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Indirect measurement of the $(n,\gamma)^{127}$Sb cross section

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Quasi-continuum
Excitation energy region above the discrete region and below S_n where the number of levels is too high to be able to separate between them (more than ~50 levels per MeV bin). Here we can use statistical tools such as the NLD and the GSF to describe nuclear properties.

NLD
Nuclear level density. Average number of energy levels per energy bin in the quasi-continuum region.

GSF
Gamma strength function. Statistical, quasi-continuum equivalent of the reduced transition probability in the discrete region. It gives us information about which energy the nucleus wants to decay by the most", and thus an insight of its internal structure and collective modes.

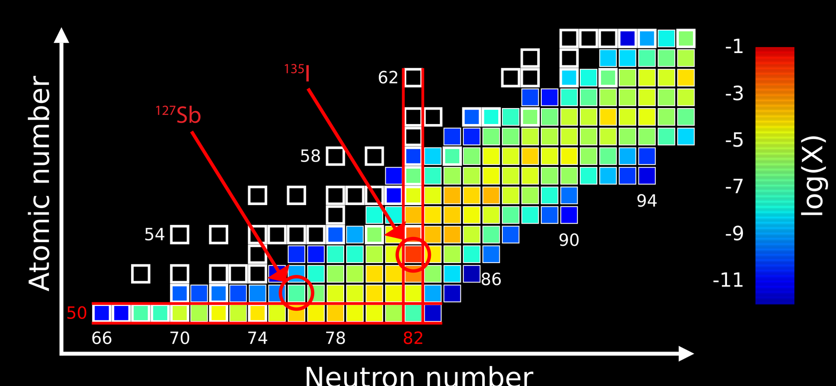
Nucleosynthesis
The phenomenon by which new nuclei are created. Can be roughly divided into Big Bang nucleosynthesis (responsible for the creation of H and most of He), stellar nucleosynthesis (elements up to iron) and heavy-element nucleosynthesis (elements above iron, mostly due to neutron-capture).

s- and r-process
Slow and rapid neutron-capture process. Heavy element nucleosynthesis processes with neutron densities of 10^{6}-10^{10} cm^{-3} the first and 10^{20}-10^{24} cm^{-3} the latter. The s-process lasts for thousands of years in e.g. AGB stars. The r-process lasts for 1-2 seconds and is thought to happen in supernovae and neutron star mergers.

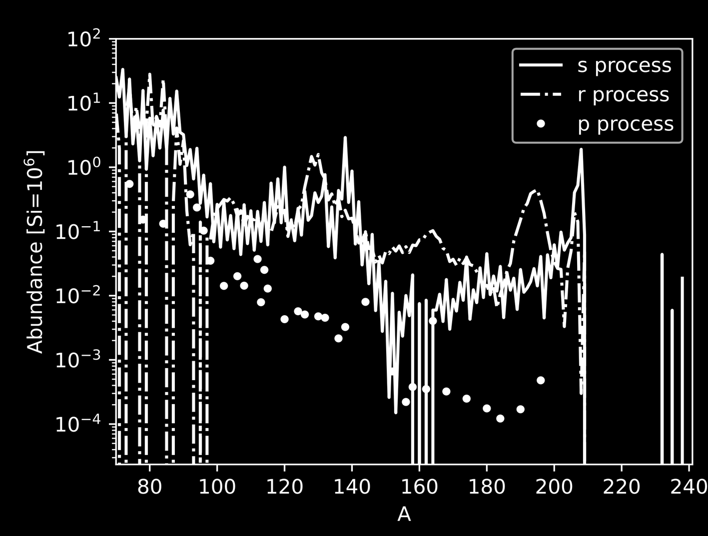
i-process
Intermediate neutron-capture process. Heavy element nucleosynthesis processes involving neutron densities of ~10^{15} cm^{-3}, lasting some few days and theorized to happen in e.g. AGB stars and rapidly accreting white dwarfs (RAWDs).

1. Motivation

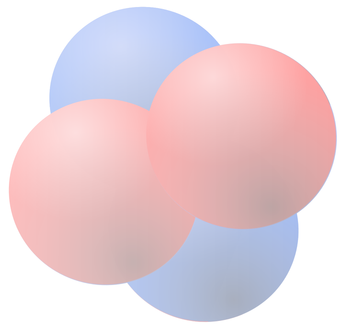
The s- and the r-processes produce different elemental abundance patterns, and these have long been enough to explain the chemical composition of stars, these usually presenting the pattern of one of a combination of the two processes. CEMP-s/r stars are in this sense peculiar, given that their abundance pattern cannot be explained in terms of an s+r elemental abundance pattern. It has been shown by Hampel et al. (2016) that the i-process can reproduce the observed abundances, and that the region around ^{135}I acts as a bottleneck for the process.
^{127}Sb belongs to this region and is reachable by the ^{124}Sn$(\alpha,p\gamma)^{127}$Sb reaction. By studying the properties of ^{127}Sb with the Oslo method we get a first glimpse of the behaviour of the nuclei involved in the i-process.

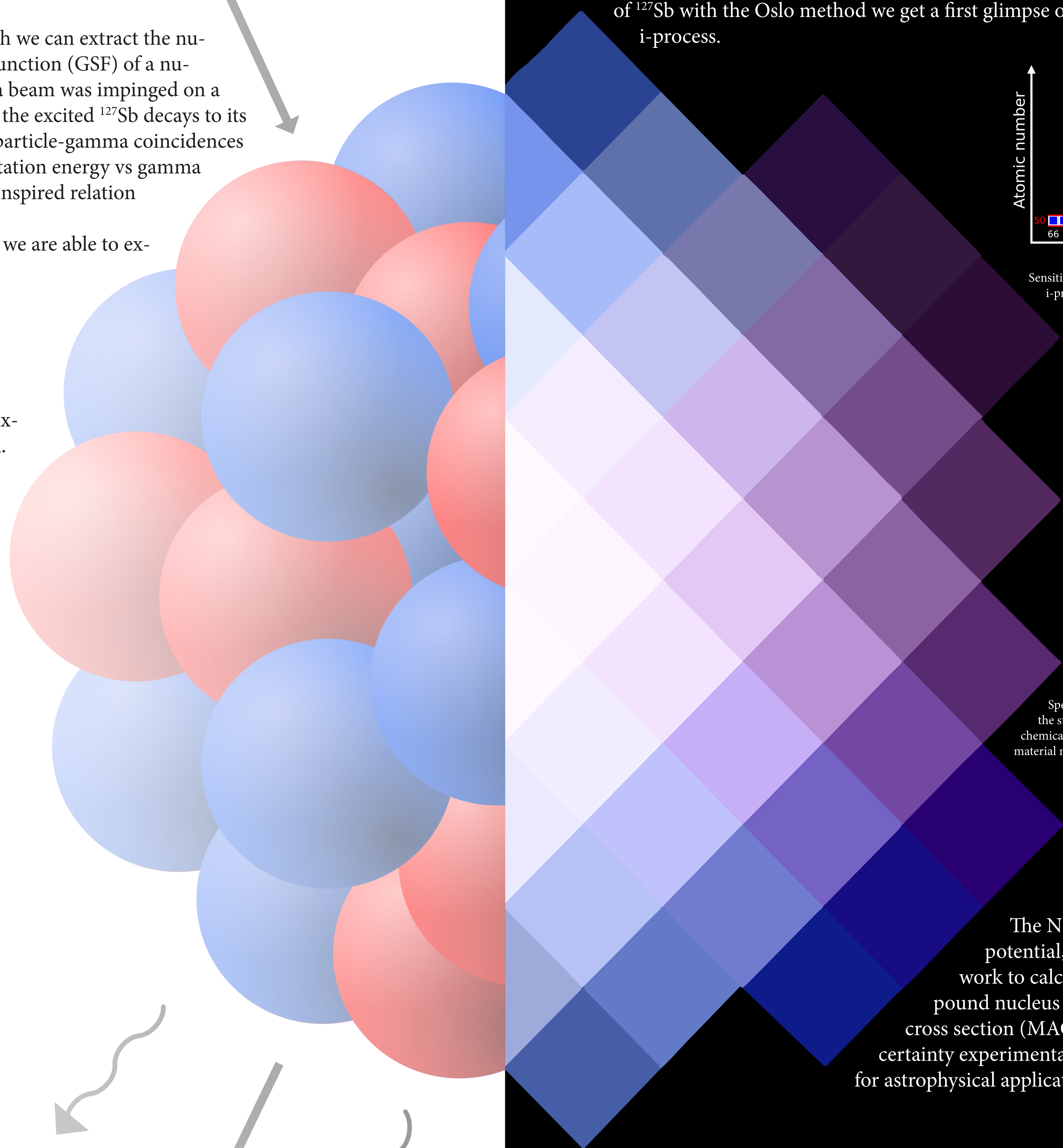


Sensitivity study from Hampel et al., showing the nucleosynthesis flow for the i-process. ^{135}I and ^{127}Sb are marked. Courtesy of Hampel et al (2016).



Solar abundances divided into s-, r- and p-process abundances. Courtesy of Asplund et al. (2007).

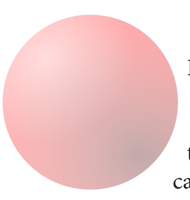

A 24 MeV beam of α-particles is impinged on a ^{124}Sn target


Spectrometric information from the star's atmosphere tells us about its chemical composition, and thus how its material may have been formed.

2. The Oslo Method

The Oslo method is an analysis technique with which we can extract the nuclear level density (NLD) and the gamma strength function (GSF) of a nucleus (see e.g. Schiller et al. (2000)). A 24 MeV alpha beam was impinged on a ^{124}Sn target. This is captured, a proton is ejected and the excited ^{127}Sb decays to its ground state releasing a gamma-ray cascade. From particle-gamma coincidences and reaction dynamics, we are able to build the excitation energy vs gamma decay energy plot. By using the Fermi's golden rule inspired relation
$F(E_x,E_\gamma) \approx \rho(E_x-E_\gamma)\,f(E_\gamma)$
And after normalizing to known experimental data, we are able to extract the NLD (ρ) and the GSF (f).

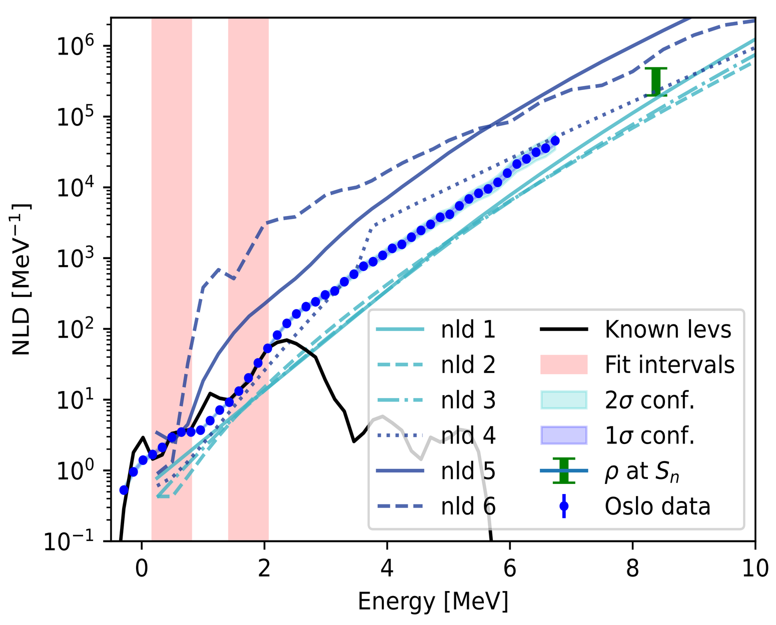
γ The γ-rays provide information on the preferred decay energy.


From the energy of the ejected proton and the Q-value of the reaction, we can calculate the excitation energy the residual nucleus is left in.

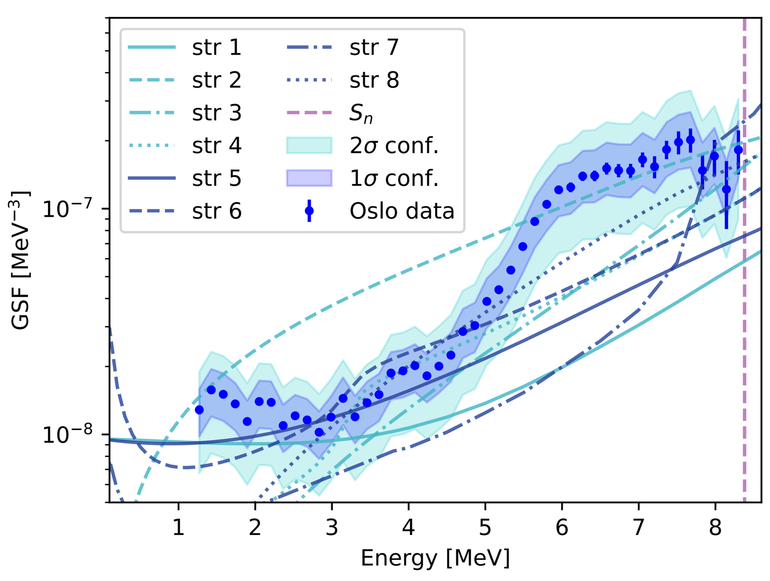
γ

3. NLD, GSF

The results are shown in the two plots. The NLD is exponential and follows a constant temperature model. The GSF presents features such as the upbend and the pygmy resonance. Both the NLD and GSF experimental results are compared to the theoretical models available in TALYS, showing the need for more predictive theories.



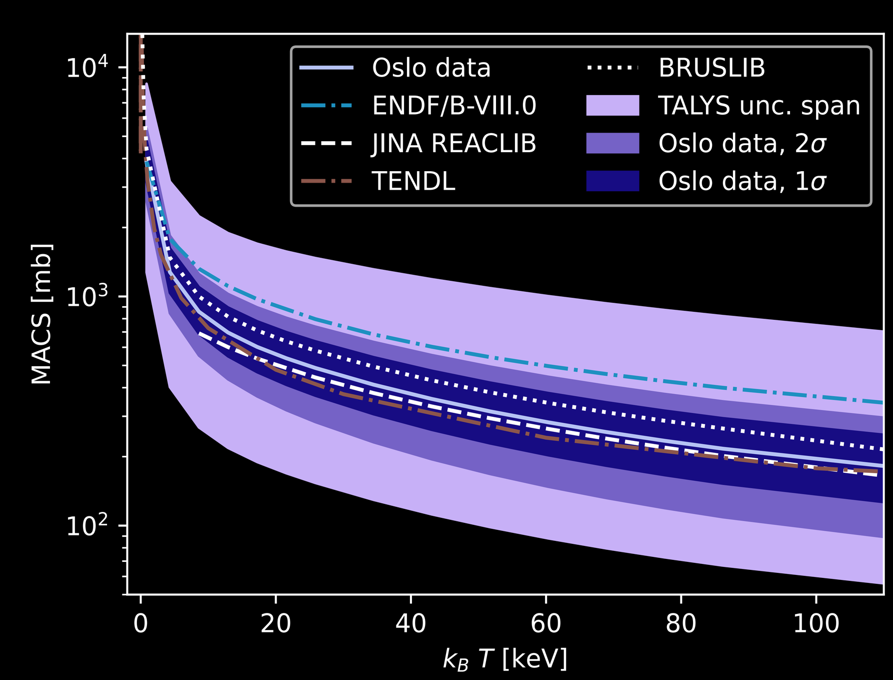
Experimental NLD compared to TALYS models. In red, the intervals used for normalization.



Experimental GSF compared to TALYS models.

4. The MACS

The NLD and GSF, together with the optical model potential, can be used in the Hauser-Feshbach framework to calculate the ^{126}Sb(n,γ) cross section in the compound nucleus picture. From this, its Maxwellian-averaged cross section (MACS) can be calculated and the theoretical uncertainty experimentally constrained. This quantity is very useful for astrophysical applications.



Experimentally constrained MACS, compared to commonly used libraries and the uncertainty span from all the combinations of TALYS NLD and GSF models.

5. Conclusion

The MACS for ^{126}Sb(n,γ) was obtained by analyzing the ^{124}Sn$(\alpha,p\gamma)^{127}$Sb experiment, and its uncertainty experimentally constrained. This provides more precise data to be used in nucleosynthesis network calculation and sensitivity studies. The NLD and GSF were also extracted providing valuable insights on the properties of nuclei in the ^{135}I region.

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Picture of CEMP star HE2339-0837, SIMBAD.unistra.fr.