Nuclear structure from fusion evaporation reactions

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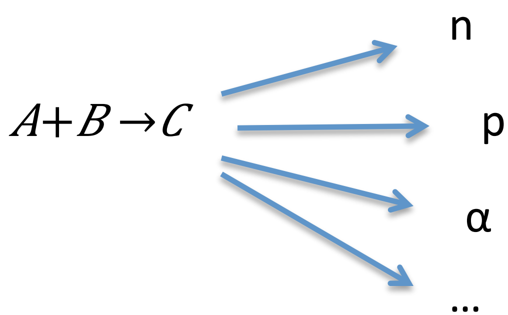

Hauser-Feshbach model for compound reaction:

$$\sigma = \sigma_c^{fus} \frac{T_{n(p\alpha)} \cdot \rho(E^* - S_{n(p,a)} - E_{n(p,a)})}{\sum_{i=n,p,\alpha,\ldots} T_i \rho_i}$$

T – transmission coefficients of outgoing particles

ρ – level density of nuclei populated by outgoing particles

} determined by nuclear structure

Transmission coefficients

1. Determine decay rates of compound nuclei
2. Determine fusion cross section $\sigma_l = (2l+1)\pi\lambda\!\!\!^{-} T_l$

neutron capture reactions, r-process

Transmission coefficients are obtained from optical model of nuclear reactions

Optical potential:

$$U = V + i \cdot W$$

$$V = V_0 + \frac{N-Z}{A} V_{iso} \qquad W = W_0 + \frac{N-Z}{A} W_{iso}$$

Ts are determined by W, for neutron rich nuclei by W_{iso}

W_{iso} is also related to the symmetry energy of nuclear matter !!!

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The isovector imaginary neutron potential: A key ingredient for the r-process nucleosynthesis

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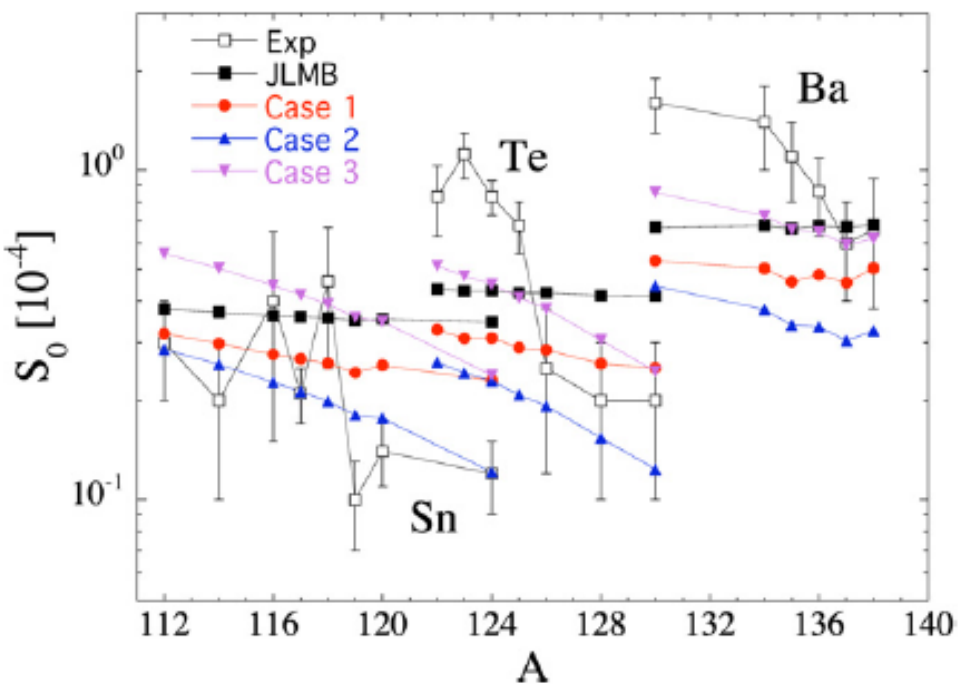

Neutron strength function:

$$S_l = \frac{T_l}{2\pi}$$

JLMB potential : J.P. Jeukenne, A. Lejeune, C. Mahaux, Phys. Rev. C 16 (1977) 80.
E. Bauge, J.P. Delaroche, M. Girod, Phys. Rev. C 58 (1998) 1118.

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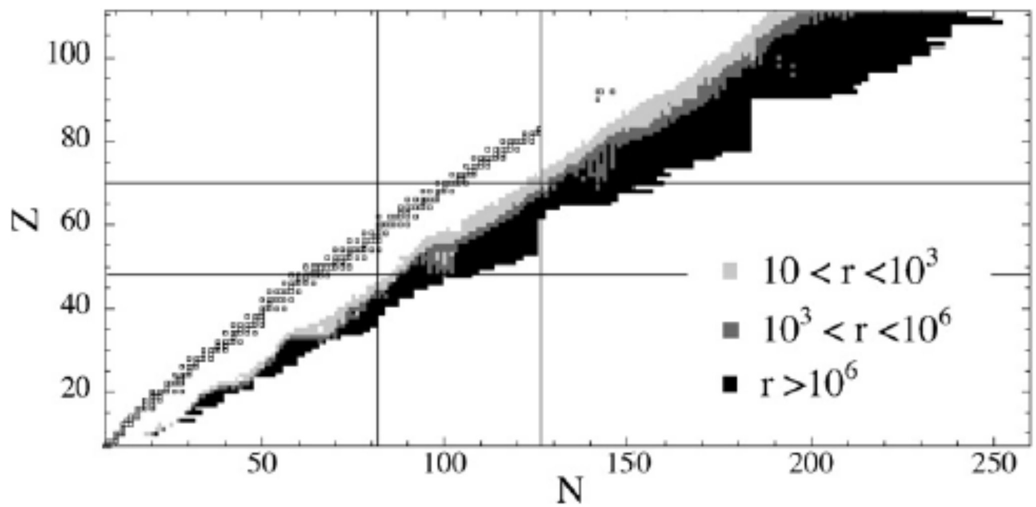


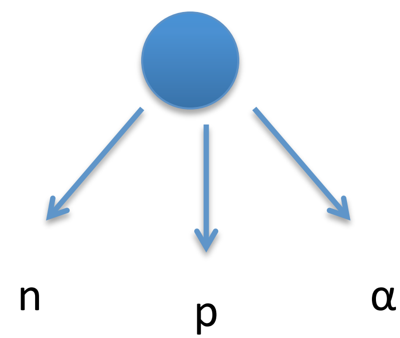
Fig. 5. Representation in the (N, Z) plane of the ratio r (as given by the legend) of the astrophysical rates at $T = 10^9$ K obtained with the JLMB potential to the one obtained with the modified imaginary potential of Case 3. The vertical lines correspond to the neutron magic number $N = 82$ and 126. The horizontal lines at $Z = 48$ and 70 are shown to guide the eye to the expected progenitor nuclei of the r-abundance peaks at $Z = 48$, $N = 82$, $A = 130$ and $Z = 70$, $N = 126$, $A = 196$.

It suggests that standard optical potentials overestimate (n,γ) reaction rates for neutron rich nuclei by orders of magnitudes !!!

Study of transmission coefficients from decay rate ratios of compound nuclei

1. Create compound neutron rich nucleus with fusion reaction
2. Measure relative neutron, proton and alpha decay rates

$$\sigma_{(z,n)} = \sigma_c^{fus} \frac{T_n \cdot \rho(E^* - S_n - E_n)}{\sum_{i=n,p,\alpha,...} T_i \rho_i}$$



$$\sigma_{(z,p)} = \sigma_c^{fus} \frac{T_p \cdot \rho(E^* - S_p - E_p)}{\sum_{i=n,p,\alpha,...} T_i \rho_i}$$

$$\frac{\sigma_{(z,n)}}{\sigma_{(z,p)}} = \frac{T_n \rho(E^* - S_n - E_n)}{T_p \rho(E^* - S_p - E_p)}$$

~100 calculated
with traditional models

Uncertainty of this ratio due to level density is estimated of about 30-50%,
up to factor of 2 in extreme cases.

The effect due to T_n can be up to orders of magnitude d+54Fe

d+56Fe

d+58Fe

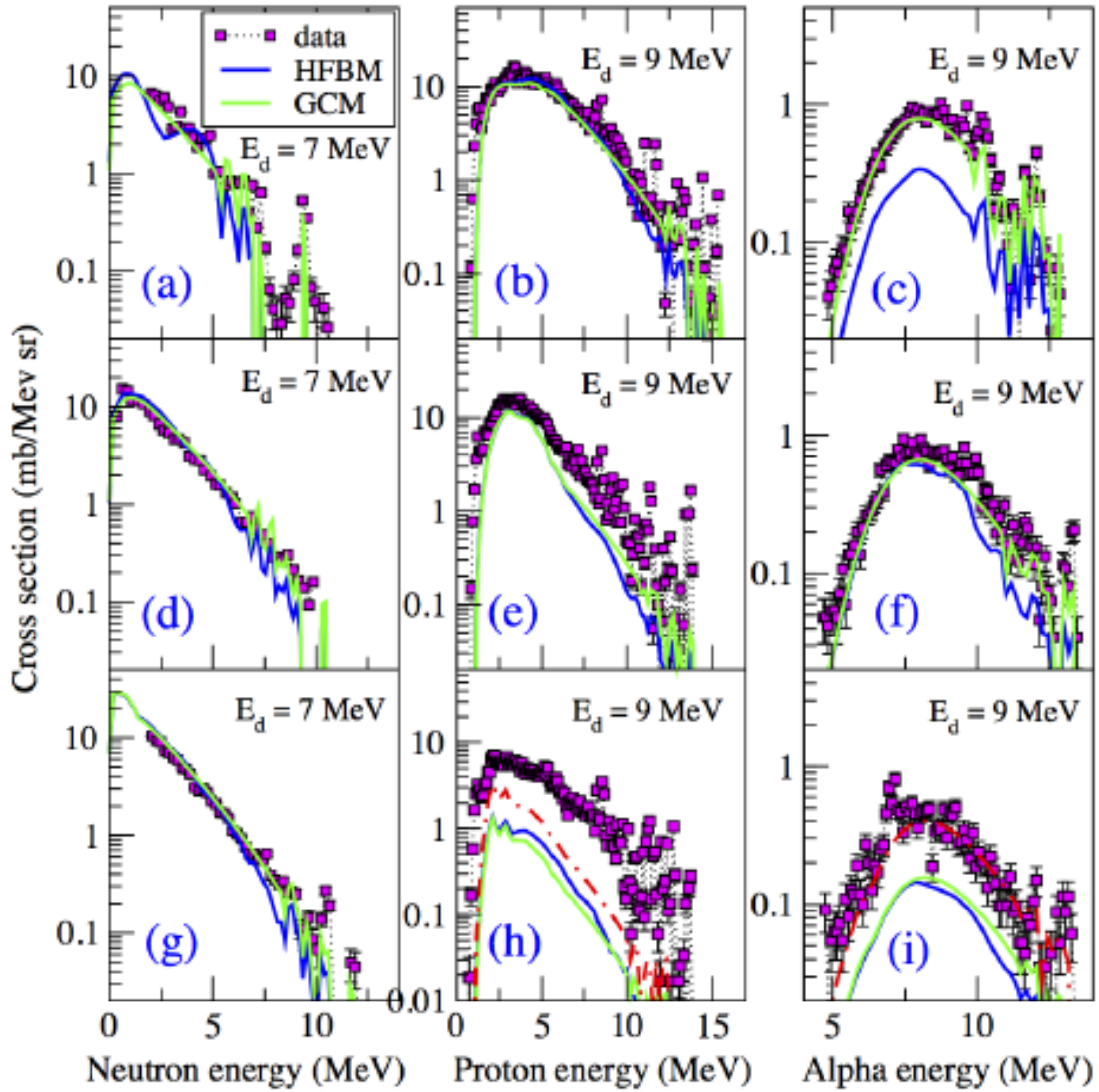


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Figure 1: Comparison of experimental (points) and theoretical (lines) differential cross sections of deuteron induced reactions on ^{54}Fe (top panel), ^{56}Fe (middle panel), and ^{58}Fe (bottom panel). The figure is from Ref. [10] Lines of different colors correspond to calculations with different level density models.

Experimental details

Beam energies

3-9 MeV/A depending on beam species, targets, cross sections.

- Different beam energies bring different angular momenta, so it would be important to study effect of angular momenta of the compound system on decay rates of different outgoing channels.
- Cross sections for some reactions increase with the beam energy.

Expected rates

Beam intensity ~5 $\times 10^4$ pps, neutron yield ~ 10^4 /day ,
proton yield ~ 500 /day

Detection systems :

due to low intensity beams and small (z,Xp) cross section,
large solid angle coverage detectors are required

Conclusions

1. Results obtained from analysis of neutron strength function for stable isotopes with different neutron number, suggests that neutron strength function can decrease very rapidly with increasing (N-Z)/A. If this is true, the traditional picture of r-process in the neutron rich region needs to be revised. (S. Goriely, J.P. Delaroche, Phys.Lett. B653, 178(2007)).

2. It appears that isovector imaginary optical potential responsible for neutron strength function can be studied experimentally from ratios of neutron/proton/alpha yields from decay of neutron rich compound nuclei created with radioactive beams.

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