



From ANC to Trojan Horse and other indirect methods

INT Workshop “Quantum Physics of Stars” 2026

Chloe Hebborn

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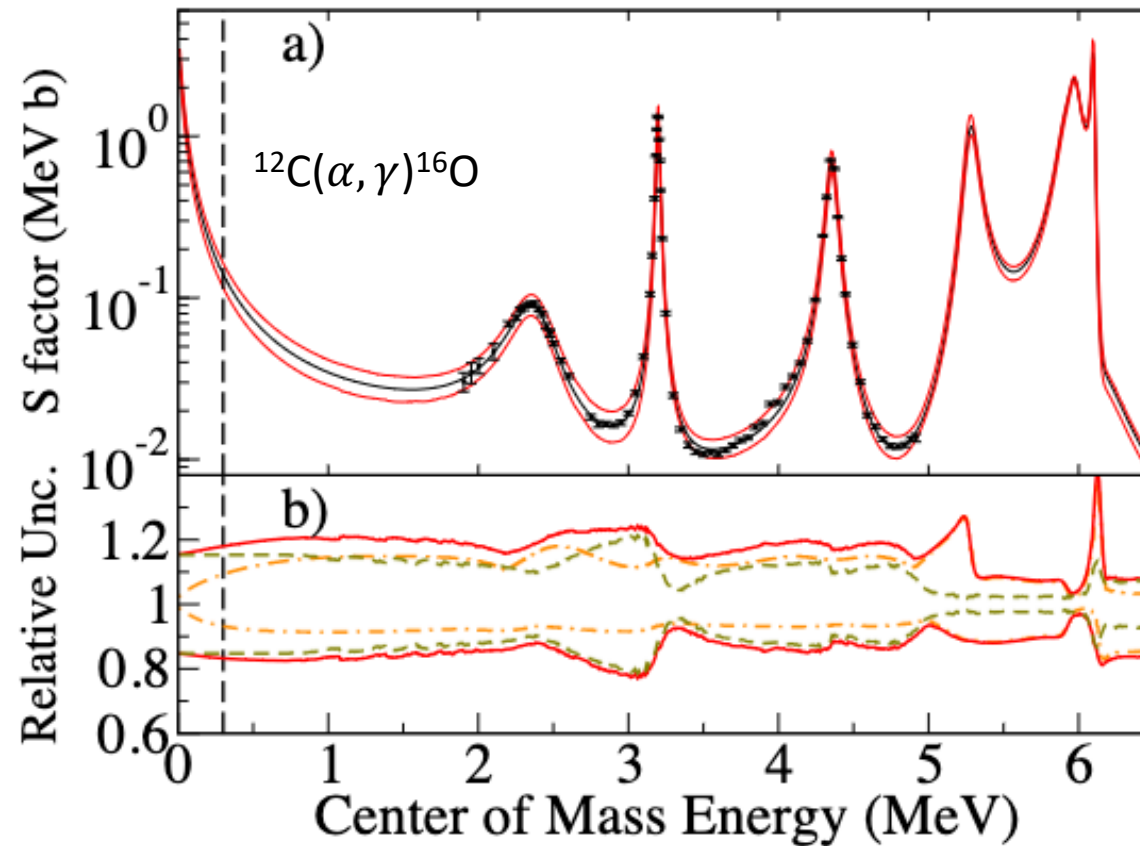
Chloe Hebborn

[Progress in Particle and Nuclear Physics 143 \(2025\) 104164](#)

Indirect methods with transfer reactions: The Trojan Horse method
and the Asymptotic Normalization Coefficient

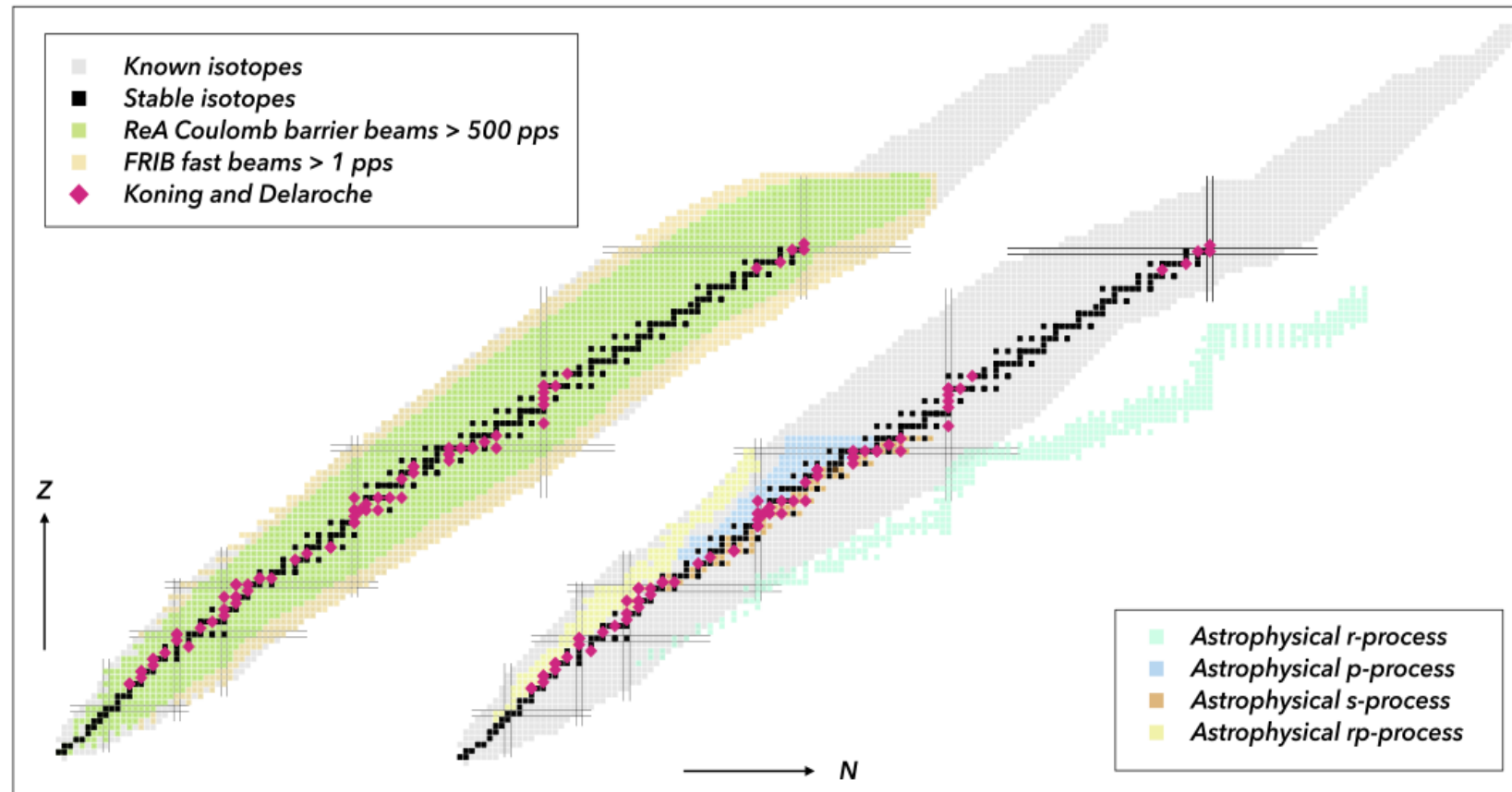
A. Tumino^{a,b}, C.A. Bertulani^c, S. Cherubini^{d,b}, G.F. D’Agata^{d,b}, A. Di Pietro^b,
P. Figuera^b, G.L. Guardo^b, M. Gulino^{a,b}, S. Hayakawa^e, M. La Cognata^b, M.
La Commara^{f,g}, L. Lamia^{d,b}, D. Lattuada^{a,b}, M. Mazzocco^{i,h}, A.M. Moro^j, J. Mraček^k,
A.A. Oliva^b, S. Palmerini^{l,m}, R.G. Pizzone^{d,b}, G.G. Rapisarda^{d,b}, S. Romano^{d,b},
M.L. Sergi^{d,b}, R. Sparta^{a,b}, S. Typel^{n,o}, H. Yamaguchi^e

Evaluation at astrophysical energies rely on accurate theory and available experimental data



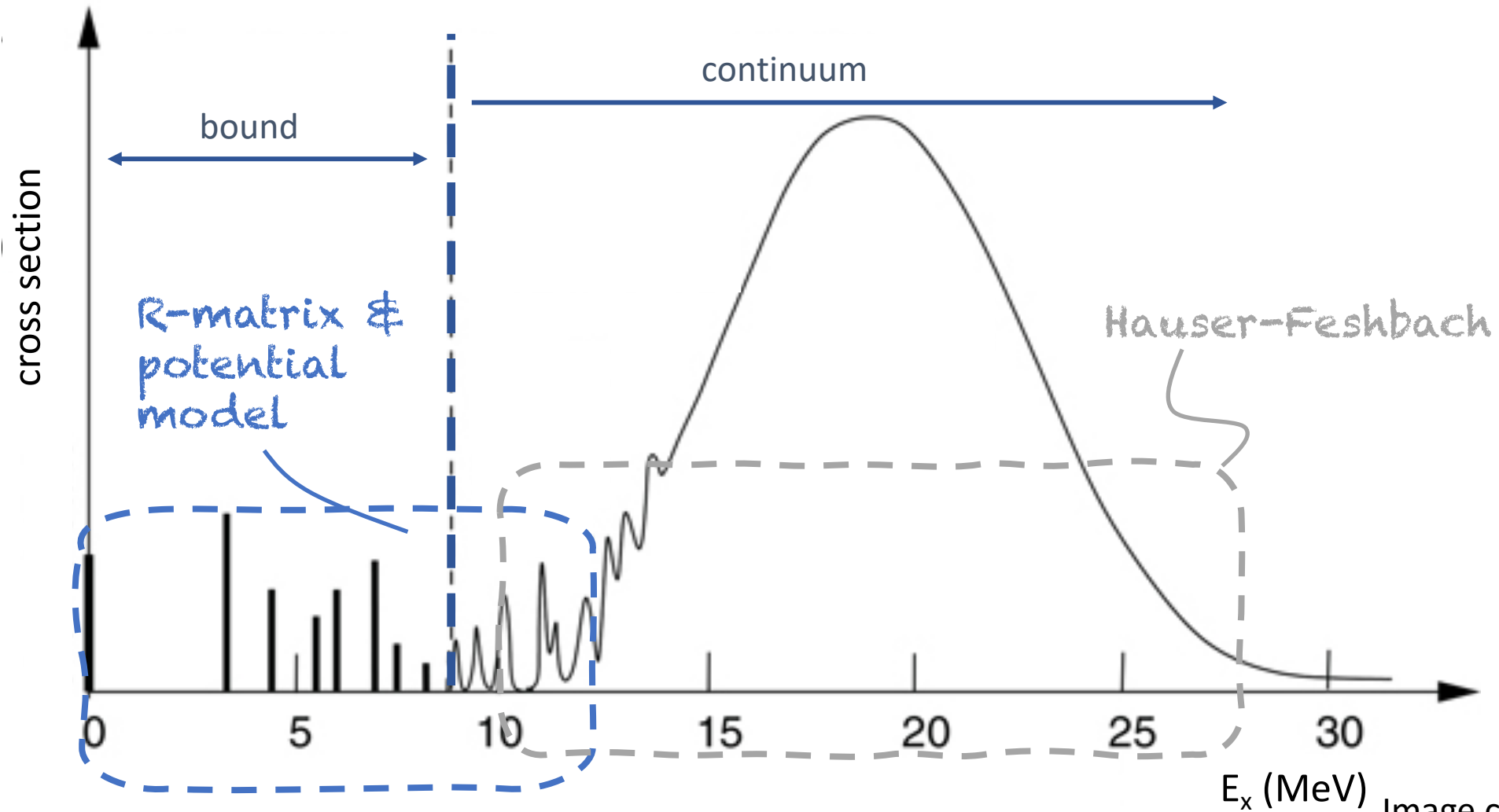
DeBoer et al. Rev. Mod. Phys. 89 035007 (2017)

Astrophysically relevant reactions span the whole nuclear chart



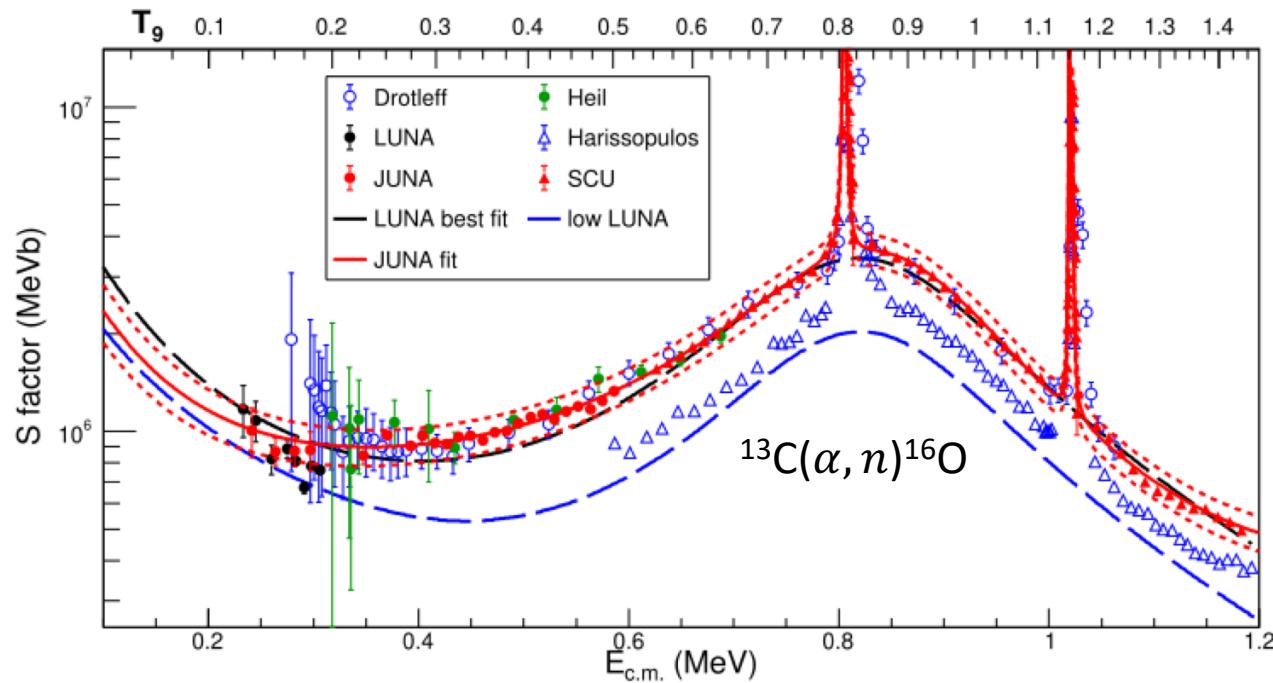
Whitepaper : JPG 50 060501 (2023)

Different theories associated for nuclei with various levels densities

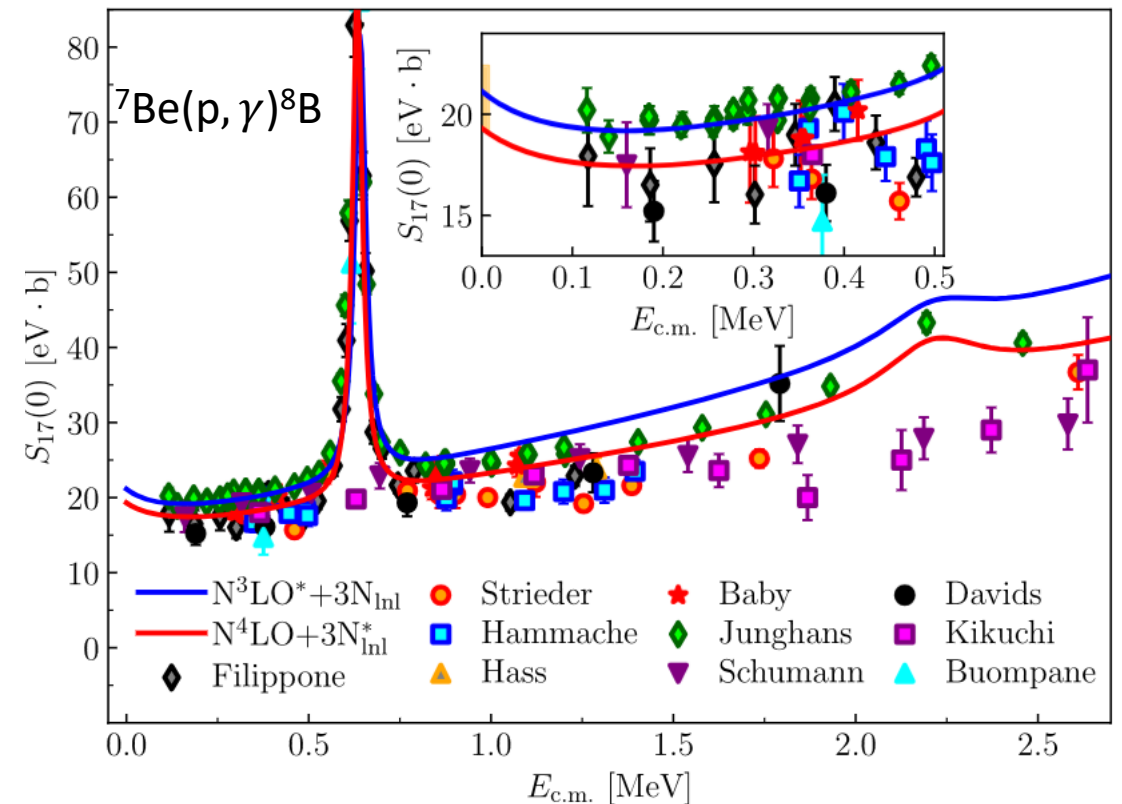


Still extrapolation can be uncertain...

Due to conflicting datasets, large experimental errors, theoretical uncertainties...

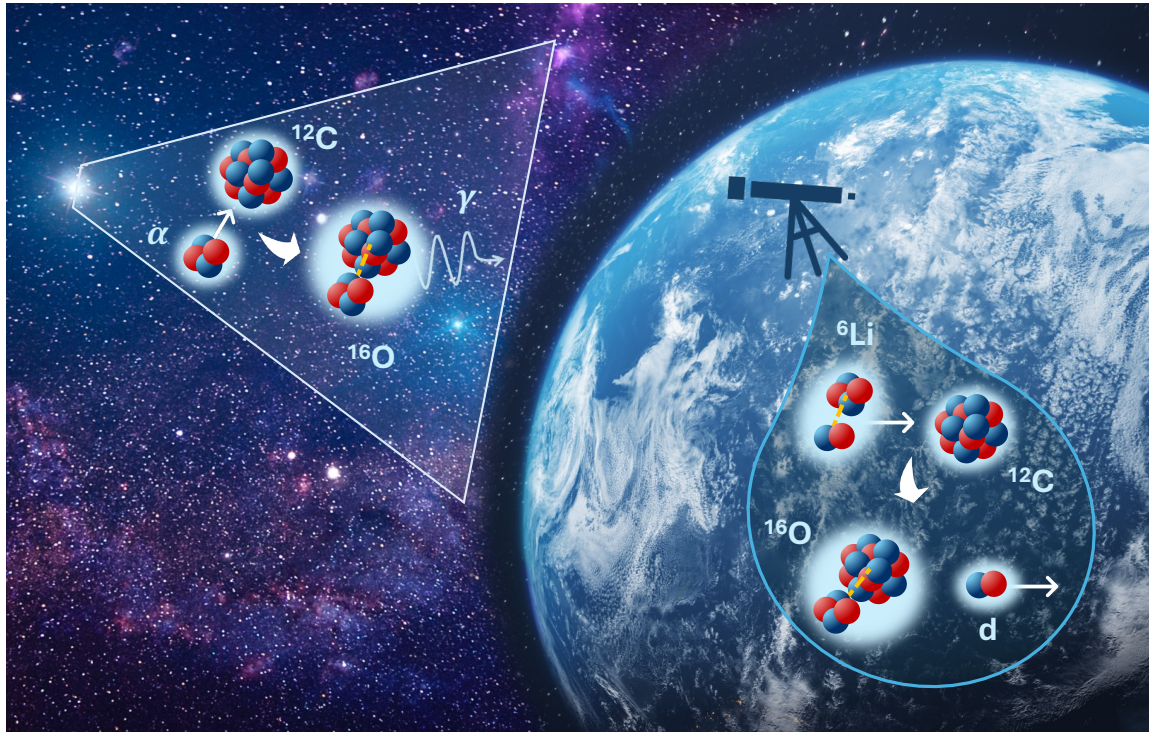


Gao et al. (JUNA) PRL 129 132701 (2022)



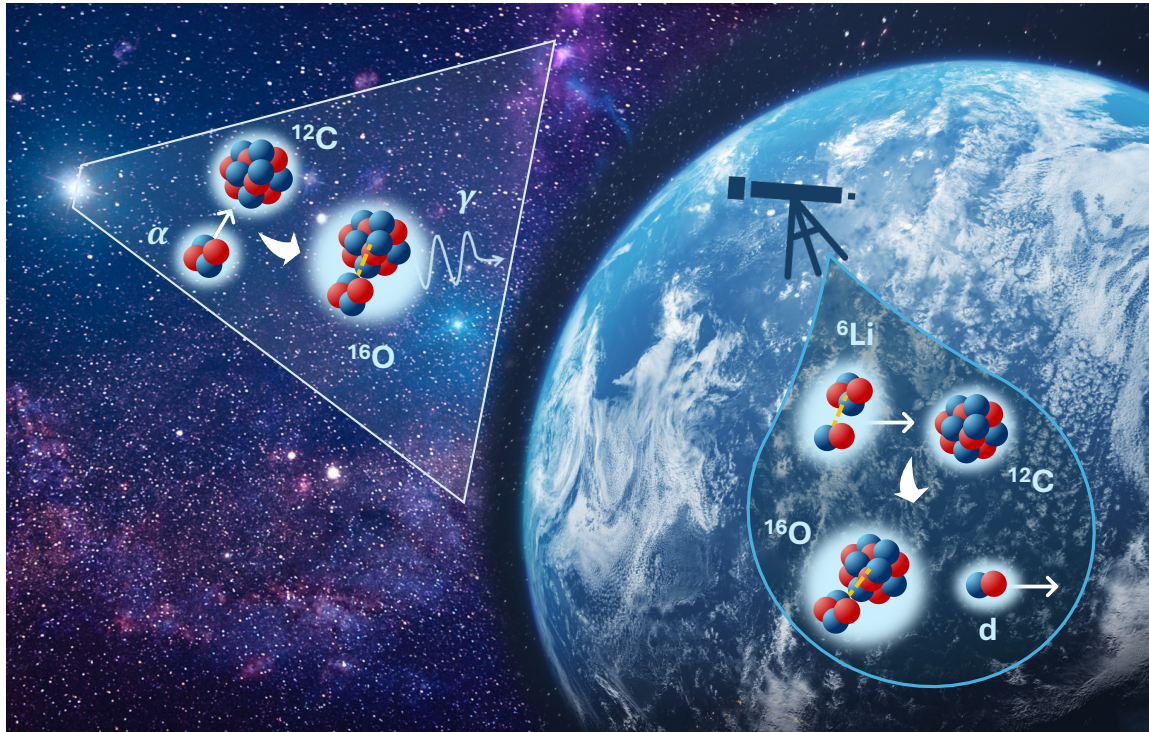
Kravvaris et al. PLB 845 138156 (2023)

Still extrapolation can be uncertain, indirect methods to the rescue to provide guidances



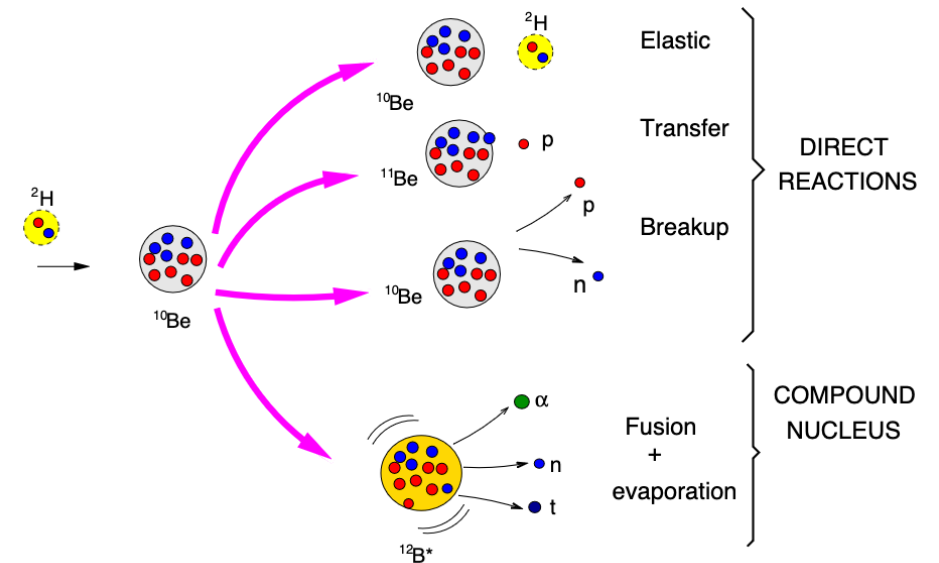
Data have higher cross sections ☺

Still extrapolation can be uncertain, indirect methods to the rescue to provide guidances



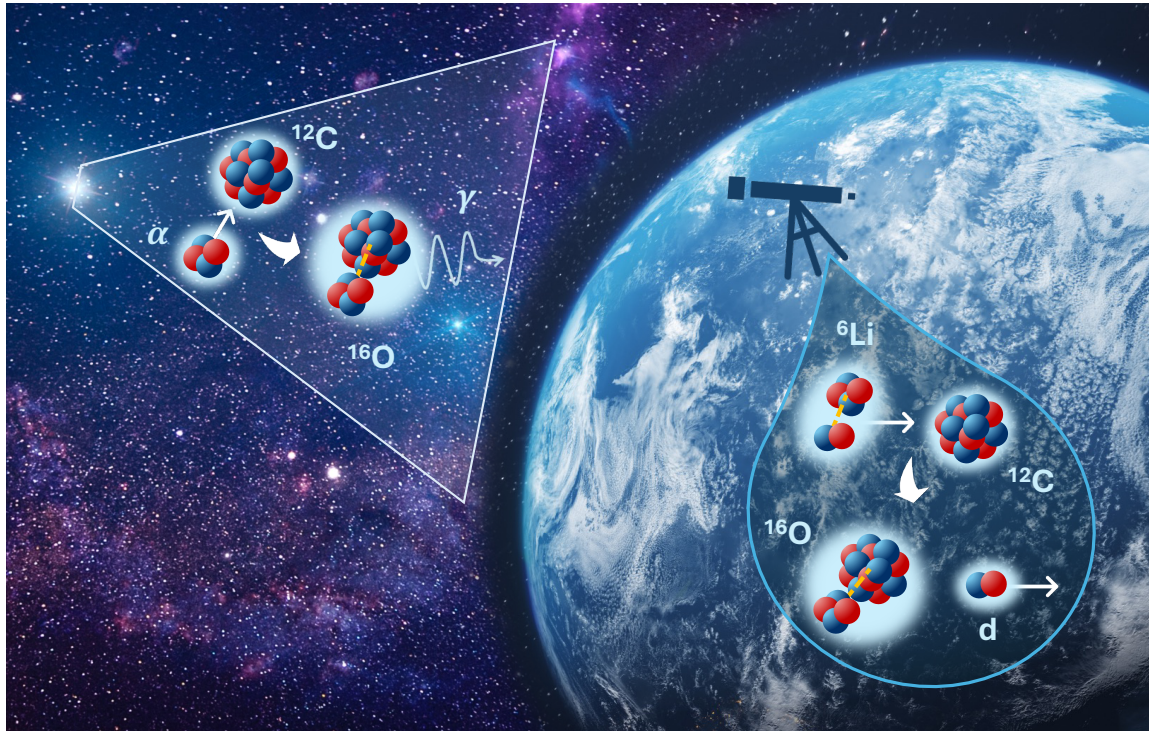
Data have higher cross sections 😊

Possibility to use various reaction probes



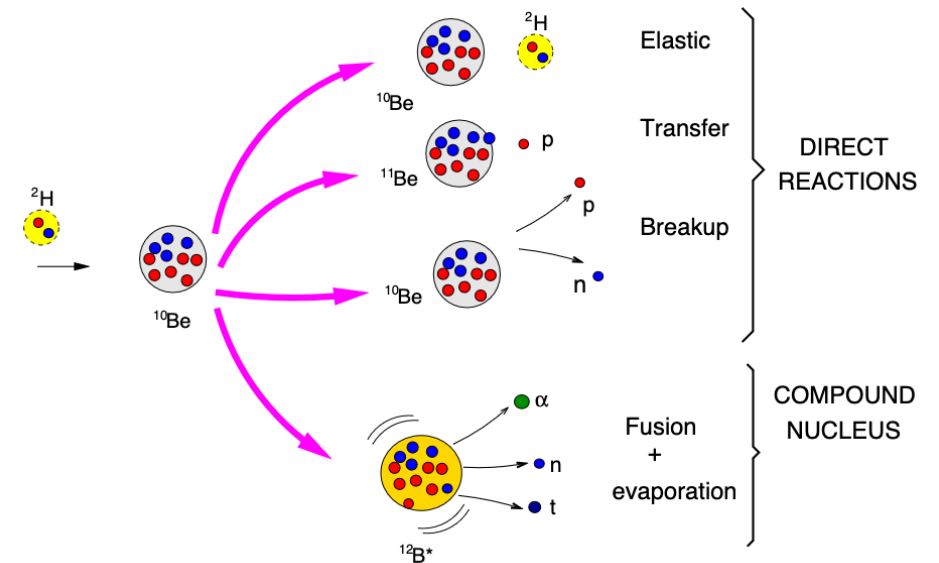
Picture from Moro (Enrico Fermi school)

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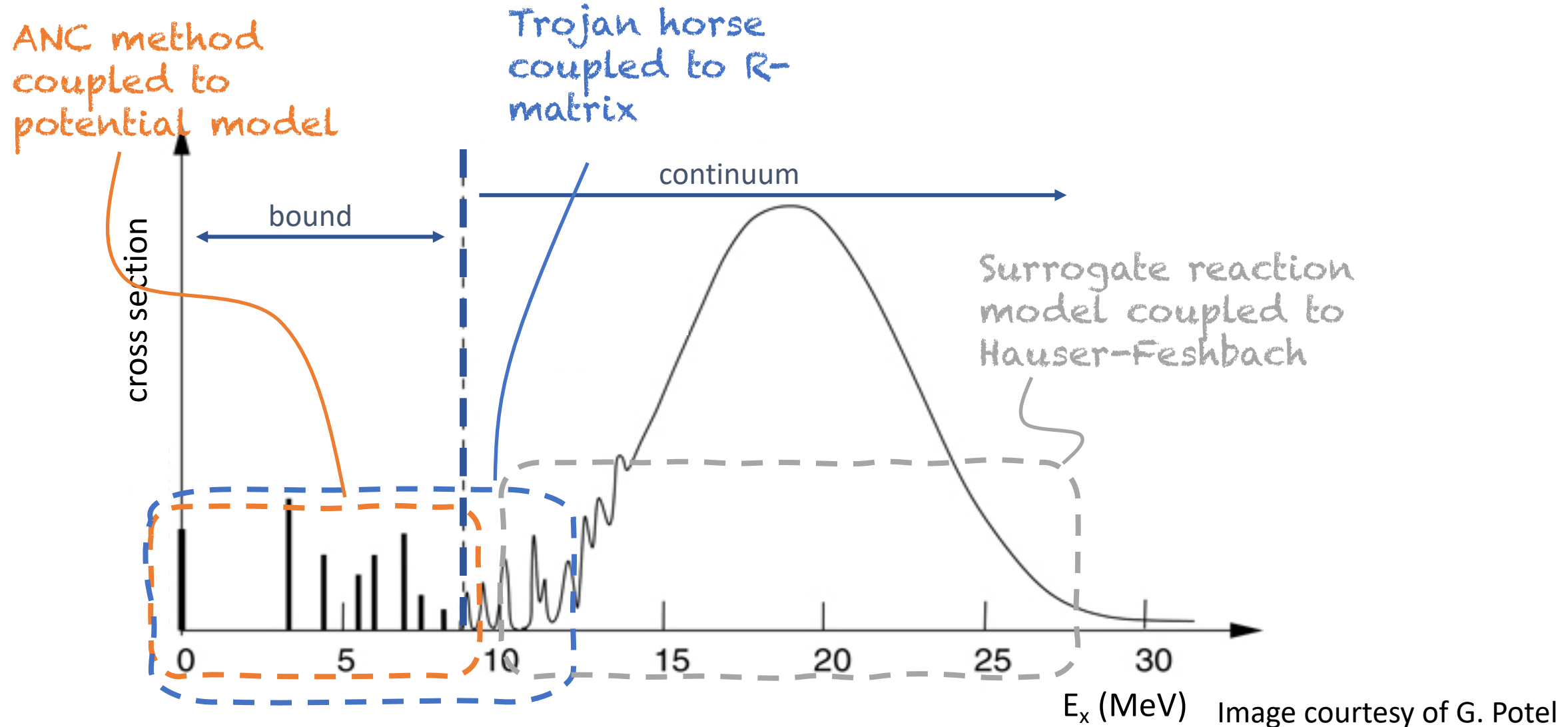
Possibility to use various reaction probes



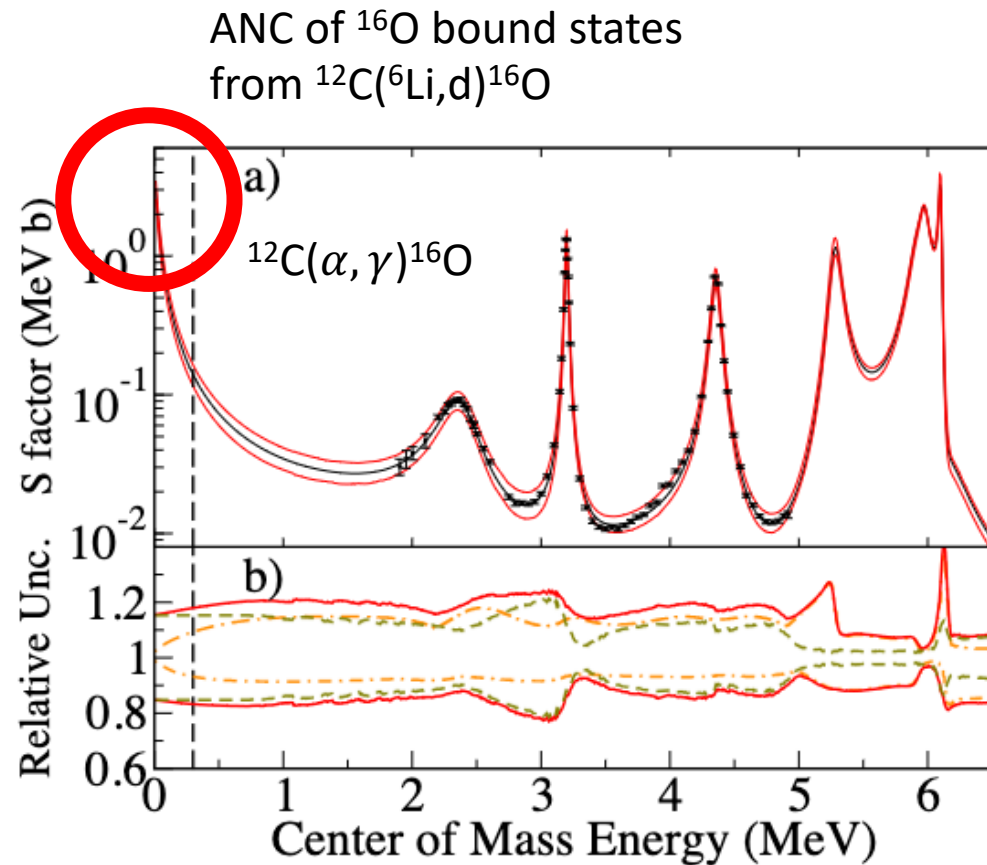
Picture from Moro (Enrico Fermi school)

Need to have an accurate reaction model to analyze these data!

Tricky nomenclature : different indirect techniques for different level densities...

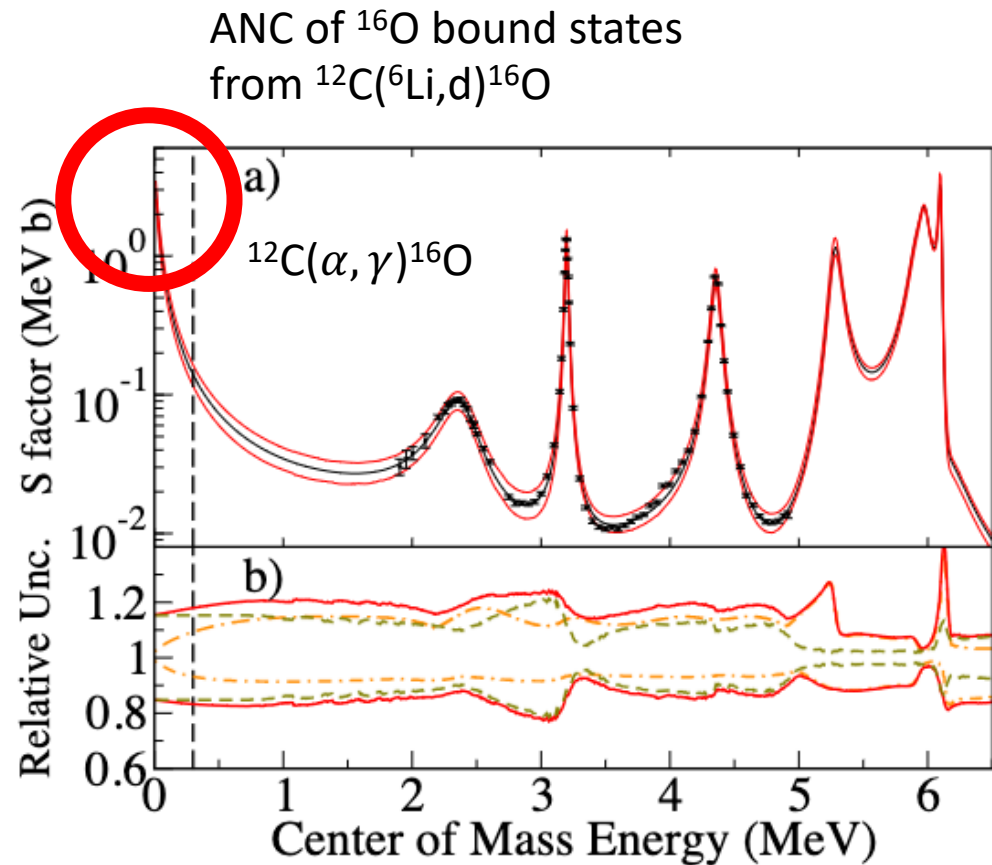


Examples of indirect reaction to constrain astrophysical reaction rates



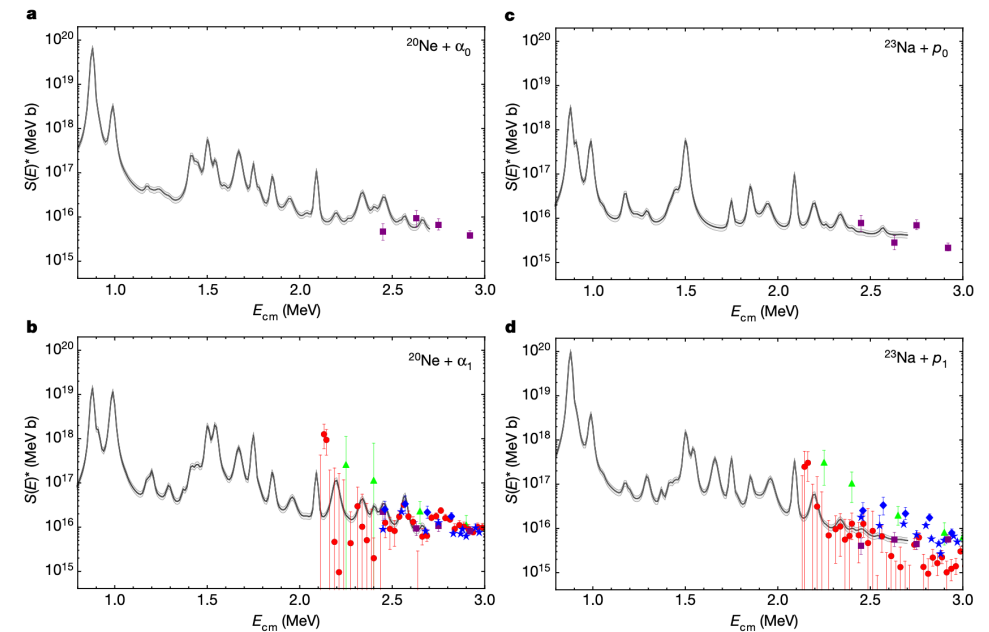
DeBoer et al. Rev. Mod. Phys. 89 035007 (2017)

Examples of indirect reaction to constrain astrophysical reaction rates



DeBoer et al. Rev. Mod. Phys. 89 035007 (2017)

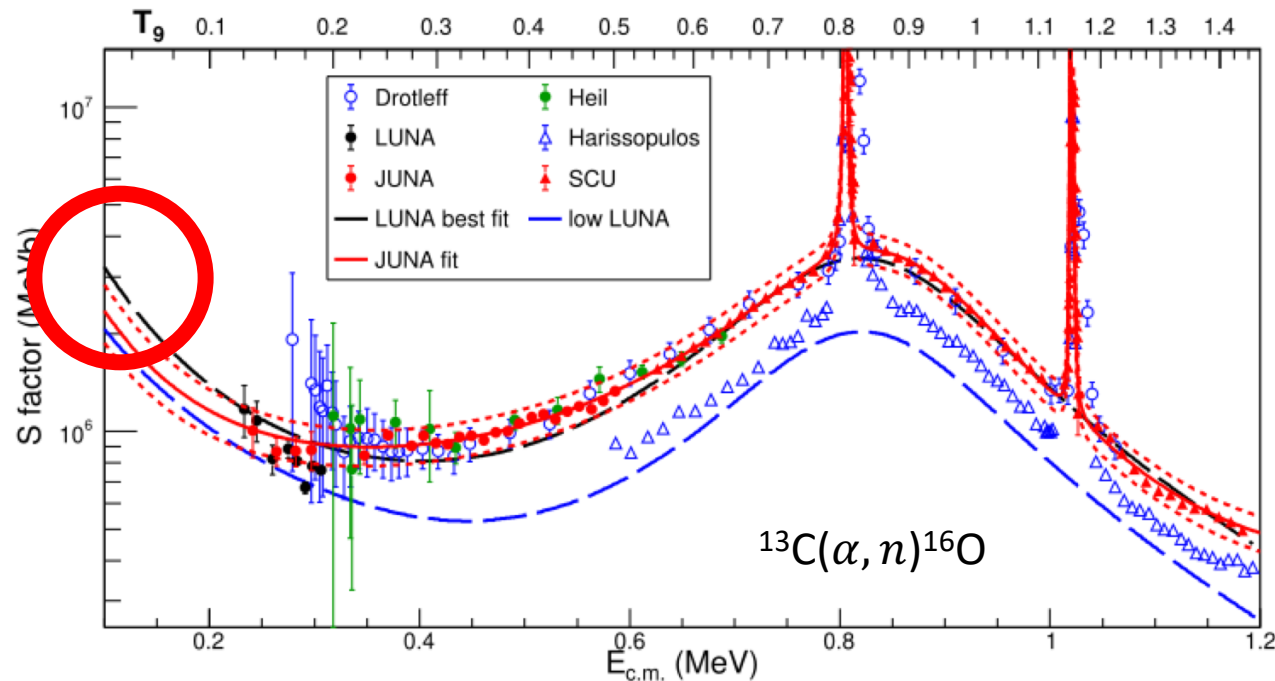
Trojan horse method $^{12}\text{C} + ^{12}\text{C}$ fusion obtained through $^{12}\text{C}(^{14}\text{N}, \alpha ^{20}\text{Ne})d$ and $^{12}\text{C}(^{14}\text{N}, p ^{23}\text{Na})d$



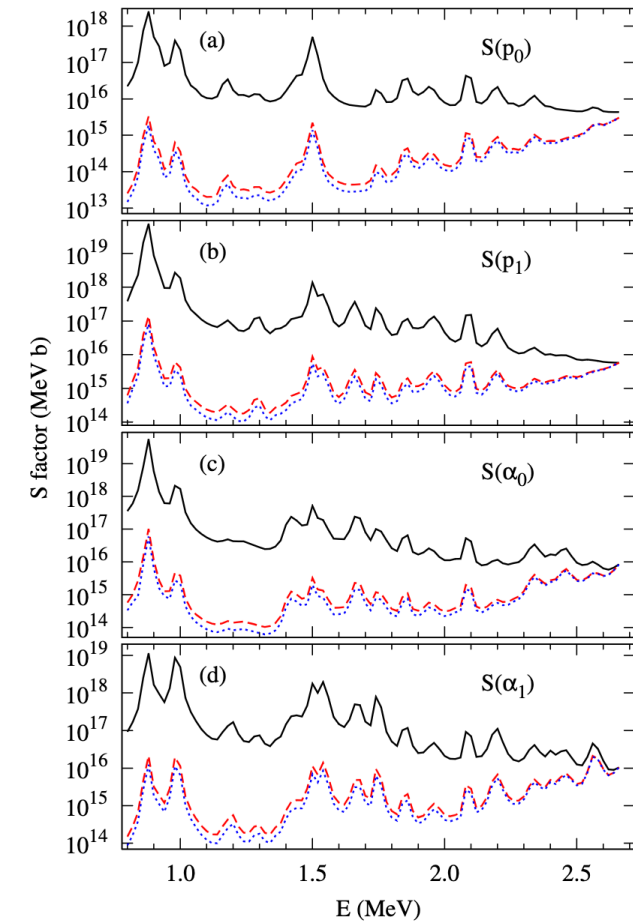
Tumino et al. Nature (2018)

Still, some discrepancies can be found..

Due to discrepancies in ANC of subthreshold states



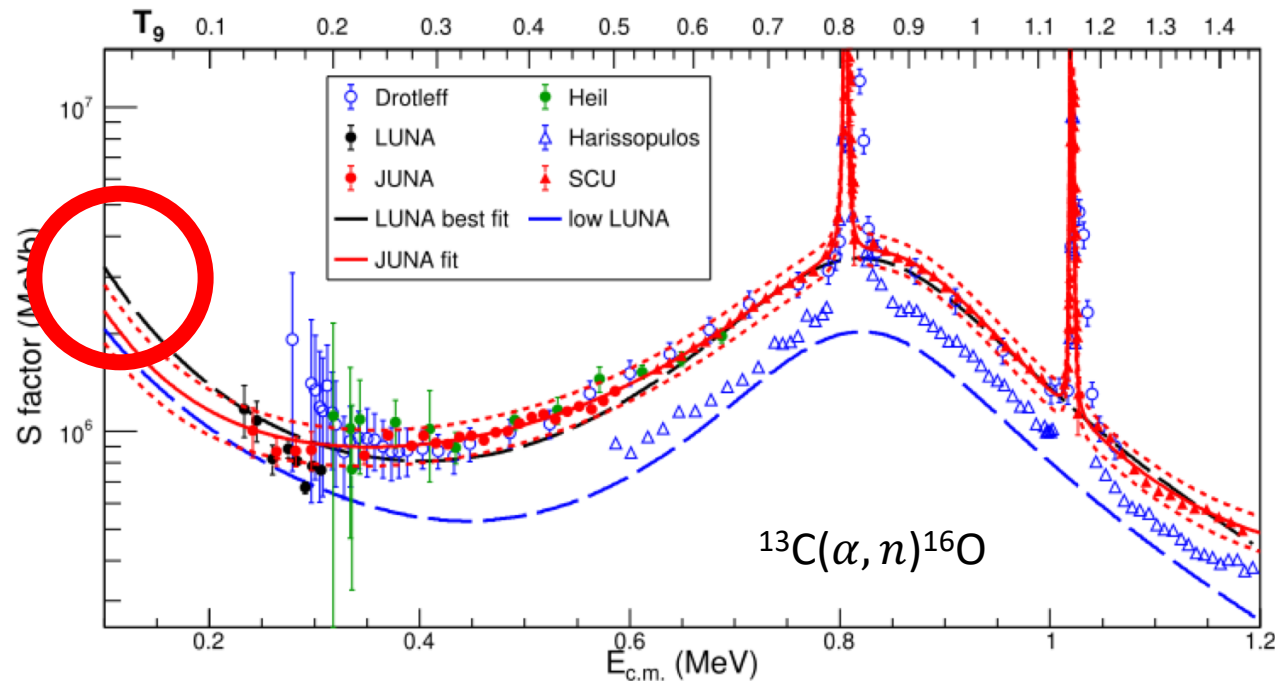
Gao et al. (JUNA) PRL 129 132701 (2022)



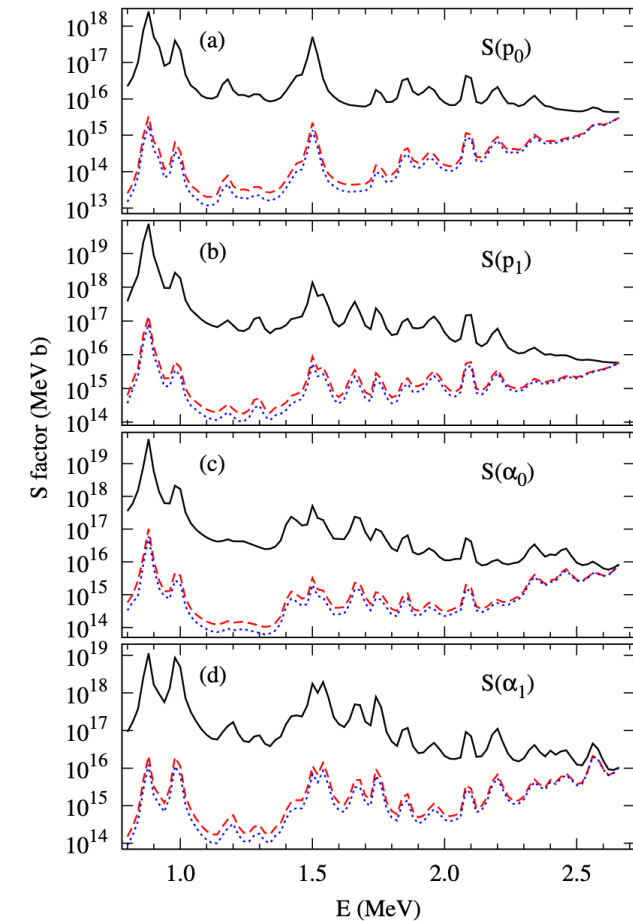
Mukhamedzanov et al. PRC 99 064618 (2019)

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Gao et al. (JUNA) PRL 129 132701 (2022)



Mukhamedzanov et al. PRC 99 064618 (2019)

Need to have accurate reaction description for the indirect reaction and reliable quantification of uncertainties

Indirect reactions' talks

- (Tuesday) La Cognata, Investigating threshold resonances using indirect methods
- Tumino, Indirect measurements of heavy-ion reactions governing C burning in stars
- Hebborn, Constraining accurately astrophysical rates using indirect reactions