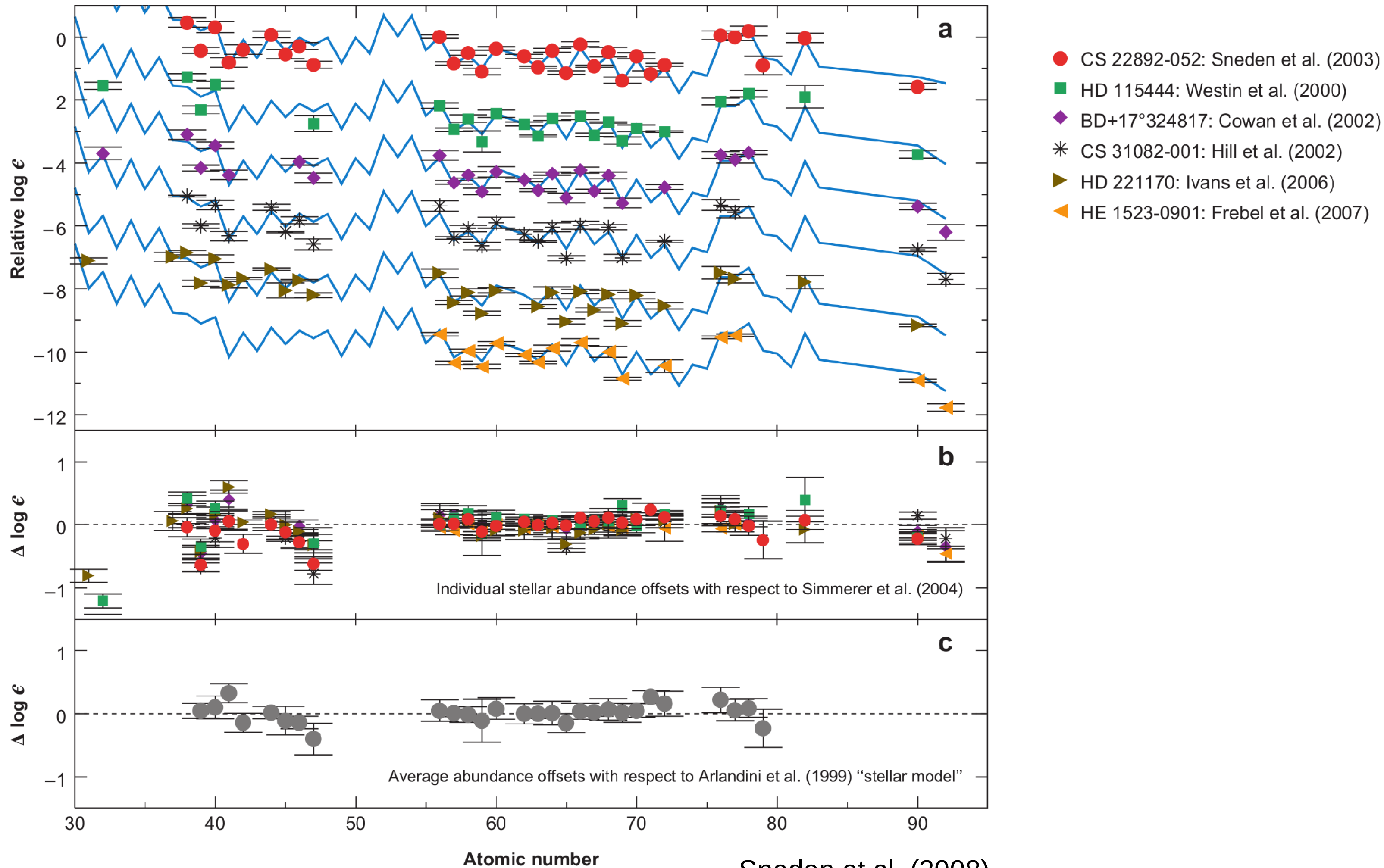
The Role of Fission on Neutron Star Merger Nucleosynthesis and its Impact on the r-Process Peaks

Hirschegg, January 17, 2017

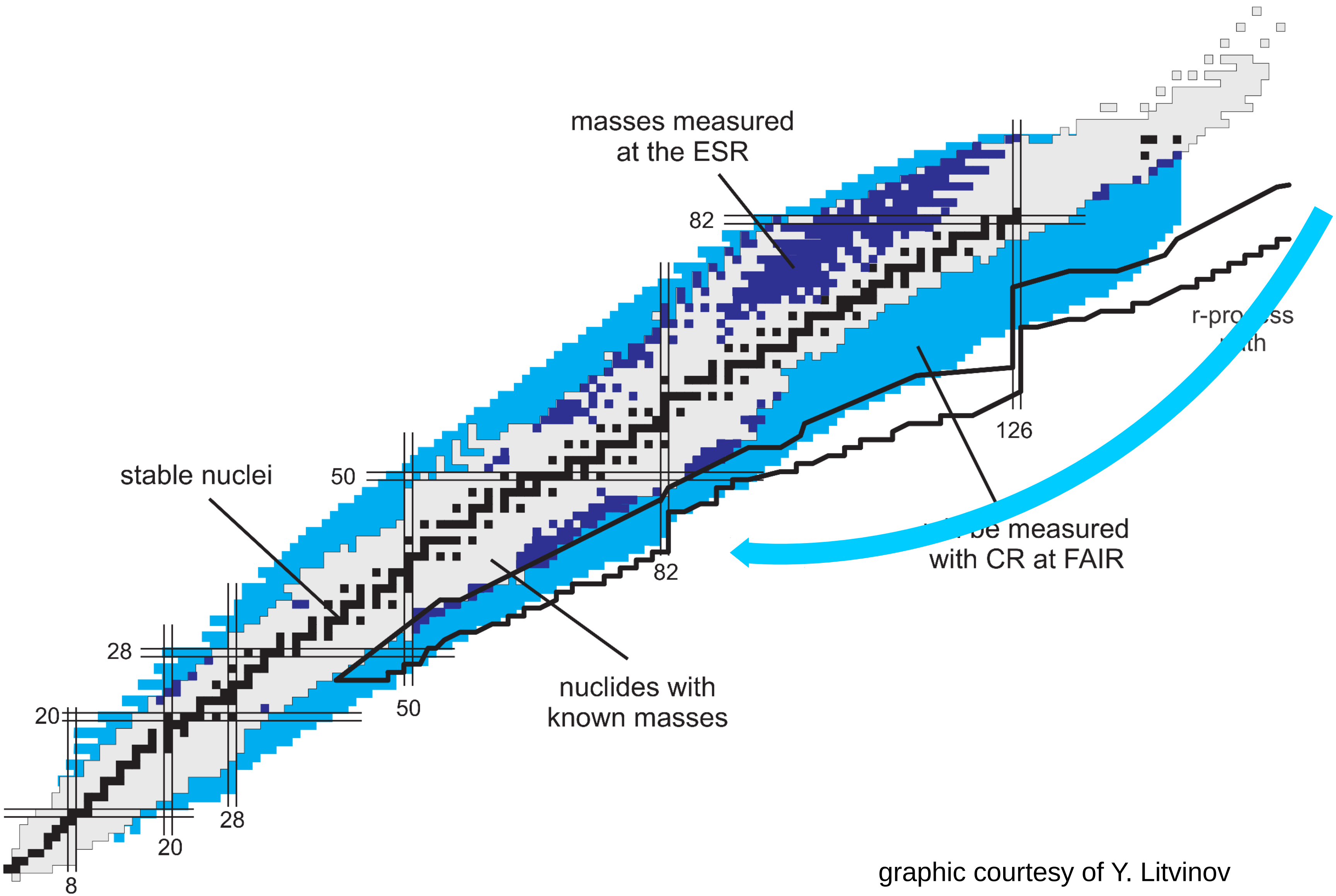
Marius Eichler (Univ. Basel, TU Darmstadt)

r-Process Abundance Pattern(s)



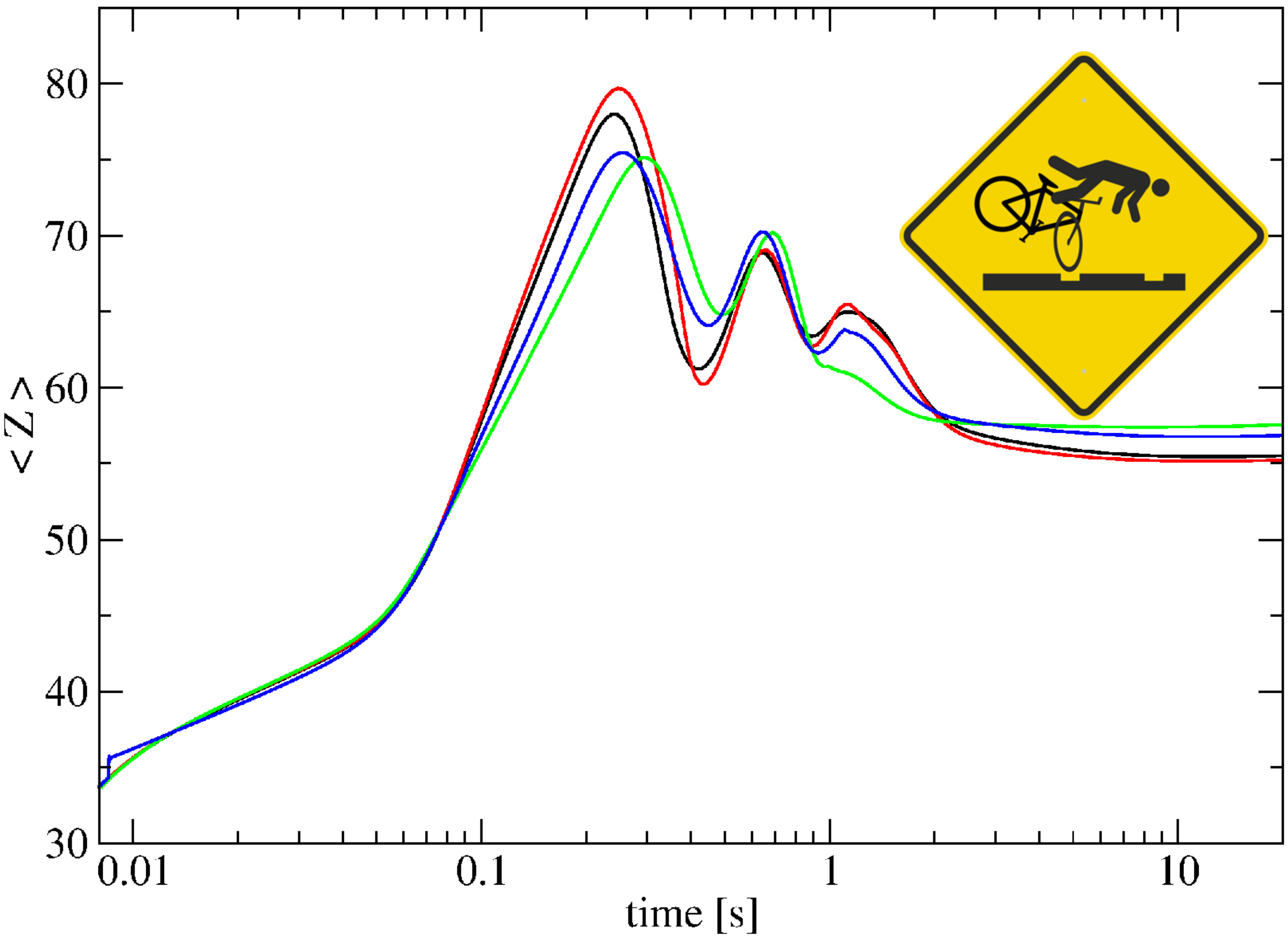
Sneden et al. (2008)

Fission Cycling



graphic courtesy of Y. Litvinov

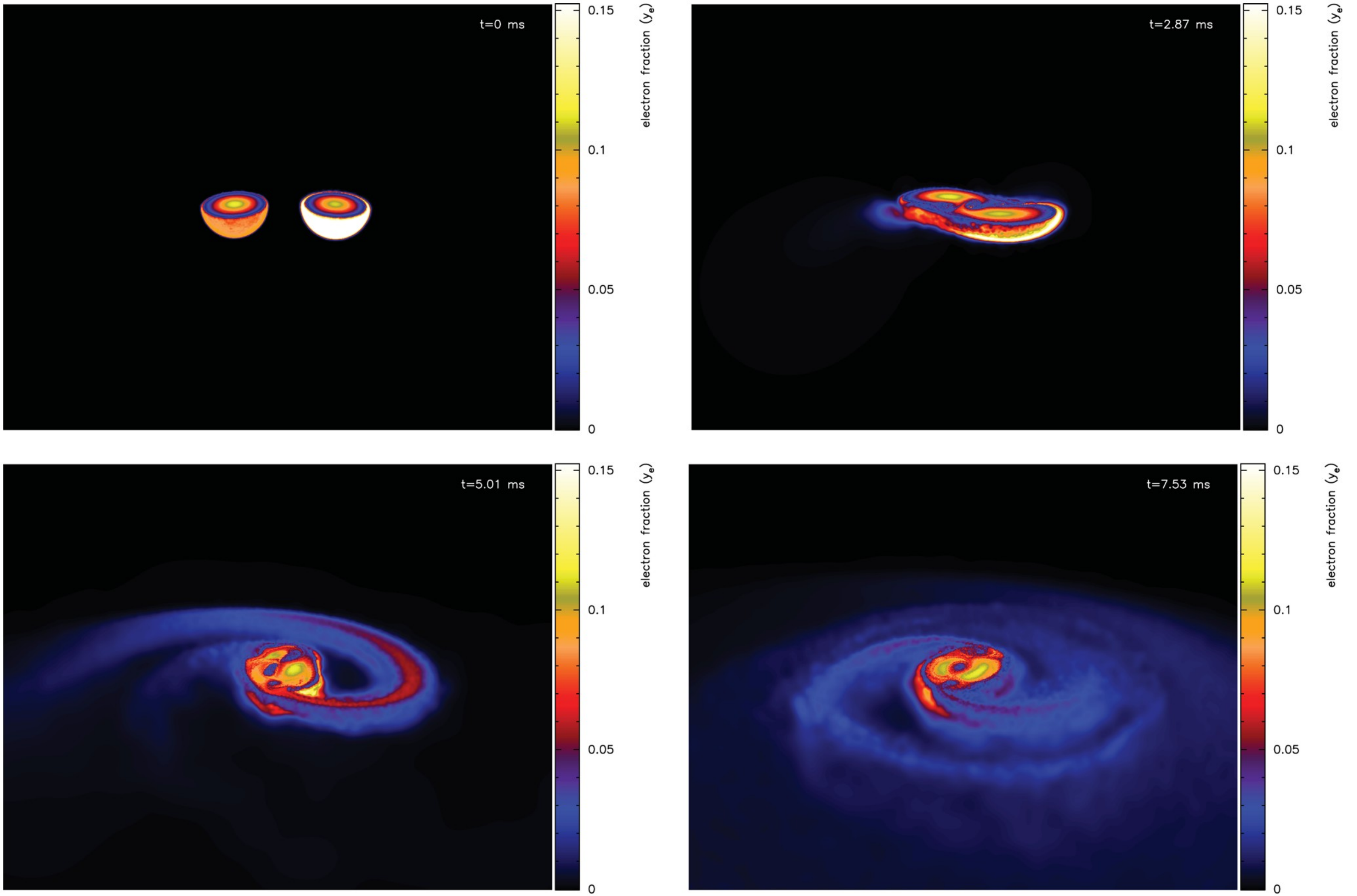
Fission Cycling



Number of fission cycles *N*:

$$N \approx \log_2 \left(\frac{\langle A \rangle_i + Y_n / Y_{seed}}{\langle A \rangle_f} \right)$$

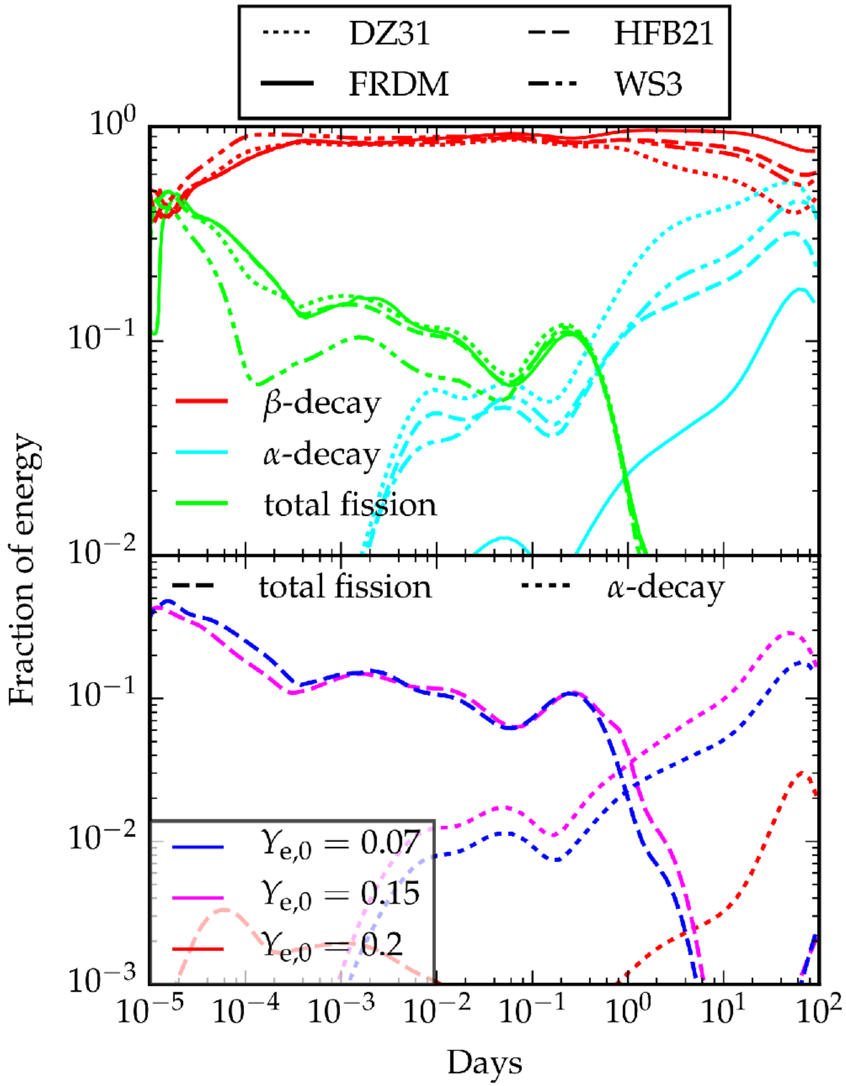
Neutron Star Mergers



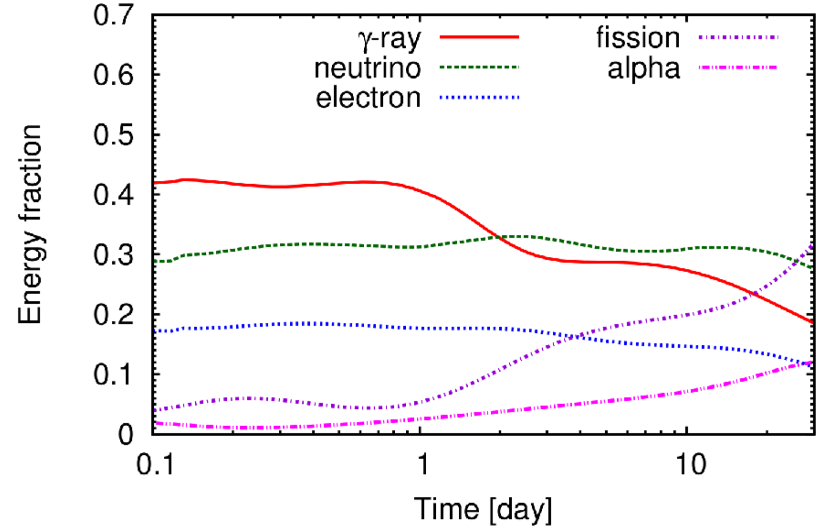
Rosswog, Piran, and Nakar (2013)

Heating Rates for Kilonovae

Barnes et al. 2016



Hotokezaka et al. 2016

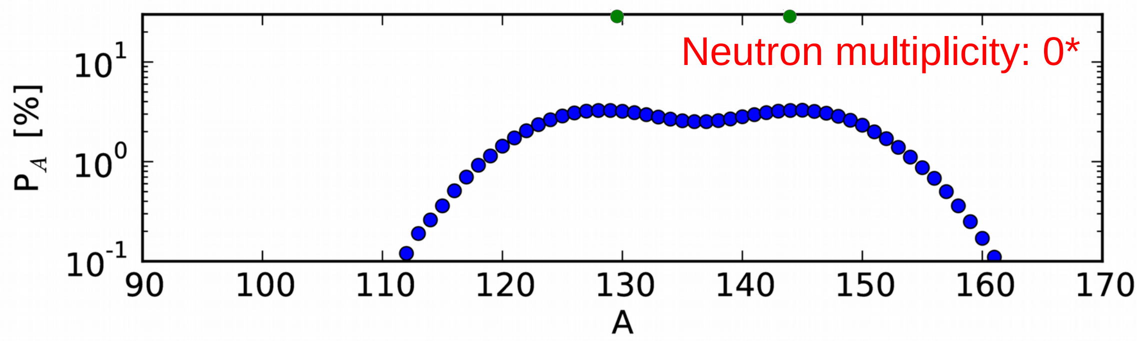


Fission Fragment Distribution Models

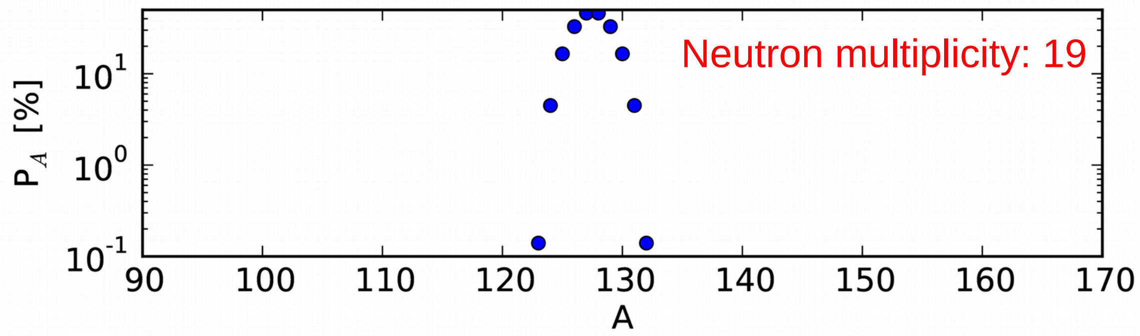
Fission Fragments of ^{274}Pu

Panov et al. 2001

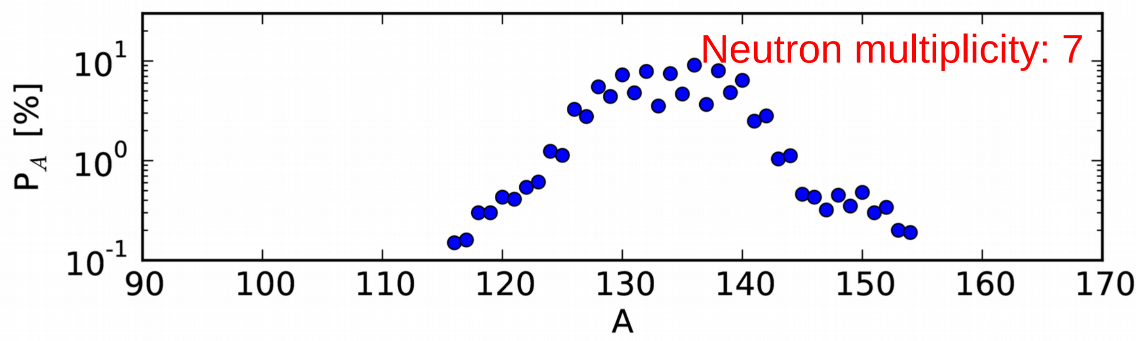
Kodama & Takahashi 1975



Panov et al. 2008

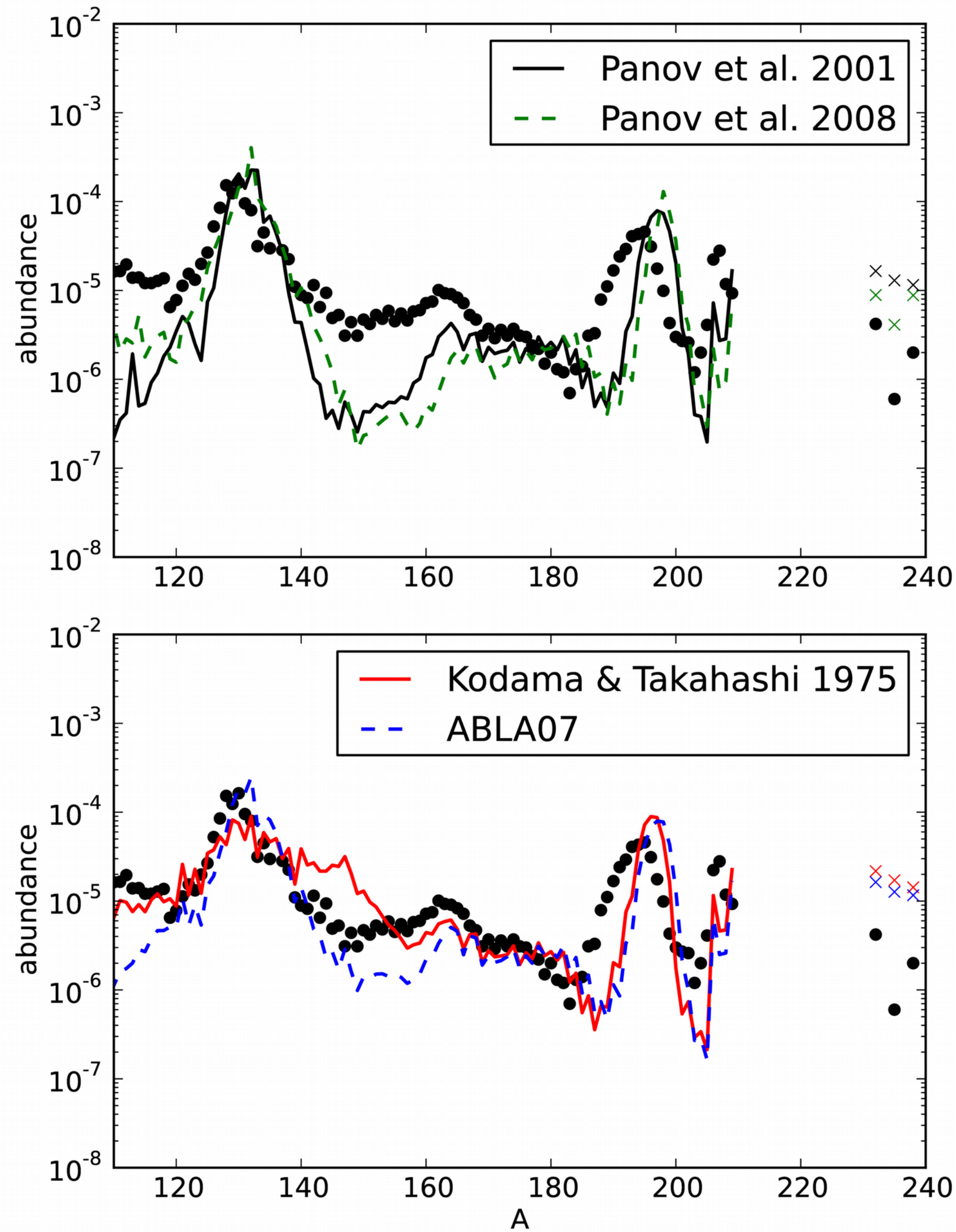


ABLA07 (Kelic et al. 2008)



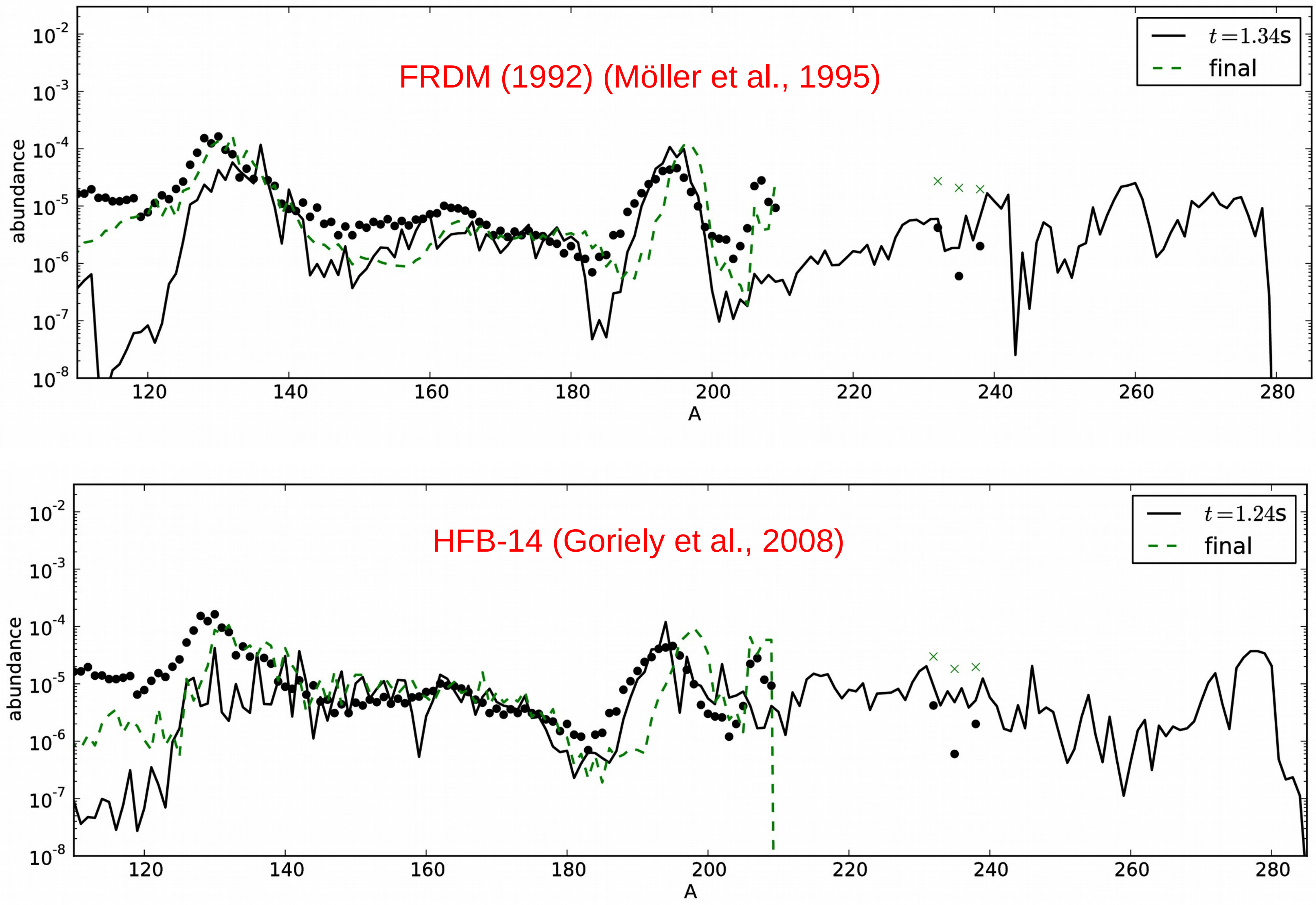
r-Process in Neutron Star Mergers

- trajectories from a neutron star merger with two 1.4 $M_\odot$ neutron stars (Korobkin et al. 2012)
- FRDM
- difference between fission fragment distribution models mainly around and after 2nd peak
- 3rd peak shifted to the right for all models



solar r-abundances: Sneden et al. 2008

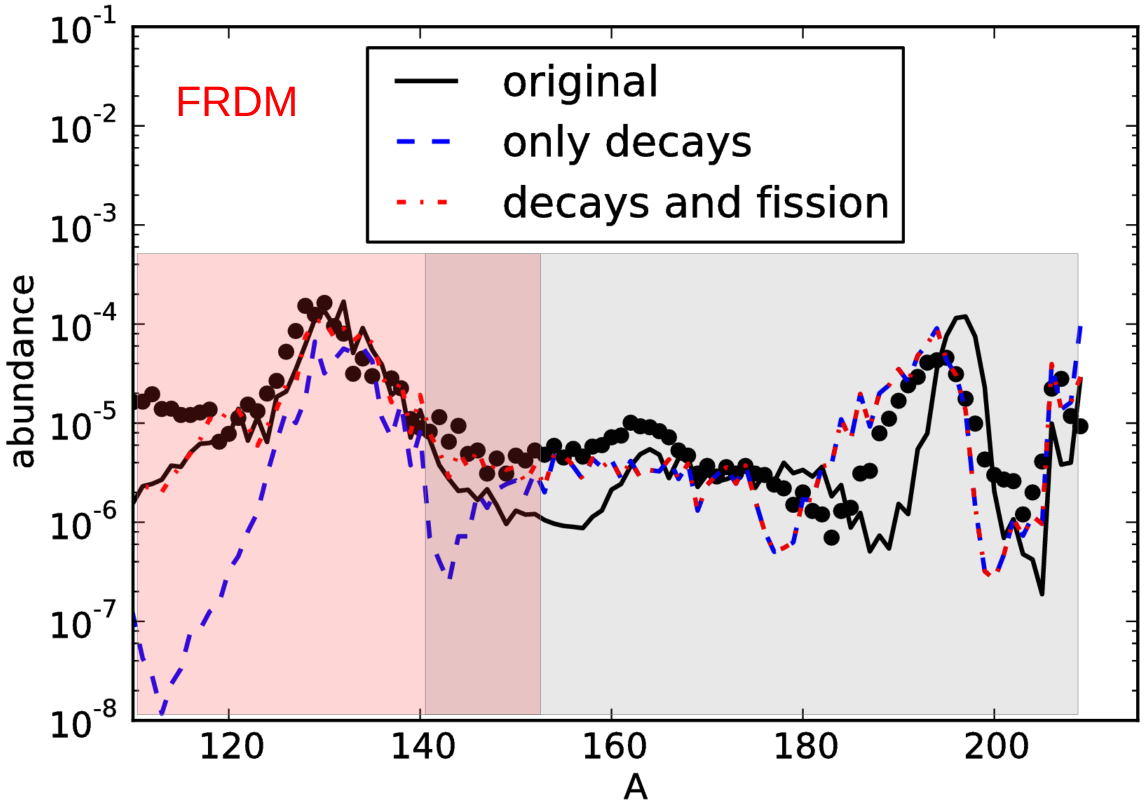
The Position of the Third Peak at Freeze-Out



Eichler et al. (2015)
→ see also Surman & Engel (2001)

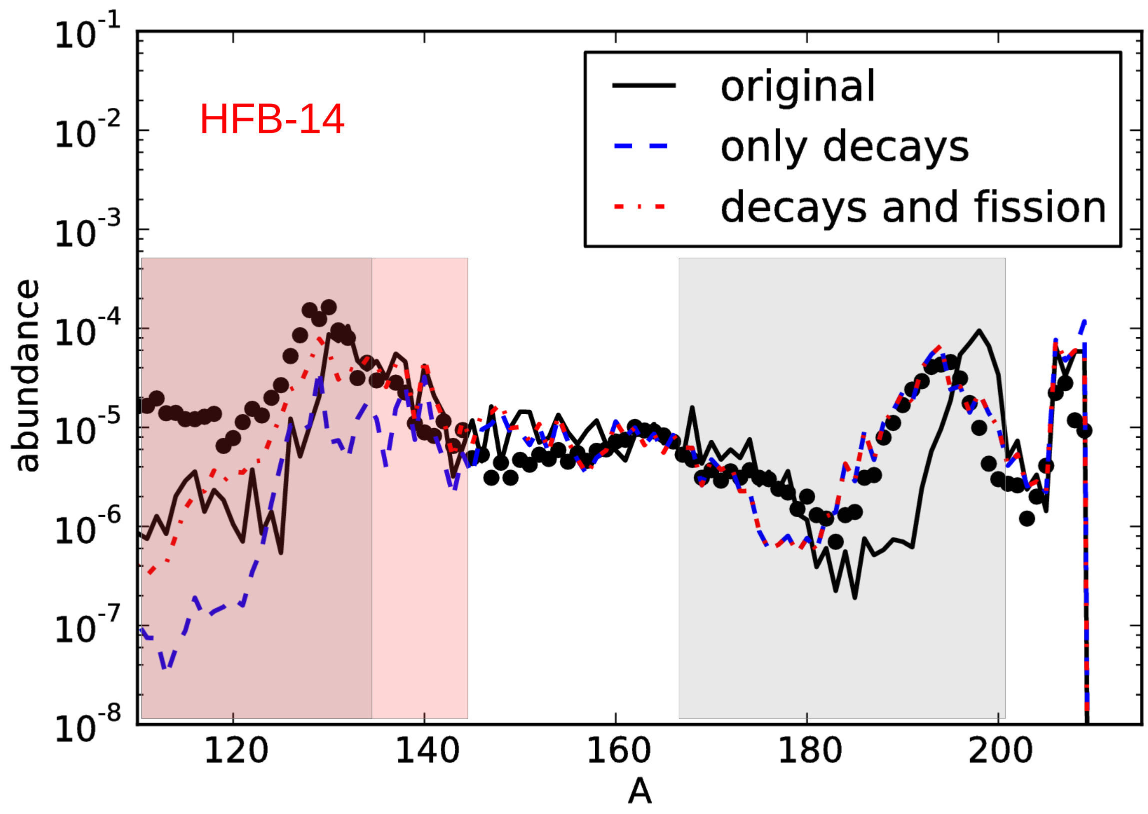
What Happens After Freeze-Out?

- Aim: Identify the reactions responsible for certain features of the final abundance distribution
- Procedure: Switch off certain types of reactions **after freeze-out**
  - FRDM: 140 < A < 160 region depleted by neutron captures

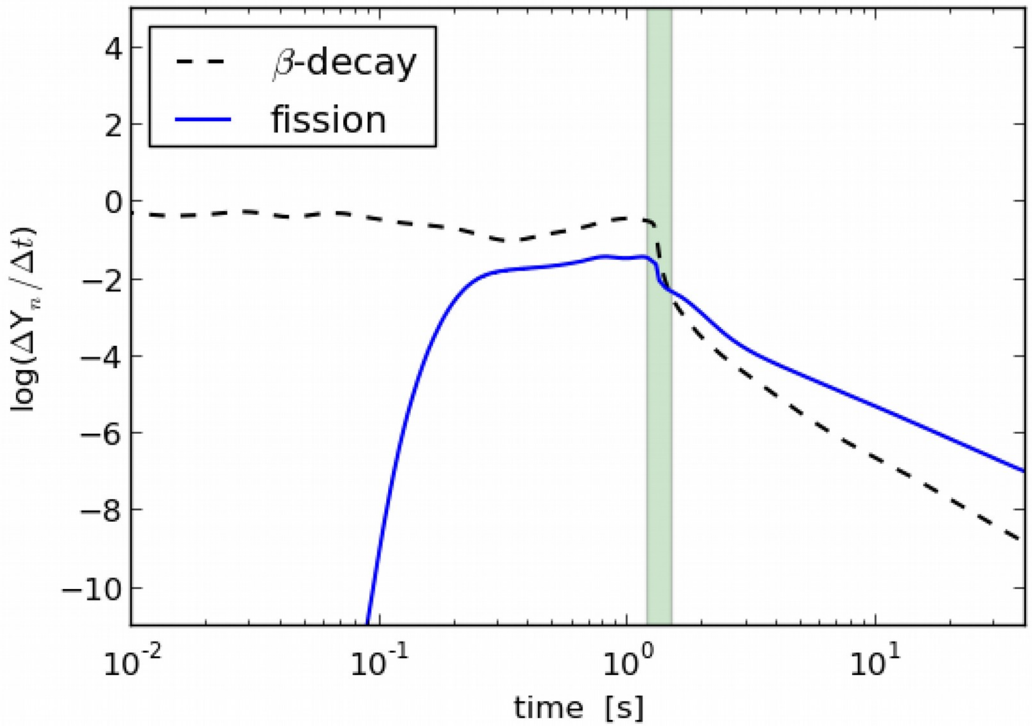


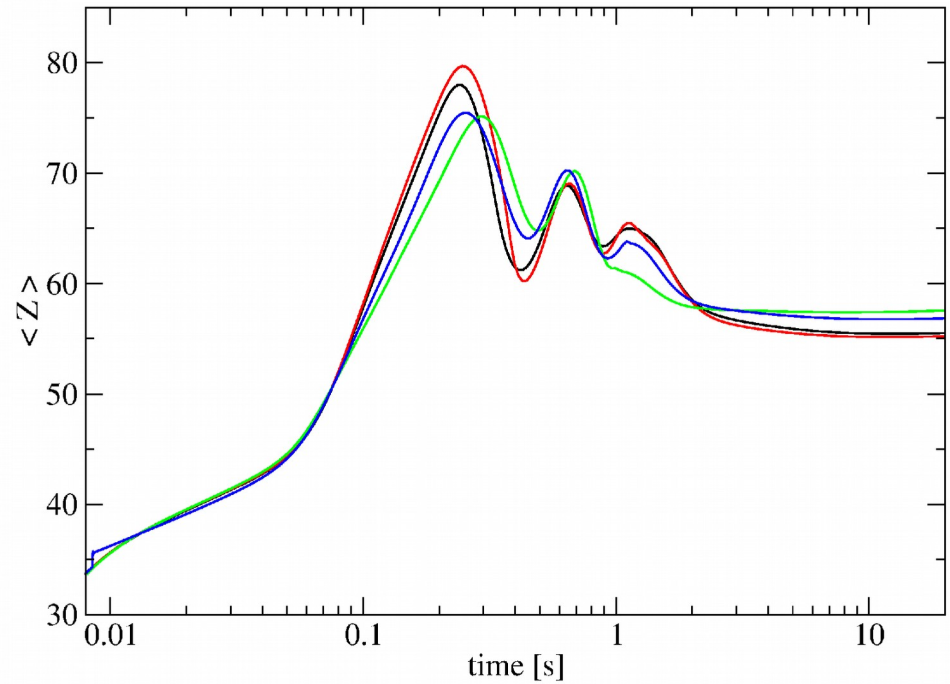
What Happens After Freeze-Out?

- HFB: 2nd and 3rd peak shifted, but not nuclei with 140 < A < 160



Neutron Release from Fission and β-Decays

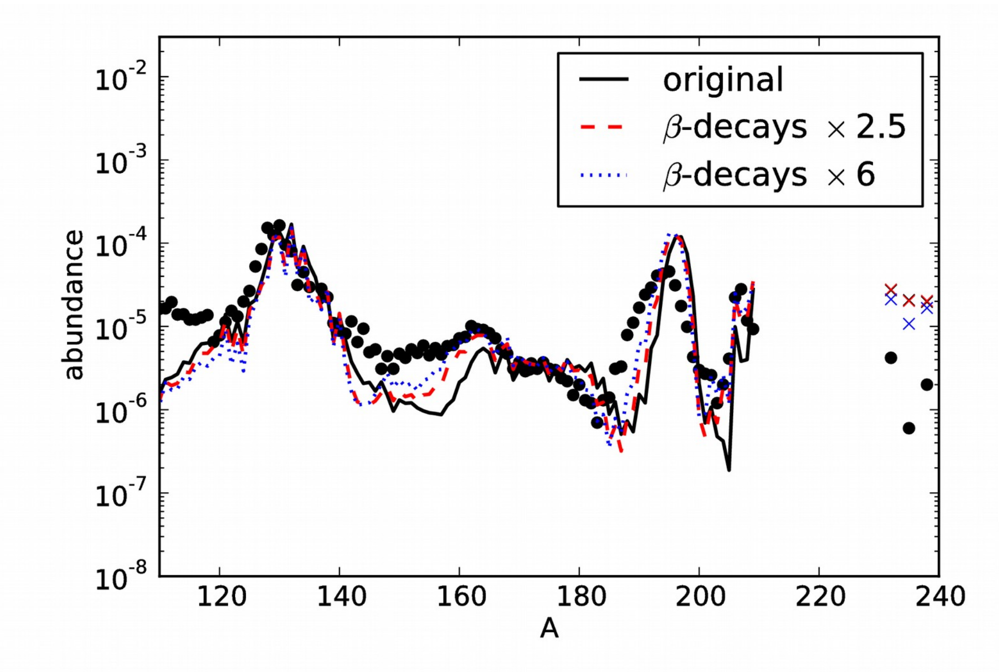




Two possible sources for free neutrons at freeze-out: fission and β-decays

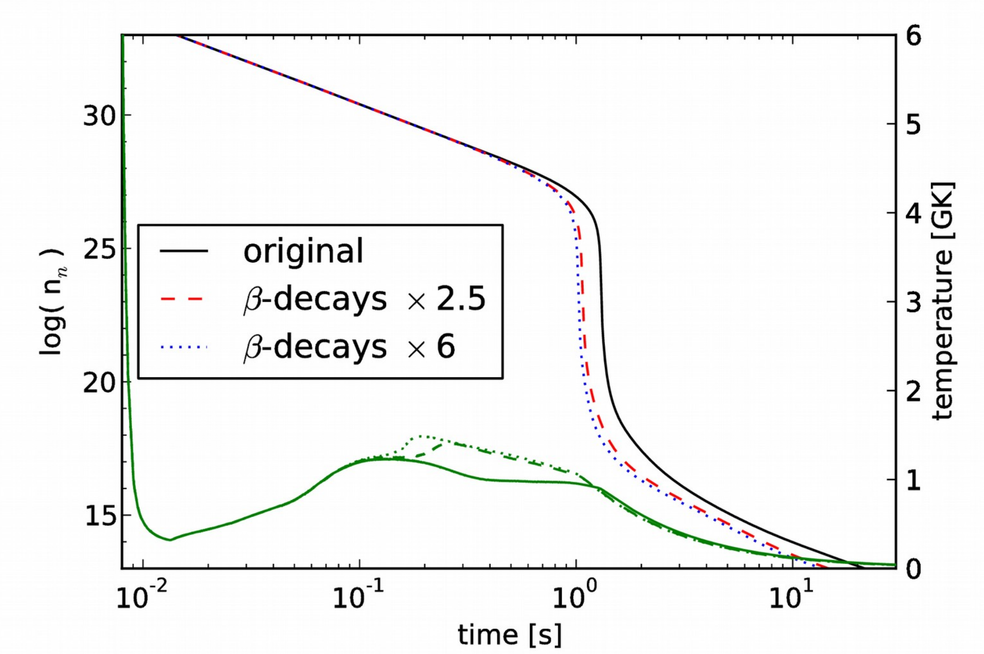
β-decays enhanced after last fission cycle because very neutron rich fission fragments are produced

The Position of the 3rd Peak



- β-decays of Z > 80 nuclei accelerated by factors of 2.5 and 6
- FRDM (1992)

- fission neutrons from the last fission cycle enforce neutron captures
- affects mainly third peak and rare earths



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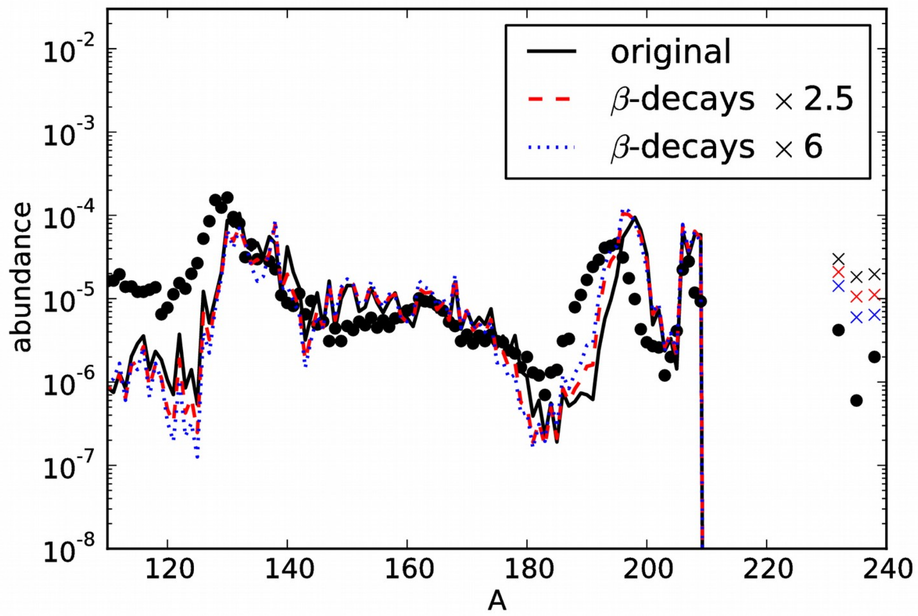
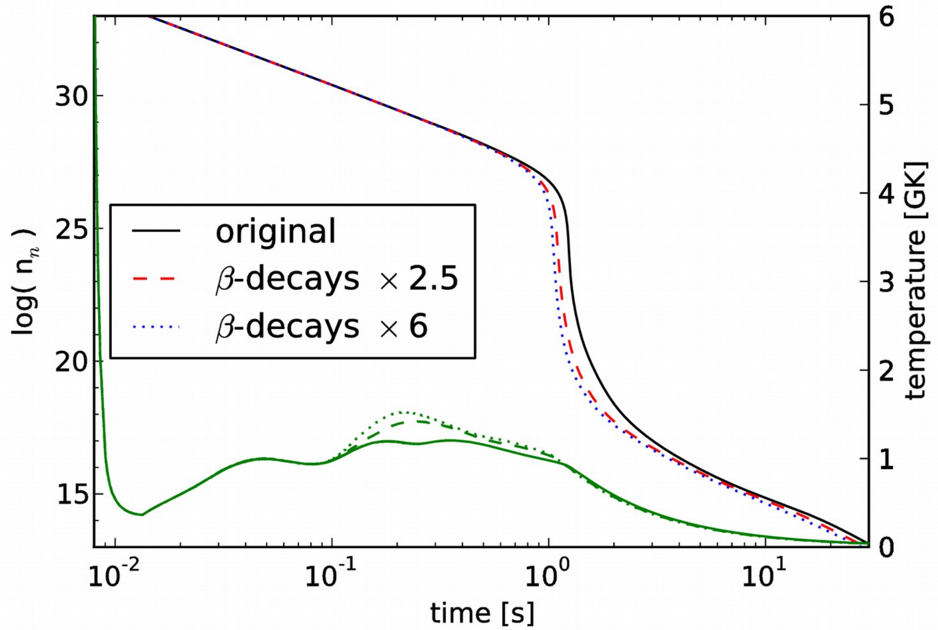
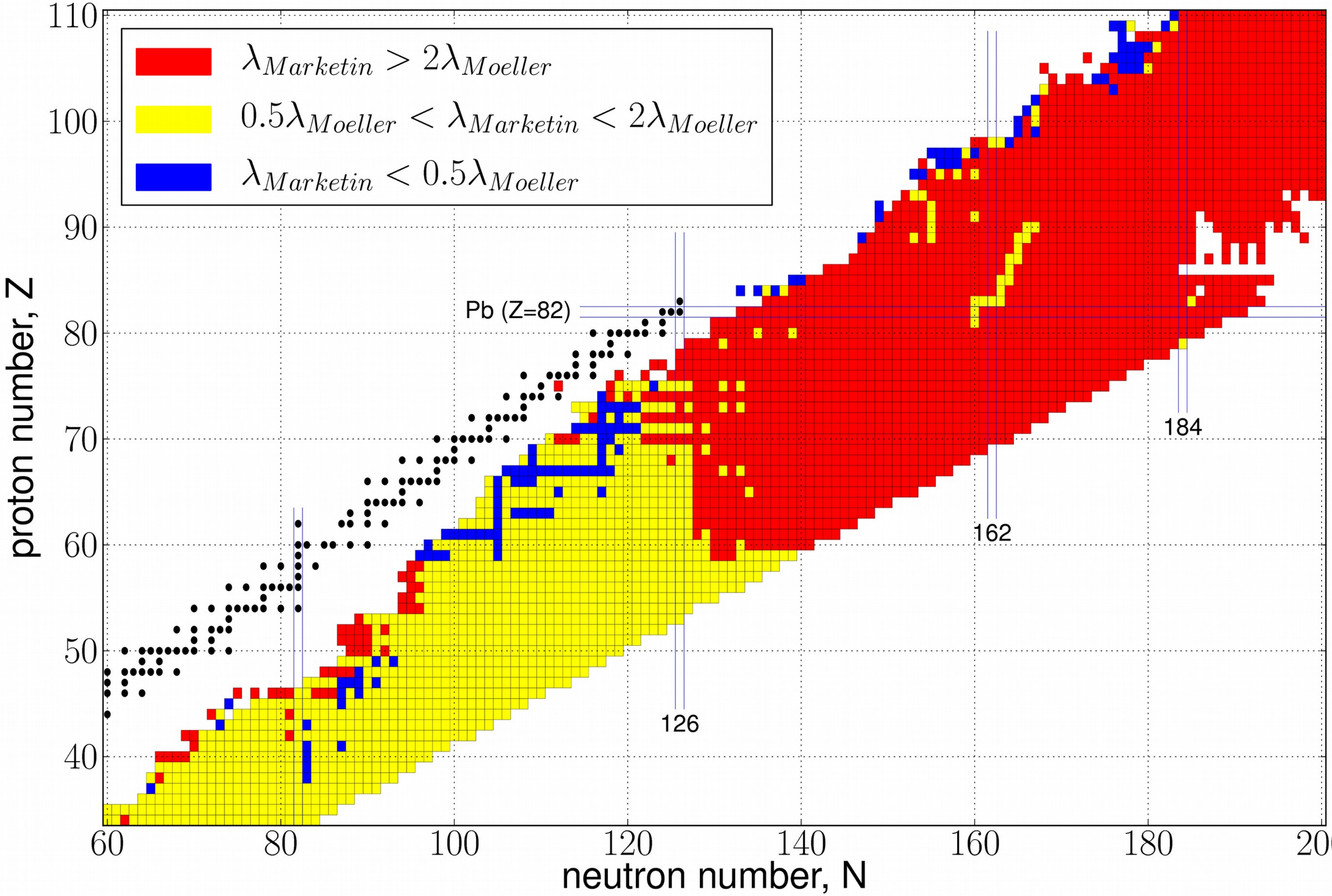


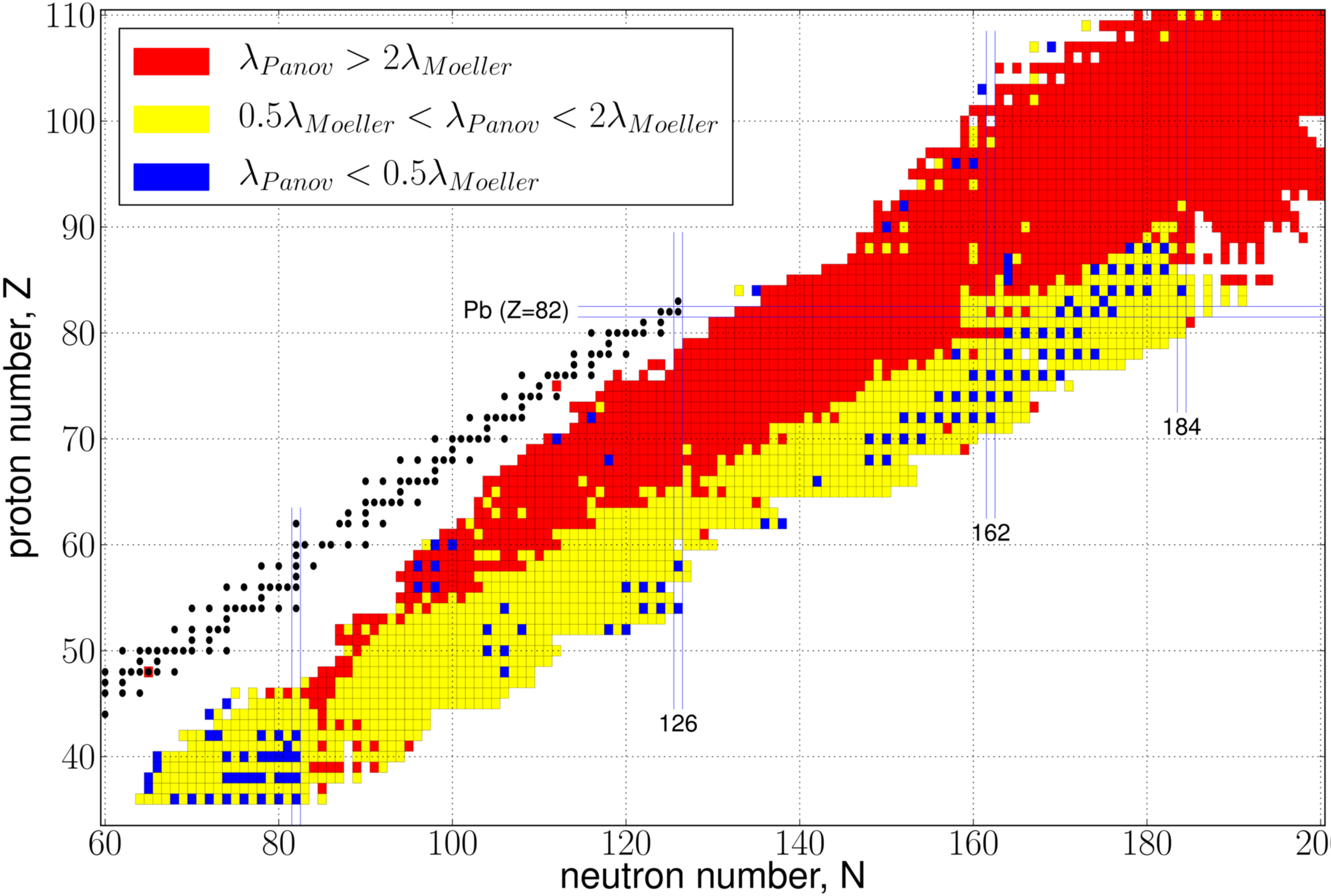
- β-decays of Z > 80 nuclei accelerated by factors of 2.5 and 6
- HFB-14



New Sets of Beta-Decay Rates: Marketin et al. 2015



New Sets of Beta-Decay Rates: Panov et al. 2015



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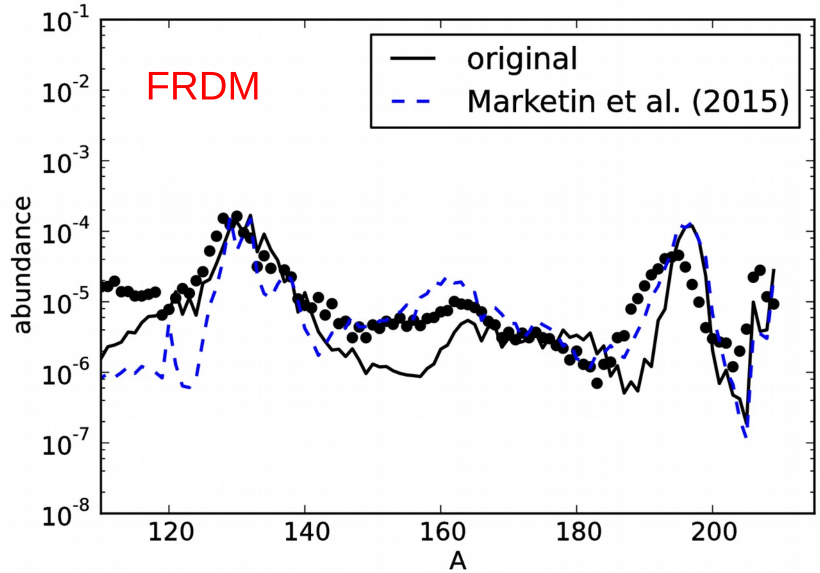

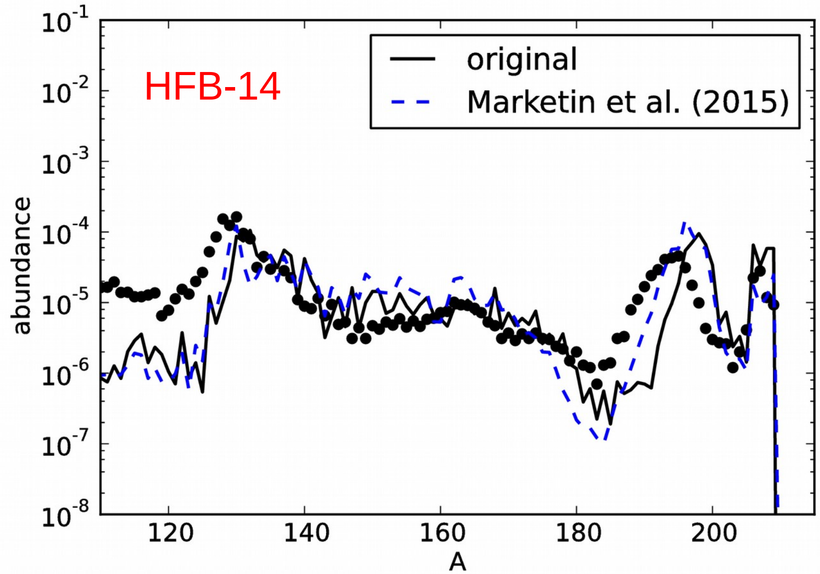

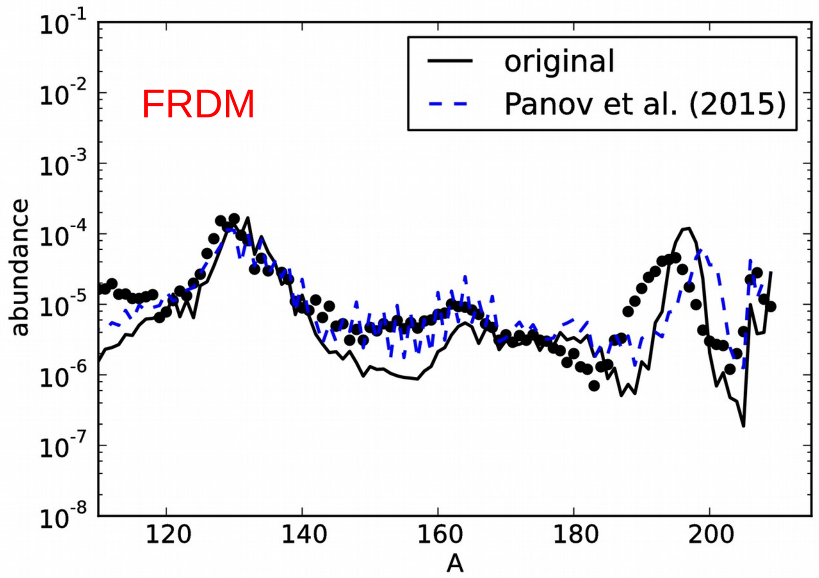

original: Möller et al. 2003

Summary

- after freeze-out, the abundance features can still be changed by several processes (e.g., neutron captures, fission)
- in our NSM calculations, the third peak is shifted towards heavier nuclei due to neutron captures after the r-process freeze-out
  - fission neutrons from last fission cycle
- β-decays have a large influence on the global abundance distribution (also indirectly, i.e., by influencing the timing of the release of fission neutrons)

Fission reactions are fundamental in shaping the r-process abundance pattern from the second peak onwards

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