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Search for a resonance in $^{25}Mg(n,\gamma)$ cross section to constrain the $^{22}Ne(\alpha,n)^{25}Mg$ neutron source reaction rate

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Department of Physics and Astronomy

Proposal layout

INTC – P – 732

Search for a resonance in ^{25}Mg(n,γ) cross section to constrain the ^{22}Ne(α,n)^{25}Mg neutron source reaction rate

January 3, 2025

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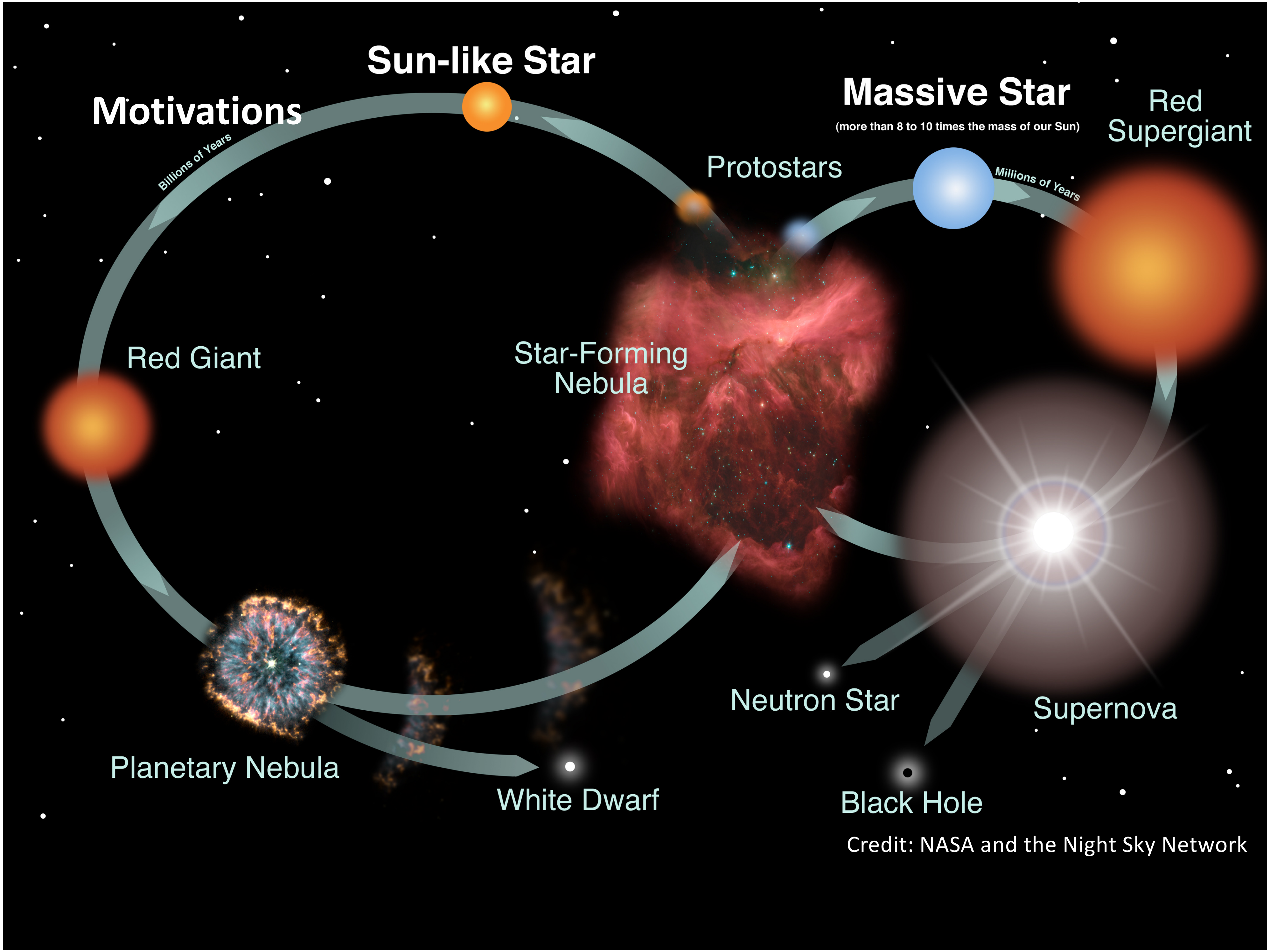
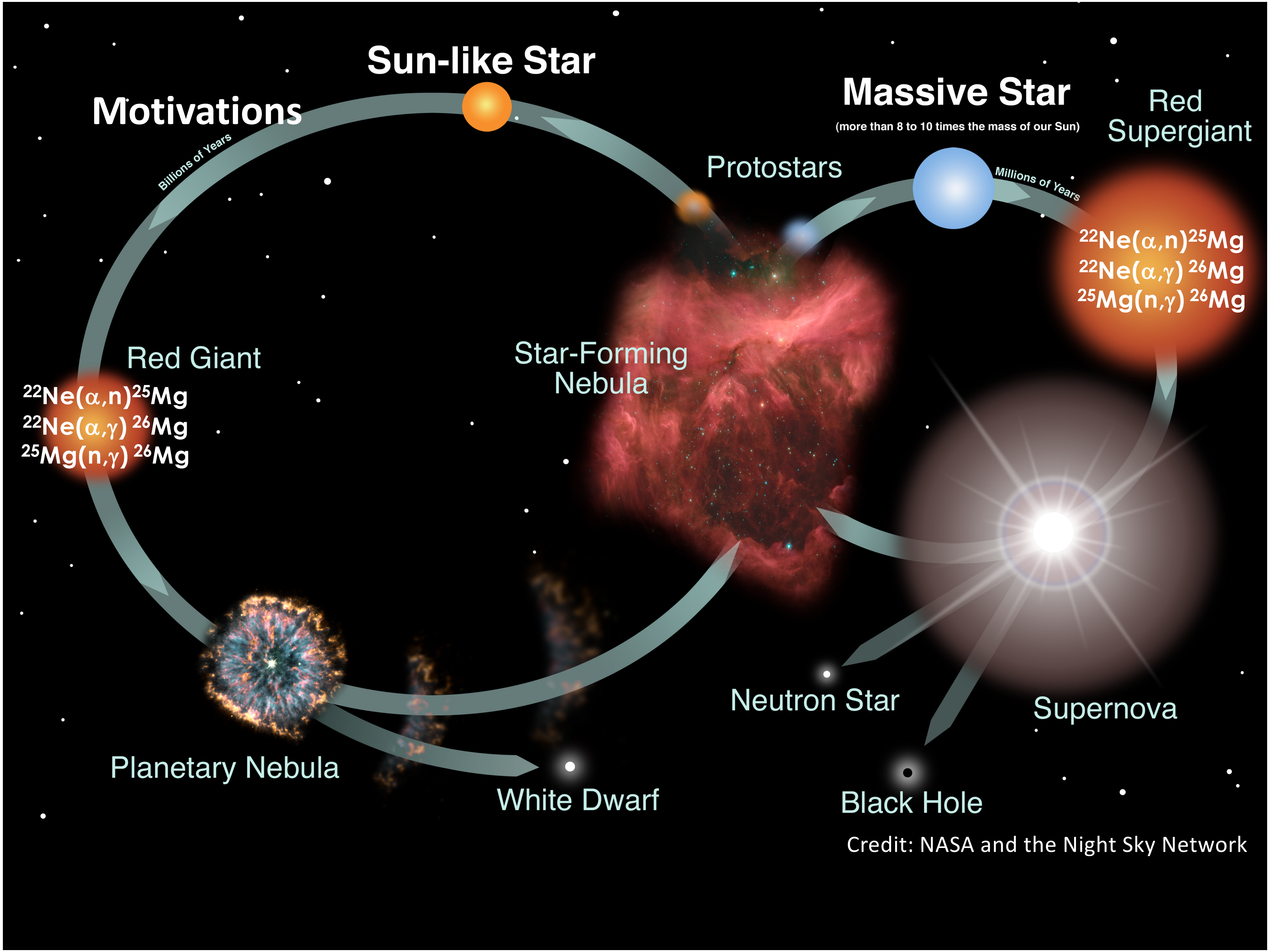
[5] *ENEA – Agency for New Technologies, Energy and Sustainable Economic Development, Italy*
[6] *INAF– National Institute for Astrophysics, Italy*
[7] *CERN*
[8] *Department of Physics and Astronomy – University of Tireste, Italy*

Motivations



Credit: NASA and the Night Sky Network


Motivations
Sun-like Star
Billions of Years
Massive Star
(more than 8 to 10 times the mass of our Sun)
Red Supergiant
Protostars
Millions of Years
$^{22}Ne(\alpha,n)^{25}Mg$
$^{22}Ne(\alpha,\gamma)^{26}Mg$
$^{25}Mg(n,\gamma)^{26}Mg$
Red Giant
$^{22}Ne(\alpha,n)^{25}Mg$
$^{22}Ne(\alpha,\gamma)^{26}Mg$
$^{25}Mg(n,\gamma)^{26}Mg$
Star-Forming Nebula
Neutron Star
Supernova
Planetary Nebula
White Dwarf
Black Hole
Credit: NASA and the Night Sky Network

Why n + ^{25}Mg ?

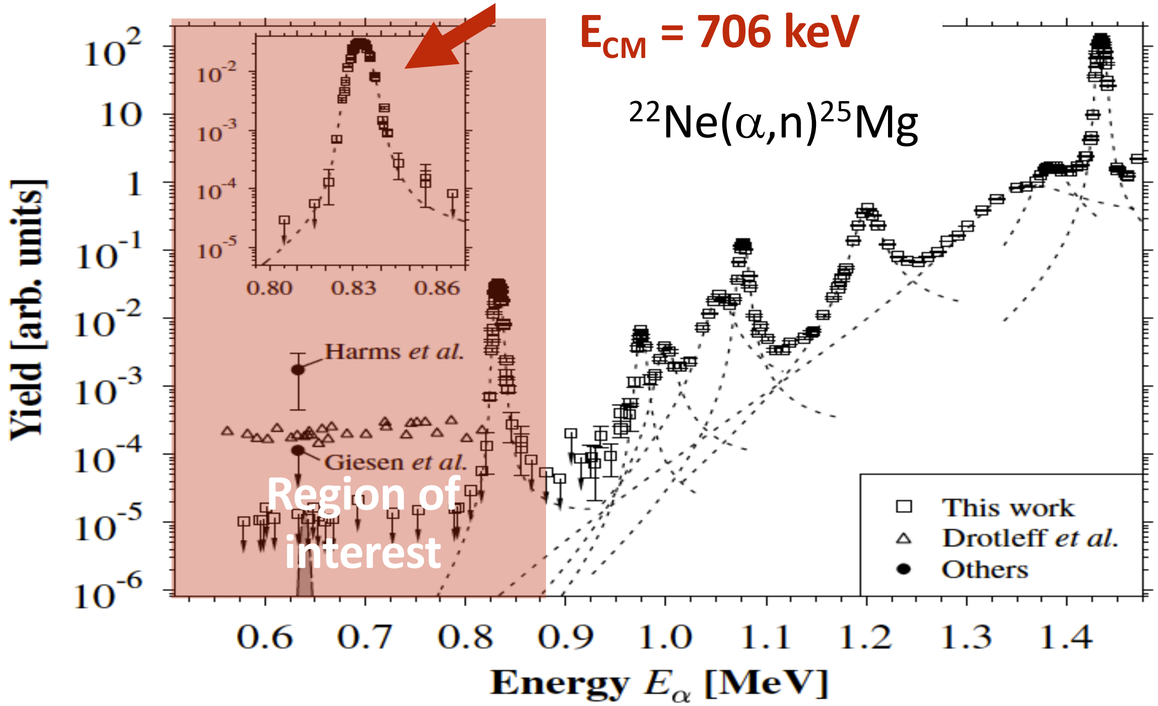
- NEUTRON POISON:
  - ^{25,26}Mg are the most important neutron poisons due to neutron capture on Mg stable isotopes, i.e. **^{25,26}Mg(n,γ),** in competition with neutron capture on ^{56}Fe (the basic s-process seed for the production of heavier isotopes).

- **CONSTRAINTS for ^{22}Ne(α,n)^{25}Mg and ^{22}Ne(α,γ)^{26}Mg**:
  - ^{22}Ne(α,n)^{25}Mg is one of the most important neutron source in Red Giant stars. Its reaction rate is very uncertain because of the poorly known property of the states in ^{26}Mg. From neutron measurements the energy, **J^{π}** and **energy** of **^{26}Mg** states can be deduced, in addition to Γ_γ and Γ_n.

Why n + ^{25}Mg ?

Data in the literature

E_{α} = 832 keV
E_{CM} = 706 keV



➢ **CONSTRAINTS for ^{22}Ne(α,n)^{25}Mg and ^{22}Ne(α,γ)^{26}Mg**:

- ^{22}Ne(α,n)^{25}Mg is one of the most important neutron source in Red Giant stars. Its reaction rate is very uncertain because of the poorly known property of the states in ^{26}Mg. From neutron measurements the energy, **J$^{\pi}$** and **energy** of **^{26}Mg** states can be deduced, in addition to Γ_γ and Γ_n.

Why n + ^{25}Mg ?

Physical Review C

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Reevaluation of the ^{22}Ne (α,γ) ^{26}Mg and ^{22}Ne (α,n) ^{25}Mg reaction rates

Philip Adsley[1,2,3,*], Umberto Battino[4,†], Andreas Best[5,6], Antonio Caciolli[7,8], Alessandra Guglielmetti[9], Gianluca Imbriani[5,6], Heshani Jayatissa[10], Marco La Cognata[11], Livio Lamia[12,11,13] *et al.*

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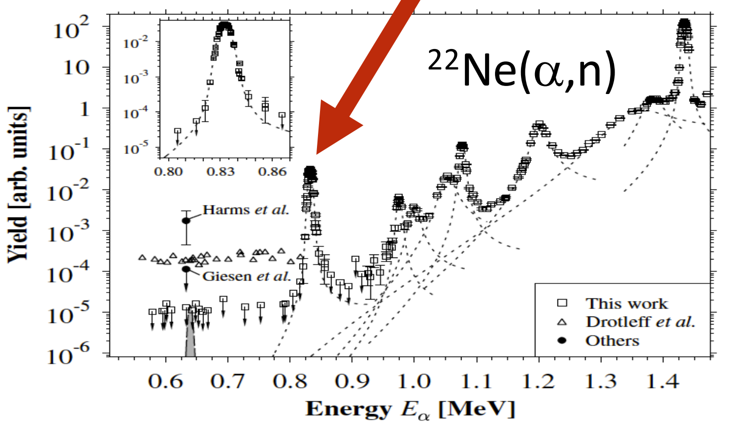
DOI: https://doi.org/10.1103/PhysRevC.103.015805



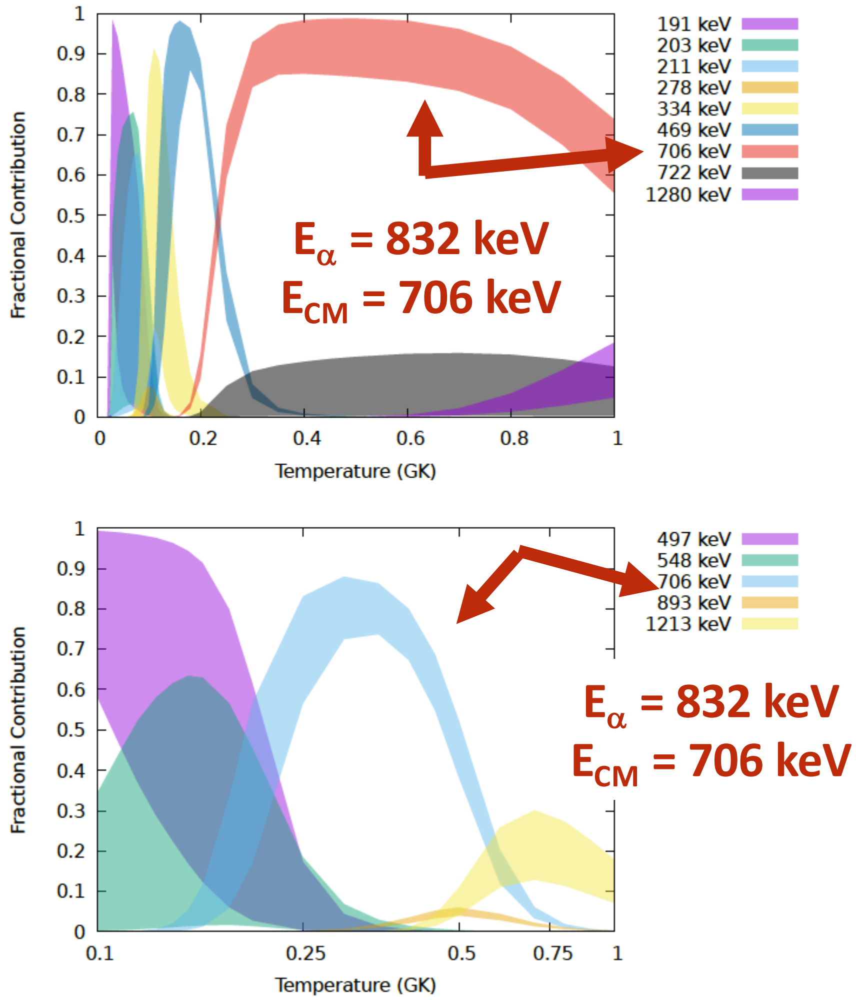


FIG. 1. Fractional contributions of selected resonances to the (top) ^{22}Ne$(\alpha,\gamma)^{26}$Mg and (bottom) ^{22}Ne$(\alpha,n)^{25}$Mg reaction rates. These fractional contributions are for the recommended reaction rates, which incorporate the Texas A&M results. The shaded region gives the 68% coverage limit for the contribution of each resonance. Note that only the most significant resonances are included in the figure; the sum of the contributions may not reach 100% due to contributions from omitted resonances.

Why n + ^{25}Mg ?

Resonance strength ^{22}Ne(α,n)^{25}Mg:

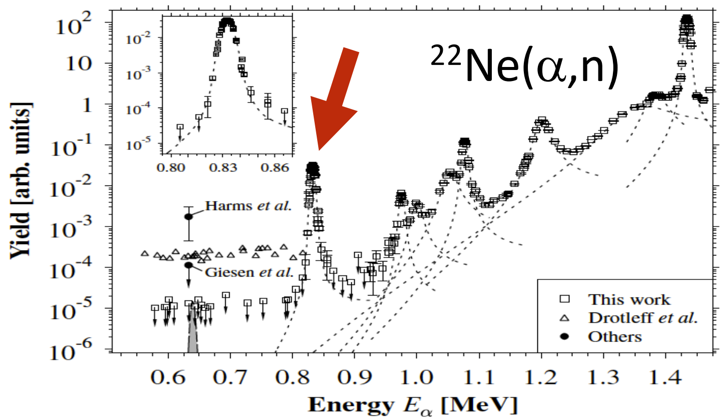
$$\omega_\alpha = g\,\Gamma_\alpha \Gamma_n / (\Gamma_\alpha + \Gamma_\gamma + \Gamma_n)$$

Resonance strength ^{22}Ne(α,γ)^{26}Mg:

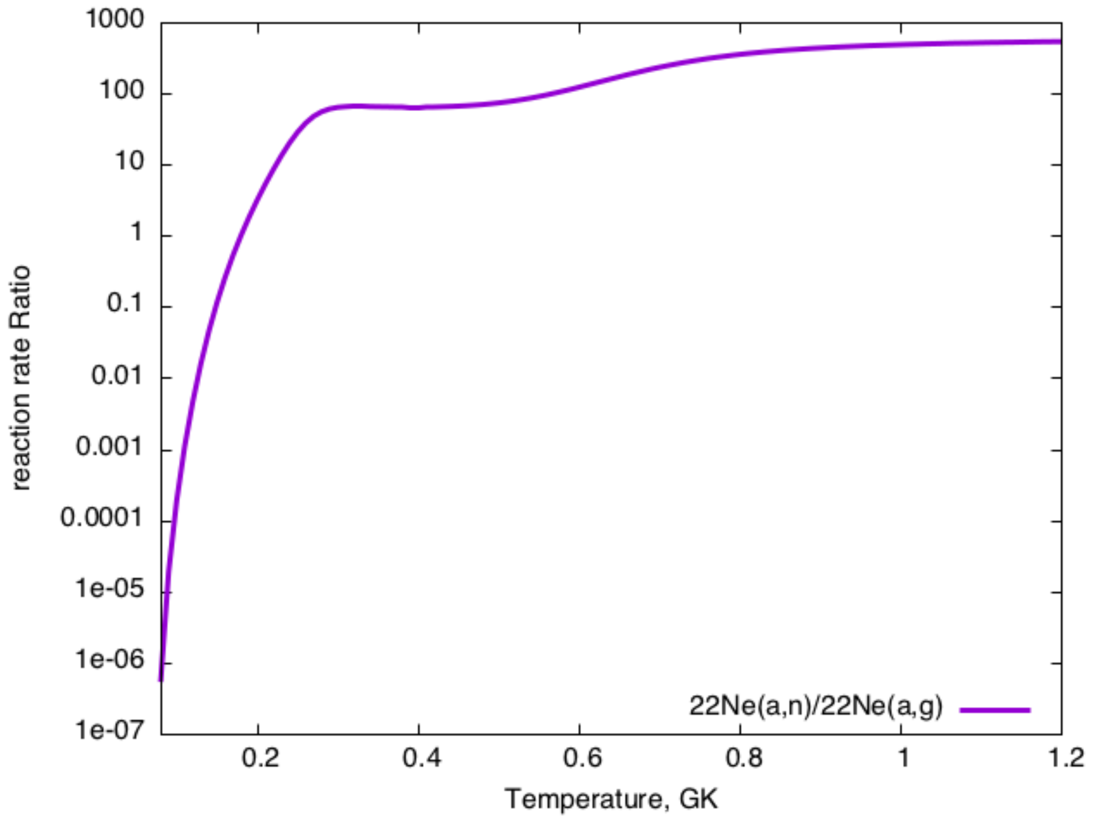
$$\omega_\gamma = g\,\Gamma_\alpha \Gamma_\gamma / (\Gamma_\alpha + \Gamma_\gamma + \Gamma_n)$$

$$\frac{\omega_\alpha}{\omega_\gamma} = \frac{\Gamma_n}{\Gamma_\gamma}$$

Resonance strength ratio and **Reaction rate ratio** independent of Γ_α



^{22}Ne(α,n) / ^{22}Ne(α,γ)



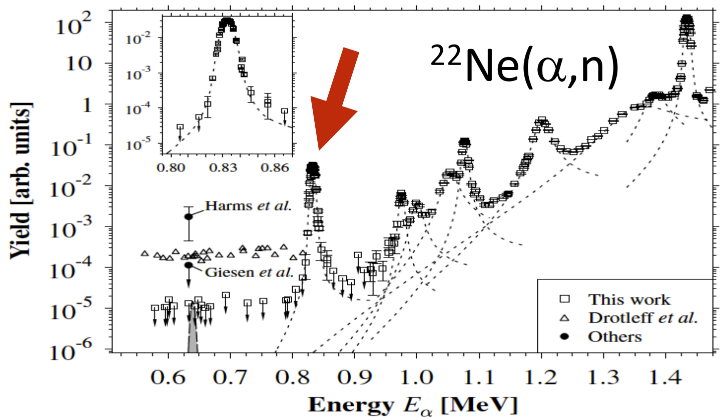
Why n + ^{25}Mg ?

Resonance strength ^{22}Ne(α,n)^{25}Mg:

$$\omega_\alpha = g\,\Gamma_\alpha\Gamma_n / (\Gamma_\alpha + \Gamma_\gamma + \Gamma_n)$$

Resonance strength ^{22}Ne(α,γ)^{26}Mg:

$$\omega_\gamma = g\,\Gamma_\alpha\Gamma_\gamma / (\Gamma_\alpha + \Gamma_\gamma + \Gamma_n)$$

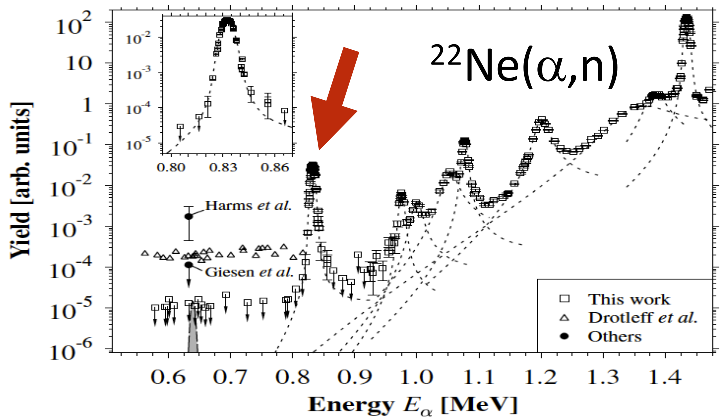


^{22}Ne(α,n) / ^{22}Ne(α,γ)

$$\frac{\omega_\alpha}{\omega_\gamma} = \frac{\Gamma_n}{\Gamma_\gamma}$$

Publication	YEAR	Result	comment
Shahina, PRC	2024	Γ_n / Γ_γ = 2.85(71)	ω_α res. strength
M. Wiescher, EPJA	2023	Γ_n = 0.4 - 1.0 eV Γ_γ = 1.33 eV	Re-evaluation
Y. Chen, PRC	2021	Γ_n = 0.4 eV Γ_γ = 1.33 eV	^{25}Mg(d,p)^{26}Mg transfer
S. Ota, PLB	2020	Γ_n / Γ_γ = 1.14(26)	transfer

Why n + ^{25}Mg ?



^{22}Ne(α,n) / ^{22}Ne(α,γ)

Resonance strength ^{22}Ne(α,n)^{25}Mg:

$$\omega_\alpha = g\,\Gamma_\alpha \Gamma_n / (\Gamma_\alpha + \Gamma_\gamma + \Gamma_n)$$

Resonance strength ^{22}Ne(α,γ)^{26}Mg:

$$\omega_\gamma = g\,\Gamma_\alpha \Gamma_\gamma / (\Gamma_\alpha + \Gamma_\gamma + \Gamma_n)$$

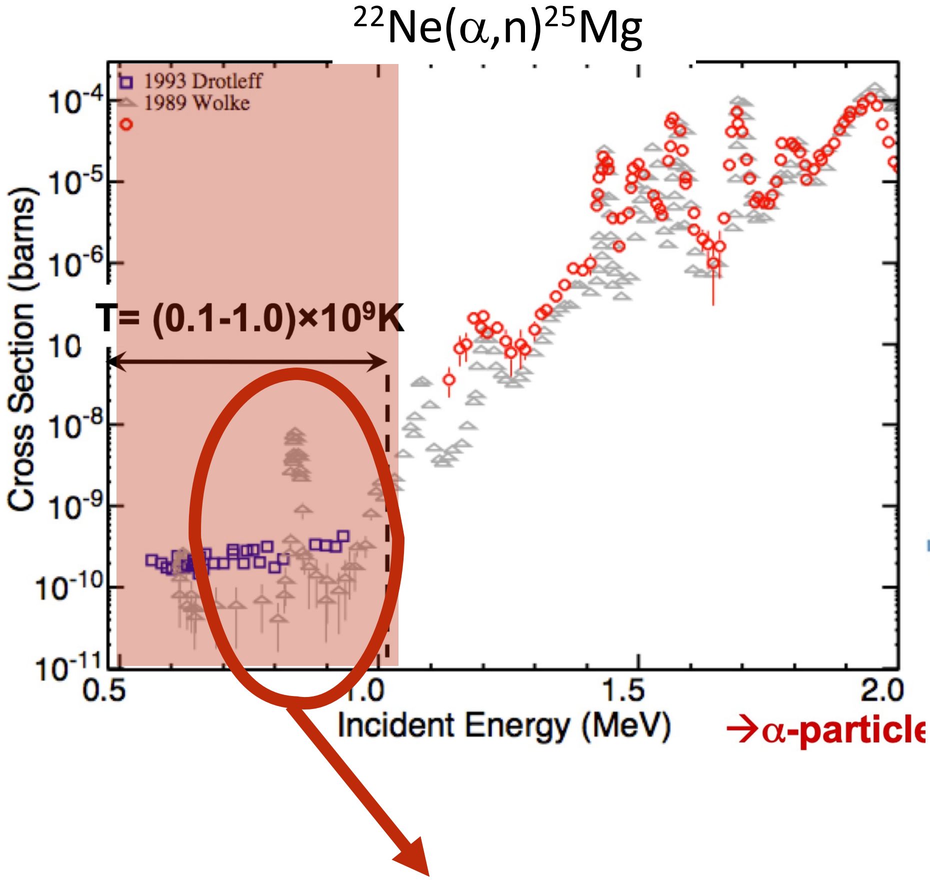
$$\frac{\omega_\alpha}{\omega_\gamma} = \frac{\Gamma_n}{\Gamma_\gamma}$$

Neutron width Γ_n and γ-ray width Γ_γ can be deduced from n + ^{25}Mg

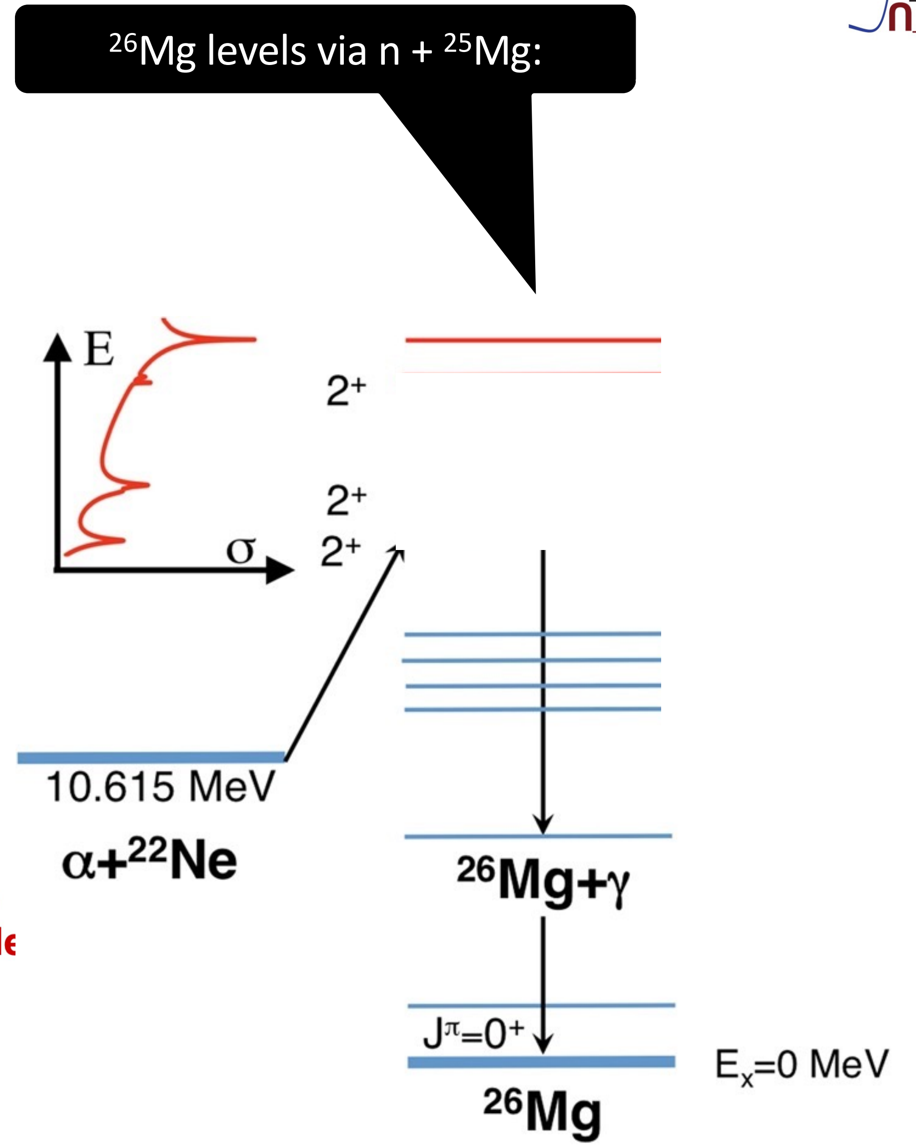
$$\sigma_\gamma(E_n) = g\,\frac{\pi}{k_n^2}\,\frac{\Gamma_n \Gamma_\gamma}{(E_n - E_R)^2 + (\Gamma/2)^2}$$

^{25}Mg(n,γ) cross section

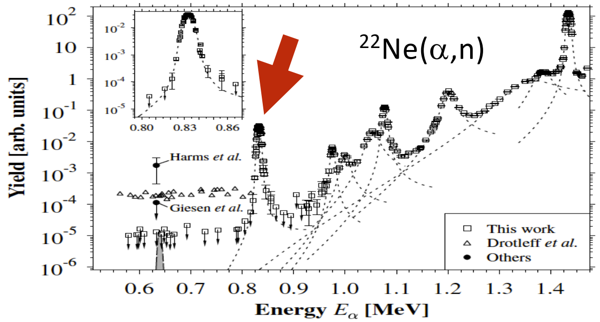
Why n + ^{25}Mg ?

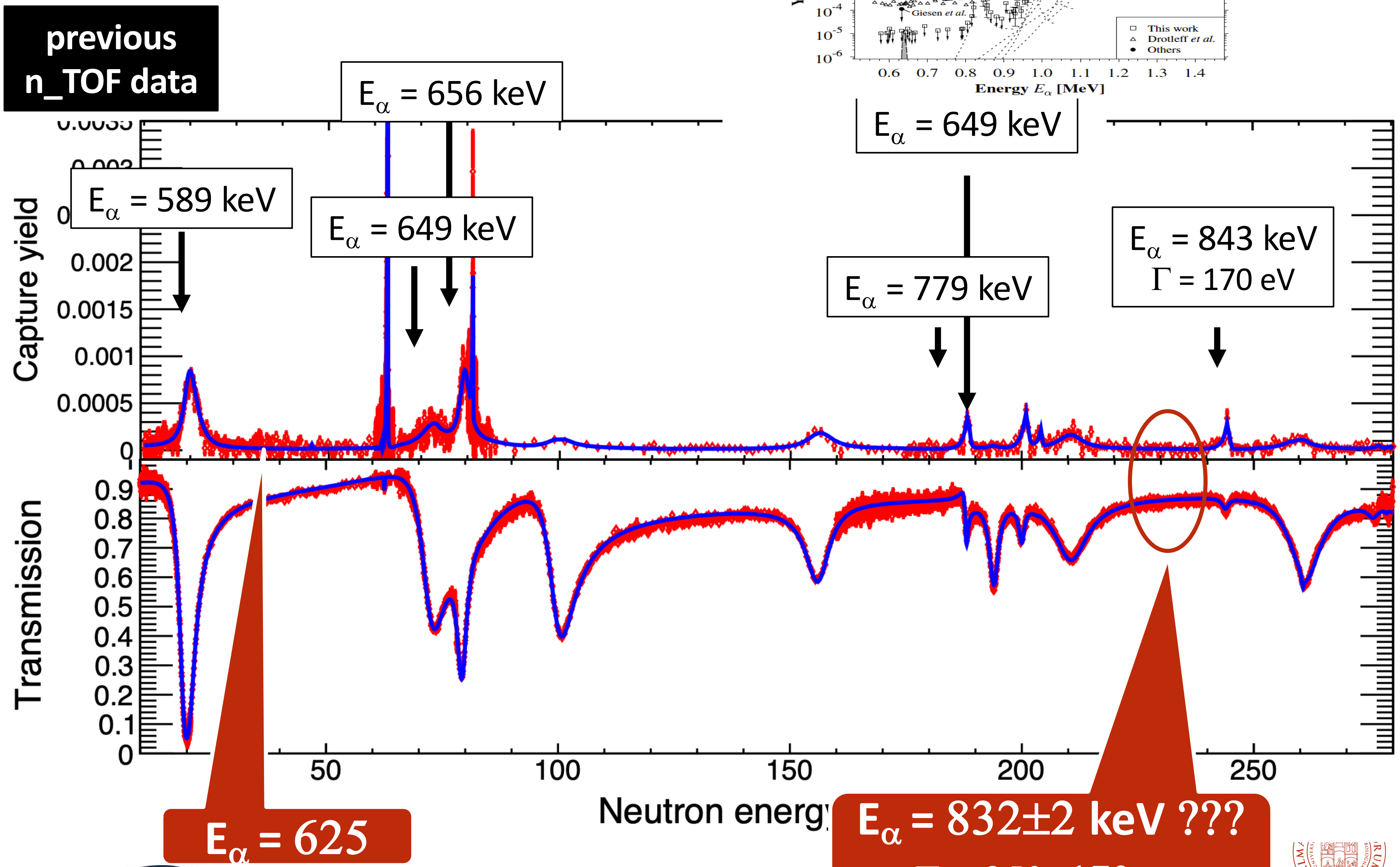


E_α = 832±2 keV
E_{CM} = 706 keV



Why n + ^{25}Mg again?

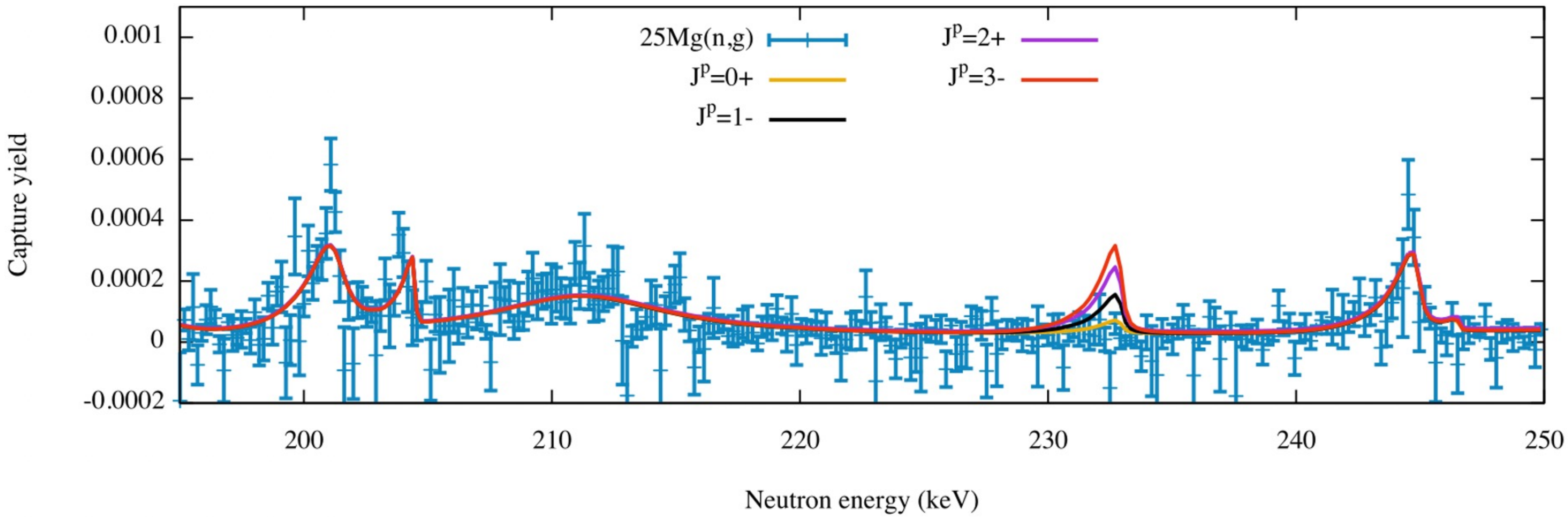




Proposal: $^{25}Mg(n,\gamma)^{26}Mg$ @ n_TOF

Our proposal is to **repeat the measurement in EAR1** with a factor 4 higher statistics (corresponding to $3x10^{18}$ protons) and with some improvements:

- use of 4 C_6D_6
- use of a thicker enriched ^{25}Mg sample
- combine with a capture measurement in EAR2



Running in parallel with other capture or transmission measurements in EAR1 might be considered

Proposal: ^{25}Mg(n,γ)^{26}Mg @ n_TOF

Aim of the experiment:

Investigate the neutron resonance at **E_{CM} = 706**; **E_α = 832**; **E_n = 234 keV** (as the neutron budget at **kT >= 30 keV** is dominated by this resonance); and Possibly provide an estimation and/or upper limit for Γ_n and Γ_γ

Check the existence of a neutron resonance at **E_α = 635 keV**

Verify the agreement between **n+^{25}Mg** and α+**^{22}Ne** – could there be a kinetic energy calibration issue?

Proposal: ^{25}Mg(n,γ)^{26}Mg @ n_TOF

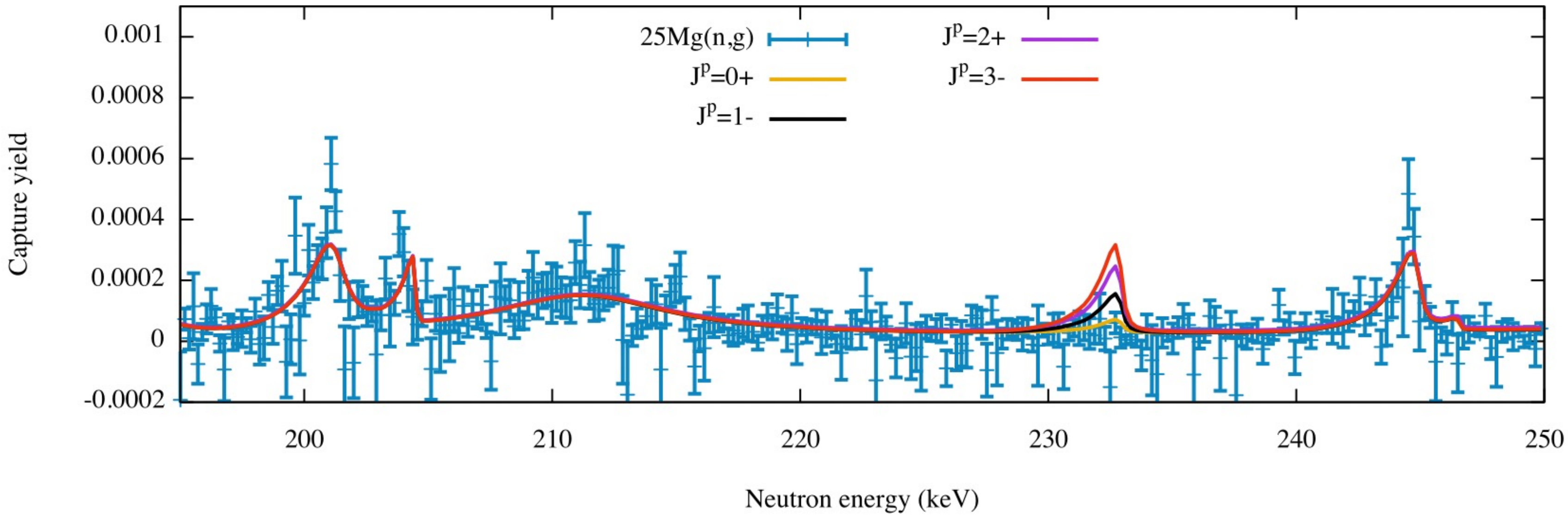
Beam-time request

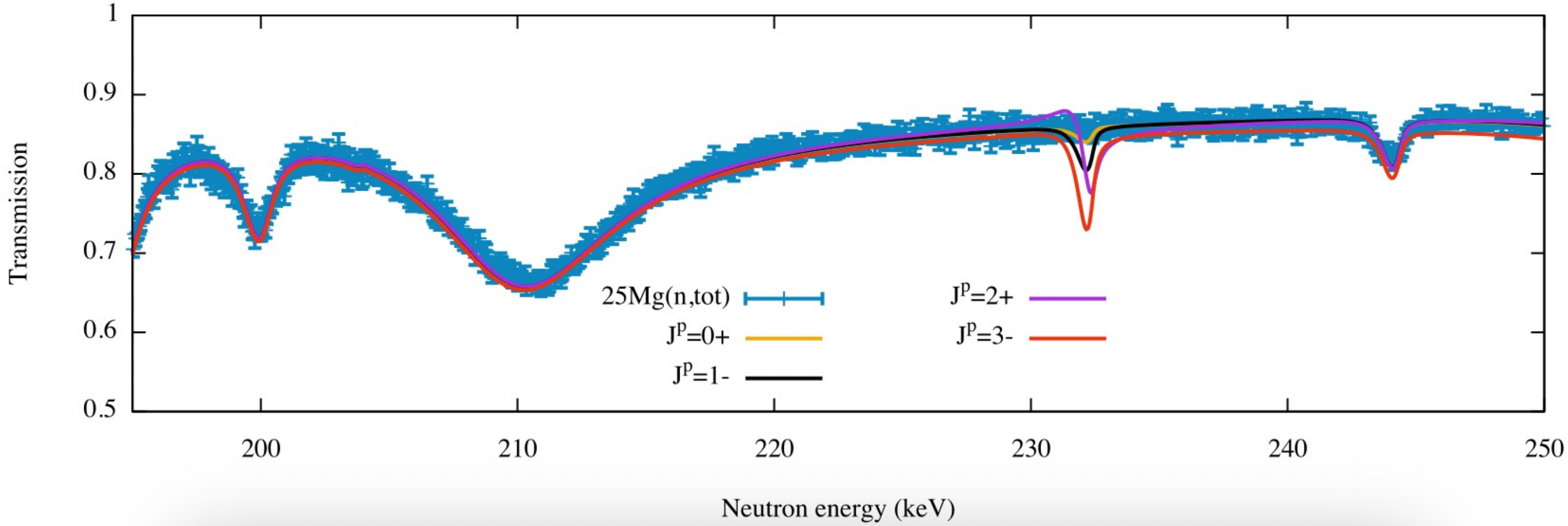
SAMPLE	EAR1, 10^{18} protons	EAR2, 10^{18} protons
^{25}Mg	2.5	0.8
^{197}Au (normalization)	0.1	0.05
Empty-sample (background)	0.4	0.15
TOTAL	**3.0**	**1.0**

THANK YOU FOR YOUR ATTENTION !

Extra slides

Proposal: $^{25}Mg(n,\gamma)^{26}Mg$ @ n_TOF





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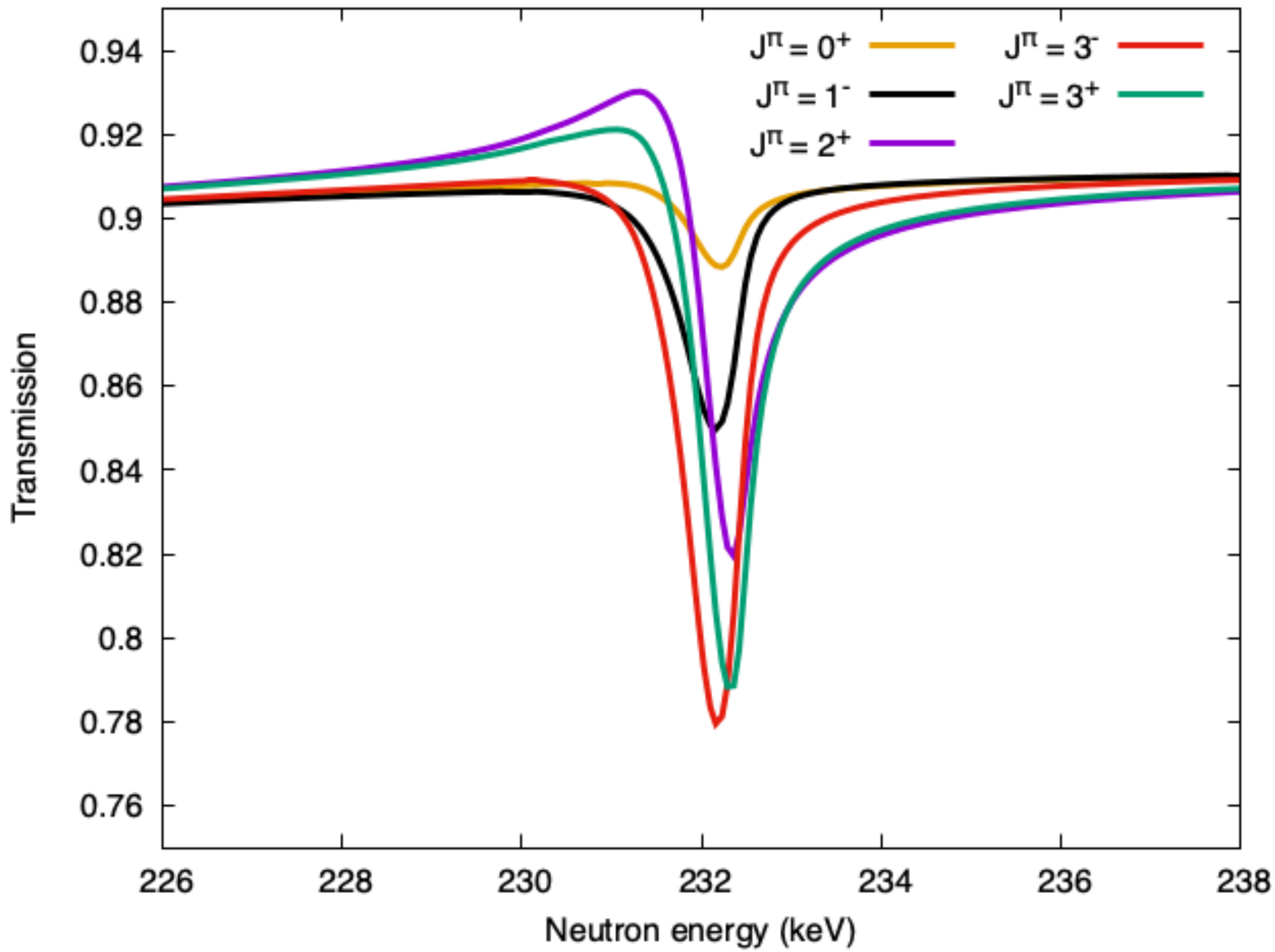
Proposal: $^{25}Mg(n,\gamma)^{26}Mg$ @ n_TOF



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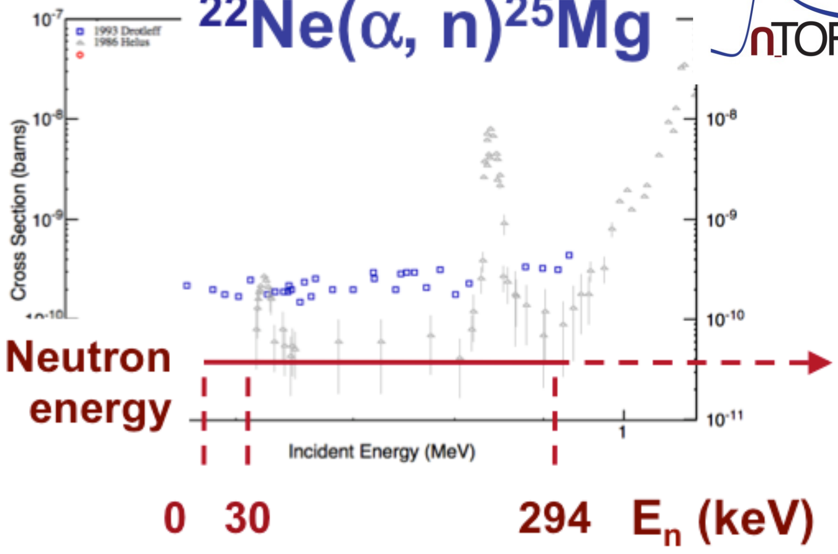
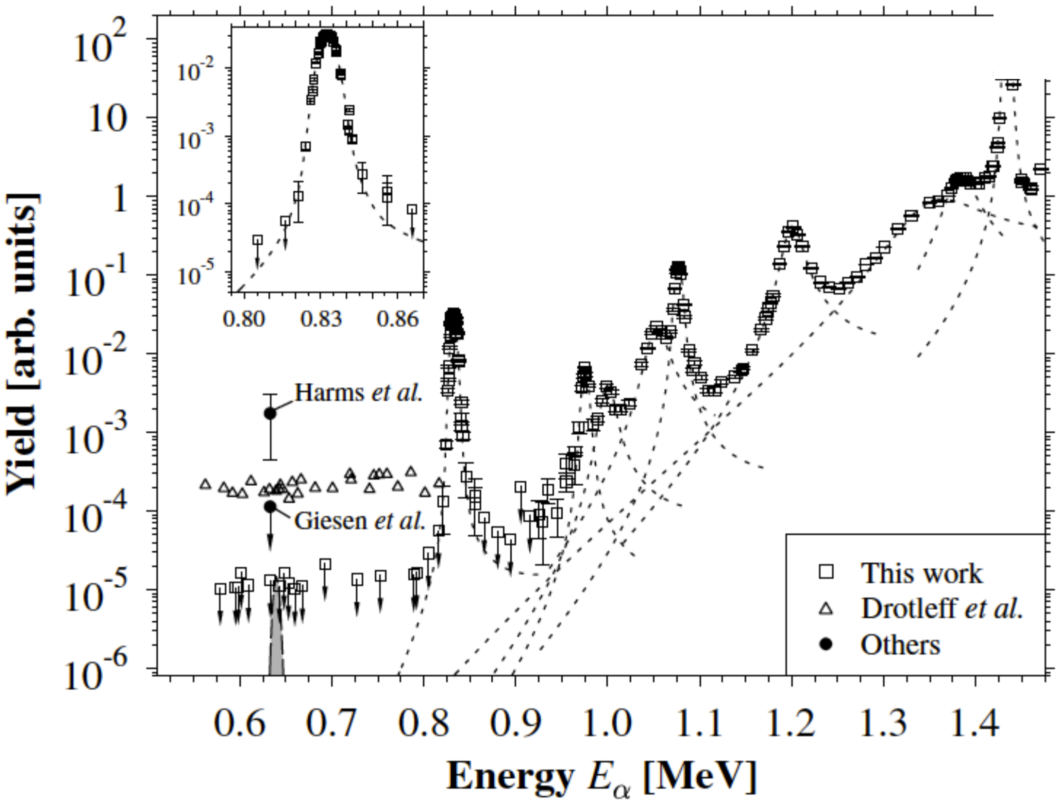
$^{22}Ne(\alpha, n)^{25}Mg$



M. Jaeger, *et al.*, Phys Rev. Lett. **87** (2001) 20



Extra slides

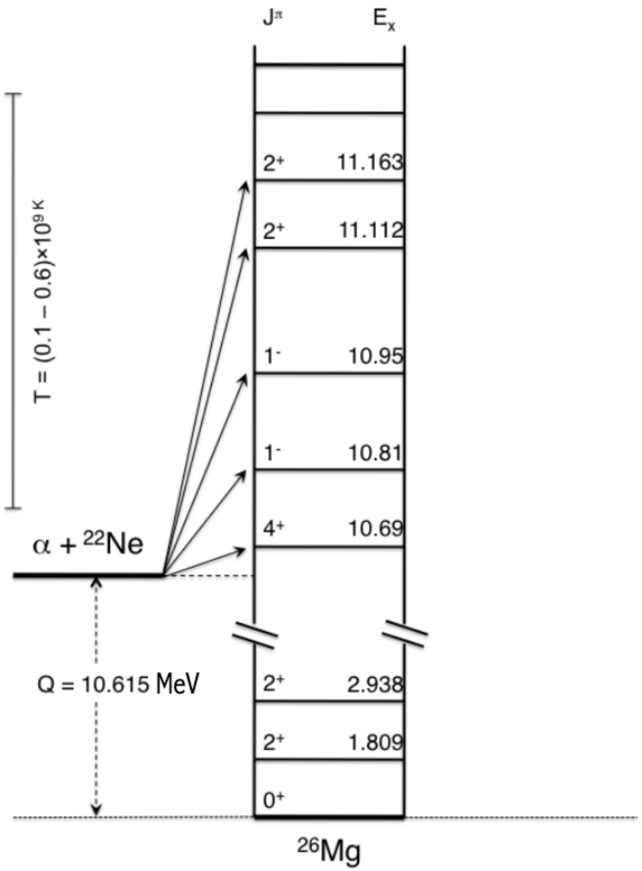
Constraints for the $^{22}Ne(\alpha,n)^{25}Mg$ reaction

Element	Spin/ parity
^{22}Ne	0^+
^{4}He	0^+

$$\vec{J} = \underbrace{\vec{I} + \vec{i}}_{} + \vec{\ell}$$

$$\vec{J} = 0 + \vec{\ell}$$

Only **natural-parity** (0^+, 1^-, 2^+, 3^-, 4^+, …) **states in ^{26}Mg** can participate in the $^{22}Ne(\alpha,n)^{25}Mg$ reaction



Extra slides

Constraints for the $^{22}Ne(\alpha,n)^{25}Mg$ reaction

Element	Spin/ parity
^{25}Mg	$5/2^+$
n	$1/2^+$

$$\vec{J} = \underbrace{\vec{I} + \vec{i}} + \vec{\ell}$$

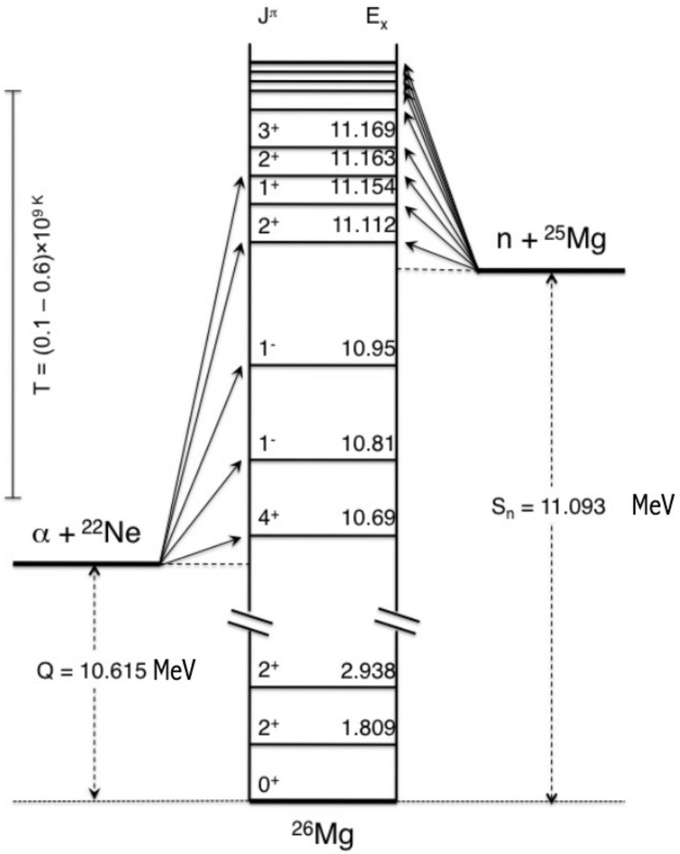
$$\vec{J} = 2 + \vec{\ell} \qquad \vec{J} = 3 + \vec{\ell}$$

s-wave → J^π= <u>2⁺</u>, 3⁺

p-wave → J^π= $\underline{1^-}$, 2^-, $\underline{3^-}$, 4^-

d-wave → J^π= $\underline{0^+}$, 1^+, $\underline{2^+}$, 3^+, $\underline{4^+}$, 5^+

States in ^{26}Mg populated by $^{25}Mg(n,\gamma)$ reaction



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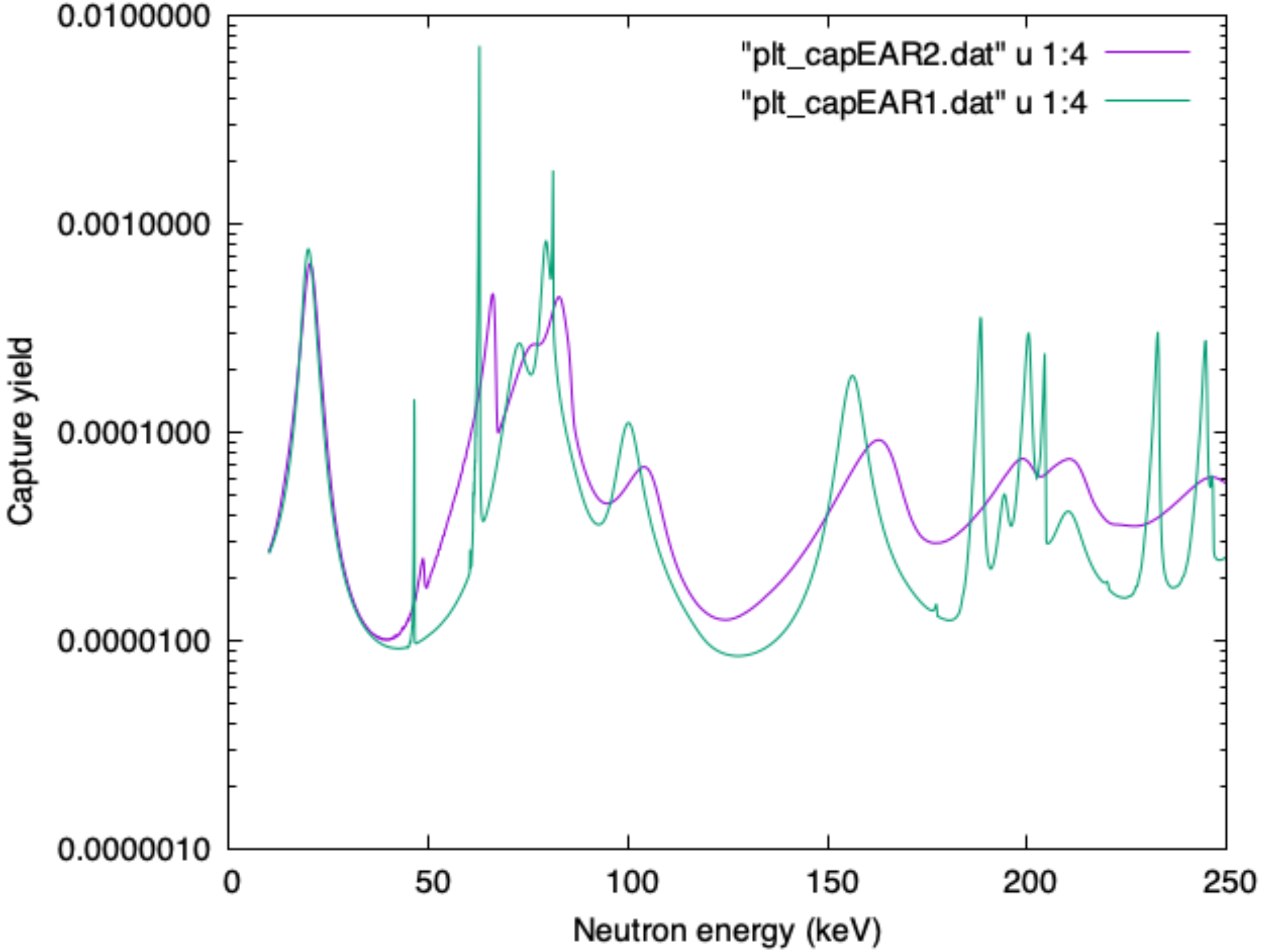

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Resonance neutron-capture cross sections of stable magnesium isotopes and their astrophysical implications

PDF

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C. Massimi[1,2,*], P. Koehler[3], S. Bisterzo[4], N. Colonna[5], R. Gallino[4], F. Gunsing[6], F. Käppeler[7], G. Lorusso[5], A. Mengoni[8,9] *et al.* (n_TOF Collaboration)

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DOI: https://doi.org/10.1103/PhysRevC.85.044615

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Phys. Lett. B 2017

Outline

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1. Introduction
2. Indirect approach
3. Measurements of $n+^{25}$Mg
4. Improved ^{25}Mg$(n,\gamma)^{26}$Mg cross section
5. Impact on reaction rate calculations
6. Astrophysical implications and conclusions
Acknowledgements
References

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Physics Letters B

Volume 768, 10 May 2017, Pages 1-6

Neutron spectroscopy of ^{26}Mg states: Constraining the stellar neutron source ^{22}Ne$(\alpha,n)^{25}$Mg

C. Massimi[a b], S. Altstadt[c], J. Andrzejewski[d], L. Audouin[e], M. Barbagallo[f], V. Bécares[g], F. Bečvář[h], F. Belloni[i], E. Berthoumieux[i], J. Billowes[j], S. Bisterzo[k l], D. Bosnar[m], M. Brugger[n], M. Calviani[n], F. Calviño[o], D. Cano-Ott[g], C. Carrapiço[p], D.M. Castelluccio[q], F. Cerutti[n], E. Chiaveri[i]...P. Žugec[m]

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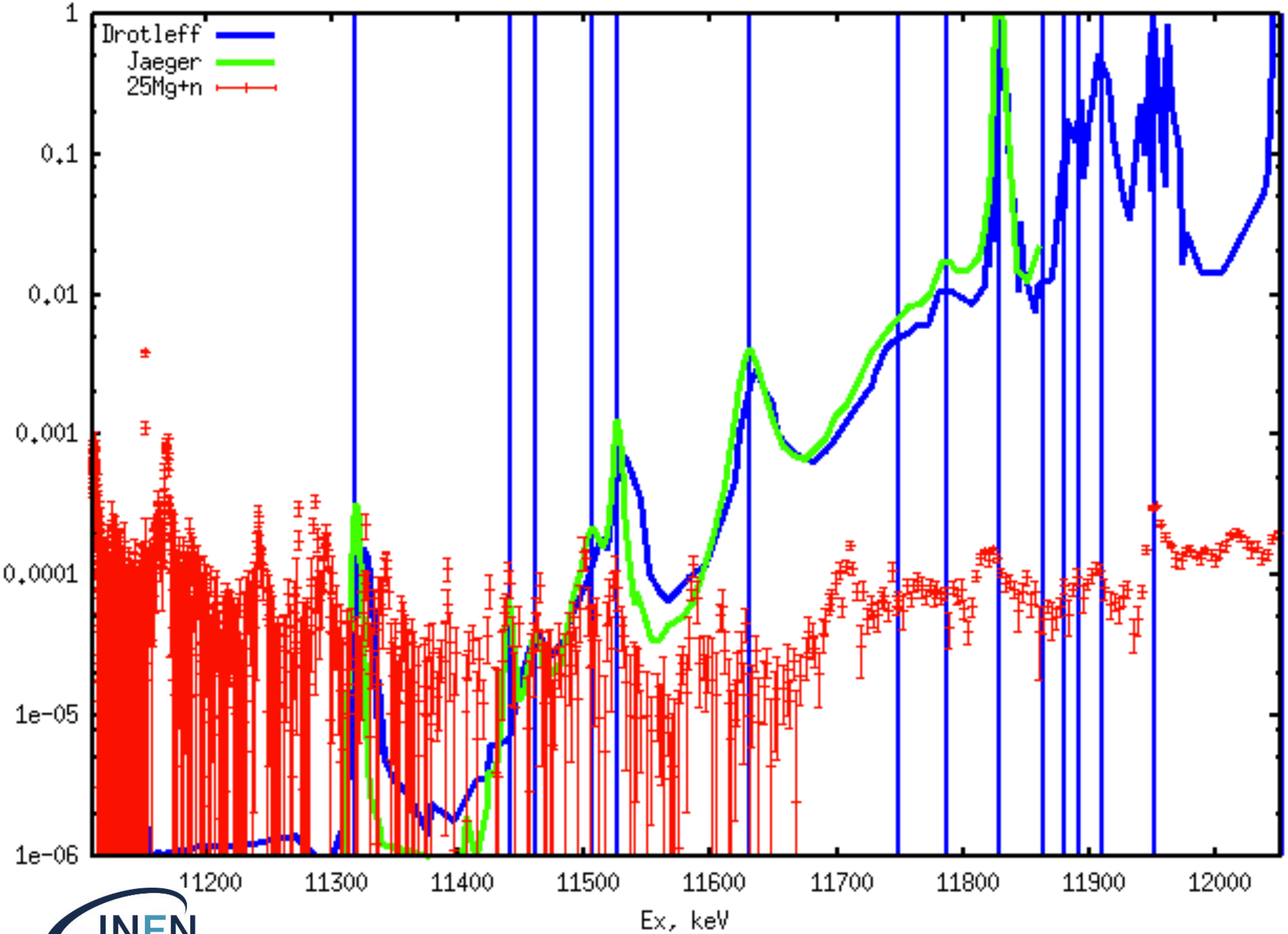
Previous Mg(n,γ) data from n_TOF

Approved 3.0 x 10^{18}
Delivered 0.7 x 10^{18}



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