Sensitivity of astrophysical reaction rate to nuclear level density across different energy intervals

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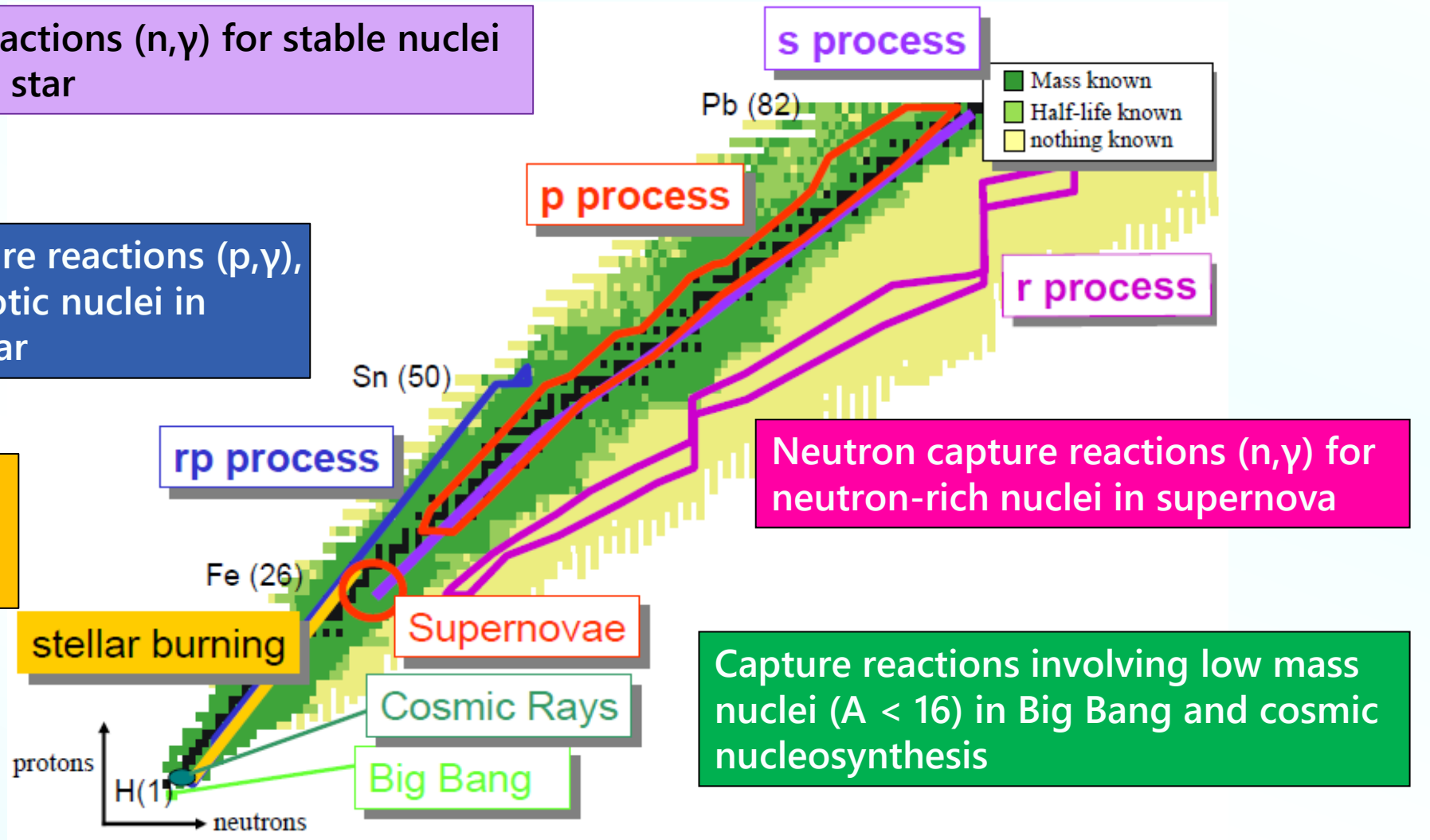
Astrophysics

Neutron capture reactions (n,γ) for stable nuclei in red (super) giant star

Charged-particles capture reactions (p,γ), (α,γ) for proton-rich exotic nuclei in supernova and dwarf star

Capture reactions involving low mass nuclei in main sequence star



Neutron capture reactions (n,γ) for neutron-rich nuclei in supernova

Capture reactions involving low mass nuclei (A < 16) in Big Bang and cosmic nucleosynthesis

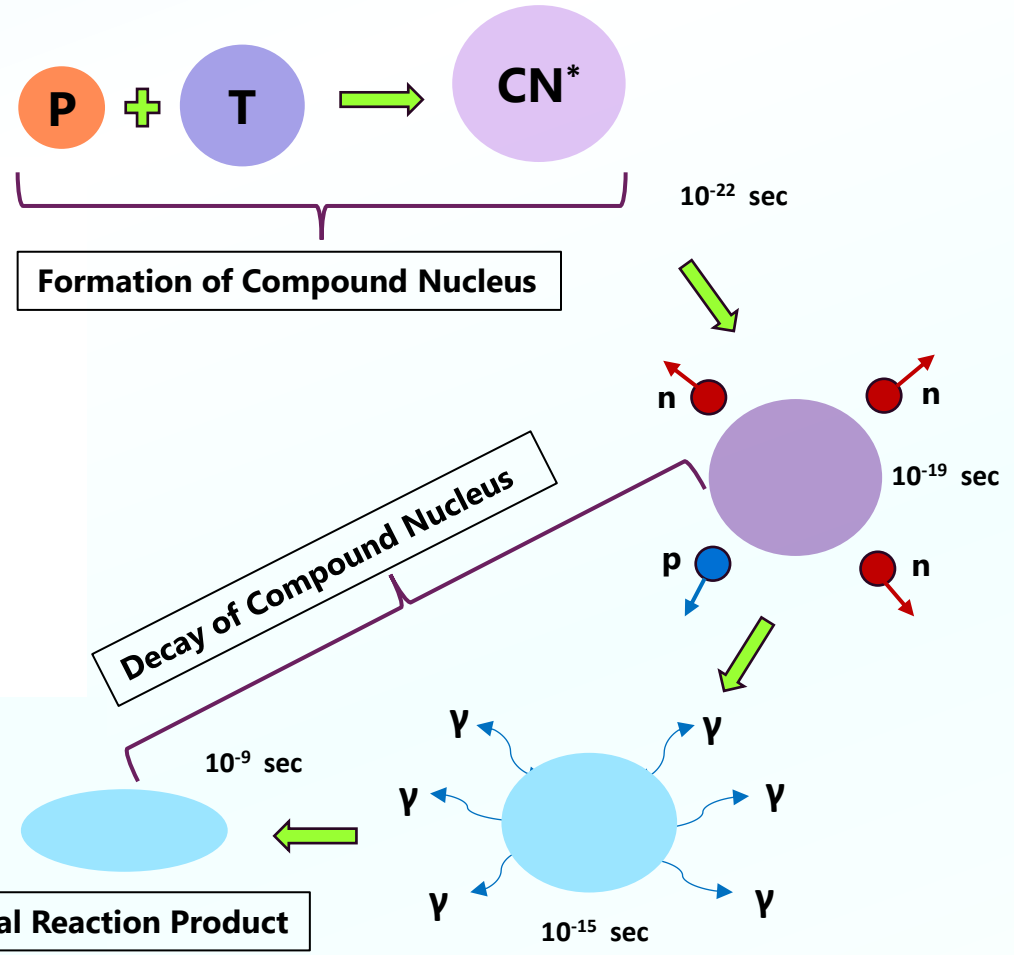
Figure taken from: H Grawe, K Langanke, and G Martinez-Pinedo, Reports on Progress in Physics (2007) 70 9

Reaction model

Hauser-Feshbach formalism of $\sigma_{(a,\gamma)}$

✓ capture reaction *A(a, γ)B*

$$\sigma^{CNC}_{A+a\to B^x+\gamma} = \frac{\pi}{k^2}\sum_{J=mod(I_A+I_a,1)}^{l_{max}+I_A+I_a}\sum_{\Pi=-1}^{1}\frac{2J+1}{(2I_A+1)(2I_a+1)}$$
$$\times\sum_{J_p=|J-J_A|}^{J+I_A}\sum_{l_i=|J_a-I_a|}^{J_a+I_a}\sum_{\lambda=|J-I^x_B|}^{J+I^x_B}\sum_{l_f=|\lambda-I_\gamma}^{\lambda+I_\gamma}\delta^{\pi}_{C_a}\delta^{\pi}_{C_\gamma}$$
$$\times\frac{\langle T^J_{C_a,l_i,J_a}(E)\rangle\langle T^J_{C_\gamma,l_f,\lambda}(E_\gamma)}{\sum_{Clj}\delta^{\pi}_{C}\langle T^J_{C,l,j}(E_C)\rangle}W^J_{C_a l_i J_a C_\gamma l_f \lambda}$$



❖ uses the nuclear level density (NLD) as an input

$$\rho_t(E_x) = \sum_J\sum_\pi \rho(E_x, J, \Pi)$$

↳ reaction rate

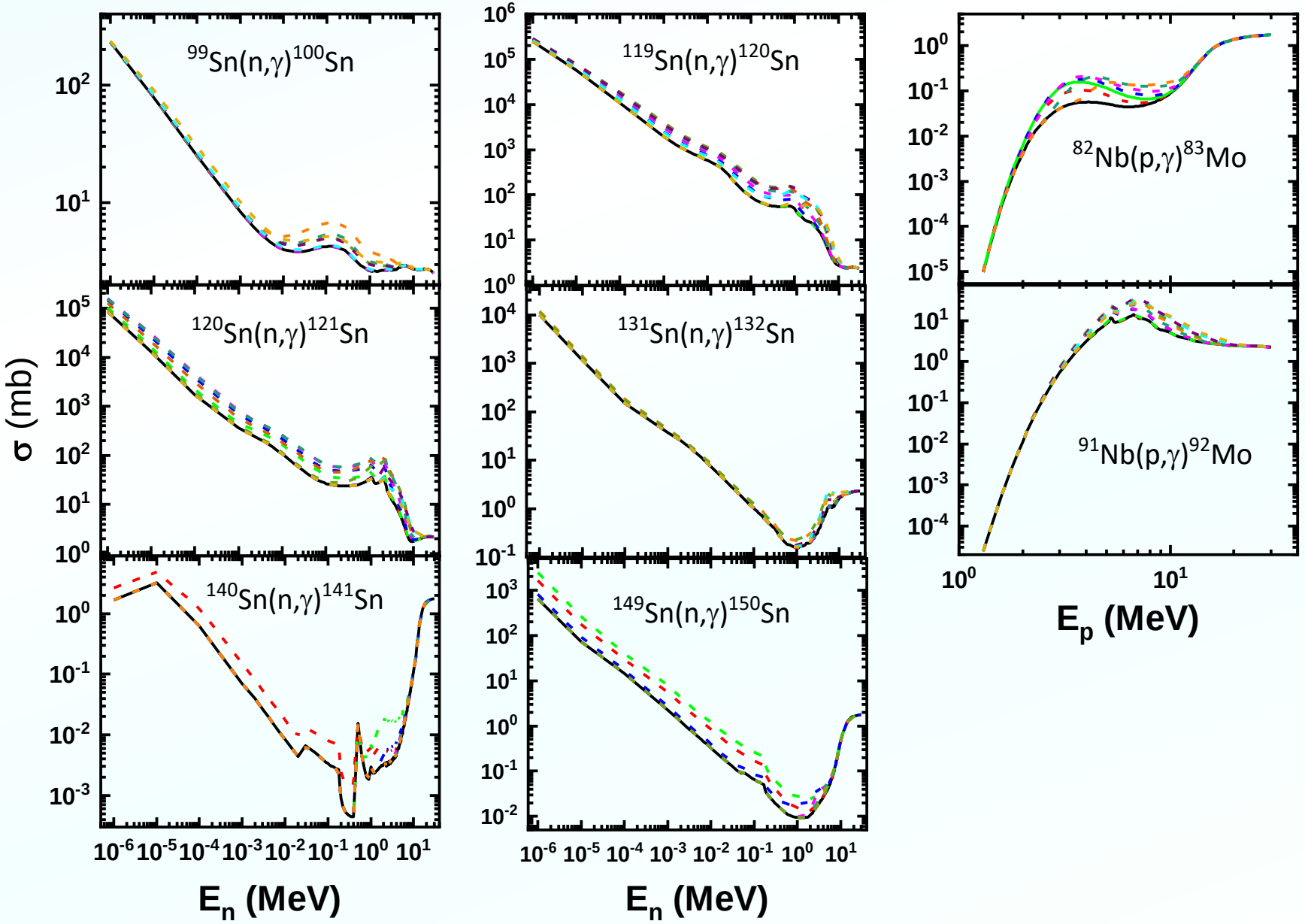
$$N_A<\sigma v> = \left(\frac{8}{\pi m_{01}}\right)^{1/2}\frac{N_A}{(kT)^{3/2}}\int_0^\infty E\sigma(E)\mathrm{e}^{-E/kT}\,\mathrm{d}E$$

Sensitivity of the reaction cross-section

- ✓ Procedure
  - microscopic HFB + comb. method
  - successively scale the energy range of NLD by 10 within an energy interval of ΔE = 1 MeV from 0 up to proton or neutron separation energy for both positive and negative parities simultaneously

$$\Omega_{S_q} = \frac{v_\Omega - 1}{v_q - 1}$$

$\hookrightarrow 10$



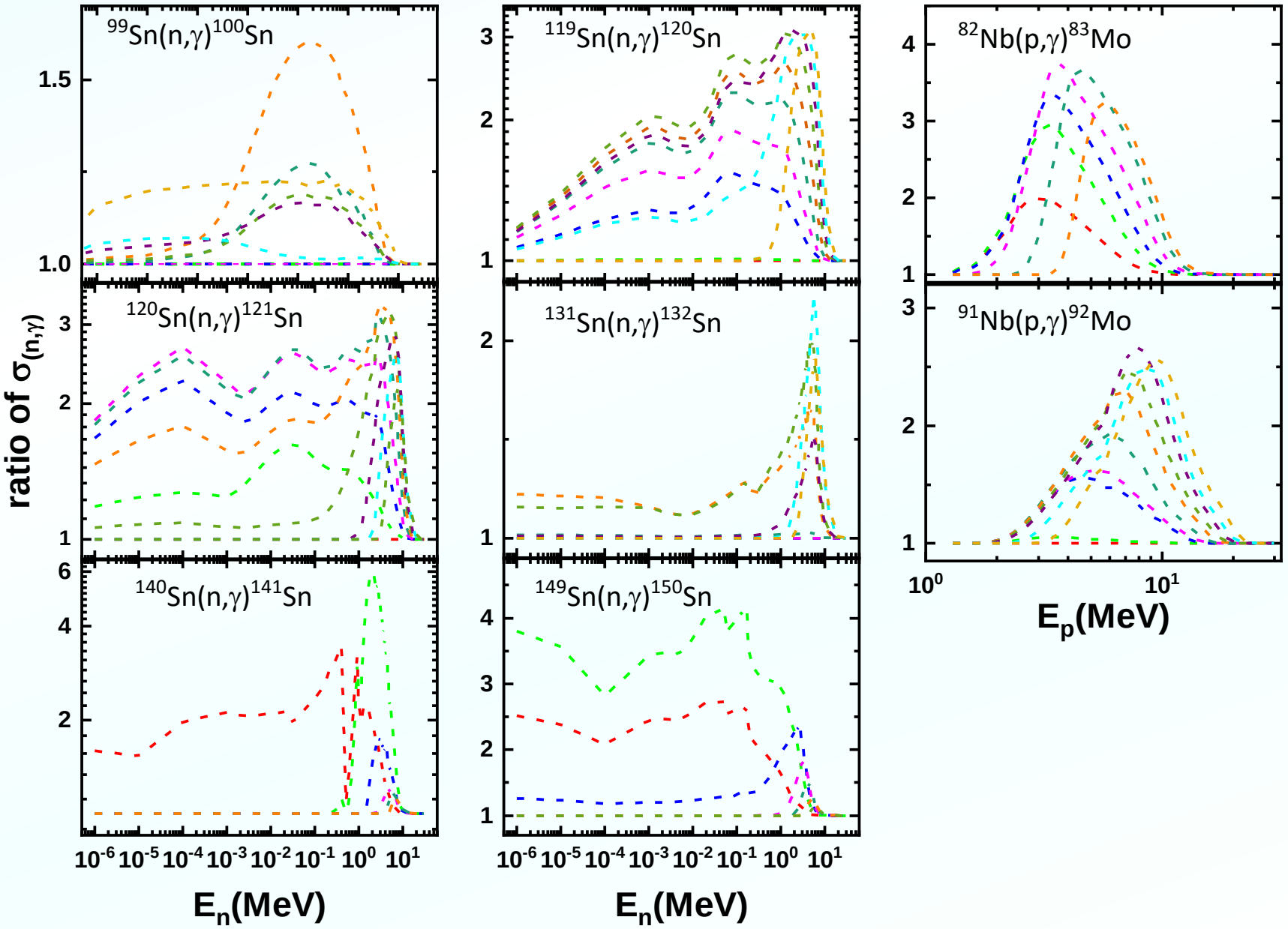
STEP I

- ✓ Procedure
  - microscopic HFB + comb. method
  - successively scale the energy range of NLD by 10 within an energy interval of ΔE = 1 MeV from 0 up to proton or neutron separation energy for both positive and negative parities simultaneously

$$\Omega_{S_q} = \frac{v_\Omega - 1}{v_q - 1}$$

v_q → 10

STEP II



- ✓ Procedure
  - microscopic HFB + comb. method
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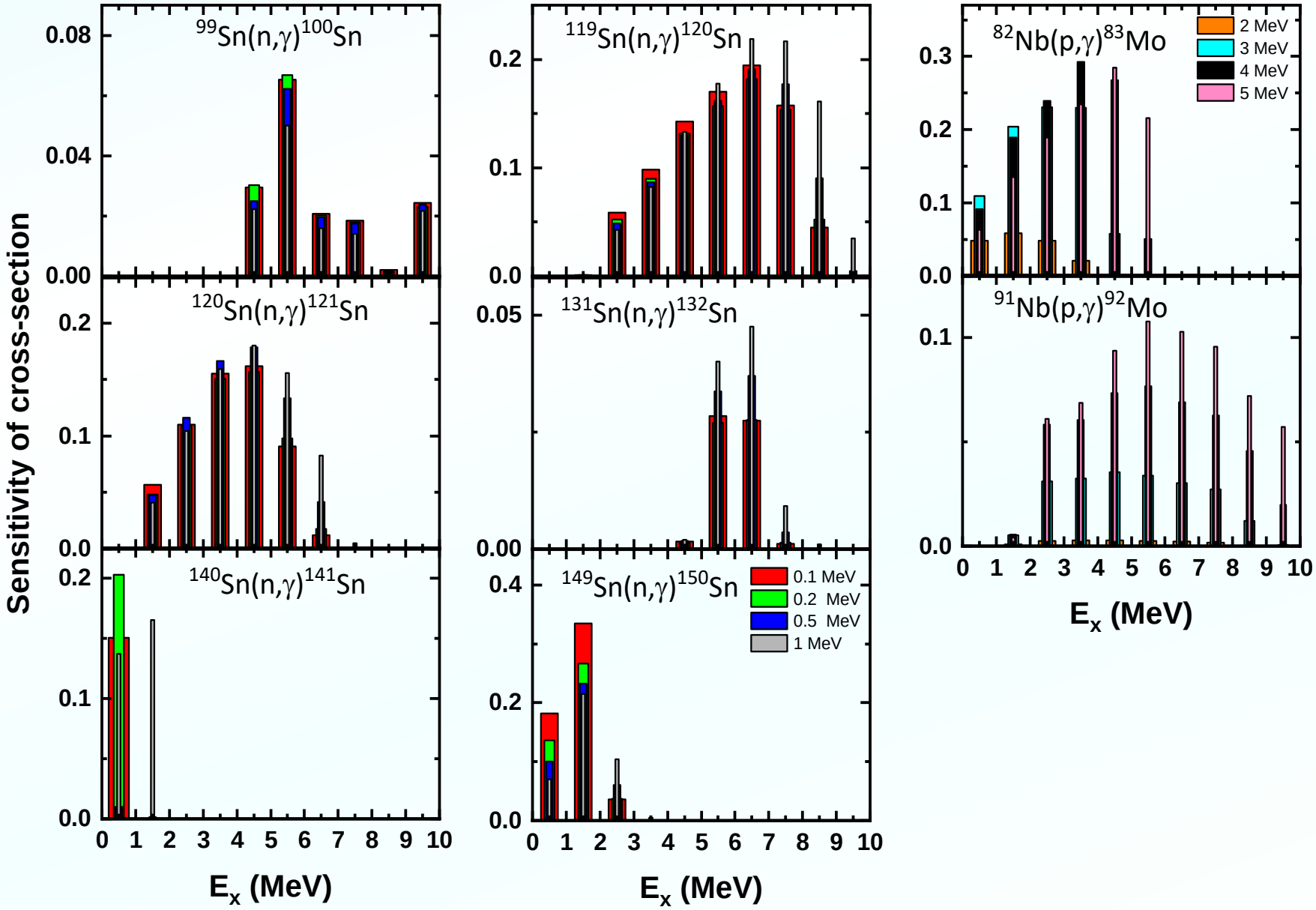
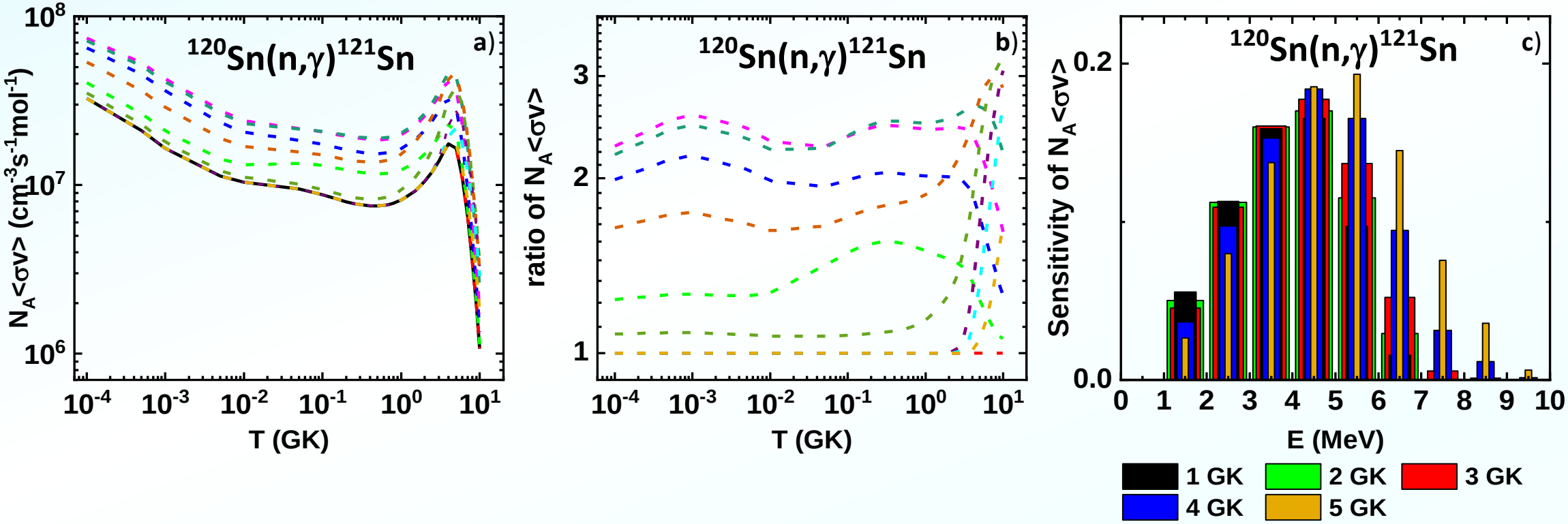
$$\Omega_{S_q} = \frac{v_\Omega - 1}{v_q - 1}$$

$v_q - 1$ → 10

STEP III

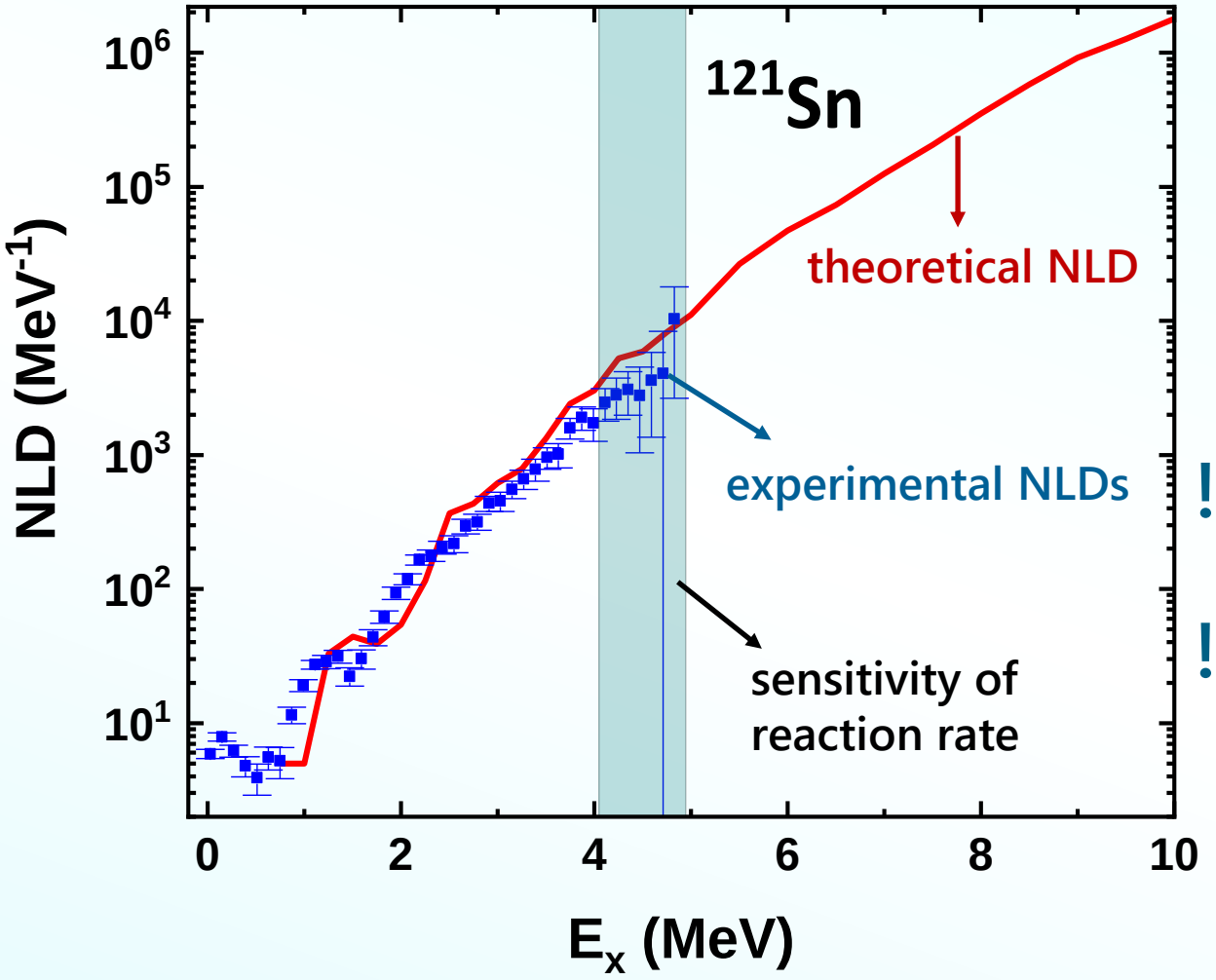


Sensitivity of the astrophysical reaction rate



- ✓ observable differences between the data
- ✓ these ratios can reach values up to 3 within 1 - 10 MeV
- ✓ *T = 1 - 4* GK: the sensitivity is confined to [4,5] MeV
- ✓ *T = 5* GK: the sensitivity predominates in [5,6] MeV

Even with an enhancement of the NLD energy by a factor of 10, the reaction rate sensitivity consistently remains within the 4 - 5 MeV



✓ the theoretical NLD is compared to the NLD measured by the Oslo method

↳ significant uncertainties

{ minimize these uncertainties

enhance the reliability and accuracy

! could provide critical insights to nuclear reaction models

! could guide experimental measurements, particularly those targeting level schemes at the excitation energies of 4 - 5 MeV

To be submitted to Physica Scripta

Take home messages

The present study examines the sensitivity of reaction cross-section and astrophysical reaction rate to NLD across different energy intervals

- ❖ nucleon capture cross-sections
  - ✓ stable nuclei contribute to nucleon capture cross-sections across a broader energy range
  - ✓ rich nuclei exhibit contributions concentrated within narrower energy intervals
- ❖ astrophysical reaction rate

4 - 5 MeV range is the critical energy interval with the most significant impact on reaction rate calculation


Thank you!