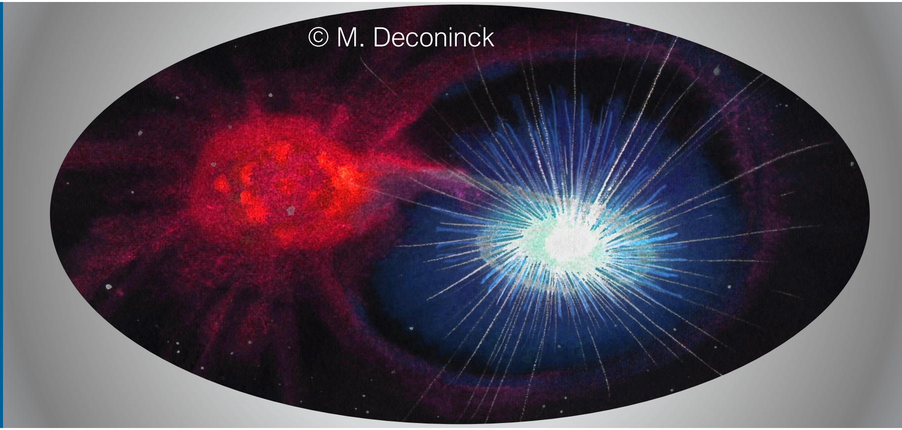
Understanding ^{22}Na cosmic abundance



C. Fougères[1,2], F. de Oliveira Santos[1] *et al.*

[1]GANIL CEA/DRF-CNRS/IN2P3, Caen (France)

[2]Argonne National Laboratory, Lemont (USA)

Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

NPA-X (CERN 2022)

ASTROPHYSICAL MOTIVATIONS

Stellar objects of interest: novæ

Bright light in sky

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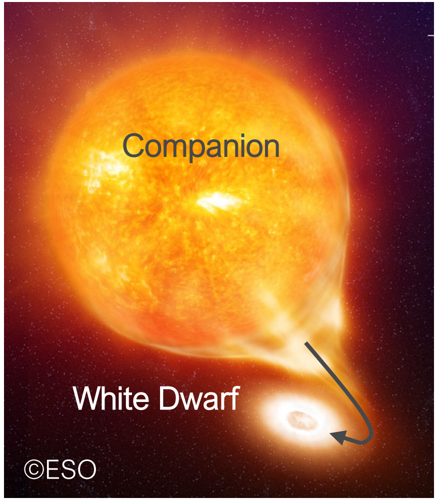
Matter accretion → explosive hydrogen burning



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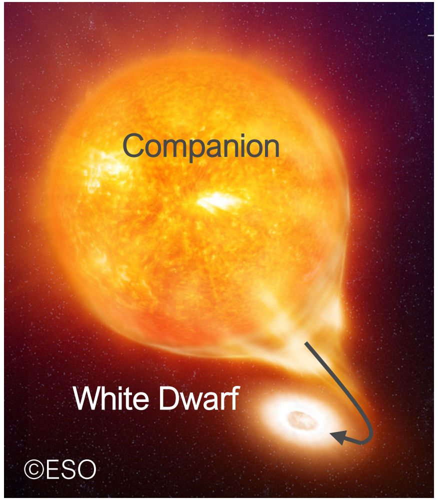

Impact

- Abundances of nuclei
- Isotopic composition of presolar grains
- Number of supernovae Ia → dark energy
- Test of novae models

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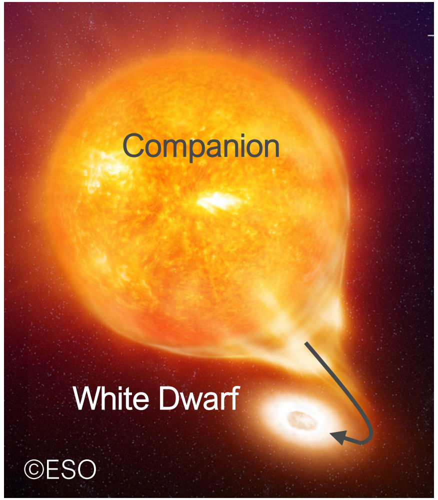

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Uncertainties

Accretion dynamics, initial WD temp., mass…

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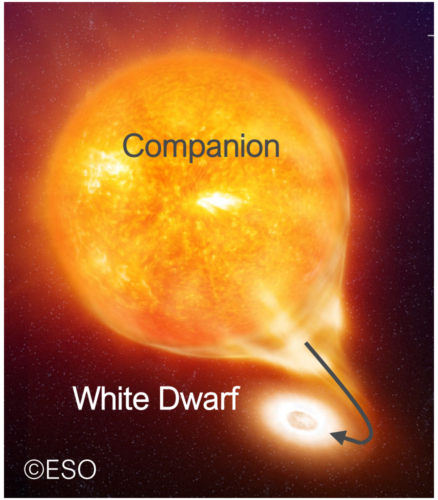

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Need of astronomical observables

Observable candidate for novae: ^{22}Na

A compass for ONe novae

Uncertainties

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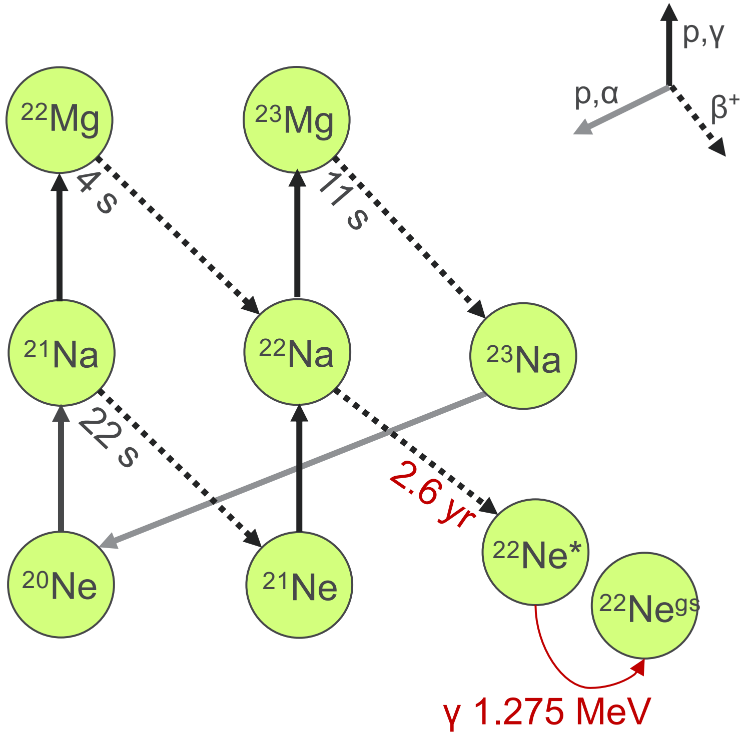
A compass for ONe novae



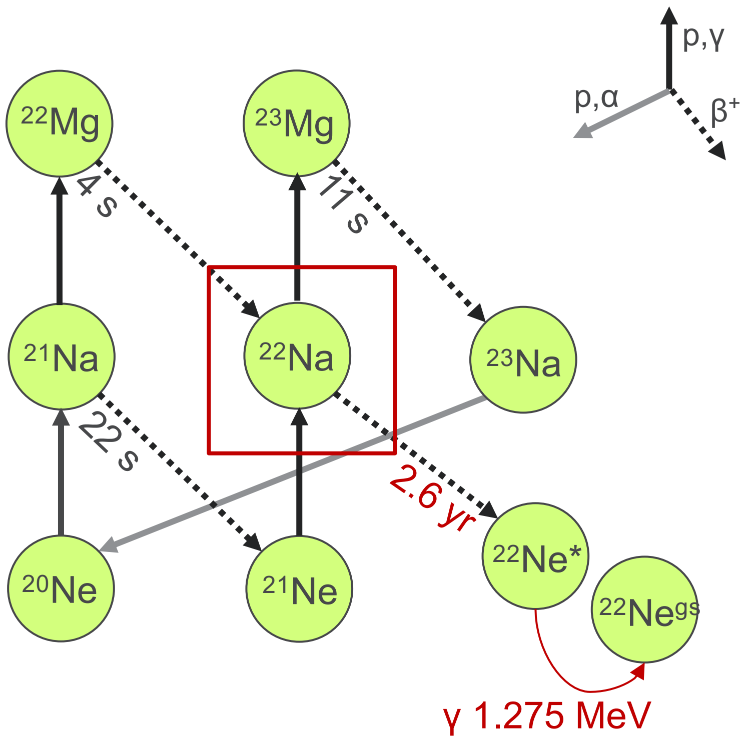
Uncertainties

Accretion dynamics, initial WD temp., mass…

Observable candidate for novae: ^{22}Na

A compass for ONe novae

Radioactive tracer
^{22}Na
τ=2.6 yr, E_γ=1.275 MeV



Uncertainties

Accretion dynamics, initial WD temp., mass…

Search for ^{22}Na

γ-ray observation campaigns (INTEGRAL, COMPTEL…)

Uncertainties

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Sensitivity improved by x30

De Angelis (2018)

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Short-lived ~yr (^{22}Na, **^{44}Ti**)

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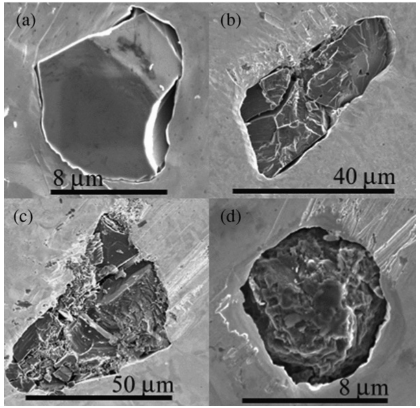
Presolar grains



Black (1972)

Uncertainties

Accretion dynamics, initial WD temp., mass…

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Excess of ^{22}Ne in presolar grains

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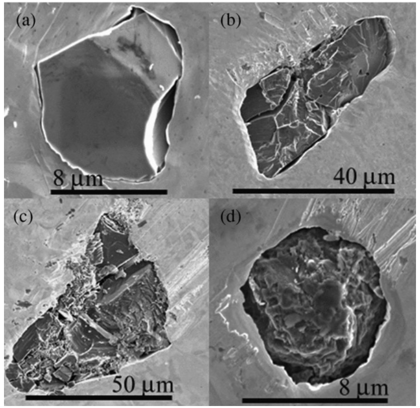

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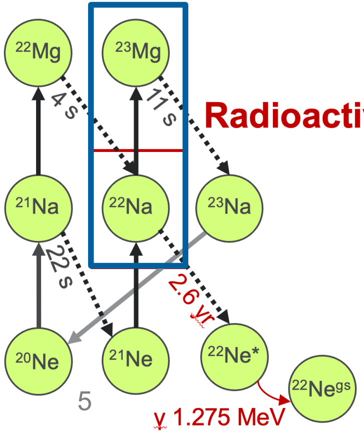

Radioactive tracer ^{22}Na

5

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^{22}Na(p,γ)^{23}Mg rate

Destruction ^{22}Na(p,γ)^{23}Mg

Resonant reaction (Breit Wigner cross section)

$$< \sigma v >_{\mathrm{tot}} = \Sigma_{\mathrm{R}} \left(\frac{2\pi}{\mu_{(^{22}\mathrm{Na},\ \mathrm{p})} \mathrm{k_B T}} \right)^{\frac{3}{2}} \times \hbar^2 \times \omega\gamma \times \exp\left(-\frac{\mathrm{E_R}}{\mathrm{k_B T}}\right)$$

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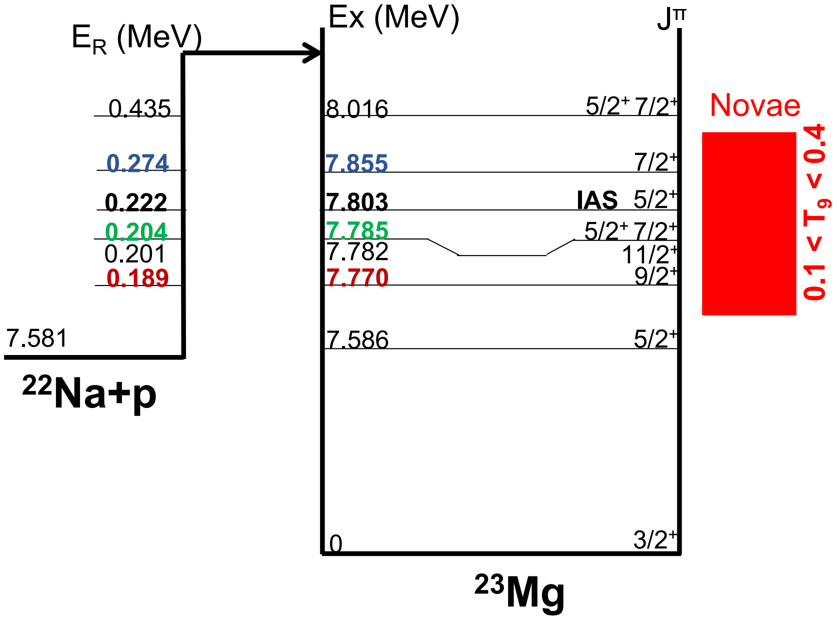

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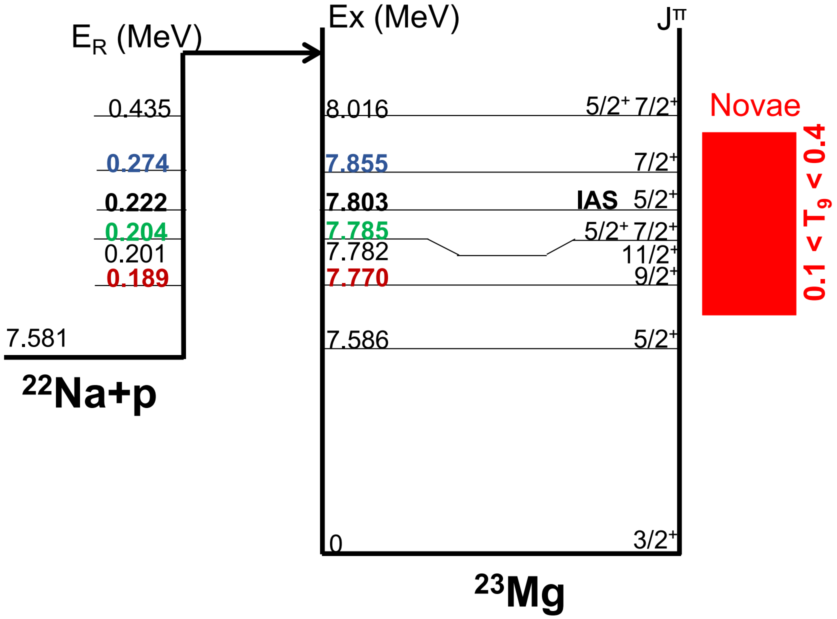
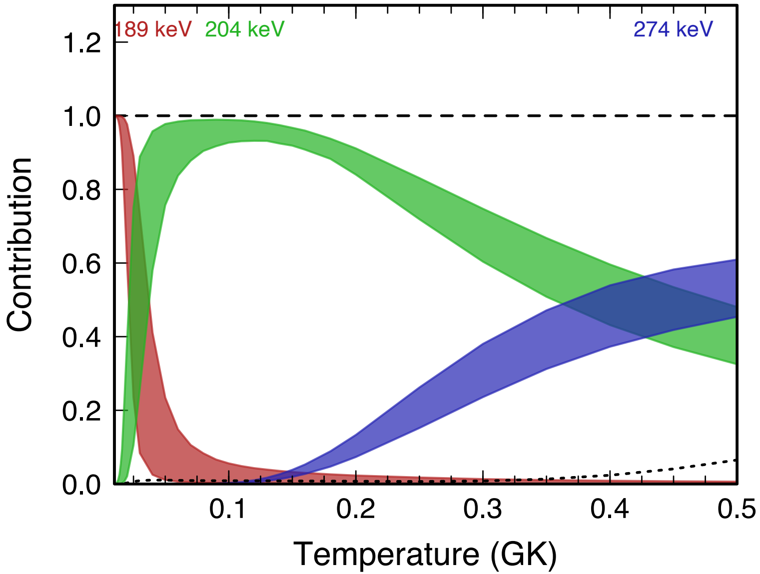


Direct measurements of ωγ *Sallaska (2010)*



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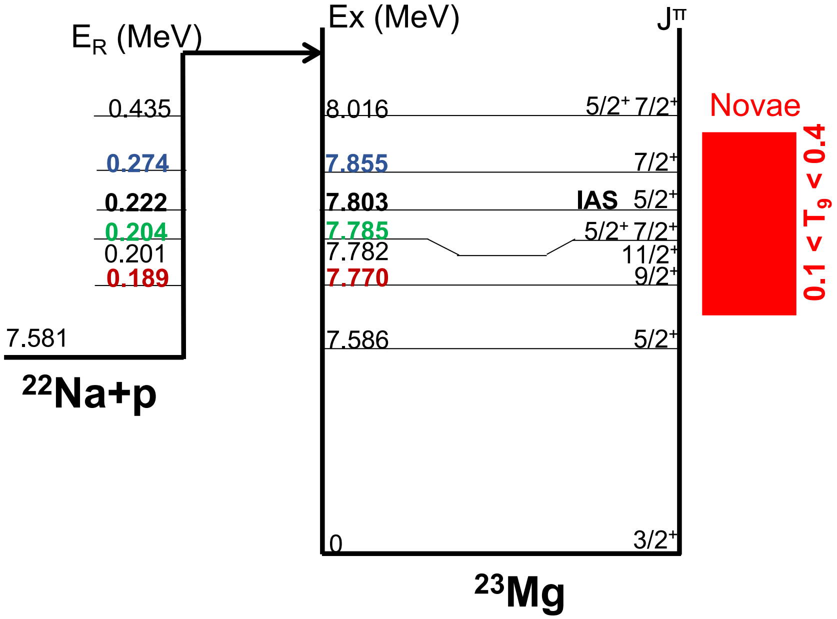

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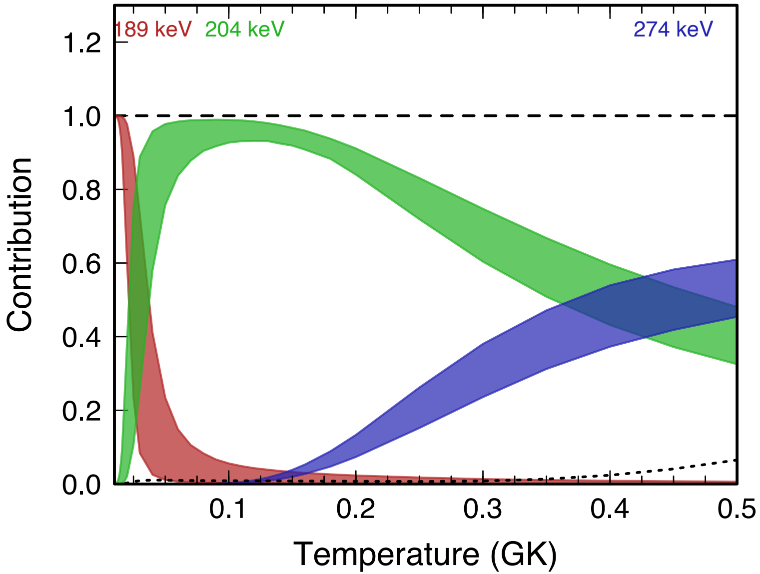
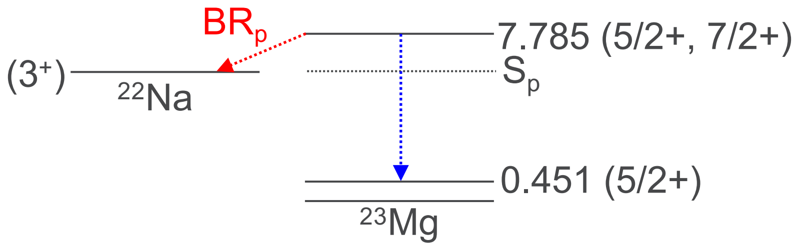


Dominant resonance in $^{23}Mg^*$
(E_x=7.785 MeV, E_R=0.204 MeV)

Indirect determination of ωγ at E_R=0.204 MeV

$$\omega\gamma = \frac{2J_{^{23}\mathrm{Mg}}+1}{(2J_{^{22}\mathrm{Na}}+1)(2J_p+1)} \times \frac{\hbar}{\tau} \times BR_p(1-BR_p)$$



Indirect determination of $\omega\gamma$ at E_R=0.204 MeV

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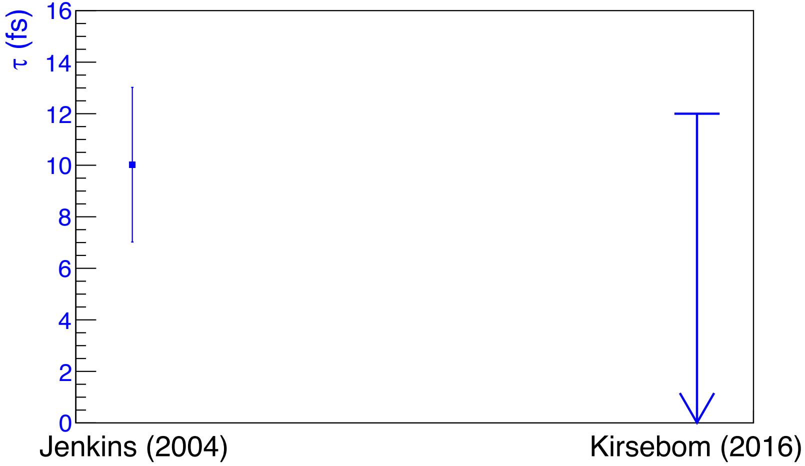

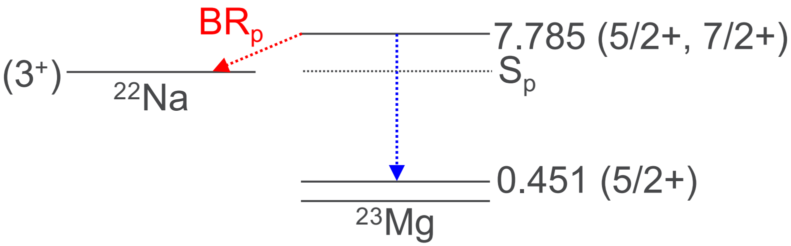

Shell model ~1 fs

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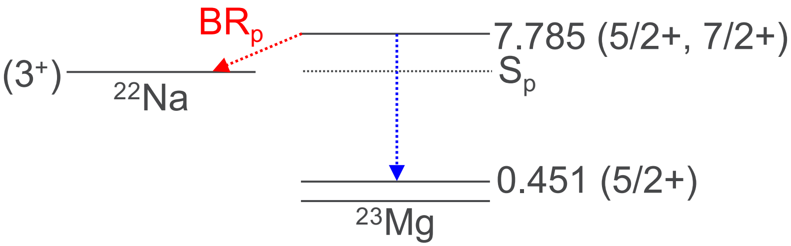
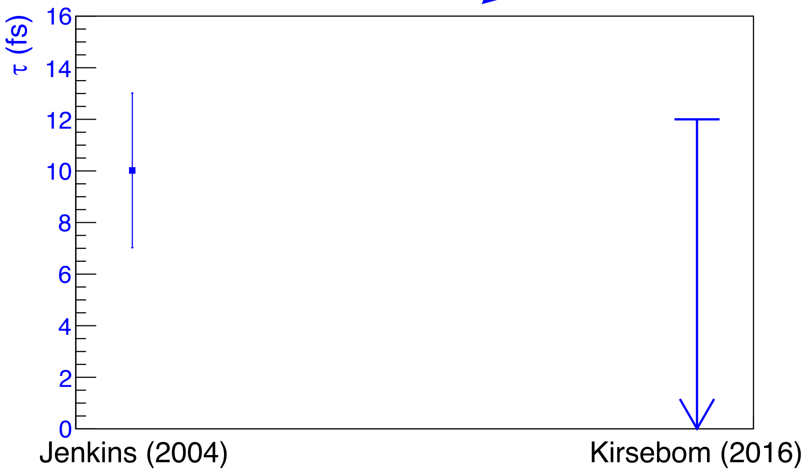
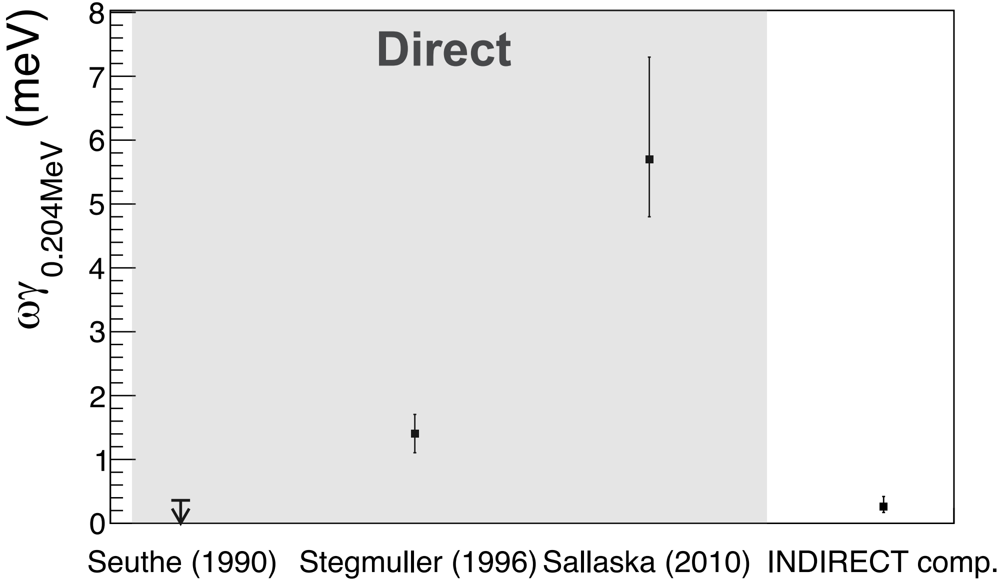




Shell model ~1 fs

Status of ωγ at E_R=0.204 MeV



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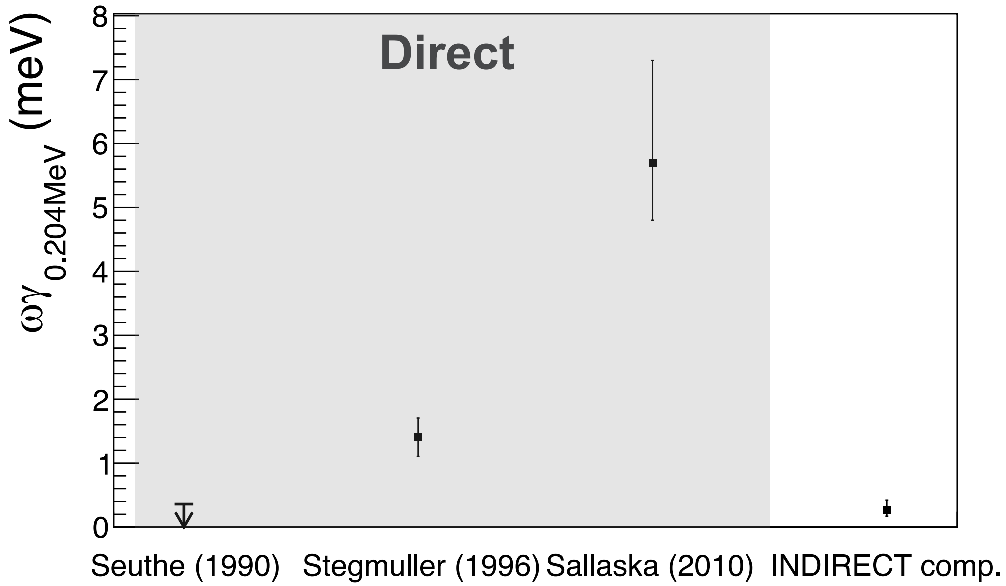
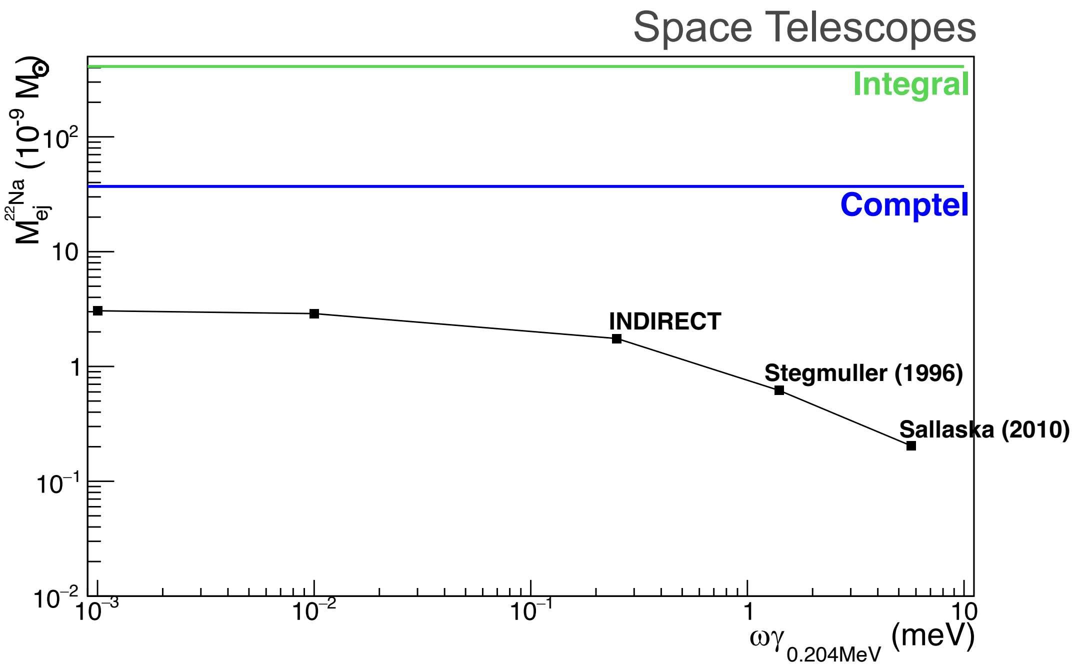


Disagreement in ωγ

Impact of $\omega\gamma_{0.204MeV}$ on ejected ^{22}Na



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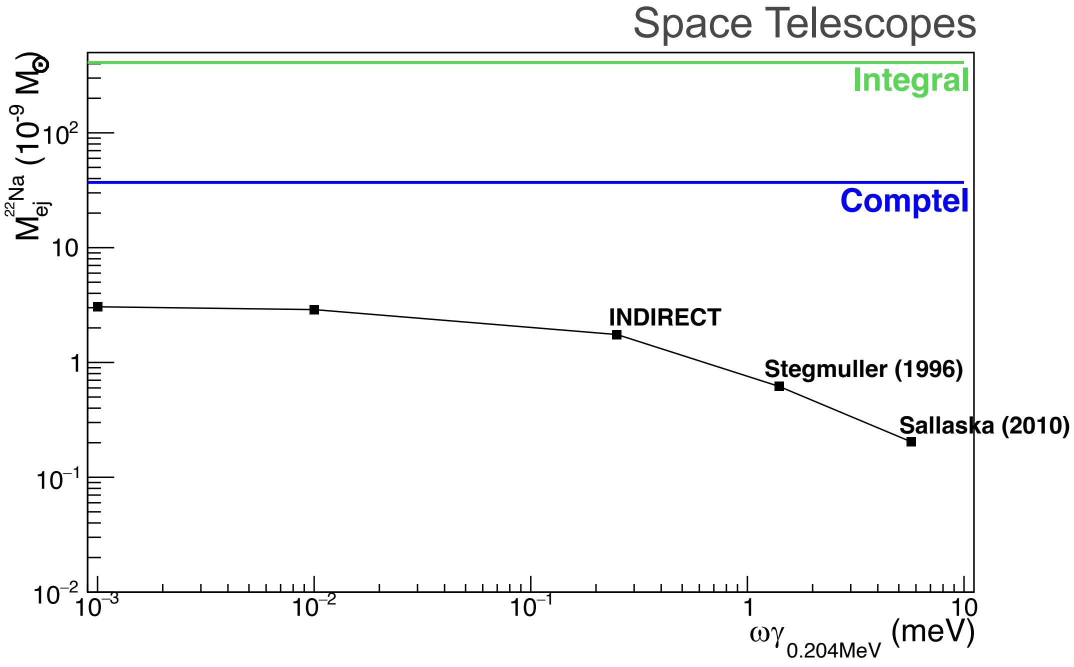
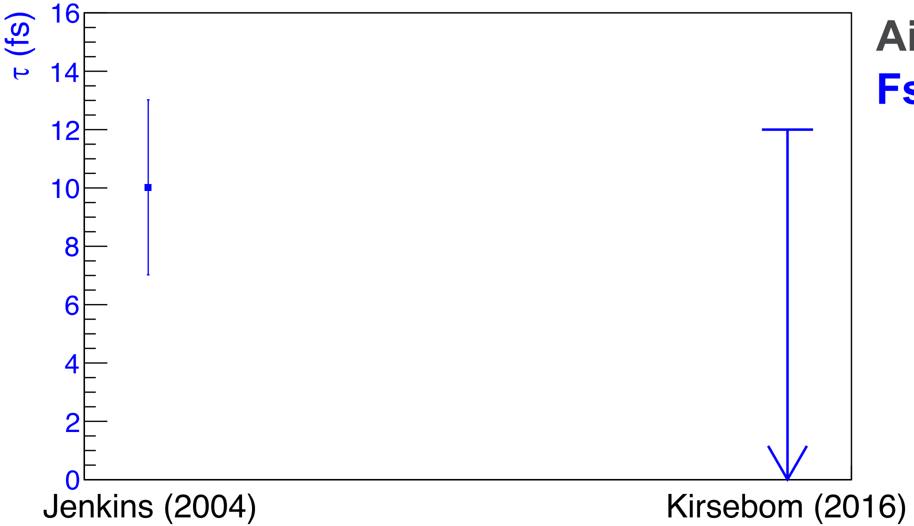


Disagreement in ωγ ➔ **predicted ^{22}Na ~ x10**

Experiment choice: indirect strength determination

$$\omega\gamma = \frac{2\mathrm{J}_{^{23}\mathrm{Mg}}+1}{(2\mathrm{J}_{^{22}\mathrm{Na}}+1)(2\mathrm{J}_\mathrm{p}+1)} \times \frac{\hbar}{\tau} \times \mathrm{BR}_\mathrm{p}(1-\mathrm{BR}_\mathrm{p})$$



Shell model ~1 fs

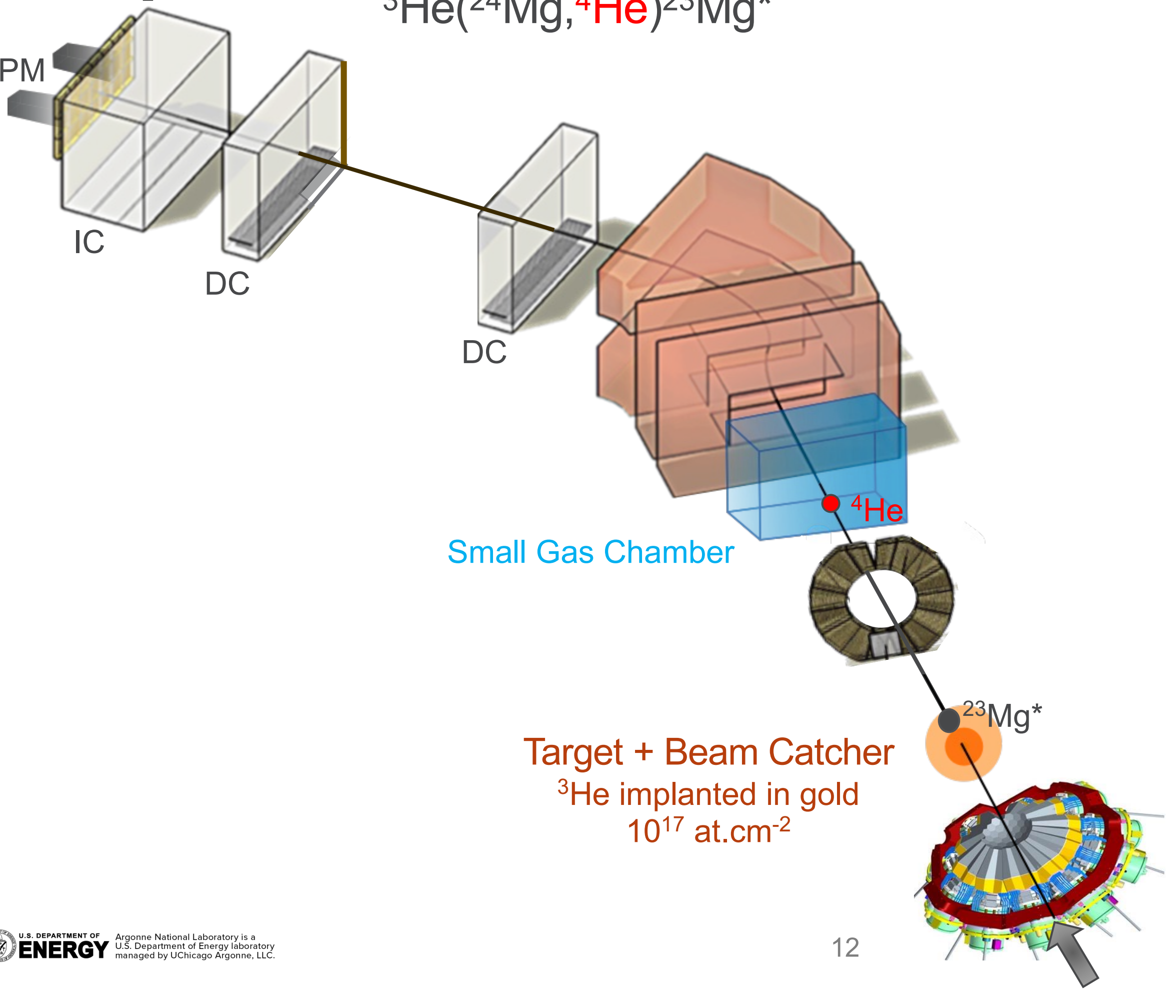
Aim: (τ, BR_p) of the Ex=7.785MeV state in $^{23}Mg^*$

Fs resolution required

EXPERIMENTAL APPROACH AND RESULTS

Set-up

C. Michelagnoli et al. (GANIL 2016)



Set-up

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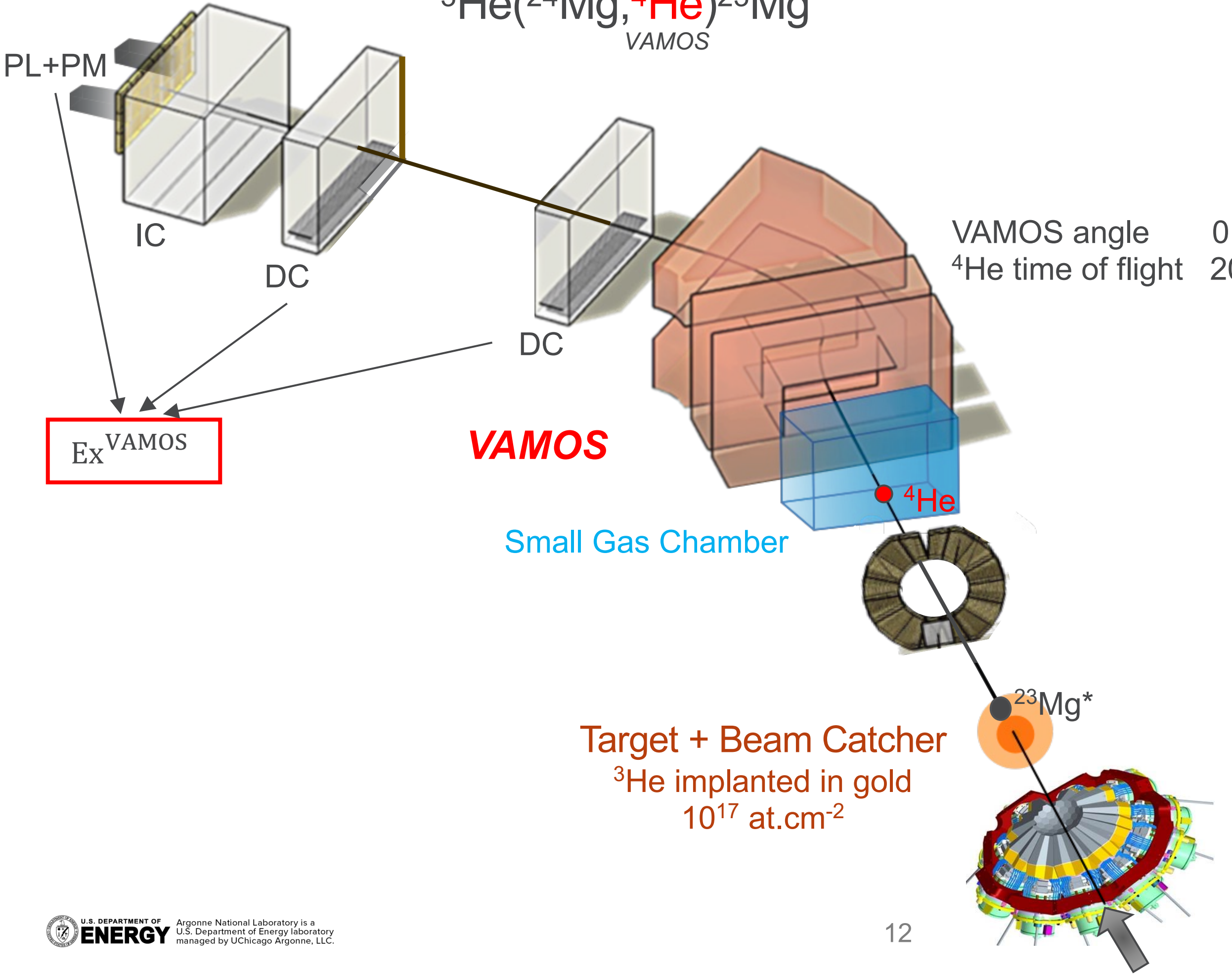
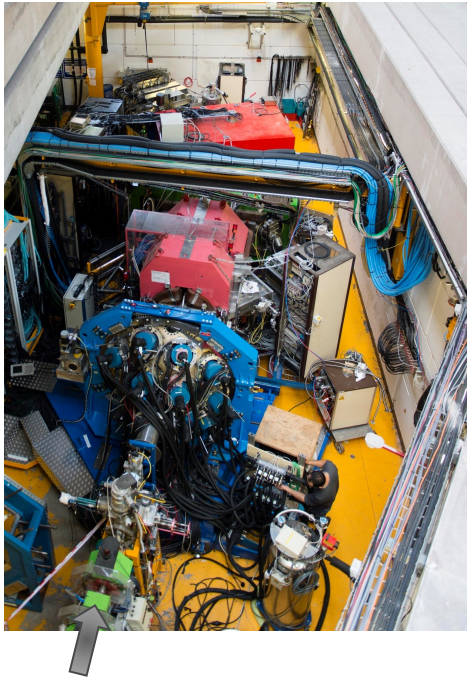
$^{3}He(^{24}Mg,{}^{4}He)^{23}Mg^{*}$

VAMOS



VAMOS angle	0 deg
^{4}He time of flight	200 ns



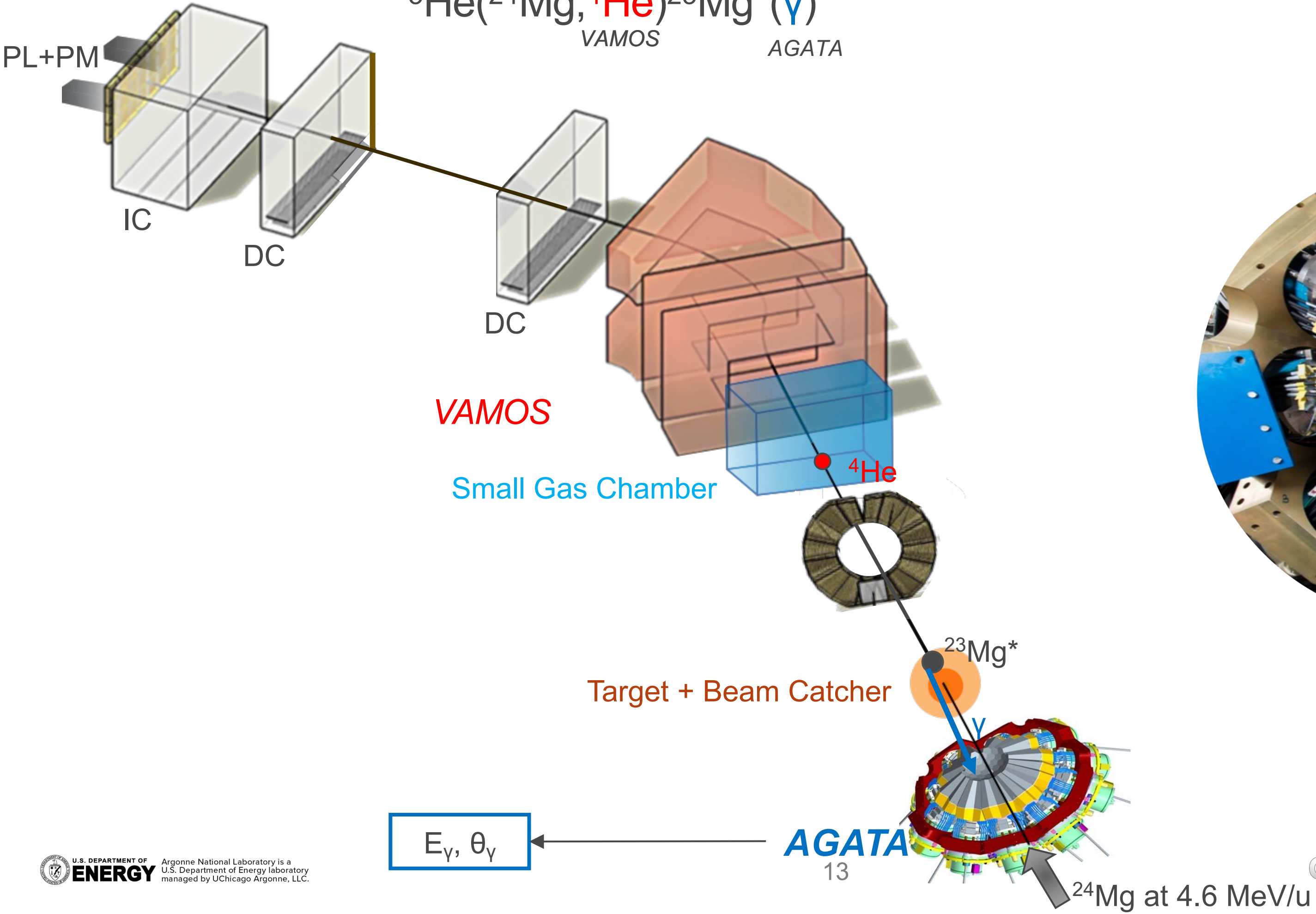
^{24}Mg at 4.6 MeV/u

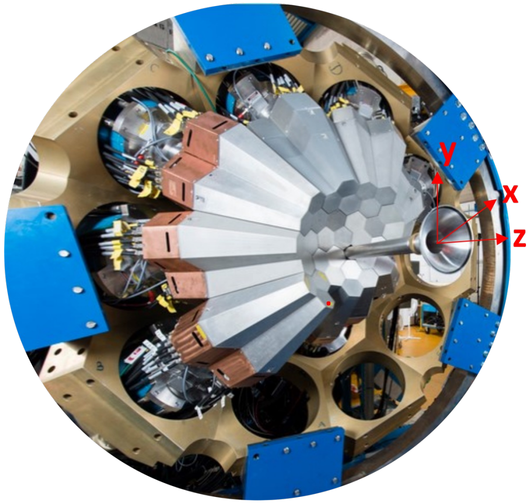
Set-up

C. Michelagnoli et al. (GANIL 2016)

$^{3}He(^{24}Mg,^{4}He)^{23}Mg^{*}(\gamma)$

VAMOS *AGATA*





NPA-X (CERN 2022)

Identification of populated states

$^{3}He(^{24}Mg,^{4}He)^{23}Mg^{*}(\gamma)$

Ex^{VAMOS} E_{γ}^{DC}

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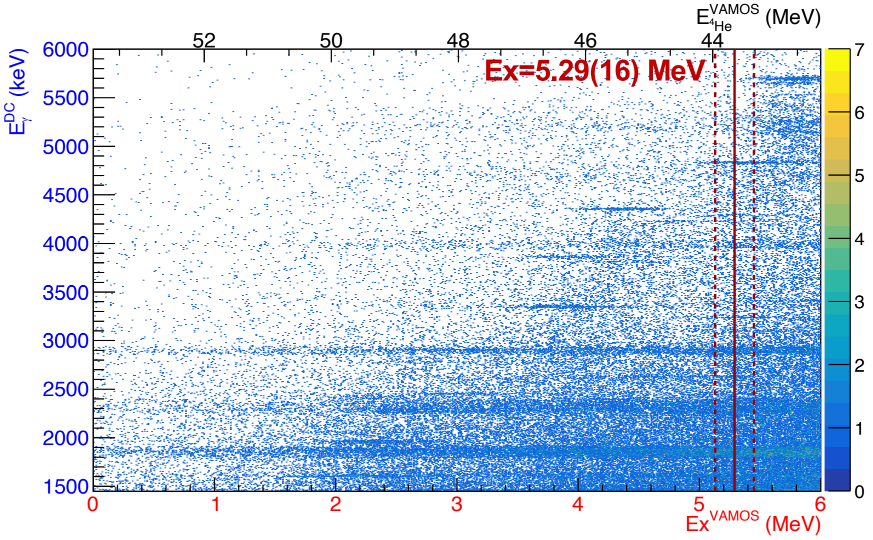

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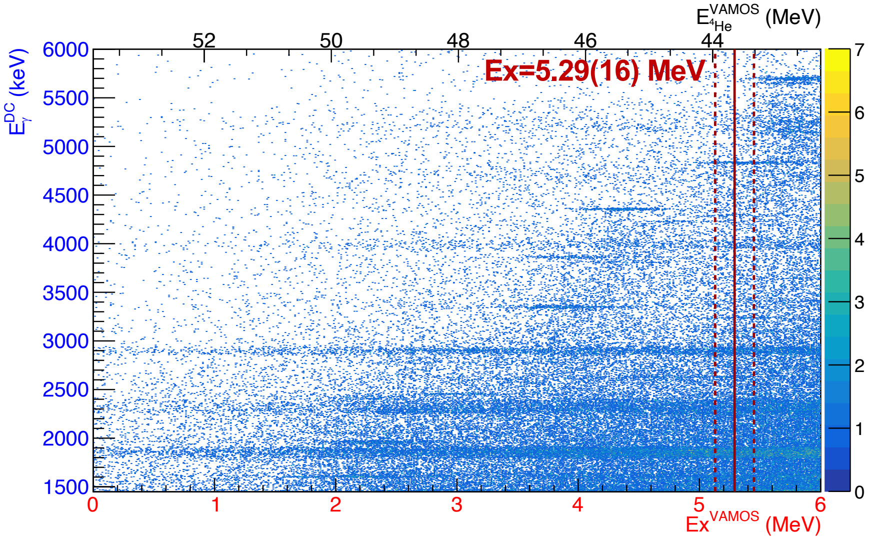
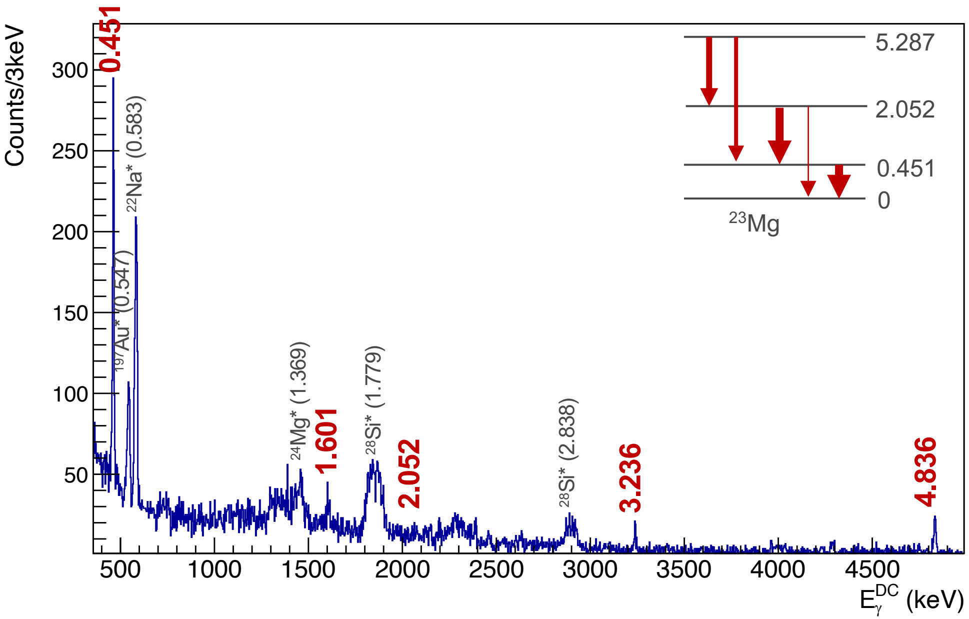
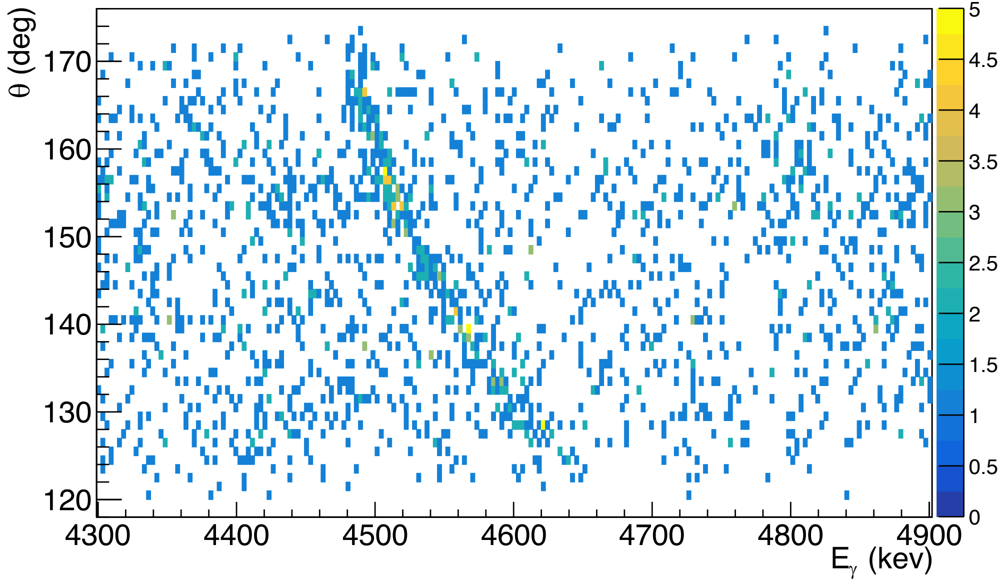




Accessing to γ–ray transitions

$^{3}He(^{24}Mg,^{4}He)^{23}Mg^{*}(\gamma)$
$Ex^{VAMOS}=5.29(16)$ MeV



New approach to lifetime measurements

Angle integrated velocity profile

Profile of β, reconstructed from (E_γ, θ_{DS})

New approach to lifetime measurements

Angle integrated velocity profile

Profile of β, reconstructed from (E_γ, θ_{DS}) ⟶ $$\beta = \frac{\mathrm{R}^2 \cos(\theta_{\mathrm{DS}}) + \sqrt{1 + \mathrm{R}^2 \cos(\theta_{\mathrm{DS}})^2 - \mathrm{R}^2}}{\mathrm{R}^2 \cos(\theta_{\mathrm{DS}})^2 + 1}$$

$$\mathrm{R} = \frac{\mathrm{E}_\gamma}{\mathrm{E}_{\gamma,0}}$$

New approach to lifetime measurements

Angle integrated velocity profile

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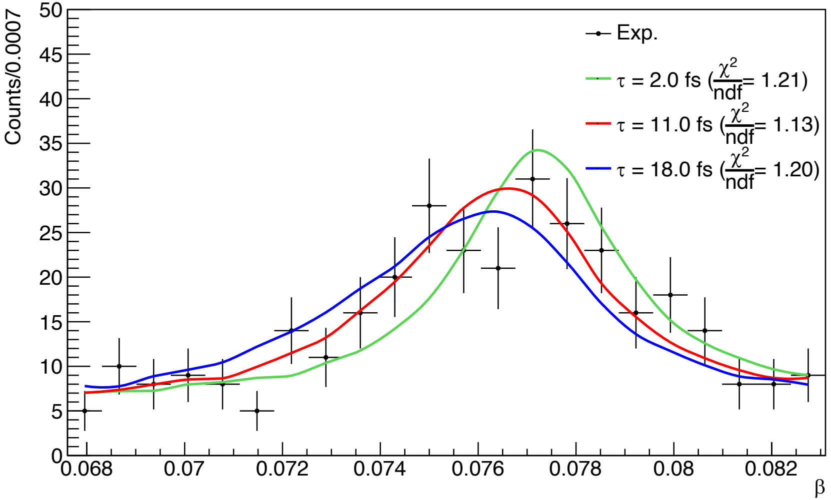

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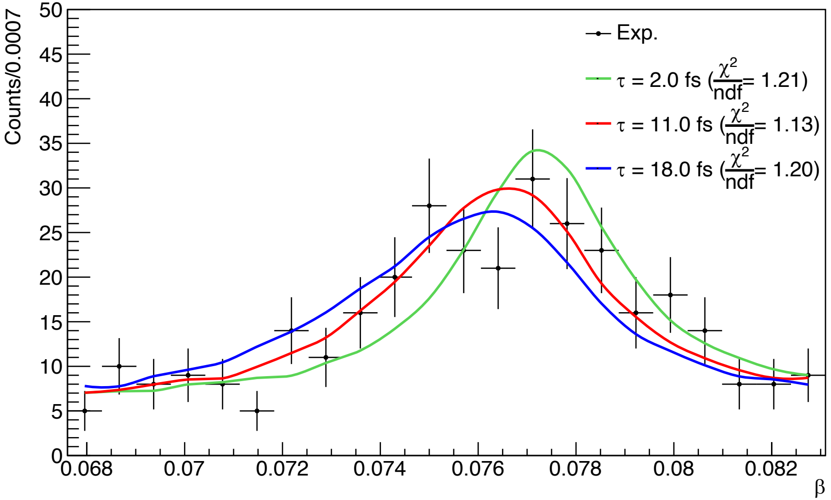
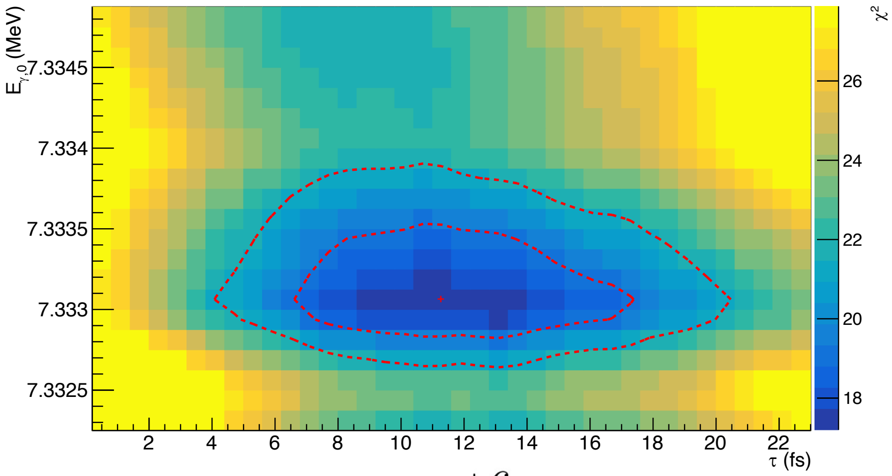




$$\tau = 11^{+6}_{-4}\ \text{fs}$$

C. Fougères et al.

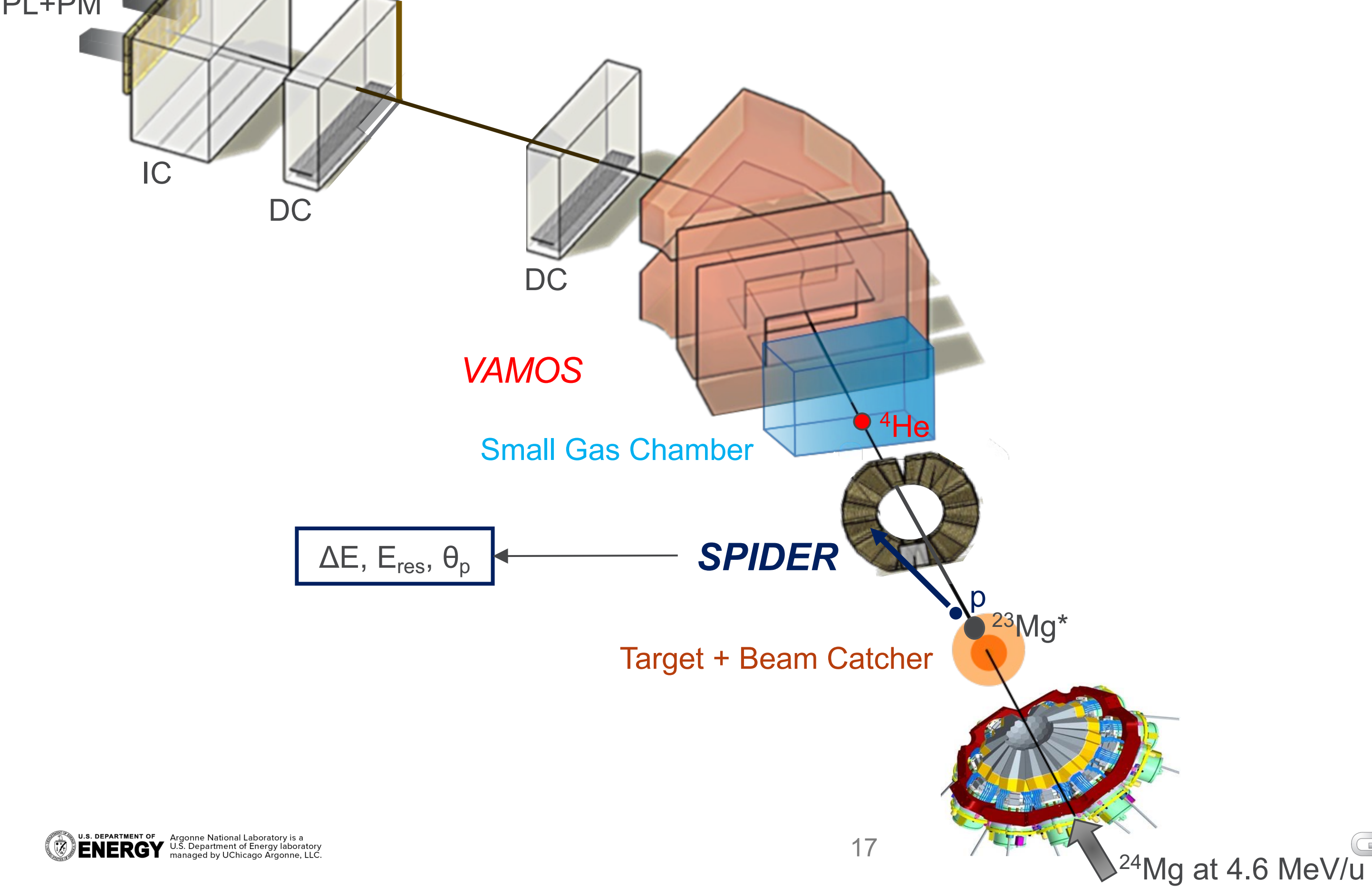
Results to be submitted, 2022

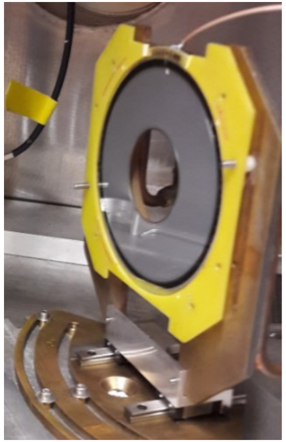
Set-up

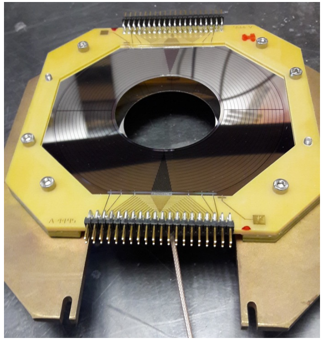
C. Michelagnoli et al. (GANIL 2016)

$^{3}He(^{24}Mg,{}^{4}He)^{23}Mg^{*}(p)$

VAMOS *SPIDER*



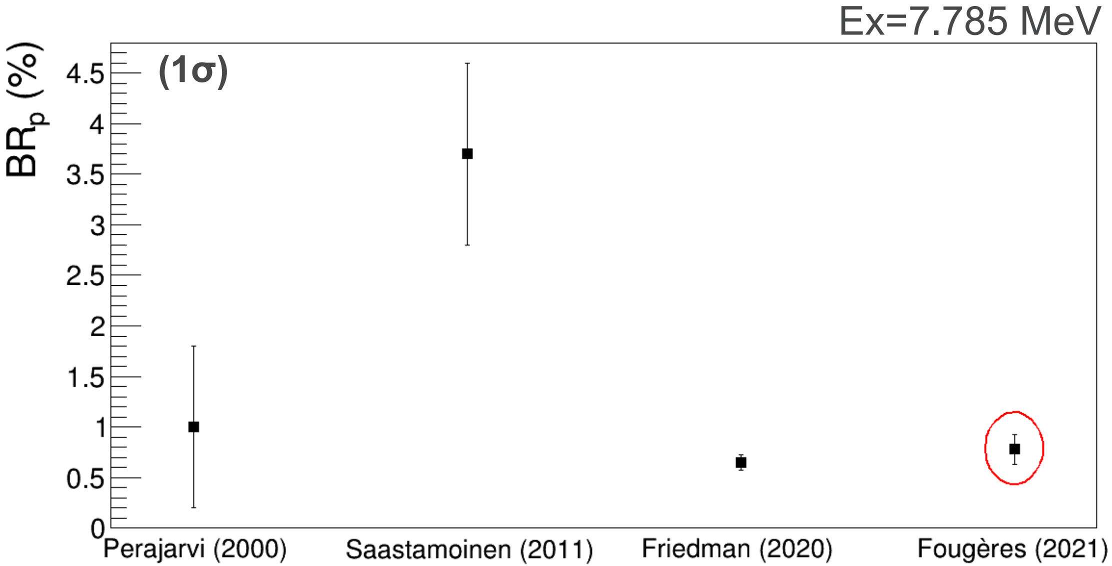




Proton branching ratio measurement

$$\omega\gamma = \frac{2J_{^{23}Mg}+1}{(2J_{^{22}Na}+1)(2J_p+1)} \times \frac{\hbar}{\tau} \times BR_p(1-BR_p)$$

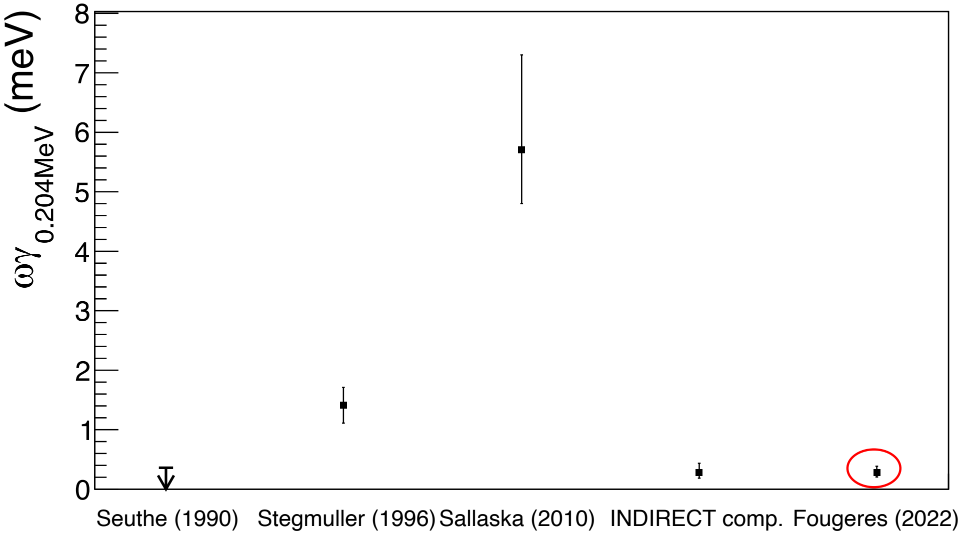
Present work



C. Fougères et al.
Results to be submitted, 2022

New status on $\omega\gamma_{0.204\ \mathrm{MeV}}$

Present work



C. Fougères et al.
Results to be submitted, 2022

ASTROPHYSICAL IMPACT

Reevaluation of the $^{22}Na(p,\gamma)^{23}Mg$ rate

Monte-Carlo calculations, with $\omega\gamma = 0.27^{+0.11}_{-0.07}$ meV at E_R=0.204 MeV

Longland (2010)

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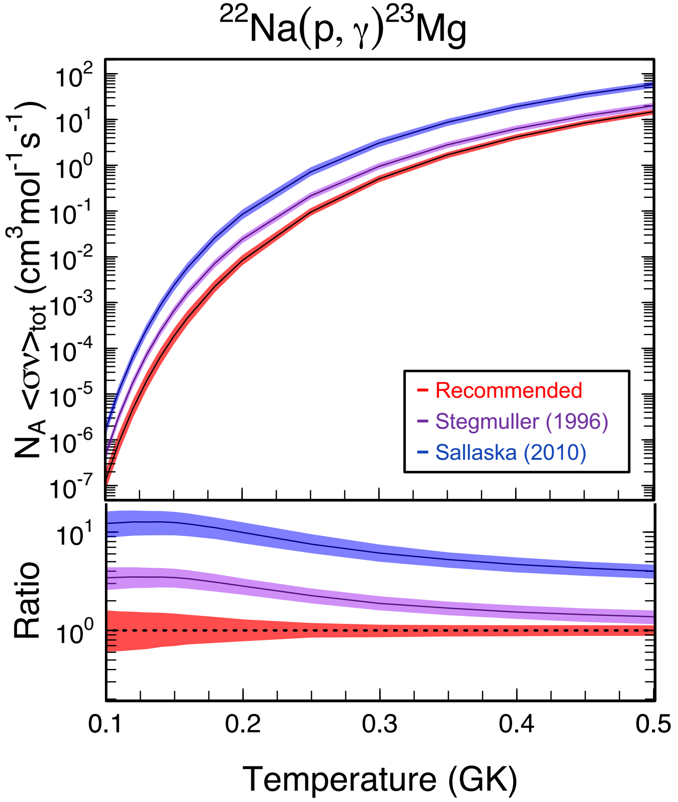

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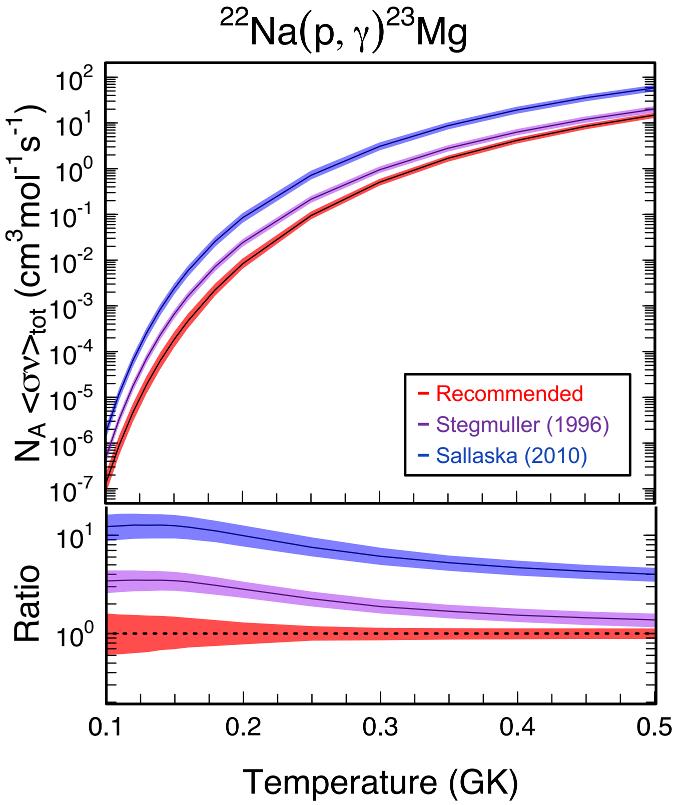

Impact on ejected ^{22}Na from novae?

C. Fougères et al.
Results to be submitted, 2022

Constrains on ONe novae

Simulations of novae

MESA

Paxton (2013)

Constrains on ONe novae

Accretion dynamics, initial WD temp.

^{22}Na abundance in novae

Simulations of novae

MESA

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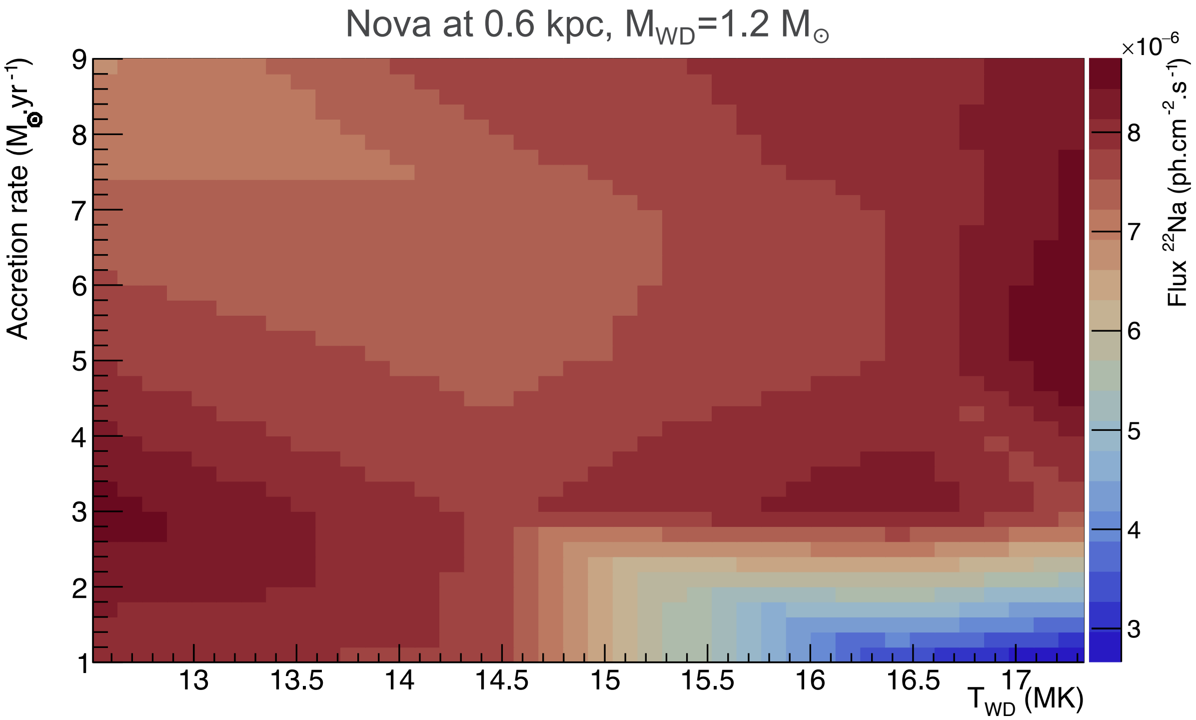

NPA-X (CERN 2022)

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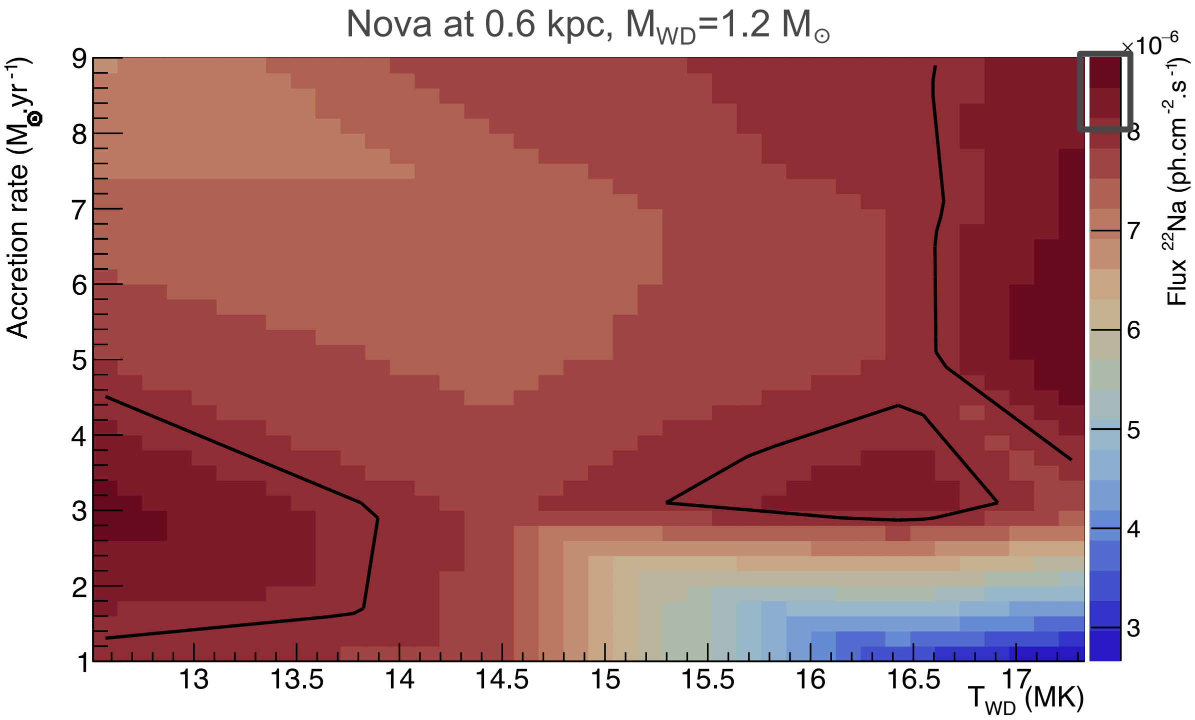
MESA

Paxton (2013)



Constrain novae parameters with observed flux

Prospects for gamma-ray astronomy

Survey of 8 observed
ONe novae (60 yr)

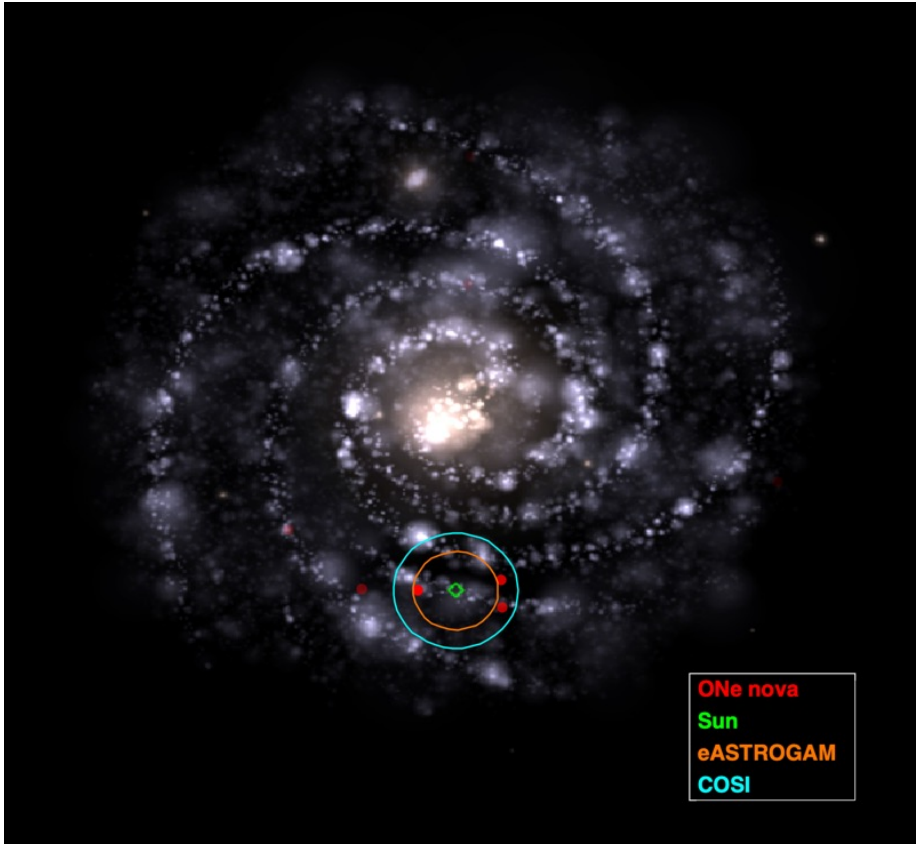
Hachisu (2019), José (2020)

Prospects for gamma-ray astronomy

Limit in detection distance

Survey of 8 observed ONe novae (60 yr)

Hachisu (2019), José (2020)

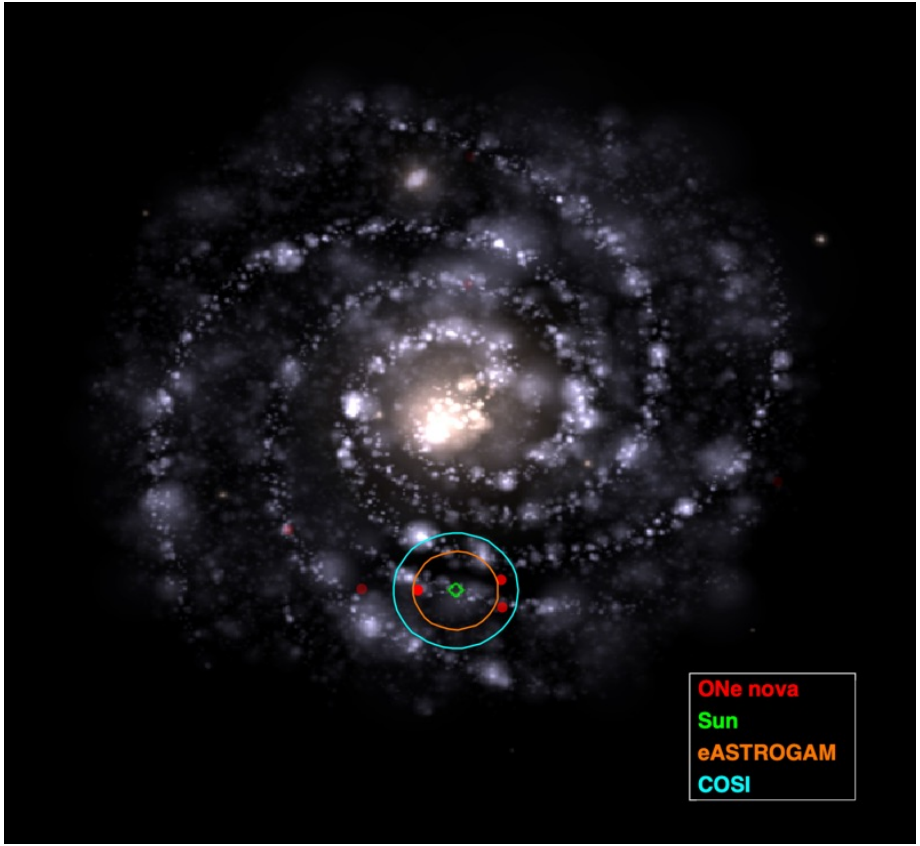


Prospects for gamma-ray astronomy

Limit in detection distance

Survey of 8 observed ONe novae (60 yr)

Hachisu (2019), José (2020)



Future MeV
γ-ray space telescopes
e-ASTROGAM *De Angelis (2018)*
COSI *Tomsick (2020)*

Detection frequency
(^{22}Na)
≥1 event / 60 yr
≥1 event / 20 yr

THANK YOU FOR THE KIND ATTENTION

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