31 gennaio 2019 - PANDORA meeting

^{87}Rb ^{176}Lu ^{26}Al ^{7}Li ^{85}Kr ^{187}Re

Prospettive in Astrofisica Nucleare

Sara Palmerini
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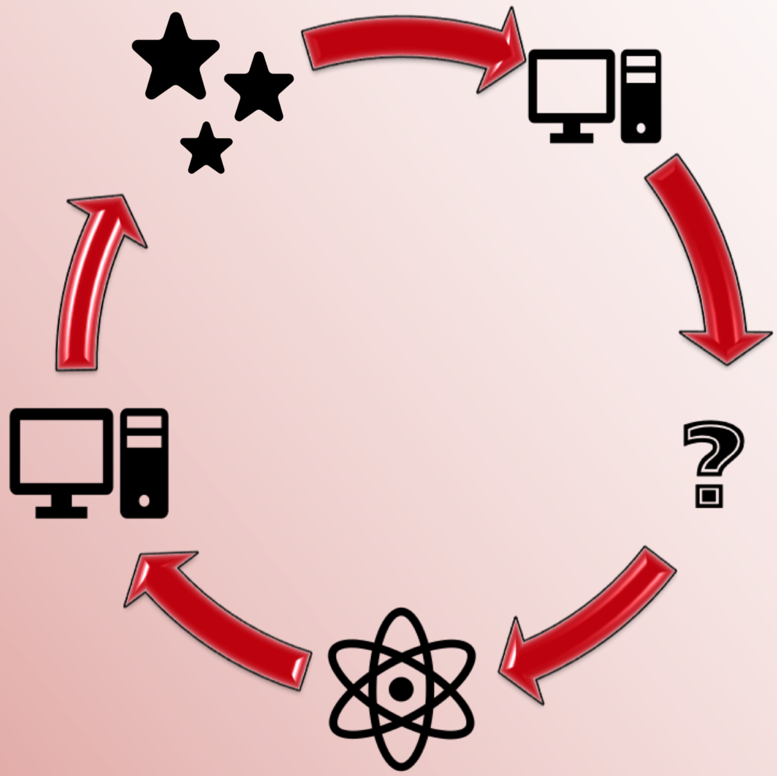
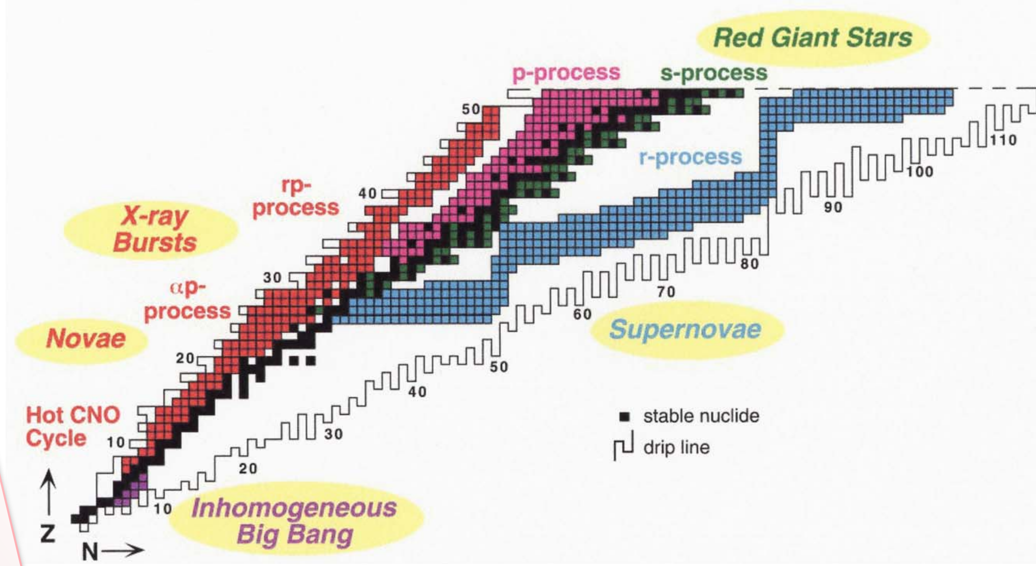
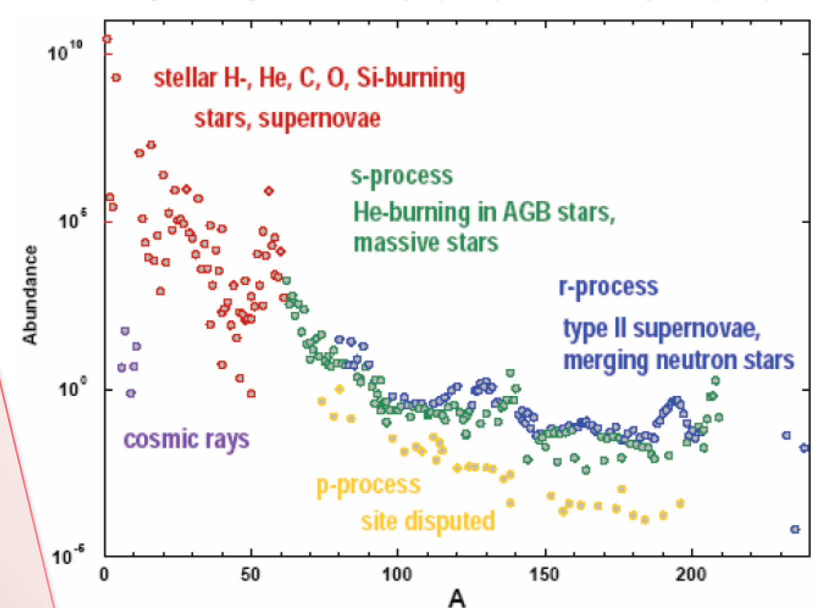
Astrofisica Nucleare





Burbidge, Burbidge, Fowler & Hoyle (B²FH): Rev. Mod. Phys. 29 (1957) 547



from: M. Wiescher, JINA lectures on Nuclear Astrophysics

31st January 2019 -PANDORA meeting

Prospettive in Astrofisica Nucleare:

- s-process branchings
- cosmocronometri
- opacità, r-process e NSM

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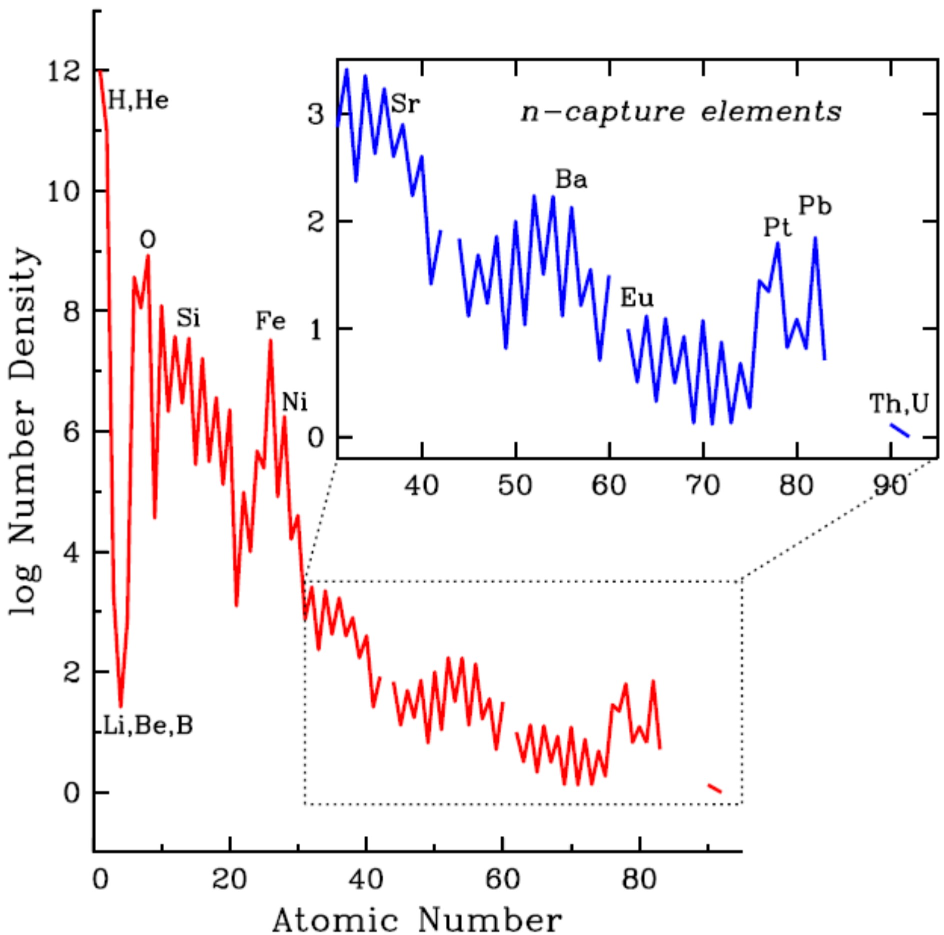
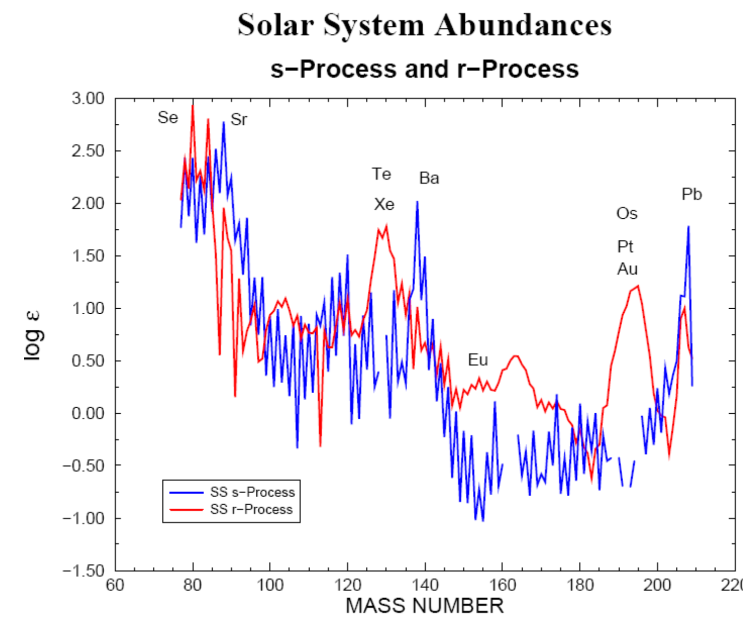
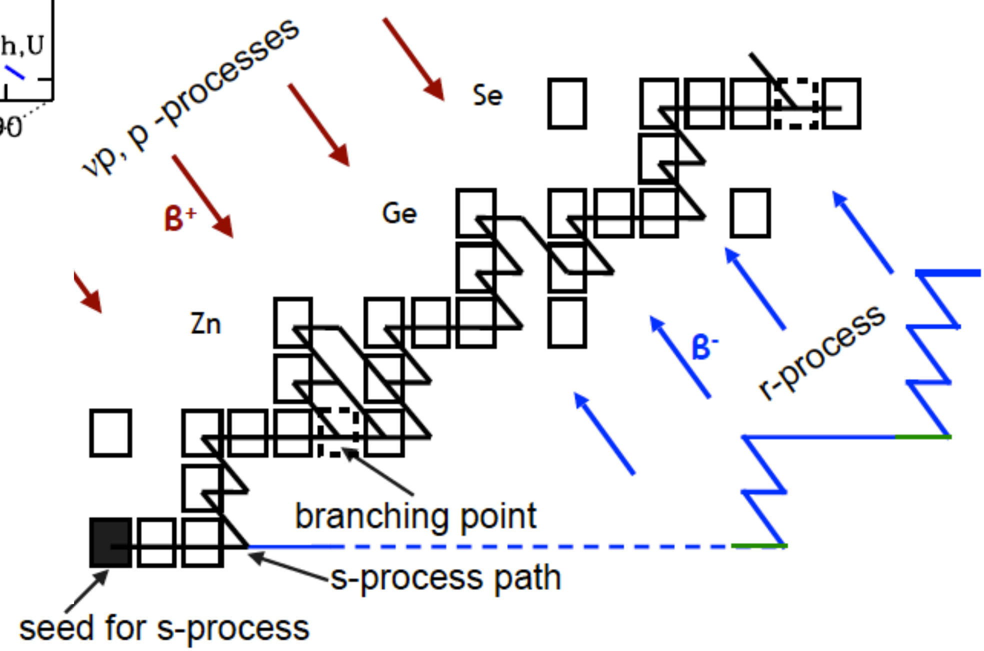
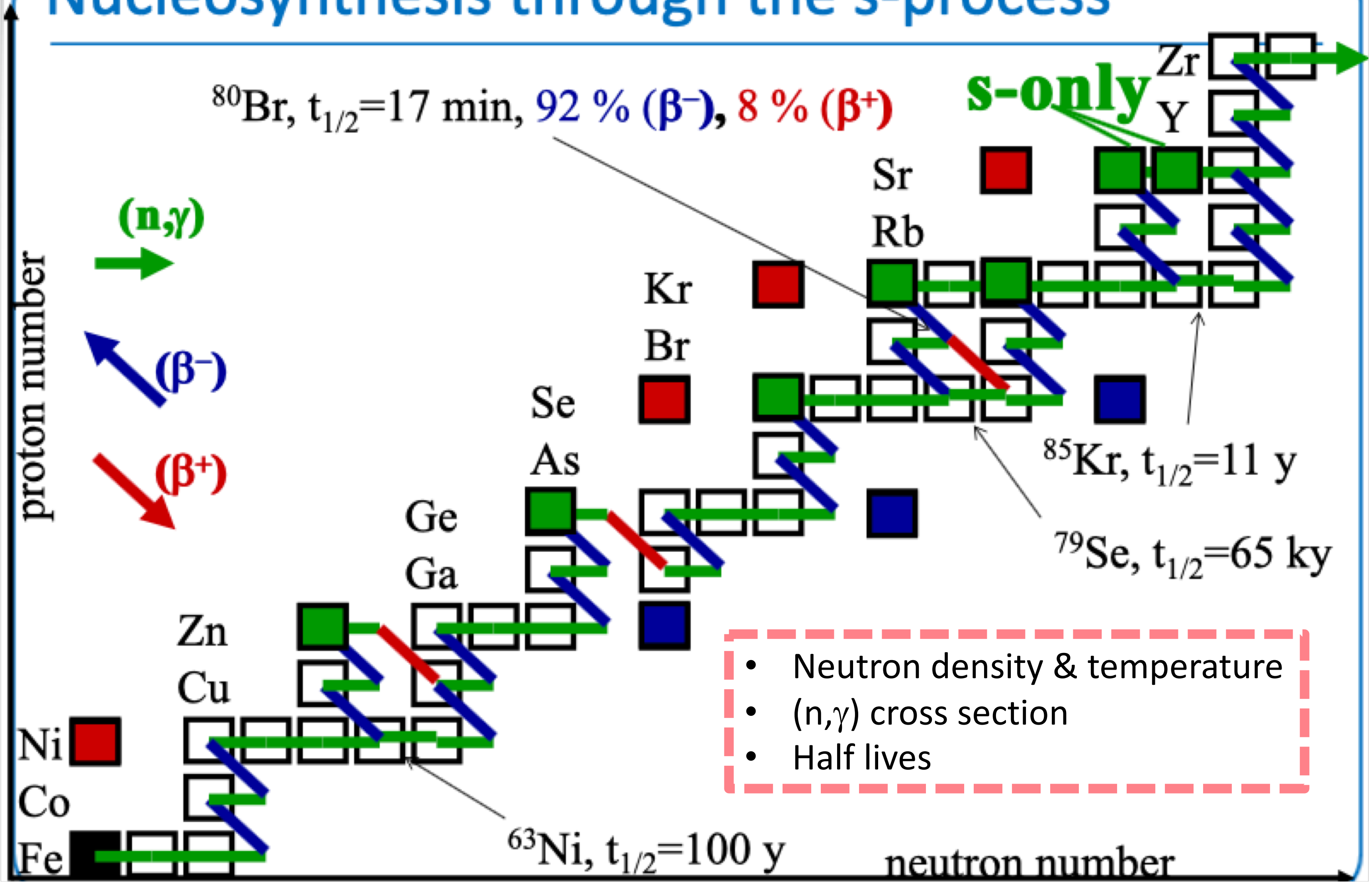
Production of heavy nuclei





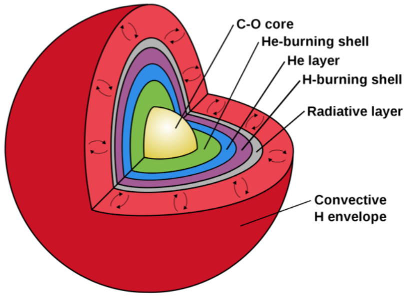


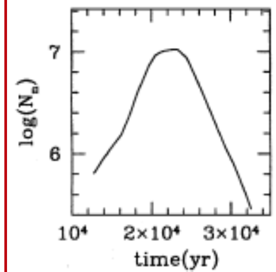
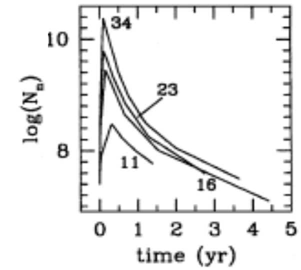
Nucleosynthesis through the s-process



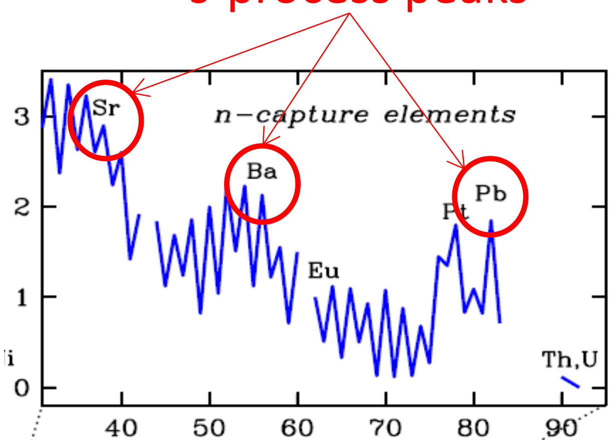
- Neutron density & temperature
- (n,γ) cross section
- Half lives

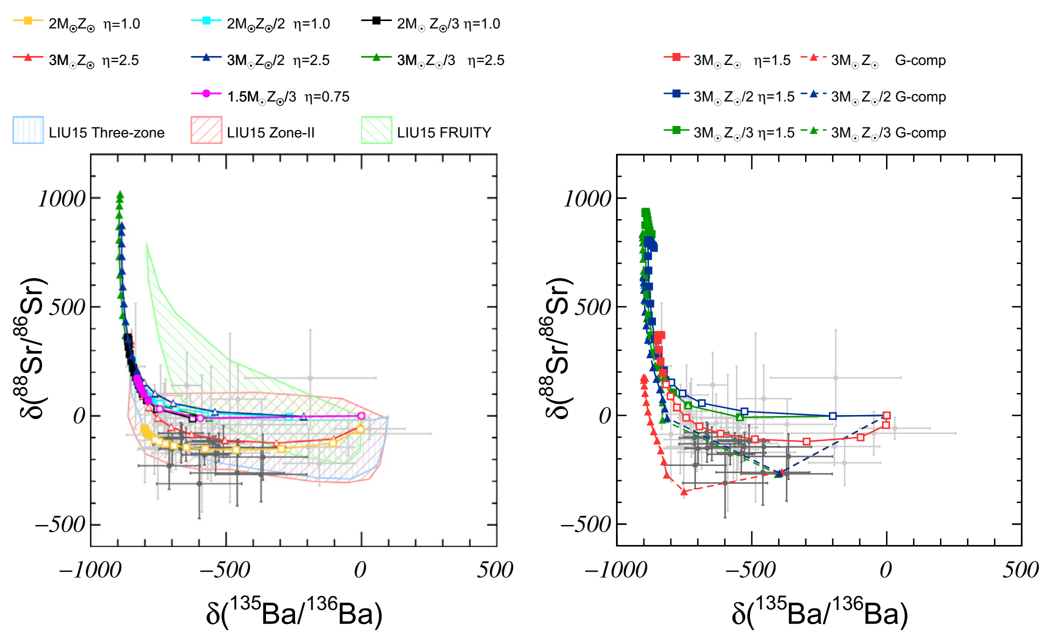
The s-process:
2 sources
3 peaks



Typical neutron density profile in time:		
Neutron source	$^{13}C(\alpha,n)\,^{16}O$	$^{22}Ne(\alpha,n)\,^{25}Mg$
Activation	Interpulse phase (radiative conditions) $T\sim10^8$ K	Thermal pulse (convective conditions) $T\geq2.5\ 10^8$ K
Timescale	10^4 yr	10 yr
Neutron exposure	0.3 $mbarn^{-1}$	0.02 $mbarn^{-1}$
Note	It is the MAIN neutron source	Important for key branching points (e.g. ^{87}Rb and ^{96}Zr production)

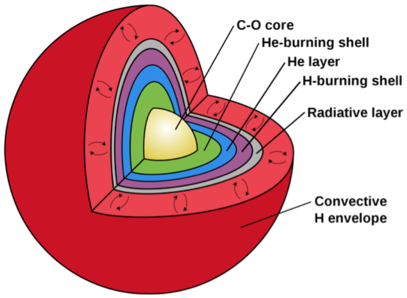
s-process peaks



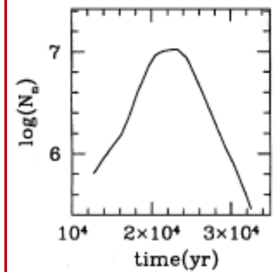
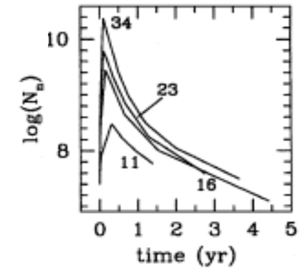


1. First peak light s-elements (ls) Sr, Y, Zr (N=50)
2. Second peak heavy s-elements (hs) Ba, La, Ce, Nd, Sm (N=90)
3. Third peak Lead (^{208}Pb) N=126 and Z=82

The s-process:
2 sources
3 peaks



some open questions

Typical neutron density profile in time:		
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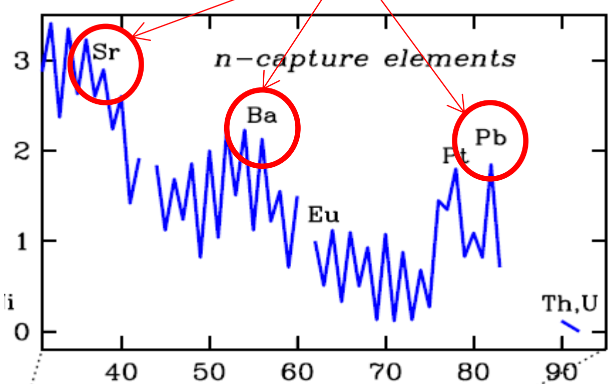
s-process peaks



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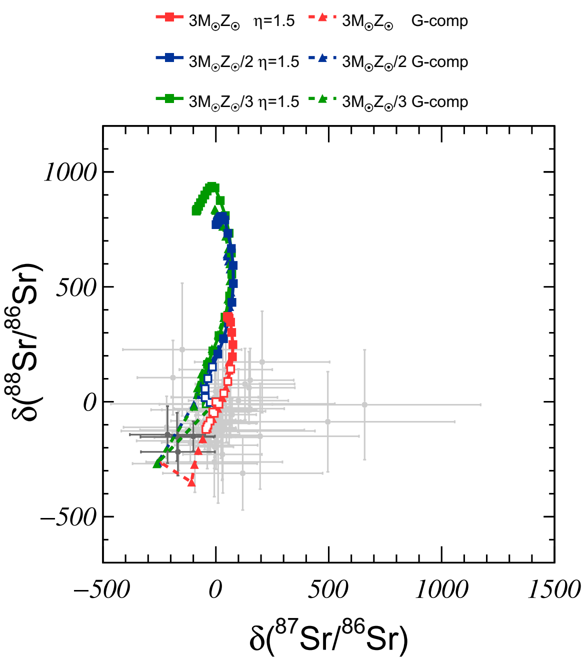
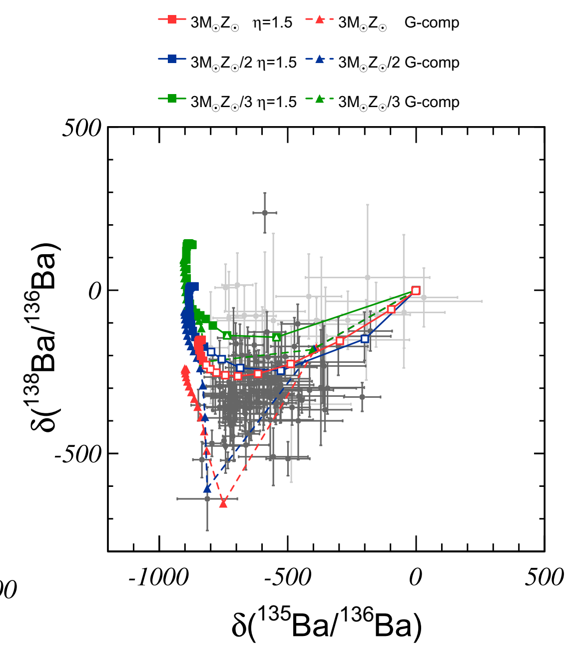
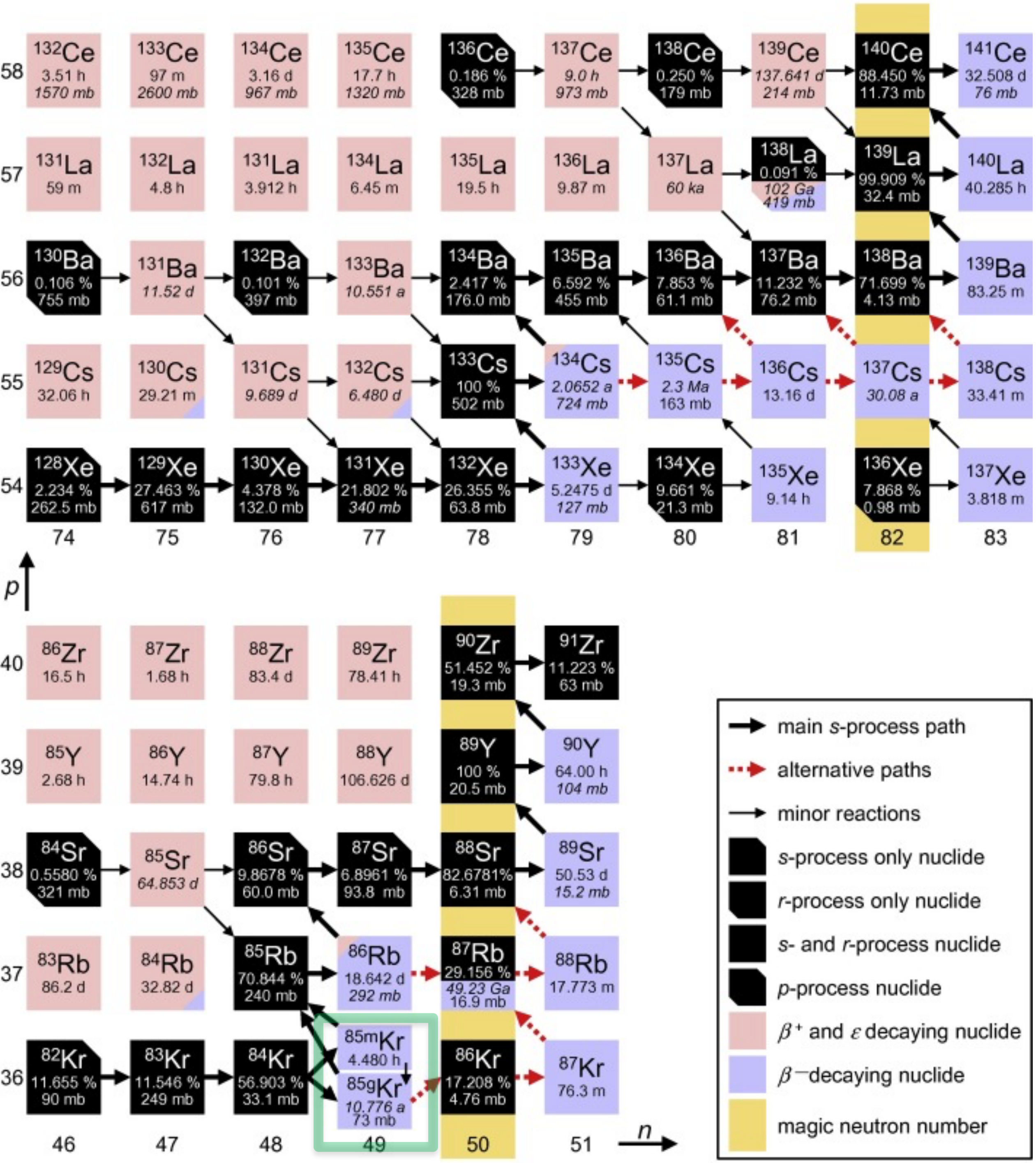
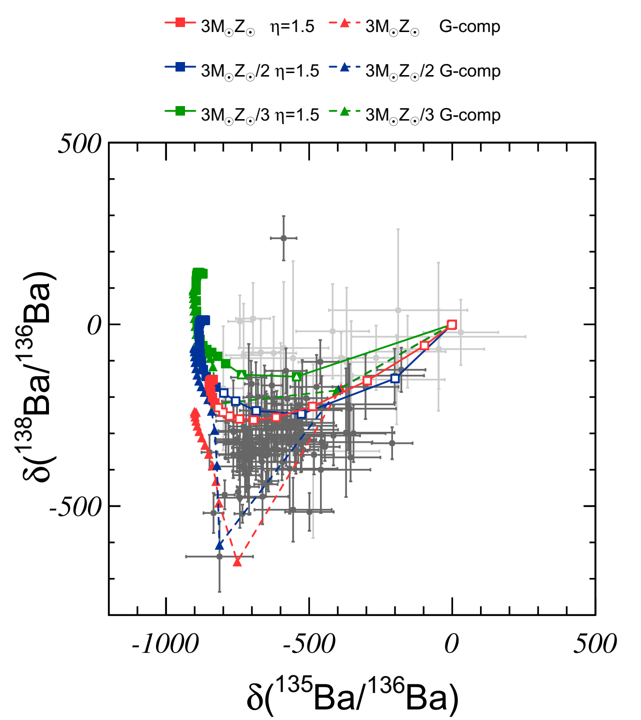


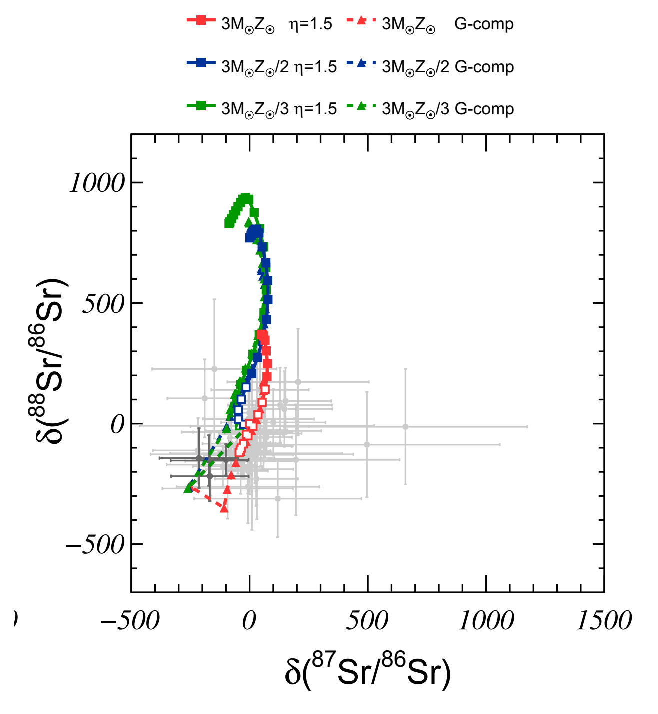




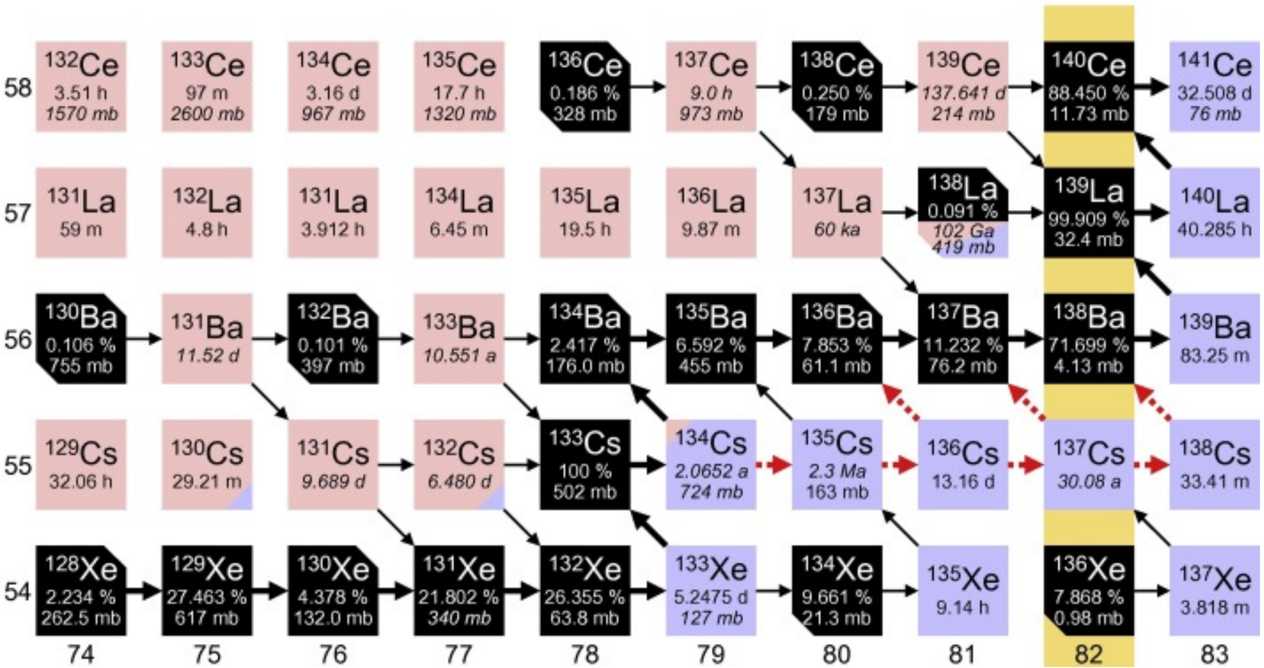
58
^{132}Ce 3.51 h 1570 mb
^{133}Ce 97 m 2600 mb
^{134}Ce 3.16 d 967 mb
^{135}Ce 17.7 h 1320 mb
^{136}Ce 0.186 % 328 mb
^{137}Ce 9.0 h 973 mb
^{138}Ce 0.250 % 179 mb
^{139}Ce 137.641 d 214 mb
^{140}Ce 88.450 % 11.73 mb
^{141}Ce 32.508 d 76 mb
57
^{131}La 59 m
^{132}La 4.8 h
^{131}La 3.912 h
^{134}La 6.45 m
^{135}La 19.5 h
^{136}La 9.87 m
^{137}La 60 ka
^{138}La 0.091 % 102 Ga 419 mb
^{139}La 99.909 % 32.4 mb
^{140}La 40.285 h
56
^{130}Ba 0.106 % 755 mb
^{131}Ba 11.52 d
^{132}Ba 0.101 % 397 mb
^{133}Ba 10.551 a
^{134}Ba 2.417 % 176.0 mb
^{135}Ba 6.592 % 455 mb
^{136}Ba 7.853 % 61.1 mb
^{137}Ba 11.232 % 76.2 mb
^{138}Ba 71.699 % 4.13 mb
^{139}Ba 83.25 m
55
^{129}Cs 32.06 h
^{130}Cs 29.21 m
^{131}Cs 9.689 d
^{132}Cs 6.480 d
^{133}Cs 100 % 502 mb
^{134}Cs 2.0652 a 724 mb
^{135}Cs 2.3 Ma 163 mb
^{136}Cs 13.16 d
^{137}Cs 30.08 a
^{138}Cs 33.41 m
54
^{128}Xe 2.234 % 262.5 mb
^{129}Xe 27.463 % 617 mb
^{130}Xe 4.378 % 132.0 mb
^{131}Xe 21.802 % 340 mb
^{132}Xe 26.355 % 63.8 mb
^{133}Xe 5.2475 d 127 mb
^{134}Xe 9.661 % 21.3 mb
^{135}Xe 9.14 h
^{136}Xe 7.868 % 0.98 mb
^{137}Xe 3.818 m
74 75 76 77 78 79 80 81 82 83
p
40
^{86}Zr 16.5 h
^{87}Zr 1.68 h
^{88}Zr 83.4 d
^{89}Zr 78.41 h
^{90}Zr 51.452 % 19.3 mb
^{91}Zr 11.223 % 63 mb
39
^{85}Y 2.68 h
^{86}Y 14.74 h
^{87}Y 79.8 h
^{88}Y 106.626 d
^{89}Y 100 % 20.5 mb
^{90}Y 64.00 h 104 mb
38
^{84}Sr 0.5580 % 321 mb
^{85}Sr 64.853 d
^{86}Sr 9.8678 % 60.0 mb
^{87}Sr 6.8961 % 93.8 mb
^{88}Sr 82.6781% 6.31 mb
^{89}Sr 50.53 d 15.2 mb
37
^{83}Rb 86.2 d
^{84}Rb 32.82 d
^{85}Rb 70.844 % 240 mb
^{86}Rb 18.642 d 292 mb
^{87}Rb 29.156 % 49.23 Ga 16.9 mb
^{88}Rb 17.773 m
36
^{82}Kr 11.655 % 90 mb
^{83}Kr 11.546 % 249 mb
^{84}Kr 56.903 % 33.1 mb
^{85m}Kr 4.480 h
^{85g}Kr 10.776 a 73 mb
^{86}Kr 17.208 % 4.76 mb
^{87}Kr 76.3 m
46 47 48 49 50 51
n
main s-process path
alternative paths
minor reactions
s-process only nuclide
r-process only nuclide
s- and r-process nuclide
p-process nuclide
β^+ and ε decaying nuclide
β^-decaying nuclide
magic neutron number



$3M_\odot Z_\odot$ η=1.5
$3M_\odot Z_\odot$ G-comp
$3M_\odot Z_\odot/2$ η=1.5
$3M_\odot Z_\odot/2$ G-comp
$3M_\odot Z_\odot/3$ η=1.5
$3M_\odot Z_\odot/3$ G-comp
500
0
-500
-1000
-500
0
500
$\delta(^{138}Ba/^{136}Ba)$
$\delta(^{135}Ba/^{136}Ba)$



$3M_\odot Z_\odot$ η=1.5
$3M_\odot Z_\odot$ G-comp
$3M_\odot Z_\odot/2$ η=1.5
$3M_\odot Z_\odot/2$ G-comp
$3M_\odot Z_\odot/3$ η=1.5
$3M_\odot Z_\odot/3$ G-comp
1000
500
0
−500
−500
0
500
1000
1500
$\delta(^{88}Sr/^{86}Sr)$
$\delta(^{87}Sr/^{86}Sr)$



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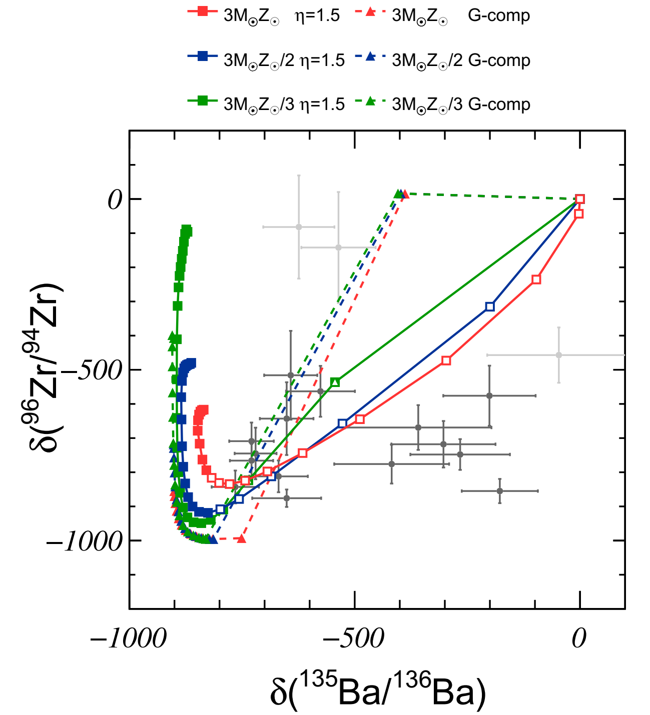
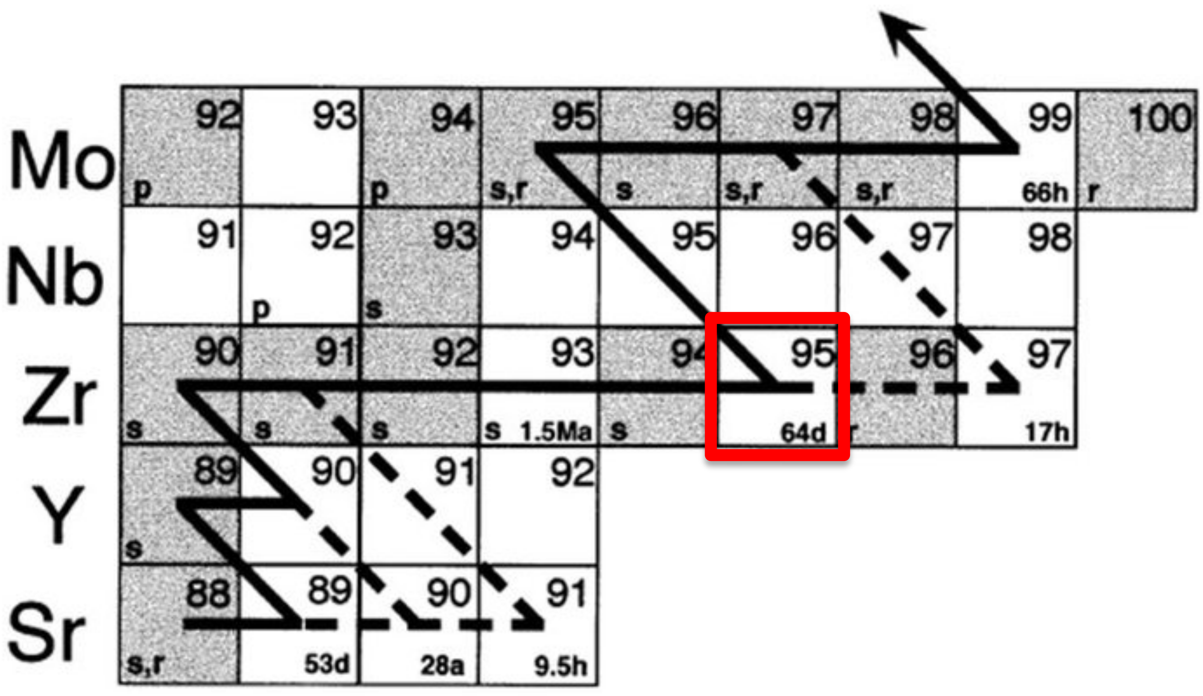
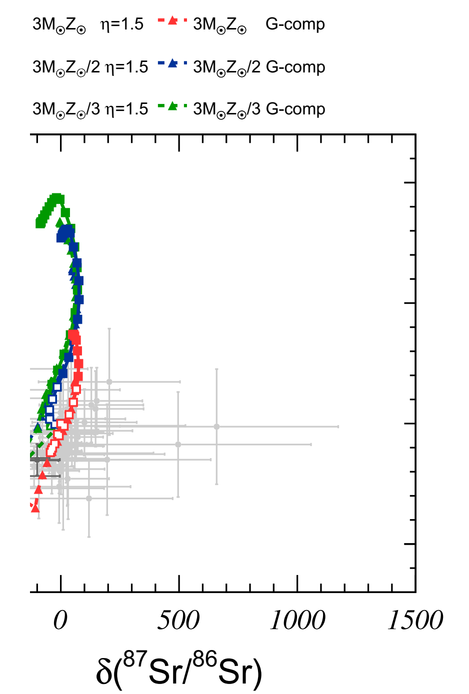


3M⊙Z⊙ η=1.5
3M⊙Z⊙ G-comp
3M⊙Z⊙/2 η=1.5
3M⊙Z⊙/2 G-comp
3M⊙Z⊙/3 η=1.5
3M⊙Z⊙/3 G-comp
0
−500
−1000
−1000
−500
0
δ(96Zr/94Zr)
δ(135Ba/136Ba)



Mo
Nb
Zr
Y
Sr
92 p
93
94 p
95 s,r
96 s
97 s,r
98 s,r
99 66h
100 r
91
92 p
93 s
94
95
96
97
98
90 s
91 s
92 s
93 s 1.5Ma
94 s
95 64d
96 r
97 17h
89 s
90
91
92
88 s,r
89 53d
90 28a
91 9.5h



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3M⊙Z⊙ G-comp
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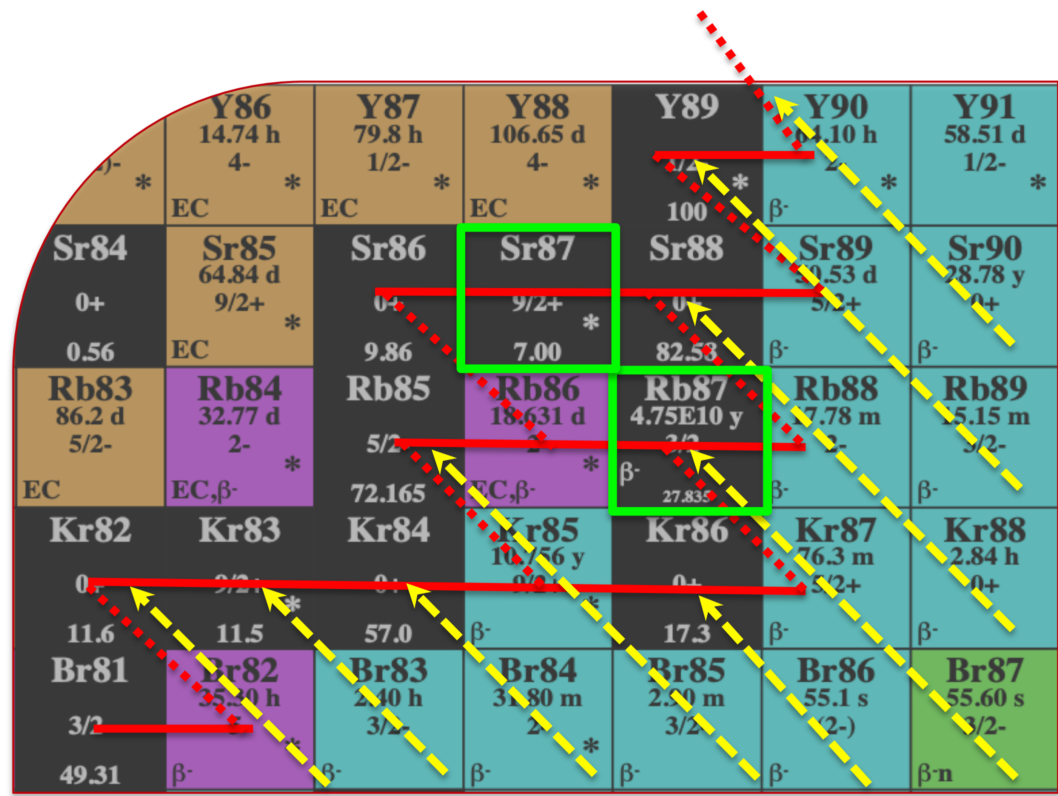
3M⊙Z⊙/3 η=1.5
3M⊙Z⊙/3 G-comp
0
500
1000
1500
δ(87Sr/86Sr)

Cosmocronometri

^{87}Sr - ^{87}Rb ($T_{1/2}$ = 48 Gy)

^{187}Os- ^{187}Re($T_{1/2}$ = 43 Gy)

2 isobar nuclei: a stable s-only and its long-lived father that is produced by both the r- and s-process and shields the first nuclues from r-process.
After subtraction of the contributions of s-process the epoch from a r-process nucleosynthesis event can be determined by the presently observed abundances of the 2 nuclei, whose ratio is then directly correlated with the age of the Universe.
However, to calibrate this “cosmic clock” <u>the half lives of the long lived one in stellar environments has to be estimated properly.</u>



Cosmocronometri

$^{87}Sr - ^{87}Rb\ (T_{1/2} = 48\ Gy)$

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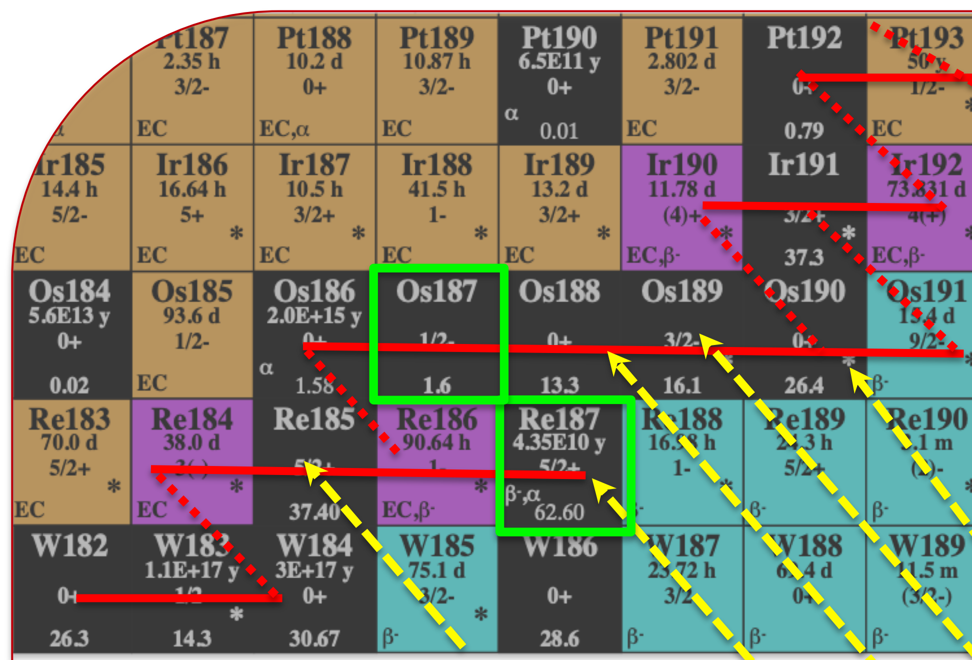


Opacity, r-process, NSM…and PANDORA

ArXiv:1303.5788v1

OPACITIES AND SPECTRA OF THE R-PROCESS EJECTA FROM NEUTRON STAR MERGERS

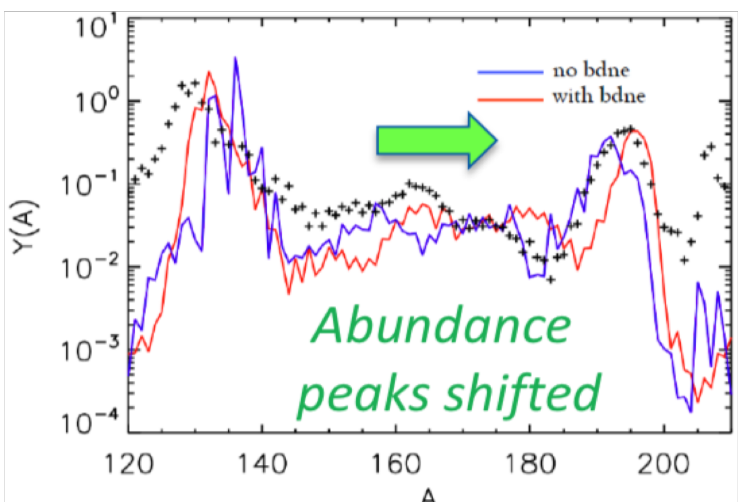
Daniel Kasen[1,2], N. R. Badnell[3], Jennifer Barnes[1,2]

[1] Department of Physics and Astronomy, University of California, Berkeley, CA 94720, USA
[2] Nuclear Science Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA and
[3] Department of Physics, University of Strathclyde, Glasgow G4 0NG, UK

Draft version October 29, 2018

ABSTRACT

Material ejected during (or immediately following) the merger of two neutron stars may assemble into heavy elements by the r-process. The subsequent radioactive decay of the nuclei can power electromagnetic emission similar to, but significantly dimmer than, an ordinary supernova. Identifying such events is an important goal of future transient surveys, offering new perspectives on the origin of r-process nuclei and the astrophysical sources of gravitational waves. Predictions of the transient light curves and spectra, however, have suffered from the uncertain optical properties of heavy ions. Here we consider the opacity of expanding r-process material and argue that it is dominated by line transitions from those ions with the most complex valence electron structure, namely the lanthanides. For a few representative ions, we run atomic structure models to calculate radiative data for tens of millions of lines. We find that the resulting r-process opacities are orders of magnitude larger than that of ordinary (e.g., iron-rich) supernova ejecta. Radiative transport calculations using these new opacities indicate that the transient emission should be dimmer and redder than previously thought. The spectra appear pseudo-blackbody, with broad absorption features, and peak in the infrared ($\sim 1\ \mu$m). We discuss uncertainties in the opacities and attempt to quantify their impact on the spectral predictions. The results have important implications for observational strategies to find and study the radioactively powered electromagnetic counterparts to compact object mergers.

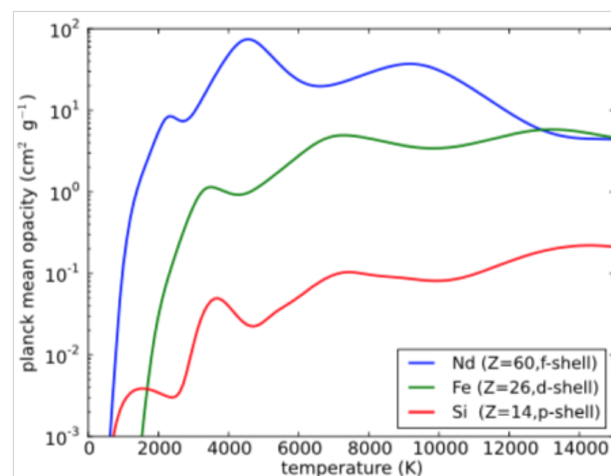


What is opacity? Photon cross section per unit mass of absorbing material

→ ∝ to the number of atomic transition in the heated matter

→ ∝ to the square of number of atomic levels

The opacity of matter containing a small fraction of lanthanides is orders of magnitude larger than one containing iron peak elements



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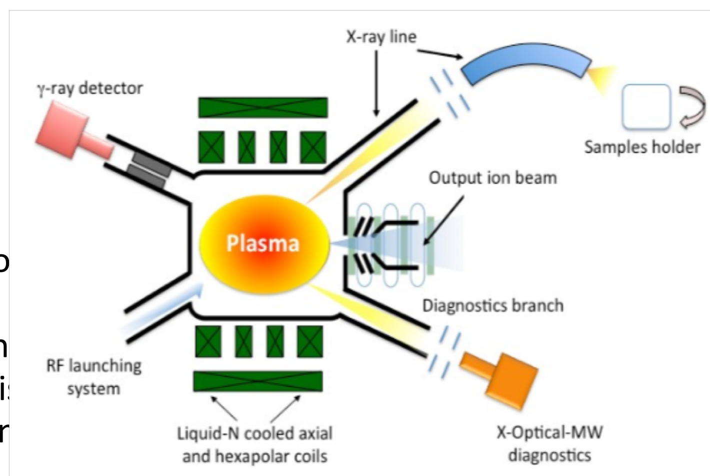

Pandora
Production of controlled plasma at the same densities of kilonovae ejecta at peak luminosity
→ Measurement of opacities of different mixtures of atomic species
→ Accurate predictions of kilonovae light curves
→ Constraining r-process yields and kilonovae energetics

…e molto altro ancora

- Il problema del Li cosmologico (e non solo)
- Il ^{26}Al la sua nucleosintesi e la radioattività fossile nel Sistema Solare