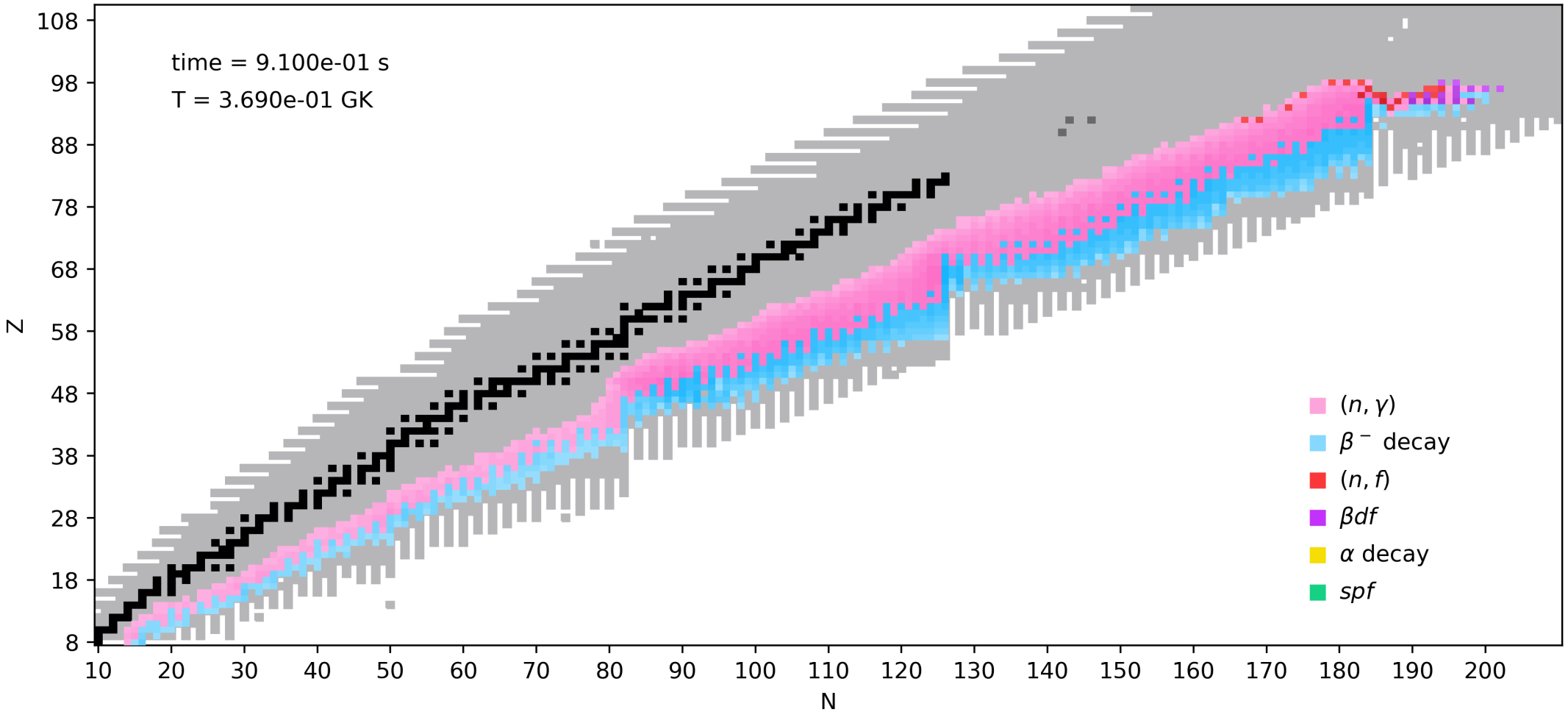
Primordial black hole + neutron star



Credit: APS/Alan Stonebraker, via *Physics*

Fuller, Kusenko, and Takhistov (2017)





Movie by
N. Vassh

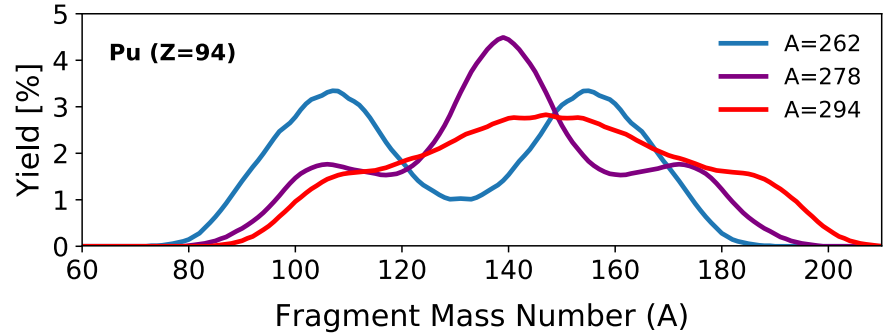
What are the heaviest nuclei reached in an astrophysical scenario?

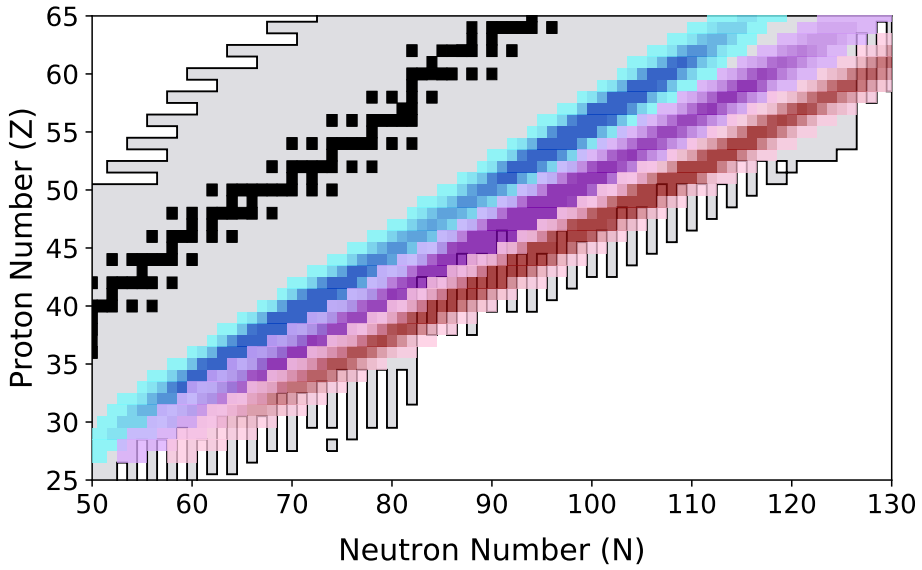
Possible signatures of actinide production (other than Cf-254)

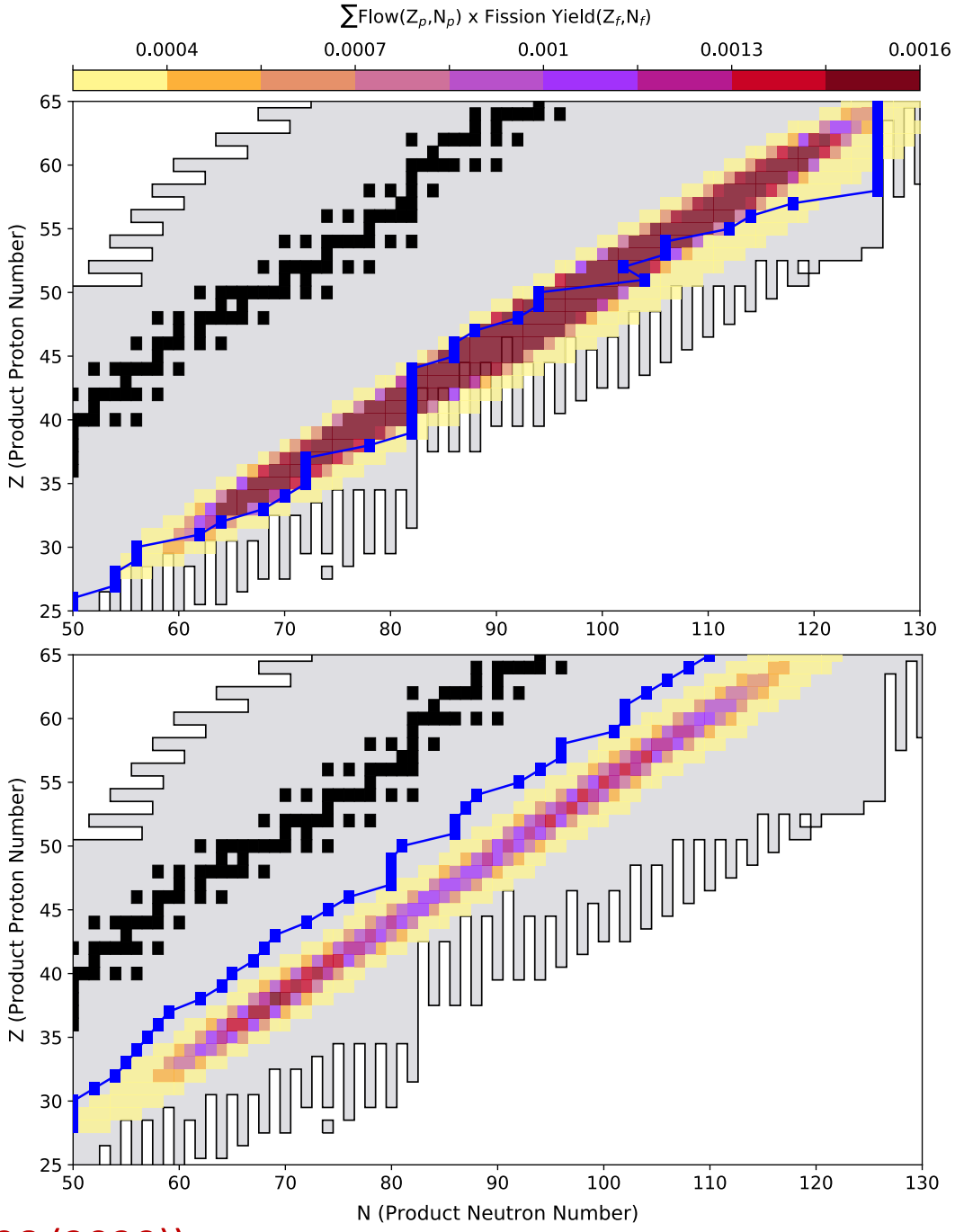
2019-2020: Published works

Macroscopic-microscopic fission yields for neutron-rich nuclei in the *r* process

FRLDM Yields from Mumpower *et al* (PRC 101, 054607 (2020))

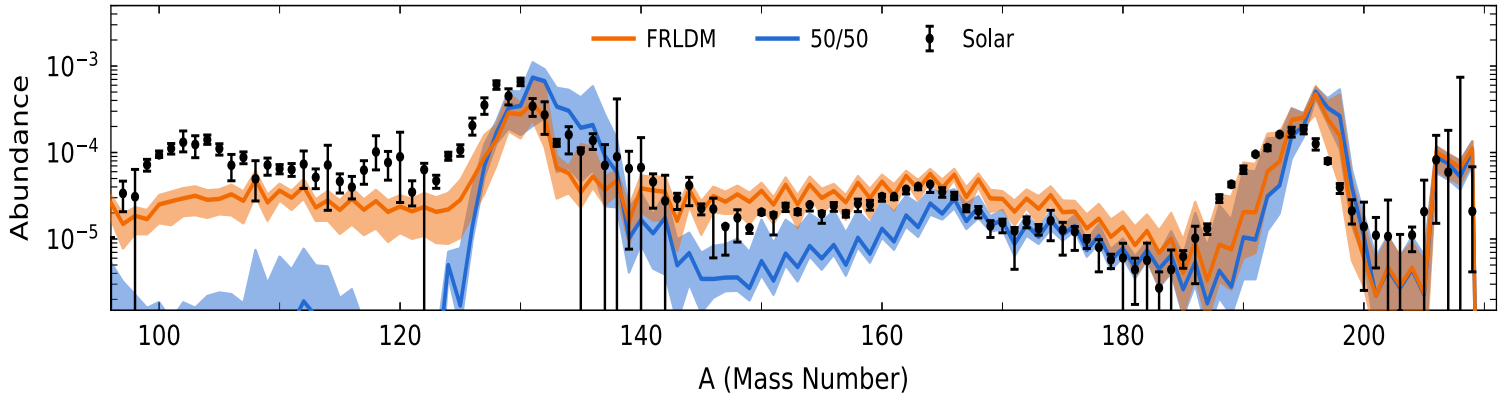


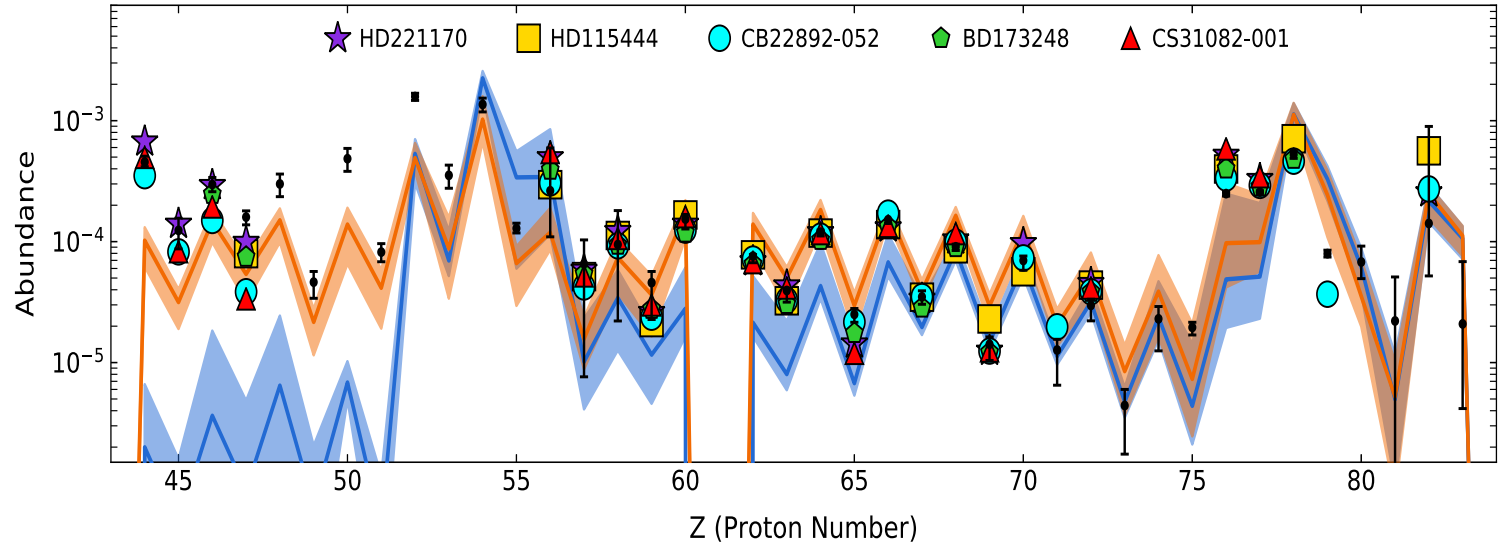




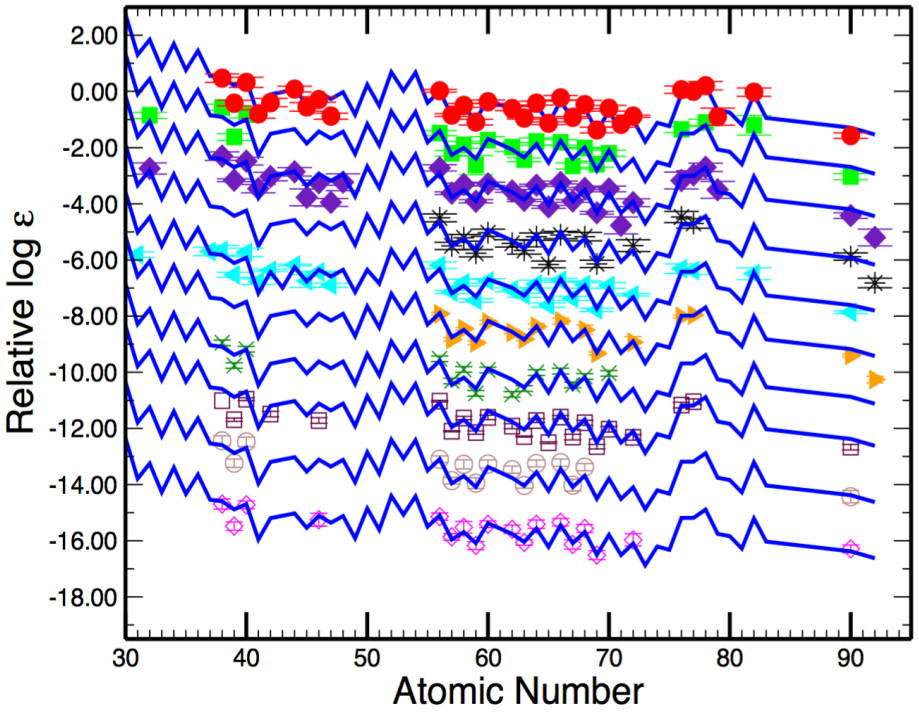
Vassh *et al* (ApJ 896, 28 (2020))

Fission deposition to explain robustness of observed elemental abundances?





10 *r*-process rich halo stars compared to Solar

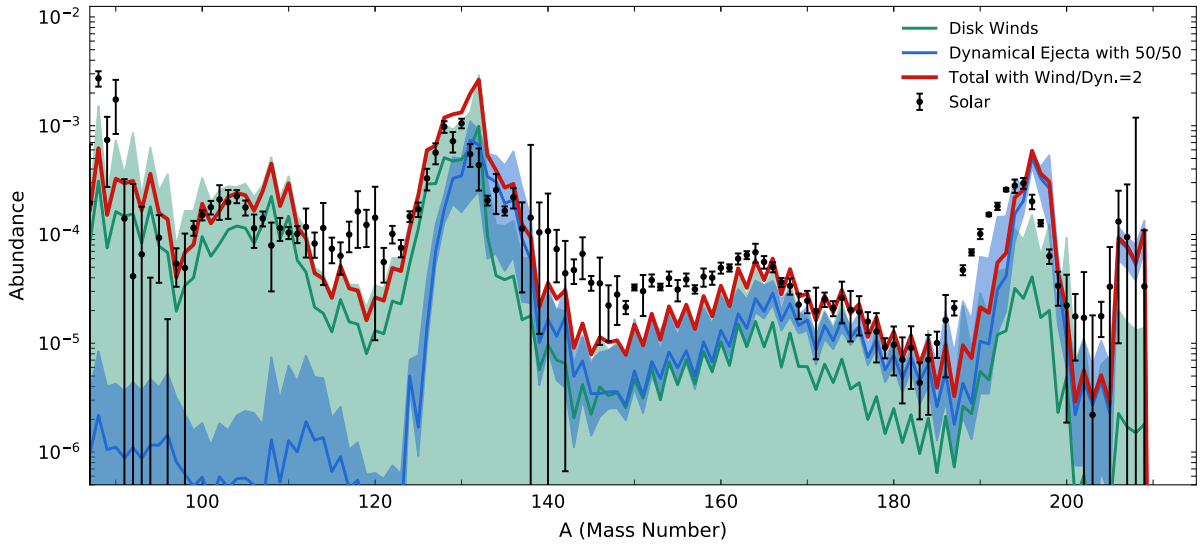


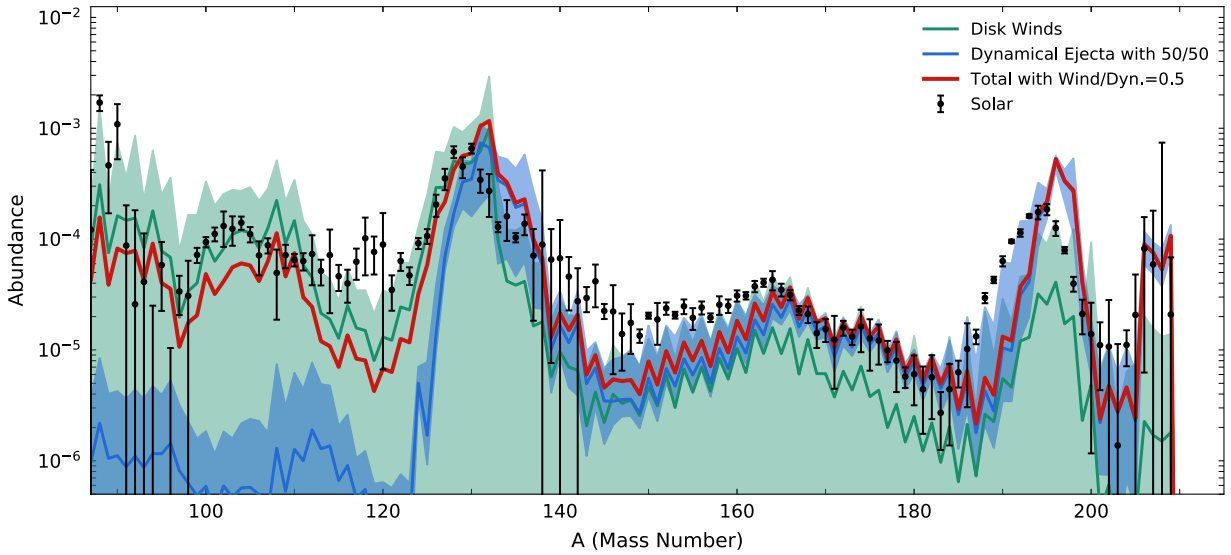
Cowan, Roederer, Sneden and Lawler (2011)

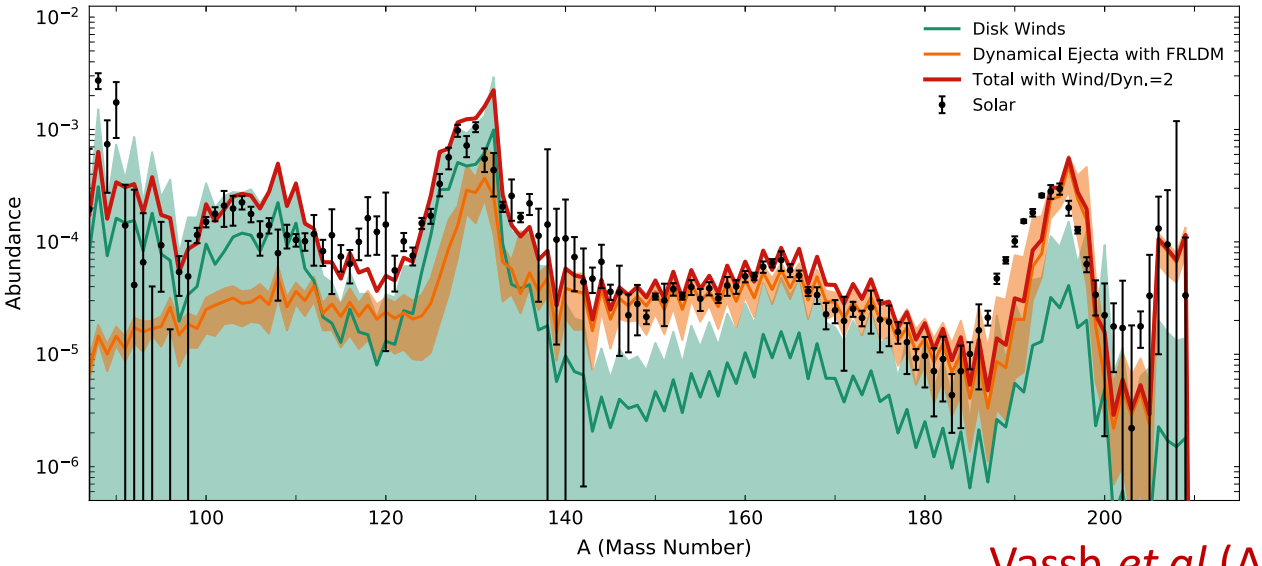
1.2-1.4 $M_\odot$ NSM dynamical ejecta using Rosswog *et al* 2013 simulation conditions (very neutron-rich with robust fission)

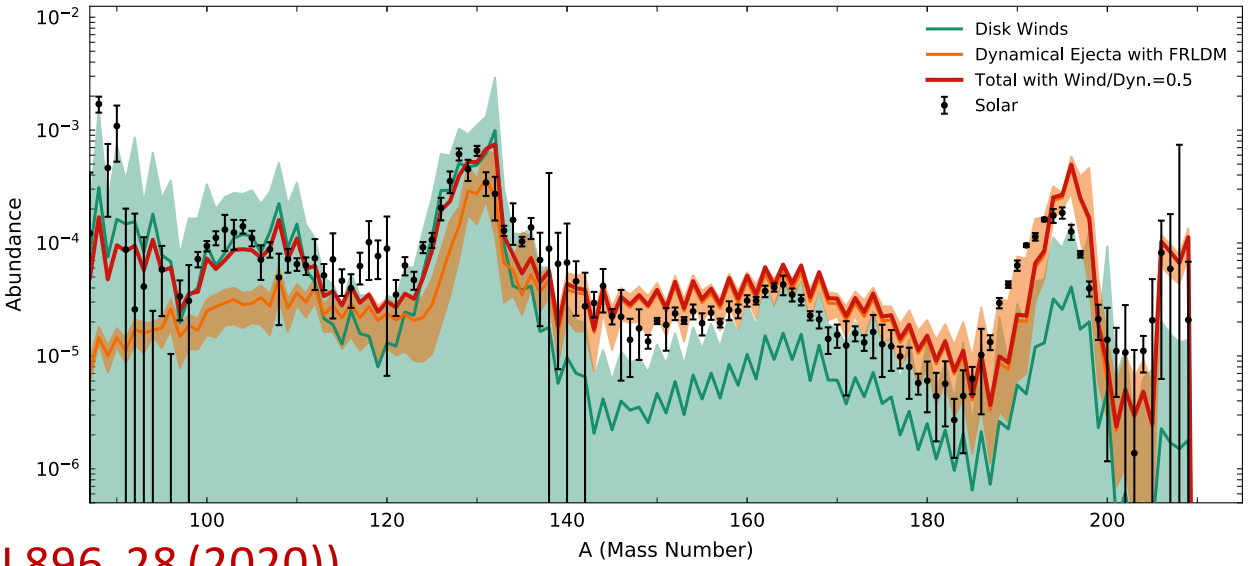
Vassh *et al* (ApJ 896, 28 (2020))

Co-production of light/heavy *r*-process elements via fission: robustness in the presence of varying ejecta compositions



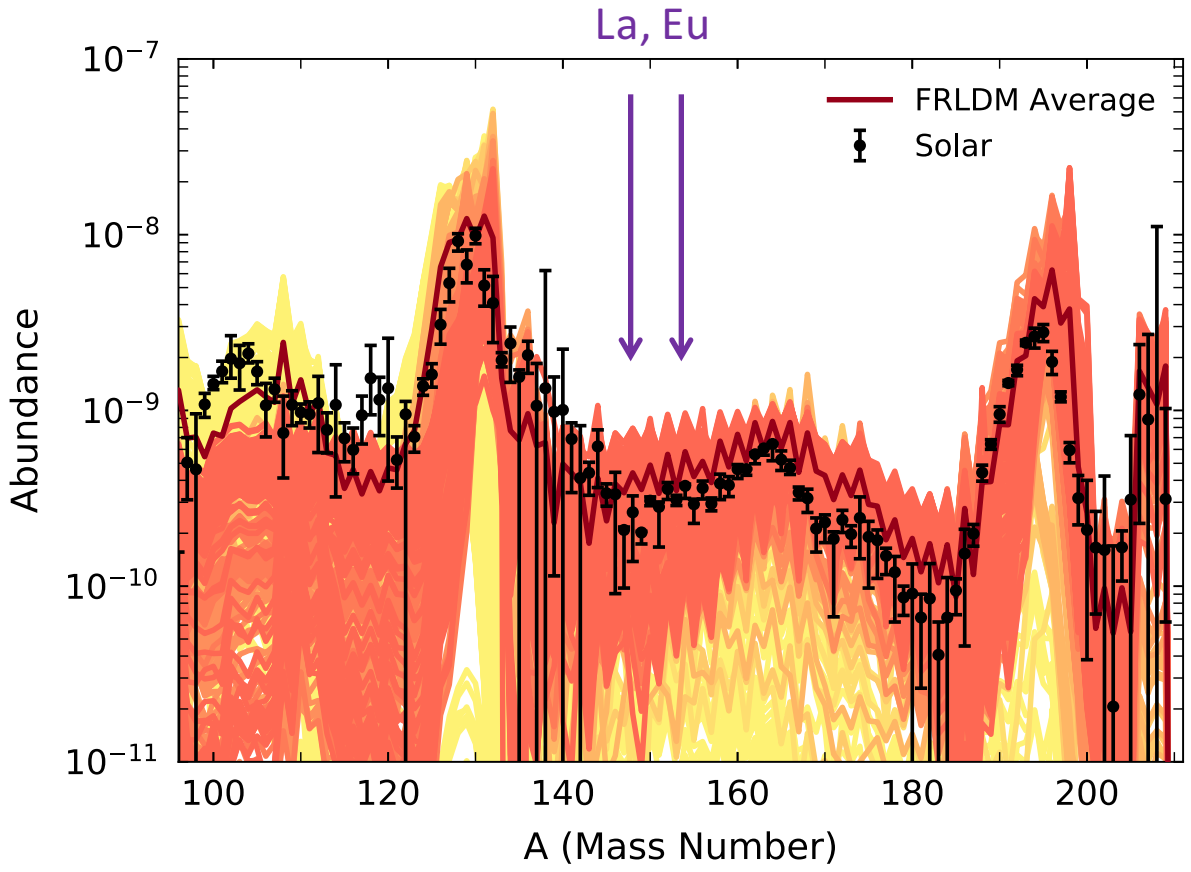




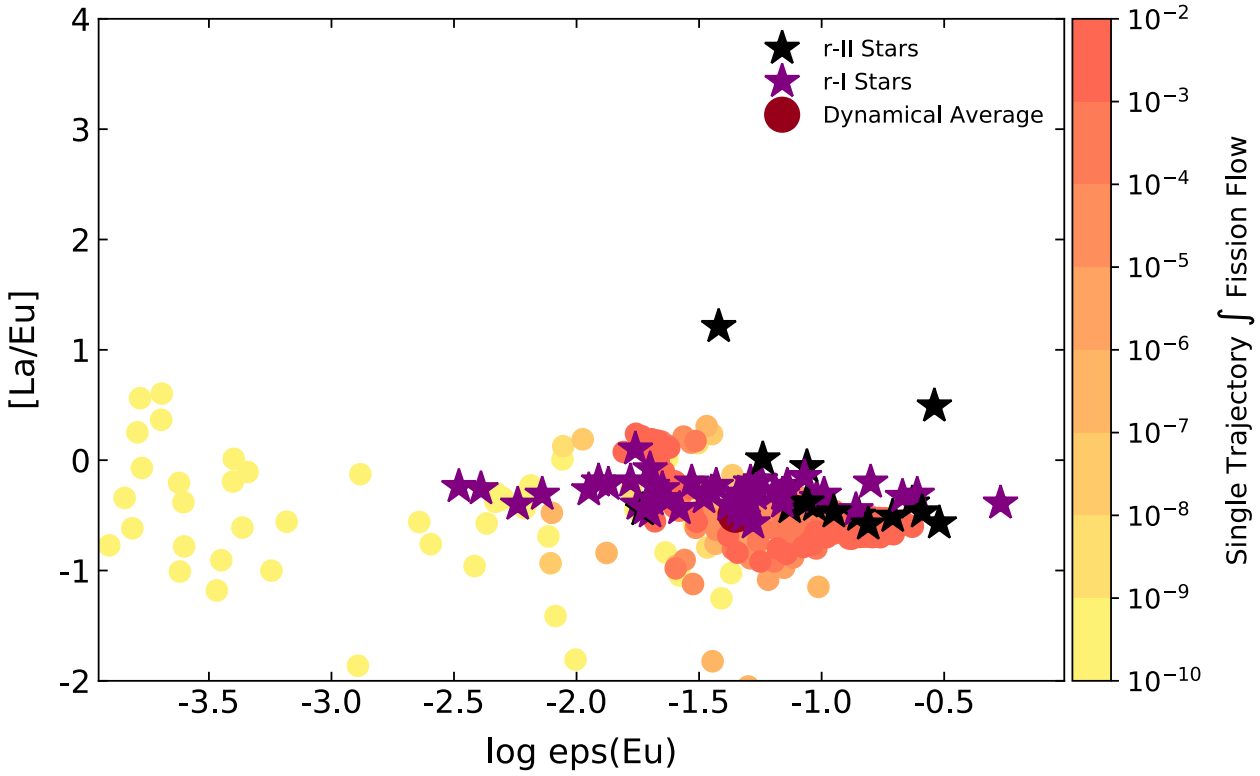


Vassh *et al* (ApJ 896, 28 (2020))

Fission deposition to explain robustness of observed elemental abundances?



1.2-1.4 $M_\odot$ NSM dynamical ejecta using simulation of Radice *et al* 2018 with M0 neutrino transport (broad range of conditions)



Vassh *et al* (ApJ 896, 28 (2020))

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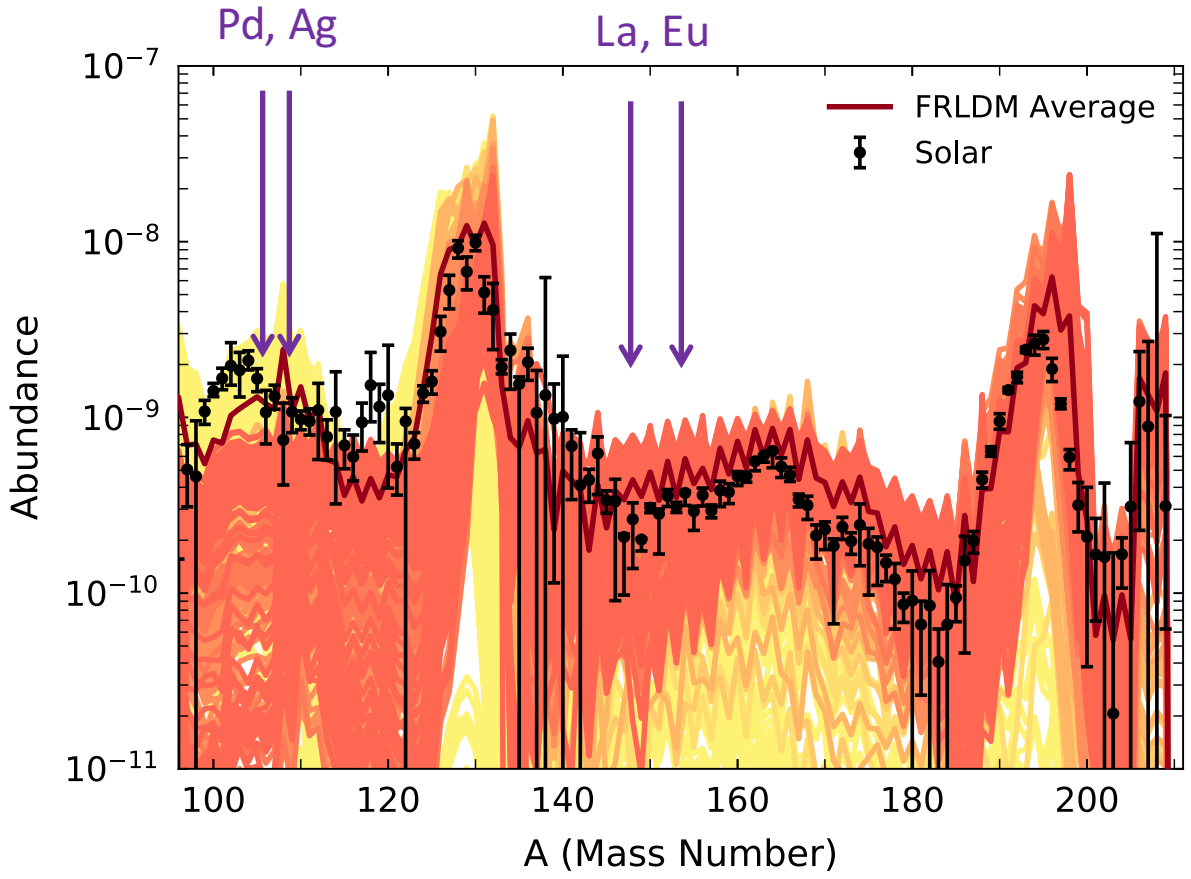

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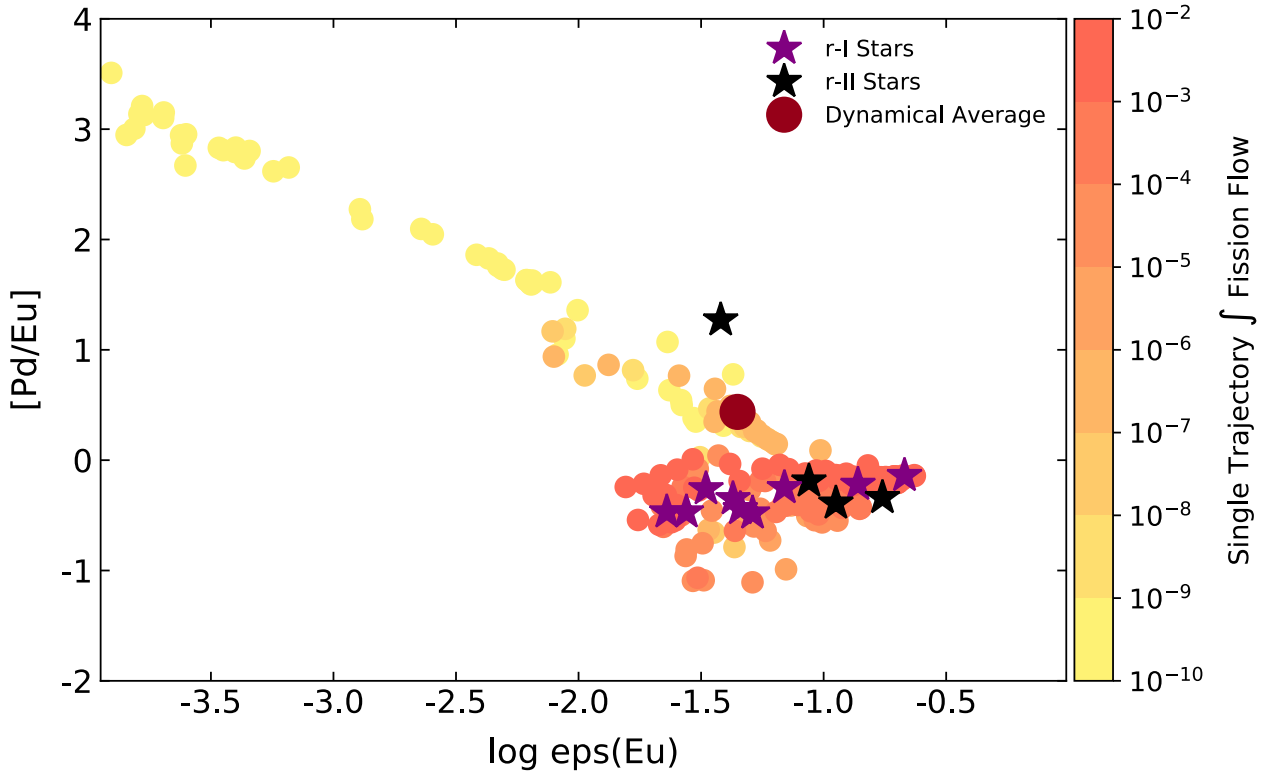
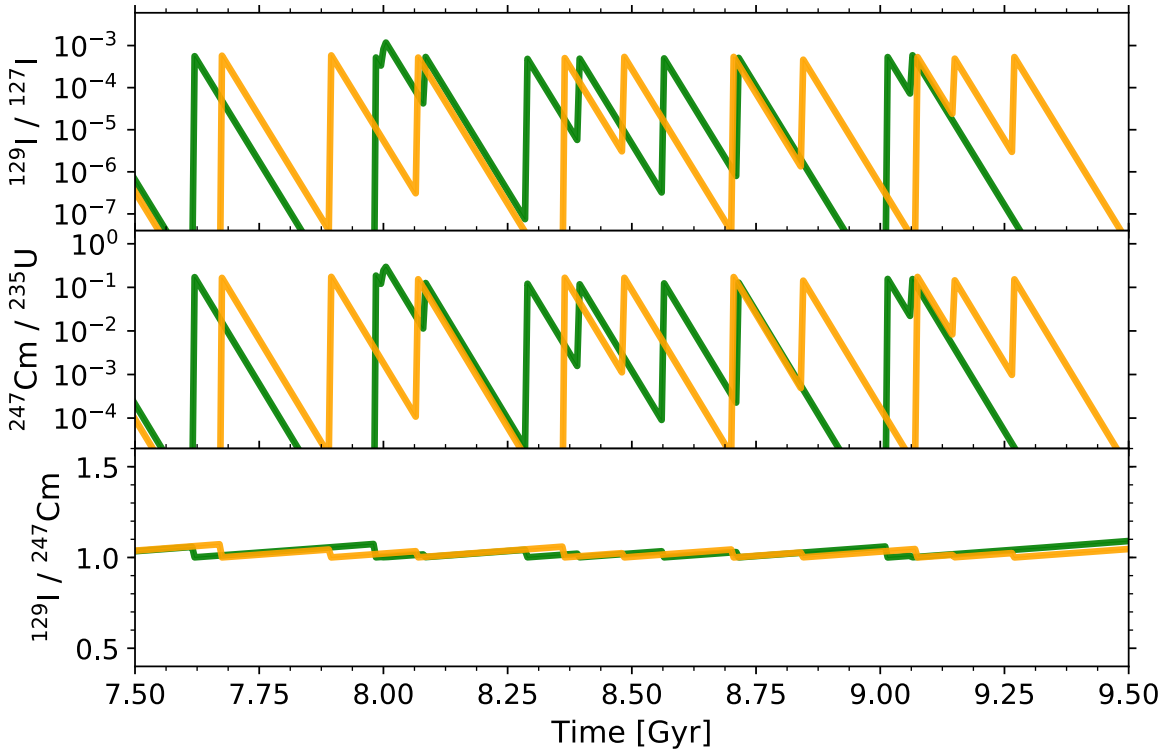
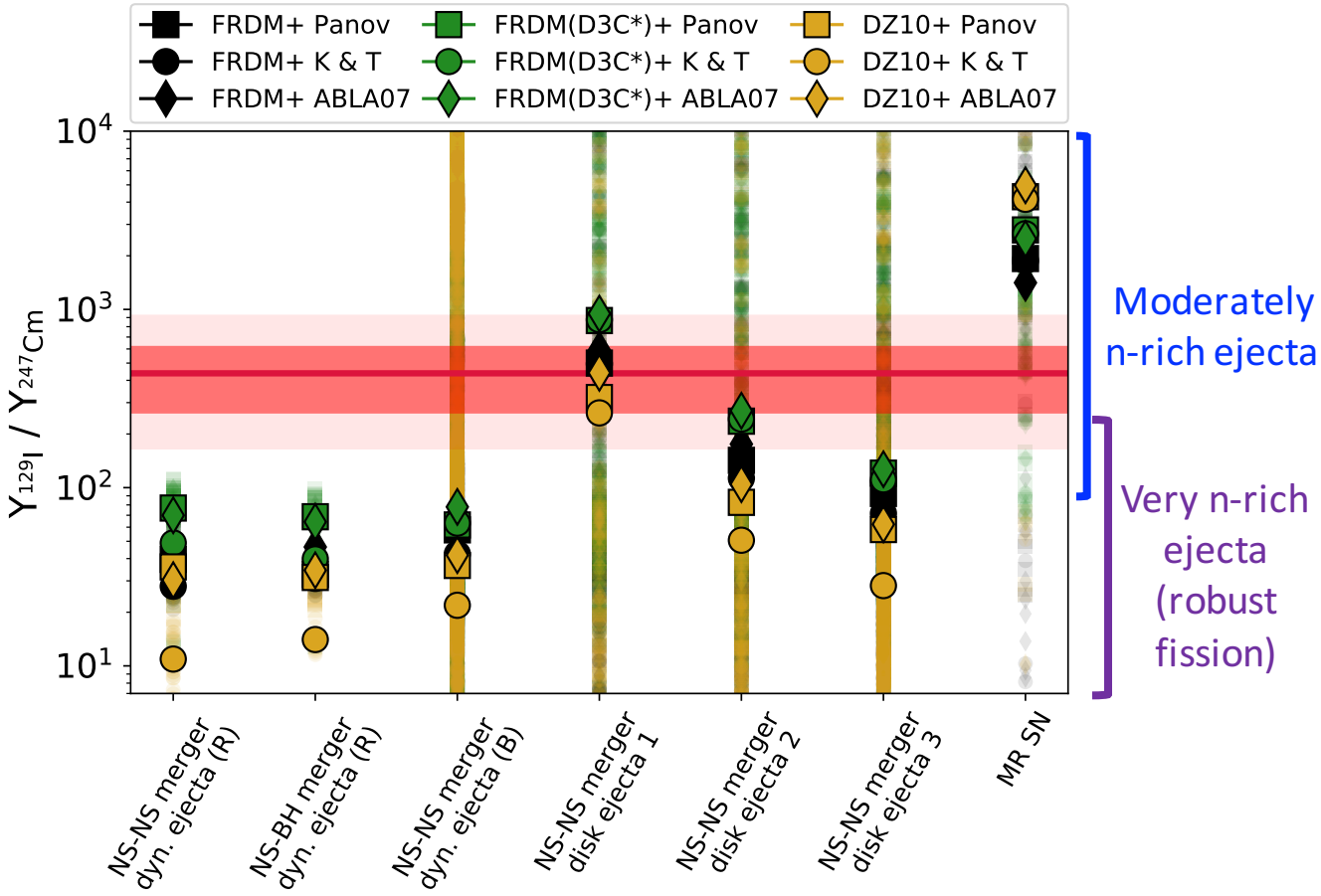


Vassh *et al* (ApJ 896, 28 (2020))

2019-2020: Submitted works

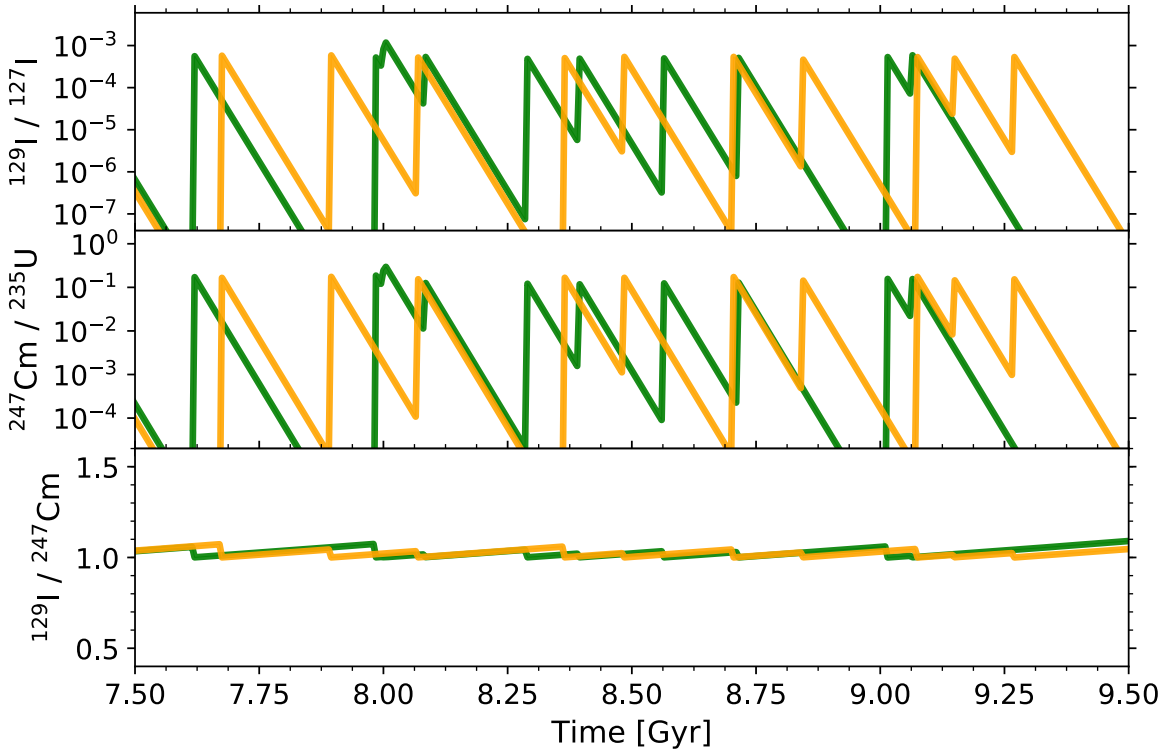
Can meteoric abundances reveal the nature of the last *r*-process enrichment of our solar system?



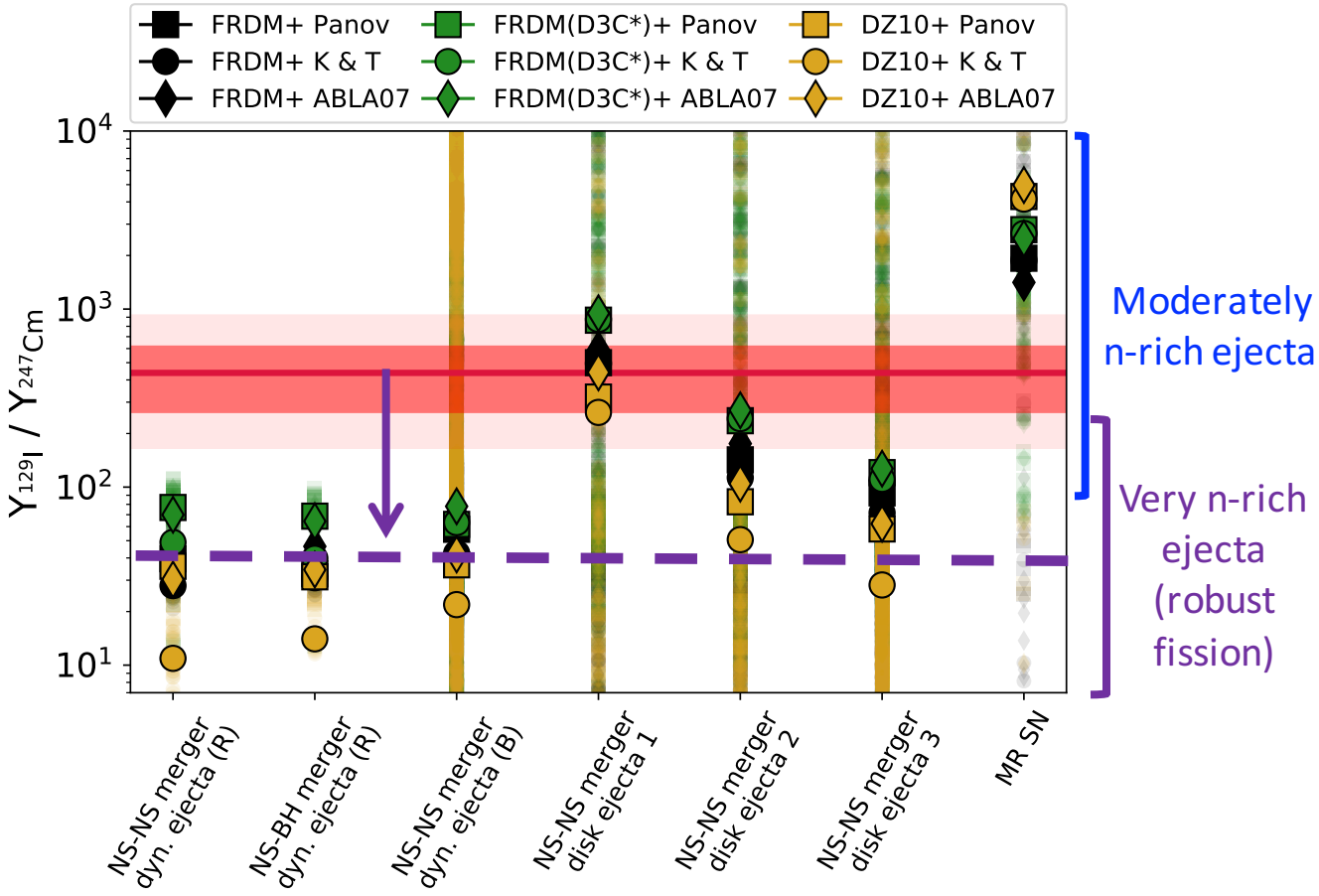


Côté, Eichler, Yagüe, Vassh, Mumpower, Világos, Soós, Arcones, Sprouse, Surman, Pignatari, Wehmeyer , Rauscher, and Lugaro (submitted to Science, 2019)

Can meteoric abundances reveal the nature of the last *r*-process enrichment of our solar system?

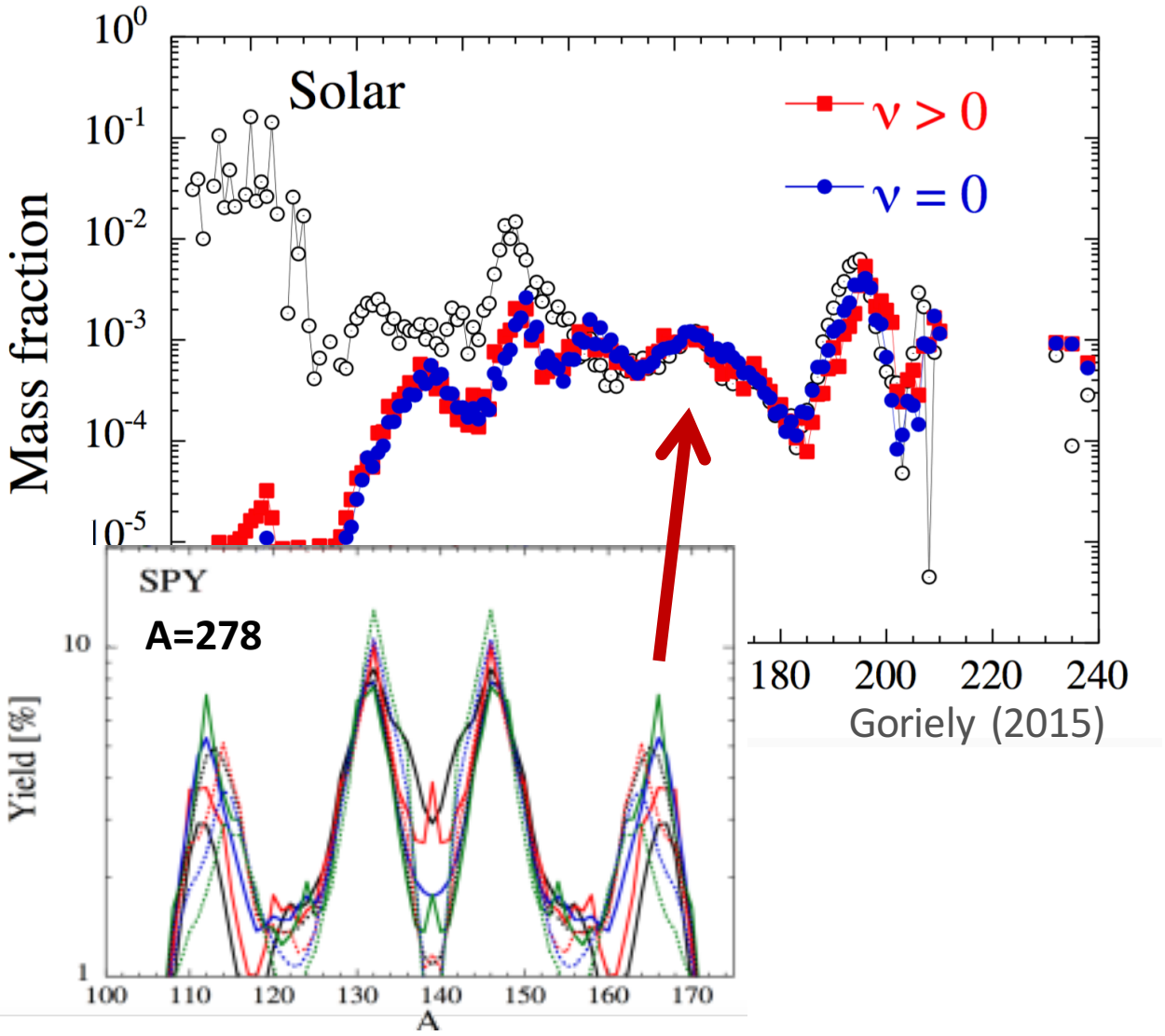


The latest evaluation on meteoric iodine suggests lower abundance than previous studies!



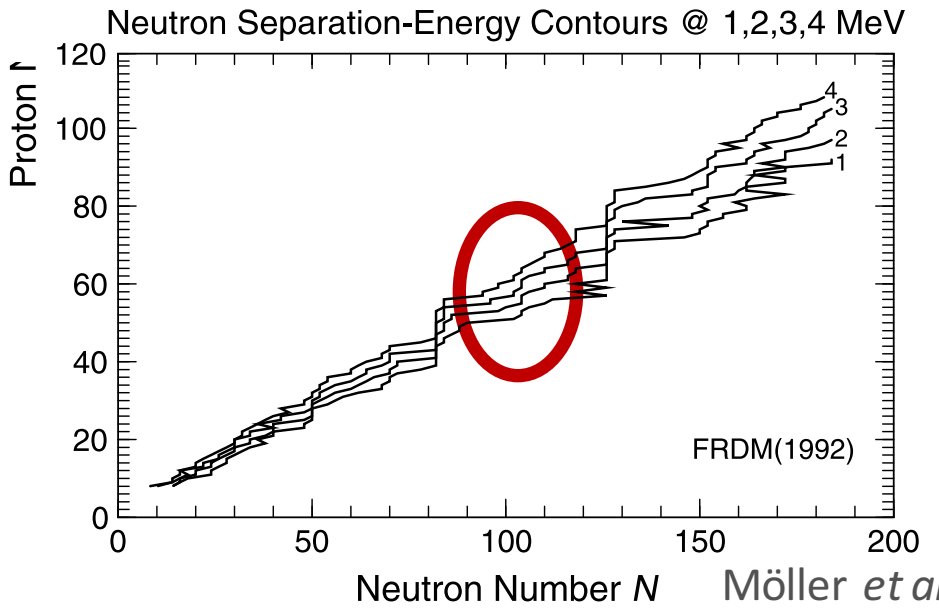
Côté, Eichler, Yagüe, Vassh, Mumpower, Világos, Soós, Arcones, Sprouse, Surman, Pignatari, Wehmeyer , Rauscher, and Lugaro (submitted to Science, 2019)

The rare-earth peak: fission deposition? Local deformation / subshell? both?

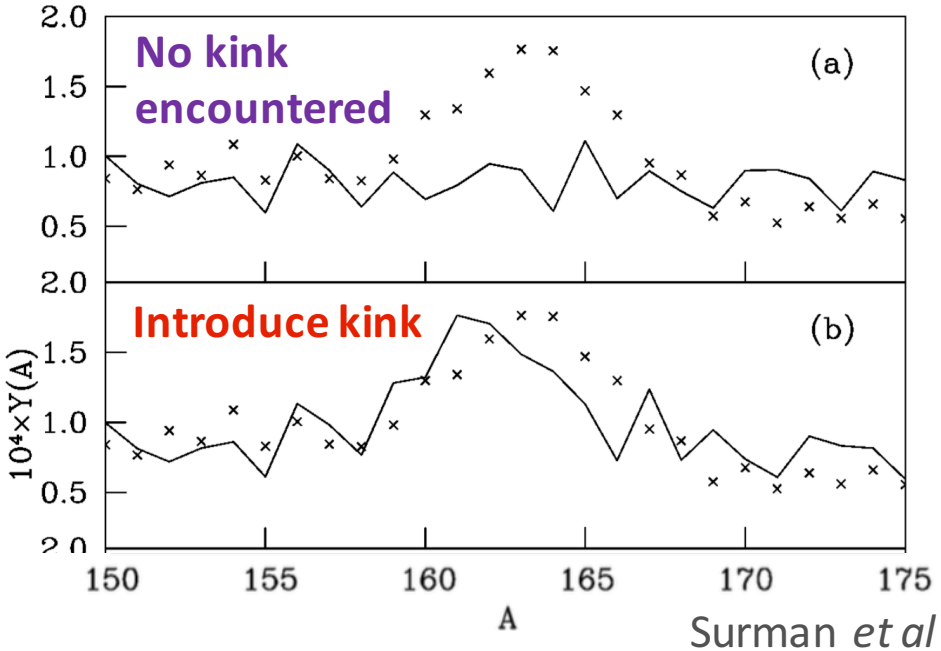


Goriely (2015)

Z=95, Z=96 , Z=97, Z=98, Z=99, Z=100, Z=101, Z=102 (dotted lines – larger Z)



Möller *et al* (2012)

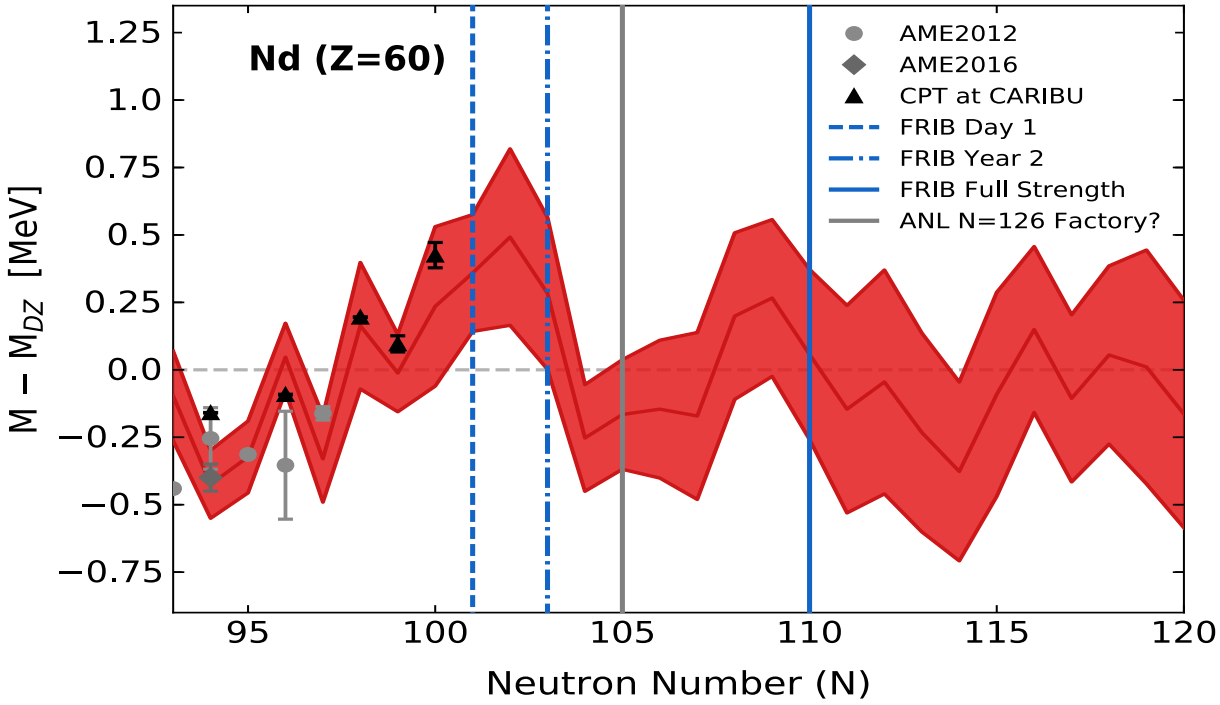


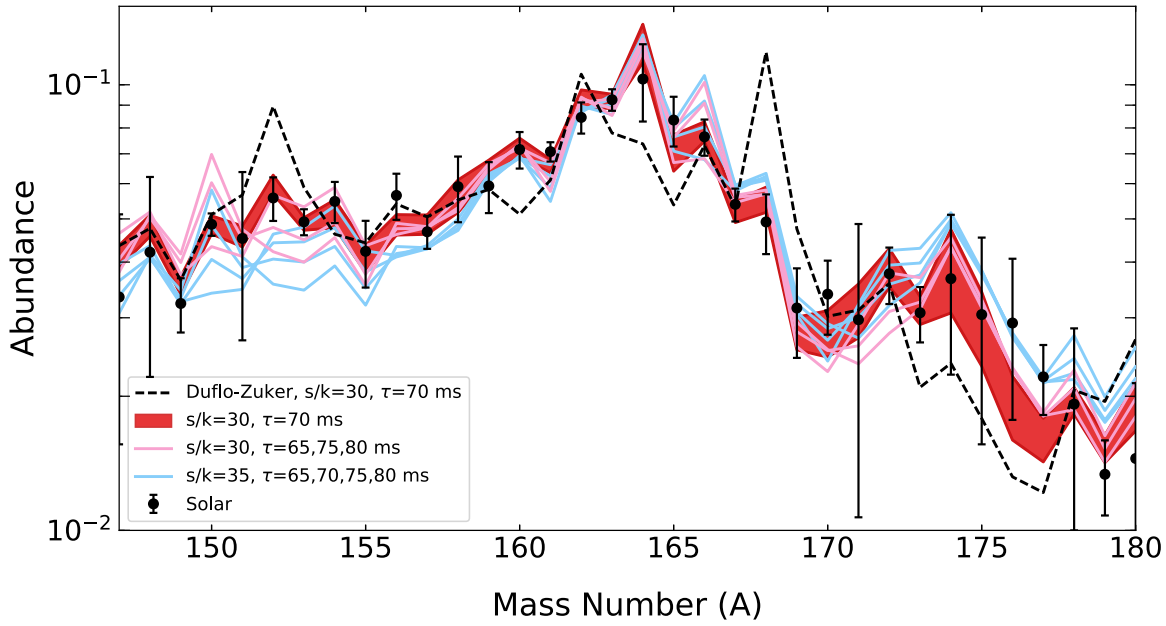
Surman *et al* (1997)

MCMC results: **rare-earth masses** to form peak in hot and *similar* astrophysical conditions

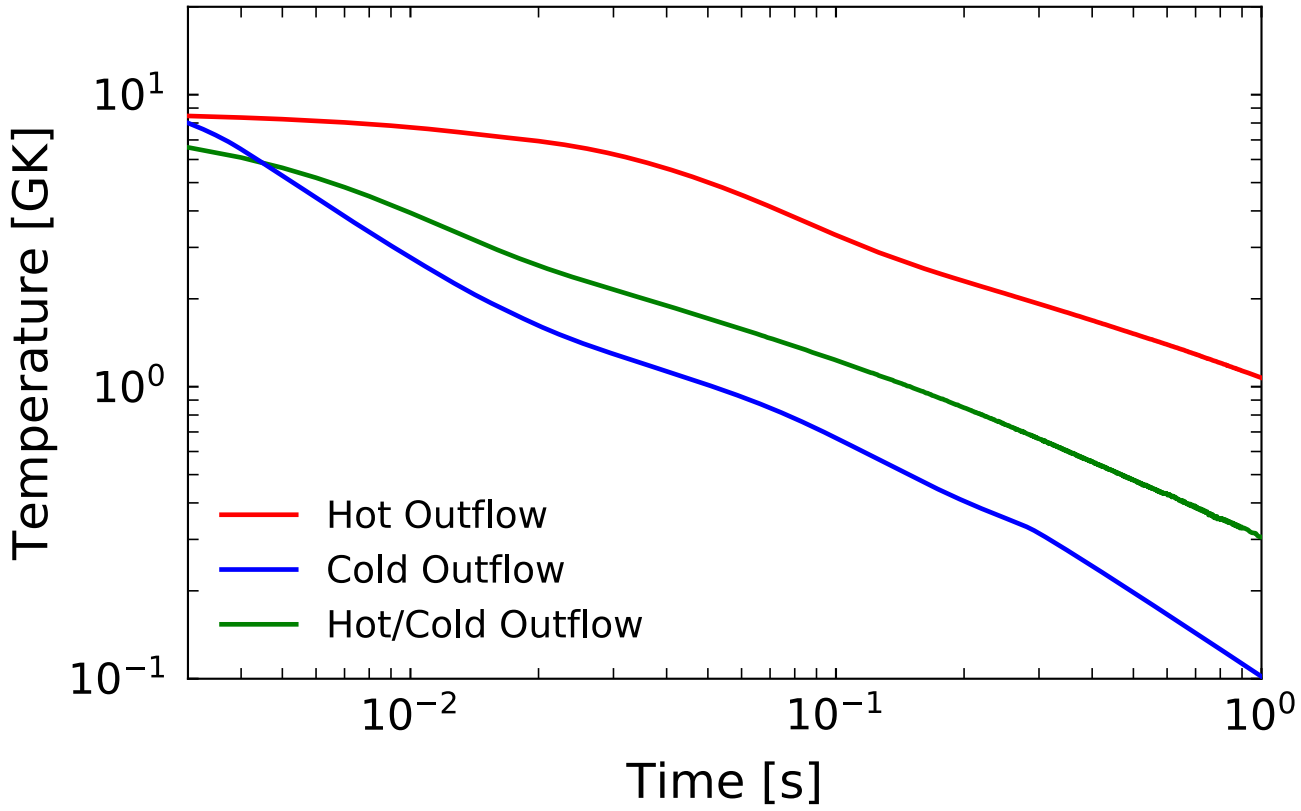
Vassh *et al* (submitted, 2020); Orford, Vassh, *et al.* (Phys. Rev. Lett. **120**, 262702 (2018))

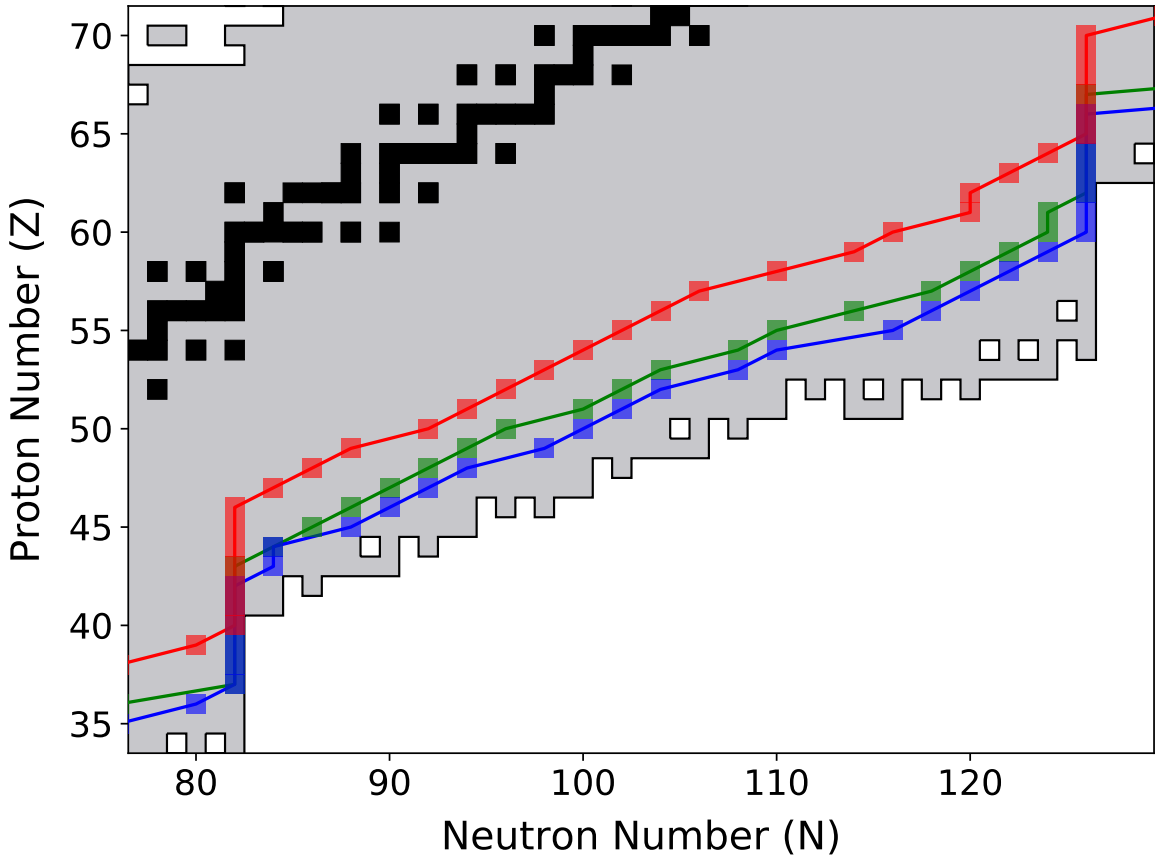
- Astrophysical trajectory: hot, low entropy outflow as from a NSM accretion disk (s/k=30, τ=70 ms, Y_e=0.2)
- 50 parallel, independent MCMC runs





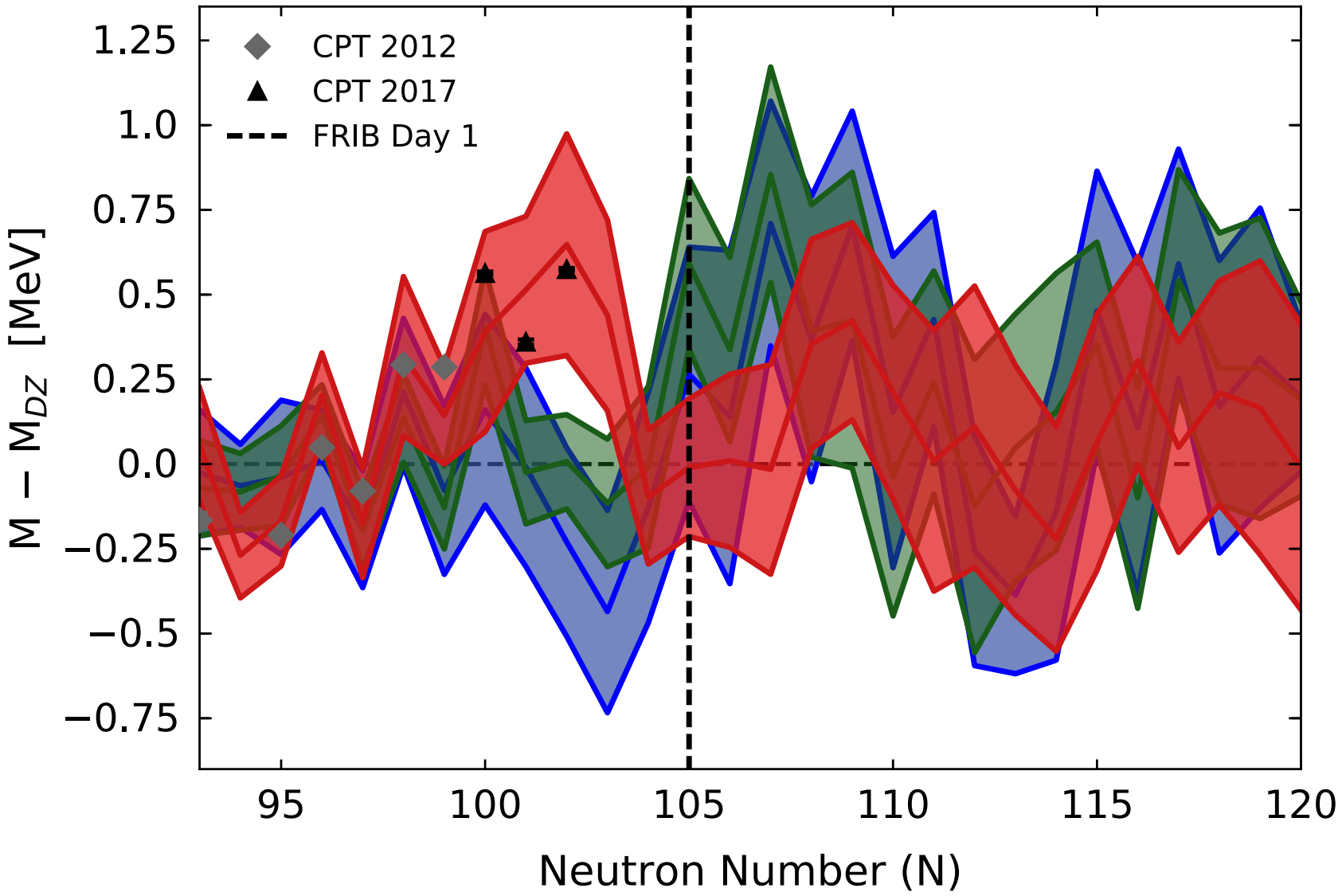
Peak formation in outflows with *distinct* astrophysical conditions





Vassh *et al* (submitted to ApJ, 2020)

Comparing to the most neutron-rich measurements: Samarium

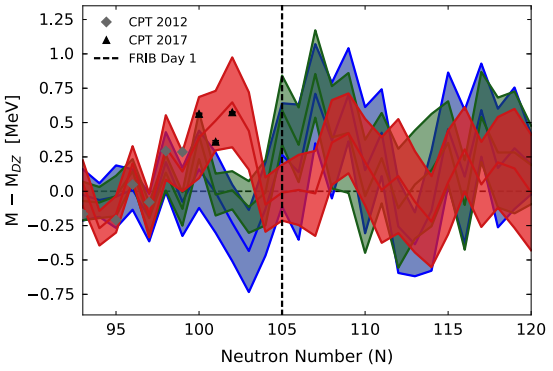


Vassh *et al* (submitted to ApJ, 2020)

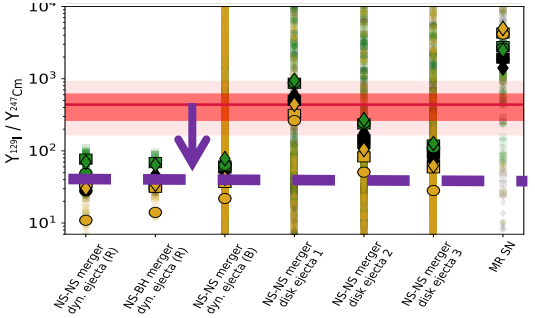
FIRE
Fission In R-process Elements

Impact on important open questions in heavy element production

- At what site(s) and under what conditions did the *r*-process element production which enriched our solar system occur?
  - **Côté et al. submitted to Science (2019)**
  - **Vassh et al. submitted to ApJ (2020); Orford, Vassh, et al. in prep. (2020)**



- Do neutron star mergers produce the heaviest elements such as gold and the actinides? Are there observable signatures of a fission cycling *r* process?
  - **Vassh et al. ApJ 896, 28 (2020)**
  - **Wang, Vassh, et al. in prep. (2020)**



- Which fissioning nuclei and fission properties are most influential?
  - **Ward, Vassh, et al. in prep. (2020)**