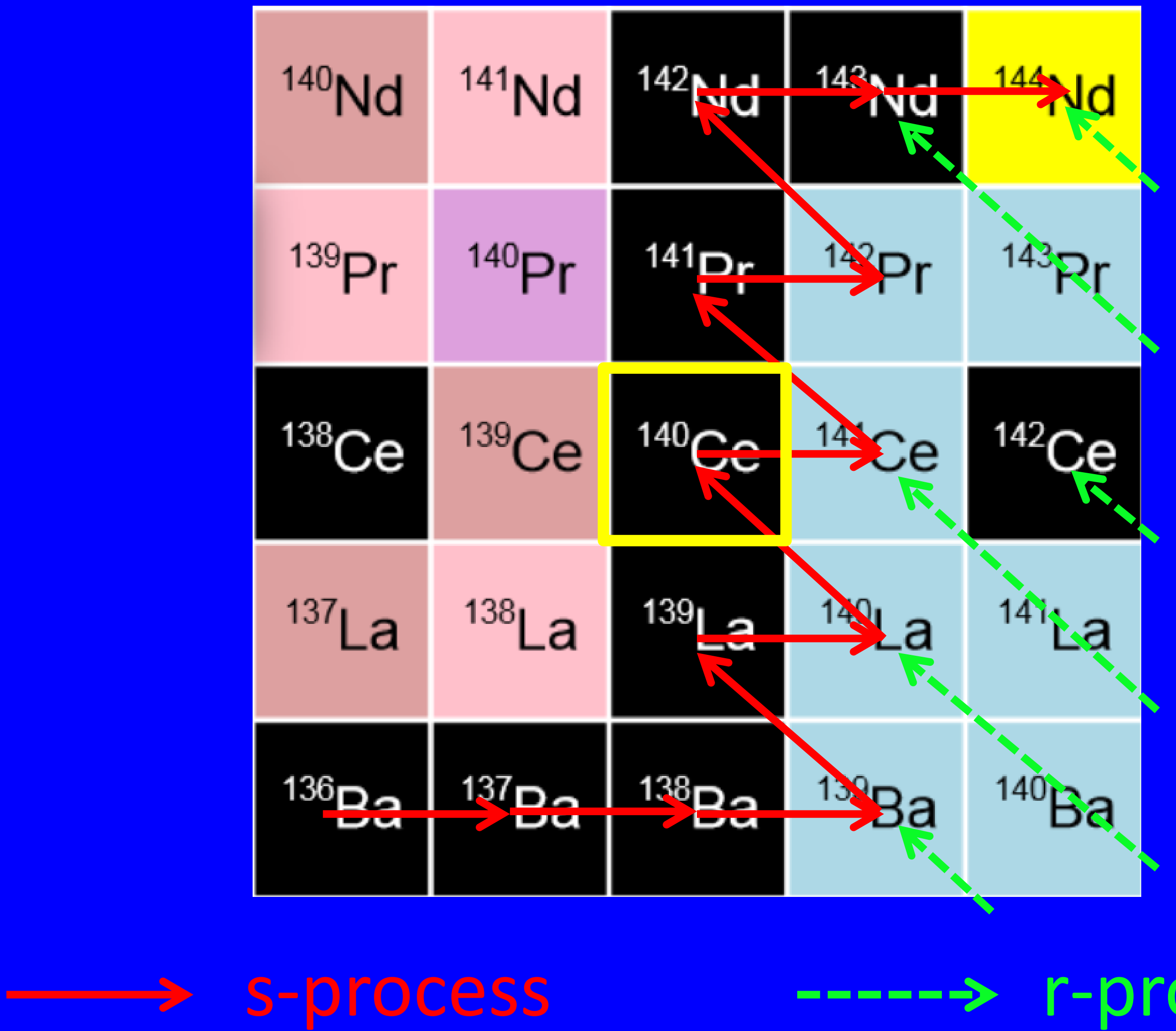
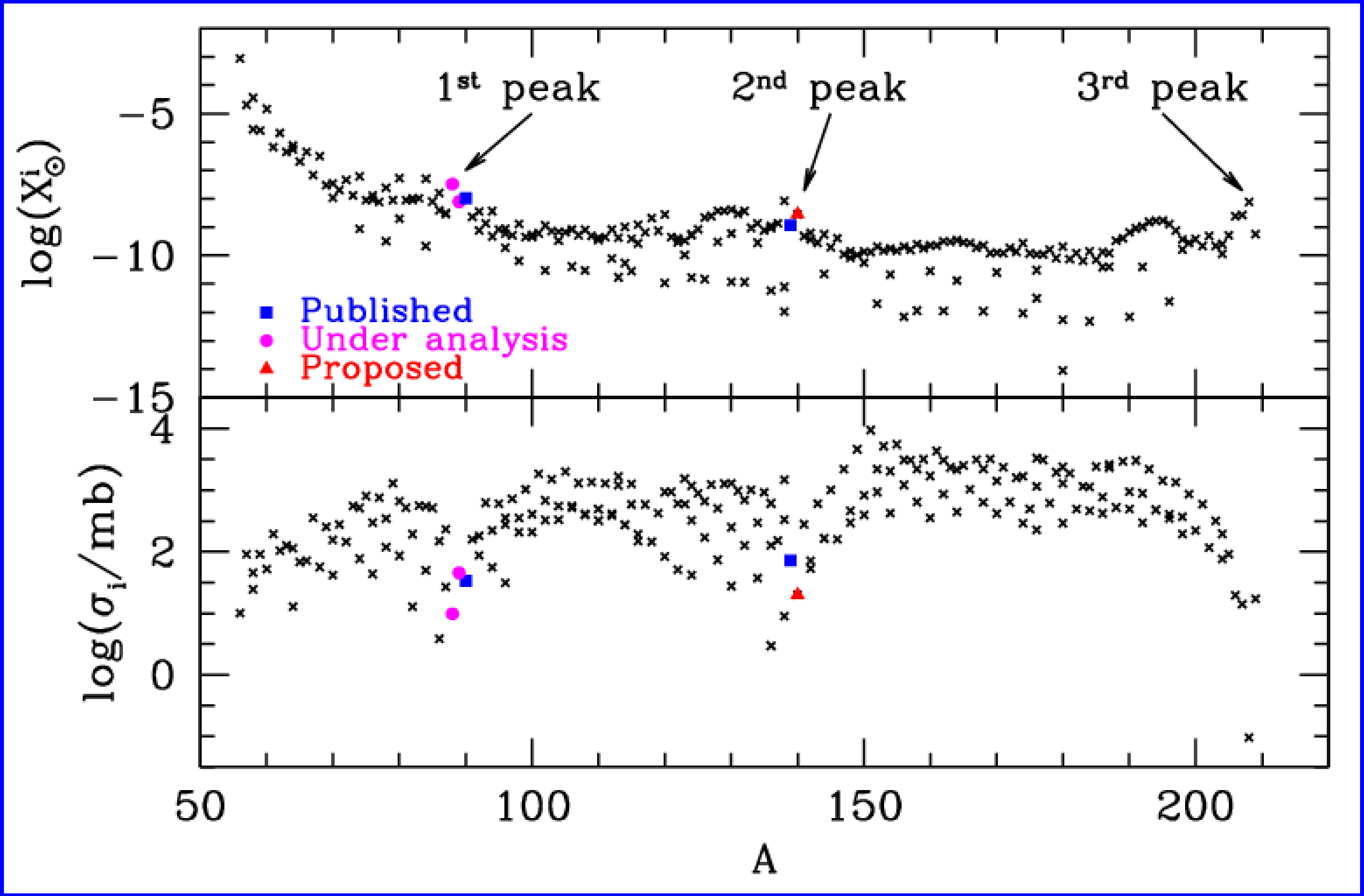
The $^{140}Ce(n,\gamma)^{141}Ce$ reaction at n_TOF-EAR1: a litmus test for theoretical stellar models.



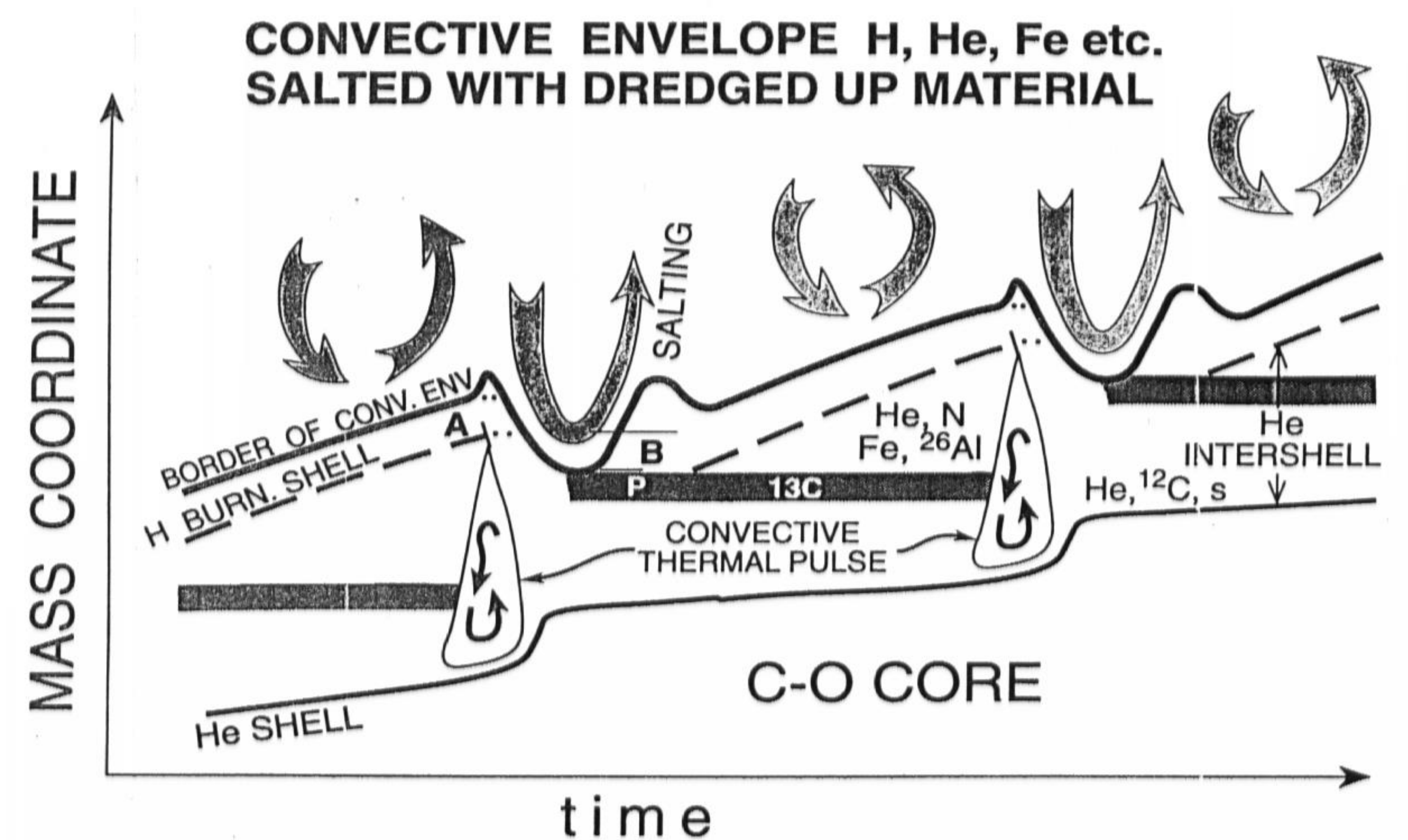
The solar distribution and the s-process peaks



Magic nuclei are bottlenecks for the s-process nucleosynthesis

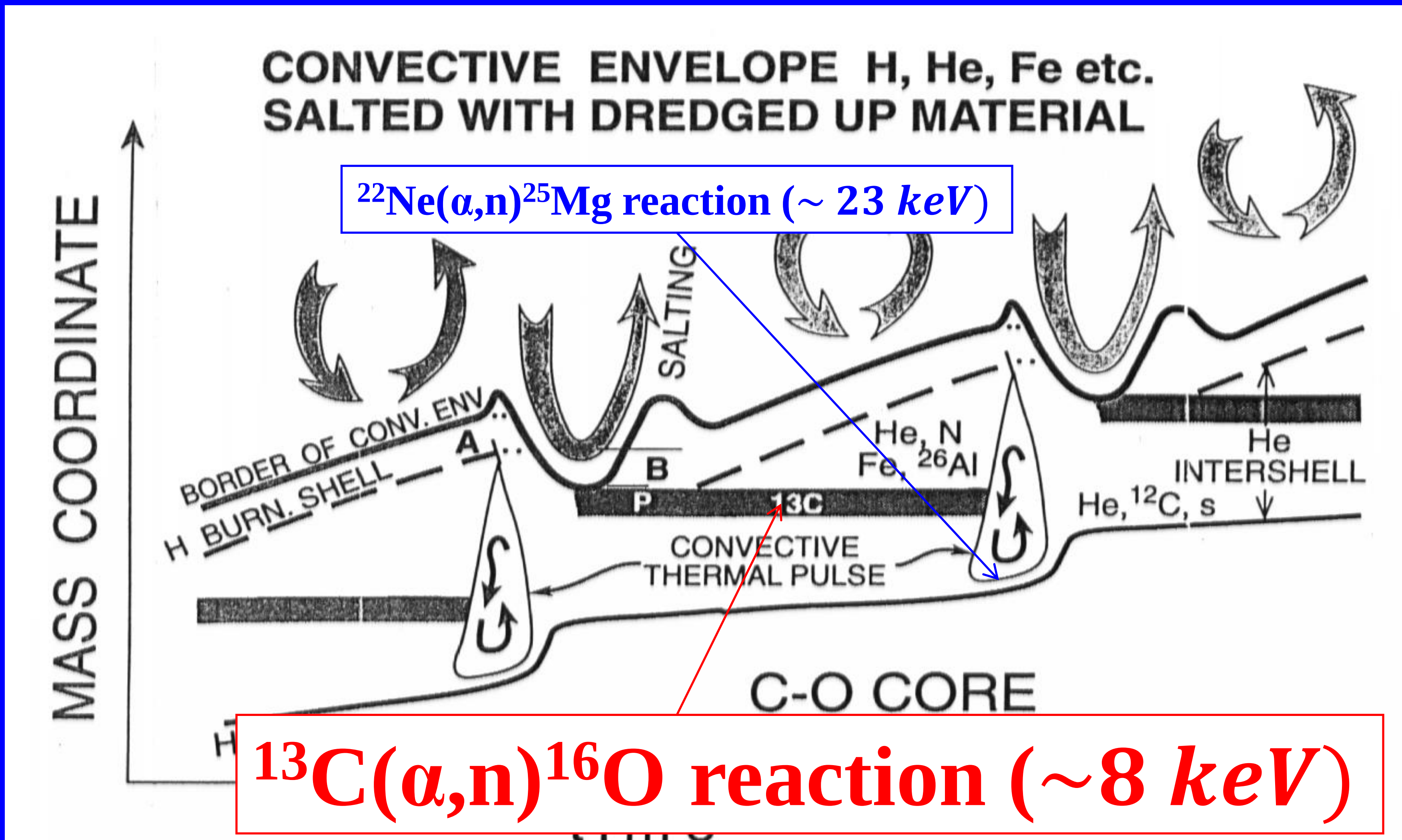
N=50 : ^{88}Sr, ^{89}Y, ^{90}Zr N=82 : ^{138}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{142}Nd N=126 : ^{208}Pb

The s-process in Asymptotic Giant Branch (AGB) stars



Busso et al. 1999

The s-process in Asymptotic Giant Branch (AGB) stars



Busso et al. 1999

The s-process in Globular Clusters

Roederer+ 2011 (6 stars)

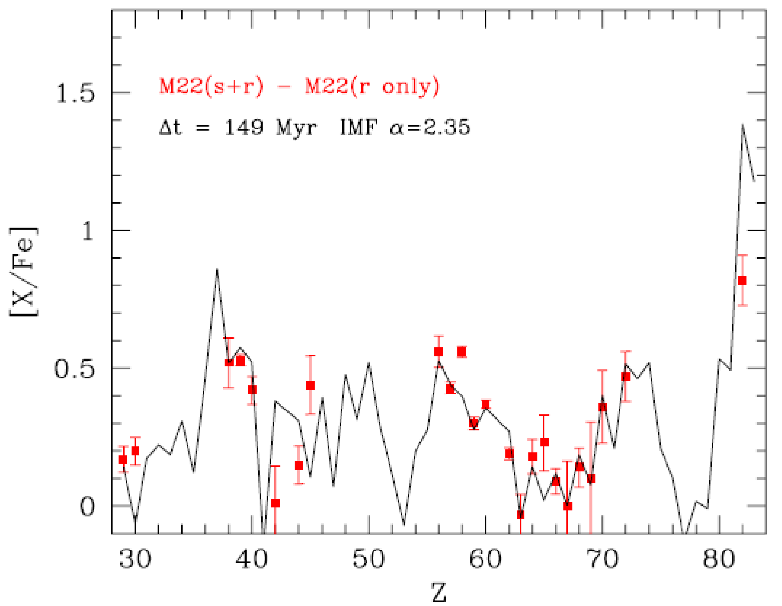


Figure 11. Best fit of the average *s*-process chemical pattern of stars in M22.

Young+ 2008 (14 stars)

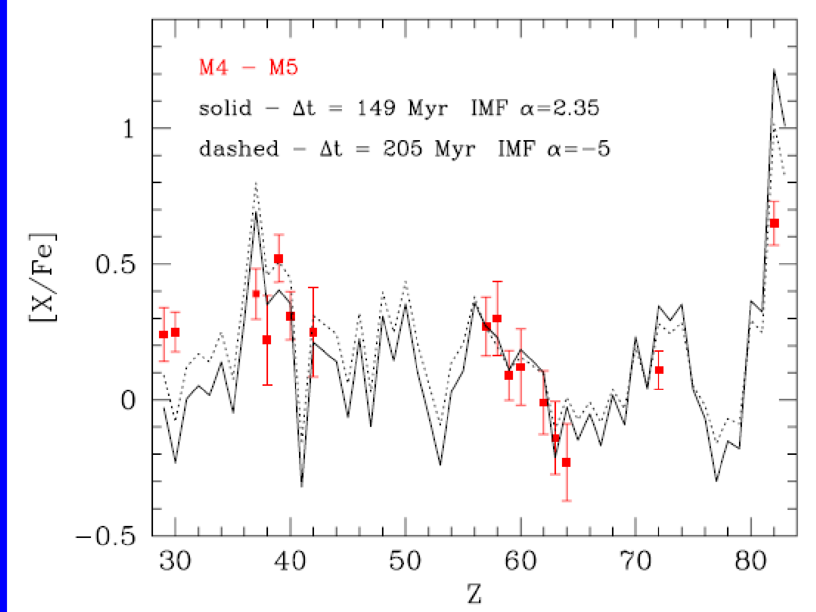


Figure 13. Best fit of the average *s*-process chemical pattern of stars in M4.

Straniero, Cristallo & Piersanti 2014

The pollution of AGB stars with a mass ranging between 3 to 6 M_{SUN} may account for most of the features of the *s*-process enrichment of M4 and M22.

M22

M4

M5

The s-process in Globular Clusters

Roederer+ 2011 (6 stars)

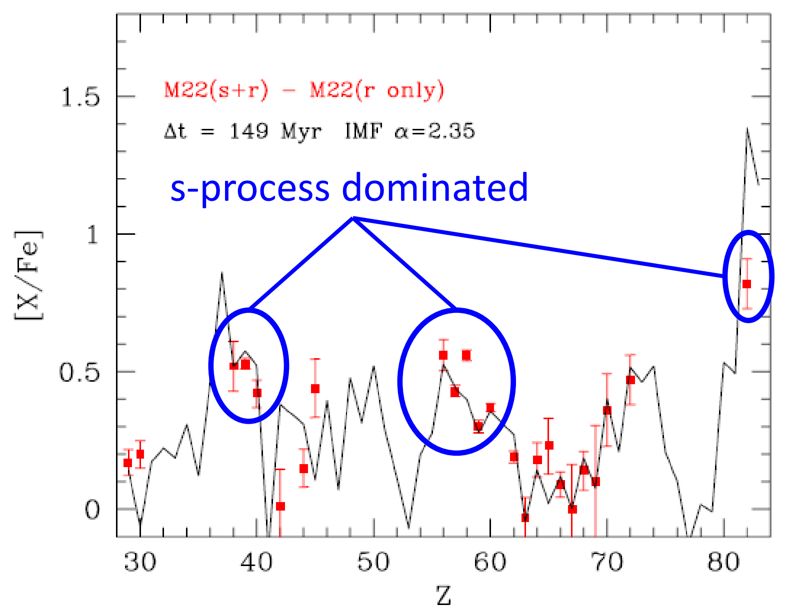


Figure 11. Best fit of the average *s*-process chemical pattern of stars in M22.

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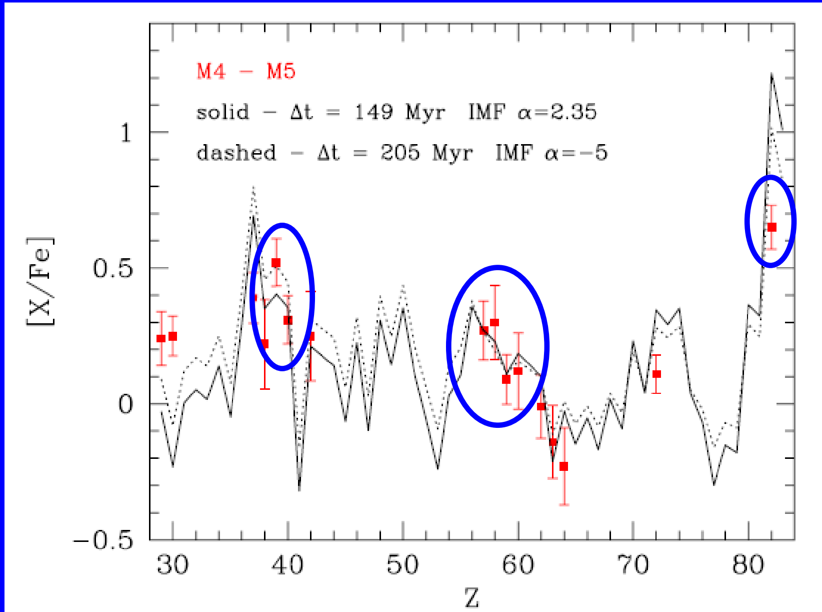

Figure 13. Best fit of the average *s*-process chemical pattern of stars in M4.

Straniero, Cristallo & Piersanti 2014

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M4

M5

The s-process in Globular Clusters

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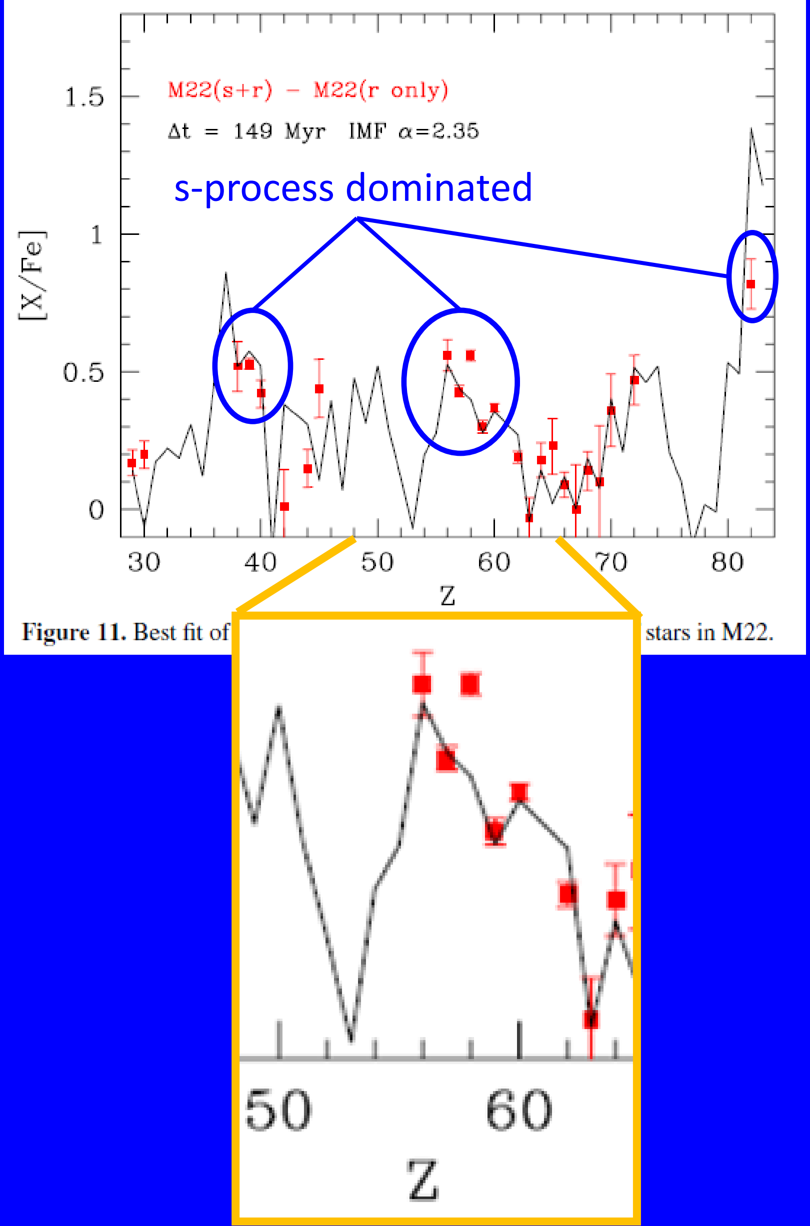


Figure 11. Best fit of ... stars in M22.

Young+ 2008 (14 stars)

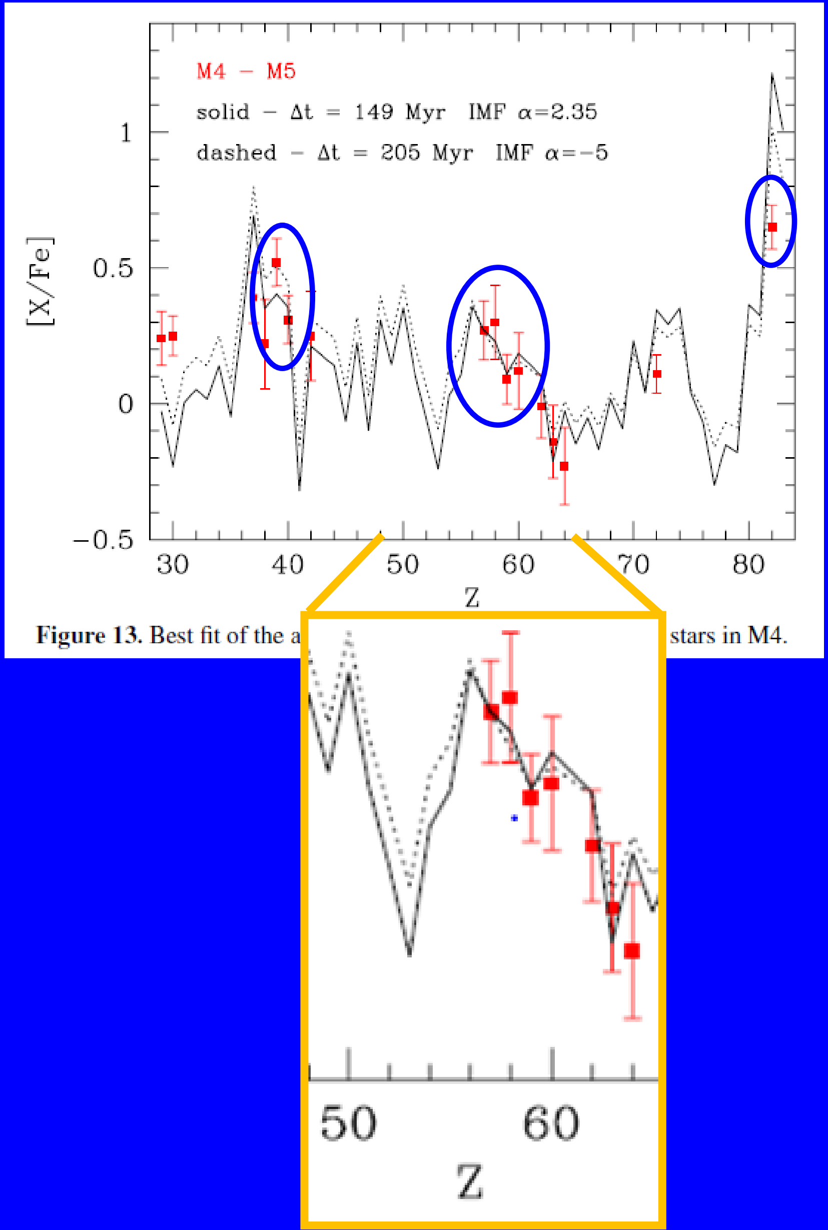
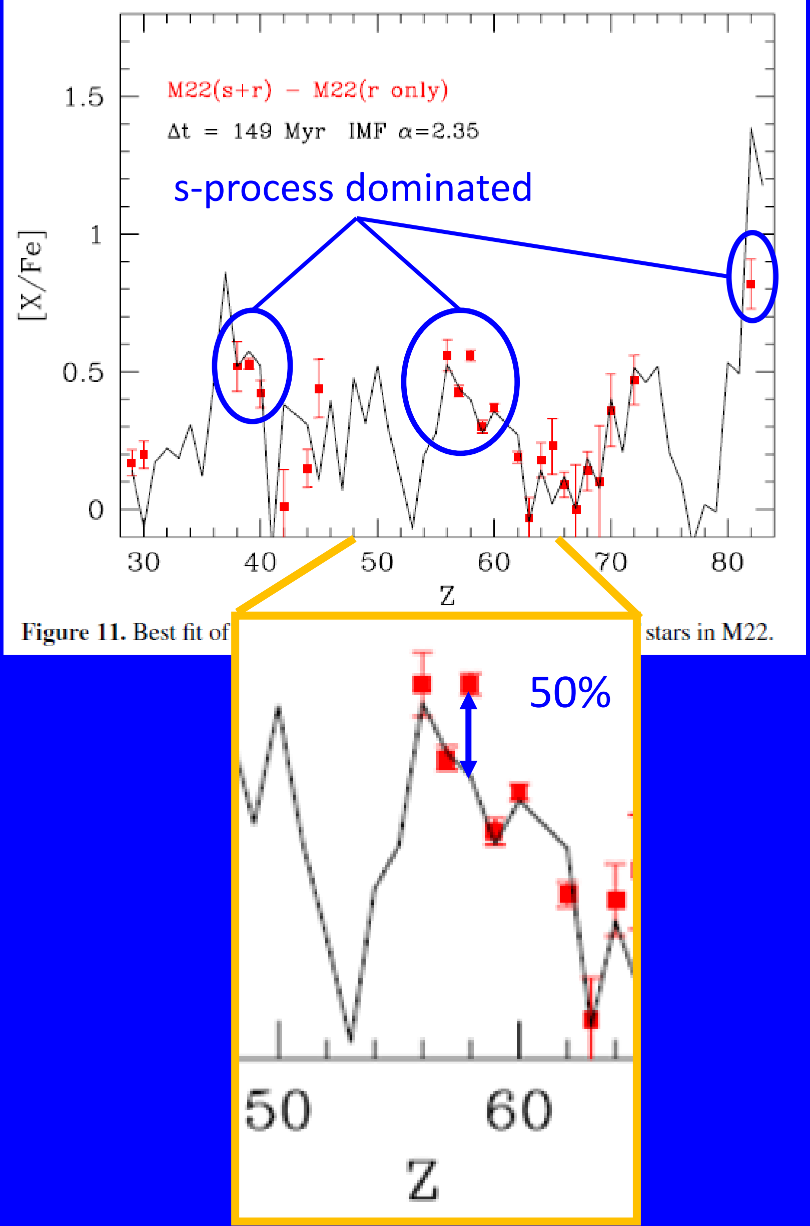


Figure 13. Best fit of the a... stars in M4.

The s-process in Globular Clusters

Roederer+ 2011 (6 stars)



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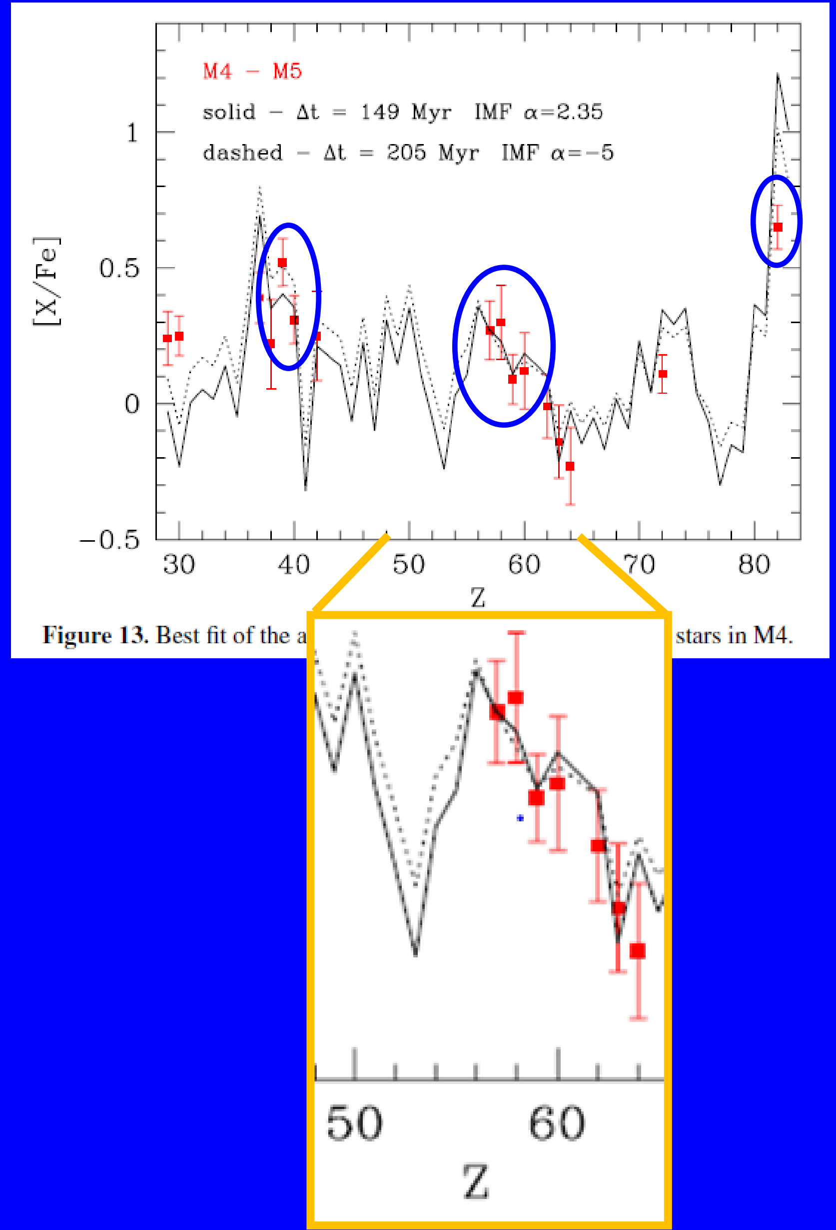

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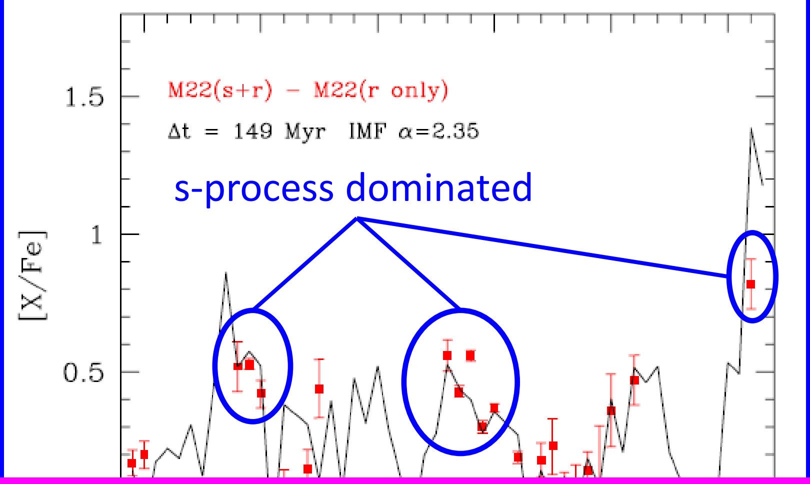

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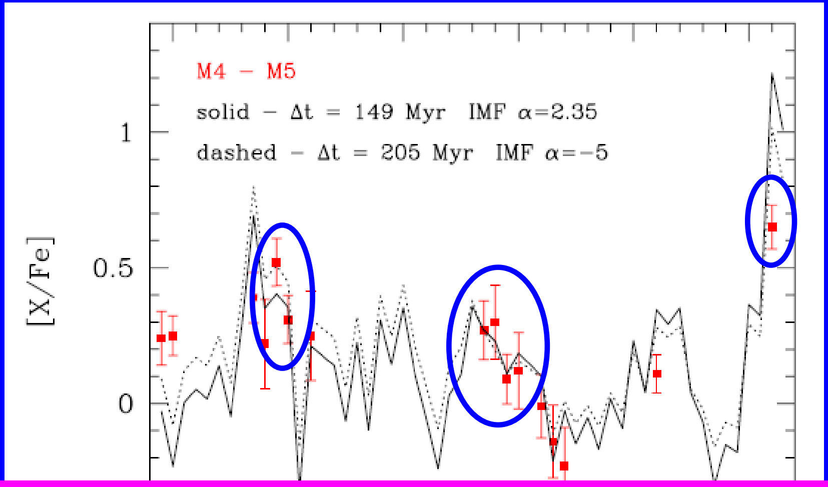

1. From the observational point of view, data relative to Ce are very robust.
2. Stellar models uncertainties affect the average absolute values of the three peaks and their relative ratios.
3. Within a single peak the relative distribution is determined by ***nuclear inputs***.

Cerium

^{140}Ce is the most abundant cerium isotope (88%)

→ (n,γ)

↖ β^{-} decay

Its production channel has already been explored by the n_TOF collaboration (Terlizzi+ 2007)

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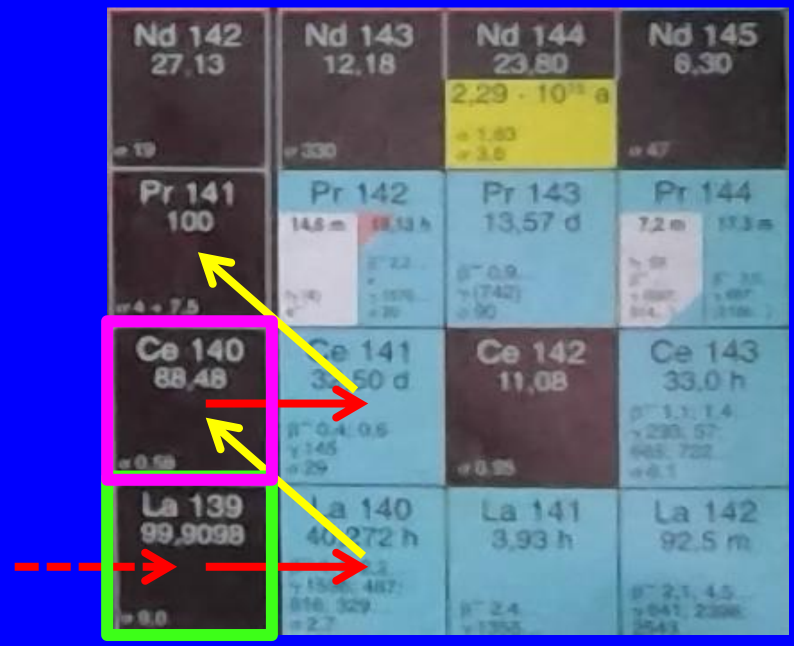
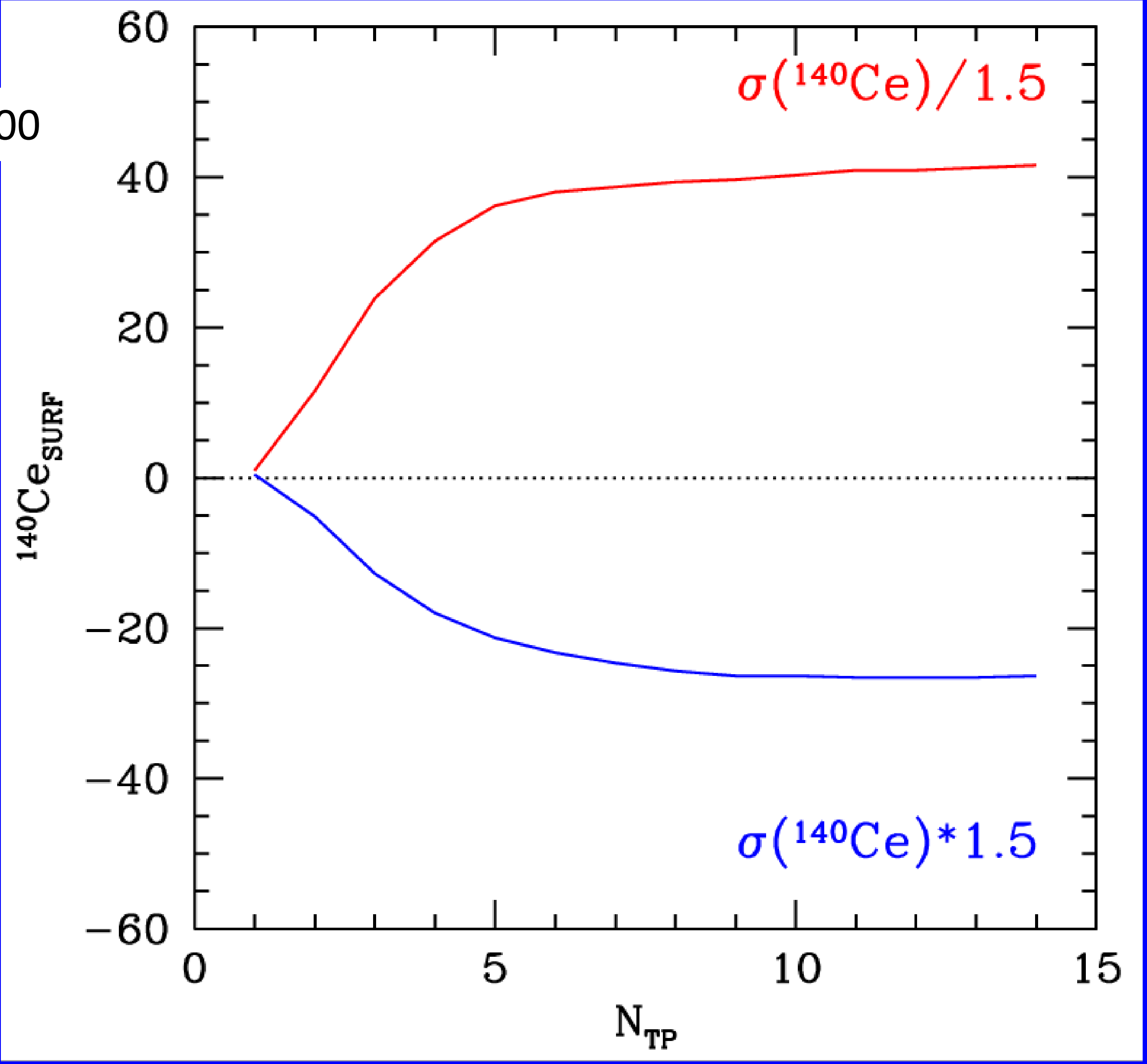


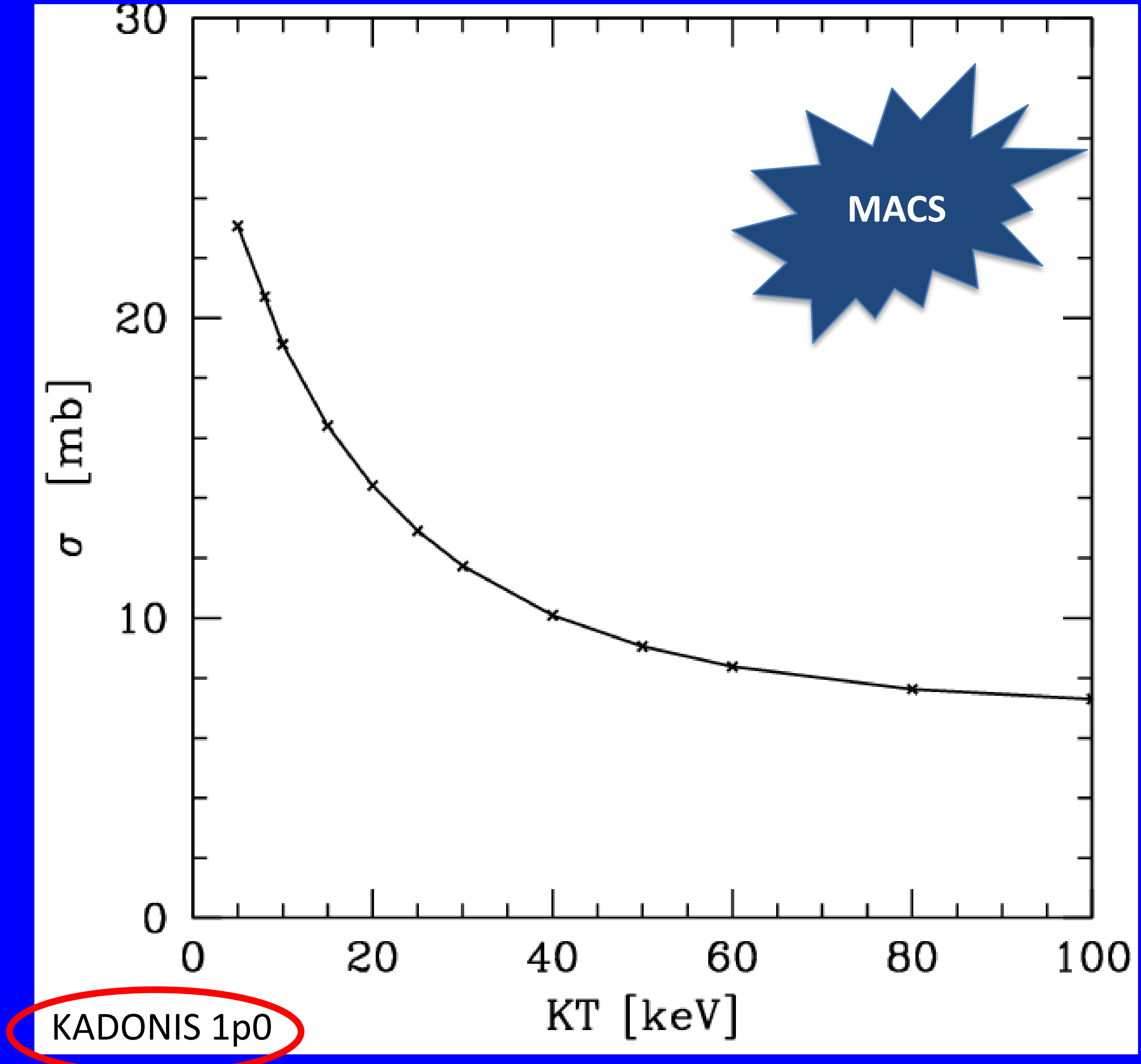
Its production channel has already been explored by the n_TOF collaboration (Terlizzi+ 2007)

Expected variations on a theoretical AGB model ($M=4\ M_{SUN}$)

(Case-REF)/REF*100



^{140}Ce neutron capture cross section (I)



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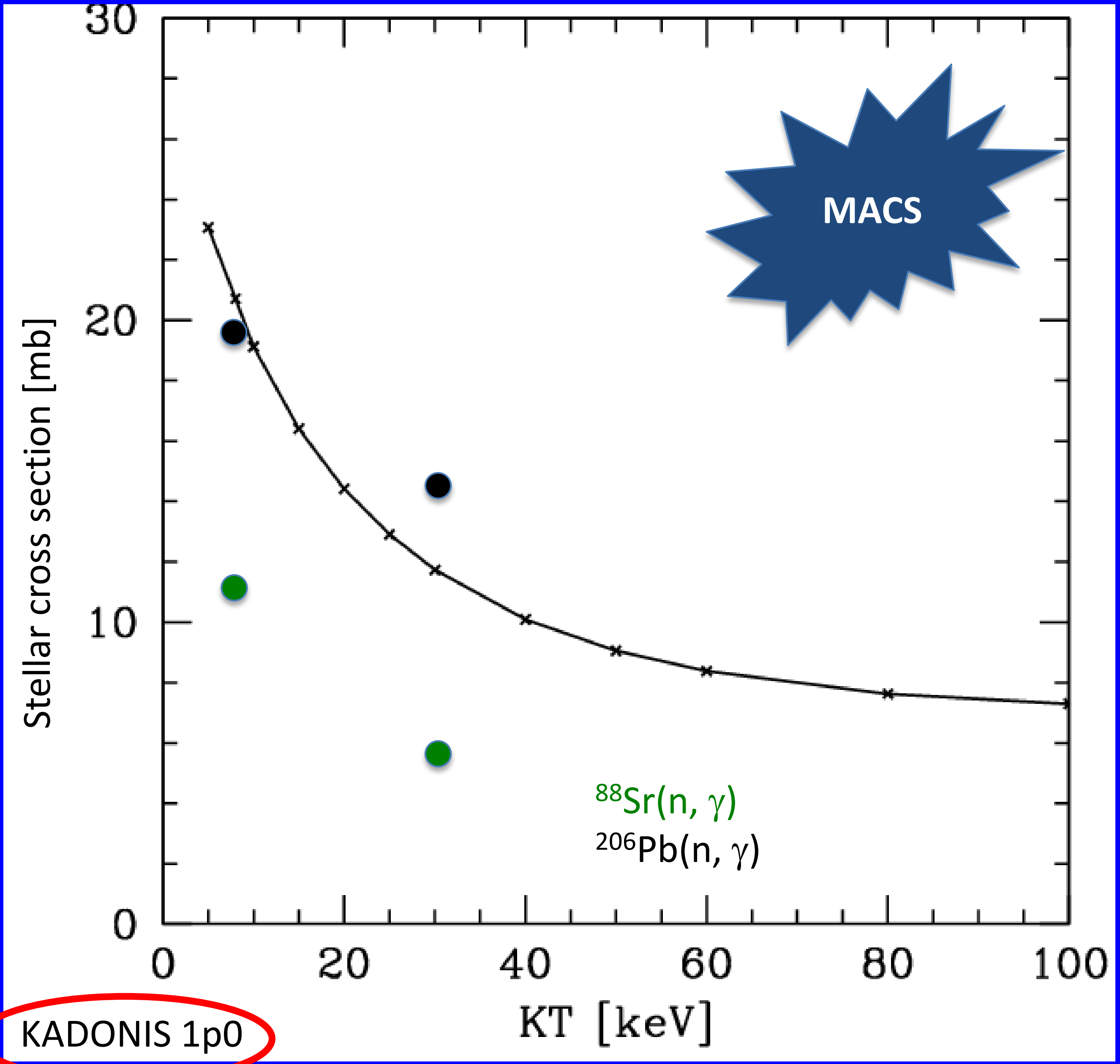

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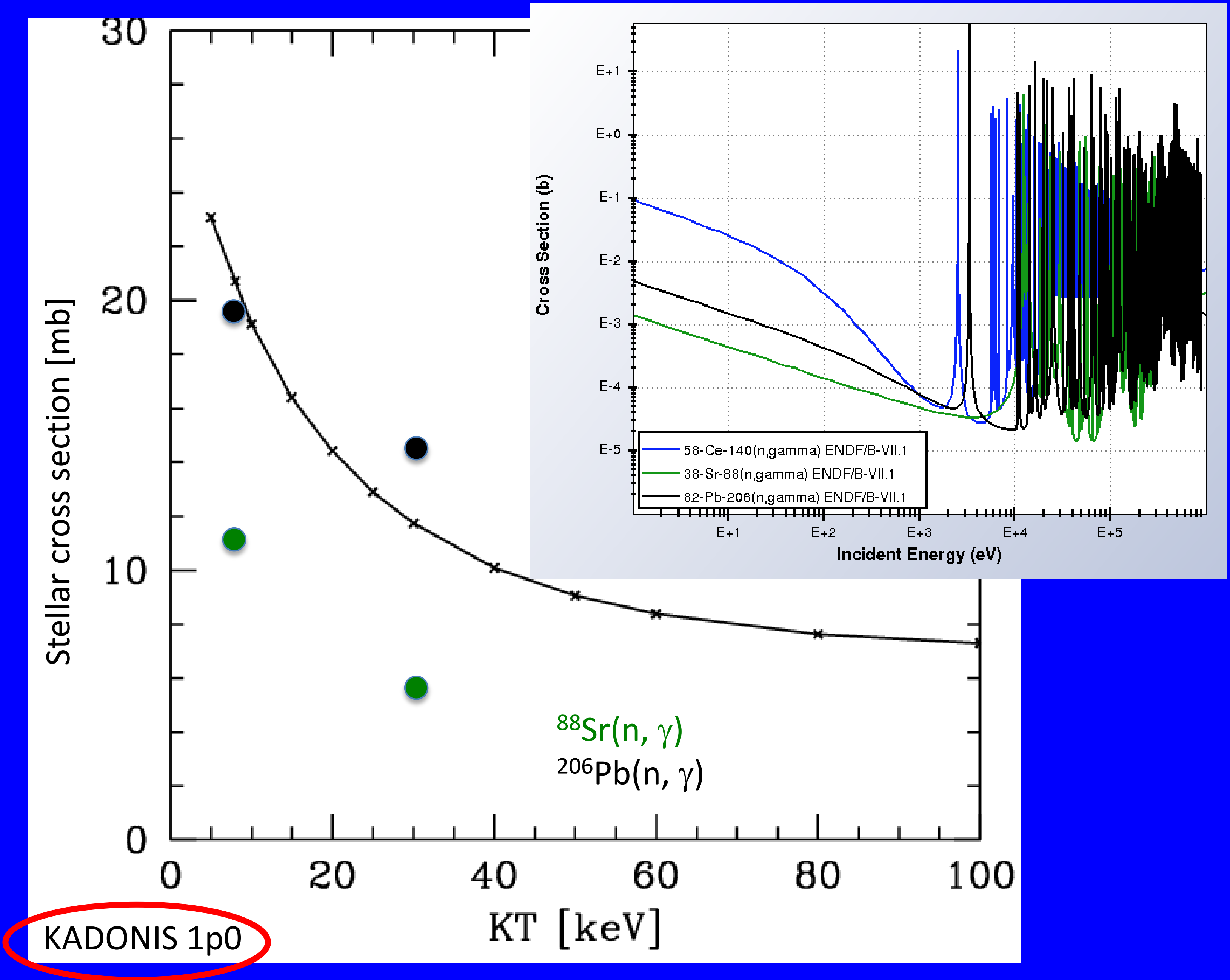
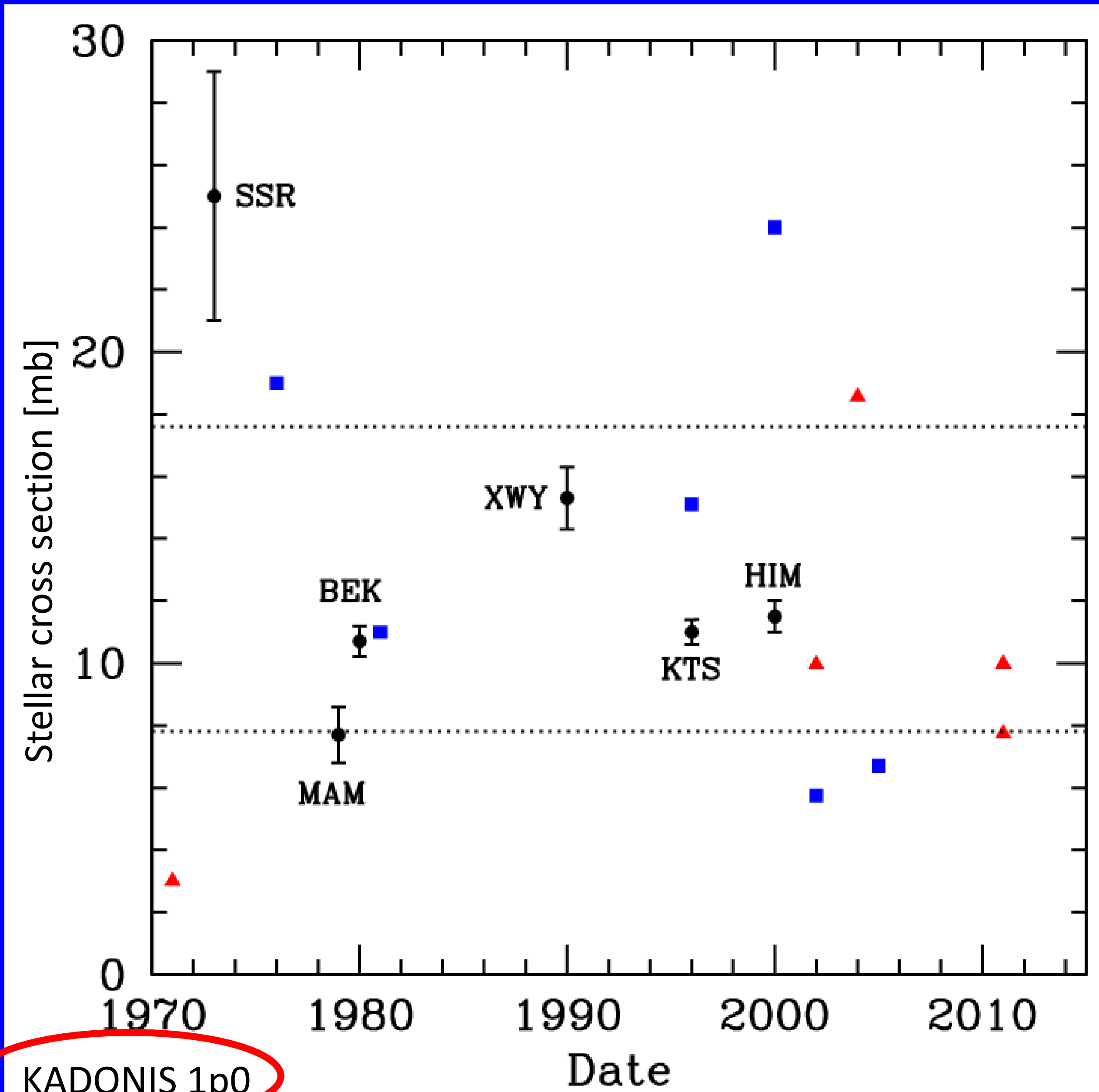


^{140}Ce neutron capture cross section (II)



SSR (1973)
K. Siddappa+, Nuovo Cim. **18A**, 48

MAM (1979)
A.de L. Musgrove+, Aust. J. Phys. **32**, 213

XWY (1990)
Y. Xia+, Chin. J. Nucl. Phys. 12, 261

KTS (1996) + BEK (1980)
F. Käppeler+, Phys. Rev. C 53, 1397
H. Beer +, Phys. Rev. C 21, 534

HIM (2000)
S. Harnood+, J. Nucl. Sci. Techn.37 740

- Experimental
- Library
- Theoretical

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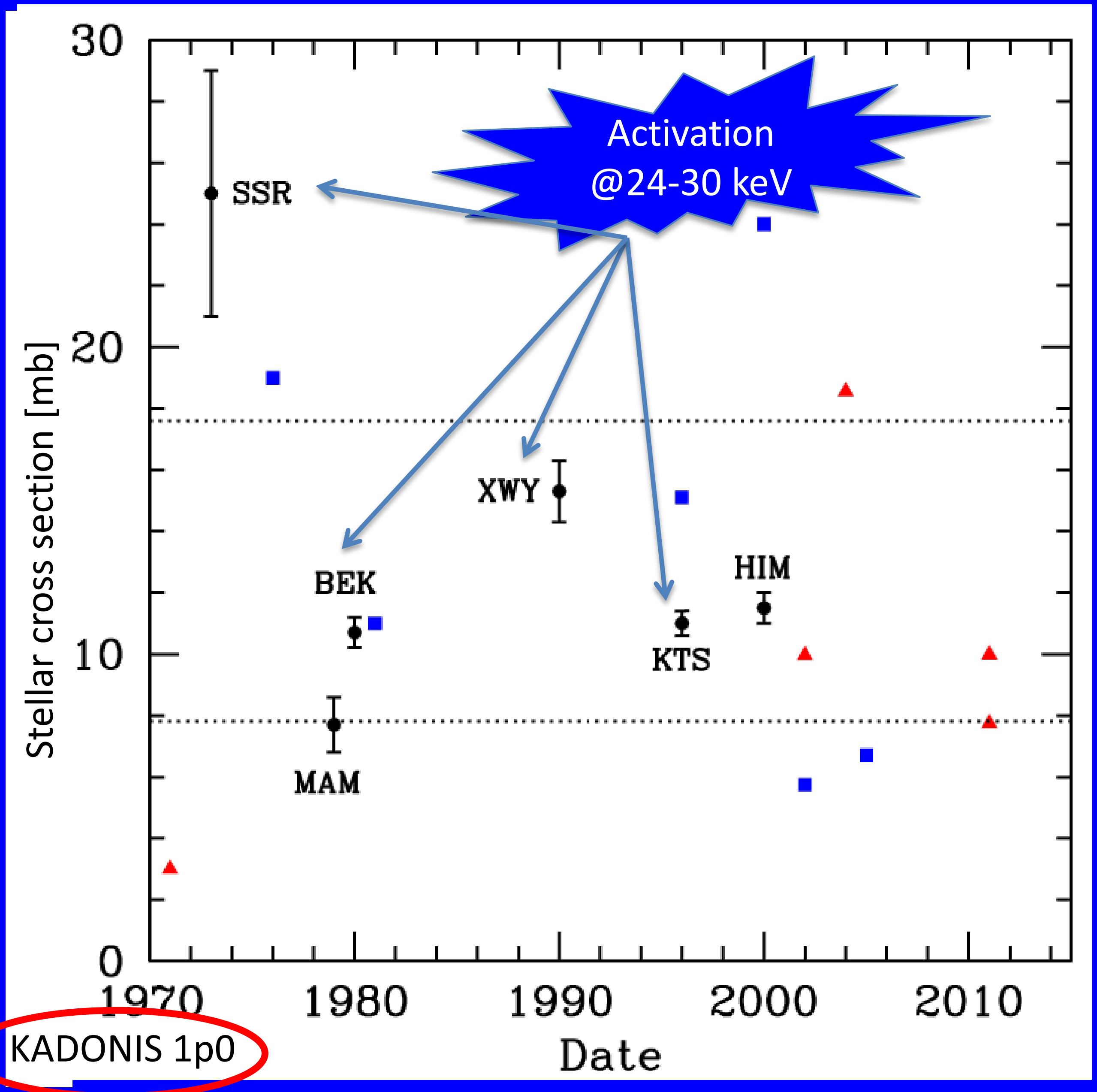

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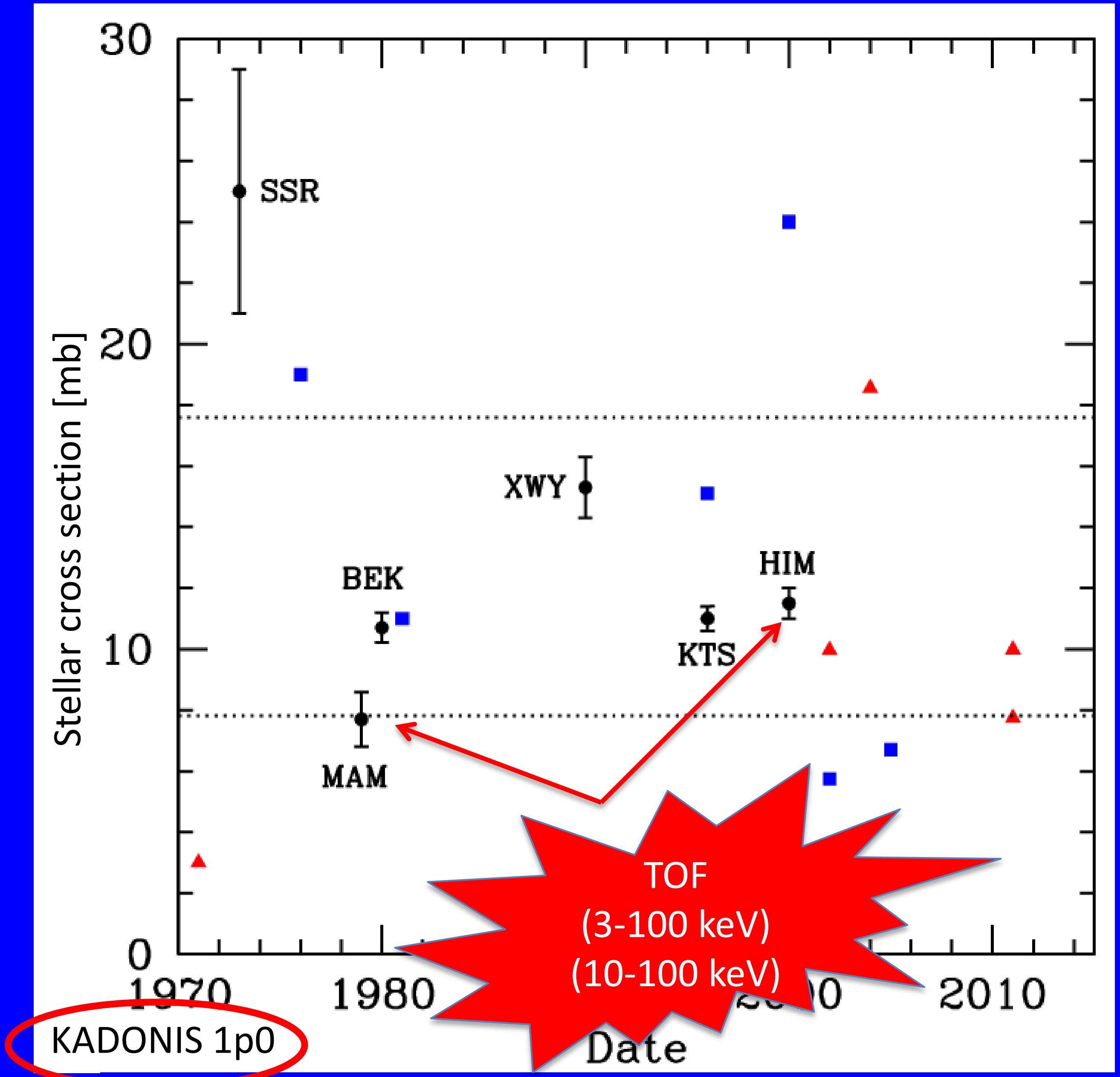

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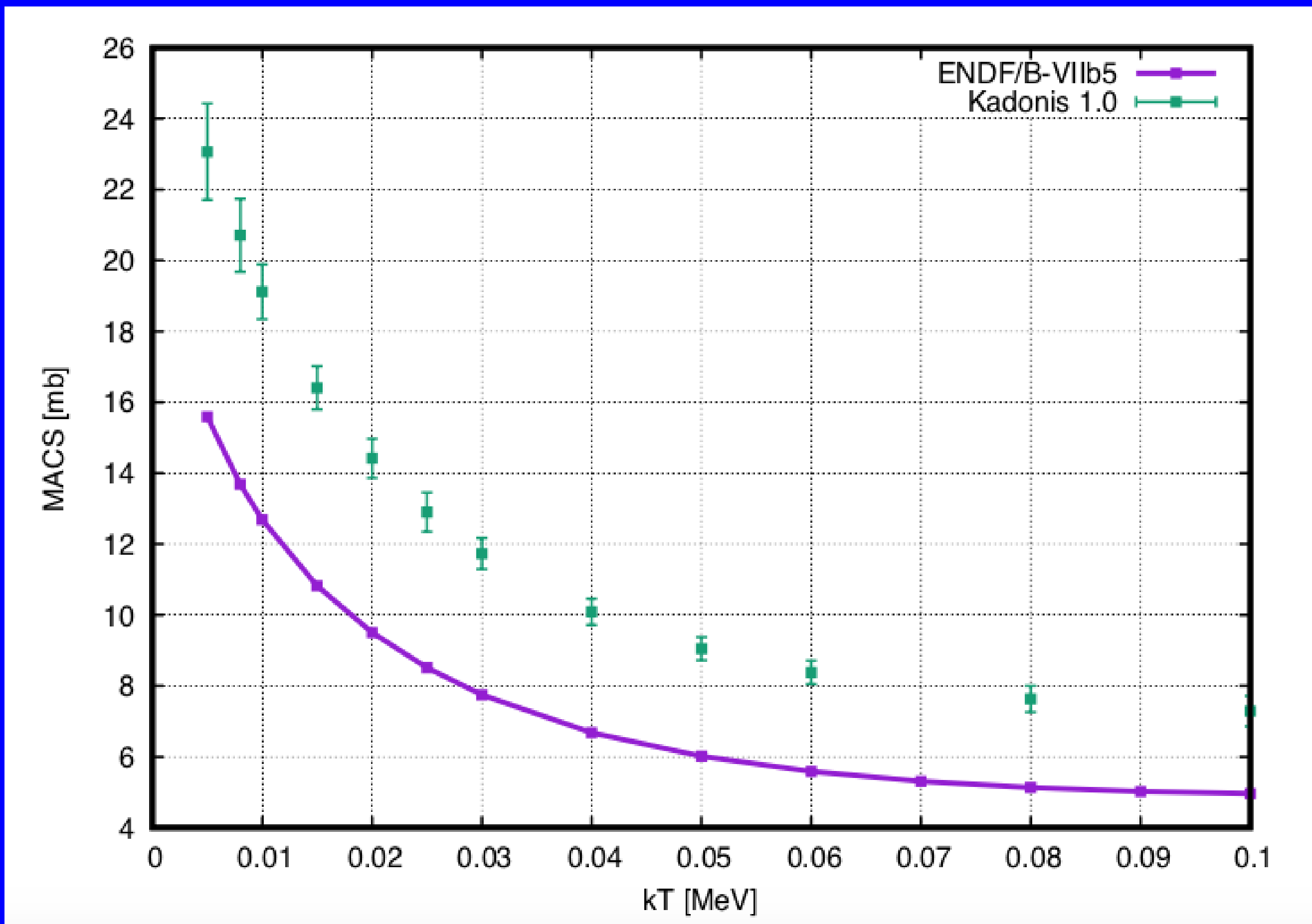

EVALUATIONS:

Capture ORELA 40 m, C_6F_6
5 < E_n < 100 keV
A.de L. Musgrove+, Aust. J. Phys. 32, 213

Transmission RPI 250 m
20 < E_n < 60 keV
H. S. Camarda. PRC 18, 1254

Transmission JAERI ^{nat}Ce
E_n < 60 keV
Ohkubo, jaeri report 1993

Capture (preliminary) 1974
En<65 keV
by Hacken (Columbia)

not published

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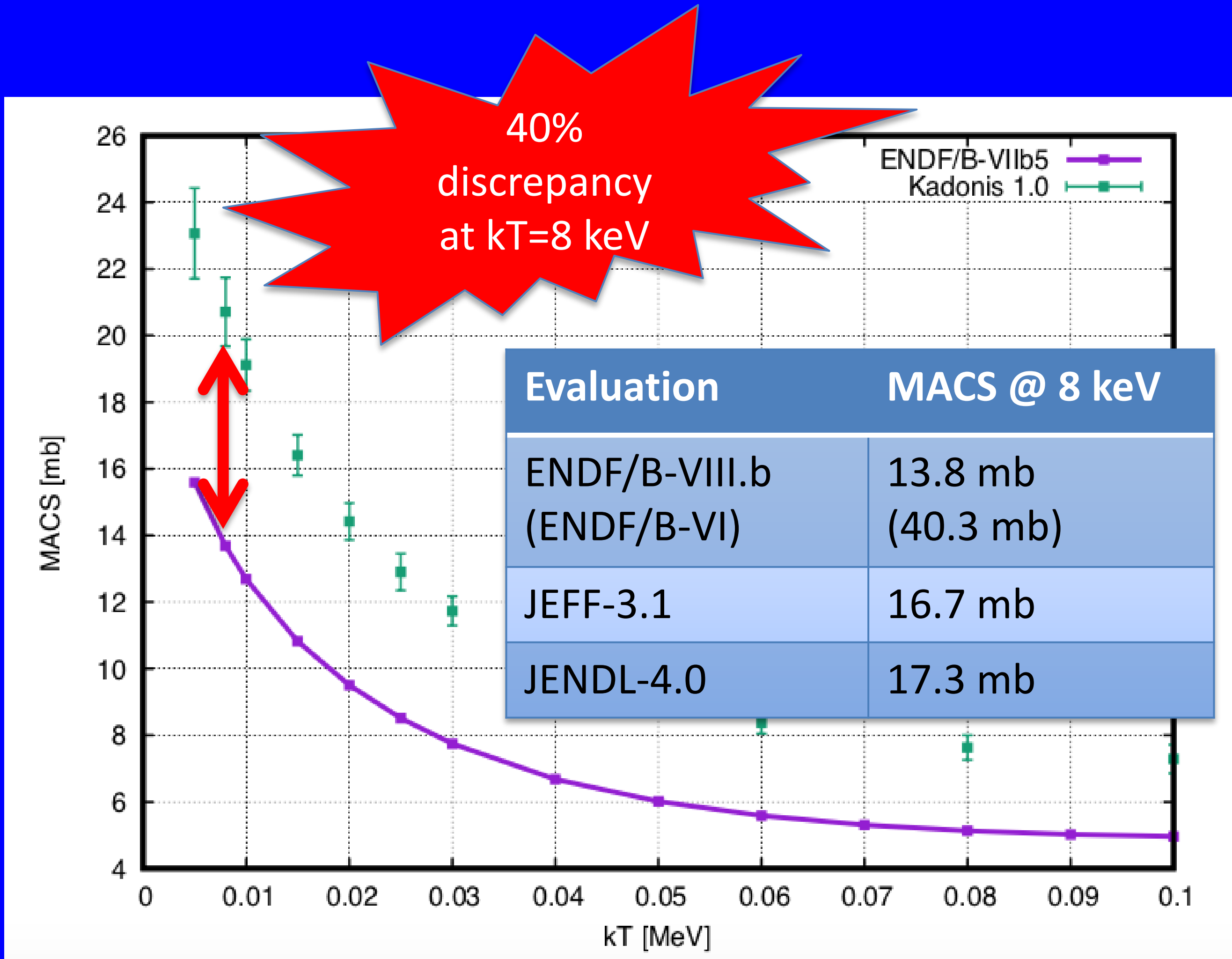

Evaluation	MACS @ 8 keV
ENDF/B-VIII.b (ENDF/B-VI)	13.8 mb (40.3 mb)
JEFF-3.1	16.7 mb
JENDL-4.0	17.3 mb

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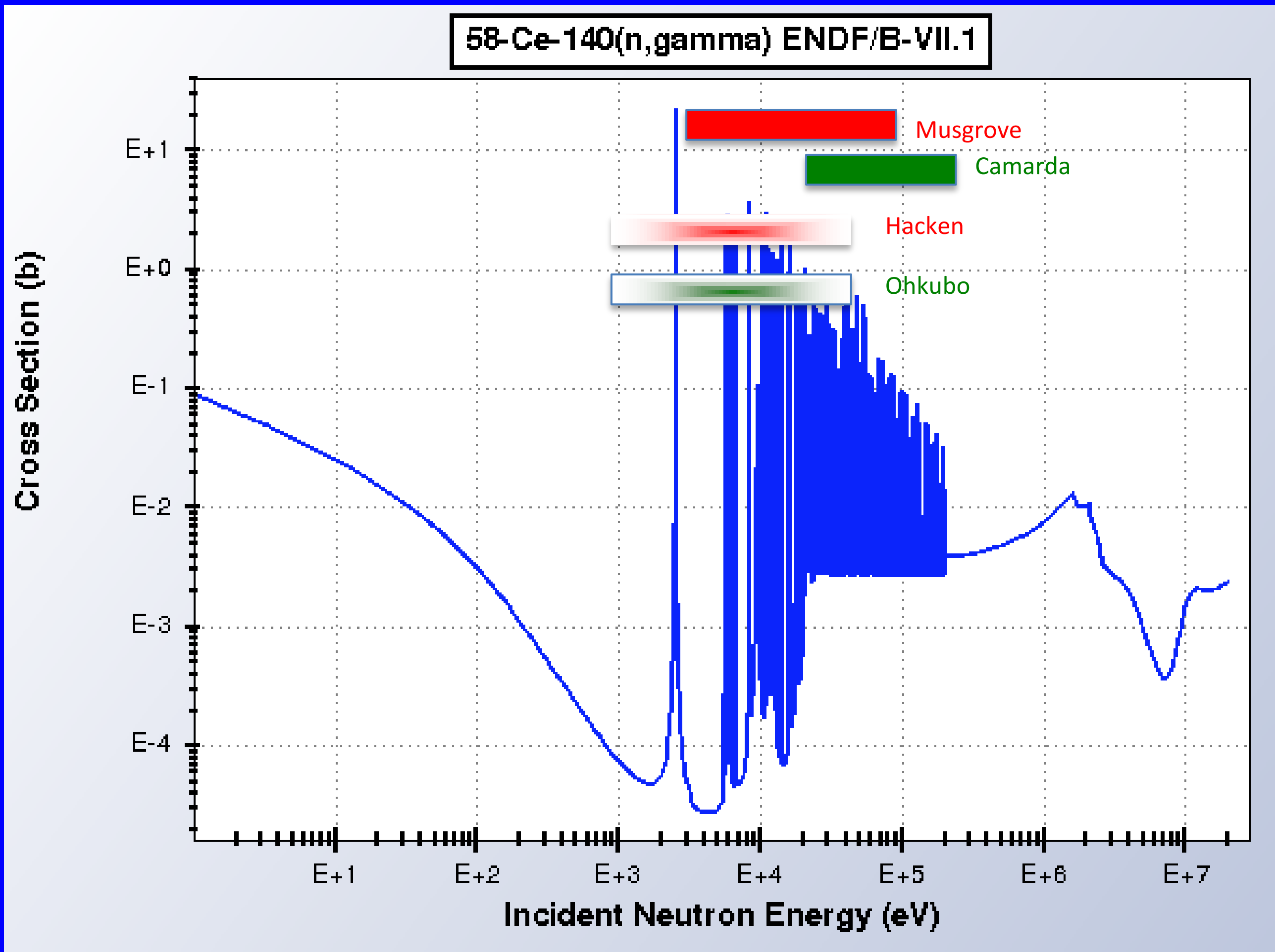

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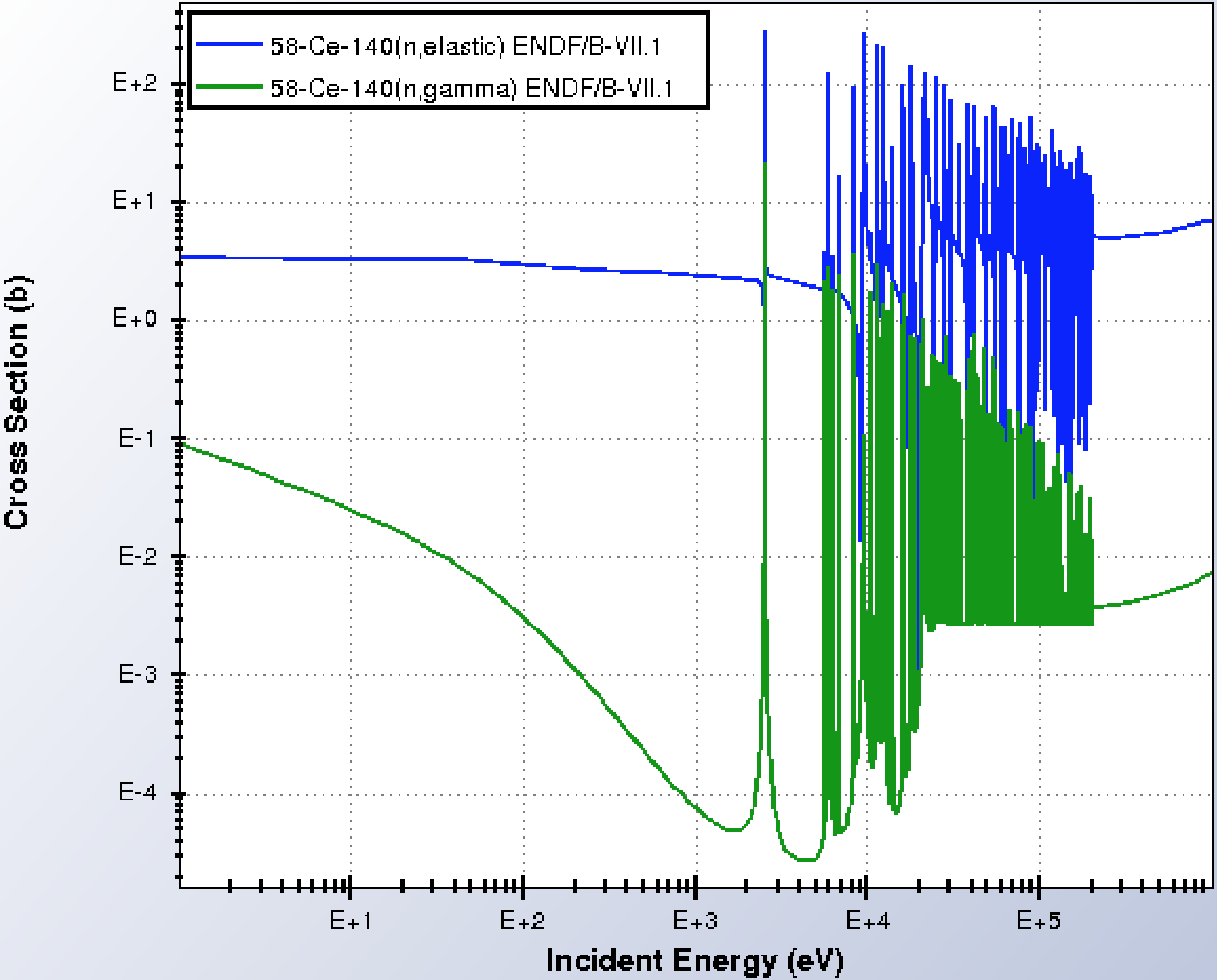
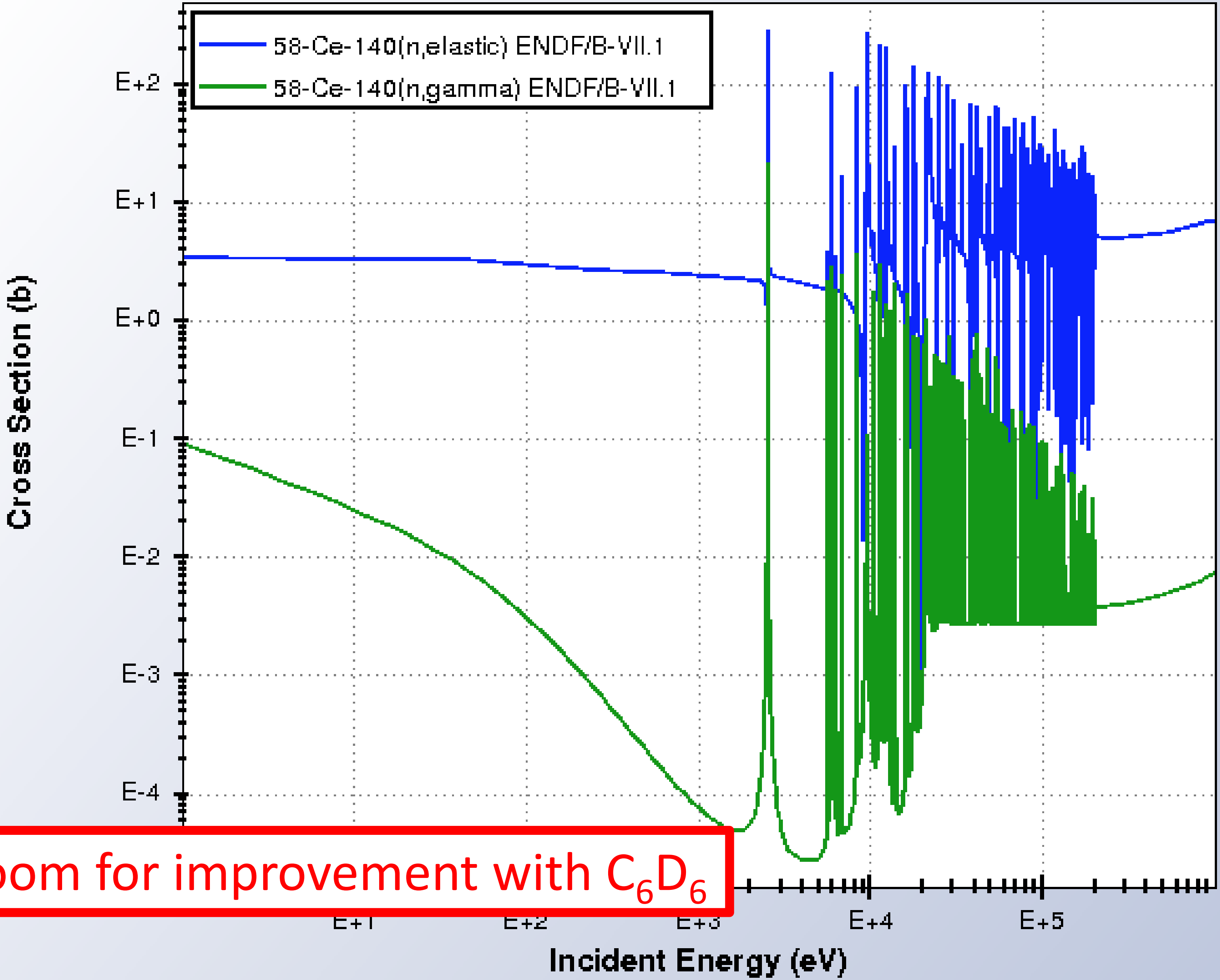
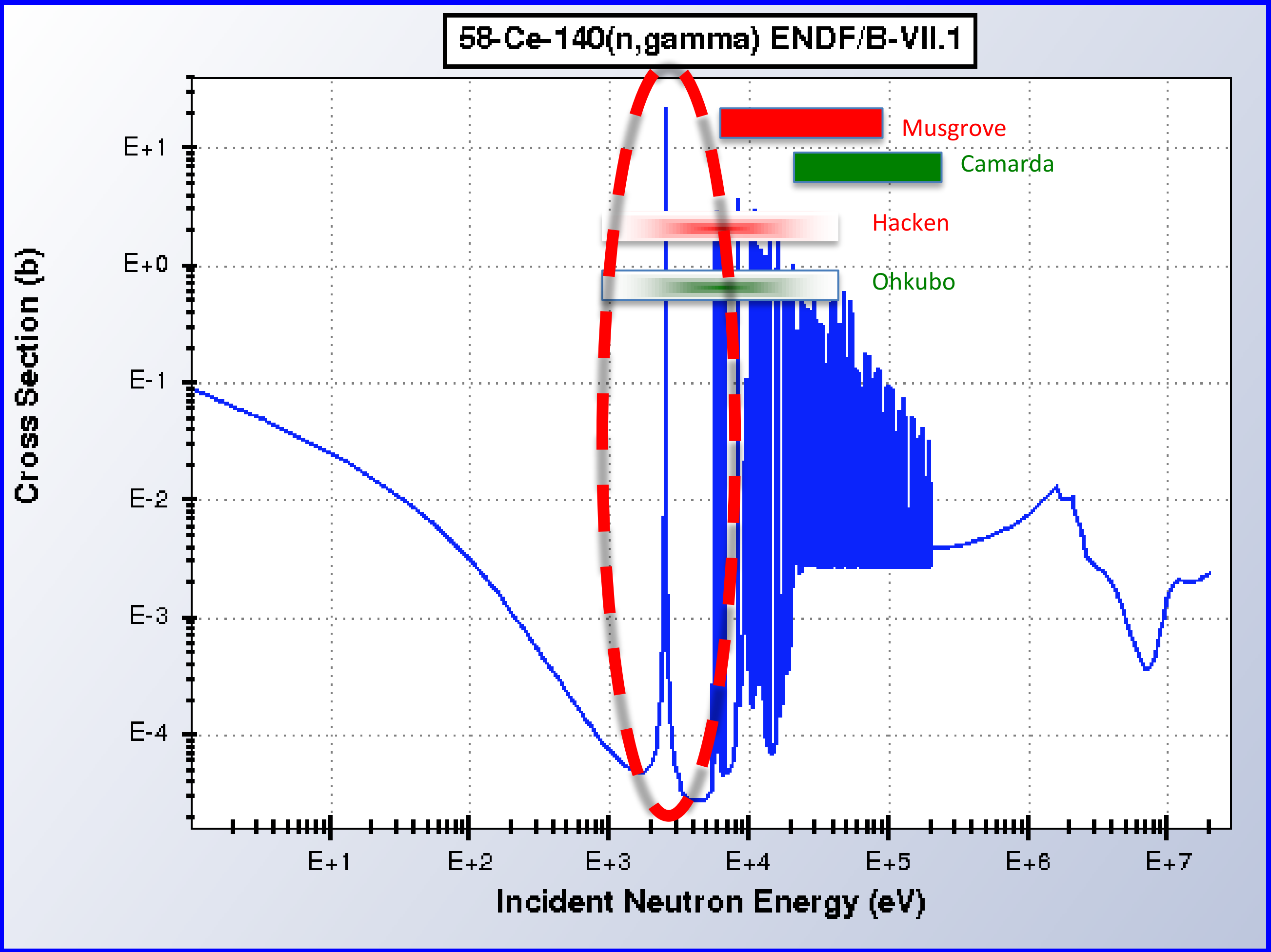


58-Ce-140(n,elastic) ENDF/B-VII.1
58-Ce-140(n,gamma) ENDF/B-VII.1
Cross Section (b)
E+2
E+1
E+0
E-1
E-2
E-3
E-4
E+1
E+2
E+3
E+4
E+5
Incident Energy (eV)



Room for improvement with C_6D_6

^{140}Ce neutron capture cross section (III)



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E_n < 60 keV
Ohkubo, jaeri report 1993

Capture (preliminary) 1974
En<65 keV
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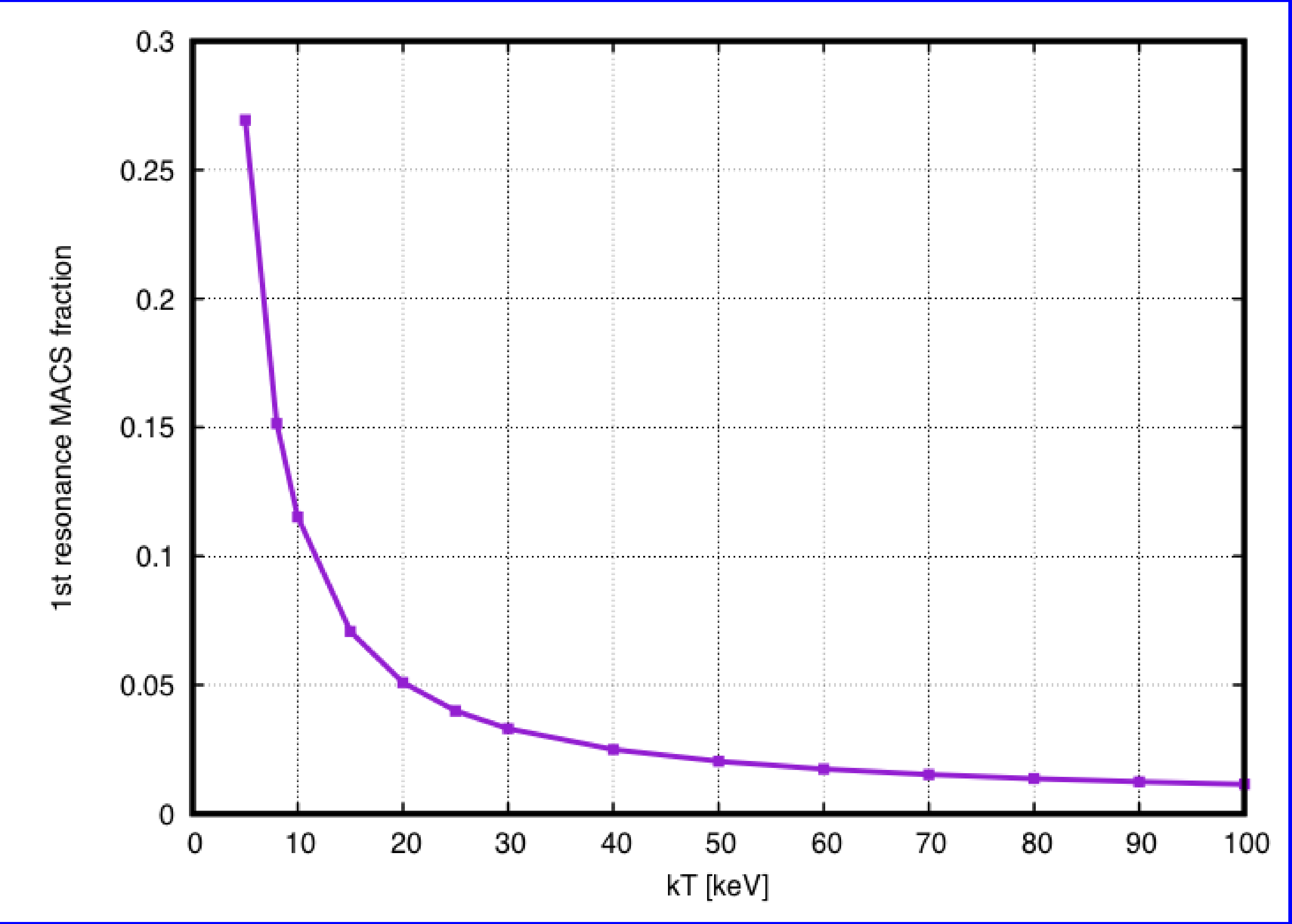
not published

$E \sim 2{,}5\ keV$

^{140}Ce neutron capture cross section (III)



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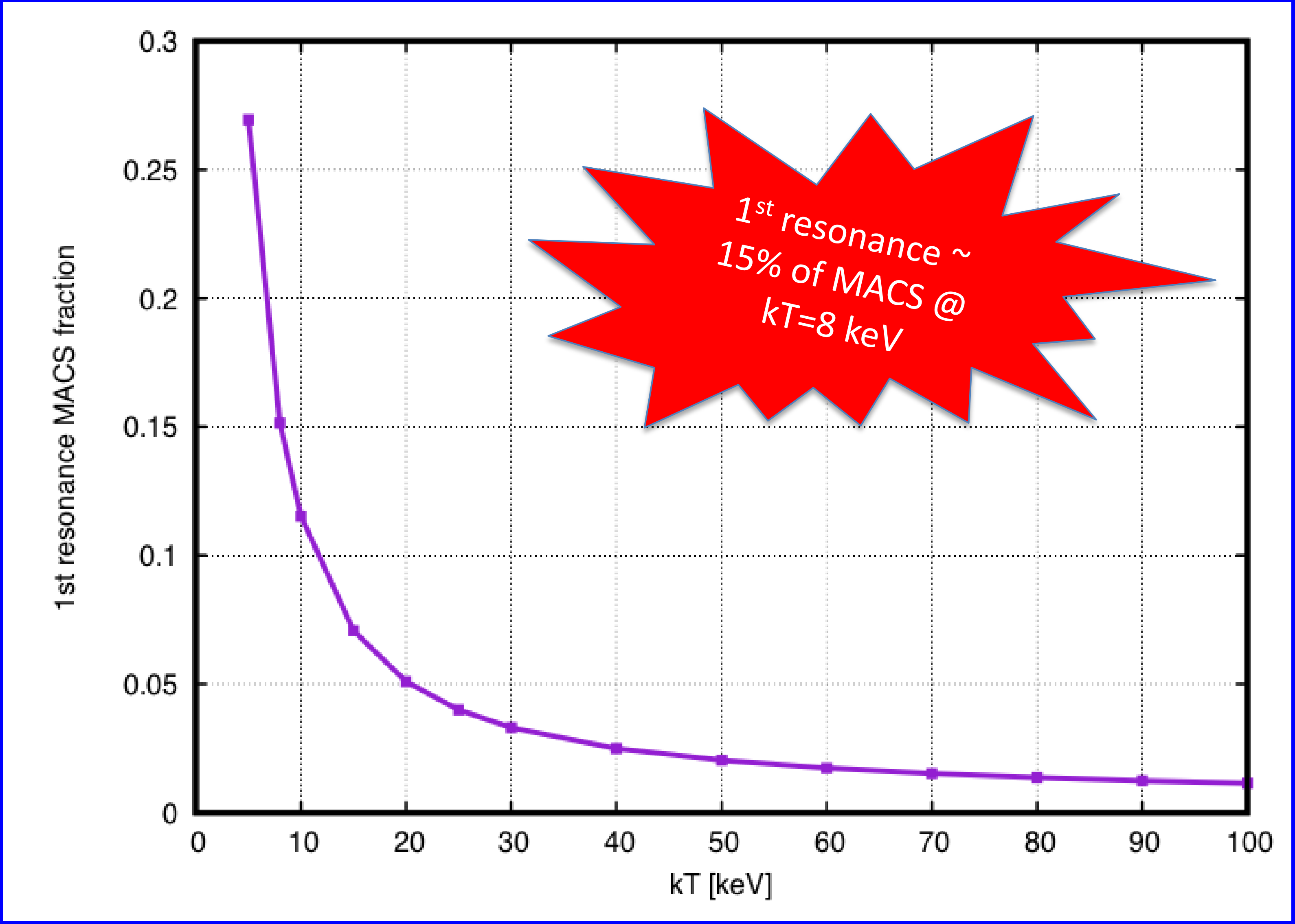
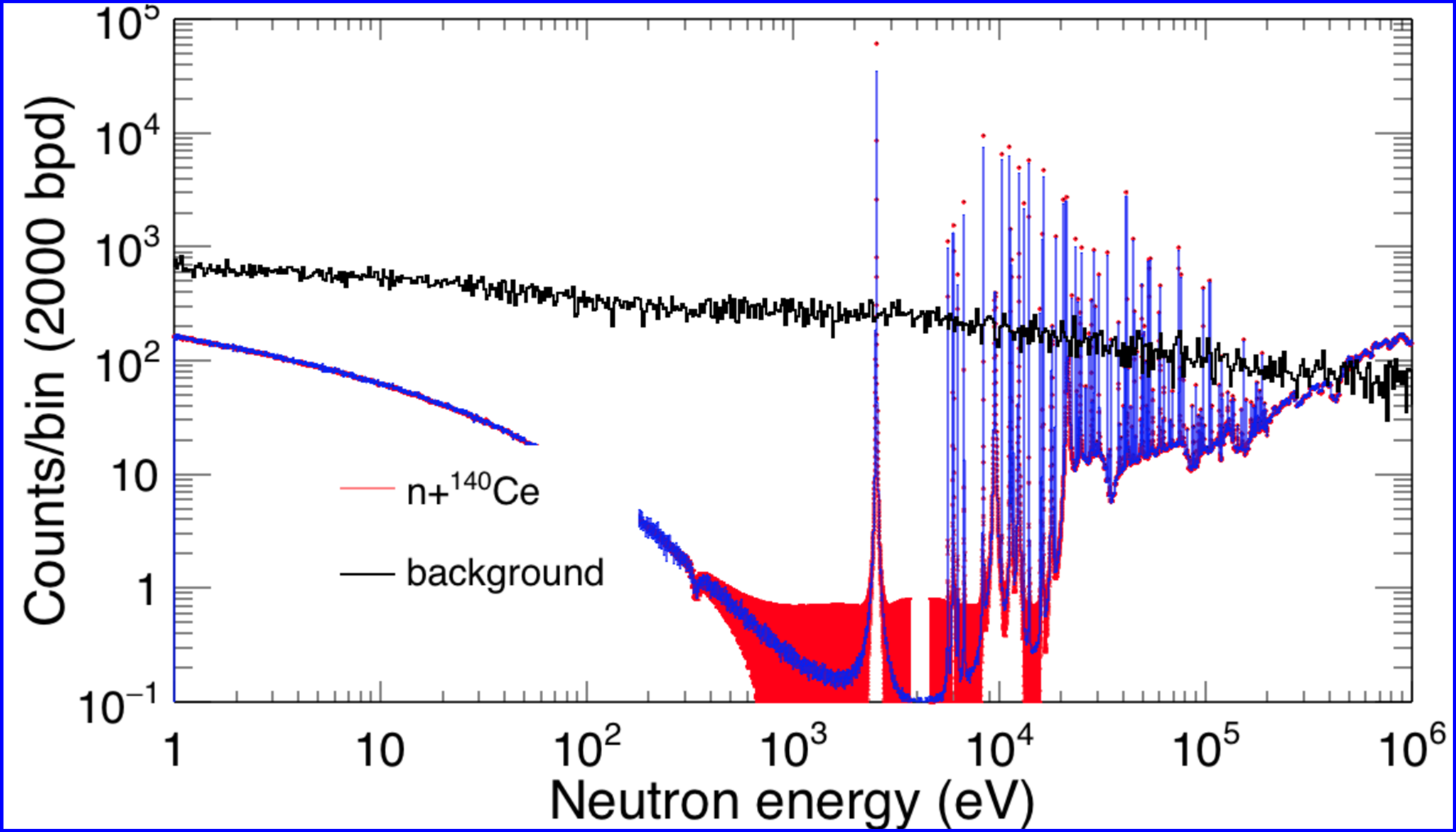


Count rate @ EAR1 – 4 g ^{140}Ce



Conclusions

- ^{140}Ce is a magic nucleus (88% os solar cerium), mostly synthesized by the s-process (81% of Galactic cerium).
- Heavy-element abundances in s-rich galactic Globular Clusters show good agreement with theoretical AGB models for elements belonging to the 2nd s-process peak…apart from cerium!
- MACS at AGB energies are highly uncertain due to lack of experimental data:
  - 2 transmission experiments in literature (^{nat}Ce was used, energy region does not cover the whole region of interest, En>20 keV)
  - 1 capture experiment in literature (C_6F_6 as capture detector, not well suited for this measurement: $\Gamma_n >> \Gamma_\gamma$)
  - No capture data below 5 keV reported in literature (just one unpublished report)!
- **Clear need of accurate capture data on ^{140}Ce**

- n_TOF can provide capture data in the energy region of interest:
  - Low cross section → 2.9×10^{18} protons
  - Resonances in the keV region → EAR1
  - $\Gamma_n >> \Gamma_\gamma$ → C_6D_6