Constraining (α,n) cross sections with indirect measurements

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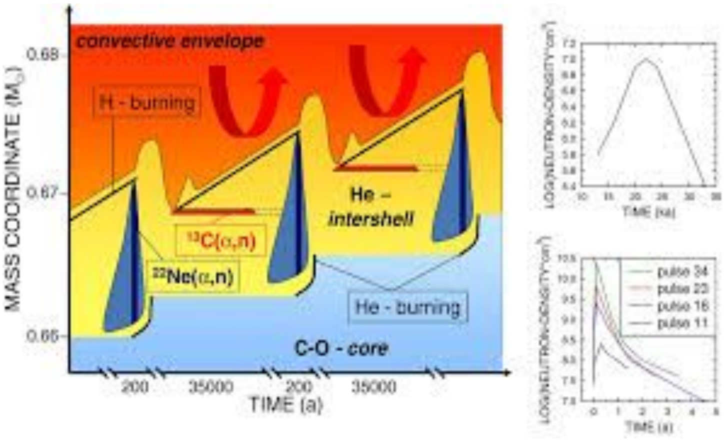
Astrophysical Motivation



Neutron reactions in astrophysics
R Reifarth, C Lederer and F Käppeler

Journal of Physics G: Nuclear and Particle Physics, Volume 41, Number 5

s-process - slow neutron captures to make heavier nuclei

Making heavier elements depends on a lot of thing but includes “amount of neutrons available”

^{22}Ne(α,n)^{25}Mg: +neutrons but competes with ^{22}Ne(α,γ)^{26}Mg

^{16}O(n,γ)^{17}O has two paths:

1: ^{17}O(α,n)^{20}Ne: same number of neutrons

2: ^{17}O(α,γ)^{21}Ne: -neutrons

The point of this talk

Indirect measurements are important in determining (α,n) reaction rates for astrophysics

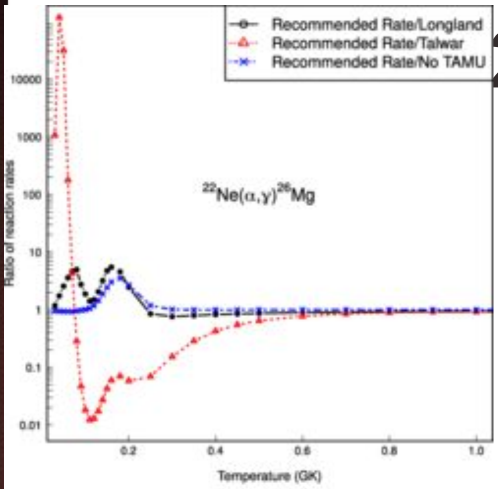
-Locating (possible) resonance states

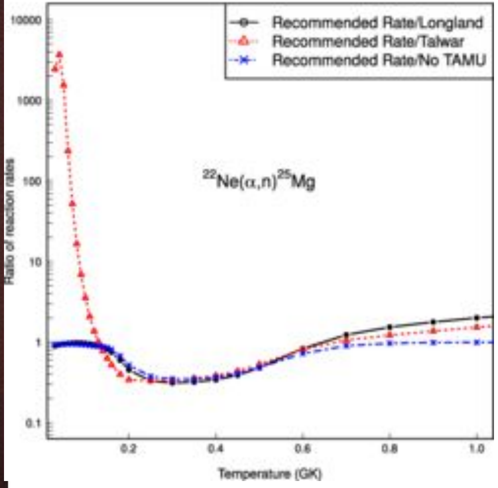
-Characterising them (spin and parity, partial widths)

-A plea for non-selective experiments! How many levels are there?

-Are there resonances? How does that affect experimental approaches? When/where do we trust statistical models?

^{22}Ne+α reactions





PA++ PRC 103, 015805

See also for references of experiments mentioned

Due to the astrophysical importance, there's a wealth of indirect data:

α-particle scattering (Talwar, PA)

Proton scattering (PA)

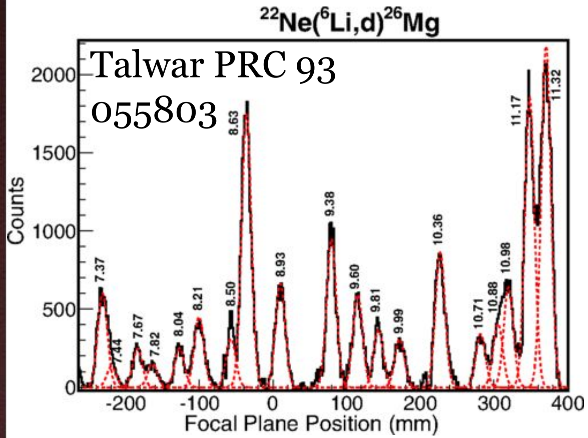
Resonance neutron scattering (Massimi, nToF)

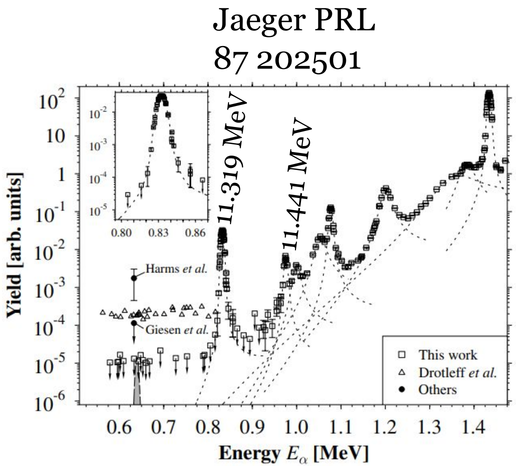
^{25}Mg(d,p) (Chen)

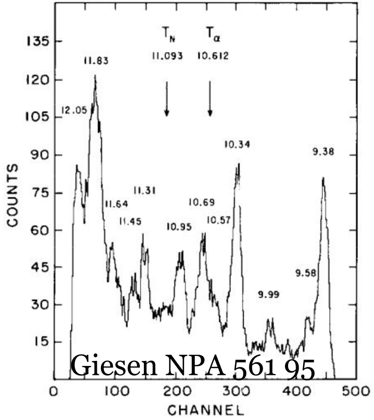
(^{6}Li,d) transfer (Ota, Jayatissa)

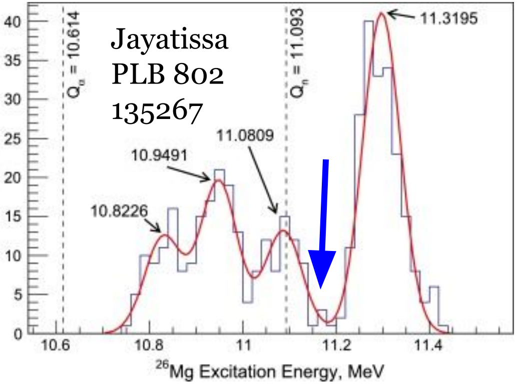
γ-ray decay data (Lotay)

What were/are the problems in ^{22}Ne+α?









Resonance levels - how many? Especially the strong resonance/s near E_{cm} = 700 keV

Lack of clarity on spins and parities, and α partial widths lower down (also the number of strong resonances from transfer reactions - possibly an energy calibration problem?)

Is there a strong ^{22}Ne(α,γ) resonance around E_{cm} = 550 keV (E_x = 11.17 MeV)?

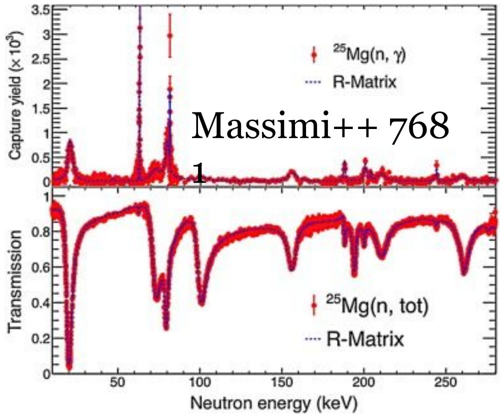
What have indirect measurements shown us?

(p,p’) -> only one resonance at E_{cm} ~ 700 keV

(α,α’) -> spins and parities, disagreement between studies is concerning (I think I’m right but I would say that)

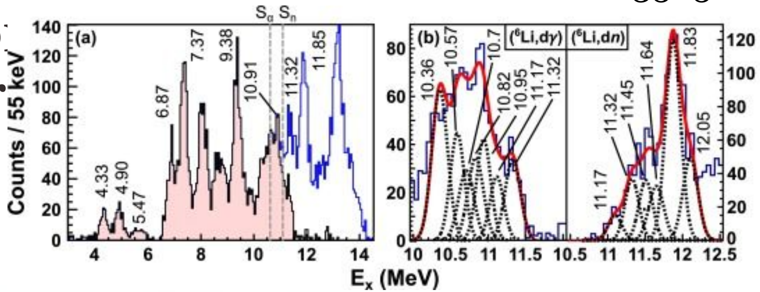
TAMU transfer experiments have provided new information on the relative (α,n) and (α,γ) strength and on α-particle partial widths

nToF data give limitations on neutro widths and neutron/γ partial width r



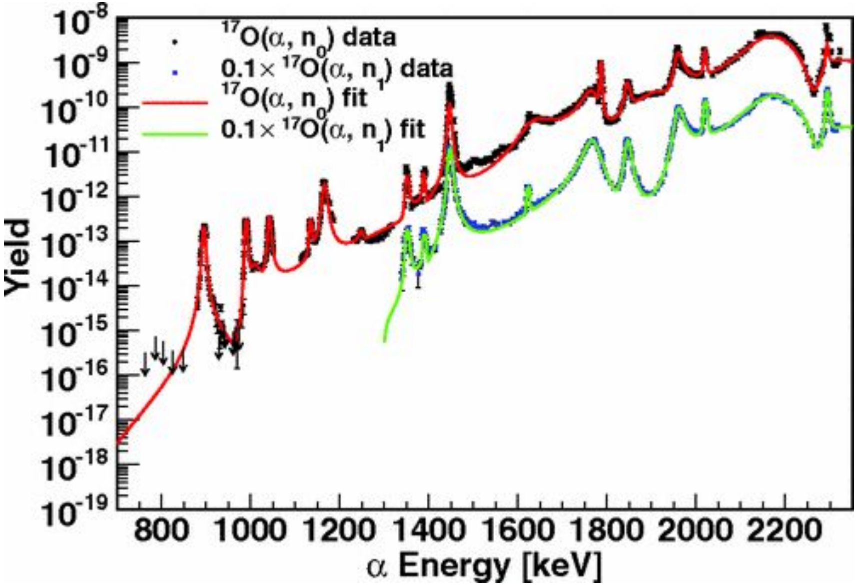
Massimi++ 768 1

Ota++ PLB 802 135256



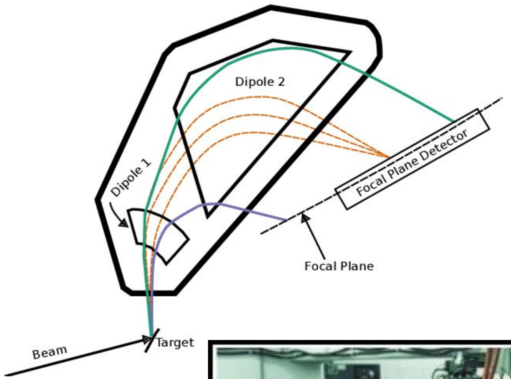
^{17}O+α reactions

- ^{17}O(α,n) isn't as well studied as ^{22}Ne+α - Andreas Best at Notre Dame is the most complete data set
- ^{17}O(α,γ) is better studied - Andreas again, Taggart/Williams at DRAGON (new results ready for submission)
- Discrepancies in number, energies of levels, properties
- The current rate in use in the community is from Andreas's paper (PRC 87 045805) which has lots of educated guesses about resonances below E_{cm} = 660 keV
- Care about the ratio of neutron/γ strength for the resonance states



Best++ PRC 87 045805

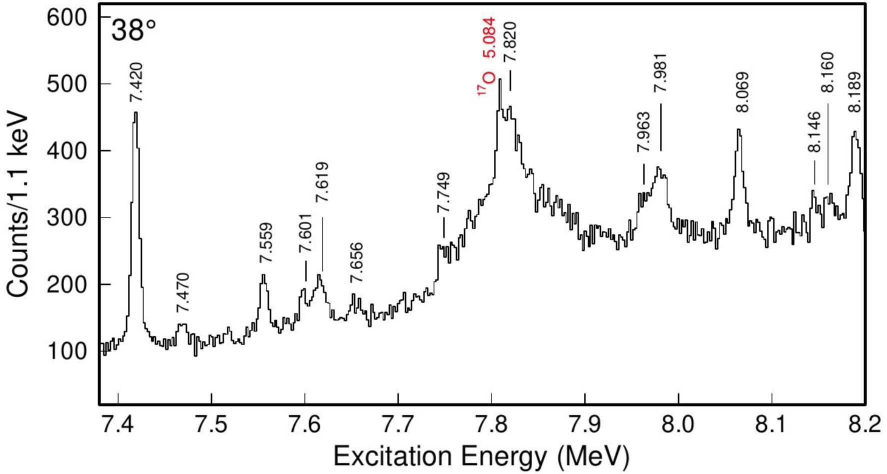
$^{20}Ne(d,p)^{21}Ne$

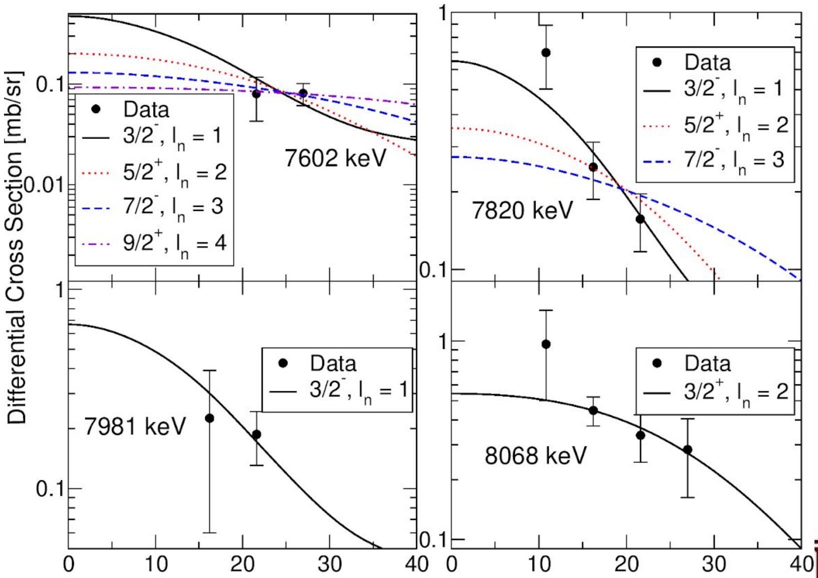


- Indirect experimental study to try to get spins and parities, and neutron widths
- 14-MeV deuterons from tandem at TUNL
- Target - ^{20}Ne implanted in
- Protons momentum-analysed in the Split-Pole spectrograph
- Angular distributions of protons - background from ^{12}C, ^{16}O, breakup

^{20}Ne(d,p) results

$$\frac{d\sigma}{d\Omega}|_{\mathrm{lab}} = C^2 S \frac{d\sigma}{d\Omega}|_{\mathrm{DWBA}}$$





Experimental background is a problem - using an implanted foil isn't great

Inverse kinematics tried with HELIOS but resolution is horrible

DWBA done with weak-binding approximation

From transfer to width

$$\frac{d\sigma}{d\Omega}|_{\text{lab}} = C^2S\frac{d\sigma}{d\Omega}|_{\text{DWBA}}$$

Some boring constants

$$\Gamma = 2P_\ell(E,R)\frac{\hbar^2 R}{2\mu}C^2S|\phi(R)|^2$$

How likely we are to get through the barrier

The scaling factor for the wavefunction

The size of the single-particle wavefunction at the nuclear surface

Updated reaction rate ratio

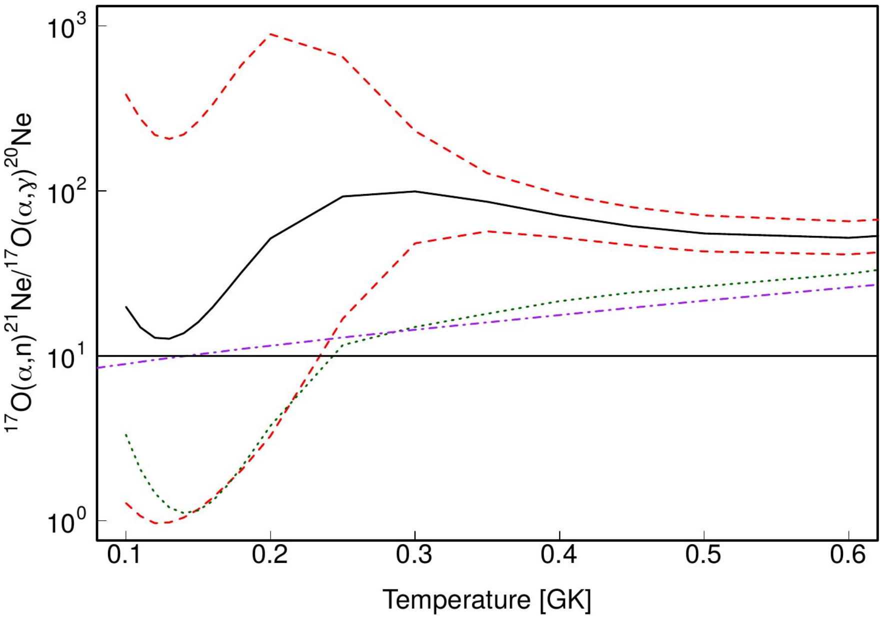
Since the neutron recycling is what mostly matters, plotting the ratio of the two rates as a function of temperature

Black solid - ratio of median rates

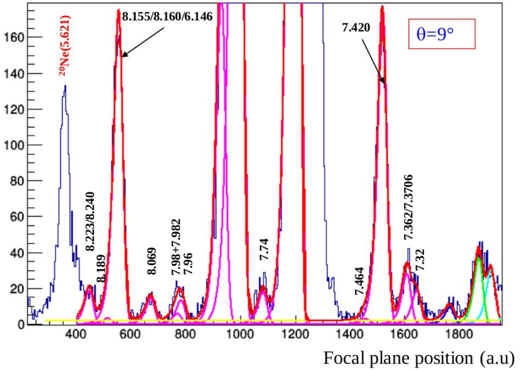
Red dashed -

Green dotted - Andreas Best

Purple dash-dots - CF88



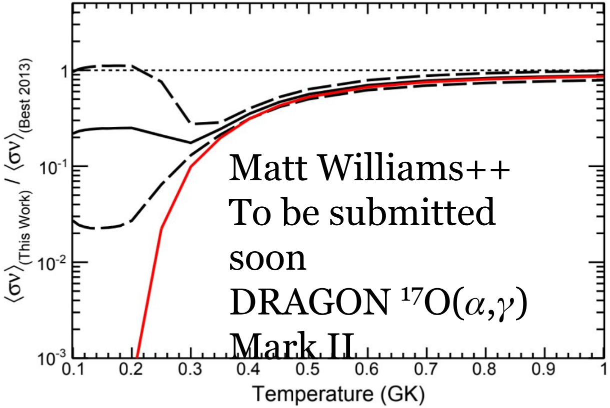
Where next for ^{17}O+α



Fairouz Hammache++
^{17}O(^{7}Li,t) at the Munich Q3D

Matt also has
EMMA+TIGRESS+SHARC
inverse kinematics transfer

Lots of data are coming soon!



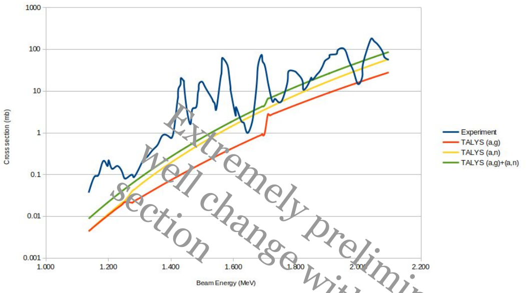
Matt Williams++
To be submitted soon
DRAGON ^{17}O(α,γ) Mark II

Wot I fink we need

(With an extremely nuclear astro hat on)

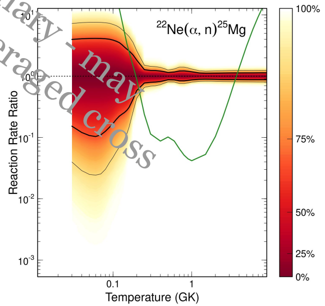
Which means that I care mainly about lighter nuclei where discrete resonances dominate

1) How many levels? Non-selective scattering
2) Information on potential (or actual) resonances. α-cluster transfer
3) Are there α-particle resonances in heavier nuclei? If "yes", what impact does this have on what measurements are needed?



Extremely preliminary - may well change with averaged cross section

^{22}Ne(α,n) comparison of cross section using ^{22}Mg(α,p) TALYS input parameters vs resulting reaction rate



Cross section isn't too bad in the higher-energy region but the rate doesn't even have the same dependence

Selectivity

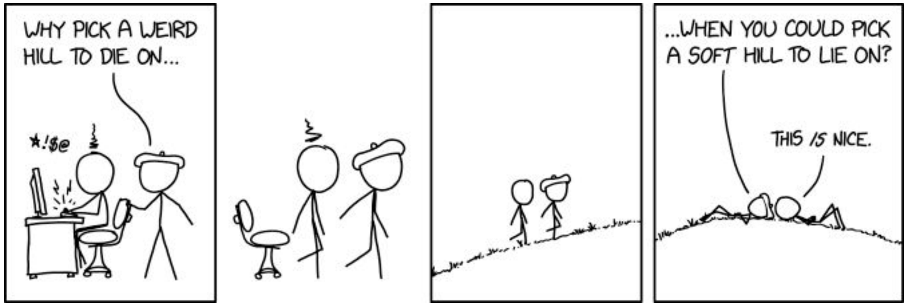
Tend to try to pick the selective reactions to populate the astrophysically important states

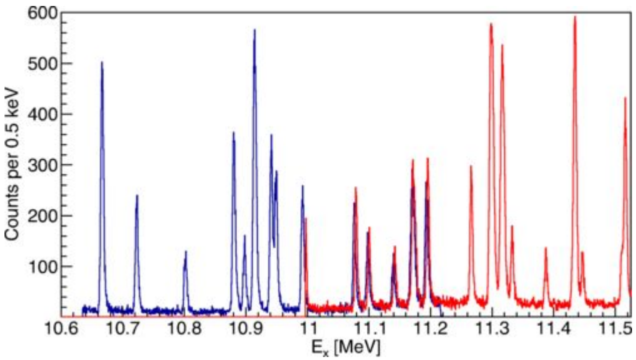
BUT we need to be careful about biases introduced by selectivity - ^{25}Mg(d,p) paper of Chen PRC 103 035809 discusses this excellently - selectivity isn't always to the right thing

Most reactions are selective, not always to the same things… ^{26}Mg levels (probably) misassigned in RCNP (α,α') data because of mistaken (though understandable) comparison with (γ,γ') data

In lighter nuclei especially using something rather indiscriminate can help in determining the number of levels and untangling different, more selective, experiments

Proton scattering at 10-20 MeV is very non-selective and helpful for this - I'm working on trying it with γ rays and not detecting the proton which can be extended to radioactive beams





PA, Laird, Meisel PRC 102 015801

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