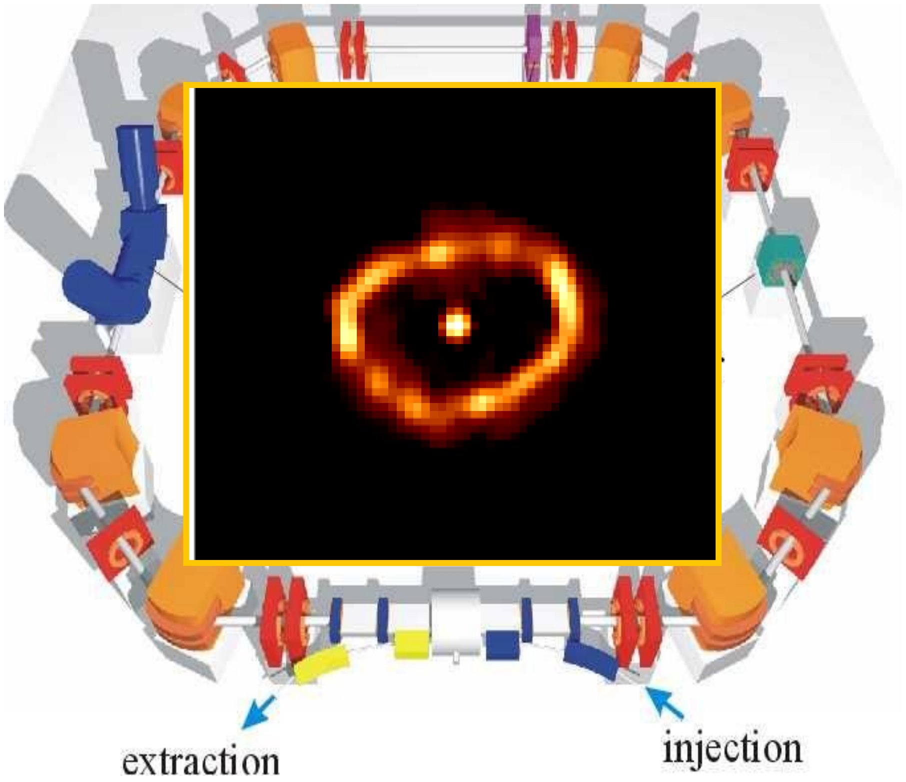
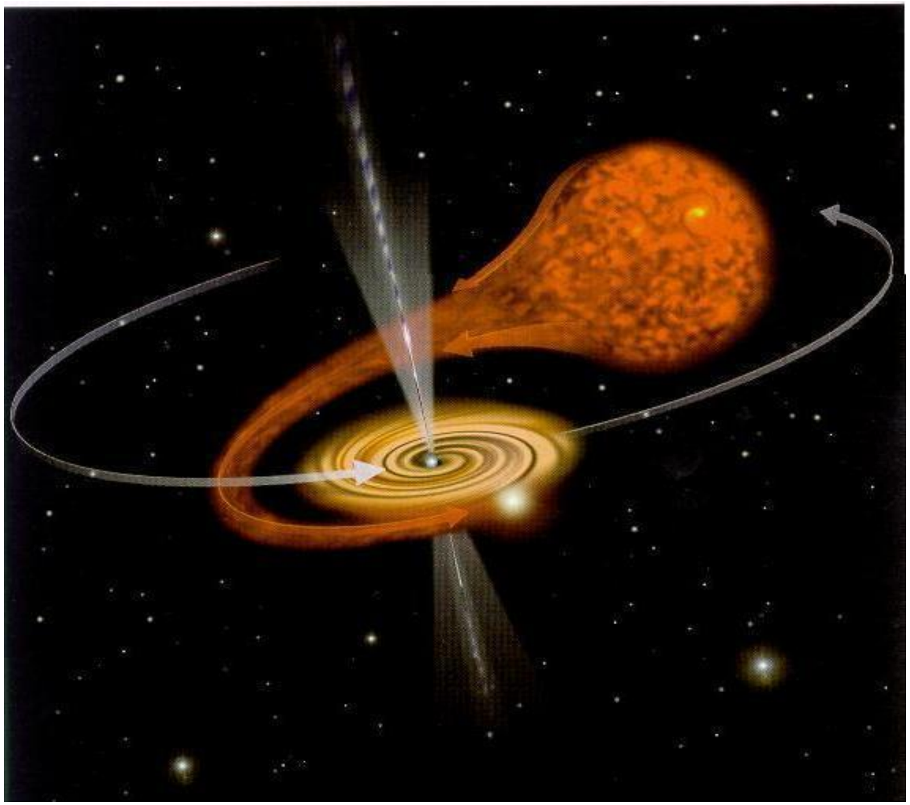
If you like it, you should have put a (storage) ring on it

PJ Woods

University of Edinburgh



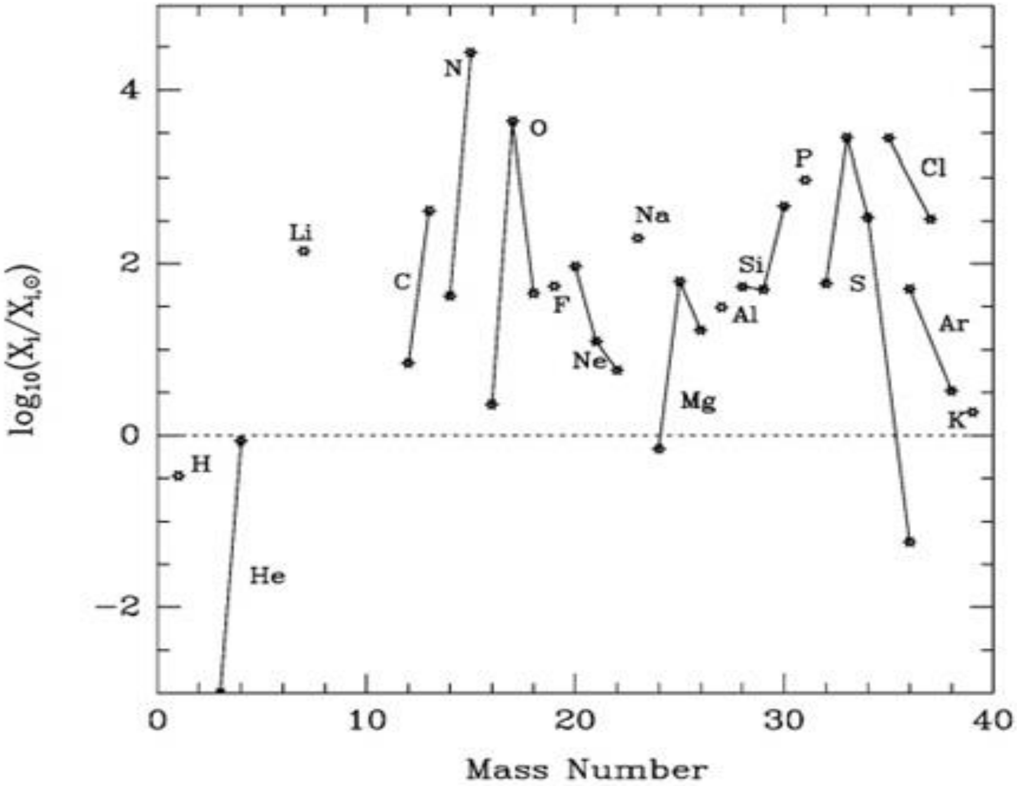
Explosive H burning in Novae



Isaac Newton, Principia Mathematica (1666): 'from this fresh supply of new fuel those old stars, acquiring new splendour, may pass for new stars'

Elemental abundances in novae ejecta

1.35 M_{Sun} ONe nova

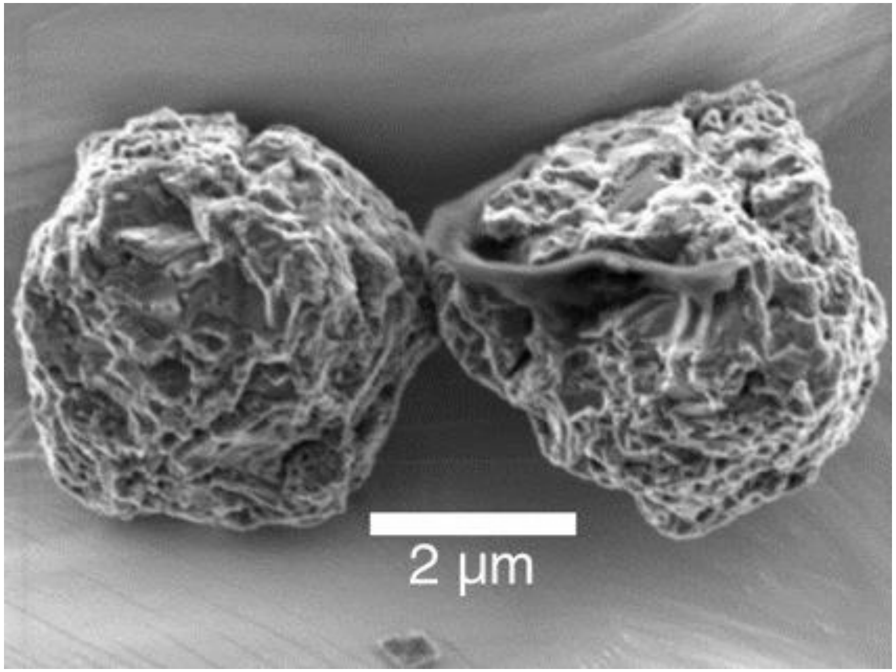


J. José, M. Hernanz, C. Iliadis. Nucl Phys A**, 777**, (2006), 550-578

Presolar grains

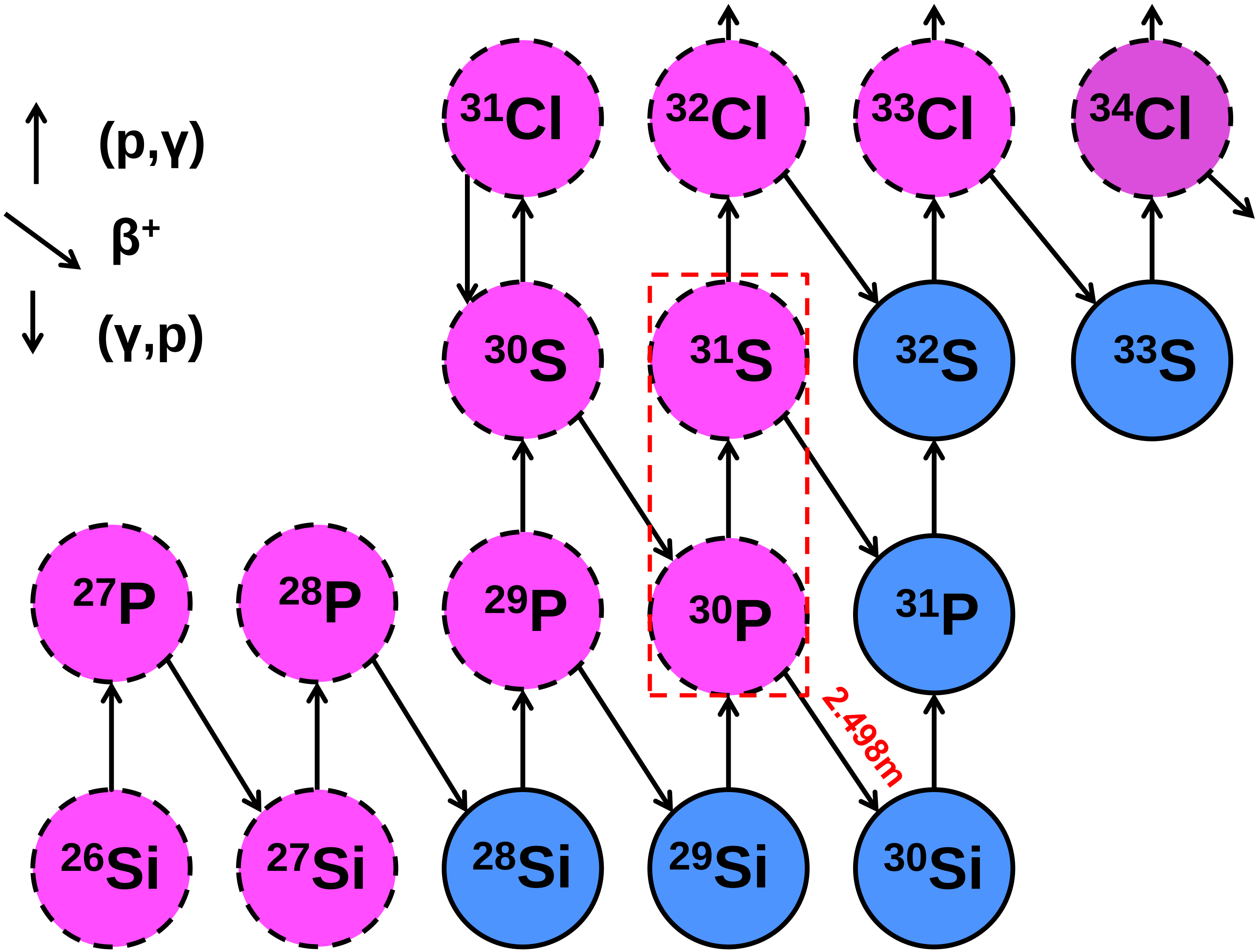
- **Grains of nova origin are thought to have a large $^{30}Si/^{28}Si$ ratio.**

- **Abundance of ^{30}Si is determined by the competition between the ^{30}P β^+ decay and the $^{30}P(p,\gamma)^{31}S$ reaction rate.**

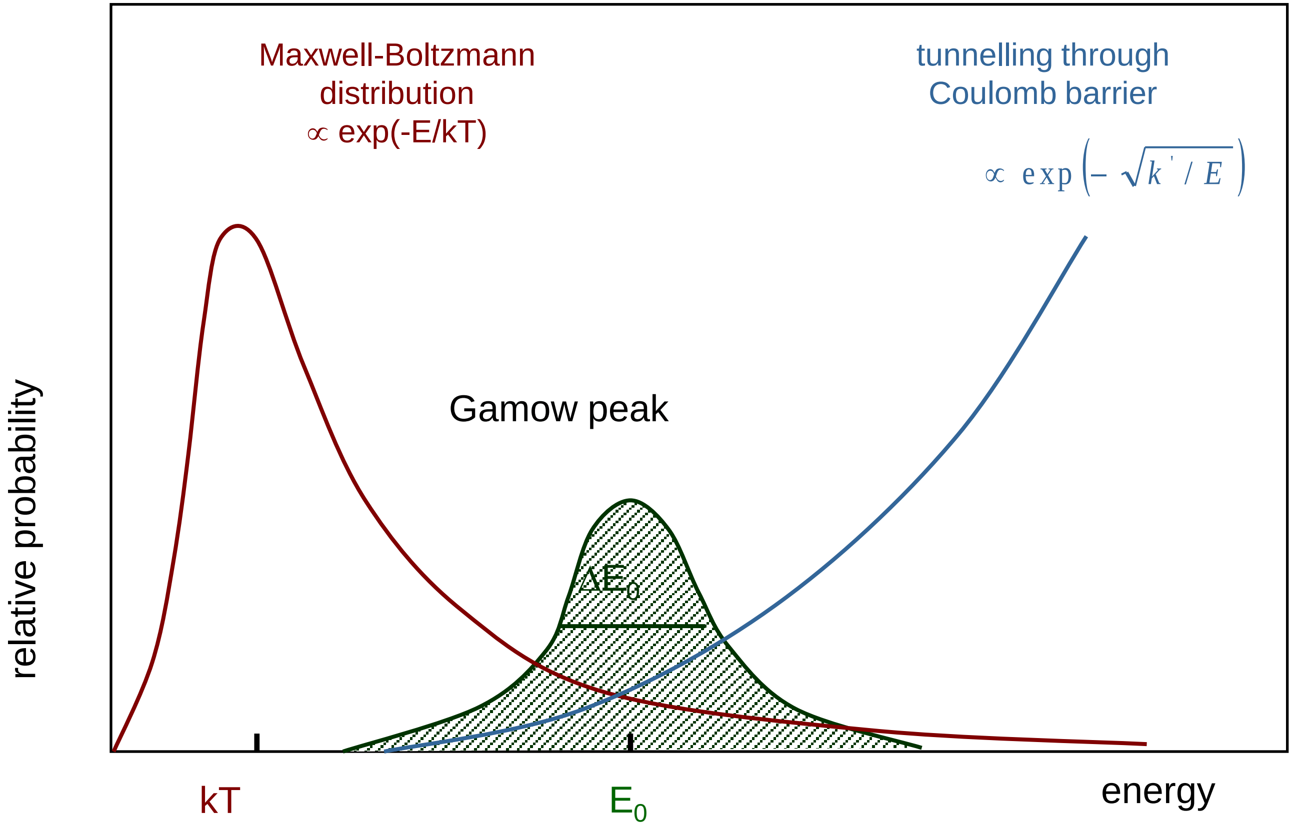


Andrew M Davis. University of Chicago

Novae Nucleosynthesis



H burning reactions at stellar energies

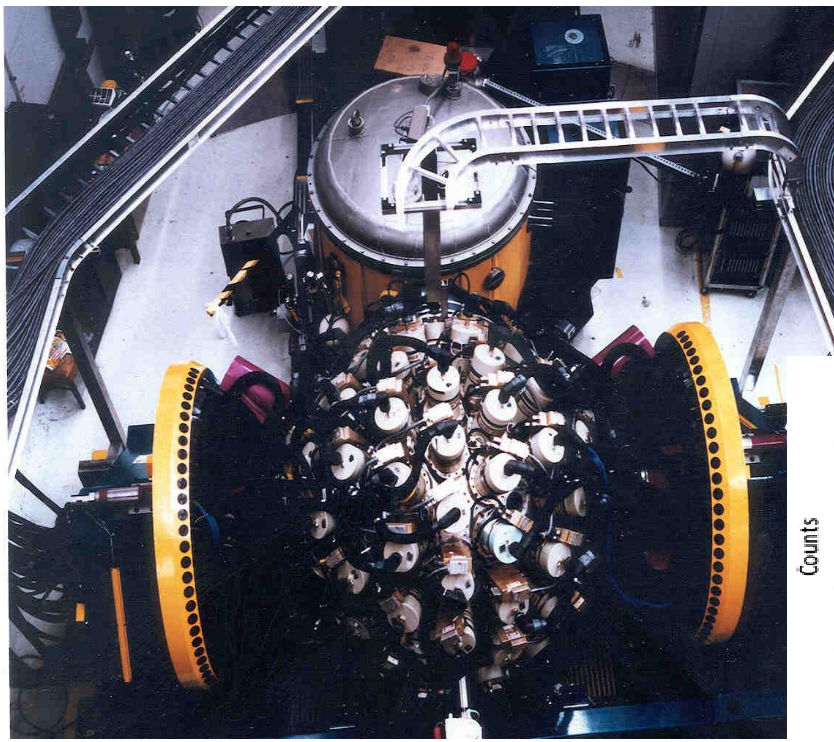


Reaction rate can be dominated by a few resonances in Gamow burning window

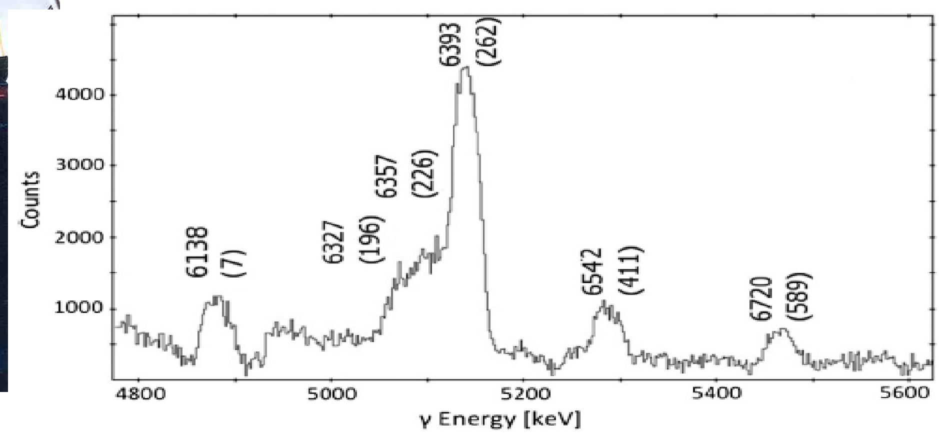
PRL **108,** 262502 (2012) PHYSICAL REVIEW LETTERS week ending 29 JUNE 2012

Key Resonances in the $^{30}P(p, \gamma)^{31}S$ Gateway Reaction for the Production of Heavy Elements in ONe Novae

D. T. Doherty,[1] G. Lotay,[1] P. J. Woods,[1] D. Seweryniak,[2] M. P. Carpenter,[2] C. J. Chiara,[2,3] H. M. David,[1] R. V. F. Janssens,[2] L. Trache,[4] and S. Zhu[2]



Identified using
$^{4}He + ^{28}Si \rightarrow ^{31}S + n$ reaction
with Gammasphere Ge-array

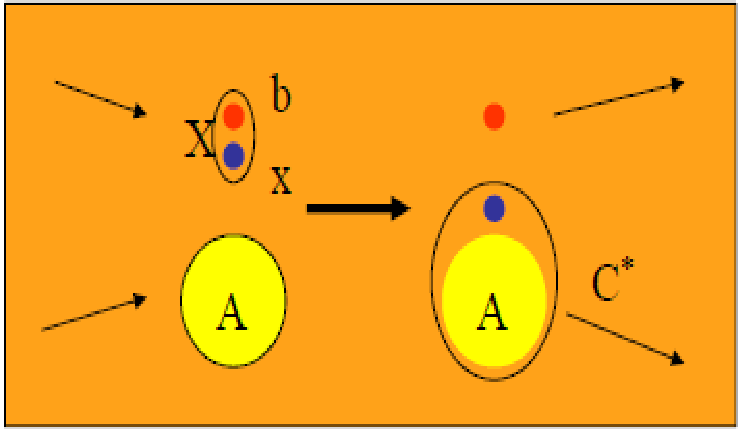


However, key resonance strengths, ω_{γ}, unknown

$$\omega\gamma = \frac{2J_R + 1}{(2J_1 + 1)(2J_2 + 1)} \frac{\Gamma_p \Gamma_\gamma}{\Gamma_{tot}}$$

use transfer reactions to estimate Γ_p for (p,γ) reactions where resonance has $\Gamma_p \ll \Gamma_\gamma$, ω_γ is proportional to Γ_{p}.

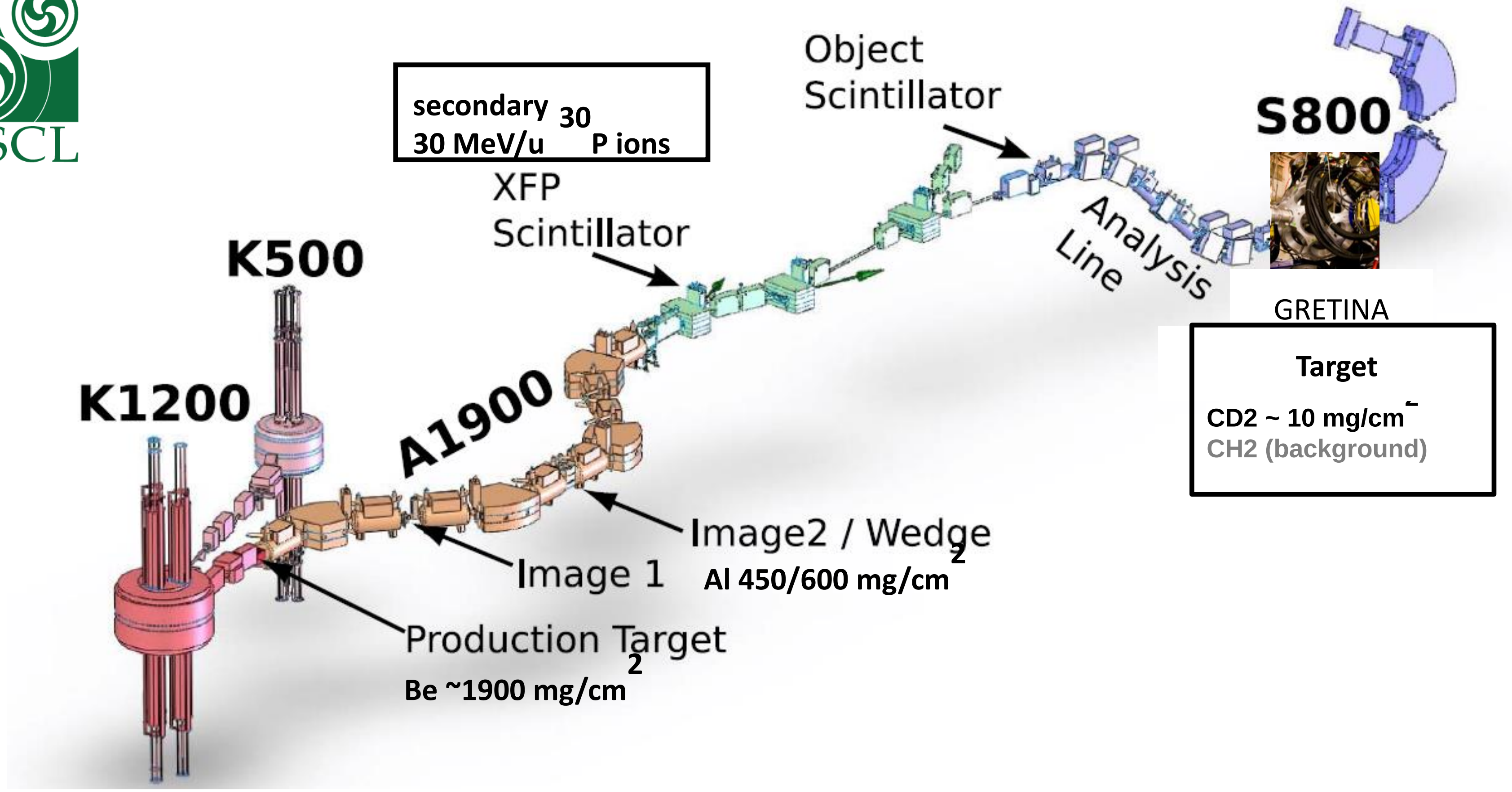
$\Gamma_p \propto P_l$ (barrier penetration factor) X S(spectroscopic factor)



$\sigma_{transfer} = \sigma_{DWBA} \times S$

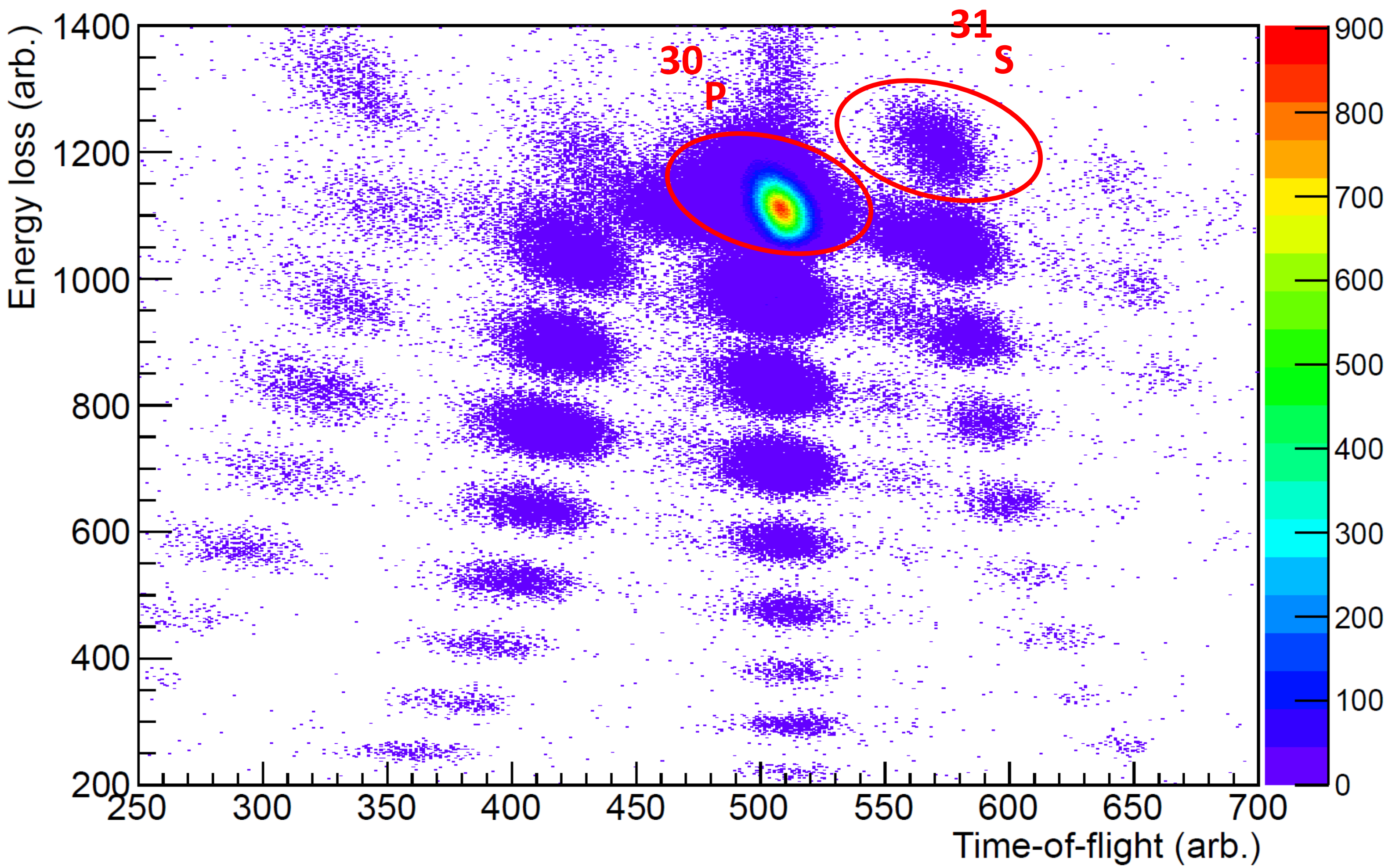
P.J. Woods, A Kankainen, H. Schatz, et al.

(d,n) transfer reaction cross-section measurements as a surrogate for (p,γ)

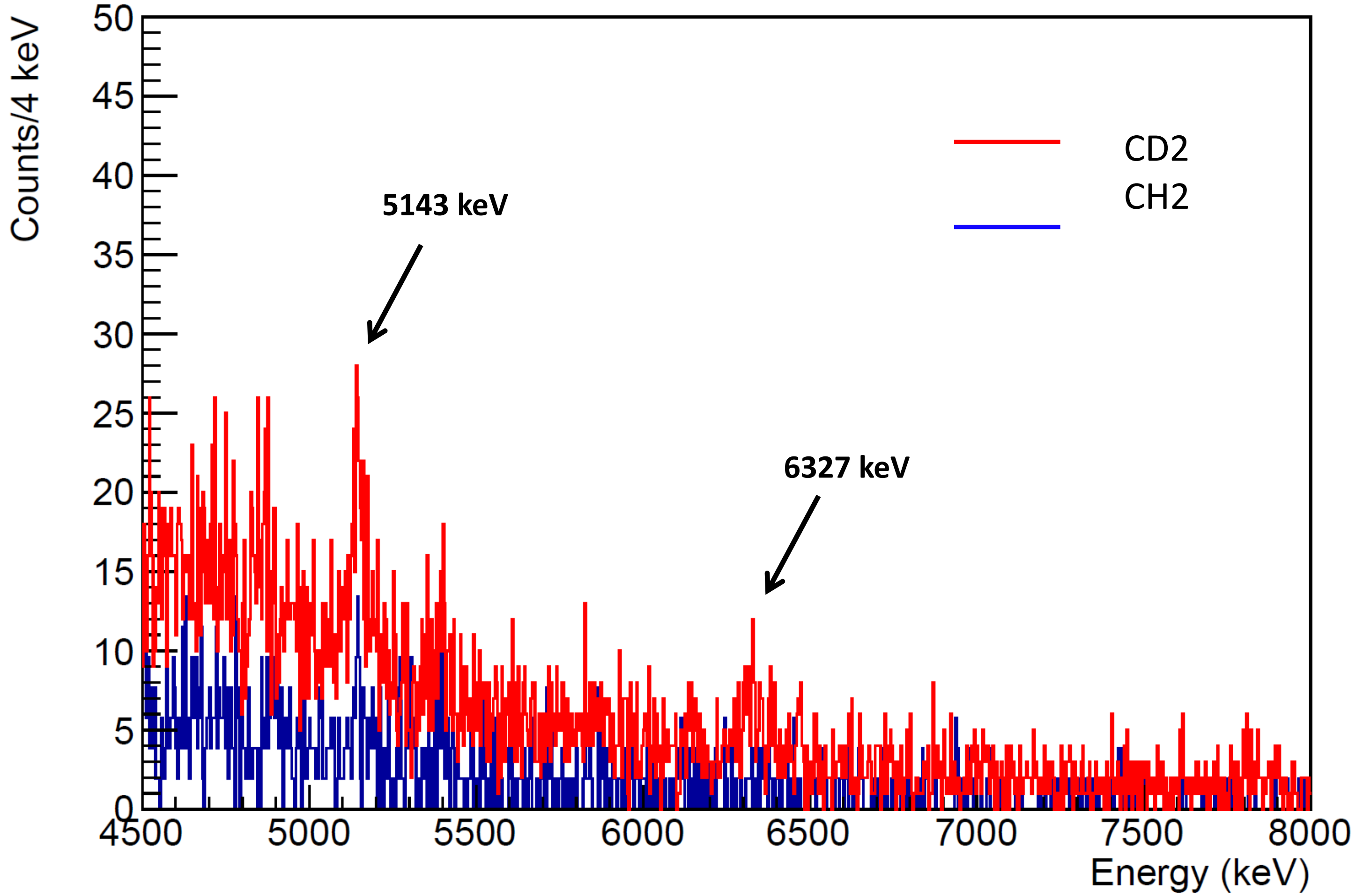


Primary beam: 150 MeV/u $^{36}Ar^{18+}$

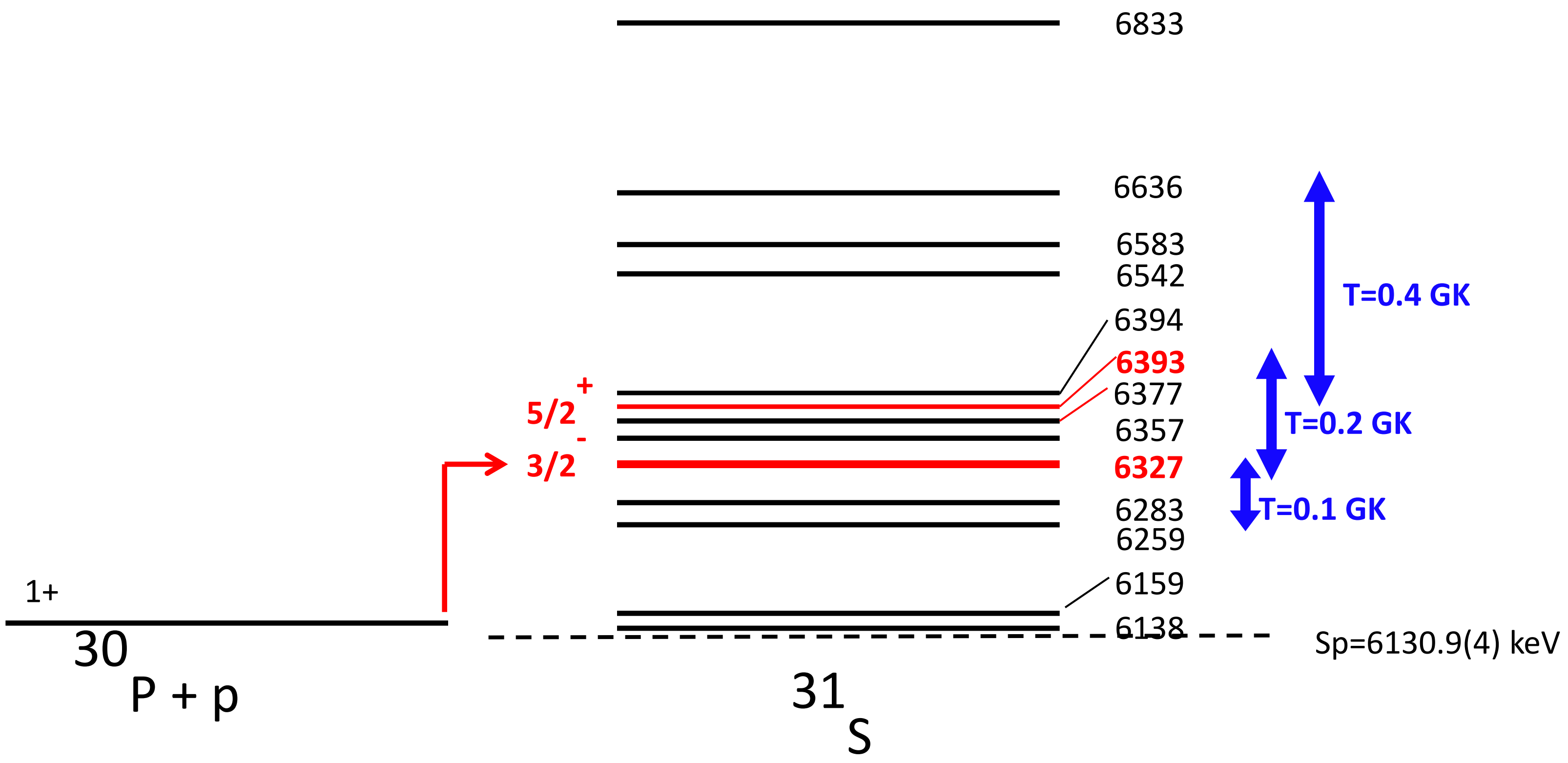
Particle identification: ^{31}S



^{31}S γ-ray energy spectrum



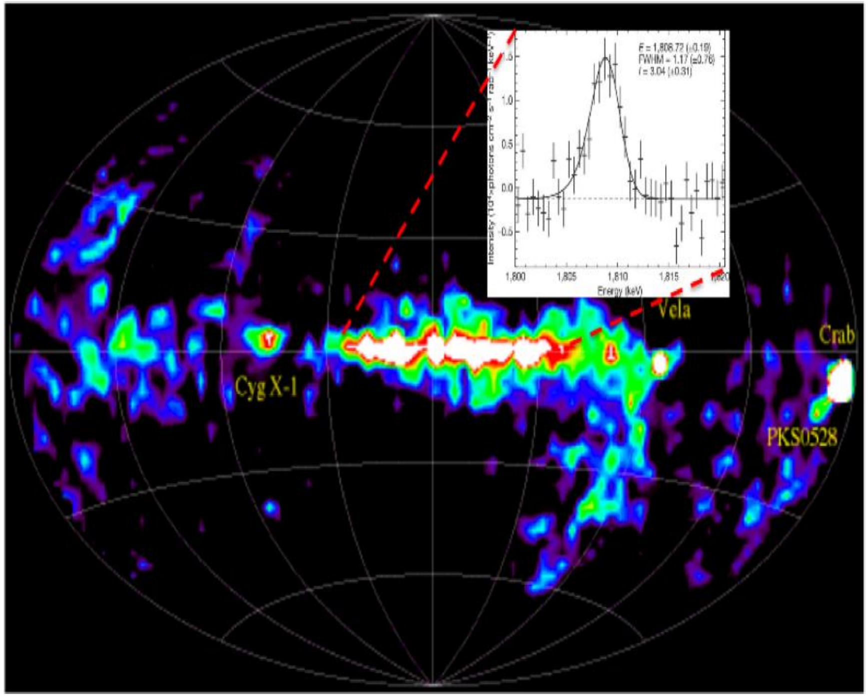
Levels above the proton threshold energy in ^{31}S

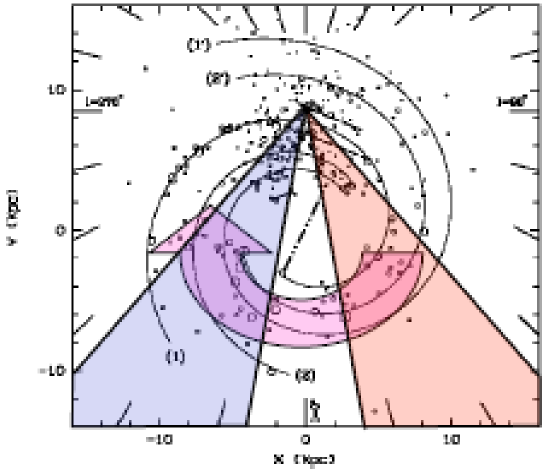


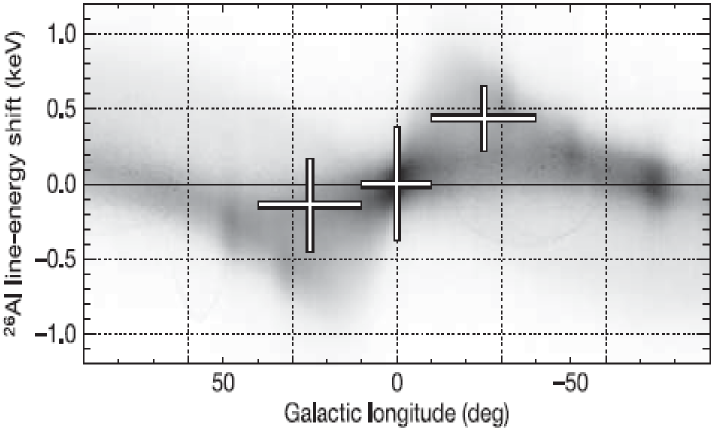
Extracted Γ_p values from cross-section indicate reaction rate is entirely dominated by a single strong –ve parity resonance at 196 keV

Galactic abundance distribution of the cosmic γ-ray emitter ^{26}Al

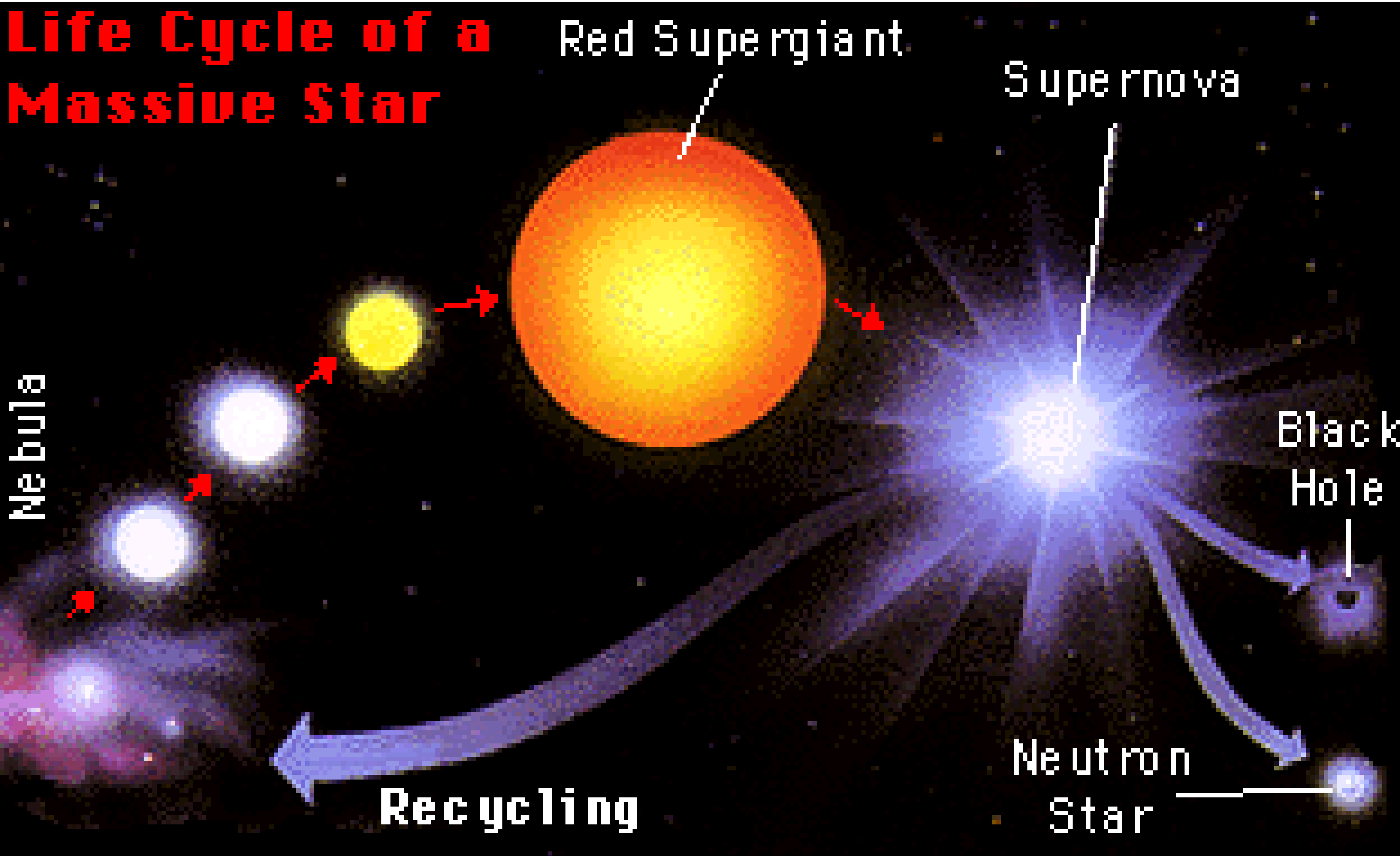
INTEGRAL satellite telescope - 2.8(8) M_{sun} of ^{26}Al in our galaxy
[R. Diehl, *Nature* ***439*** *45(2006)*]



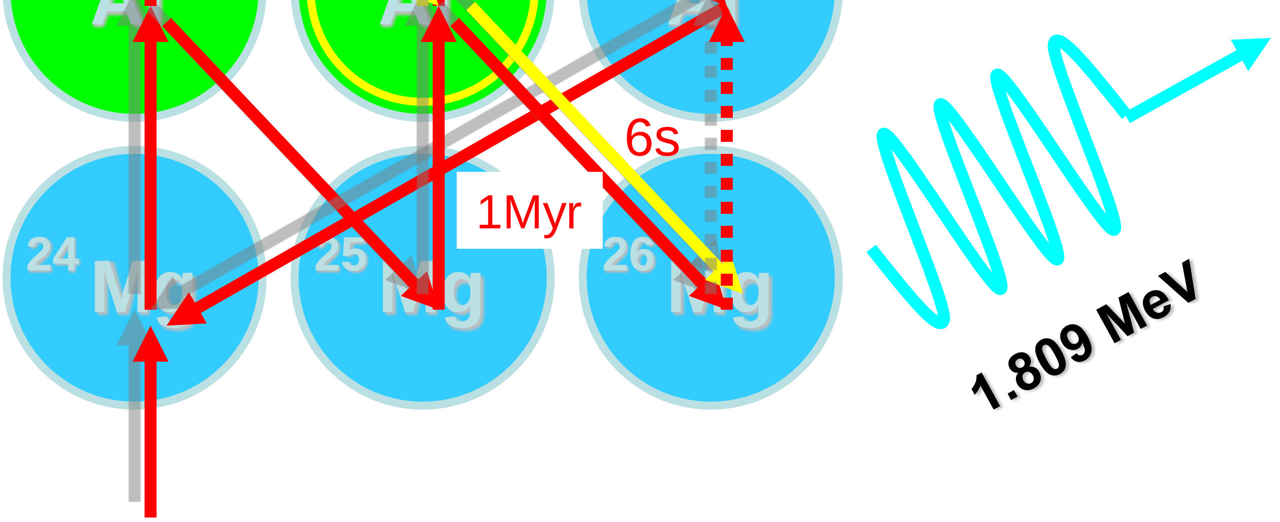


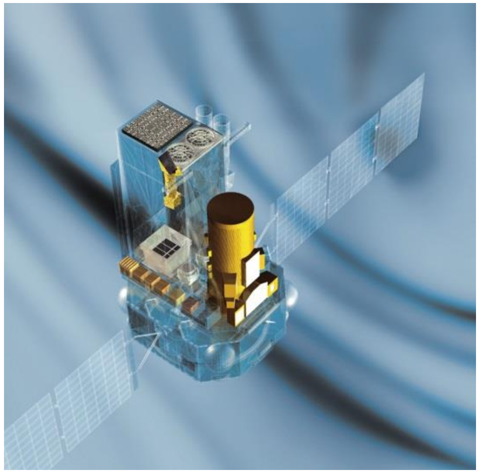


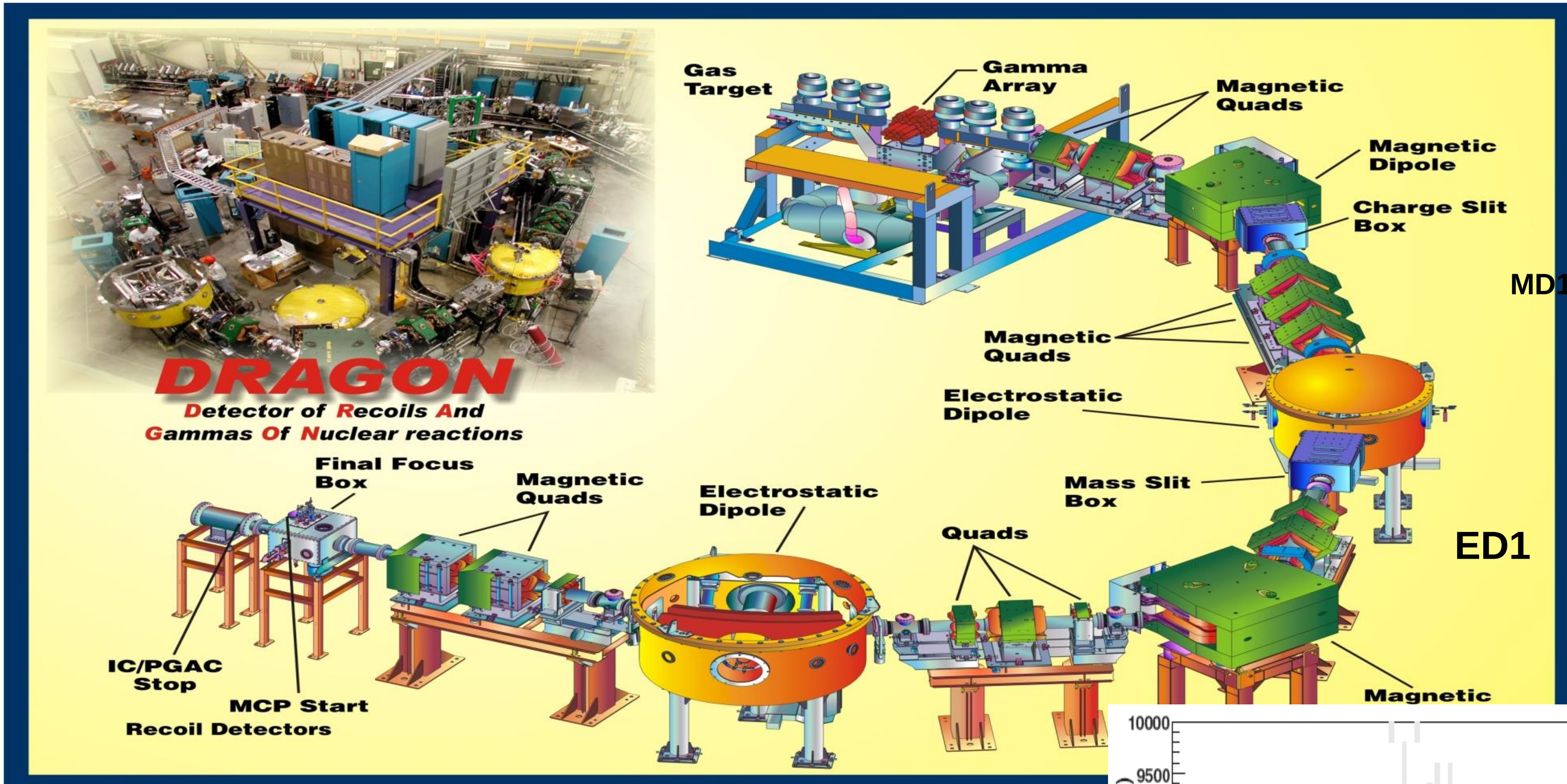
Supernova Cycle



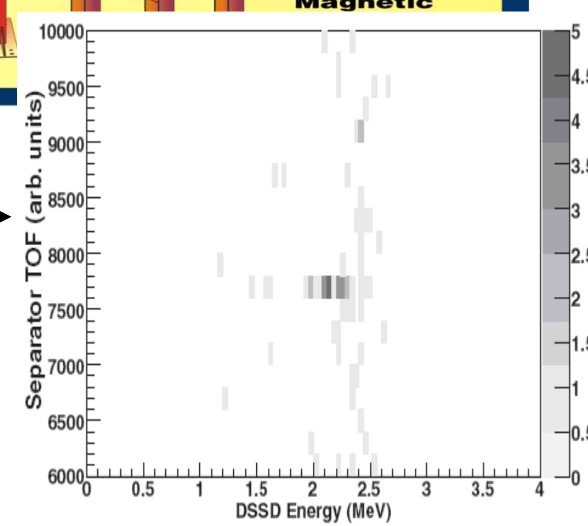
Hydrogen burning in Mg – Al Cycle







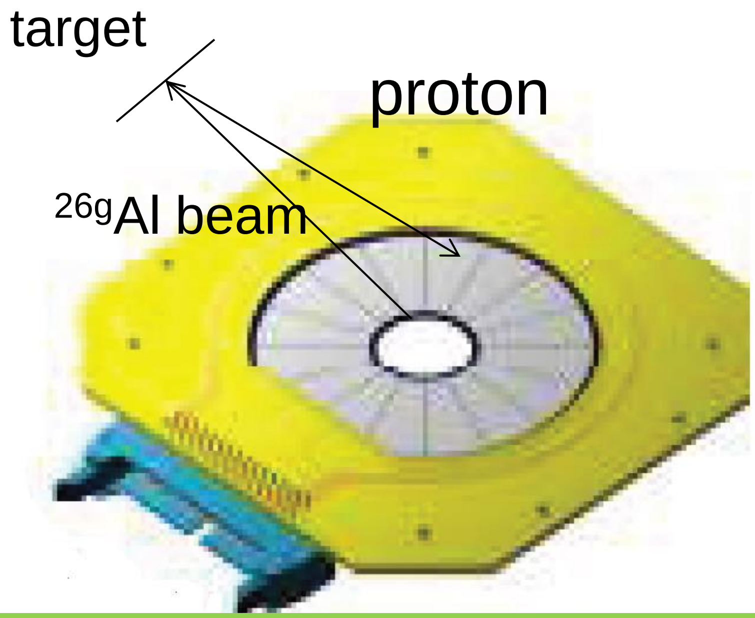
Direct measurement of $^{26g}Al(p,\gamma)^{27}Si$ reaction on 189 keV resonance, PRL 96 252501(2006)



→ lower energy resonances may dominate destruction of ^{26}Al burning in massive stars?

High resolution d(^{26g}Al,p)^{27}Al study of analog states of ^{27}Si resonances using Edinburgh TUDA Si array @ ISAC II Triumf

150 MeV ^{26g}Al beam bombarding 50 μg.cm^{-2} $(CD_2)_n$ target
I_{beam}~ 5*10^8 pps

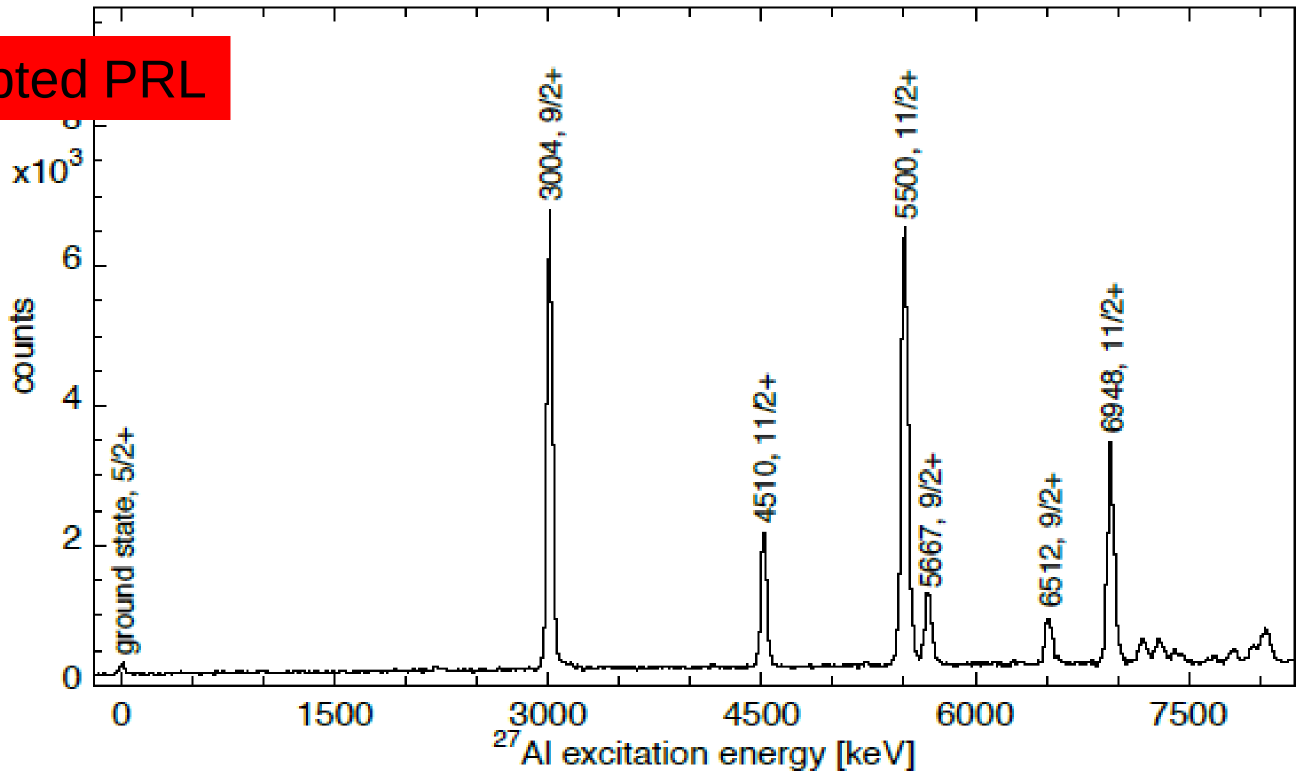


Silicon detectors placed at backward angles, corresponding to forward angle transfer in CoM

Destruction of the cosmic γ-ray emitting nucleus ^{26}Al in Wolf-Rayet and AGB Stars

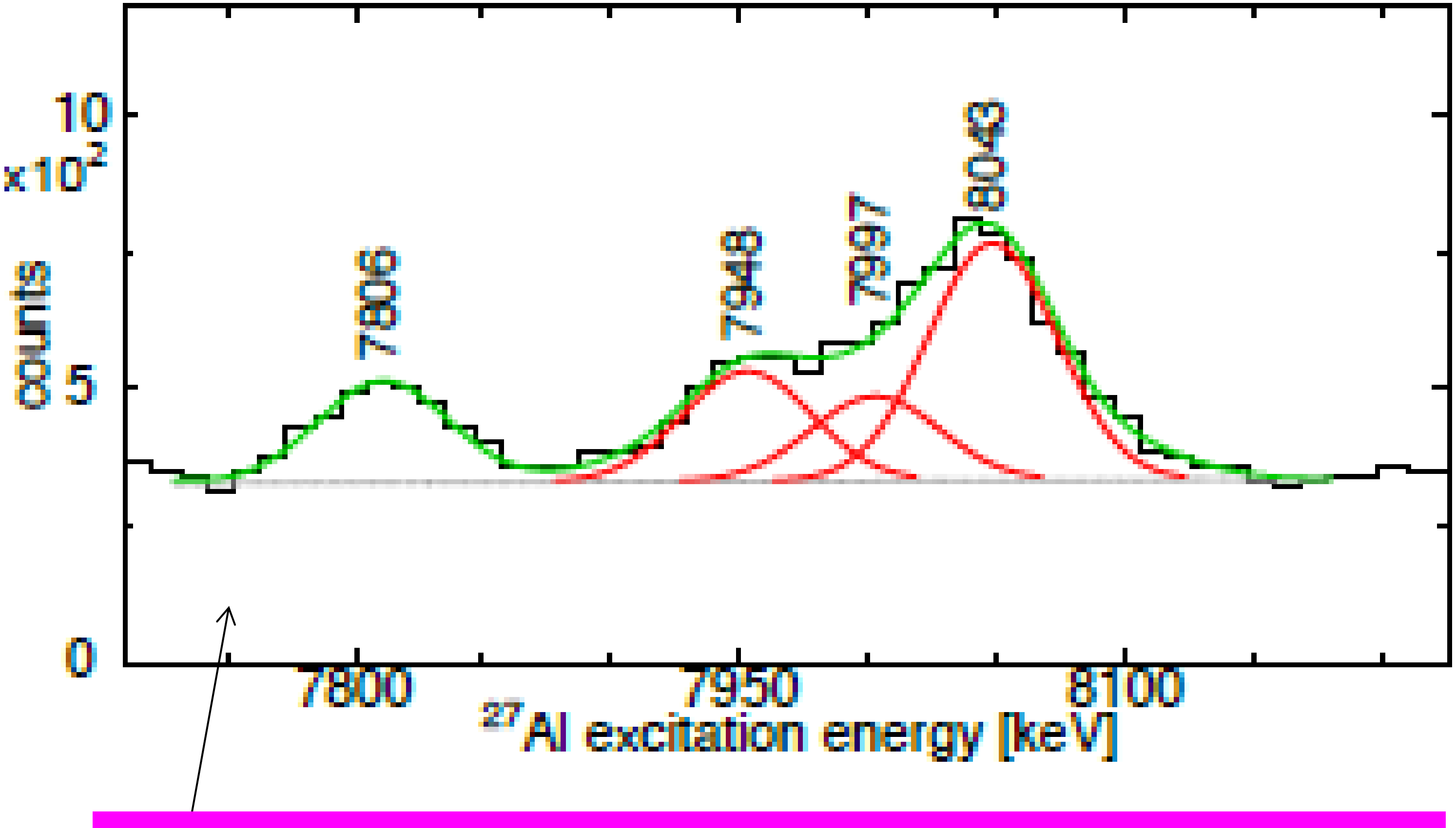
V. Margerin,[1] G. Lotay,[1,2,3,*] P.J. Woods,[1] M. Aliotta,[1] G. Christian,[4] B. Davids,[4] T. Davinson,[1] D.T. Doherty,[1,†] J. Fallis,[4] D. Howell,[4] O. Kirsebom,[4] A. Rojas,[4] C. Ruiz,[4] N.K. Timofeyuk,[2] and J.A. Tostevin[2]

Accepted PRL

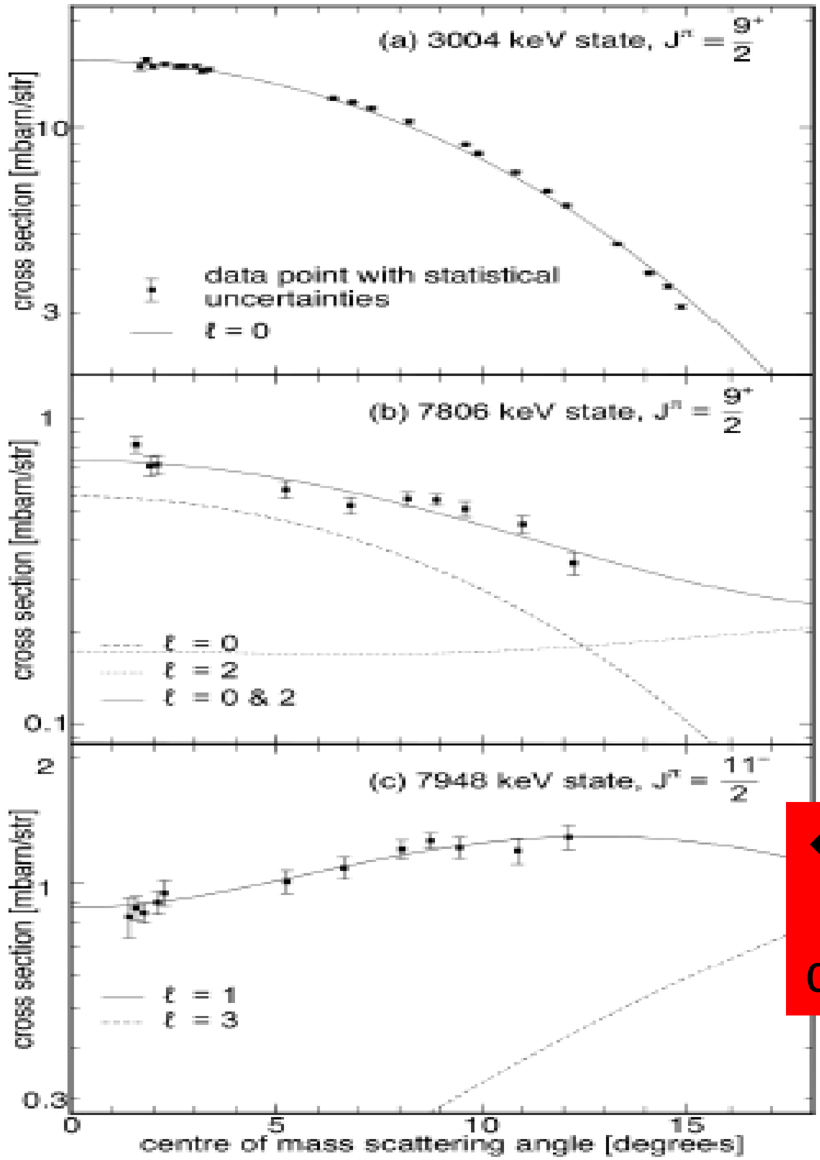


Energy Resolution in lab frame ~ 40 keV (FWHM)

Analogue states to key astrophysical resonances

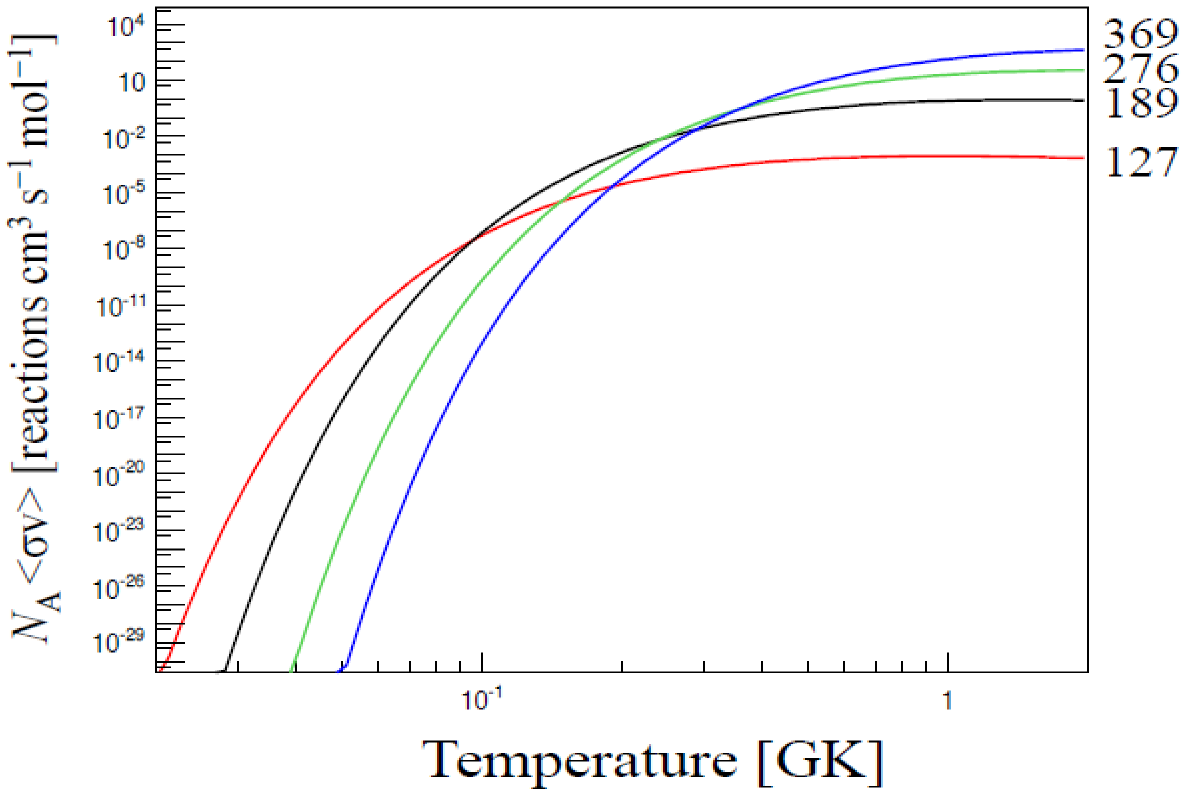


Continuous background due to protons from fusion
reactions with Carbon atoms in target



← Strong single particle –ve parity state dominates destruction in novae

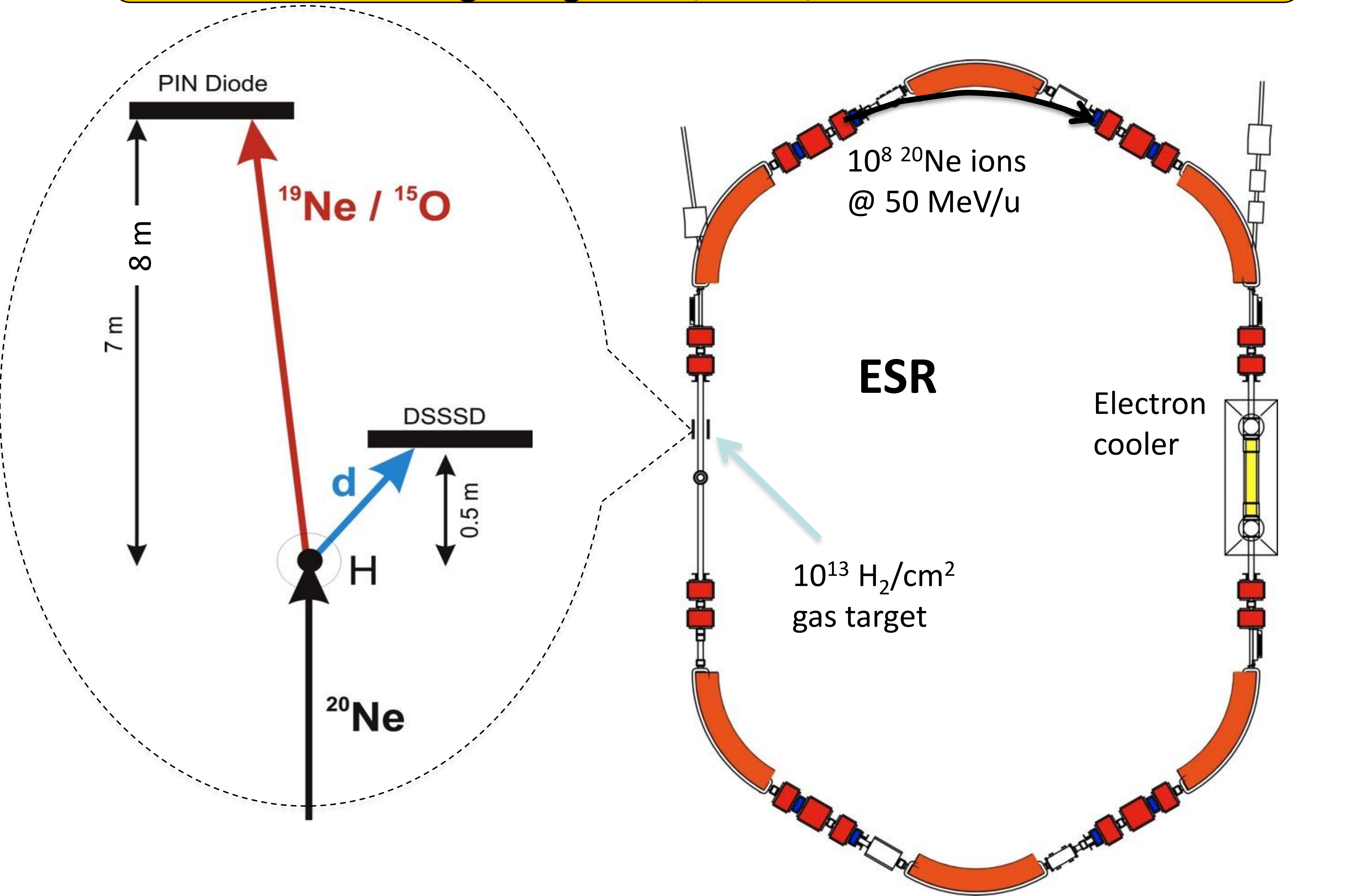
$^{26}Al(p,\gamma)^{27}Si$ reaction rate



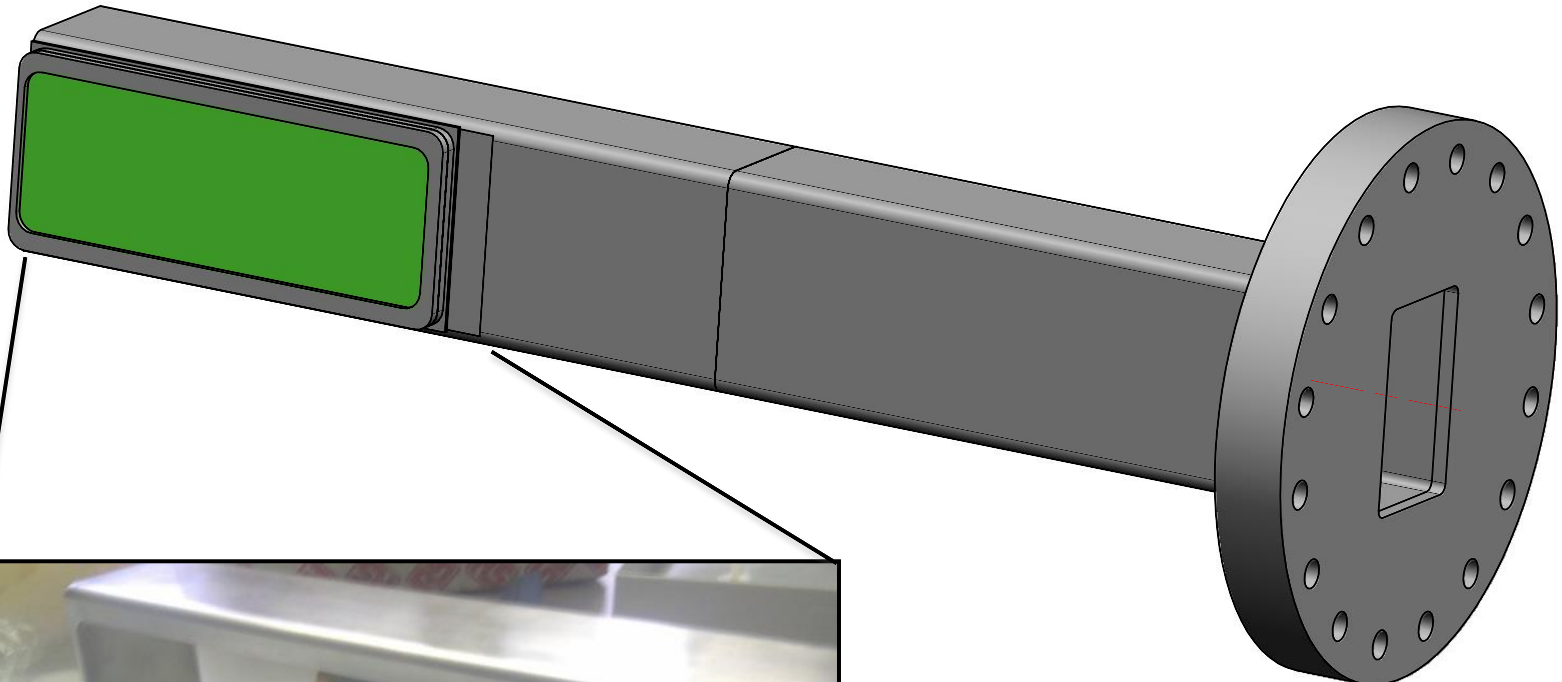
→ Conclude 9/2$^+$ 127 keV resonance in ^{27}Si dominates burning of ^{26}Al in Wolf Rayet and AGB stellar environments ~ 0.3- 0.8 .10^8 K

See also independent study by Pain et al. PRL 114,212501 (2015)

Study of the p(^{20}Ne,^{2}H)^{19}Ne transfer reaction on the ESR heavy ion storage ring @GSI, PJW, Y Litvinov et al.

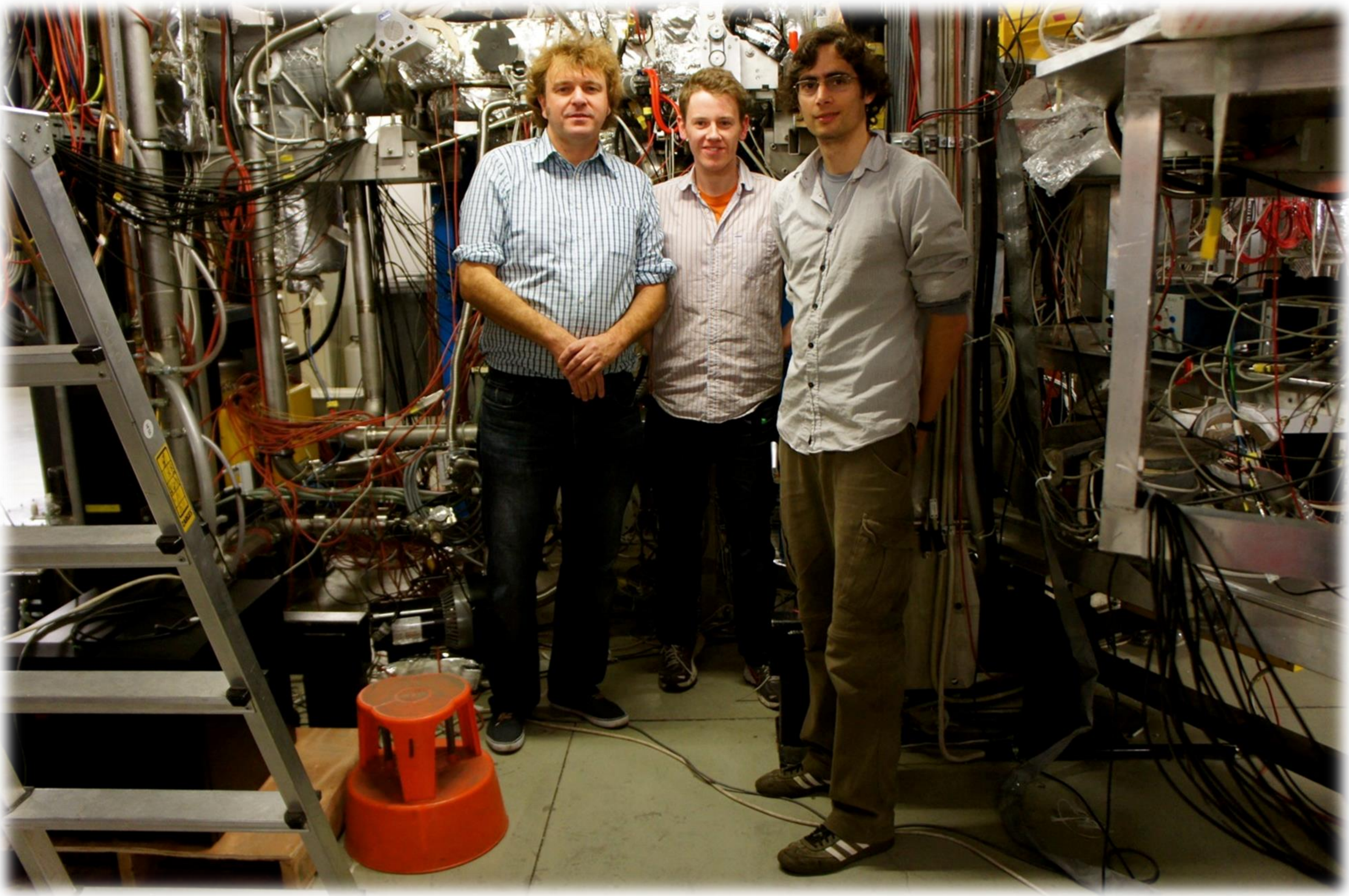


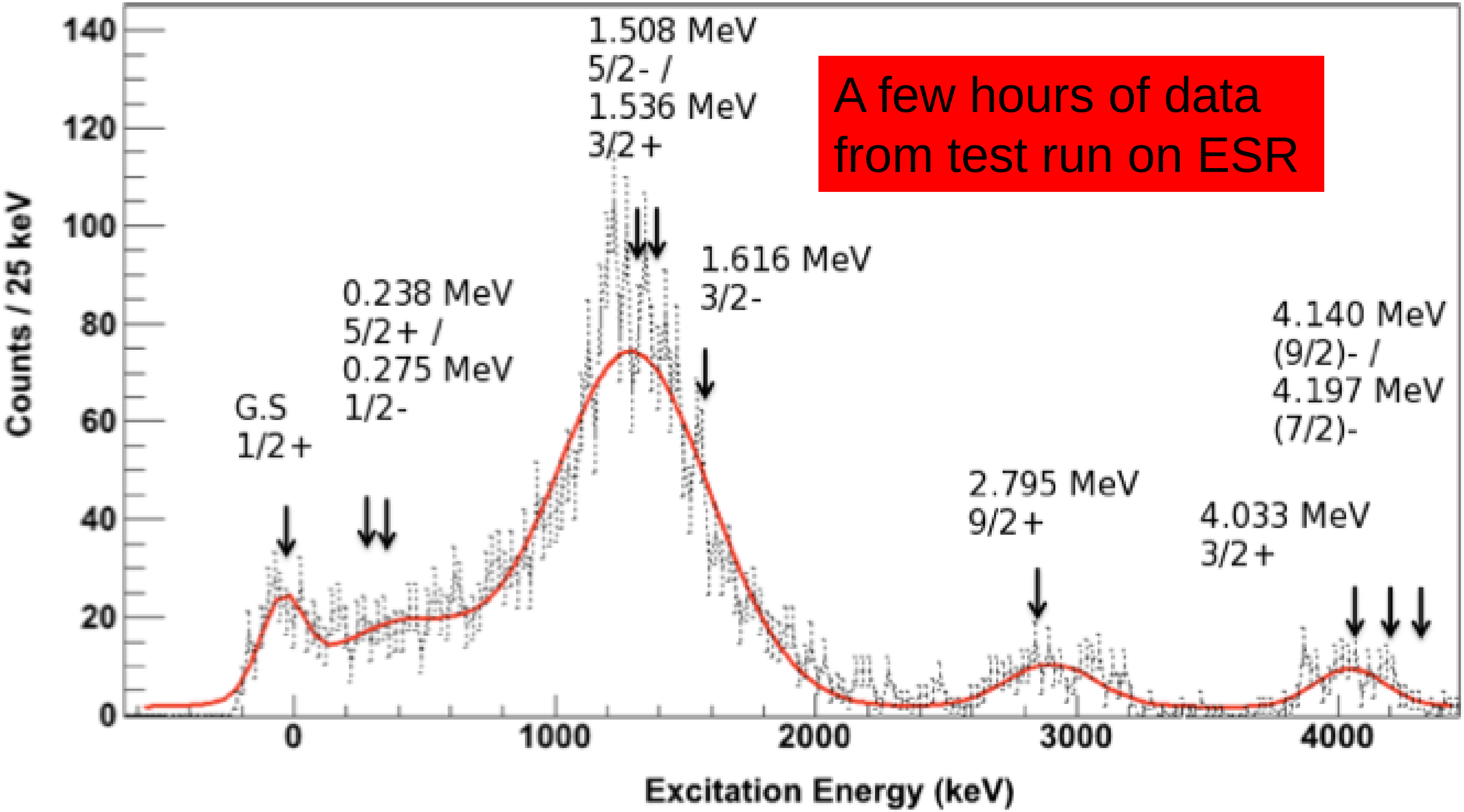
Detector Pocket



Si –telescope

- 2 x ~1mm ‘W’-type detectors
- 16x16 strips





A few hours of data from test run on ESR

DT Doherty, PhD Thesis (2014)

TSR@ISOLDE – Injection of RIBs into ring at MeV/u energies

Spokesperson: K Blaum (Heidelberg)

Deputies: R Raabe(Leuven), PJW (Edinburgh)

Physics Co-ordinator P Butler (Liverpool, our man at CERN)

entire issue of EPJ 207 1-117 (2012)

In-ring DSSD System for ultra-high resolution (d,p), (p,d) and (^{3}He,d) transfer studies of astrophysical resonances
→ Newly funded UK ISOL-SRS project (Spokesperson PJW)

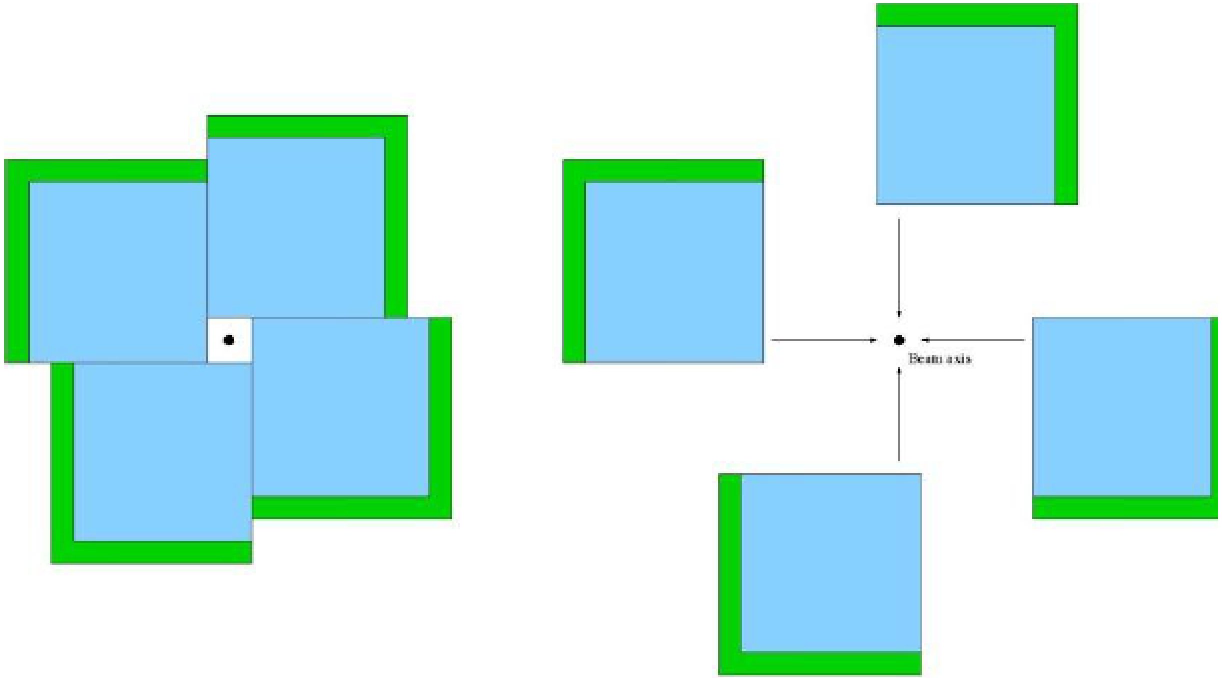
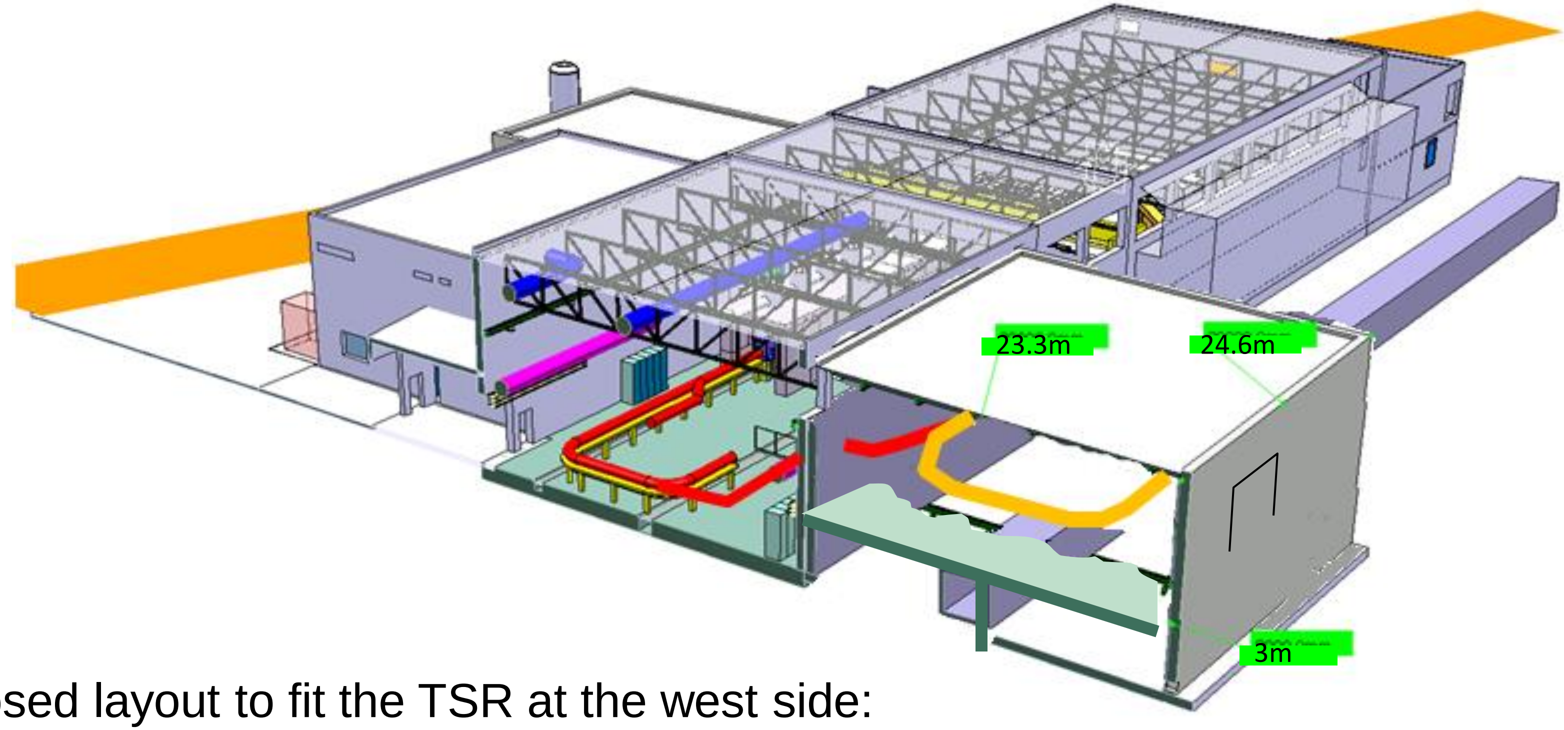


Figure 1: Illustration of upstream or downstream assembly of 4 DSSDs about beam axis

For ultra high resolution mode resolution should be entirely limited by transverse beam emittance

→ resolutions approaching 10 keV FWHM attainable

ISOLDE site
(west) side



Proposed layout to fit the TSR at the west side:

Installation above the CERN infrastructure-tunnel

CERN say they will put a ring on it……hopefully sooner rather than later!

Summary and Future

We are entering an exciting phase of development combining a variety of different experimental approaches to measuring reactions and properties relevant to our understanding of explosive astrophysical events. Storage rings will play an important role in this process.

Thanks to Peter for some fun times together, and for his untiring efforts on the TSR@ISOLDE and UK ISOL-SRS projects – we definitely could not have done this without you!!