Global effects of beta decay on r-process nucleosynthesis

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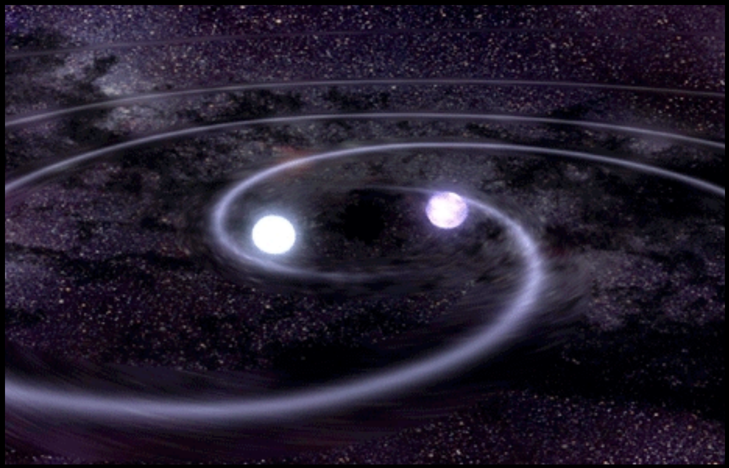
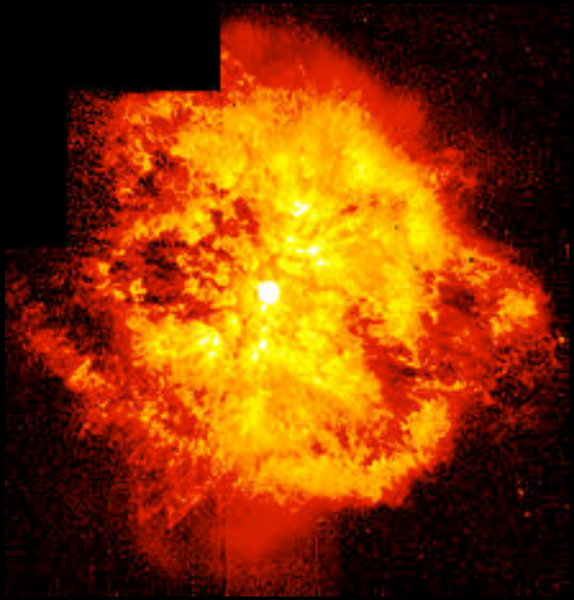
r-process sites

Mergers: NS-NS, BH- NS

Decompression of cold NS matter
(Lattimer et al 1974, Freiburghaus et al 1999, Metzger et al 2010)

Hot matter ejected from accretion disk (e.g Surman et al 2008 , Wanajo & Janka 2012)





Supernovae

Neutrino-driven winds

Nuclear Physics Input: r-process network

(Arcones & Martínez-Pinedo 2011)

- Mass model
- Neutron captures
- Photodissociation
- Beta decay
- Alpha decay
- Fission
- Beta-delayed neutron emission

Beta decay of r-process waiting-point nuclei in a self-consistent approach

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(February 19 1999)

Beta decay and the *r*-process

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pieces of nuclear data for calculations of
ances that have pushed measurement ca-
it the role of individual beta decay rates
consider hot *r*-processes characterized by
-processes where (n,γ)-(γ,n) equilibrium
n each of these scenarios whose beta de-
cess abundance pattern and describe the

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New Half-lives of *r*-process Zn and Ga Isotopes Measured with Electromagnetic Separation

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The Astrophysical Journal, 606:1057–1069, 2004 May 10

THE *r*-PROCESS IN SUPERNOVAE: IMPACT OF NEW MICROSCOPIC MASS FORMULAE

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Received 2003 November 10; accepted 2004 January 23

PHYSICAL REVIEW C **85**, 048801 (2012)

Impact of new β-decay half-lives on *r*-process nucleosynthesis

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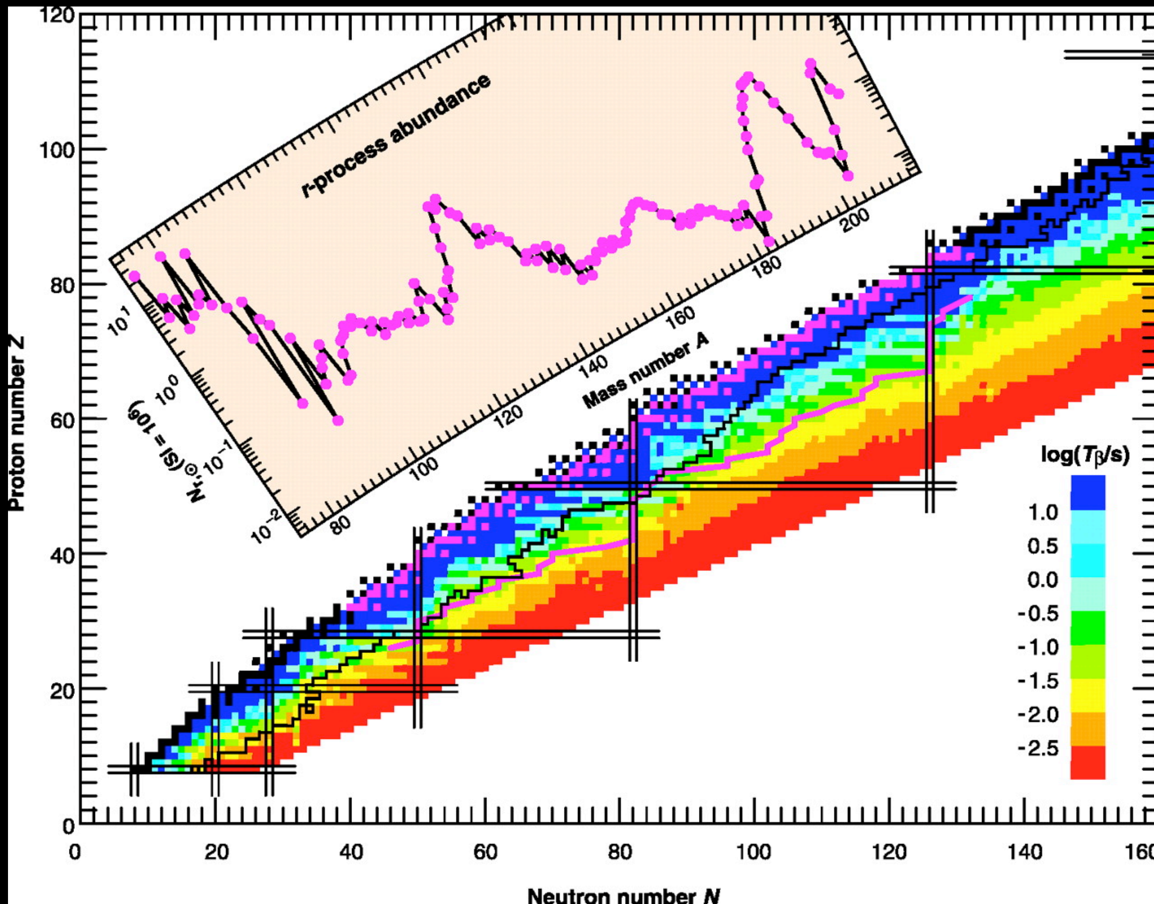
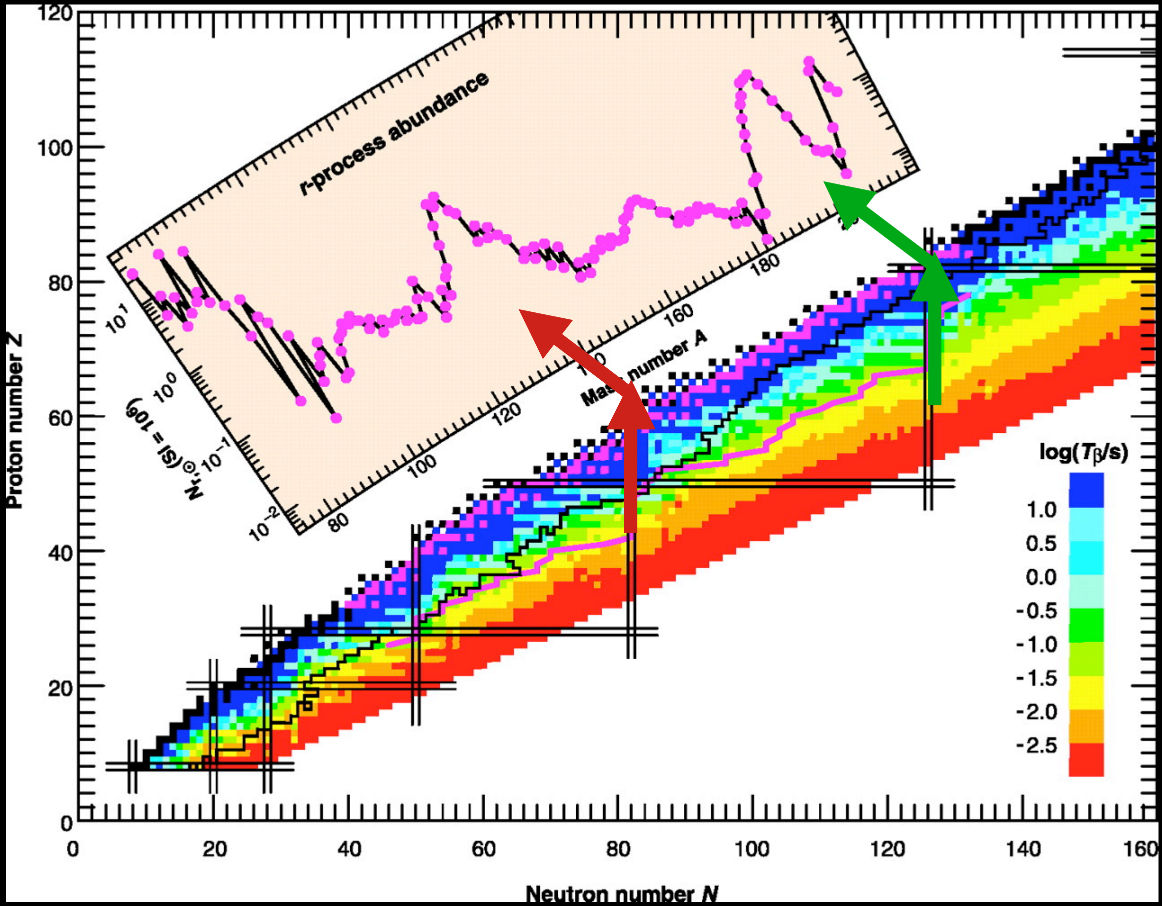
(Received 21 February 2012; published 4 April 2012)



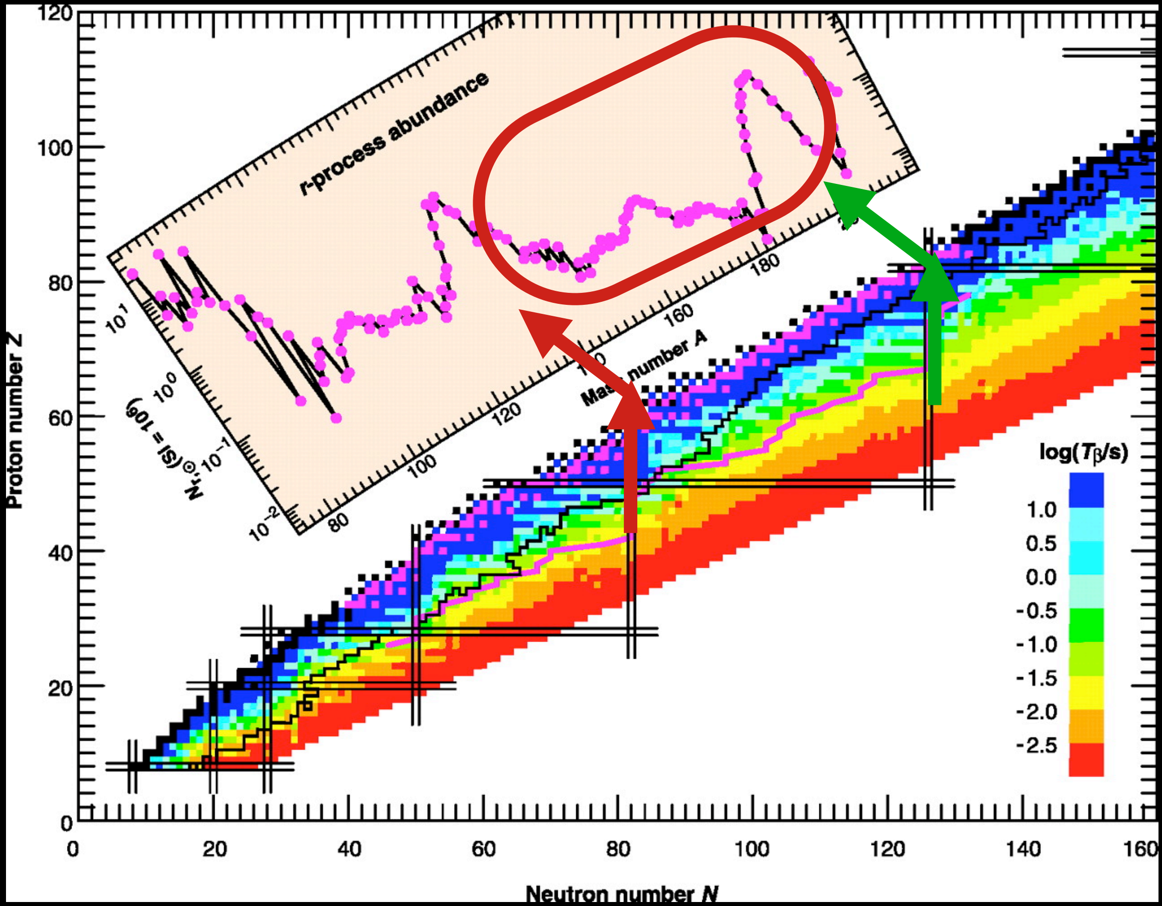
(P. Moeller et al 2003)



(P. Moeller et al 2003)

Local: affects the abundances of the region where new rates are introduced.

Global: affects abundances in other regions.



(P. Moeller et al 2003)

Local: affects the abundances of the region where new rates are introduced.

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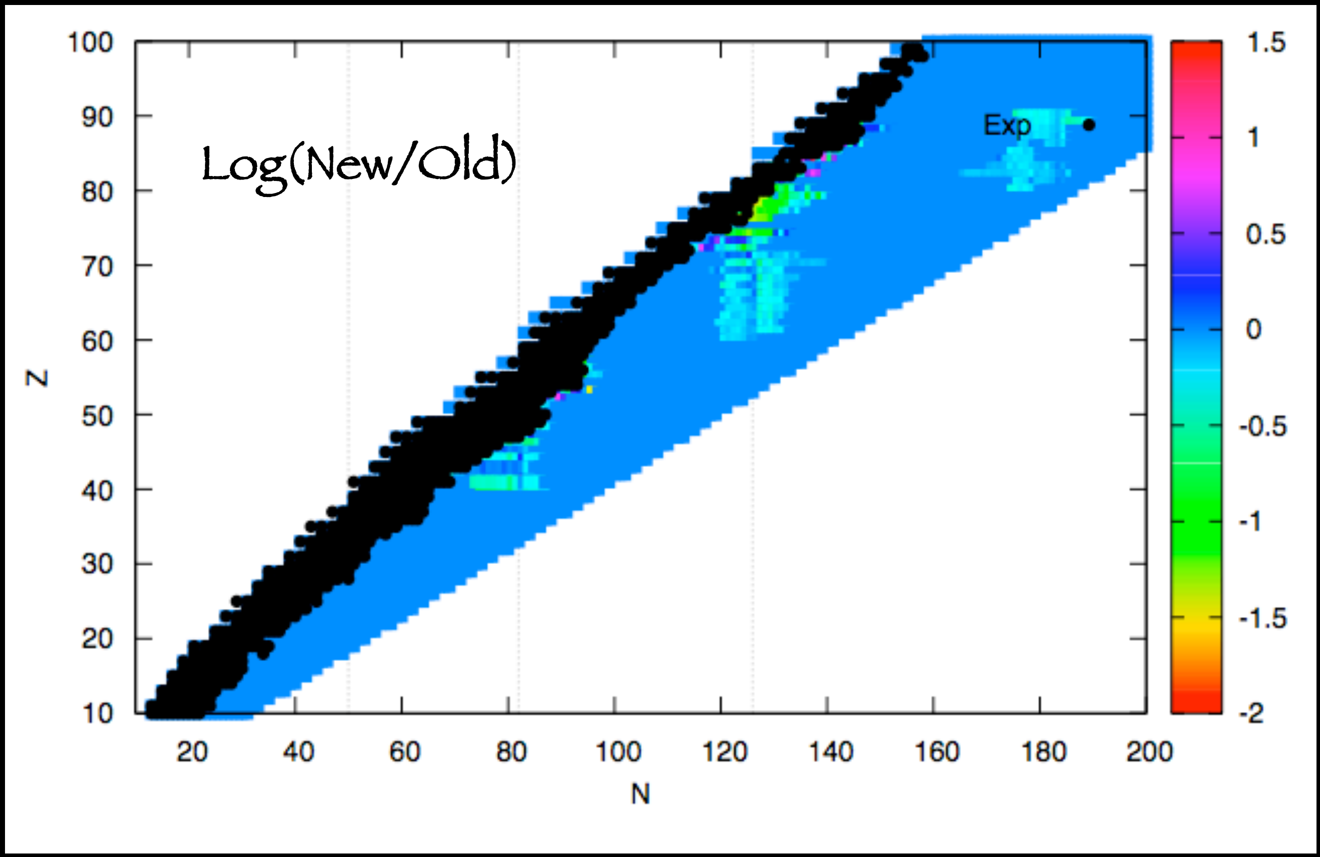
Beta decay rates

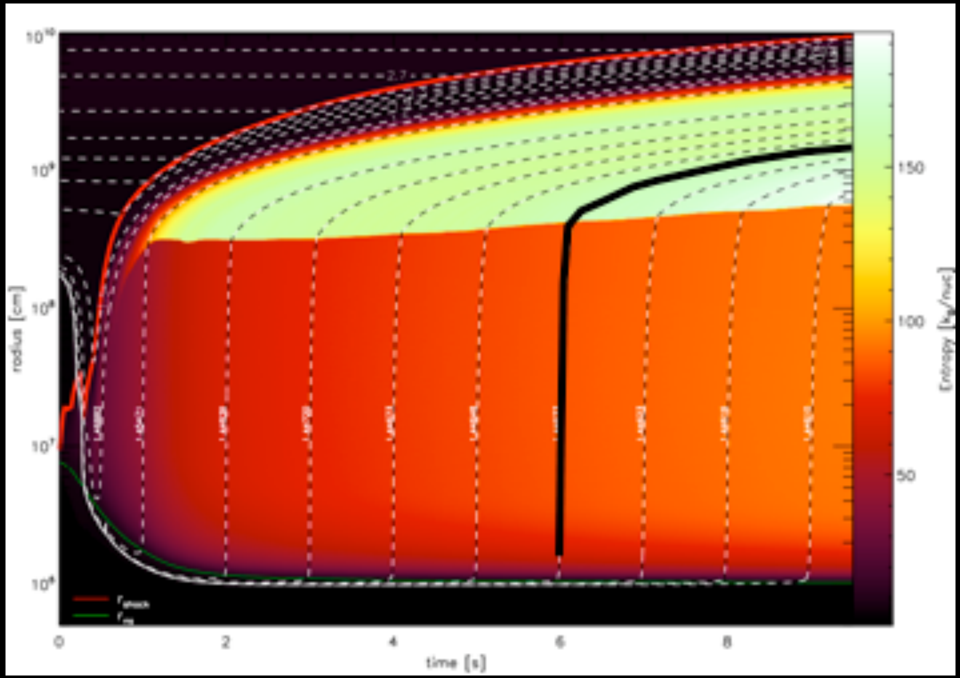


Old: Peter Moeller 2003 (Finite Range Drop Model+QRPA)

New: Ivan Borzov 2011 (Density Functional Theory+QRPA)

Neutrino-driven wind

- Spherically symmetric hydrodynamical simulation (A. Arcones & H. -Th Janka, L. Scheck (2007))
- Progenitor: 15 solar-mass star
- Entropy increased to obtain a successful r-process (Arcones & Martínez-Pinedo (2011))
- Entropy ≈ 200 k_B/nuc
- $Y_n/Y_{seed} \approx 70$
- $Y_e \approx 0.47$



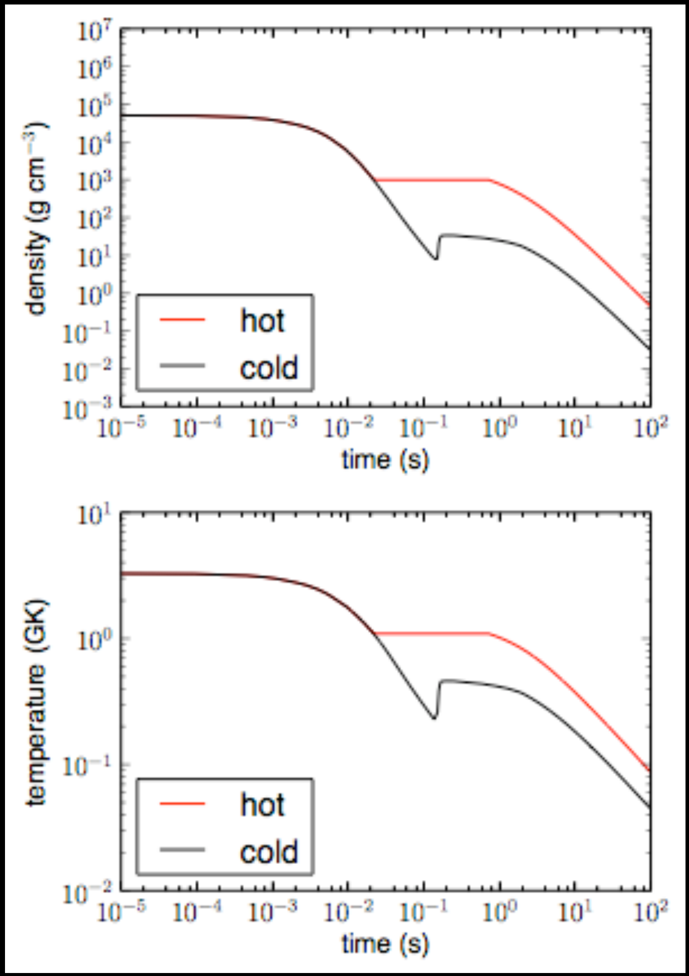
Neutrino-driven wind

Hot r-process: evolution takes place under

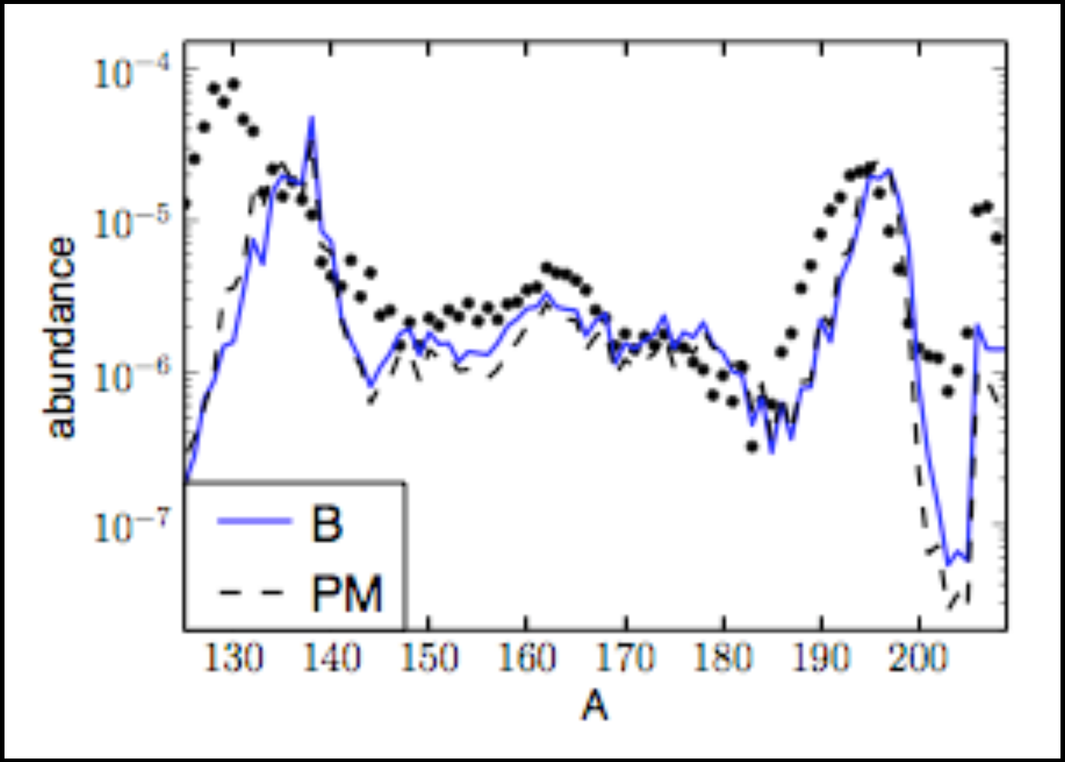
$$(n\gamma) \leftrightarrow (\gamma n)$$

equilibrium. Classical r-process (Seeger, Fowler & Clayton 1965, Kratz et al 1993)

Cold r-process: n-capture and β-decay competition (Blake & Schramm 1976, Wanajo 2007, Janka & Panov 2009)



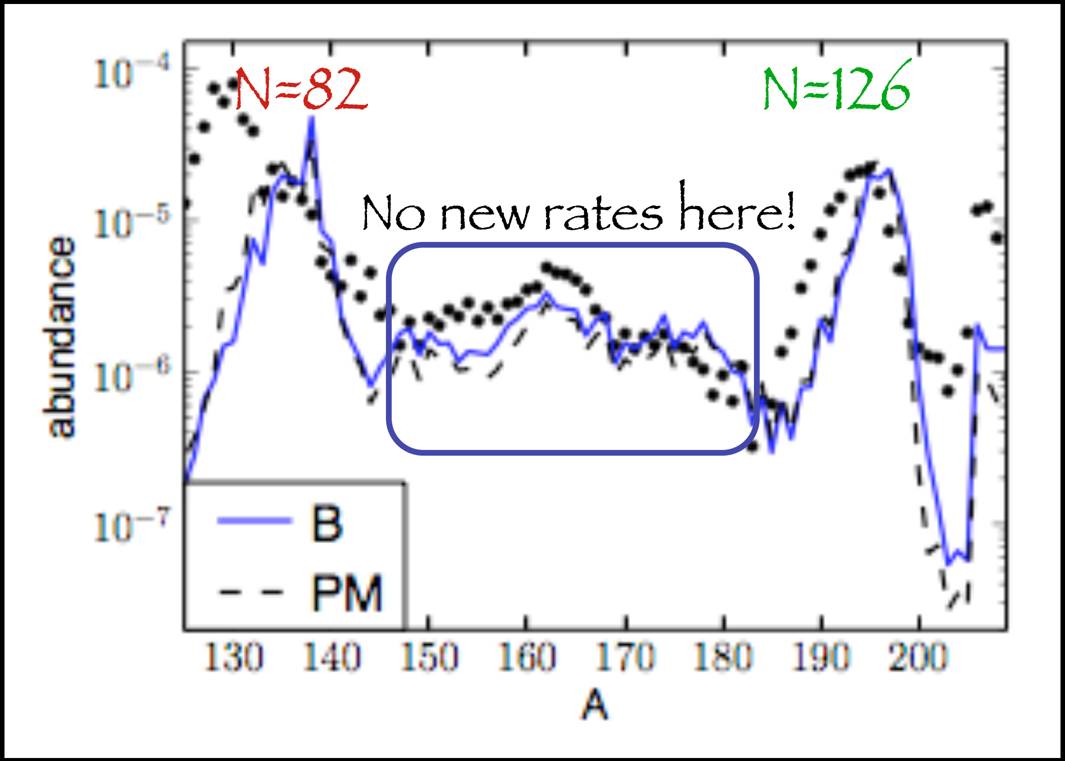
Neutrino-driven wind: Cold r-process



B= New rates

PM= Old rates

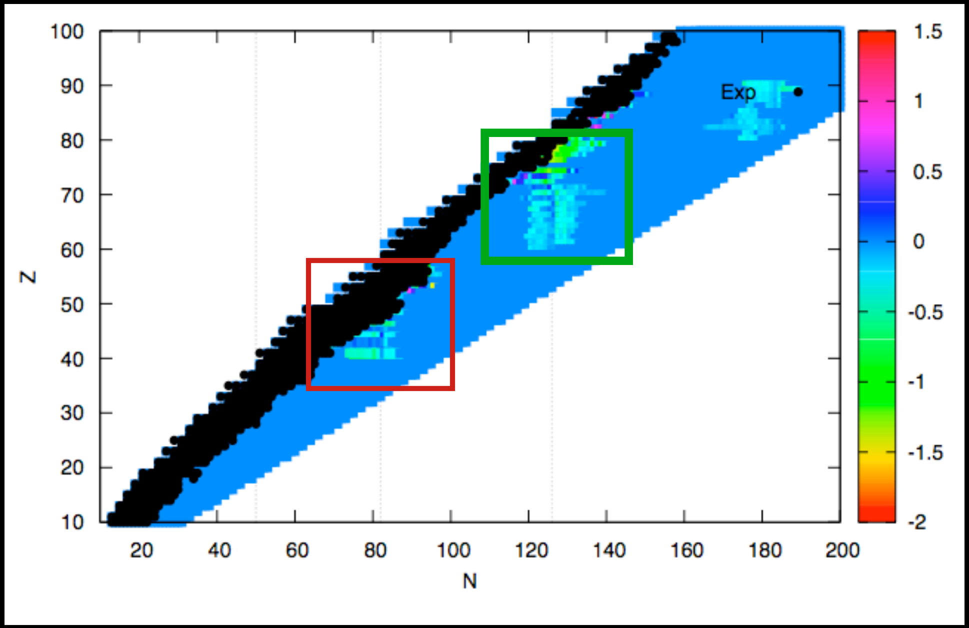
Neutrino-driven wind: Cold r-process



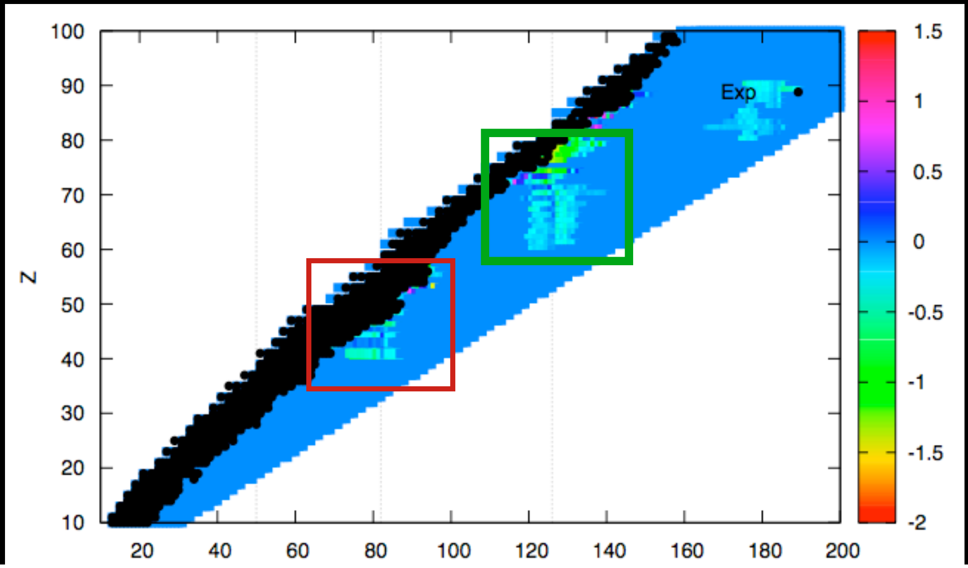
B= New rates

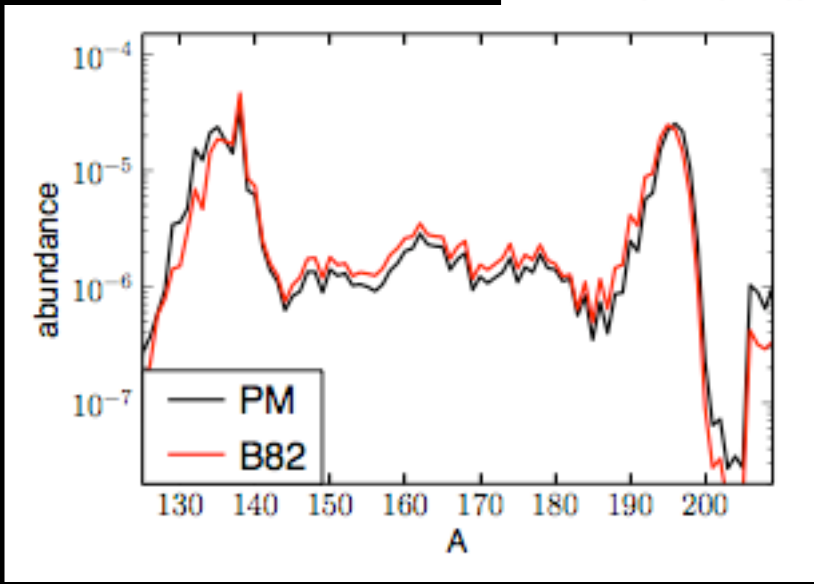
PM= Old rates

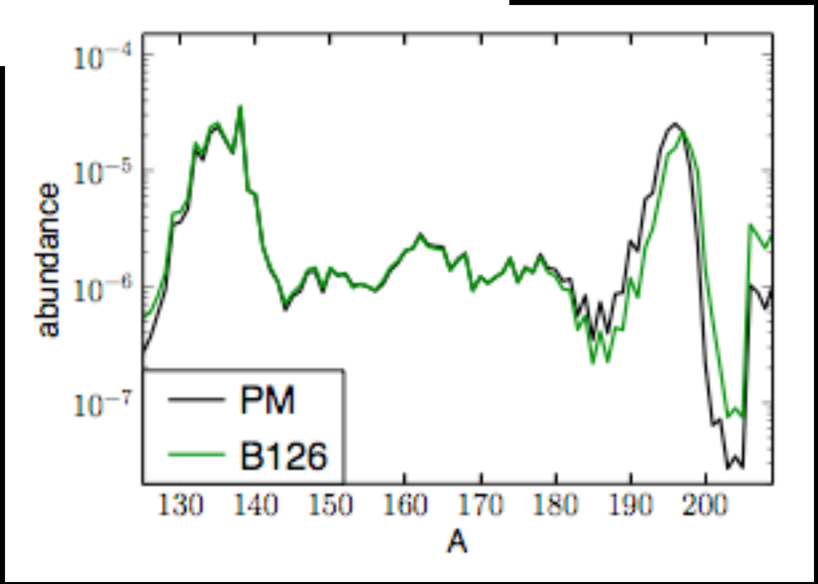
Neutrino-driven wind, cold r-process, split rates



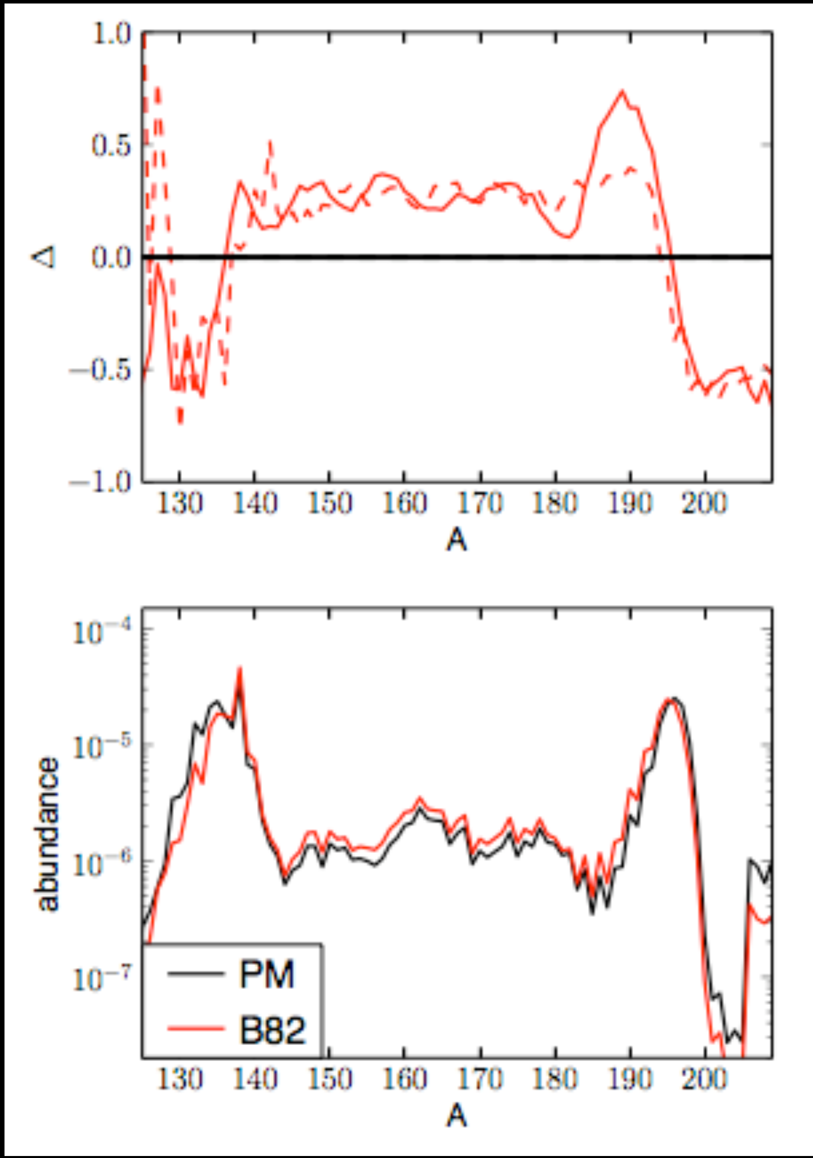
Neutrino-driven wind, cold r-process, split rates







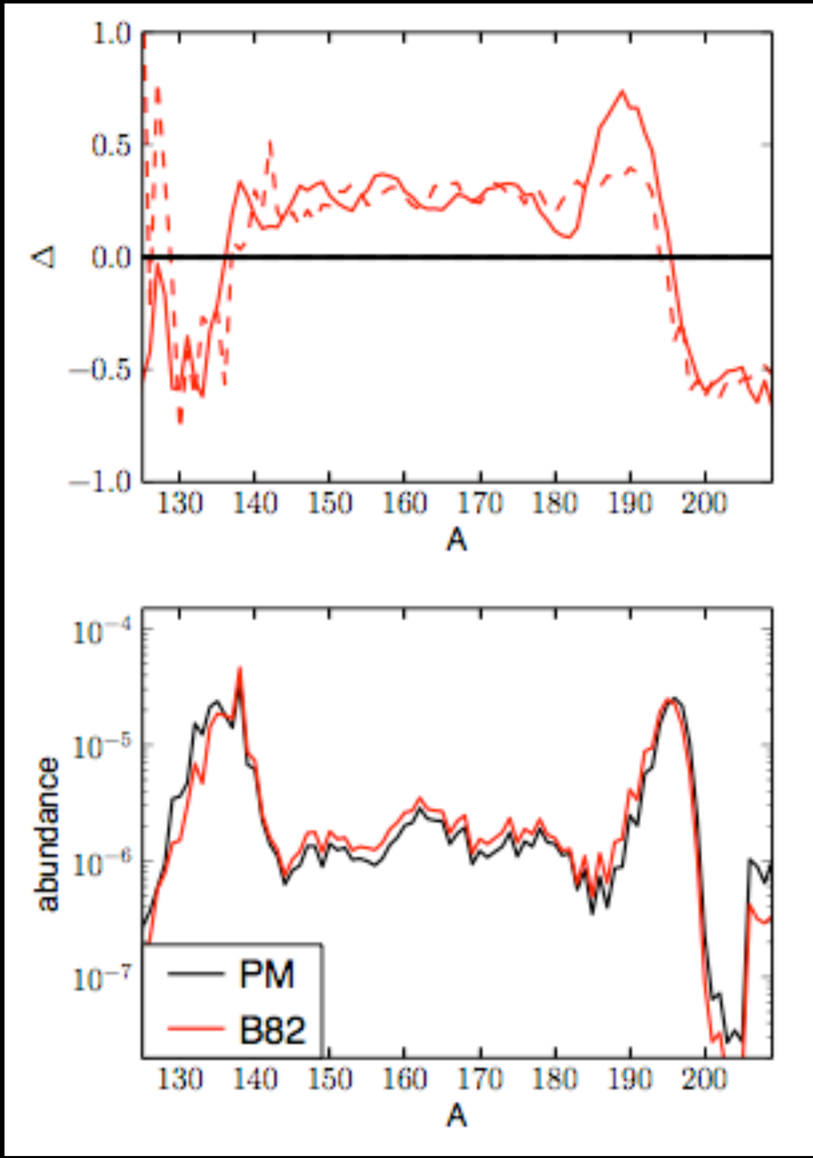
Split rates : N=82 region

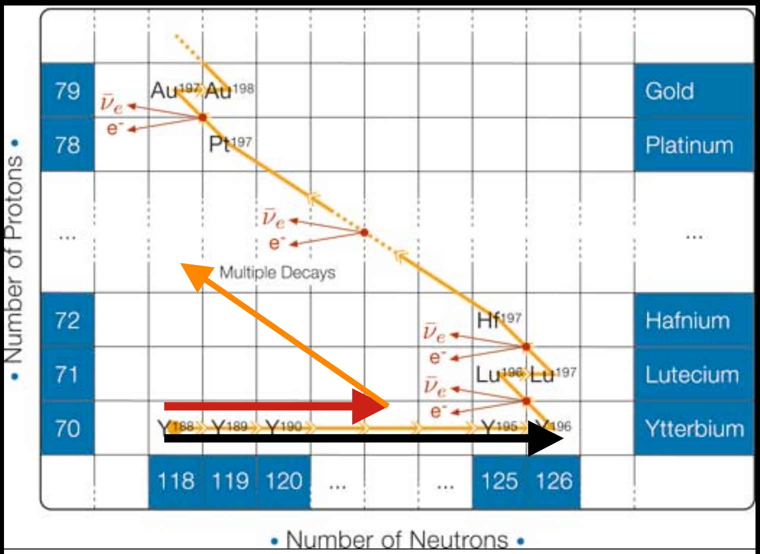


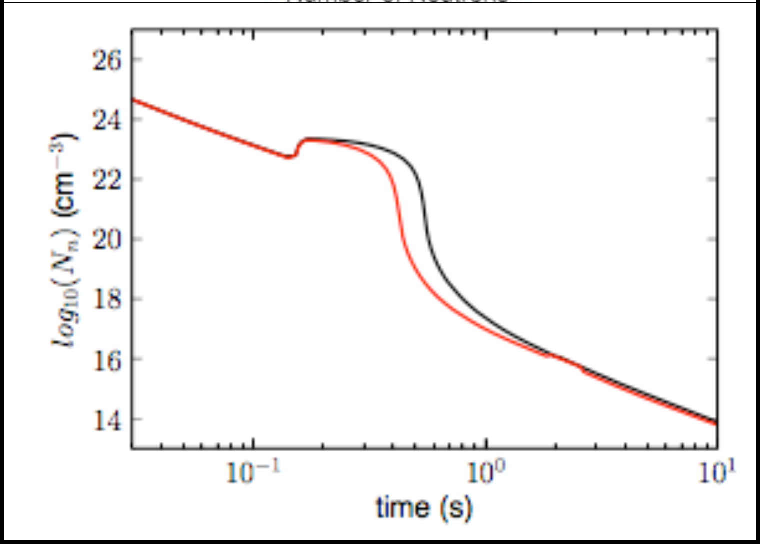
$$\Delta = \frac{Y_B - Y_{PM}}{Y_{PM}}$$

B82: reduced abundances in the 2nd peak region, larger after that. Shift of the third peak.

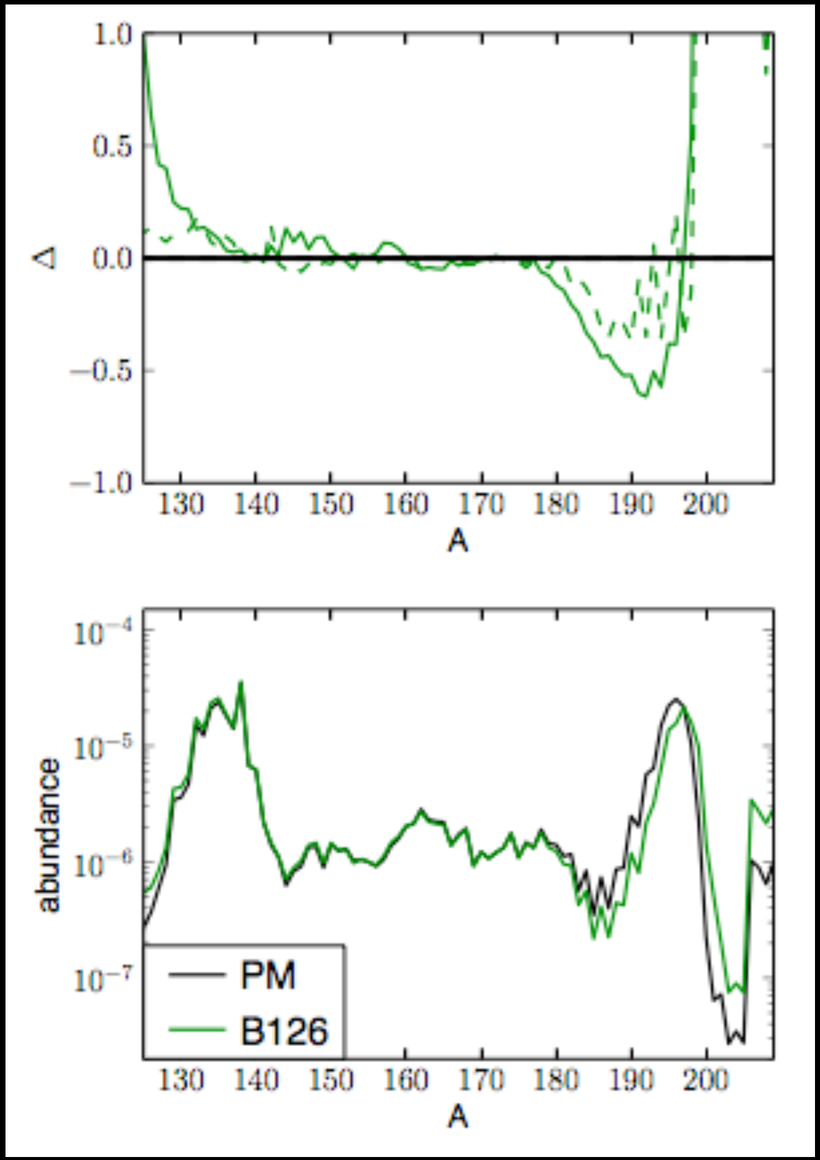
Split rates : N=82 region





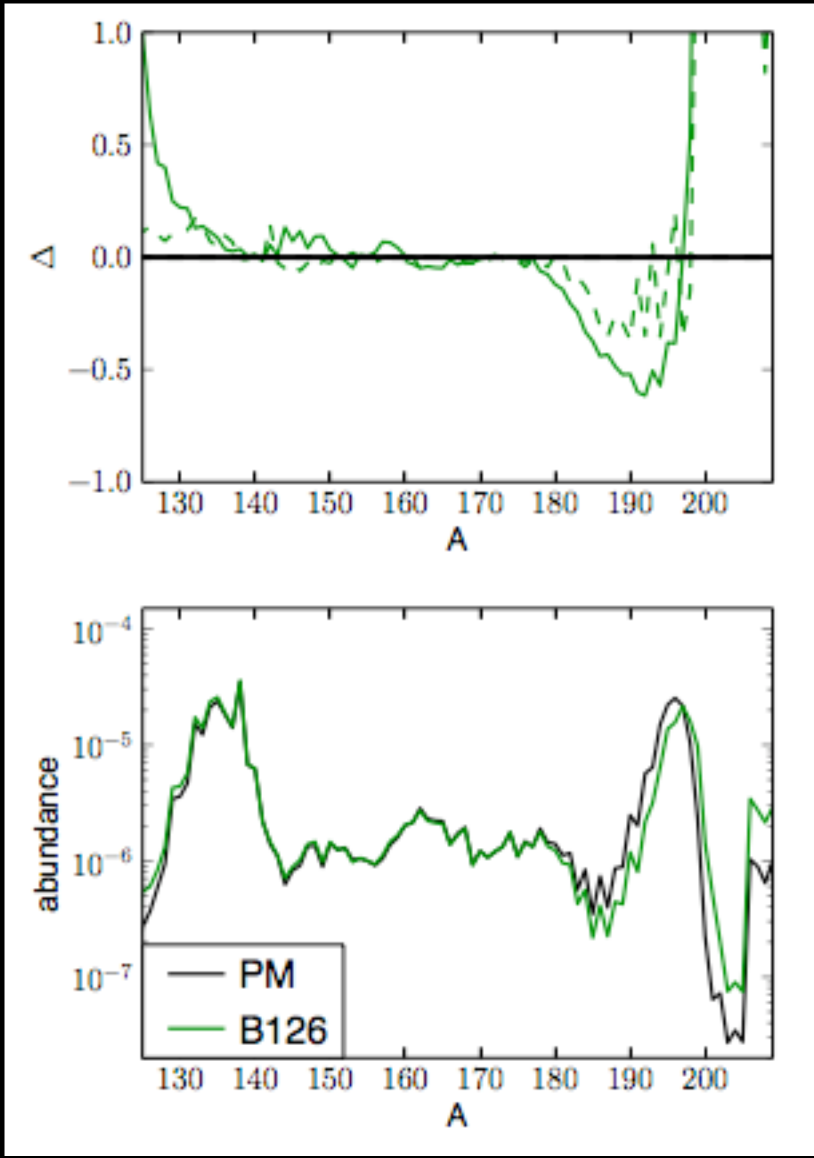


Split rates : N=126 region

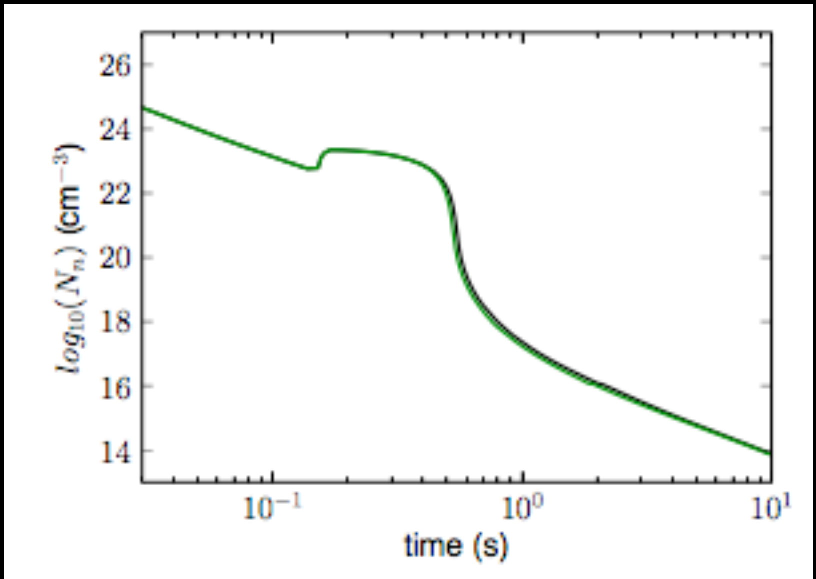


B126: smaller abundances in the 3rd peak region. Larger abundances in the 2nd peak.

Split rates : N=126 region



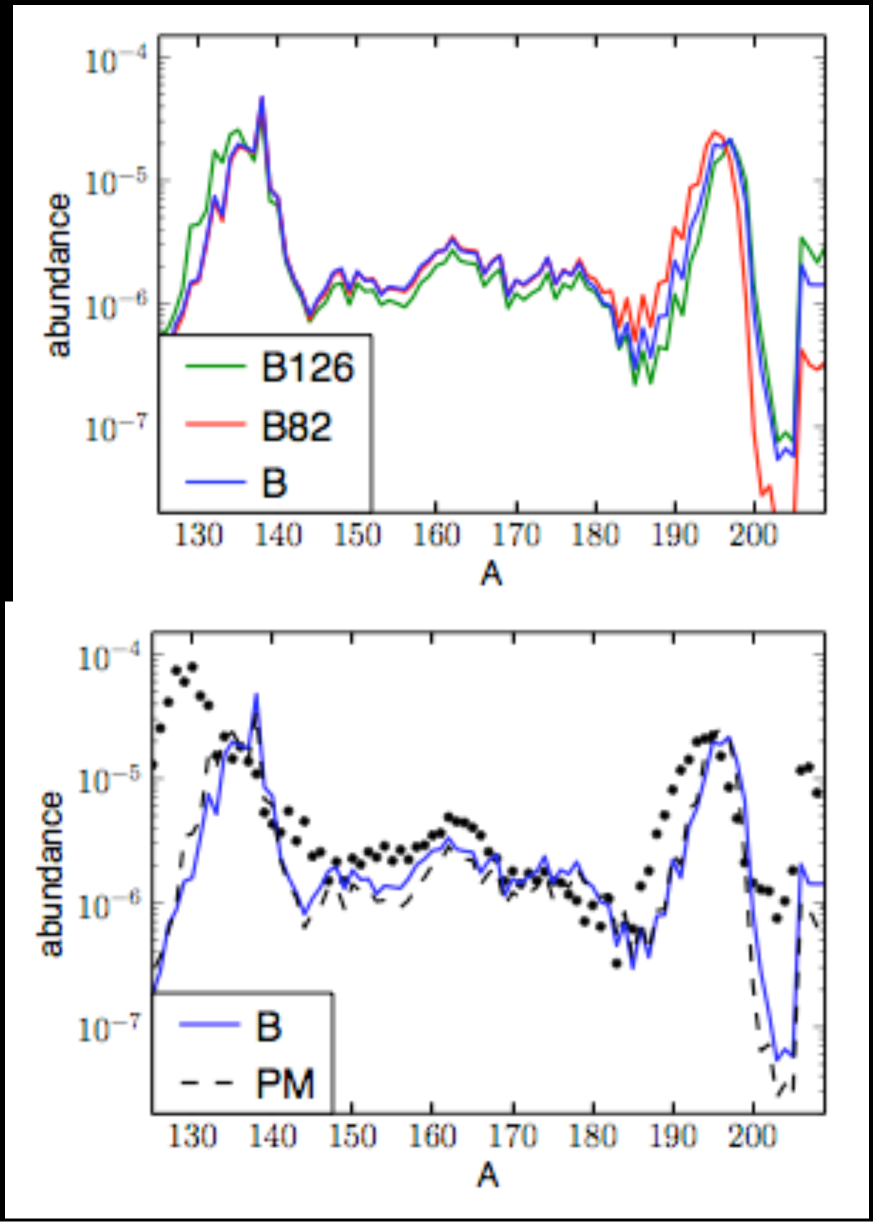
B126: smaller abundances in the 3rd peak region. Larger abundances in the 2nd peak.



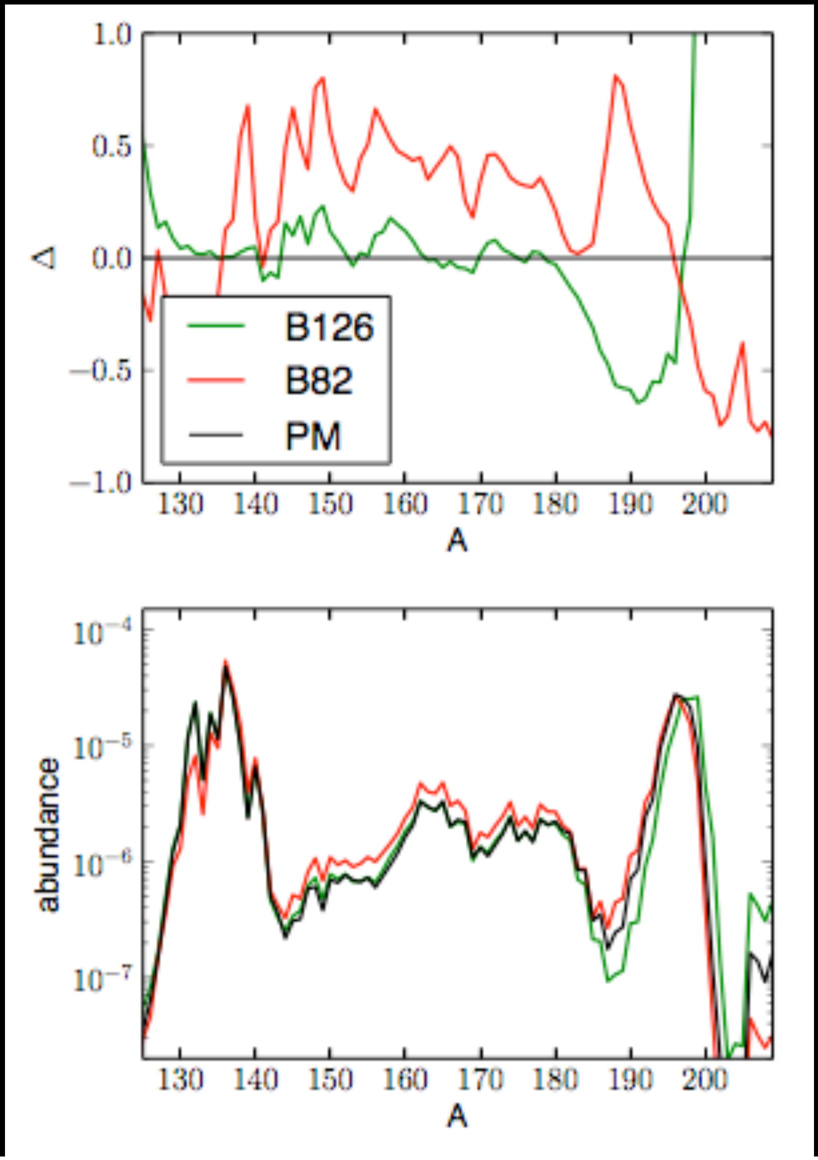
Cold process: neutrino-driven wind

Local effect : faster flow of matter

Global effect: changes in neutron density



Hot r-process: neutrino-driven wind



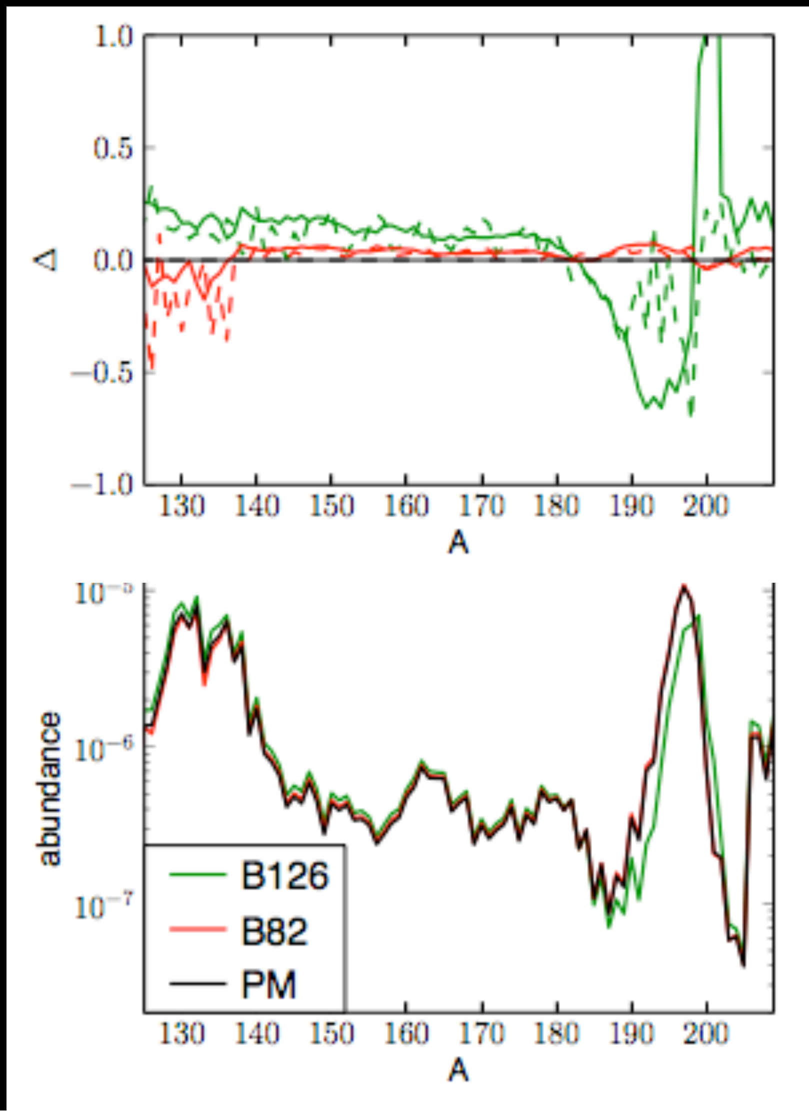
B82: smaller abundances in the 2nd peak region, larger after that. Shift of the third peak.

B126: smaller abundances in the 3rd peak region. Minor global effects.

Beta decay is less important than photodissociation and neutron captures.

Neutrino-driven wind : high Y_n/Y_{seed}

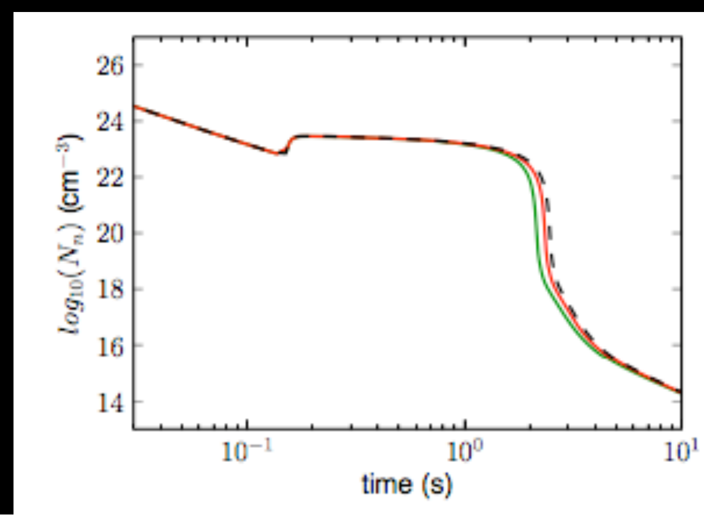
Entropy 250 k_B/nuc, cold r-process



B82 :very small local and global impact.

Very neutron-rich conditions. Path does not reach the new rates.

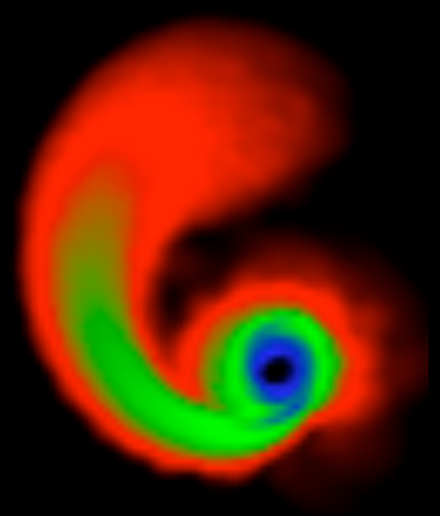
B126: strong global effect. Changes in neutron density.



Neutron Star merger

Hydrodynamical simulation

(O. Korobkin et al 2012)

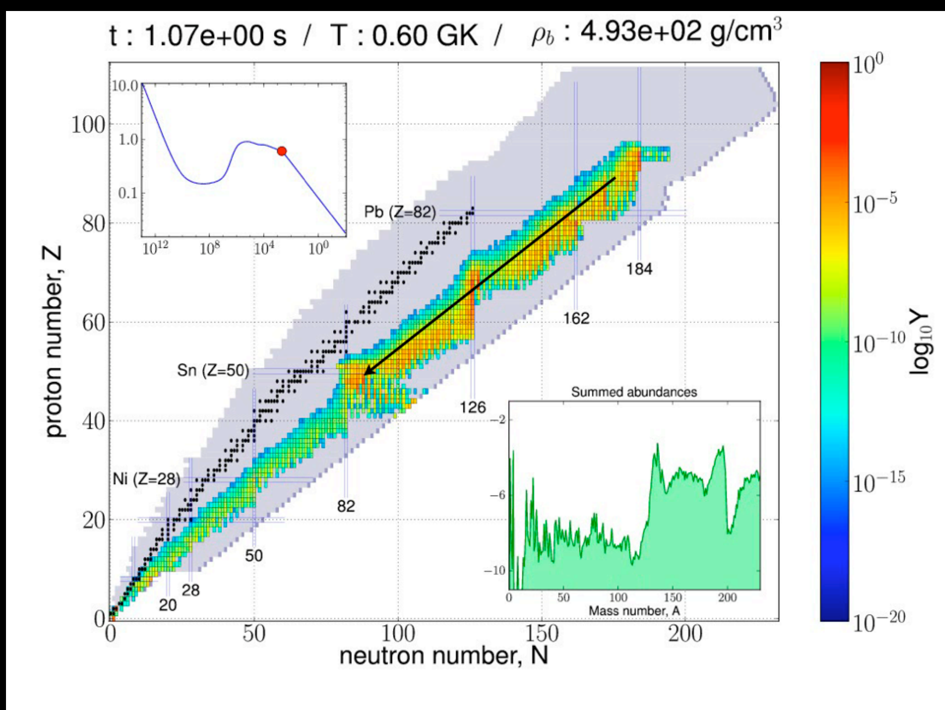


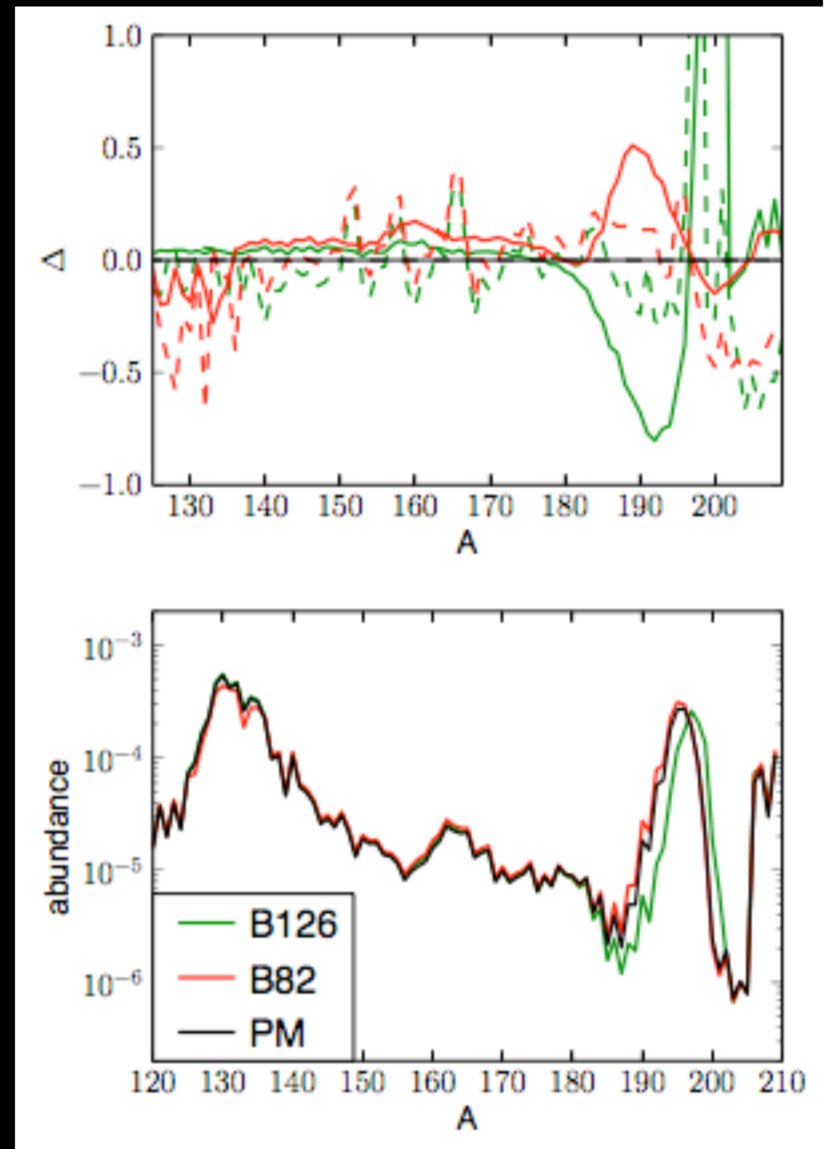
Ye≈0.04

NS-NS

1.4 solar-mass

Neutron star merger





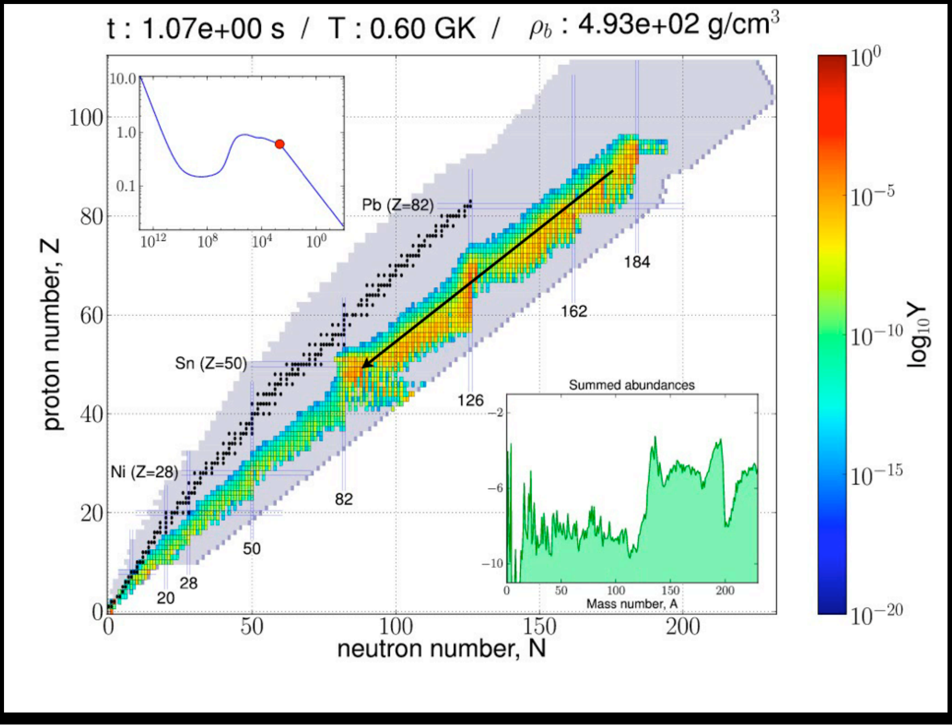
Neutron star merger

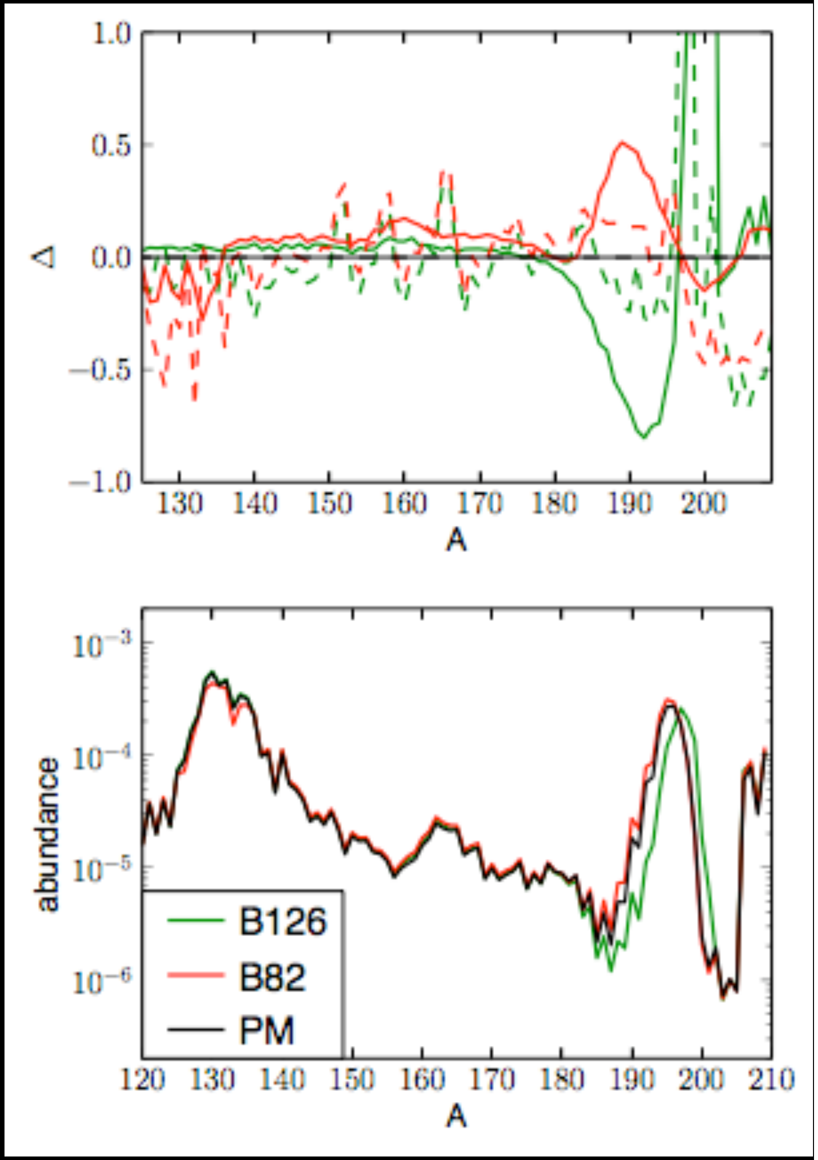
B82

Small local changes.

Initial path is on the neutron drip line and does not pass by the new rates.

Fission keeps bringing matter to the N=82 region making the process faster.





Neutron star merger

B82

Small local changes.

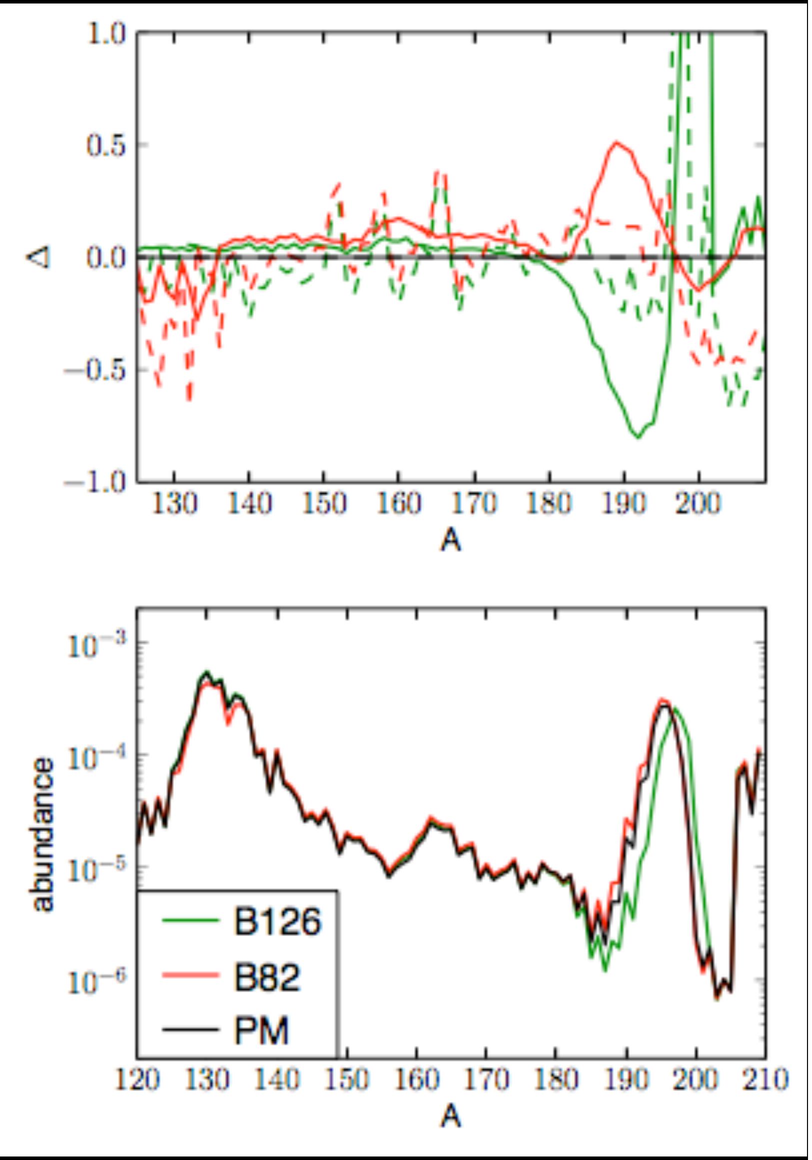
Initial path is on the neutron drip line and does not pass by the new rates.

Fission keeps bringing matter to the N=82 region making the process faster.

B126

Fission does not affect the third peak: large local effect.

Fission time-scale changes.



Conclusions

Changes introduced in beta decay rates have local and global effects on the final abundances of the r-process.

Local effect: impact the abundances where new rates are used

Global effect: influences the speed at which neutrons are consumed and the amount of neutrons available during decay to stability.

The strength of the local and global effects depend on the astrophysical conditions and the rates themselves.

Global and local effects are present regardless of the astrophysical environment.

To do: Theoretical rates

To do: Experimental rates needed