

Statistical Hauser-Feshbach Model Description of (n, α) Reaction Cross Sections for the Weak s-Process

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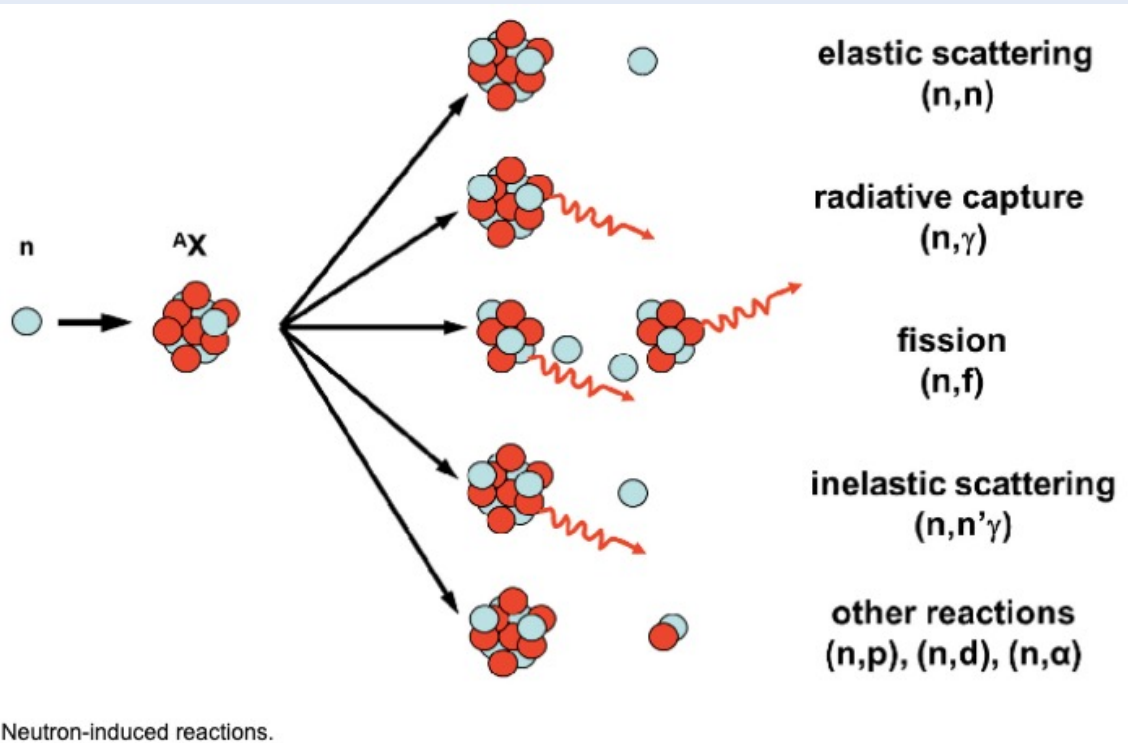
Faculty of Science

Department of Physics



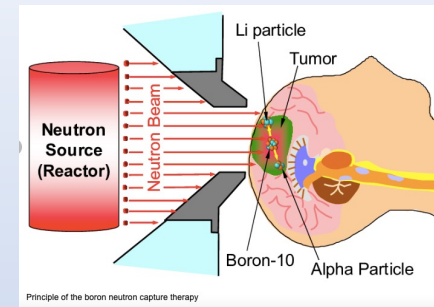
- ***Introduction***
- ***Statistical Hauser-Feshbach Model***
- ***(n, α) Reaction Cross-sections***
- ***Astrophysically Relevant Neutron Energy Range for (n, α) Reactions***
- ***Isotopic Dependence of (n, α) and (n, x) Reactions Cross-section***
- ***Conclusions***

Neutron induced reactions with nuclei



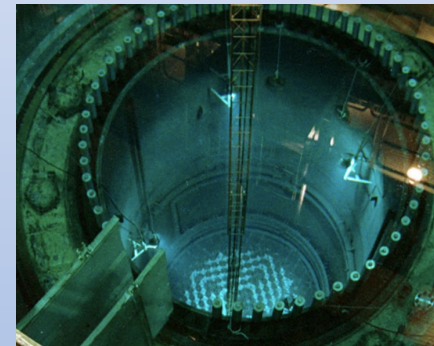
S, Goedele, G. Alf, EPJ Web of Conf., 229. 04003.
10.1051/epjconf/202022904003, 2020.

(n, α) Reaction Applications



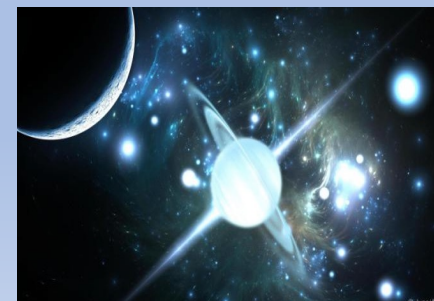
Medical Applications:
Boron Neutron
Capture Therapy

K. Hiroaki, N. Takemi, et al., AIP Conf. Proceedings.
1153. 377-387. 10.1063/1.3204547, 2009.



Nuclear Reactors

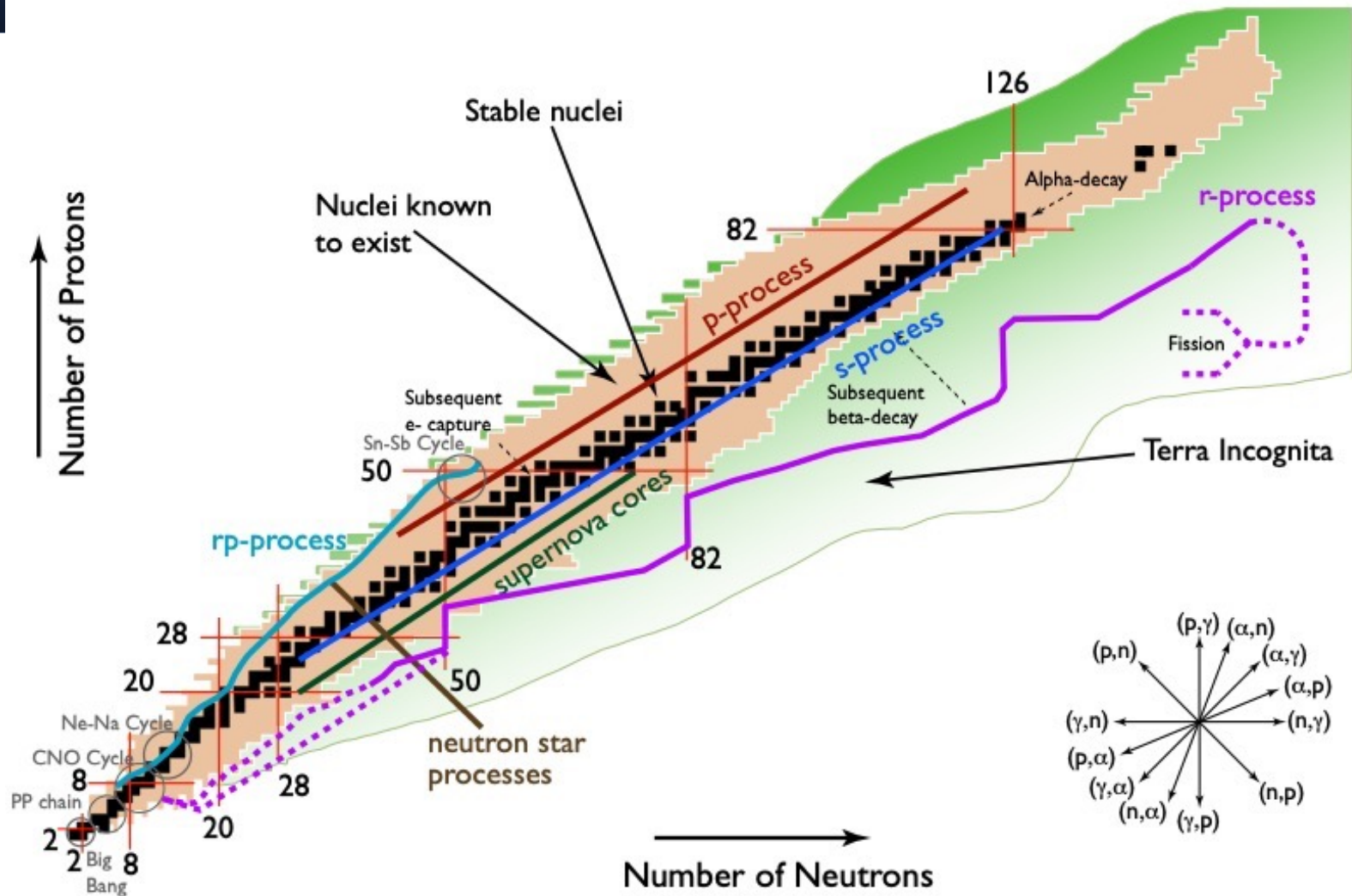
Toby Talbot, Ap photo



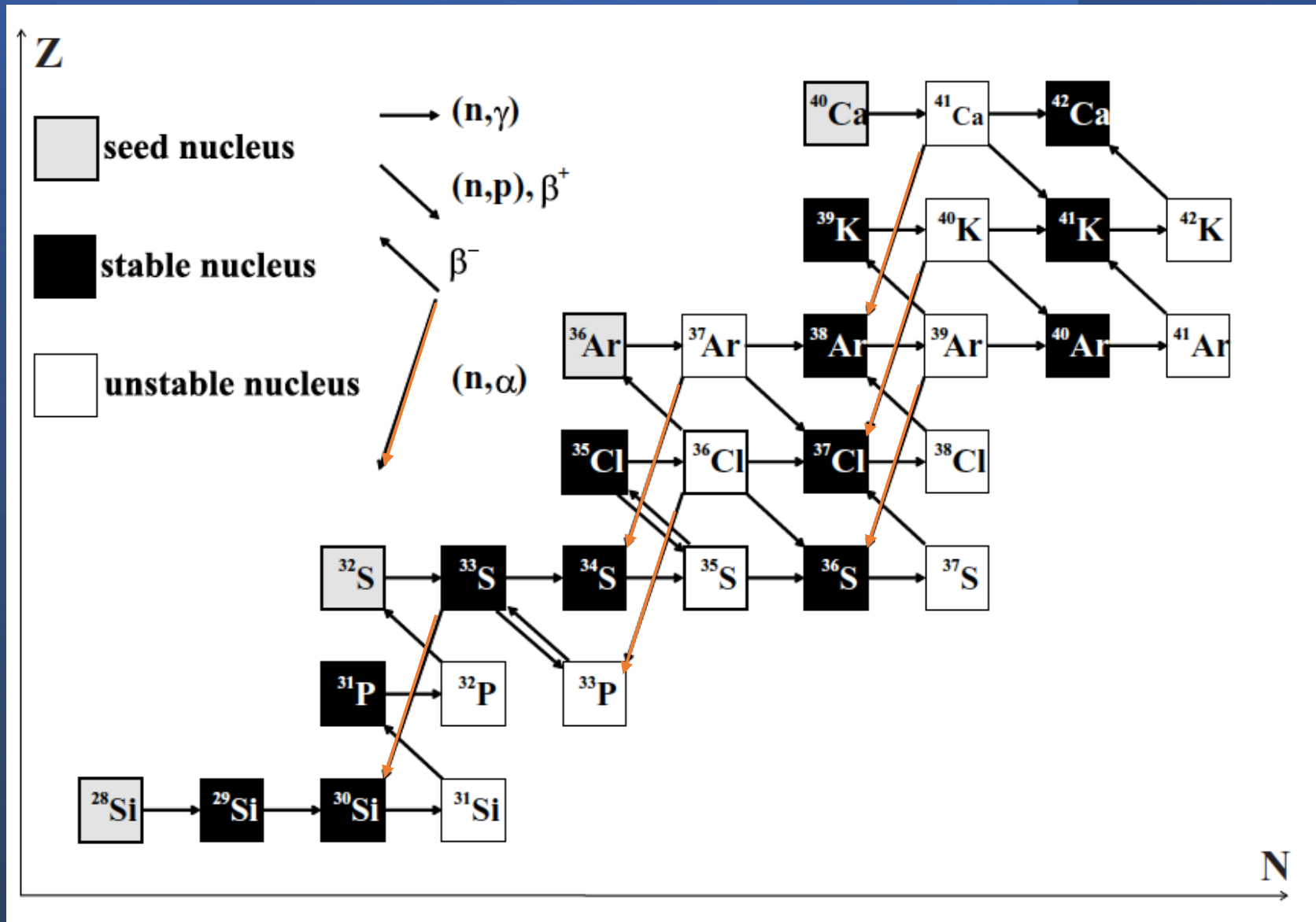
Nucleosynthesis

Jupe/Alamy

Synthesis of Chemical Elements in the Universe

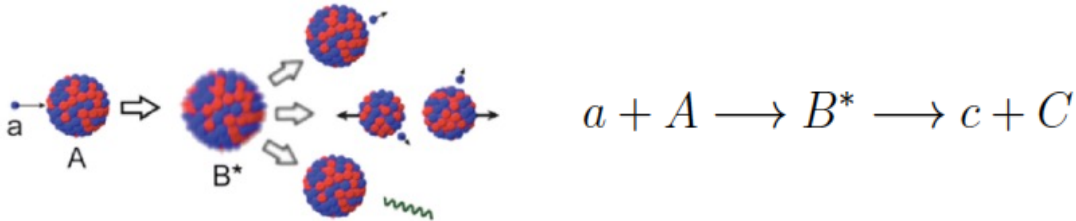


(n, α) reactions slowing down the process.



Statistical Hauser-Feshbach Model

COMPOUND NUCLEUS REACTION



J. Benstead, T. Jeffrey, et al., EPJ Web of Conf. 122, 12002 (2016)

$$E_a + E_A = E_C = E_b + E_B$$

$$\vec{p}_a + \vec{p}_A = \vec{p}_b + \vec{p}_B$$

$$\vec{l}_a + \vec{s}_a + \vec{I}_A = \vec{J}_C = \vec{l}_b + \vec{s}_b + \vec{I}_B$$

$$(-l)^{l_a} \pi_a \pi_A = \pi_C = (-l)^{l_b} \pi_b \pi_B$$

**Conservation of
energy, angular
momentum, orbital
angular momentum,
spin angular
momentum and
parity.**

HAUSER-FESHBACH CROSS-SECTION FORMULA

$$\sigma_{ab} = \frac{\pi}{k_a^2} \sum_{J_C=|I_A-s_a|}^{l_a^{max}+I_A+s_a} \sum_{\Pi_C=+,-} \frac{2J_C+1}{(2I_A+1)(2s_a+1)} \sum_{j_a=|J_C-I_A|}^{J_C+I_A} \sum_{l_a=|j_a-s_a|}^{j_a+s_a} \sum_{J_C+I_B}^{j_b=J_C-I_B} \sum_{l_b=|j_b-s_b|}^{j_b+s_b} \delta(a, \Pi_C) \delta(b, \Pi_C) \frac{T_{\alpha l_a j_a}^J T_{\beta l_b j_b}^{J_C}}{\sum_{\gamma} T_{\gamma}}$$

Walter Hauser and Herman Feshbach, Phys. Rev. 87, 366 (1952)

TALYS 1.95 Nuclear Reaction Code

A.J. Koning, S. Hilaire and M.C. Duijvestijn, "TALYS-1.0", Proceedings of the International Conference on Nuclear Data for Science and Technology, April 22-27, 2007, Nice, France, EDP Sciences, 2008, p. 211-214.

Mass Model → Skyrme force HFB-17

S. Goriely and J.M. Pearson, PRL. 102, 152503 (2009)

Level Density → Microscopic level densities (Skyrme force)

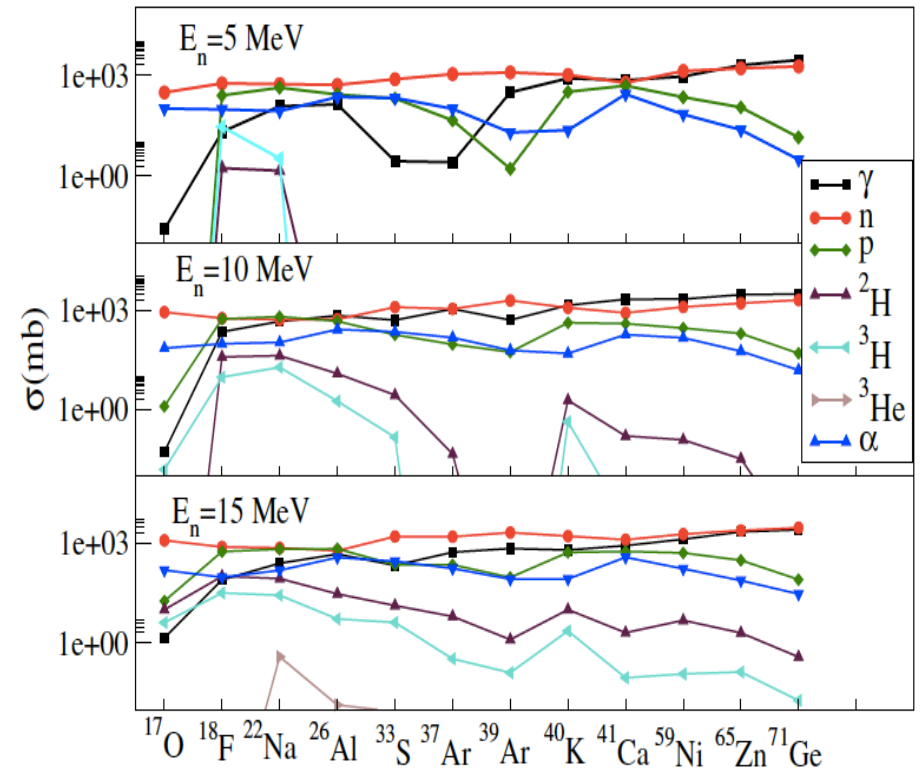
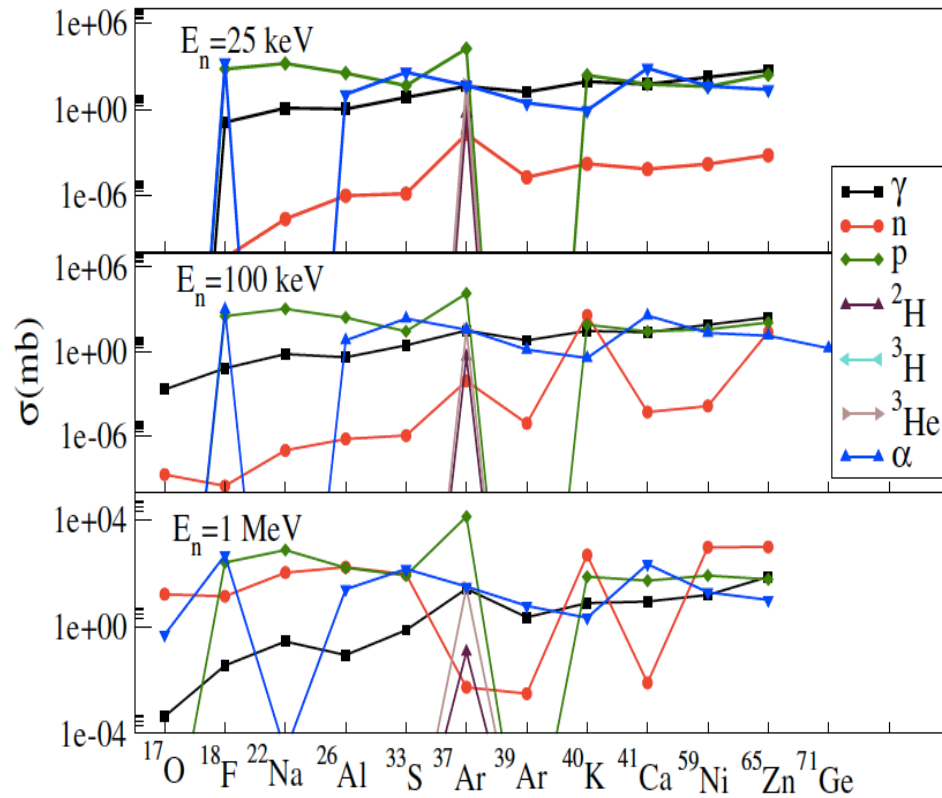
S. Goriely, S. Hilaire, and A. J. Koning, PRC 78, 064307 (2008)

Optical Model → Alpha potential from Avrigeanu

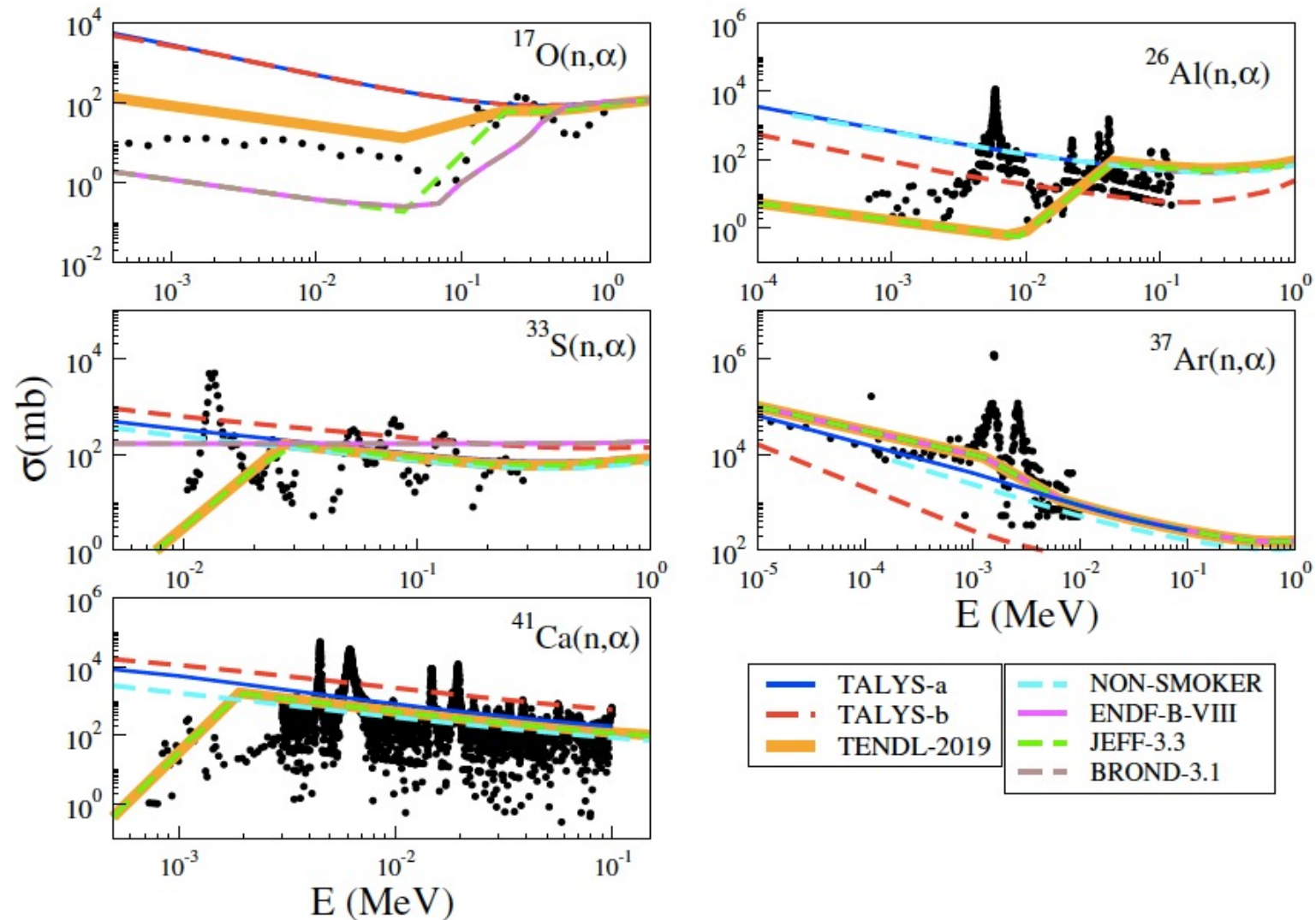
V. Avrigeanu et al., PRC, 90, 044612 (2014).

In the first step we studied (n, α) reactions for nuclei used in weak s-process network calculations: ^{17}O , ^{18}F , ^{22}Na , ^{26}Al , ^{33}S , ^{37}Ar , ^{39}Ar , ^{40}K , ^{41}Ca , ^{59}Ni , ^{65}Zn and ^{71}Ge . M. Pignatari, R. Gallino, et al., *Astrophys. J.*, 710, 1557–1577, 2010.

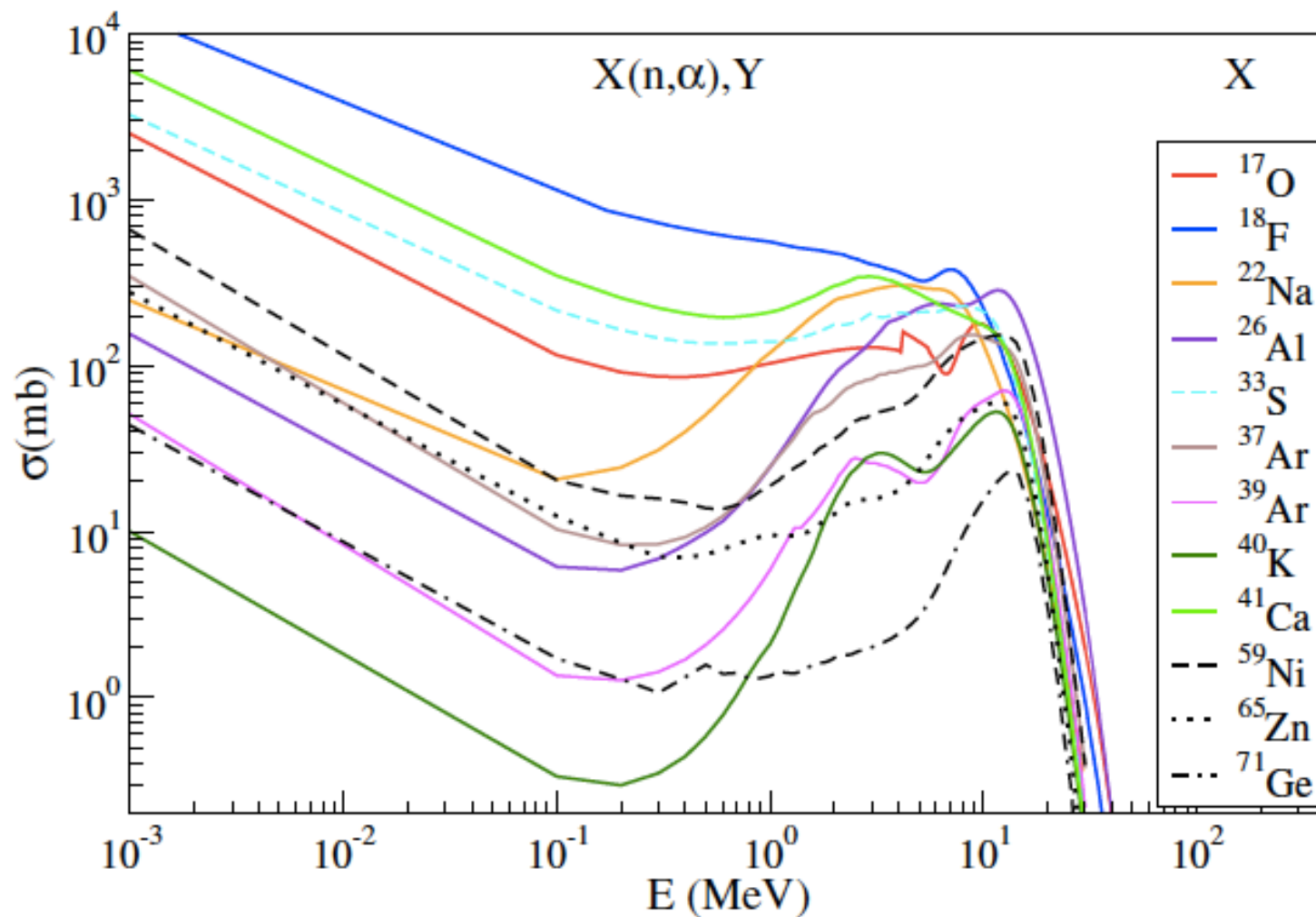
The reaction cross sections of all particle and gamma output channels induced by neutrons



Comparison of calculated and experimental (n, α) reaction cross sections for ^{17}O , ^{26}Al , ^{33}S , ^{37}Ar and ^{41}Ca .

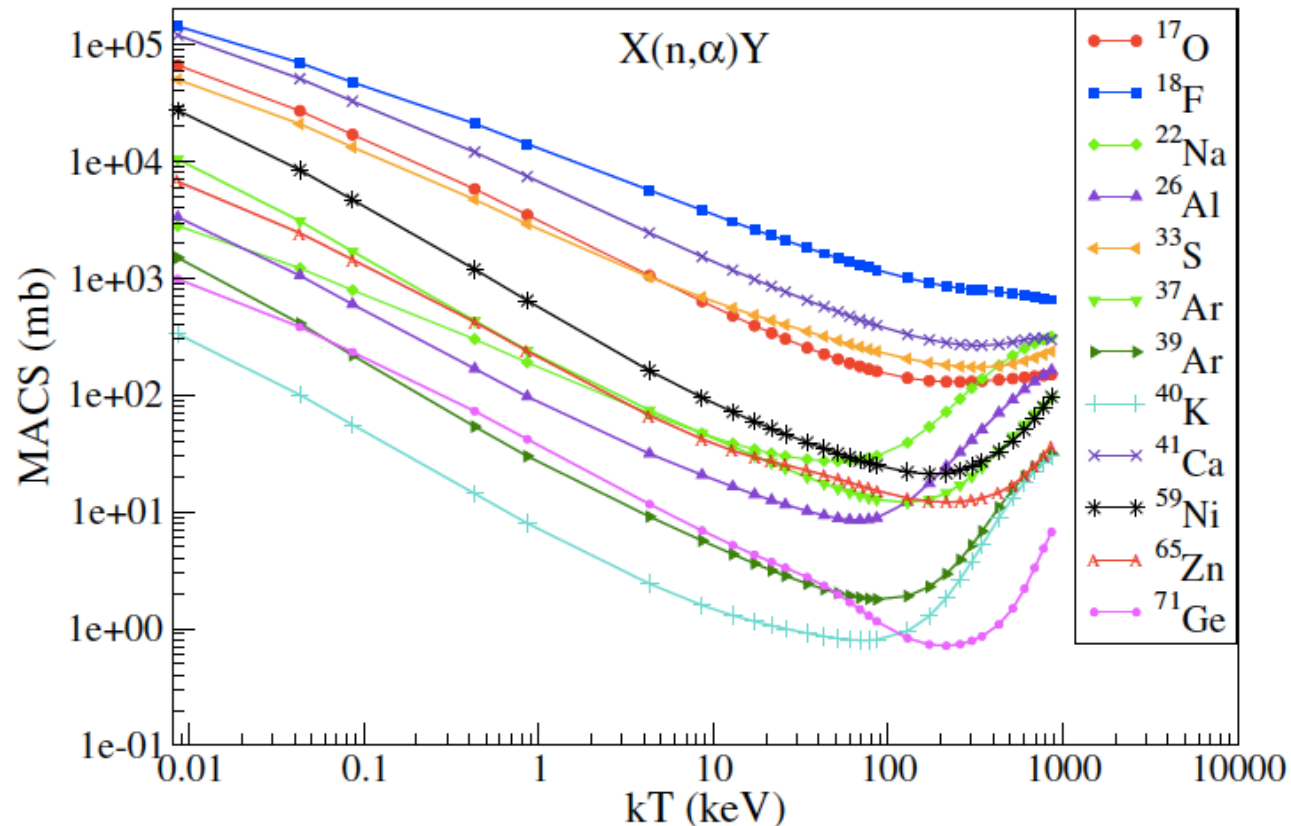


Cross-section for (n,α) reactions as a function of incident neutron energy.

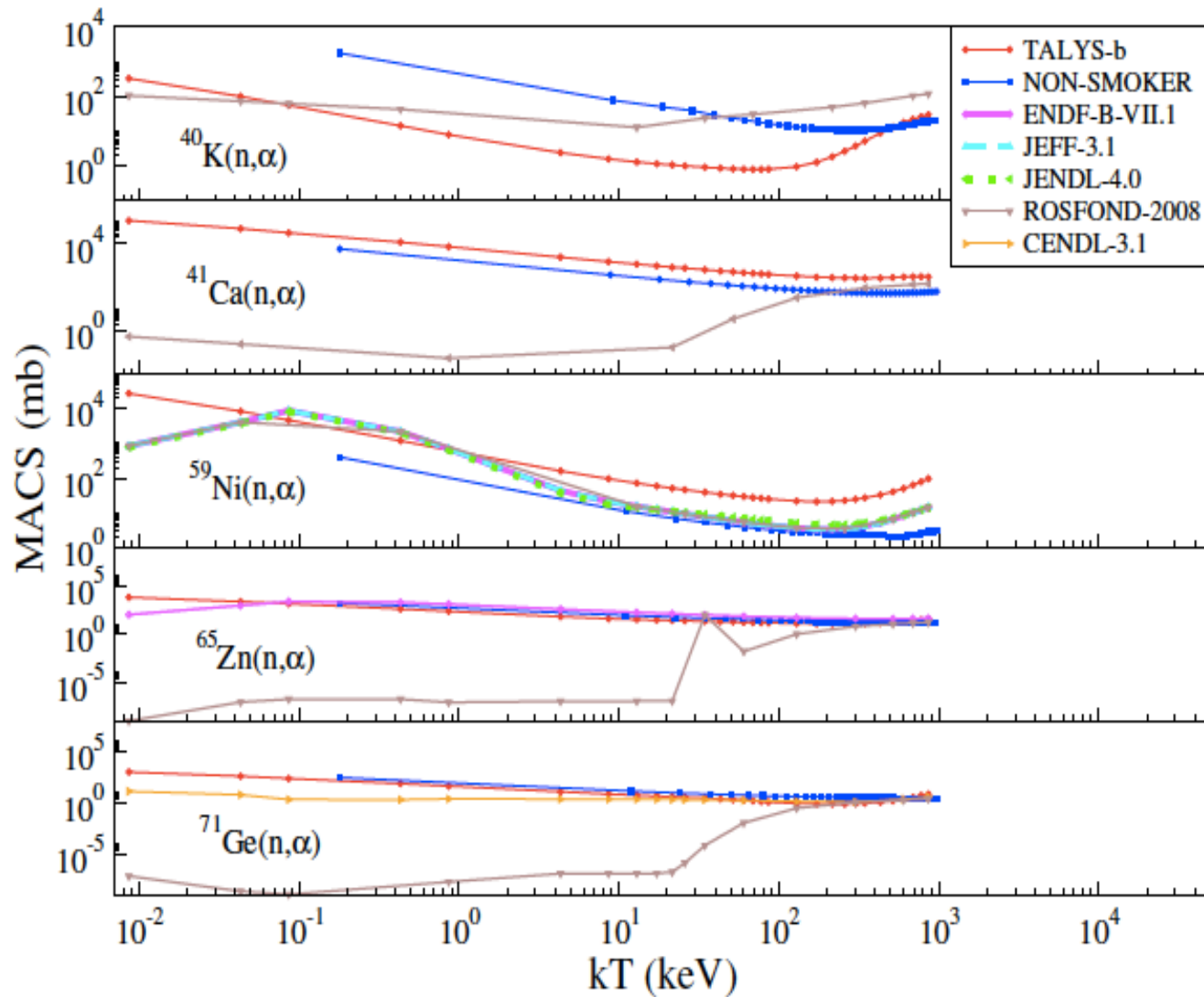


Maxwellian averaged cross-section (MACS) for (n, α) reaction Astrophysical Relevance

$$\langle \sigma \rangle (kT) = \frac{2}{\sqrt{\pi}} (kT)^{-2} \int_0^{\infty} \sigma(E) E e^{-\frac{E}{kT}} dE$$



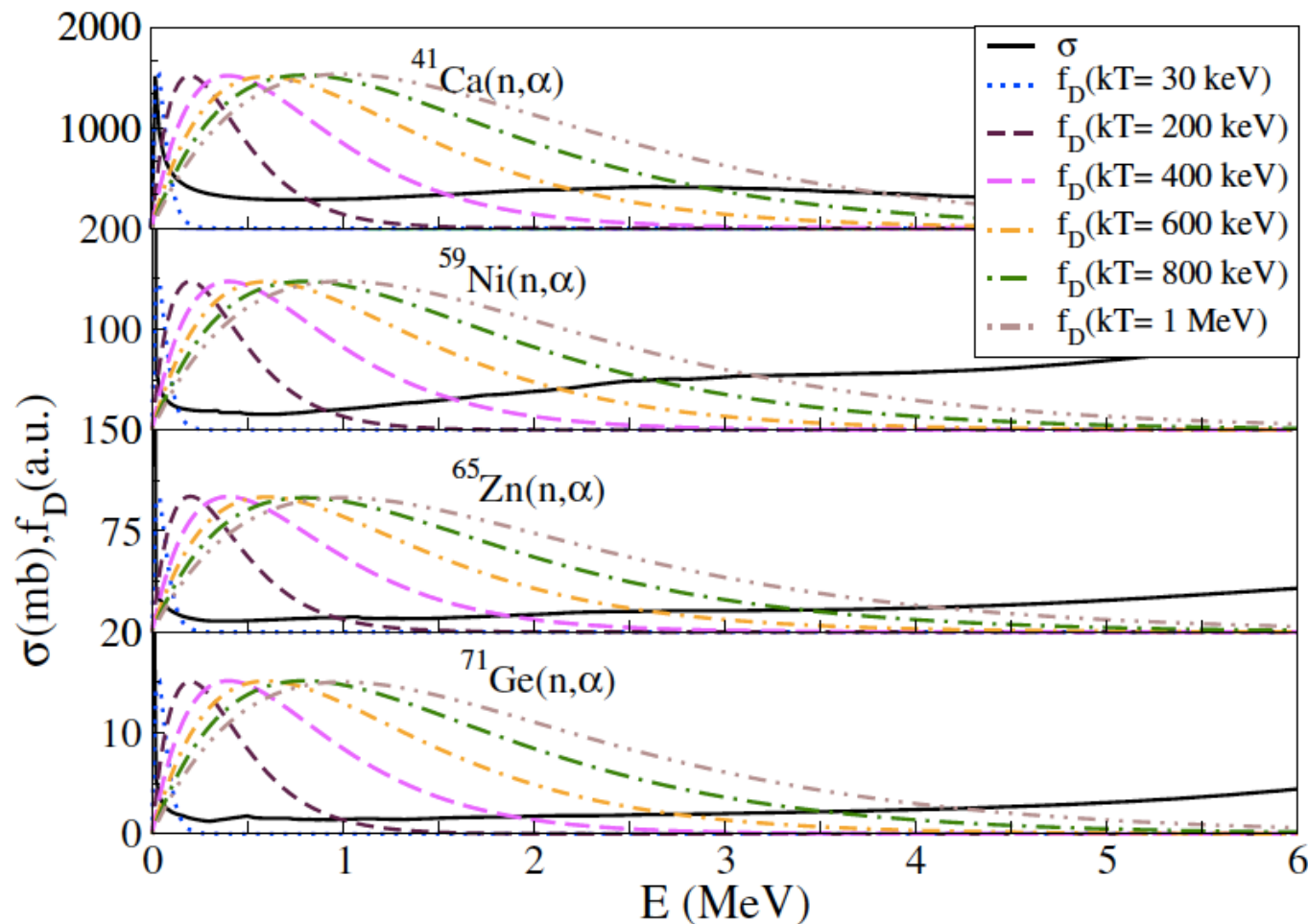
Model Dependence of the MACS Values



There are uncertainties due to different models and assumptions used in calculations.

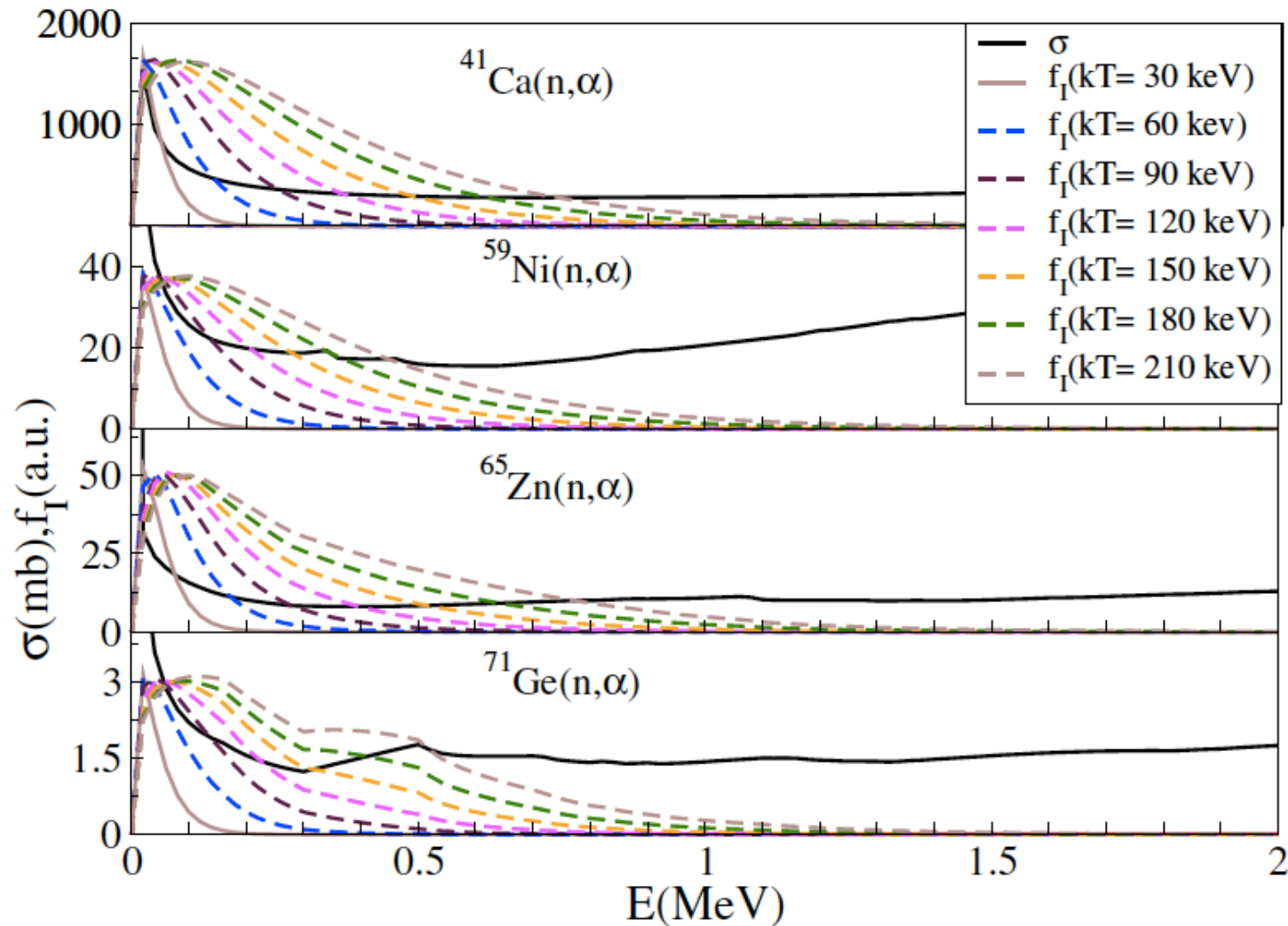
Astrophysically Relevant Neutron Energy Range for (n, α) Reactions

$$f_D = Ae^{-E/kT}$$

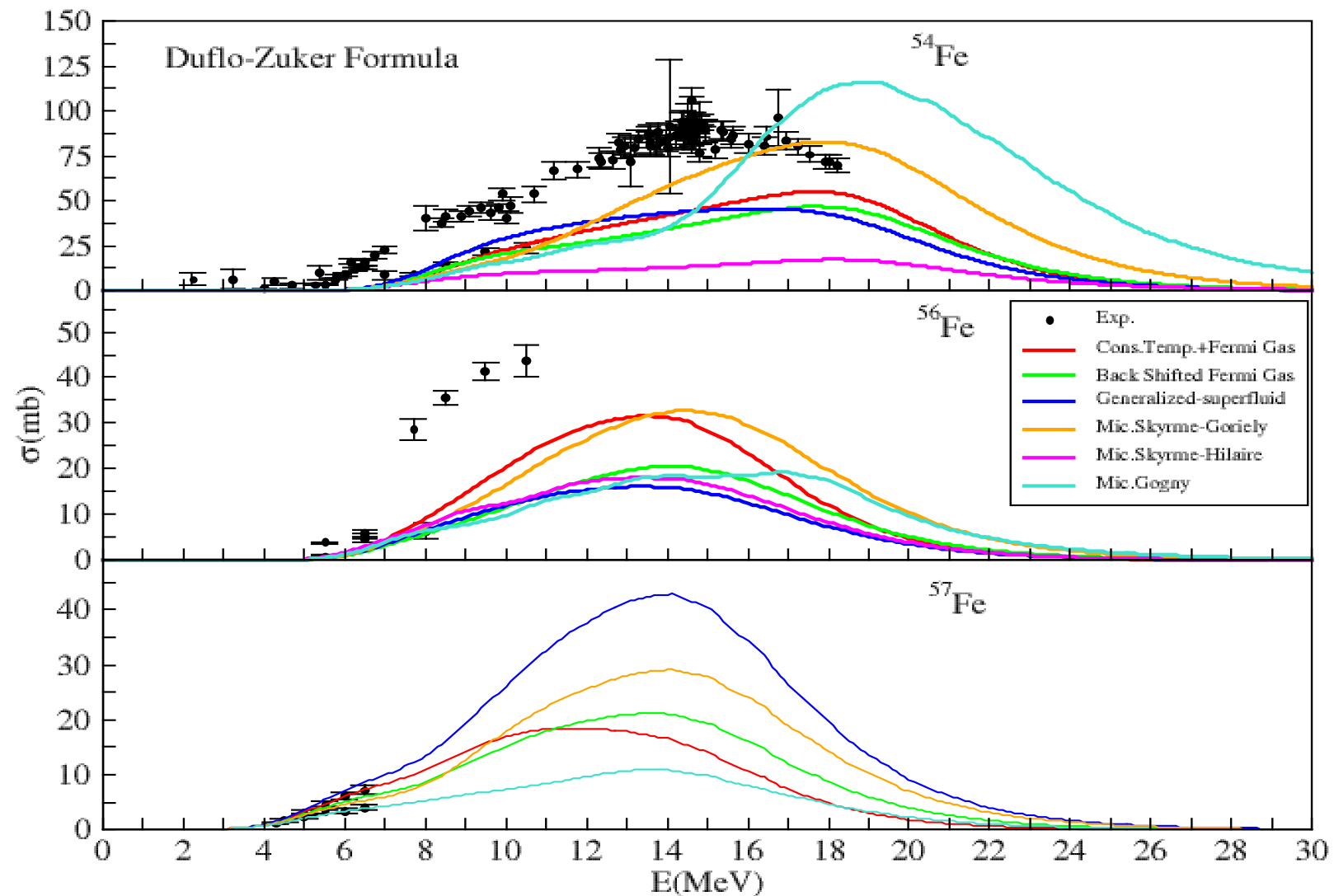


Relevant Energy Range for (n, α) Reactions

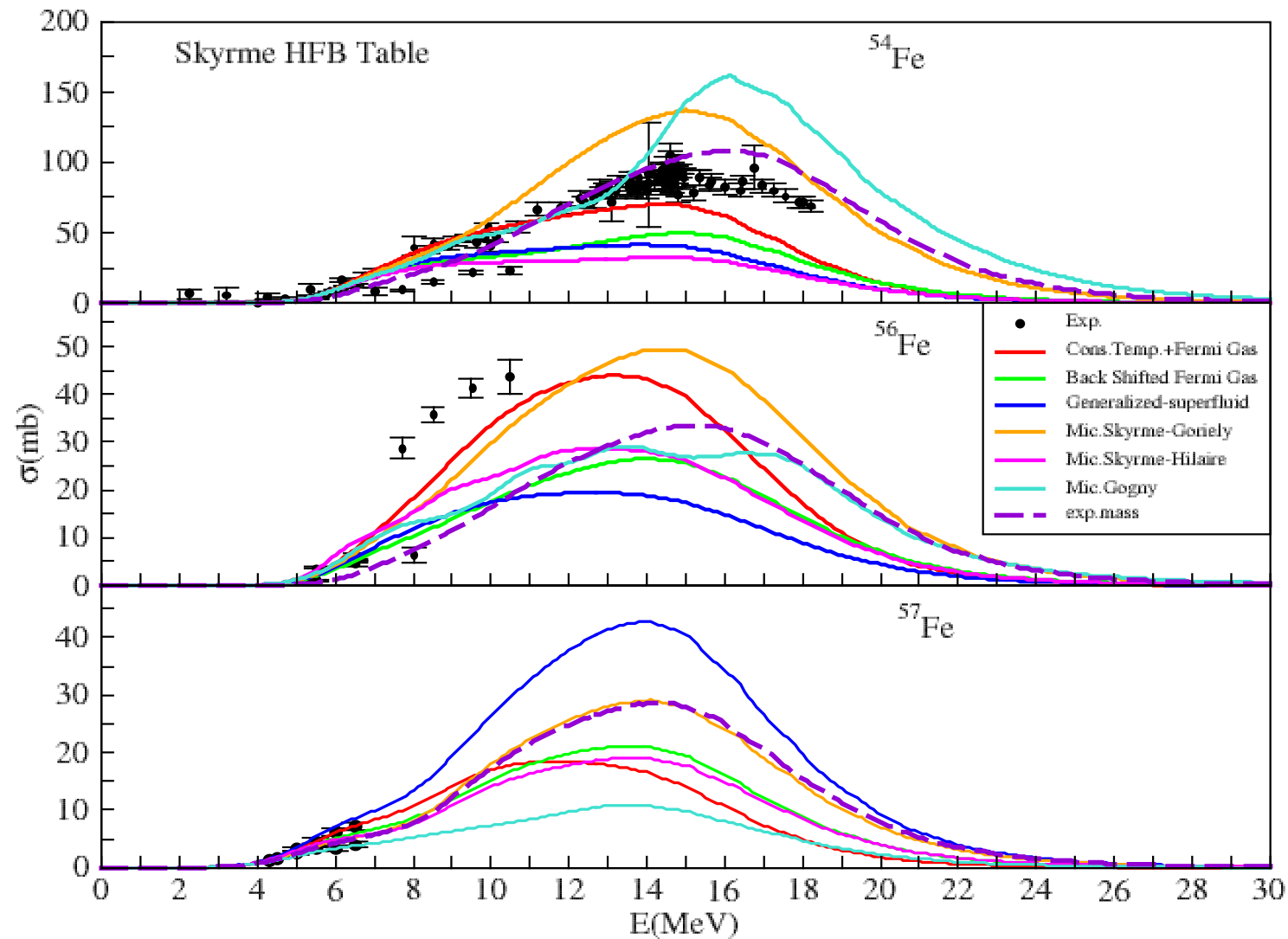
$$f_I(E) = \sigma(E) E e^{-\frac{E}{kT}}$$



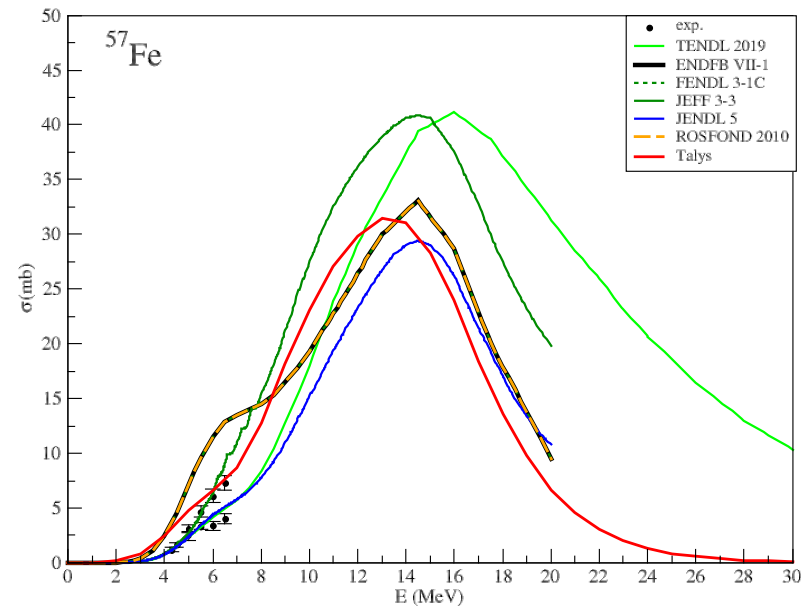
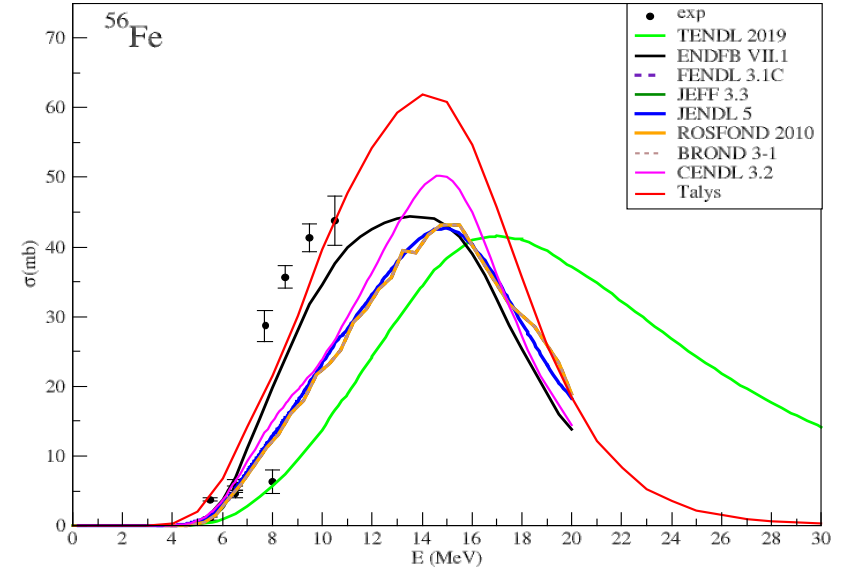
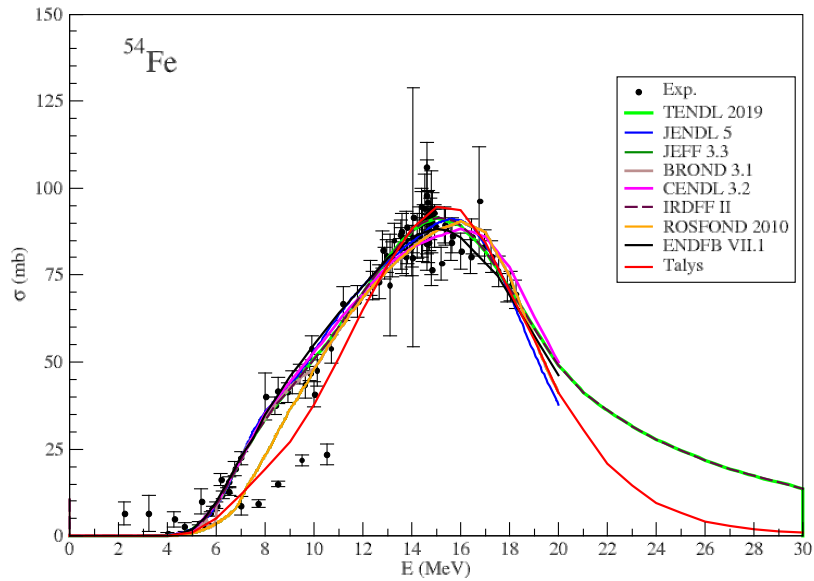
Isotopic Dependence of (n, α) Reaction Cross-section



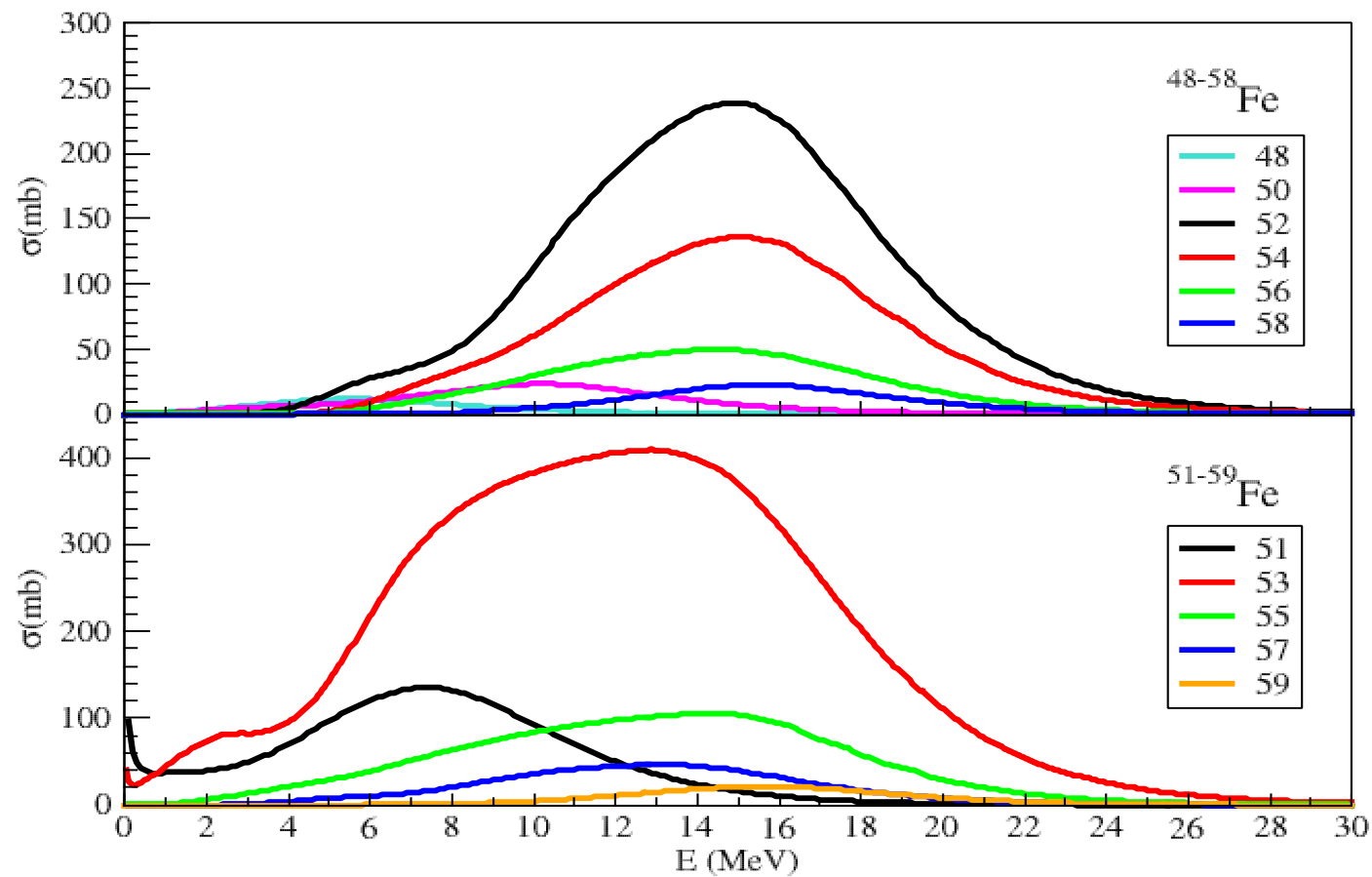
Isotopic Dependence of (n, α) Reaction Cross-section



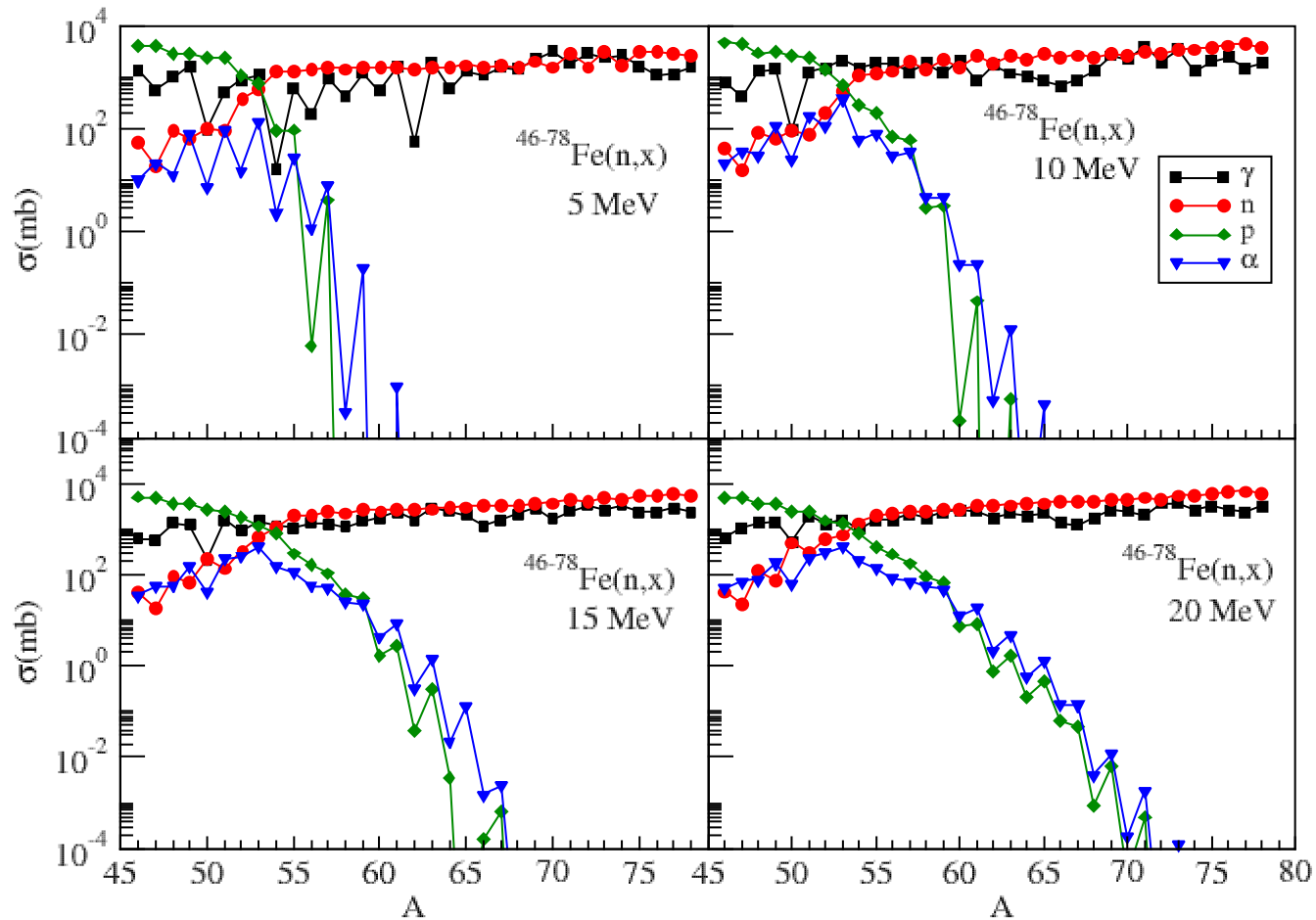
Comparison of Different Models



Cross-Section for even and odd nuclei for Fe isotopes



Cross-sections of different exit channels for Fe isotopes



CONCLUSIONS

- We have investigated (n, α) reaction cross sections for the set of nuclei contributing to the s-process nucleosynthesis . Calculations are based on Hauser-Feshbach model implemented in Talys code.
- The MACS values are considered for the range of temperatures. The cross-sections are subject to a considerable systematic model dependence.
- We have determined relevant energy windows for (n, α) reactions for the range of astrophysically represented temperatures, indicating a strong dependence of the exact location of the energy window on specific target nucleus under consideration.
- We have investigated isotopic dependence of (n, α) reaction cross-sections and studied their systematics for other isotope chains.

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Mustafa Yigit (Aksaray University)

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- Kucuksucu, S.; Yigit, M.; Paar, N. Statistical Hauser-Feshbach Model Description of (n,α) Reaction Cross Sections for the Weak s-Process. Universe 2022, 8, 25. <https://doi.org/10.3390/universe8010025>.
- Kucuksucu, S.; Yigit, M.; Paar, N. Isotopic dependence of (n,α) reaction cross-section, in preparation.

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<https://strukturnifondovi.hr/>

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