High precision measurement of alpha-induced reactions for weak r-process nucleosynthesis

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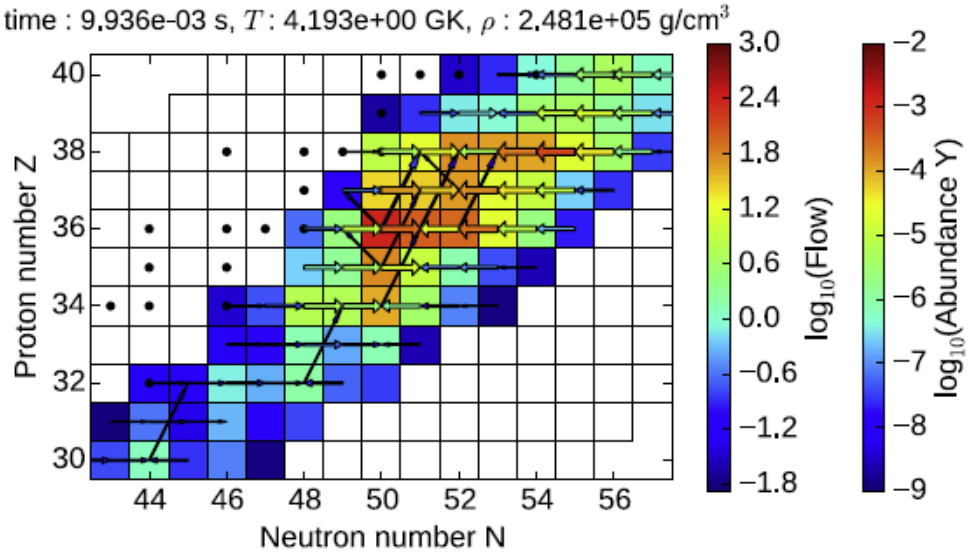
The weak r-process and its nuclear physics-related uncertainty

- Low mass (38 [Sr] ≤ Z ≤ 47 [Ag]) neutron-rich isotopes might be synthesized by charged particle-induced reactions in neutrino driven winds.
- Reaction path: located in the region of unstable isotopes relatively close the valley of stability.
- (α,n) & (p,n) is faster then β-decay → reactions drive the material toward heavier masses.



Nuclear reaction network
Astrophysical input: 36 trajectories

Nuclear physics input from H-F model (Talys code)

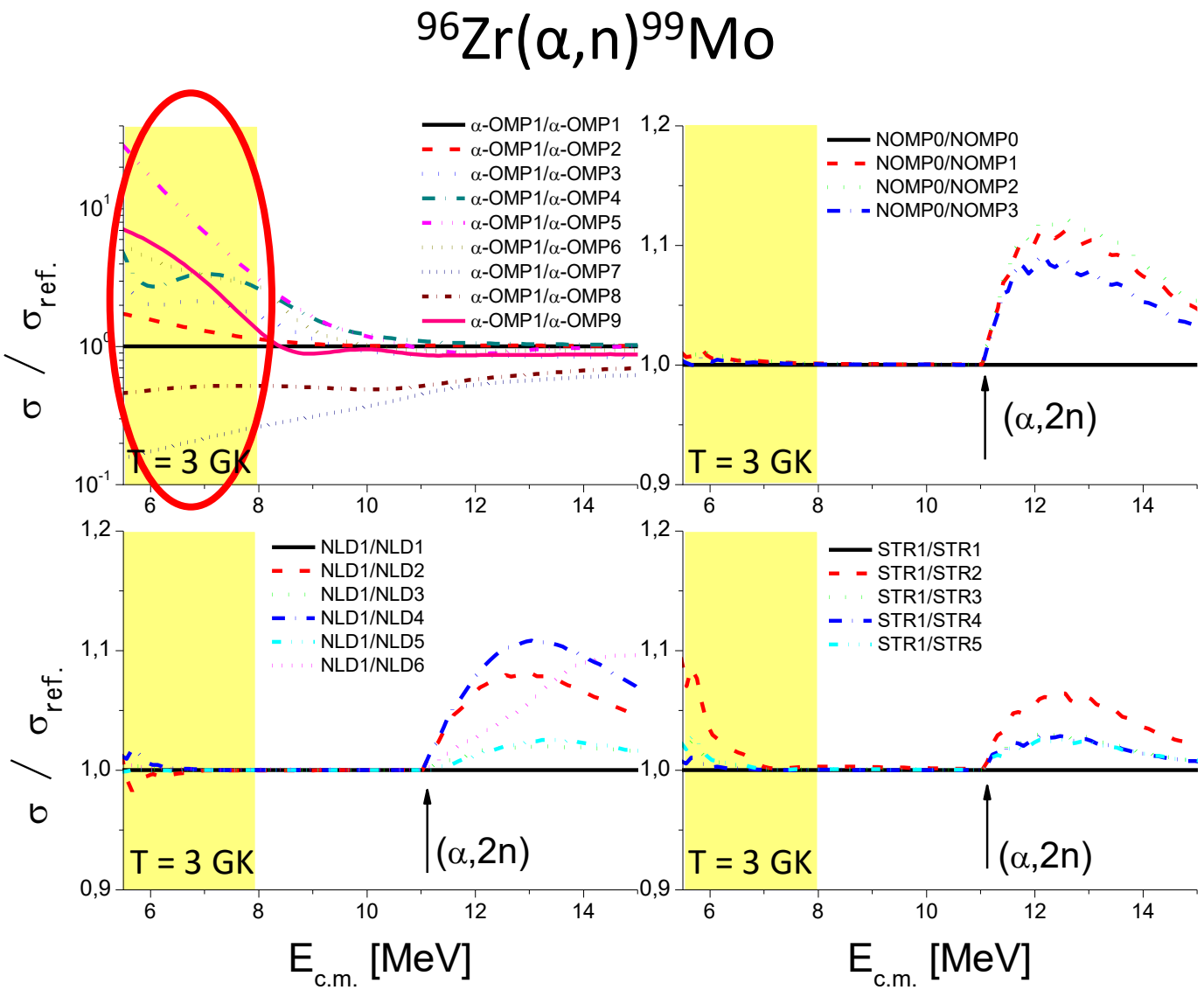
S. Woosley & R. D. Hoffman APJ. **395** (1992) 202
Y. Z. Qian & S. Woosley APJ. **471** (1996) 331
A. Arcones & F. Montes APJ. **731** (2011) 5

How accurately do we know the cross-sections of (α,n) reactions?

More than an order of magnitude difference!

Dominant source of nuclear physics uncertainty!

Cross section data is needed at astrophysical energies!



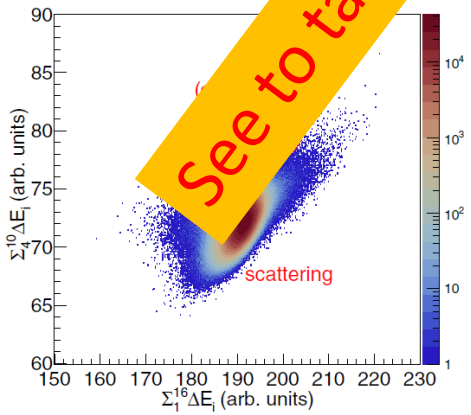
Experimental approaches

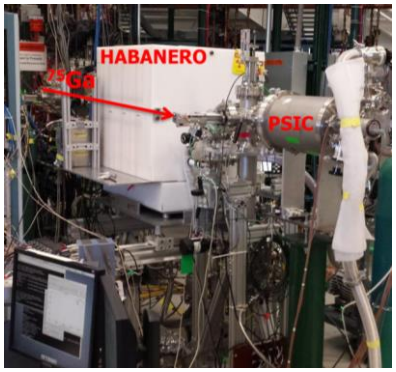
Inverse kinematics

- Suitable to be used with RI beams
- MUSIC detector (
- Neutron detect FRIB)

→ several expe nts in progress

See to talk of Fernando!

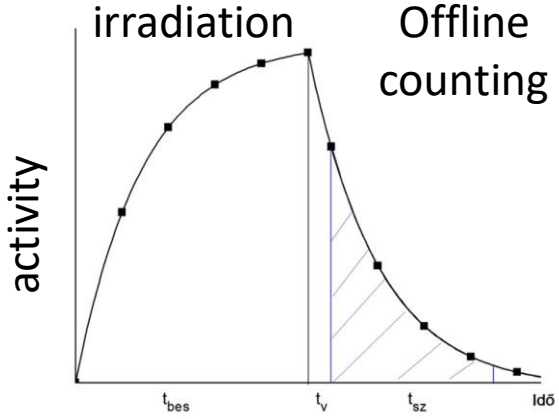




C. Fougères *et al.,* PRC **109** (2024) 065805
W. J. Ong *et al.,* PRC **105** (2022) 055803

Direct kinematics

- Activation technique
- Stable target + alpha beam

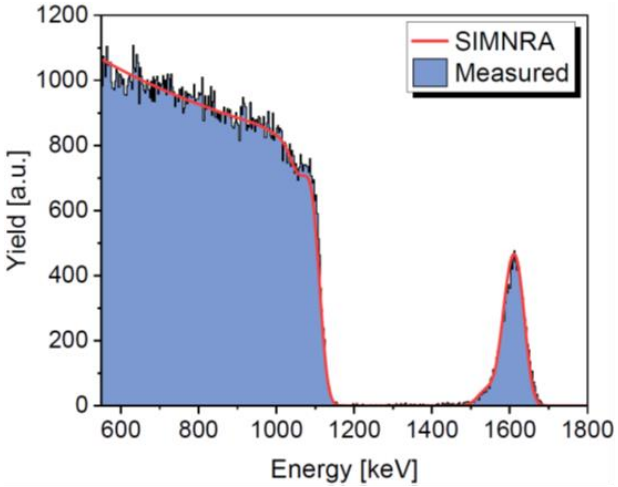


- Measuring γ- & β- radiation with HPGe & Si detectors

G.G. Kiss *et al.*, APJ **908** (2021) 202
G.G. Kiss *et al.,* submitted to APJ

Investigated reactions

$^{96}Zr(\alpha,n)^{99}Mo$

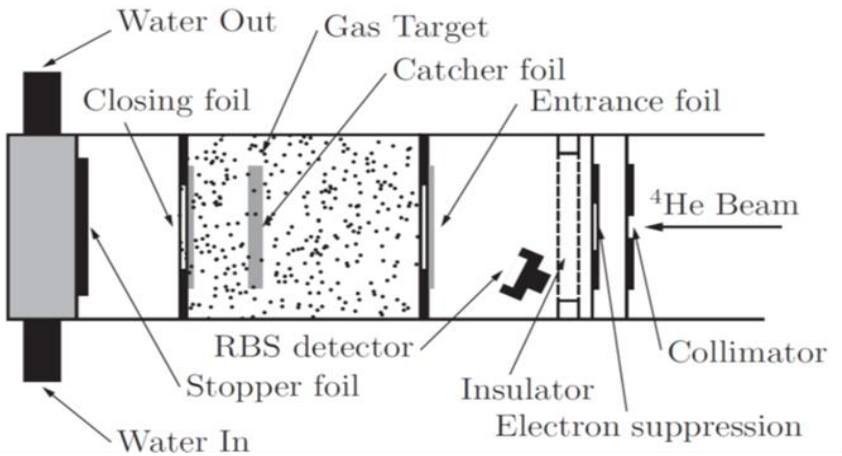


Solid targets (vacuum evaporation), RBS

β-decay populates excited states →
γ-counting by HPGe detectors

J. Bliss *et al.*, PRC **101** (2020) 055807
A. Psaltis *et al.*, APJ. **935** (2022) 27

$^{86}Kr(\alpha,n)^{89}Sr$



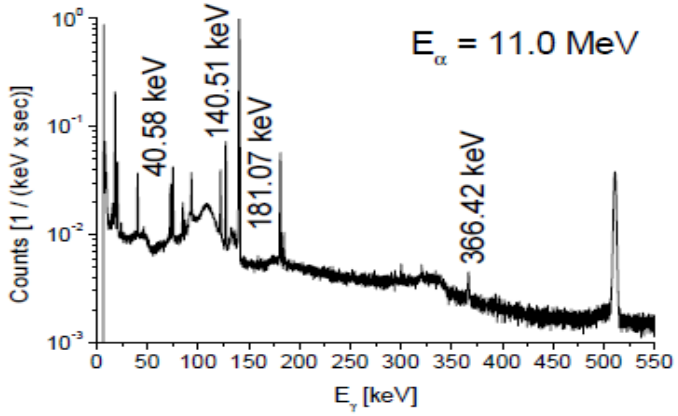
Noble gas → gas or / and implanted target

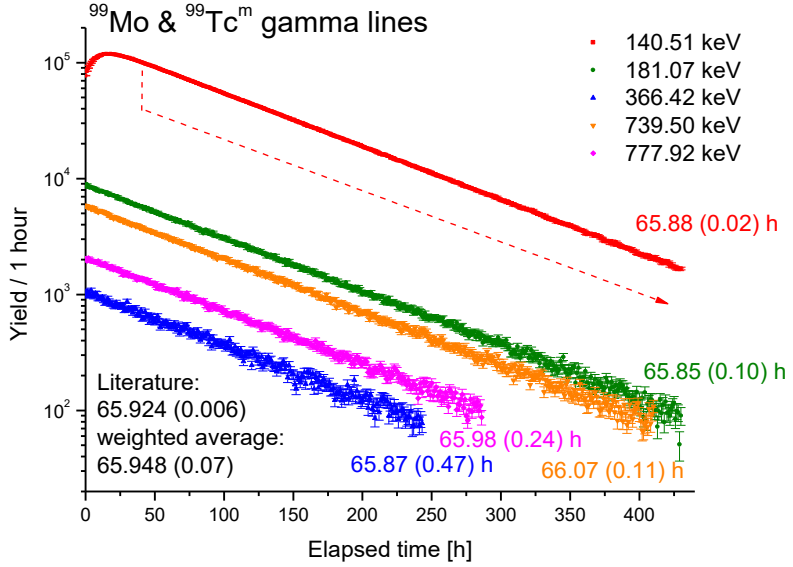
β-decay to ground state (i.e. no gamma emission) → β-particle counting

G.G. Kiss *et al.*, APJ **908** (2021) 202
S. Kovács *et al.*, NIM B, submitted

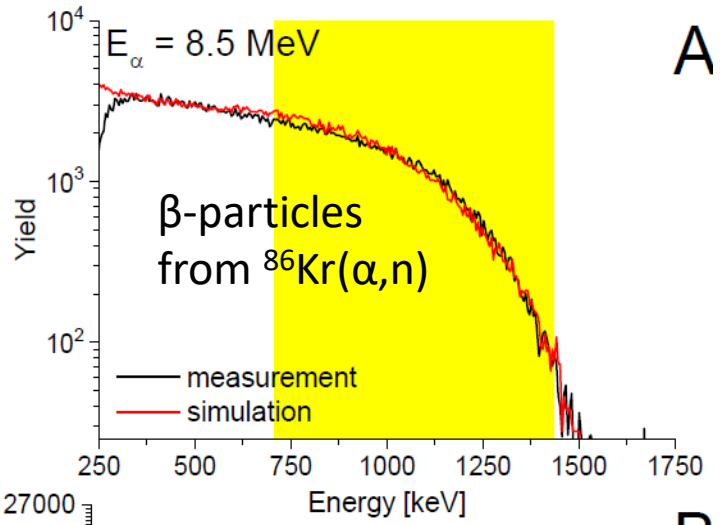
Measurement of the induced activity

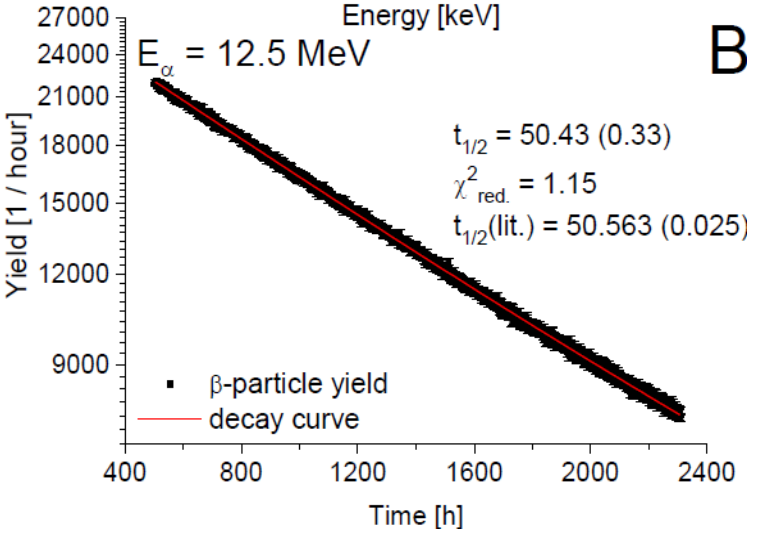
$^{96}Zr(\alpha,n)^{99}Mo$



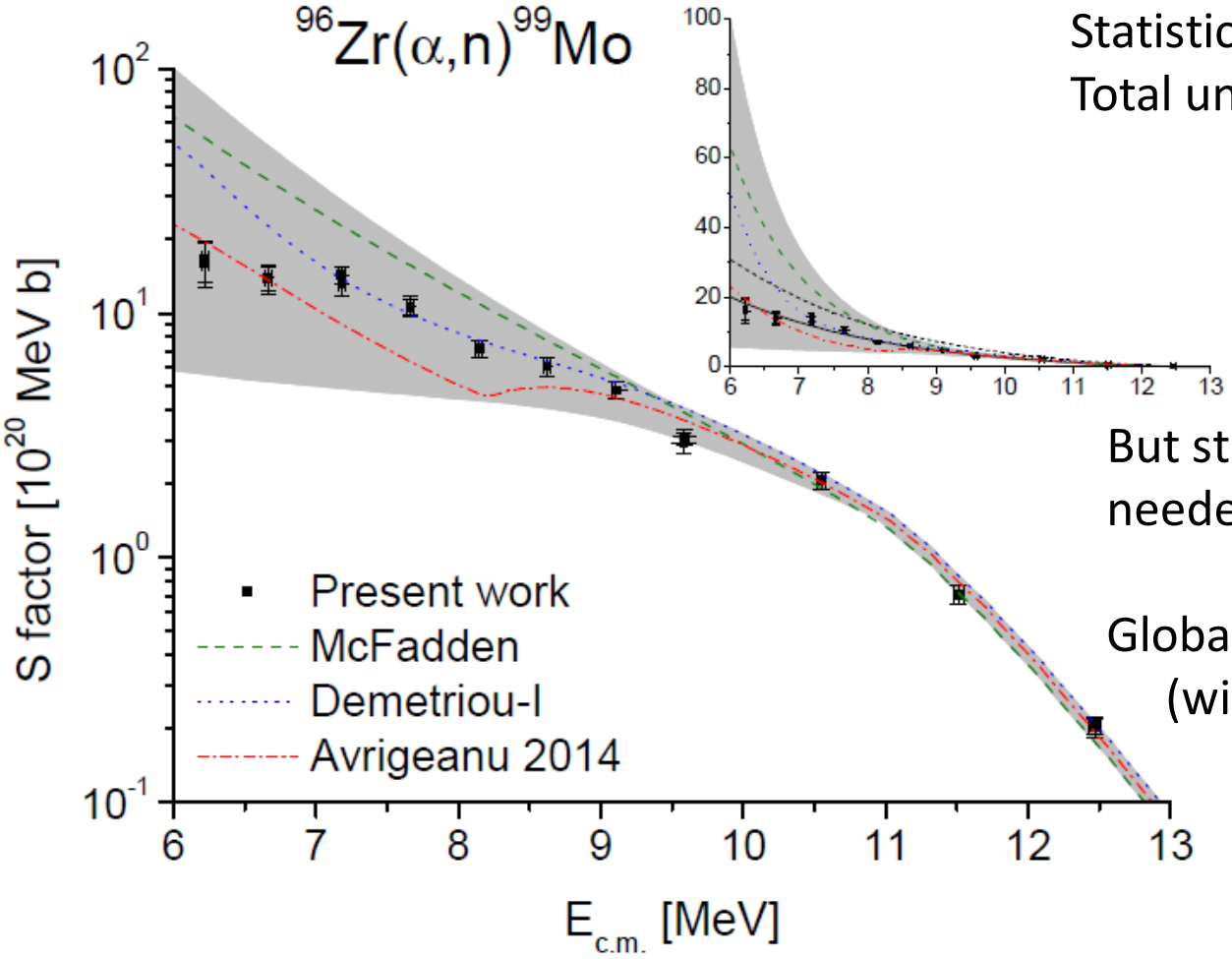


$^{86}Kr(\alpha,n)^{89}Sr$





Experimental results



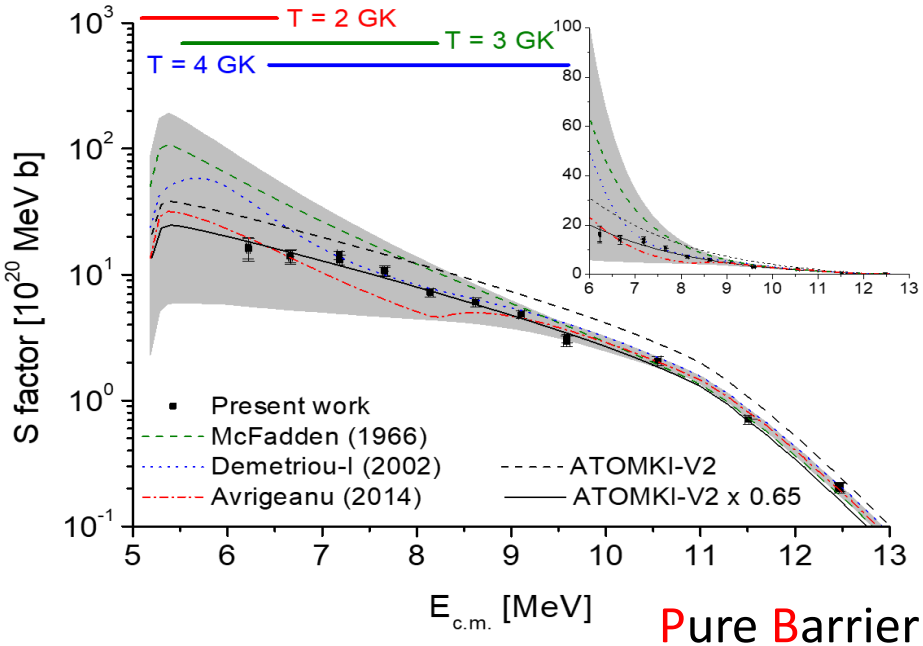
Statistical uncertainty: 1%-19%
Total uncertainty < 21%

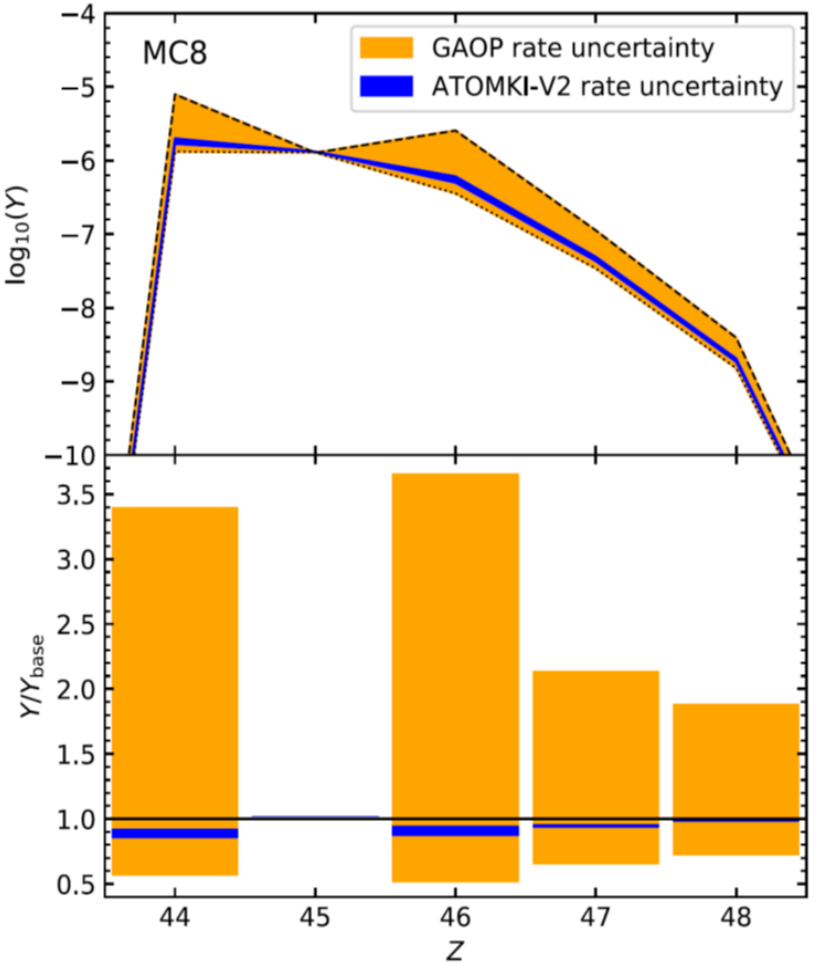
But still (some) extrapolation is needed…

Global α-OMPs: $\chi^2/N > 3$
(with arb. scaling factor)

G. G. Kiss *et al.,* APJ. **908** (2021) 202

Cross section calculations





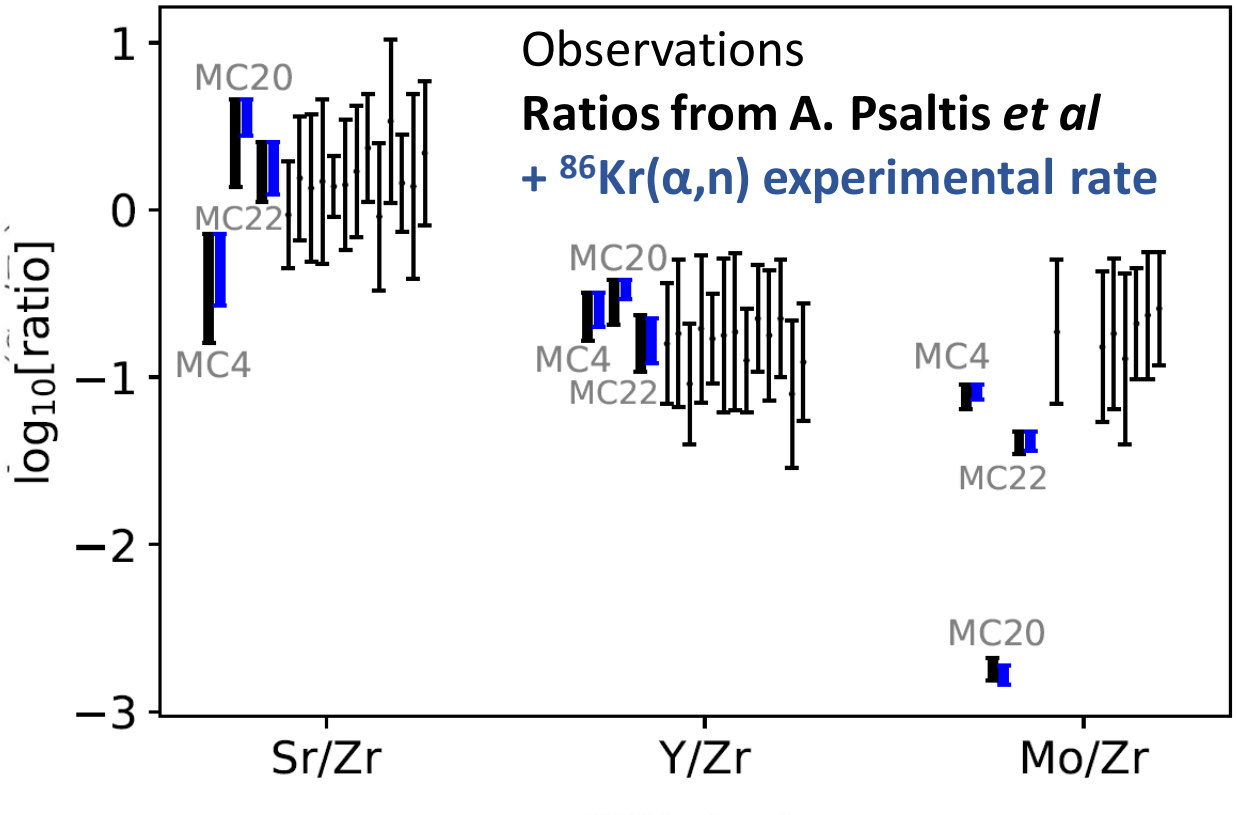
- Global α-OMPs: $\chi^2/N > 3$ (with arb. scaling factor)
- **ATOMKI-V2: $\chi^2/N \approx 0.6$ (after scaling with 0.65)**

Pure Barrier Tra
physics)

1. Real part of
   penetratior
   penetratior
2. Decay of the compound – calculation using „standard" OMP's.

P. Mohr *et al.*, PRL **124** (2020) 252701
P. Mohr *et al.*, ADNDT **142** (2021) 101453

Nucleosynthesis calculations & observations



^{86}Kr(α,n)^{89}Sr

Trajectories:
1, 2, 4, 7, 8, 10, 17, 20, 25, 26, 31

Elemental ratios:
Sr/Zr, Y/Zr, Mo/Zr

P. Mohr *et al.*, ADNDT **142** (2021) 101453
A. Psaltis *et al.*, APJ. **935** (2022) 27

G. G. Kiss et al., APJ, submitted

Summary

- Low mass (Fe-Ag) neutron-rich isotopes may be formed in neutrino-driven winds.
- (α,n) reactions play crucial role in this so-called weak r-process nucleosynthesis scenario.
- Activation cross section measurements were used to constrain nucleosynthesis calculations.
- RI beam experiments are in progress…
- Elastic alpha scattering in inverse kinematic with RI beams can be used also to constrain the α-OMP's!

A novel understanding on this nucleosynthesis process

Thank you for your attention!

Collaborators:

A. Arcones & F. Montes (weak r-process calculations)
P. Mohr (nuclear theory)
S. Kovács, T. N. Szegedi (experiment)