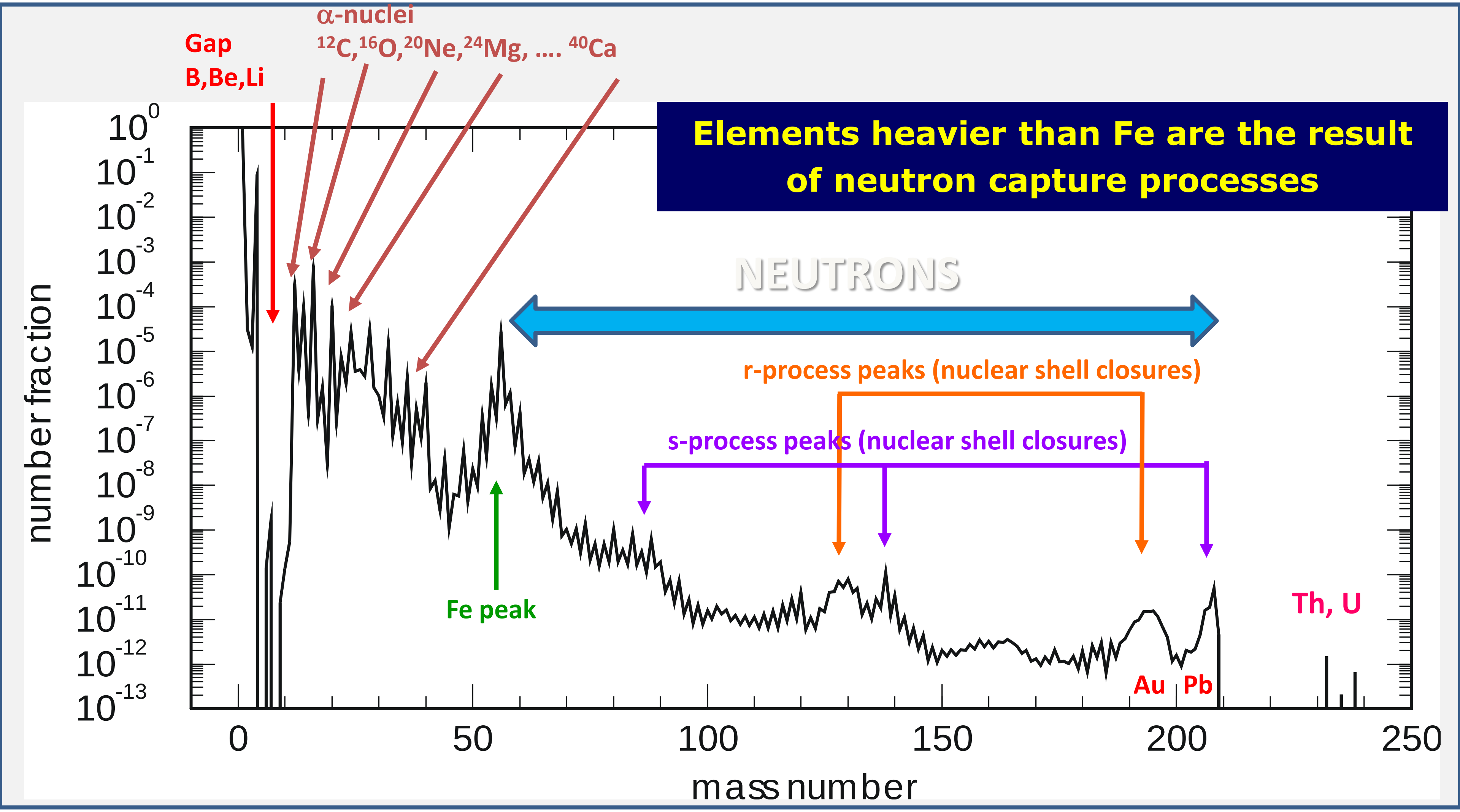
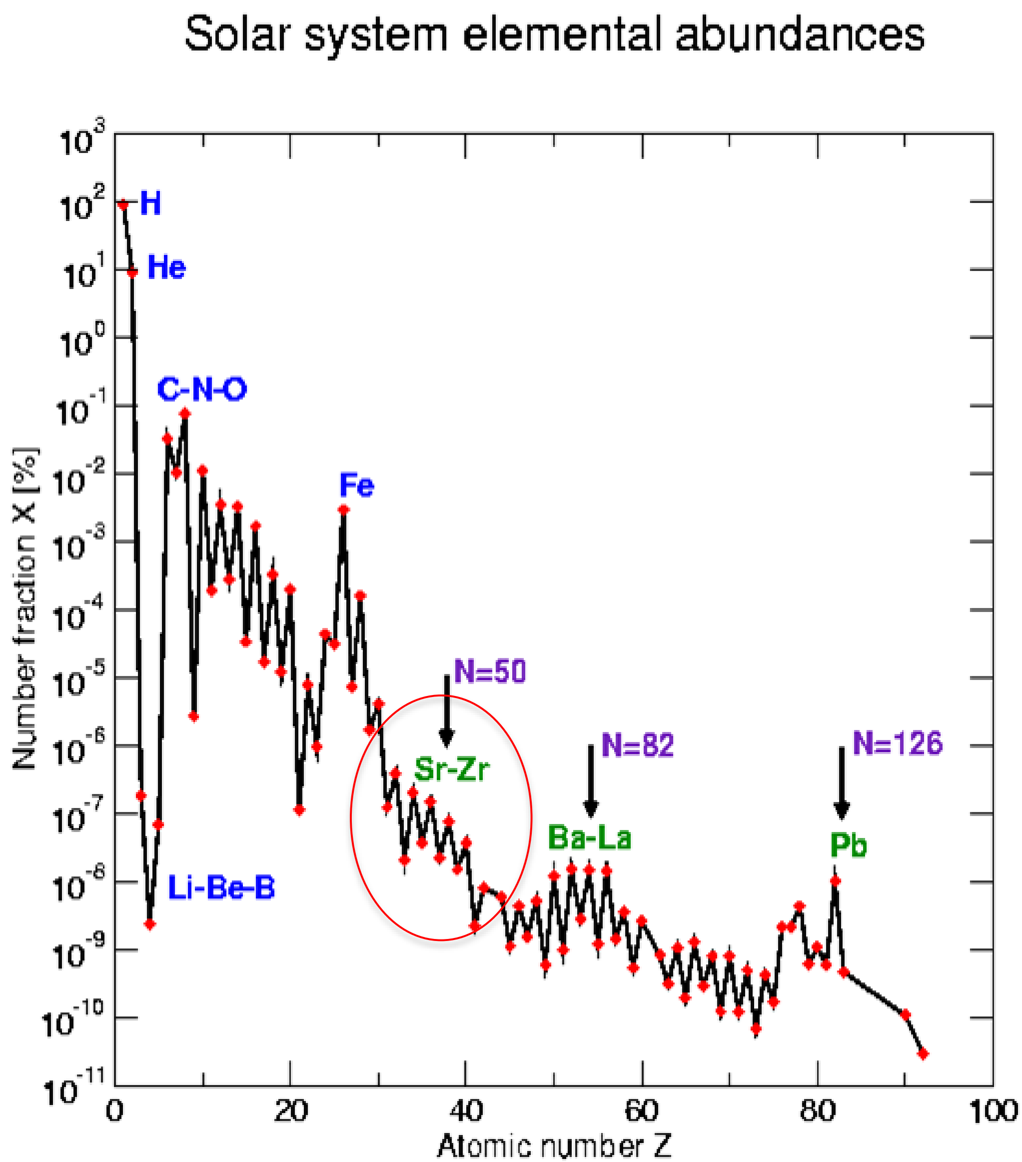
Neutron capture cross section of ^{88}Sr(n,γ), ^{89}Y(n,γ) @ EAR1

G. Tagliente(INFN), N. Colonna(INFN), S. Cristallo(INAF), A.C. Larsen(OCL), M. Lugaro(MTA)

Abundances beyond Fe–ashes of stellar burning



s-process bottlenecks



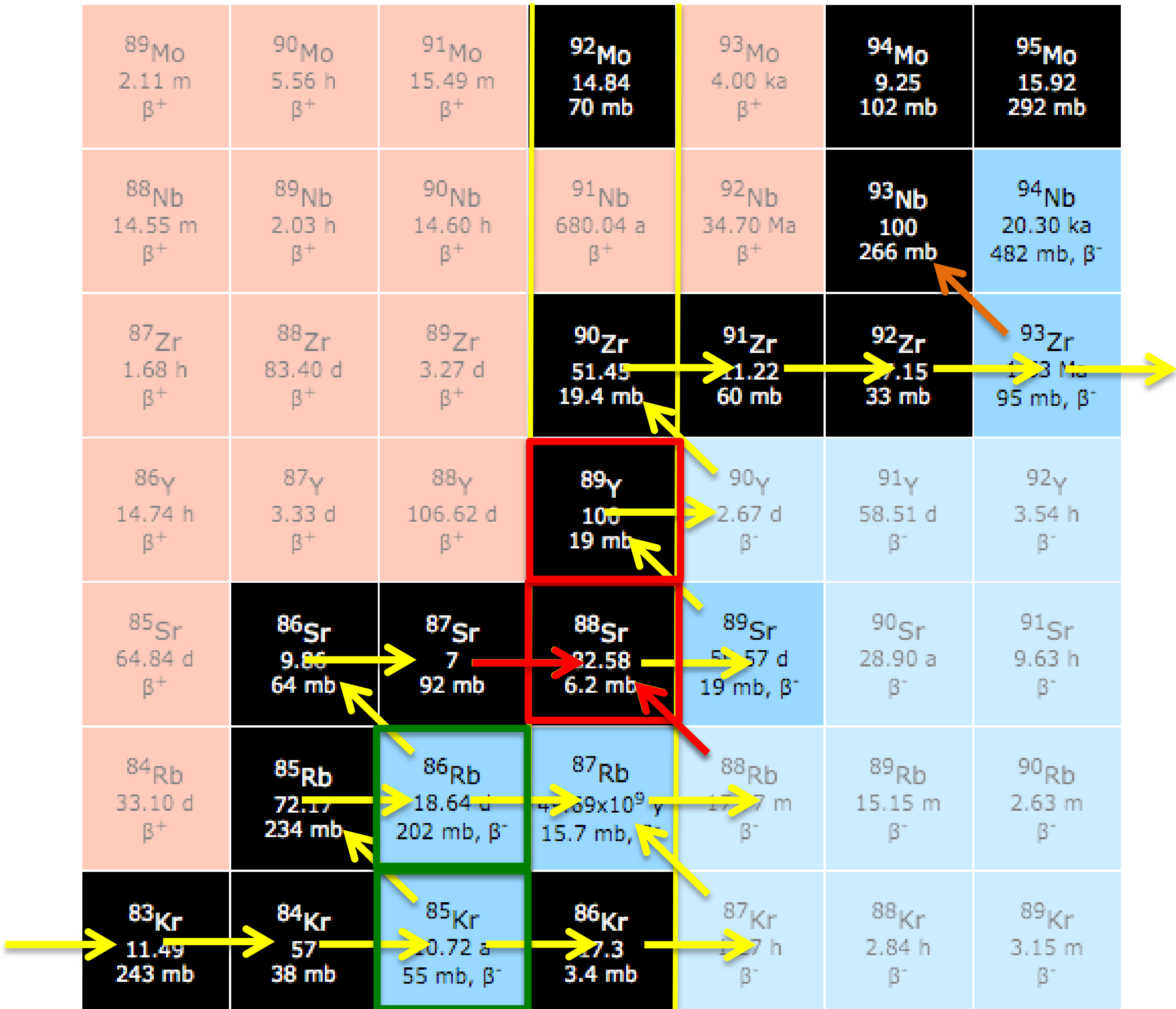
N = 50 first bottle neck in the s-process path, it controls the neutron flux necessary to proceed to the production of heavier elements up to N = 82

N=50 neutron magic isotopes

^{89}Mo 2.11 m β^+	^{90}Mo 5.56 h β^+	^{91}Mo 15.49 m β^+	^{92}Mo 14.84 70 mb	^{93}Mo 4.00 ka β^+	^{94}Mo 9.25 102 mb	^{95}Mo 15.92 292 mb
^{88}Nb 14.55 m β^+	^{89}Nb 2.03 h β^+	^{90}Nb 14.60 h β^+	^{91}Nb 680.04 a β^+	^{92}Nb 34.70 Ma β^+	^{93}Nb 100 266 mb	^{94}Nb 20.30 ka 482 mb, β^-
^{87}Zr 1.68 h β^+	^{88}Zr 83.40 d β^+	^{89}Zr 3.27 d β^+	^{90}Zr 51.45 19.4 mb	^{91}Zr 11.22 60 mb	^{92}Zr 17.15 33 mb	^{93}Zr 1.53 Ma 95 mb, β^-
^{86}Y 14.74 h β^+	^{87}Y 3.33 d β^+	^{88}Y 106.62 d β^+	^{89}Y 100 19 mb	^{90}Y 2.67 d β^-	^{91}Y 58.51 d β^-	^{92}Y 3.54 h β^-
^{85}Sr 64.84 d β^+	^{86}Sr 9.86 64 mb	^{87}Sr 7 92 mb	^{88}Sr 82.58 6.2 mb	^{89}Sr 50.57 d 19 mb, β^-	^{90}Sr 28.90 a β^-	^{91}Sr 9.63 h β^-
^{84}Rb 33.10 d β^+	^{85}Rb 72.17 234 mb	^{86}Rb 18.64 d 202 mb, β^-	^{87}Rb 49.69×10^9 y 15.7 mb, β^-	^{88}Rb 17.77 m β^-	^{89}Rb 15.15 m β^-	^{90}Rb 2.63 m β^-
^{83}Kr 11.49 243 mb	^{84}Kr 57 38 mb	^{85}Kr 10.72 a 55 mb, β^-	^{86}Kr 17.3 3.4 mb	^{87}Kr 1.27 h β^-	^{88}Kr 2.84 h β^-	^{89}Kr 3.15 m β^-

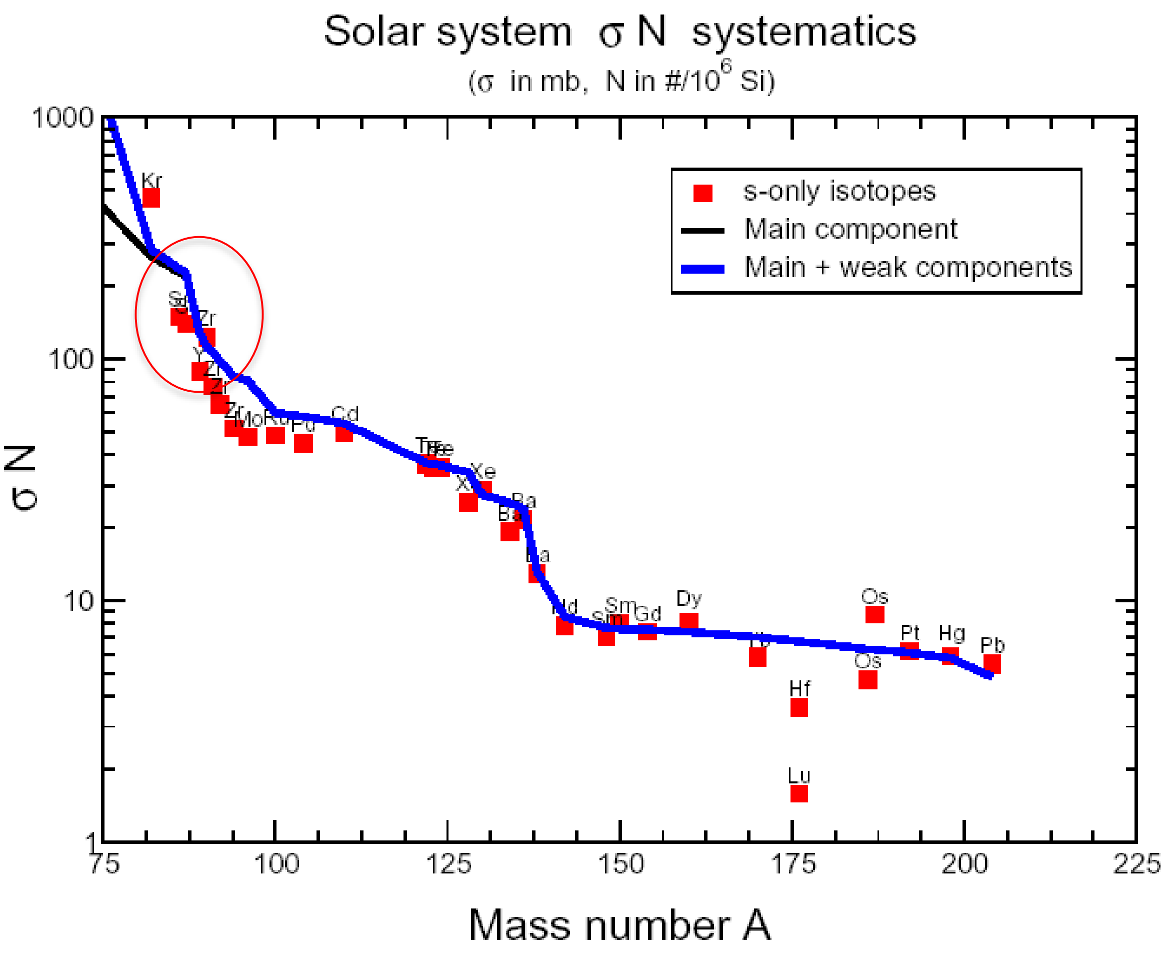
N=50

s-process path around N=50



s-process path

Stellar models: s-process components



f ≈ 0,06% $\tau_0 \approx 0{,}3\ \mathrm{mb}^{-1} \rightarrow n_c = 10$

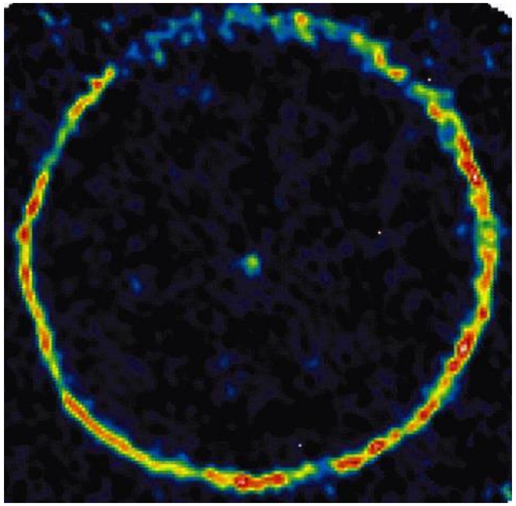
Main component: A ≥ 90

f ≈ 1,6% $\tau_0 \approx 0{,}07\ \mathrm{mb}^{-1} \rightarrow n_c = 3$

Weak component: A < 90

$$\langle\sigma\rangle_A N_s(A) = \frac{f N_S^{seed}}{\tau_0} \prod_{i=56}^{A} \frac{1}{\left[1 + \frac{1}{\tau_0 \langle\sigma\rangle_i}\right]}$$

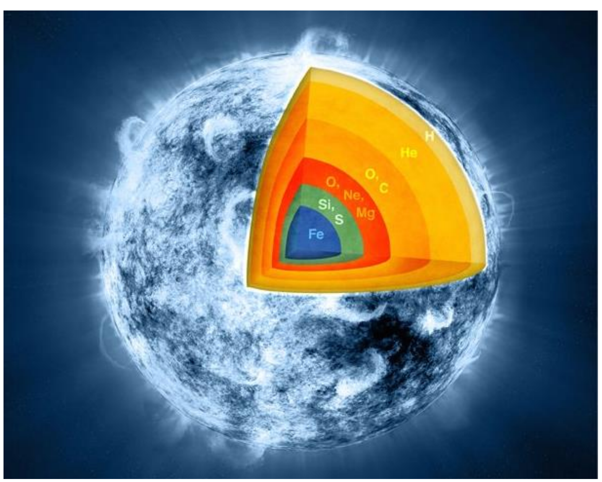
s-process stellar sites



Main component

Low mass Asympotic Giant Branch (AGB) M≈1.5 - 3 $M_\odot$

- $^{13}C(\alpha,n)^{16}O$ T ~ 8 keV $N_n < 10^7$ n/cm^3
- $^{22}Ne(\alpha,n)^{25}Mg$ T ~ 23 keV $N_n \sim 10^{10}-10^{12}$ n/cm^3



Weak component

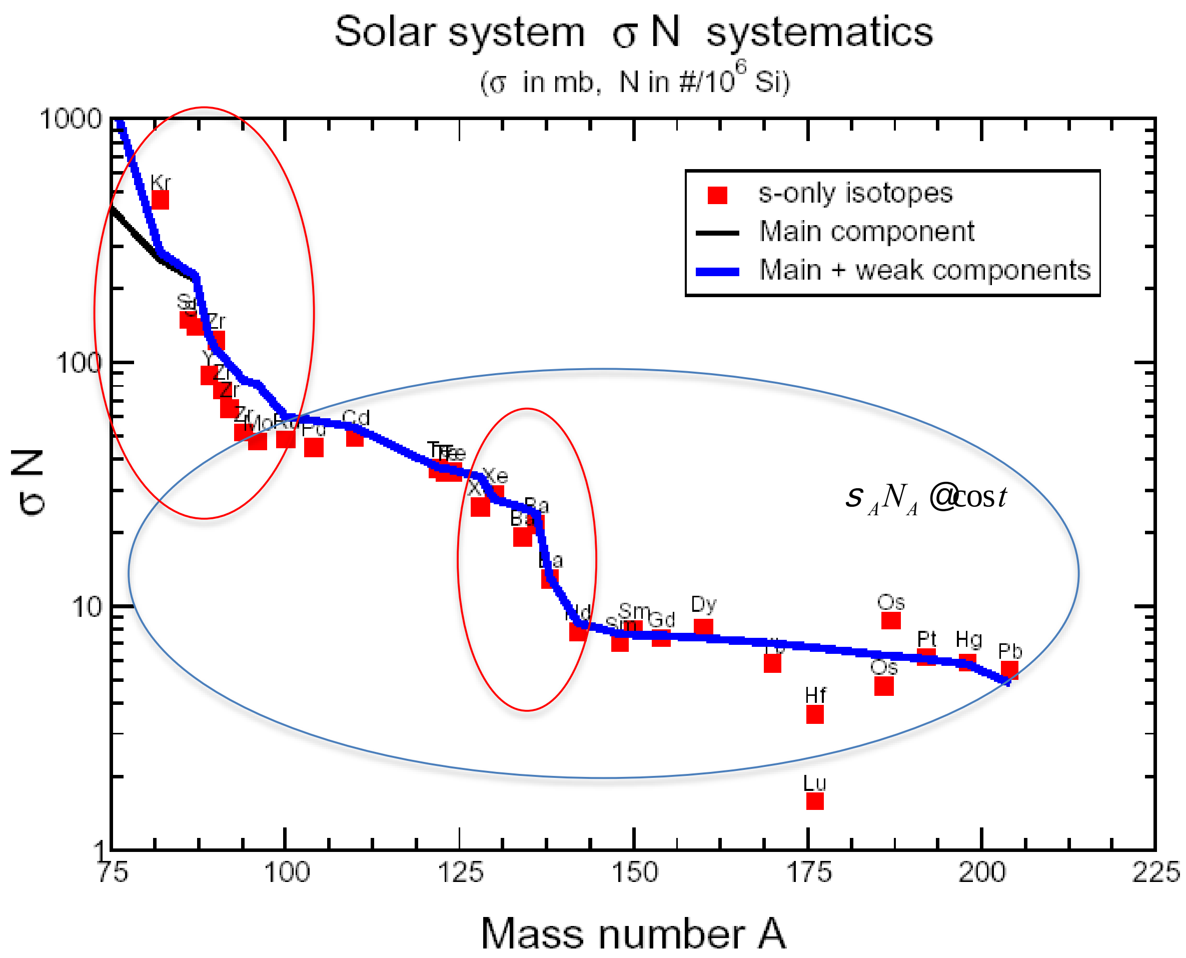
Massive stars M≈15 - 25 $M_\odot$

$^{22}Ne(\alpha,n)^{25}Mg$

In core He-burning T ~ 26 keV $N_n \sim 10^6$ n/cm^3

In shell C-burnig T ~ 90 keV $N_n \sim 10^{11}$ n/cm^3

Stellar Models: local equilibrium approximation

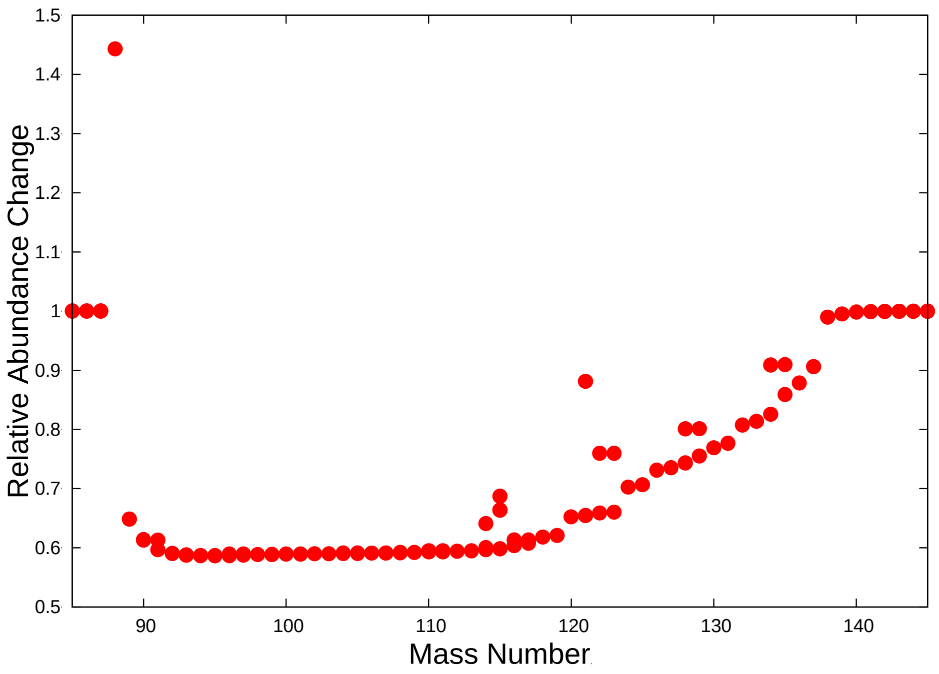


A>90

Local equilibrium approximation

$$\sigma_A N_A \cong cost$$

s-process abundance sensitivity: ^{88}Sr

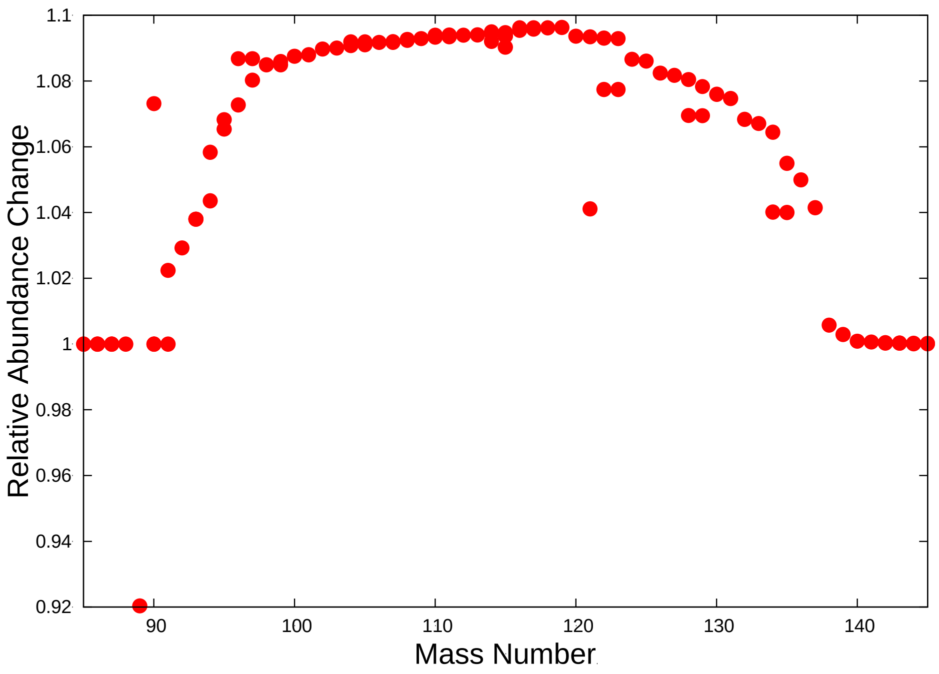


Effect of cross section uncertainty on the s-process efficiency in massive stars

Results obtained with the reaction network NETZ

http://exp-astro.physik.uni-frankfurt.de/netz

s-process abundance sensitivity: ^{89}Y

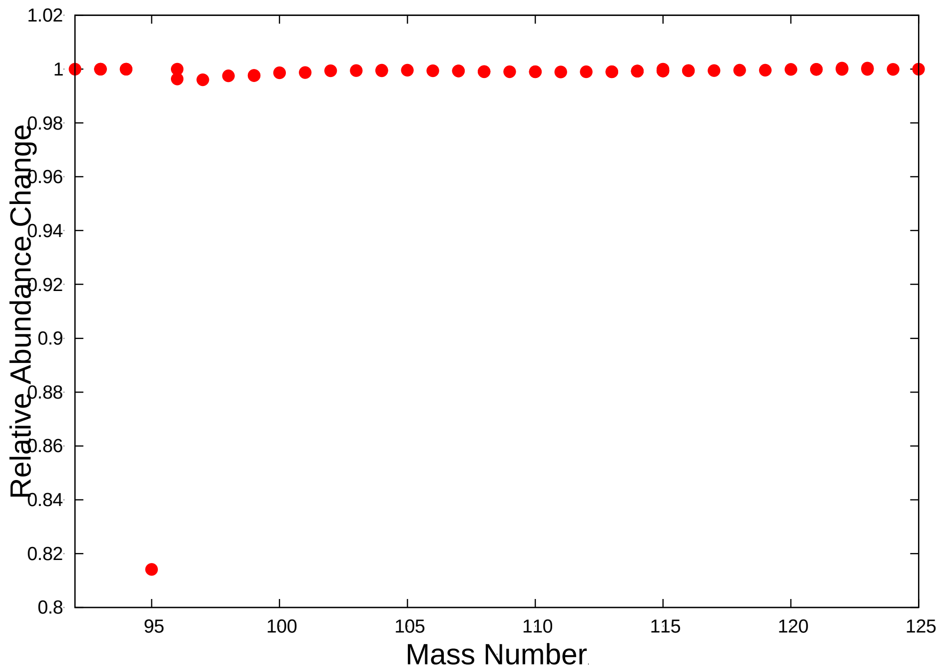


Effect of cross section uncertainty on the s-process efficiency in massive stars

Results obtained with the reaction network NETZ:

http://exp-astro.physik.uni-frankfurt.de/netz

s-process abundance sensitivity in the main component (A>90)

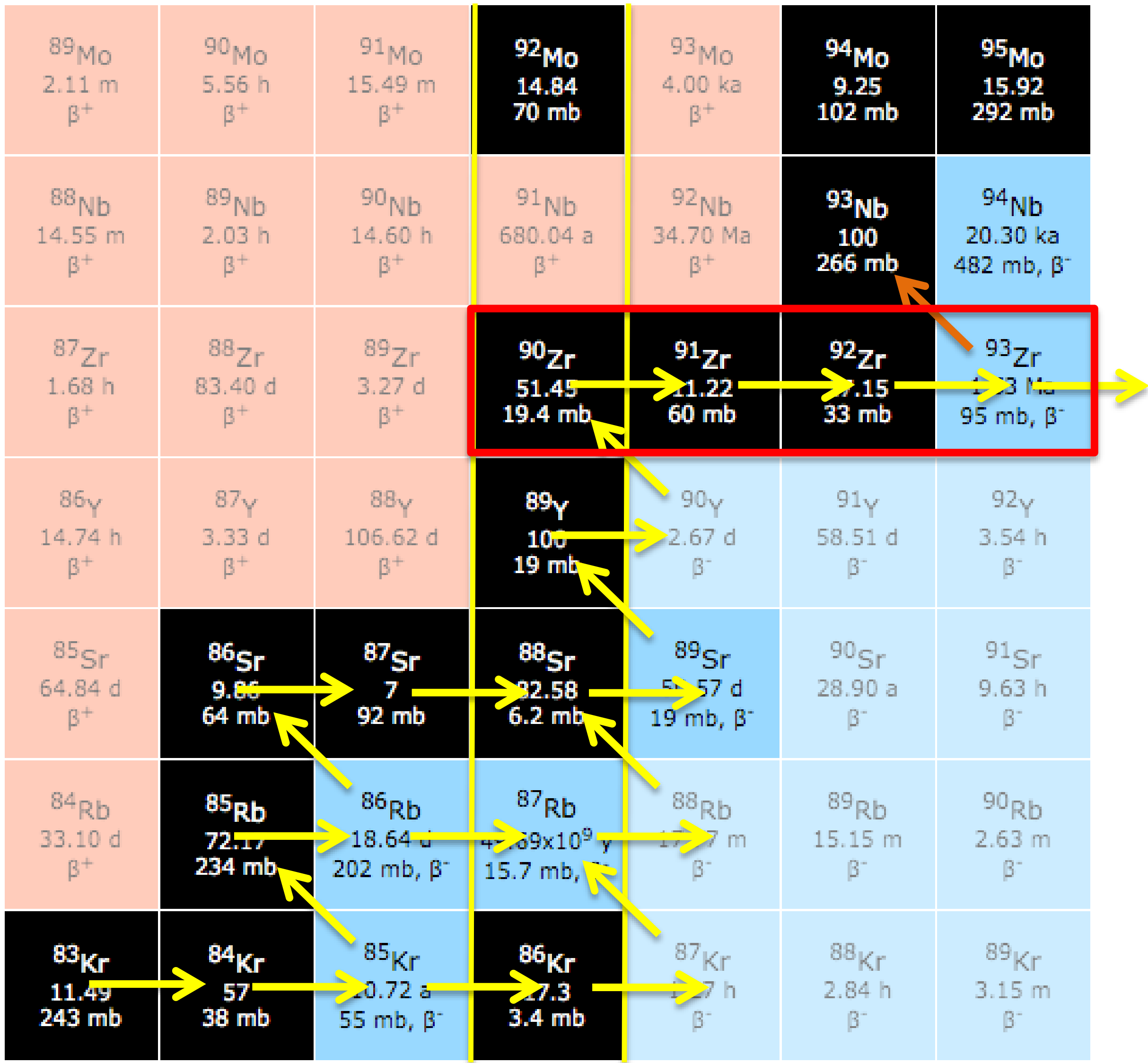


Effect of cross section uncertainty on the s-process efficiency in low mass AGB stars

Results obtained with the reaction network NETZ:

http://exp-astro.physik.uni-frankfurt.de/netz

s-process path around N=50



PHYSICAL REVIEW C **77**, 035802 (2008)

Neutron capture cross section of ^{90}Zr: Bottleneck in the *s*-process reaction flow

G. Tagliente,[1,*] K. Fujii,[2] P. M. Milazzo,[2] C. Moreau,[2] G. Aerts,[3] U. Abbondanno,[2] H. Álvarez,[4] F. Alvarez-Velarde,[5]

PHYSICAL REVIEW C **78**, 045804 (2008)

Experimental study of the ^{91}Zr(n, γ) reaction up to 26 keV

G. Tagliente,[1,*] P. M. Milazzo,[2] K. Fujii,[2] G. Aerts,[3] U. Abbondanno,[2] H. Álvarez,[4] F. Alvarez-Velarde,[5]

PHYSICAL REVIEW C **81**, 055801 (2010)

The ^{92}Zr(n,γ) reaction and its implications for stellar nucleosynthesis

G. Tagliente,[1,2,*] P. M. Milazzo,[3] K. Fujii,[3] U. Abbondanno,[3] G. Aerts,[4] H. Álvarez,[5] F. Alvarez-Velarde,[6] S. Andriamonje,[4]

PHYSICAL REVIEW C **87**, 014622 (2013)

The ^{93}Zr(n, γ) reaction up to 8 keV neutron energy

G. Tagliente,[1,*] P. M. Milazzo,[2] K. Fujii,[2] U. Abbondanno,[2] G. Aerts,[3] H. Álvarez,[4] F. Alvarez-Velarde,[5] S. Andriamonje,[3]

PHYSICAL REVIEW C **84**, 015801 (2011)

Neutron capture on ^{94}Zr: Resonance parameters and Maxwellian-averaged cross sections

G. Tagliente,[1,2,*] P. M. Milazzo,[3] K. Fujii,[3] U. Abbondanno,[3] G. Aerts,[4] H. Álvarez,[5] F. Alvarez-Velarde,[6] S. Andriamonje,[4]

PHYSICAL REVIEW C **84**, 055802 (2011)

^{96}Zr(n,γ) measurement at the n_TOF facility at CERN

G. Tagliente,[1,*] P. M. Milazzo,[2] K. Fujii,[2] U. Abbondanno,[2] G. Aerts,[3] H. Álvarez,[4] F. Alvarez-Velarde,[5] S. Andriamonje,[3]

THE ASTROPHYSICAL JOURNAL, 780:95 (14pp), 2014 January 1 doi:10.1088/0004-637X/780/1/95

THE IMPACT OF UPDATED Zr NEUTRON-CAPTURE CROSS SECTIONS AND NEW ASYMPTOTIC GIANT BRANCH MODELS ON OUR UNDERSTANDING OF THE S PROCESS AND THE ORIGIN OF STARDUST

MARIA LUGARO[1], GIUSEPPE TAGLIENTE[2,8], AMANDA I. KARAKAS[3], PAOLO M. MILAZZO[4], FRANZ KÄPPELER[5], ANDREW M. DAVIS[6,9,10], AND MICHAEL R. SAVINA[7,9]
[1] Monash Centre for Astrophysics (MoCA), Monash University, Clayton, VIC 3800, Australia; maria.lugaro@monash.edu
[2] Istituto Nazionale di Fisica Nucleare (INFN), Bari, Italy; giuseppe.tagliente@ba.infn.it
[3] Research School of Astronomy and Astrophysics, Australian National University, Canberra, ACT 2611, Australia; amanda.karakas@anu.edu.au
[4] Istituto Nazionale di Fisica Nucleare (INFN), Trieste, Italy; paolo.milazzo@ts.infn.it
[5] Karlsruhe Institute of Technology, Campus North, D-76021 Karlsruhe, Germany; franz.kaeppeler@kit.edu
[6] The Department of the Geophysical Sciences, The University of Chicago, Chicago, IL 60637, USA; a-davis@uchicago.edu
[7] Materials Science Division, Argonne National Laboratory, Argonne, IL 60439, USA; msavina@anl.gov
Received 2013 August 5; accepted 2013 November 11; published 2013 December 13

ABSTRACT

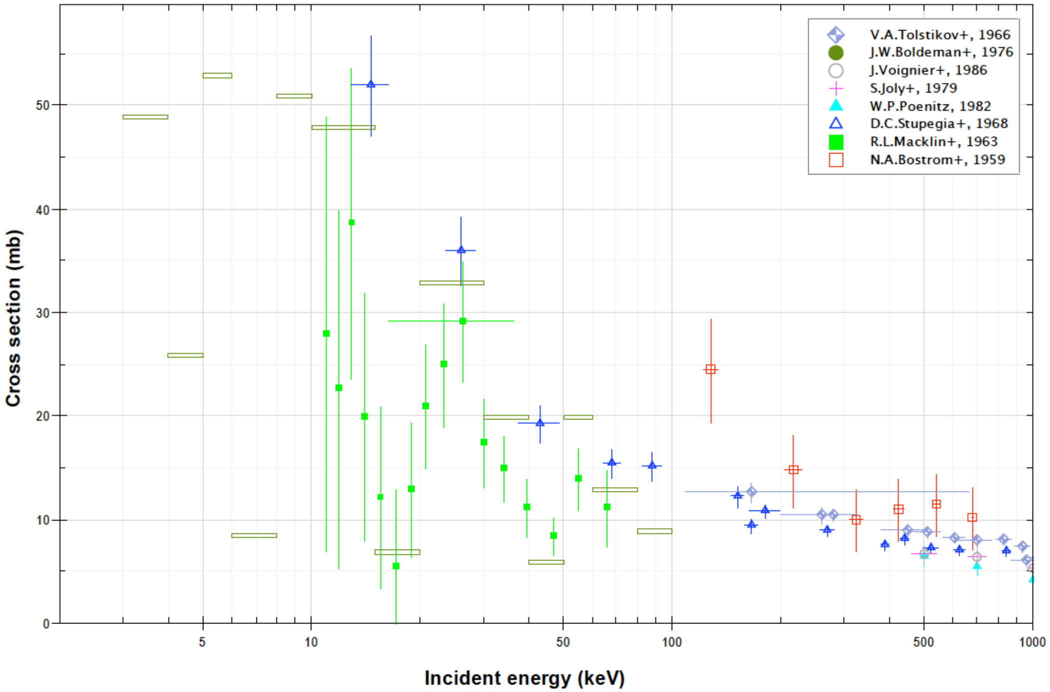
LETTER

doi:10.1038/nature14050

The temperature and chronology of heavy-element synthesis in low-mass stars

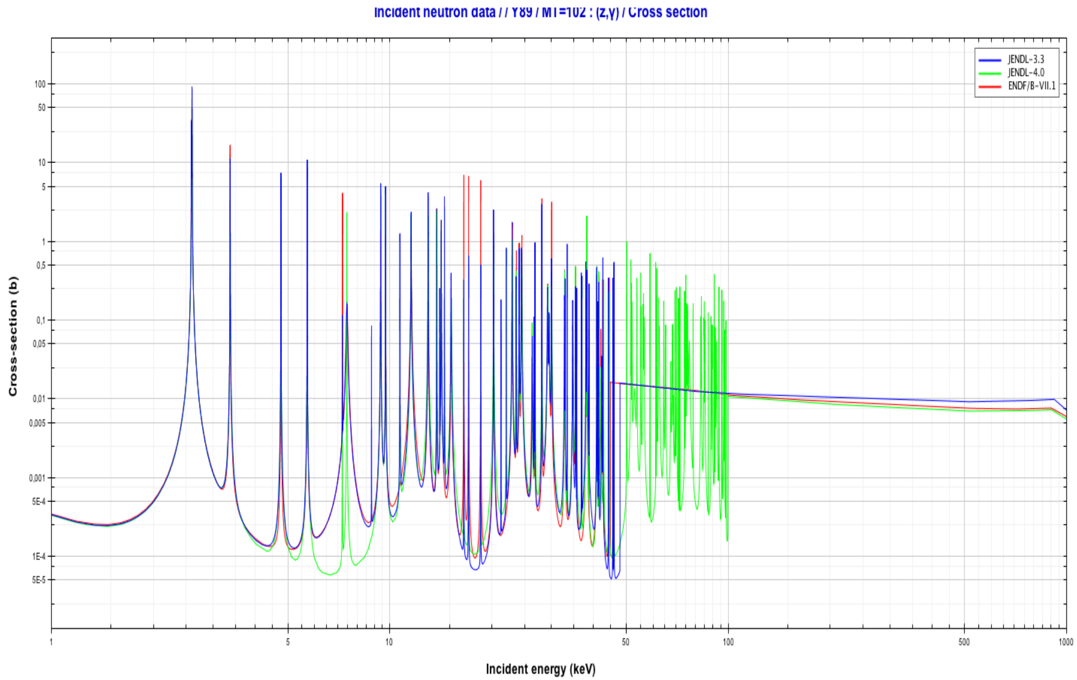
P. Neyskens[1], S. Van Eck[1], A. Jorissen[1], S. Goriely[1], L. Siess[1] & B. Plez[2]

Measurements status: ^{89}Y



Cross section data for $^{89}Y(n,\gamma)^{90}Y$ (EXFOR data base)

Libraries status: ^{89}Y



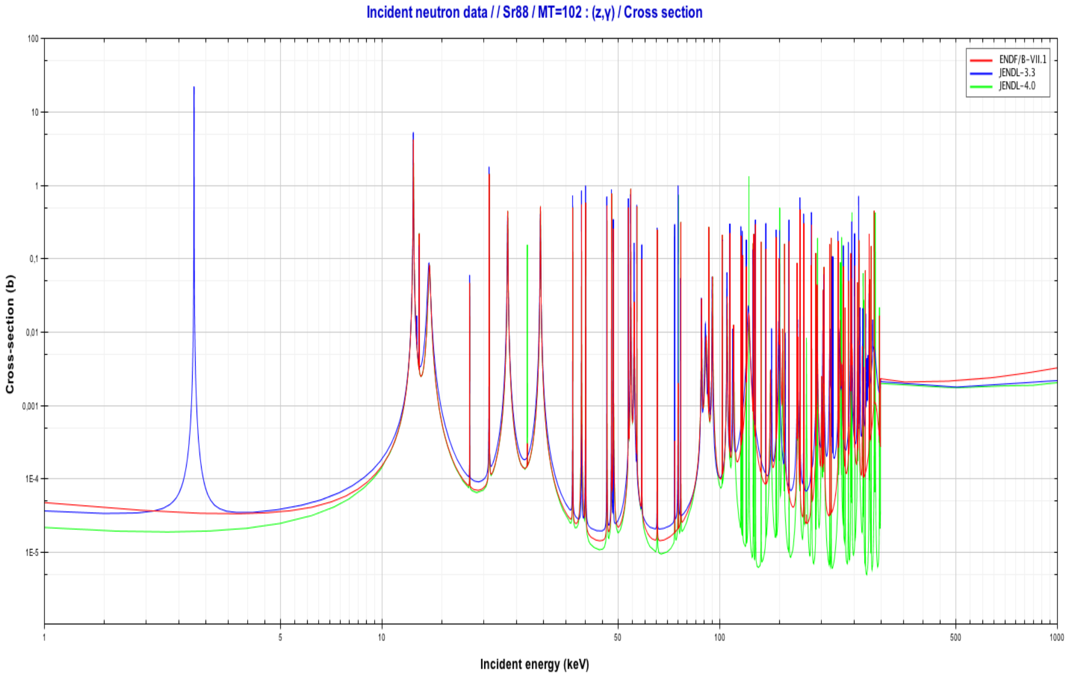
MACS status: ^{89}Y

Maxwellian Averaged Cross Section (MACS) @ 30 keV

▾ List of all available values

original	renorm.	year	type	Comment	Ref
19.0 ± 0.6		1990	c	VdG, Act., 1/v(kT), Au:RaK88	KZB90
21 ± 3		1978	c,2	Linac, TOF, ^{6}Li, Au:Sat., k=1.0360	MAM78a
13.5 ± 1.3		1977	c,2	Linac, TOF, ^{6}Li, Au:Sat., k=1.0360	BAM77
21 ± 4		1971	e		AGM71
17.01		2006	e		endfb7
27.26		2004	e		jeff31
20.64		2002	e		jendl33
65		2000	t		RaT99
32		1981	t		Har81
41		1976	t		HWF76
18.8		2002	t	MOST 2002	Gor02
16.6		2005	t	MOST 2005	Gor05

Libraries status: ^{88}Sr



MACS status: ^{89}Y

Maxwellian Averaged Cross Section (MACS) @ 30 keV

Karlsruhe Astrophysical Database of Nucleosynthesis in Stars • KADoNiS

List of all available values

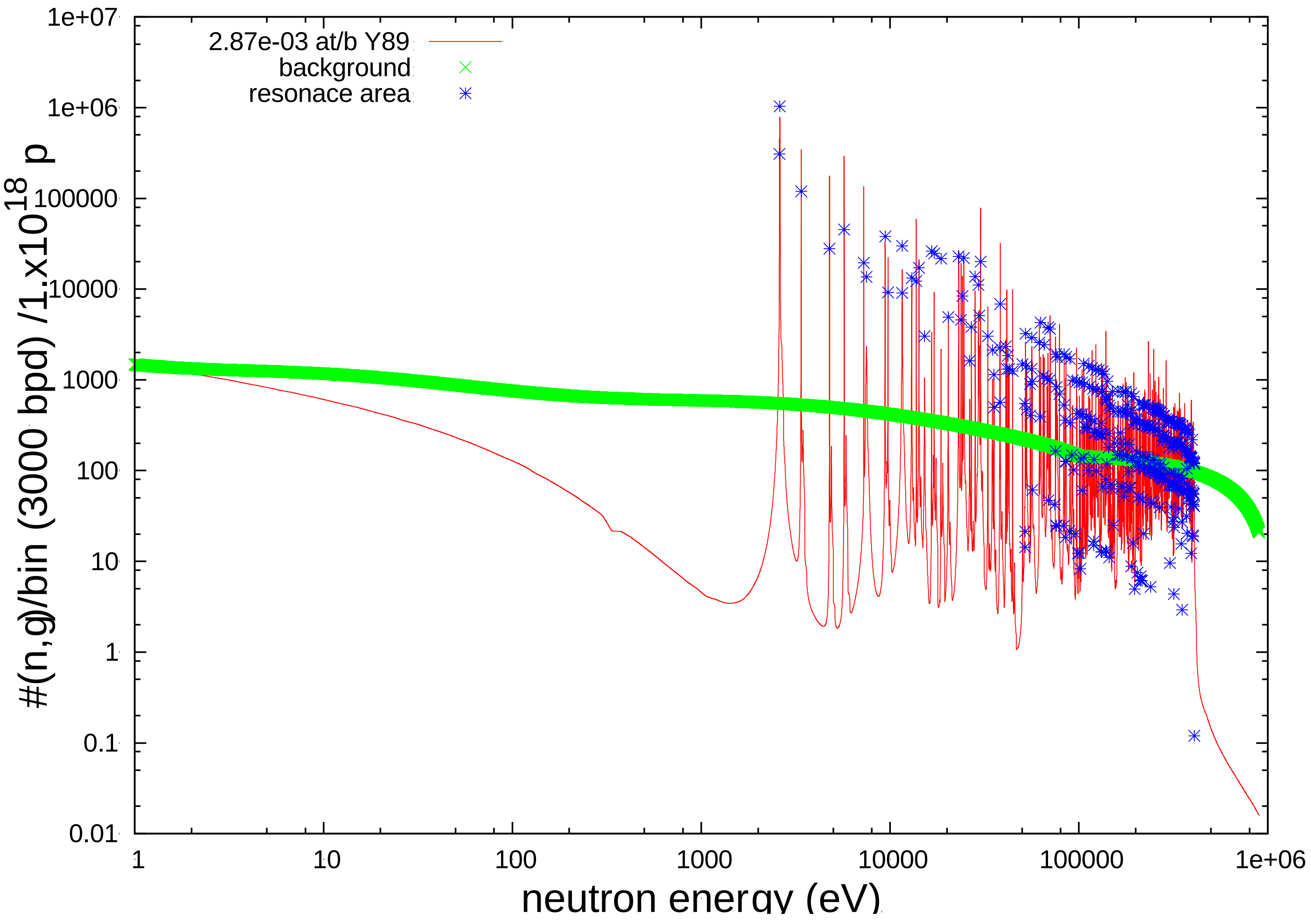
original	renorm.	year	type	Comment	Ref
9.40 ± 0.63 E(n,av.)= 30 (4) keV		2011	c	Pelletron, TOF, Au:ENDF/B-VI and MaG67b	KHI11
6.01 ± 0.17		2000	c	LinAc, TOF, Au: Sat.; DC component is 0.61 mb	Koe00, Koe00E
6.13 ± 0.18	6.61 ± 0.19	1990,2015	c	VdG, Act., 1/v(kT), Au:RaK88 corrected by 632/586= 1.0785	KZB90
6.5 ± 0.3		1989	c	Linac, TOF, ^{6}Li, Au:Sat.	Mac89
6.2 ± 0.5		1978	c,2	Linac, TOF, ^{6}Li, Au:Sat., k=1.0737	MAM78a
5.6 ± 0.5		1976	c	Linac, TOF, ^{6}Li, Au:Sat.	BAM76
6.9 ± 1.7		1967	c	VdG, TOF, ^{181}Ta:762mb	MaG67b
5.22		2011	e	ENDF/B-VII.1	endfb71
5.33		2011	e	JENDL-4.0	jendl40
0.85		2004	e	JEFF-3.1	jeff31
6.35		2002	e	JENDL-3.3	jendl33
6.9 ± 2.5		1971	e		AGM71
5.02		2005	t	MOST 2005	Gor05
5.59		2002	t	MOST 2002	Gor02
13		2000	t	NON-SMOKER	RaT99
12.5		1981	t		Har81
9.5		1976	t		HWF76

Samples & Protons

Sample	Mass(g)	Purity	Thickness (at/b)	No. of protons($x10^{18}$)
^{88}Sr	4	99.9	3.88×10^{-3}	1,5
^{89}Y	3	99.9	2.87×10^{-3}	1.0
Au				0.2
Empty frame				0.4
Filters				0.2
Al(can)				0.2
Total				**3.5**

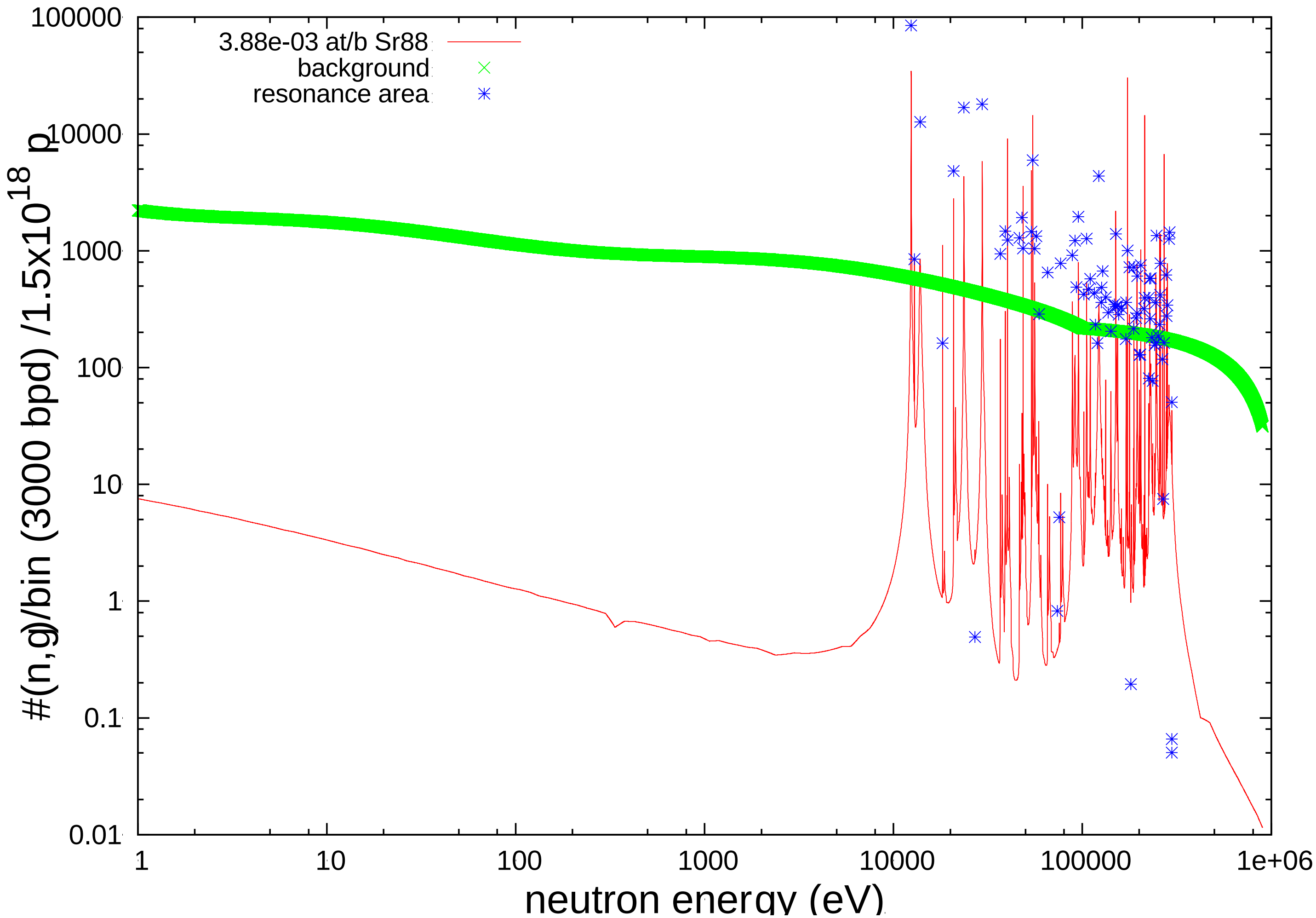
Proton request: ^{89}Y

Count rate estimates for ^{89}Y



Proton request: ^{88}Sr

Count rate estimates for ^{88}Sr



Conclusion

- We propose to measure the $^{88}Sr(n,\gamma)$, $^{89}Y(n,\gamma)$ cross sections with an accuracy better than 5% in the neutron energy region from thermal to 50 keV and 10% from 50 up 100 keV
- The measure should be performed at n_TOF EAR-1
- The total number of protons required to perform the measurements is 3.5×10^{18}