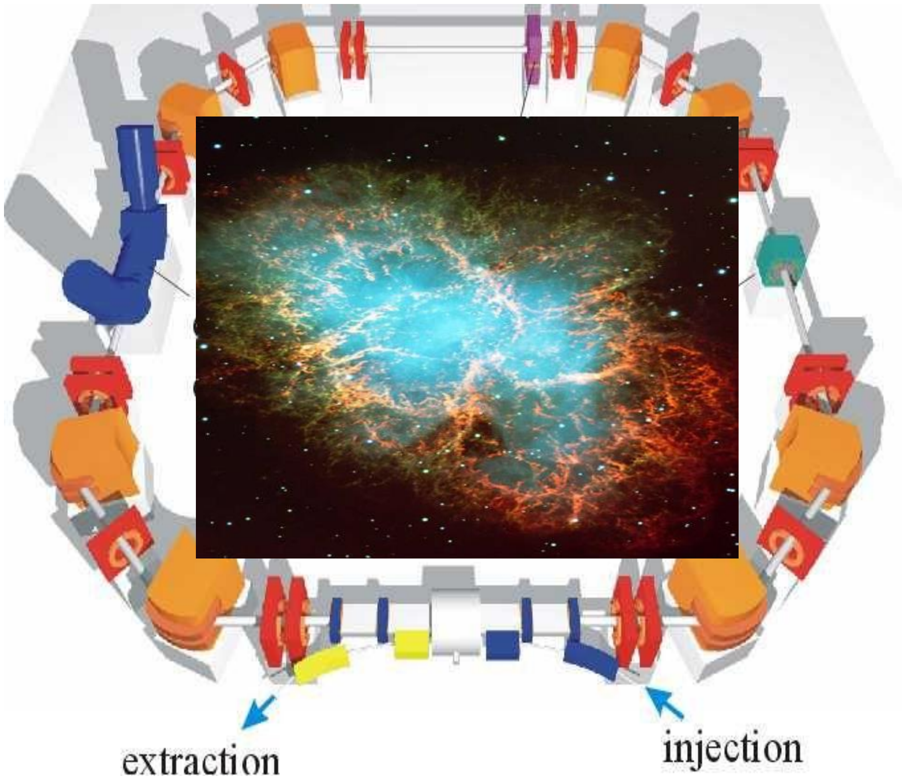
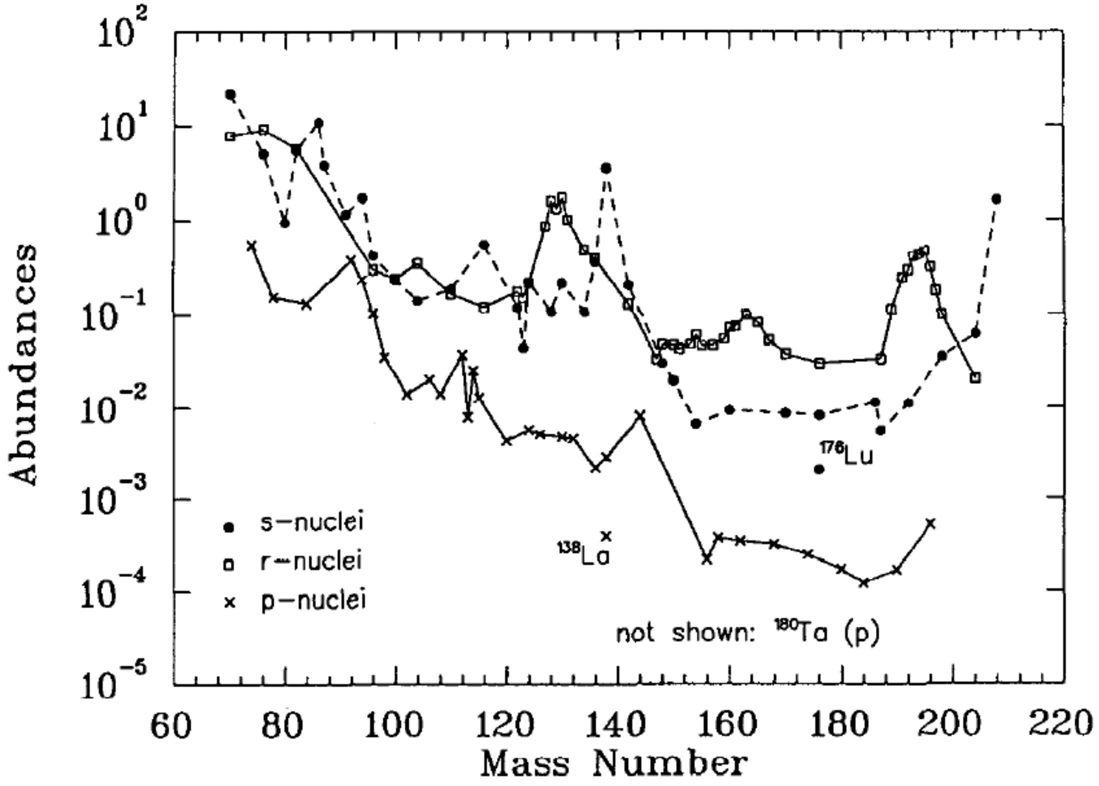
Nuclear Astrophysics in-ring and TSR plans

PJ Woods

University of Edinburgh

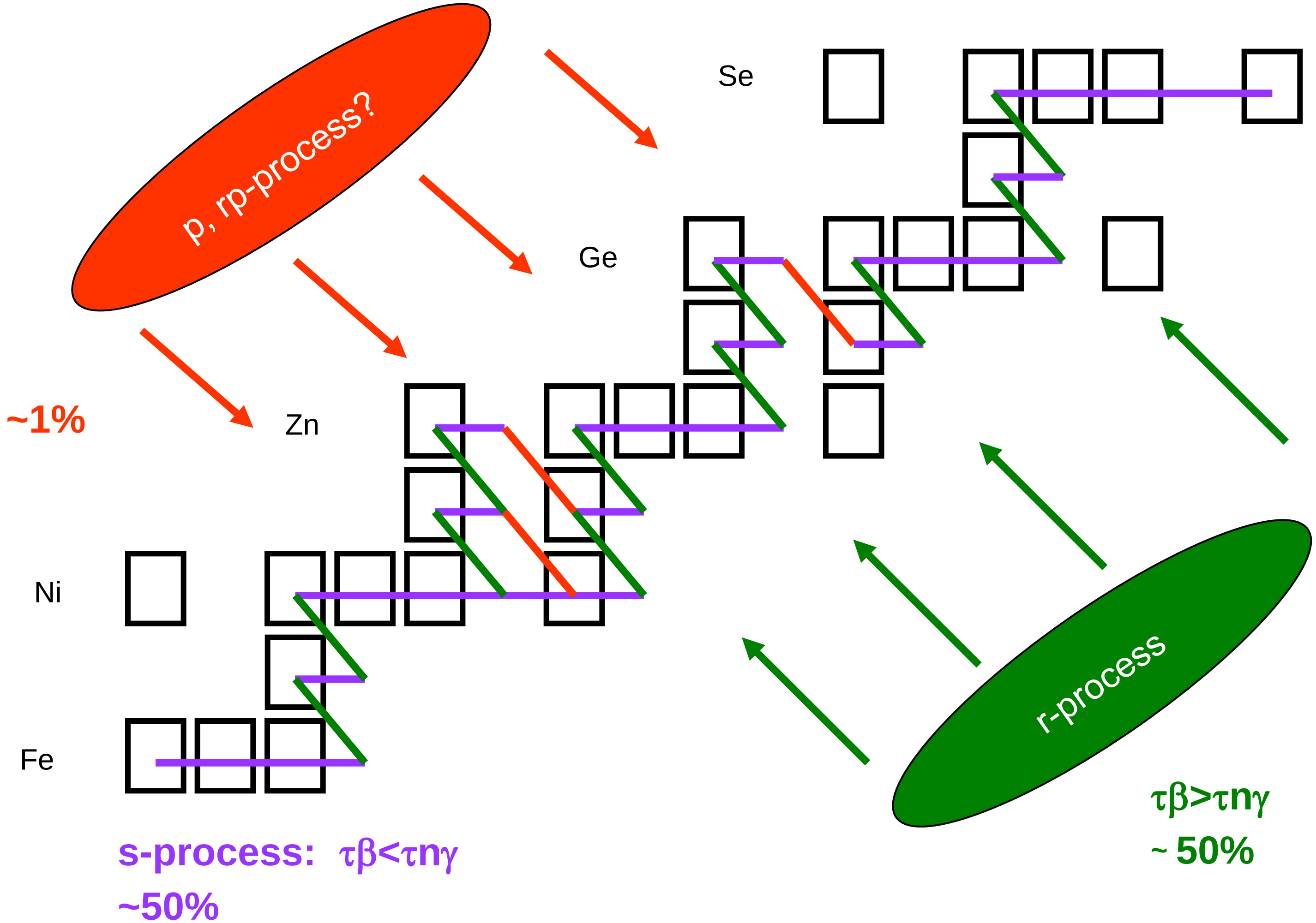


Heavy Element Abundance: Solar System

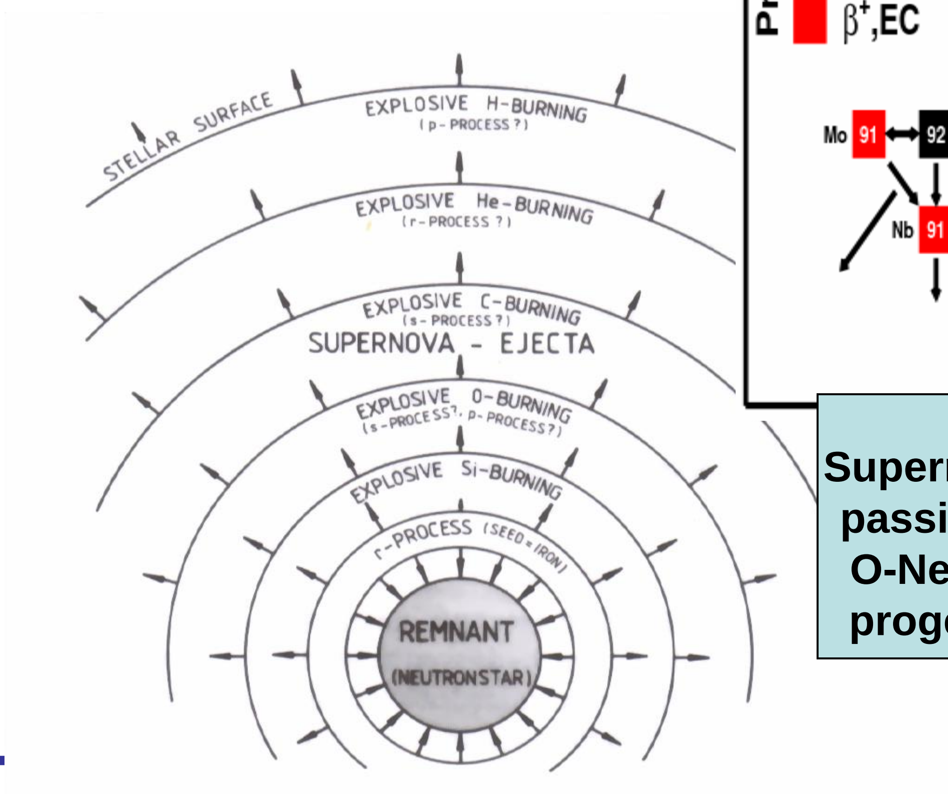


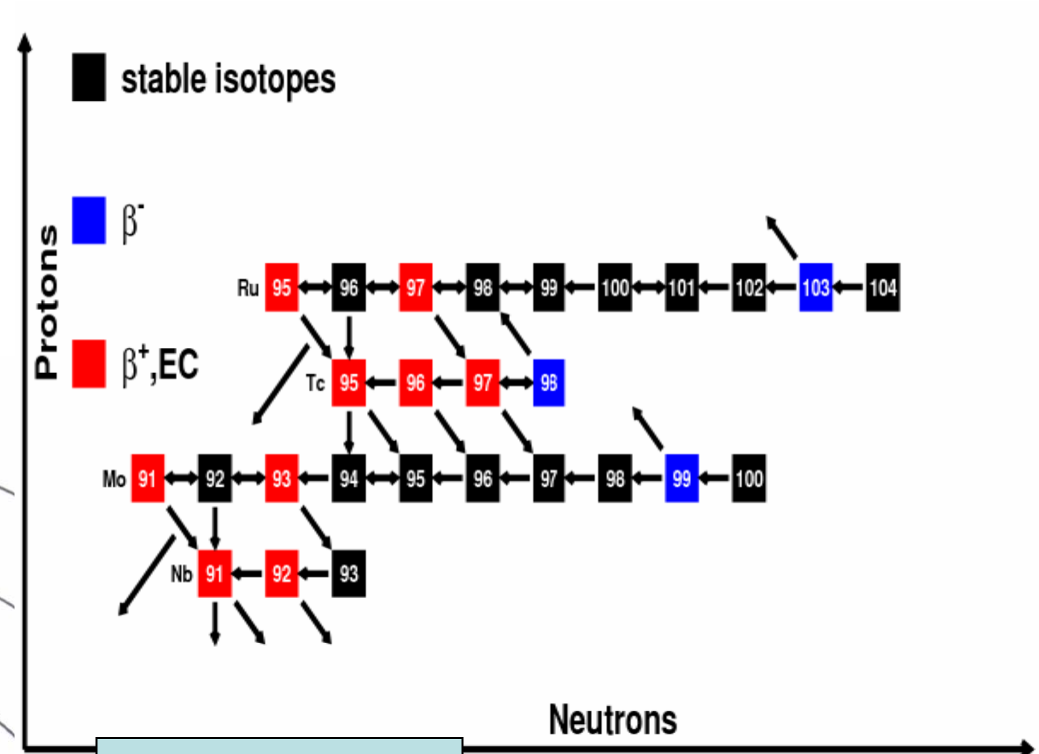
from *B.S.Meyer*, Ann. Rev. Astron. Astrophys. 32 (1994) 153

Nucleosynthesis above Fe



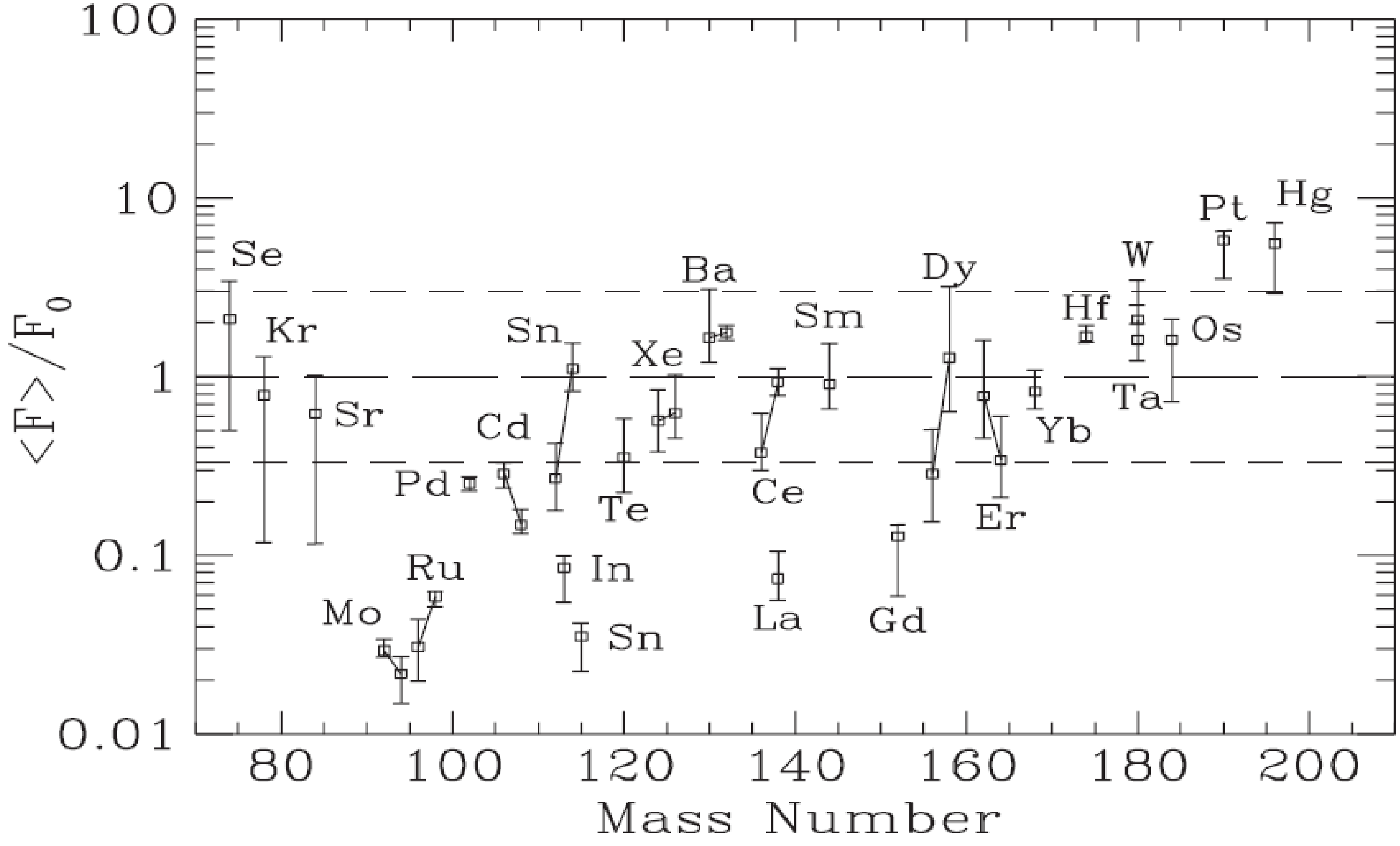
Puzzle of the origin of heavy 'p-nuclei' – abundant proton-rich isotopes eg ^{92}Mo and ^{96}Ru





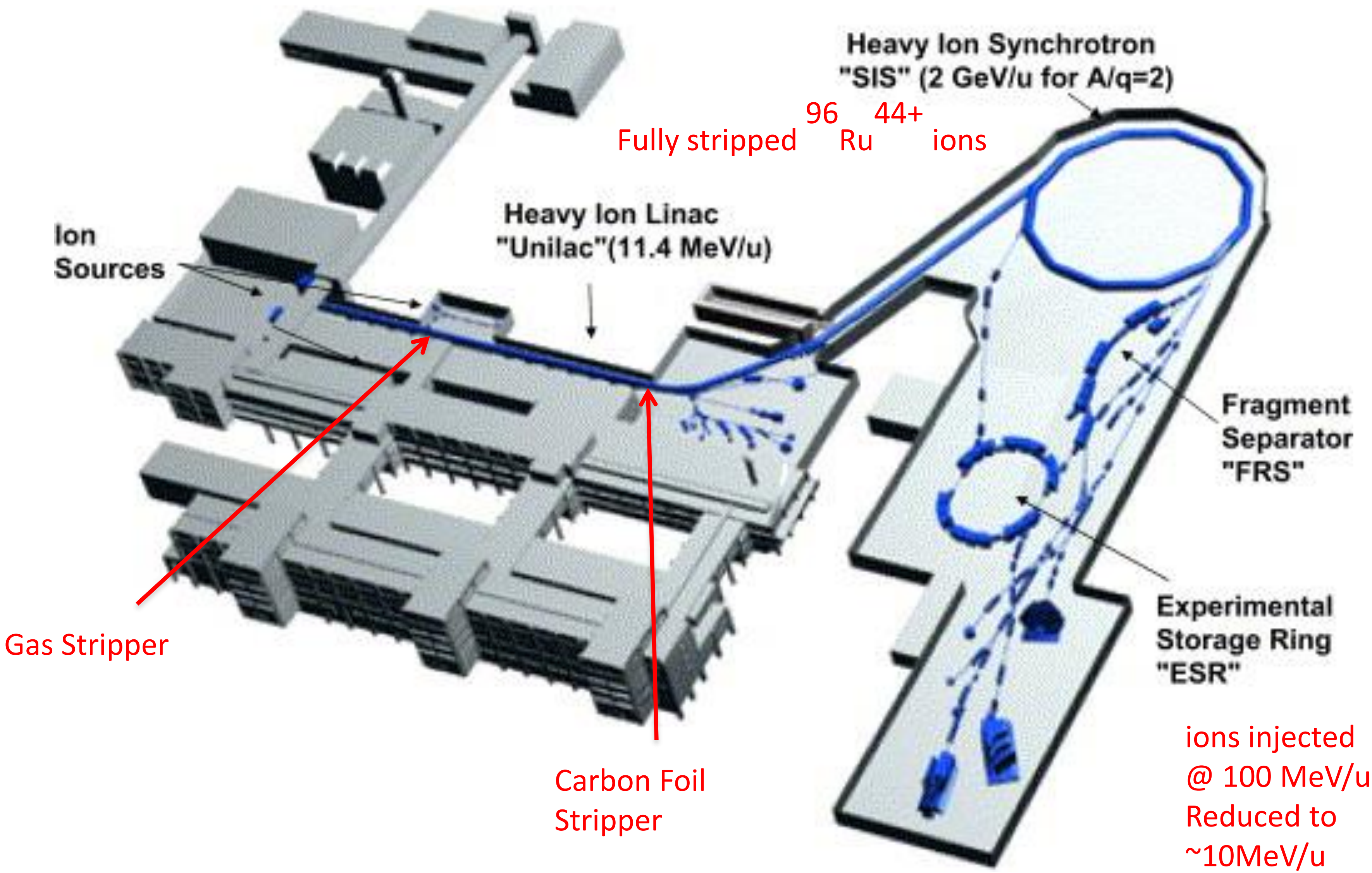
Supernova shock passing through O-Ne layers of progenitor star

Predicted p-process abundances compared to observed abundances

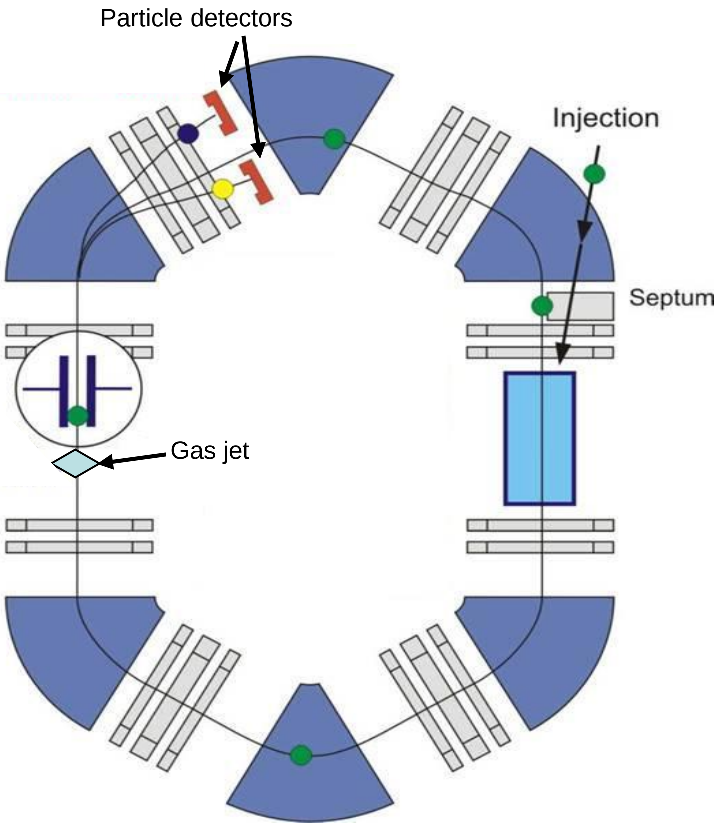


Arnould & Goriely Phys. Rep. **384**,1 (2003)

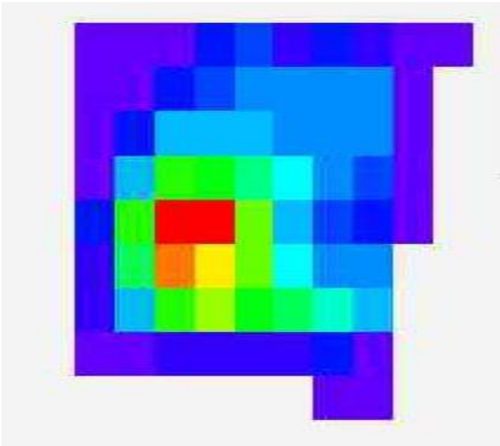
Study of ^{96}Ru(p,γ)^{97}Rh reaction with decelerated beams using the ESR storage ring at GSI



Pioneering new technique on ESR (Heil, Reifarth) – heavy recoils detected with double-sided silicon strip detector (Edinburgh)



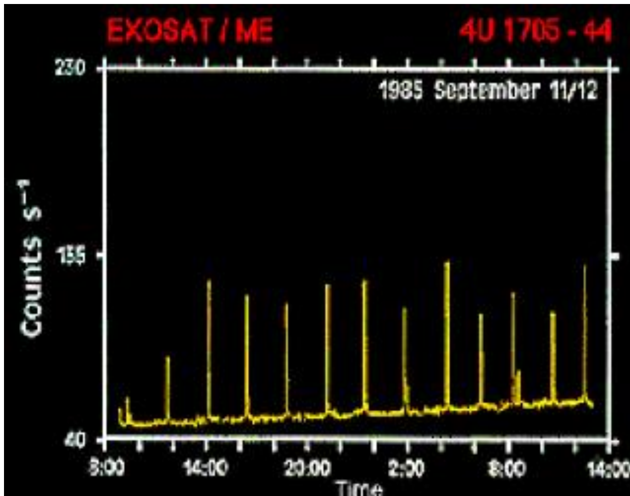
Position distribution of recoiling ions measured by DSSD

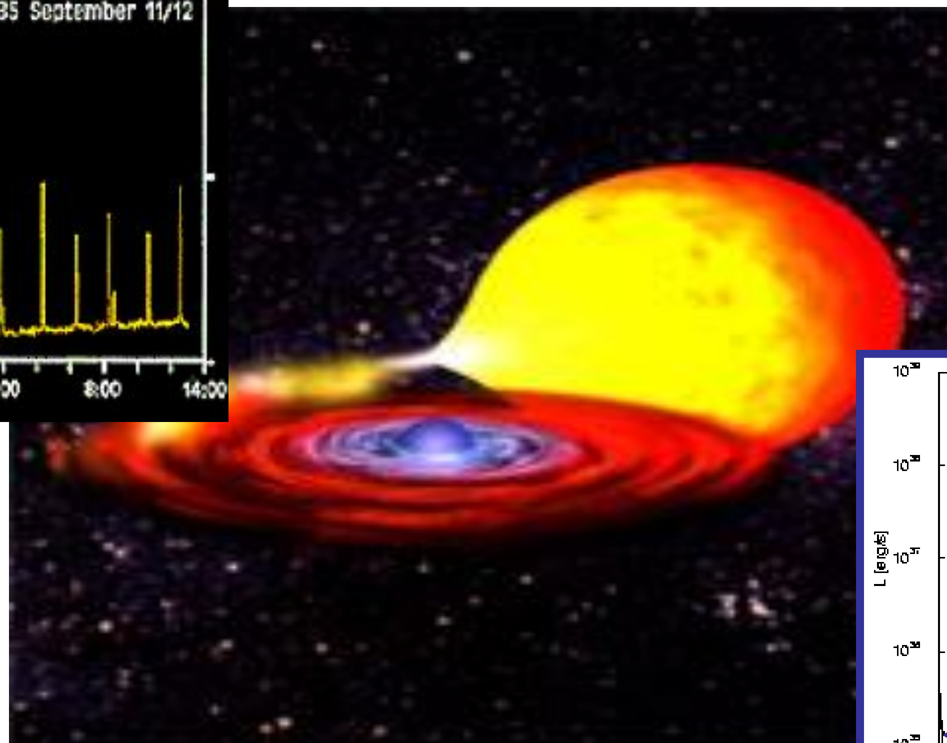


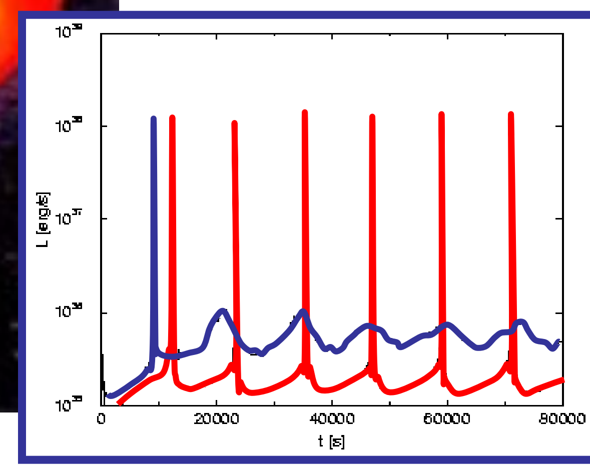
σ(p,γ)= 3.6(5) mb

New ceramic-mounted DSSD system developed (Edinburgh/GSI/Frankfurt) for use in UHV on ESR to measure p-process reactions in Gamow burning energy region will be tested in September.

The $^{15}O(\alpha,\gamma)^{19}Ne$ reaction: the nuclear trigger of X-ray bursts

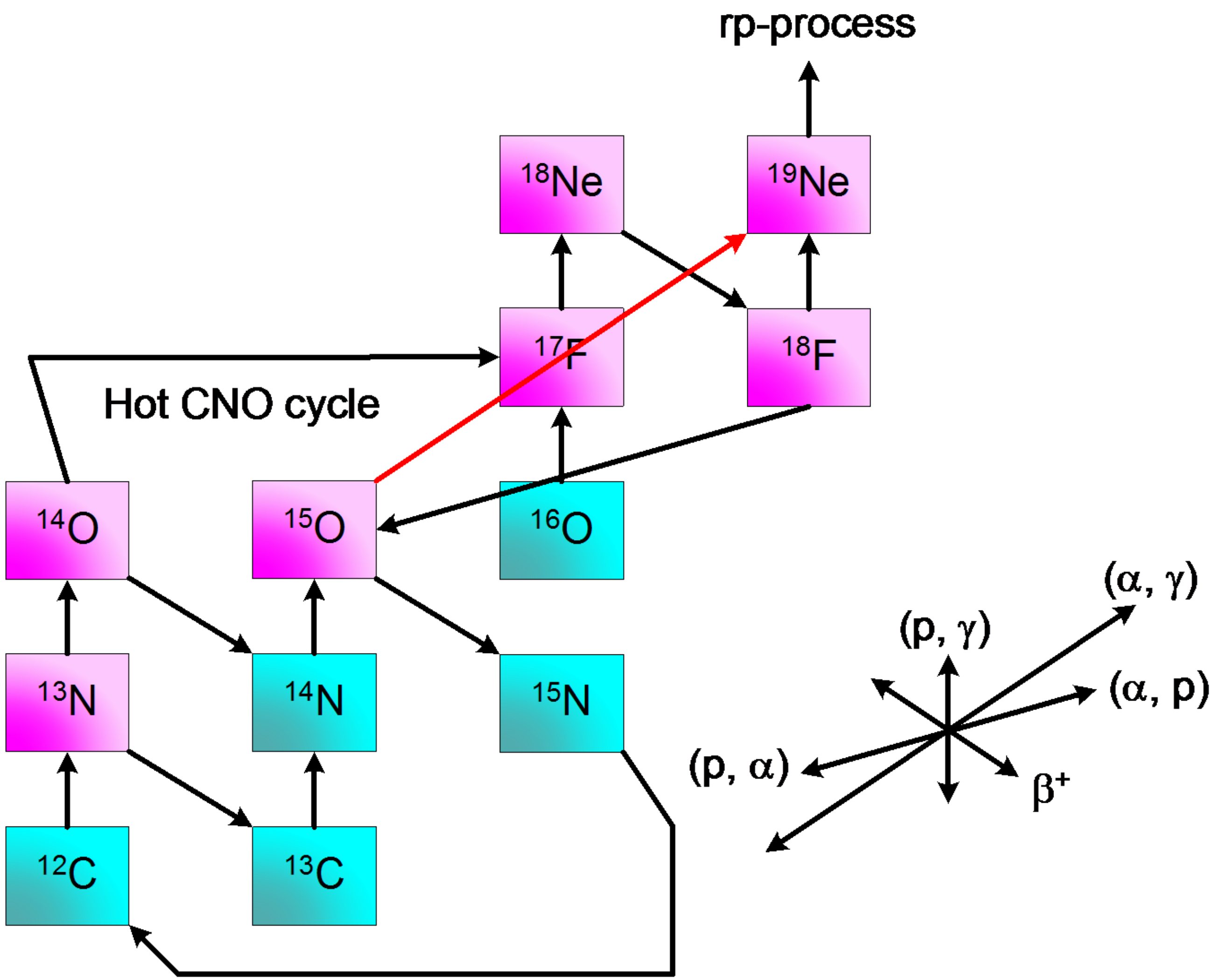






Reaction regulates flow between the hot CNO cycles and rp process
→ critical for explanation of amplitude and periodicity of bursts

The Hot CNO Cycles



THE ASTROPHYSICAL JOURNAL, **301**:629–633, 1986 February 15

A NEW ESTIMATE OF THE $^{19}Ne(p, \gamma)^{20}Na$ AND $^{15}O(\alpha, \gamma)^{19}Ne$ REACTION RATES AT STELLAR ENERGIES

K. LANGANKE,[1] M. WIESCHER,[2] AND W. A. FOWLER
W. K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena

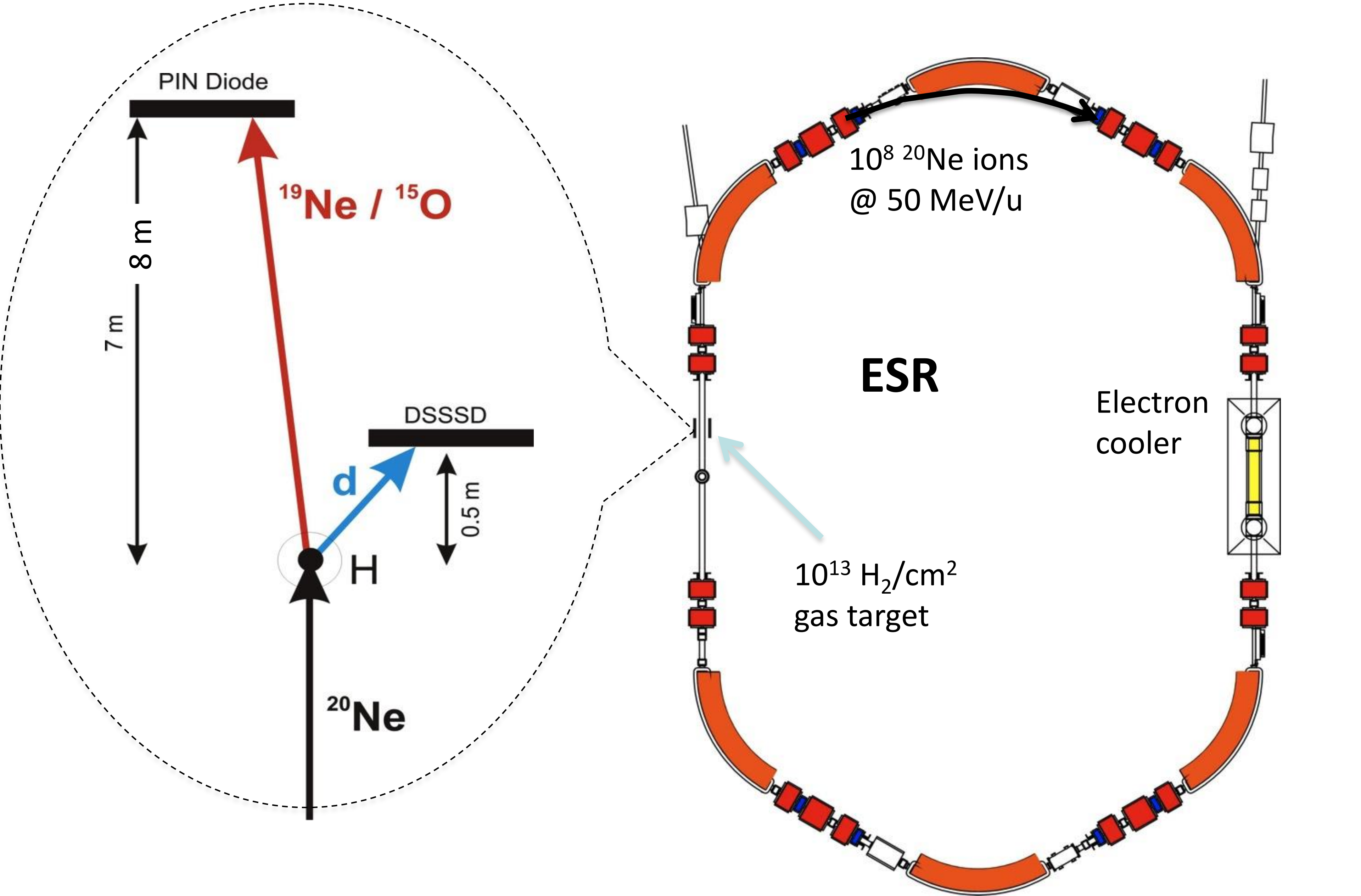
AND

J. GÖRRES
Department of Physics, University of Pennsylvania, Philadelphia
Received 1985 May 24; accepted 1985 August 19

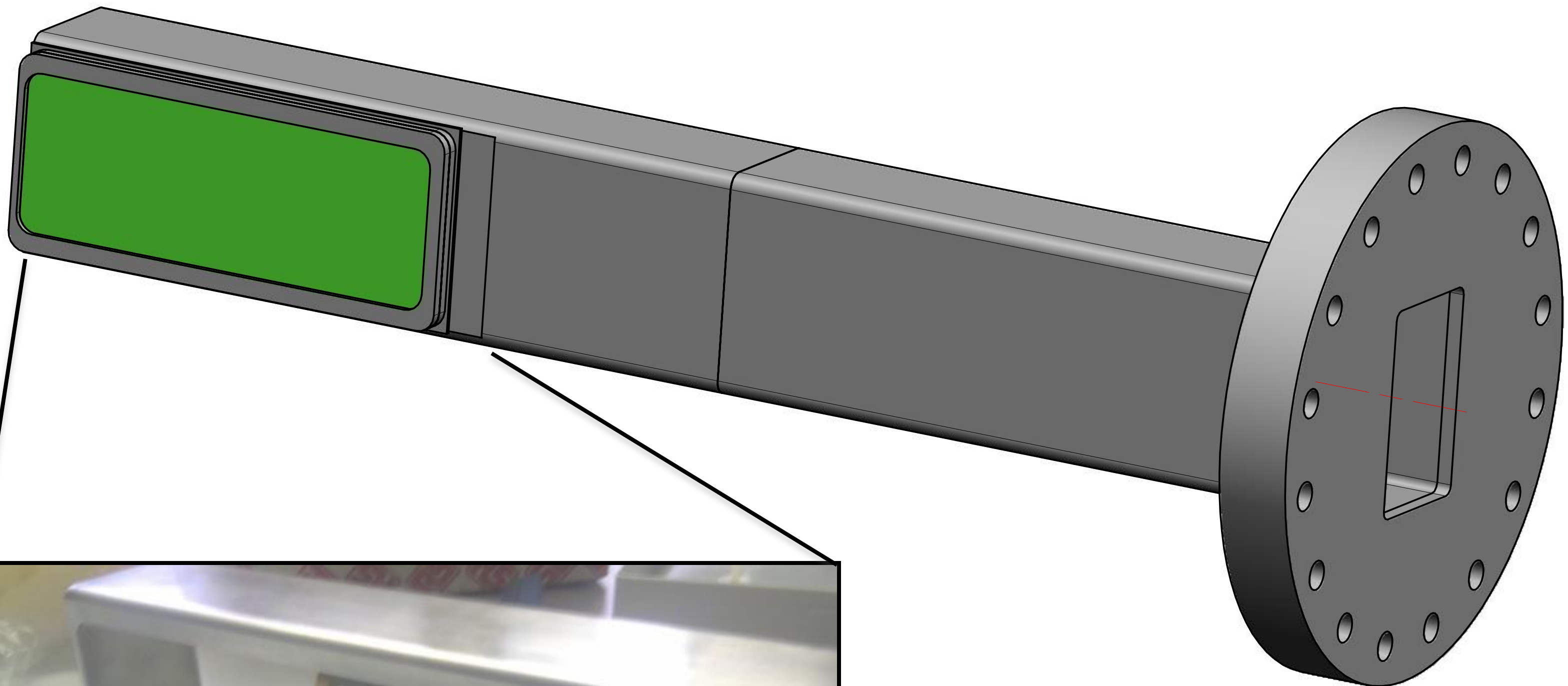
$^{15}O(\alpha,\gamma)^{19}Ne$ reaction rate predicted to be dominated by a single resonance at a CoM energy of 504 keV

Key unknown - α-decay probability from excited state at 4.03 MeV in ^{19}Ne compared to γ-decay, predicted to be ~ 10^{-4}

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



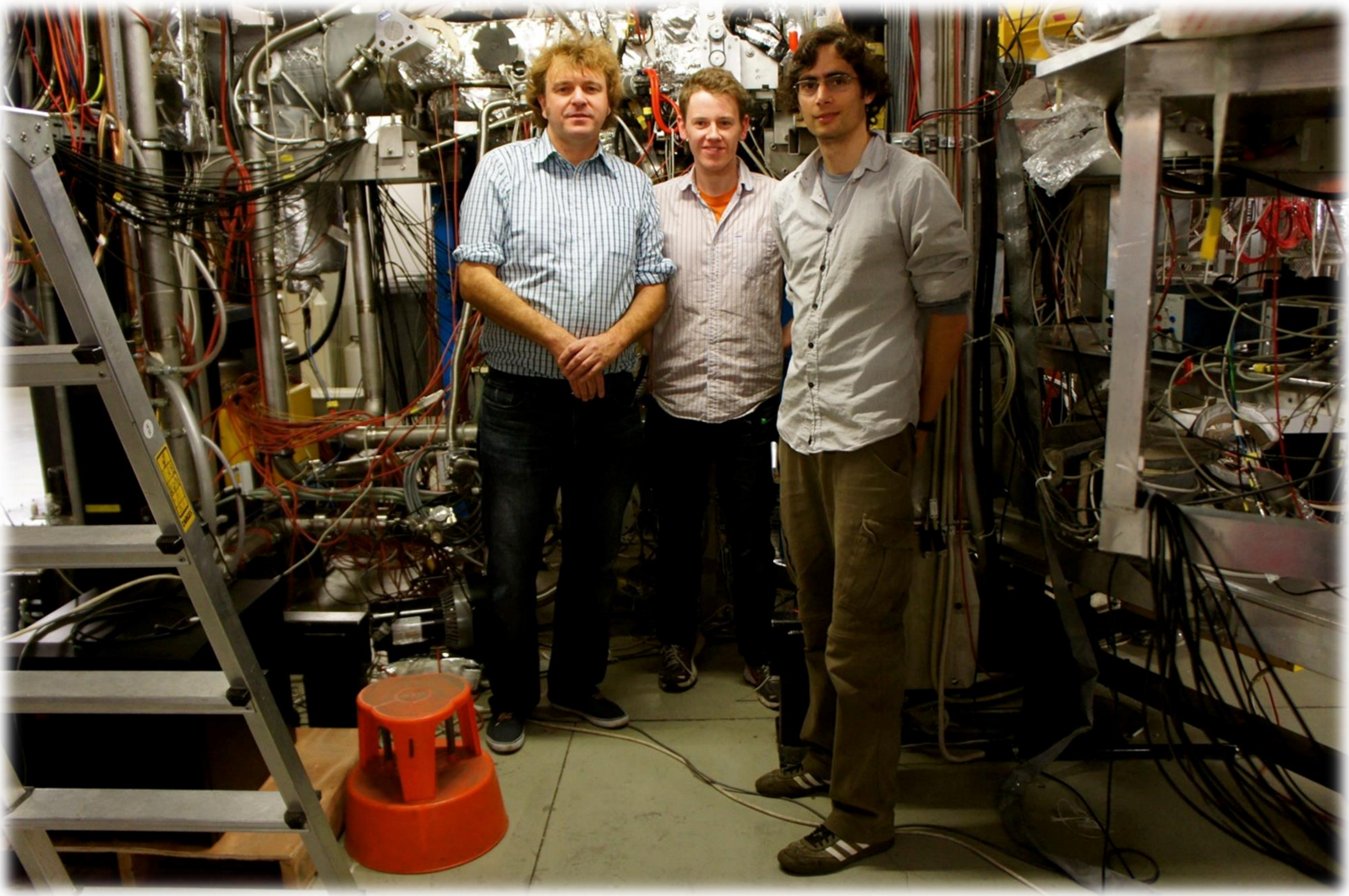
Detector Pocket



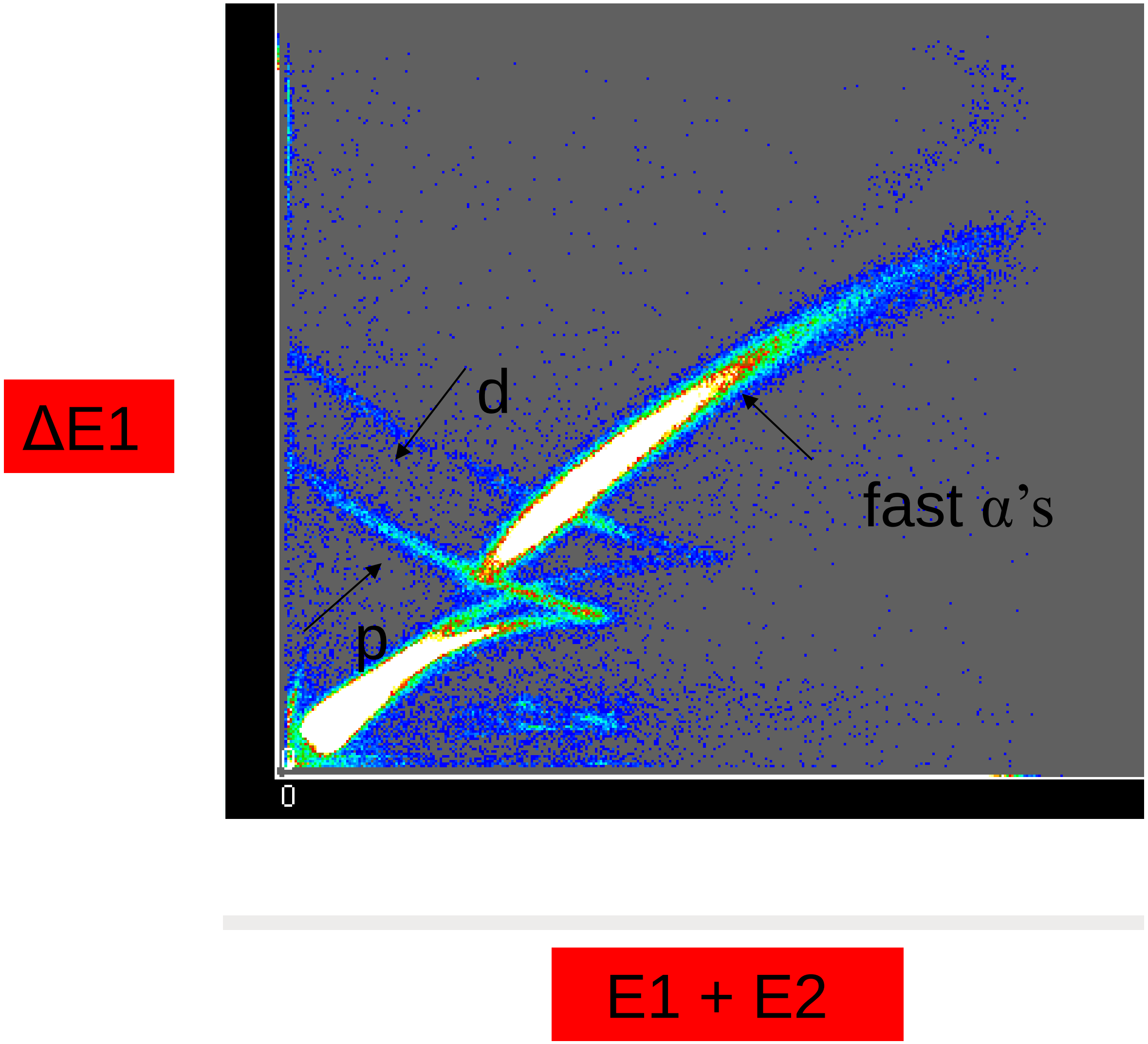
Si –telescope

•2 x ~1mm ‘W’-type detectors

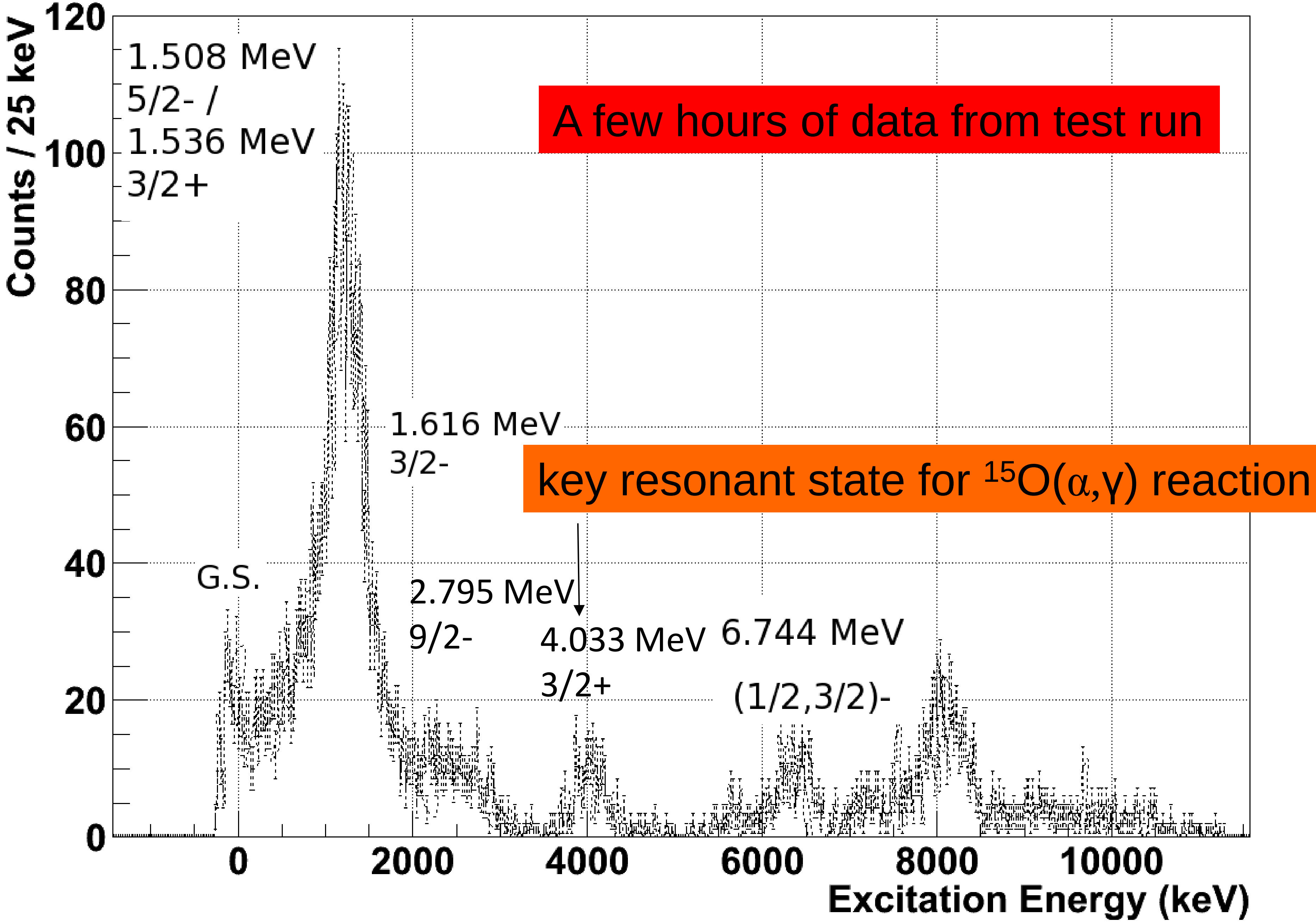
•16x16 strips



Particle ID plot for DSSD

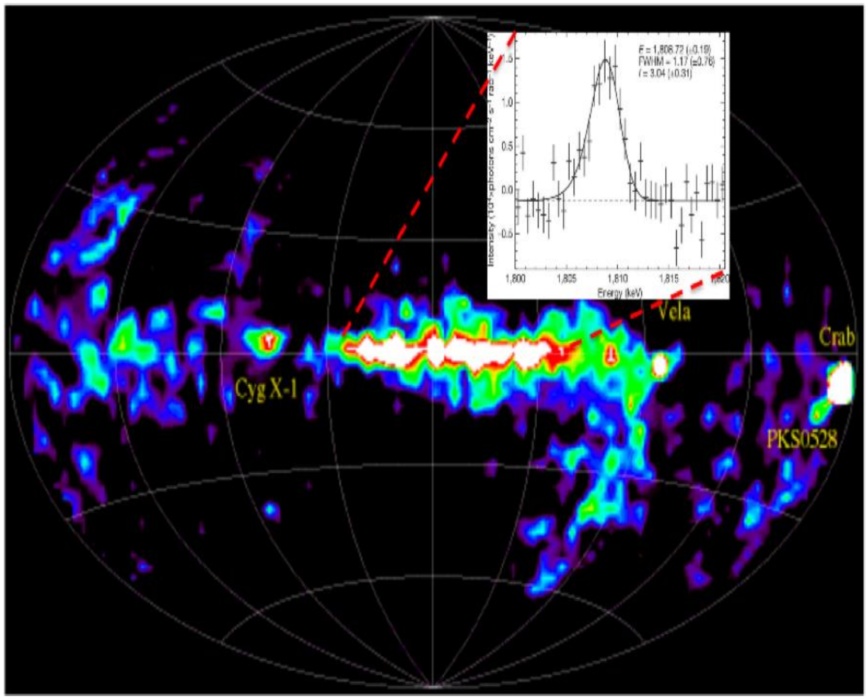


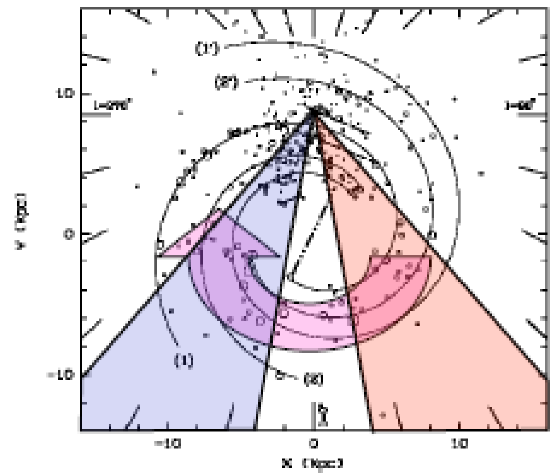
Excitation Energy Spectrum @ 72mm

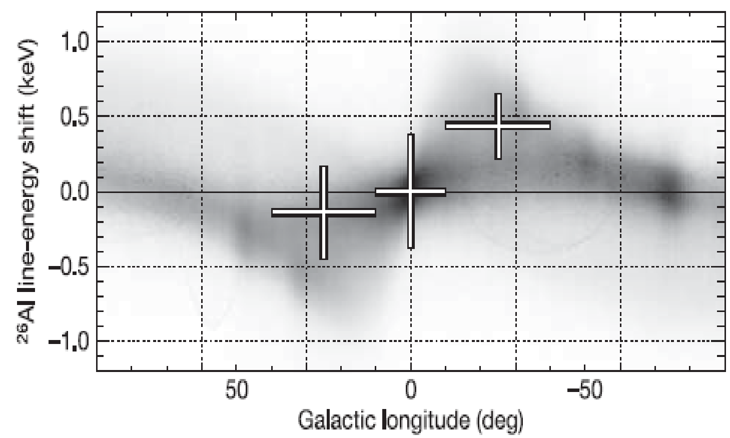


Galactic abundance distribution of the cosmic γ-ray emitter ^{26}Al

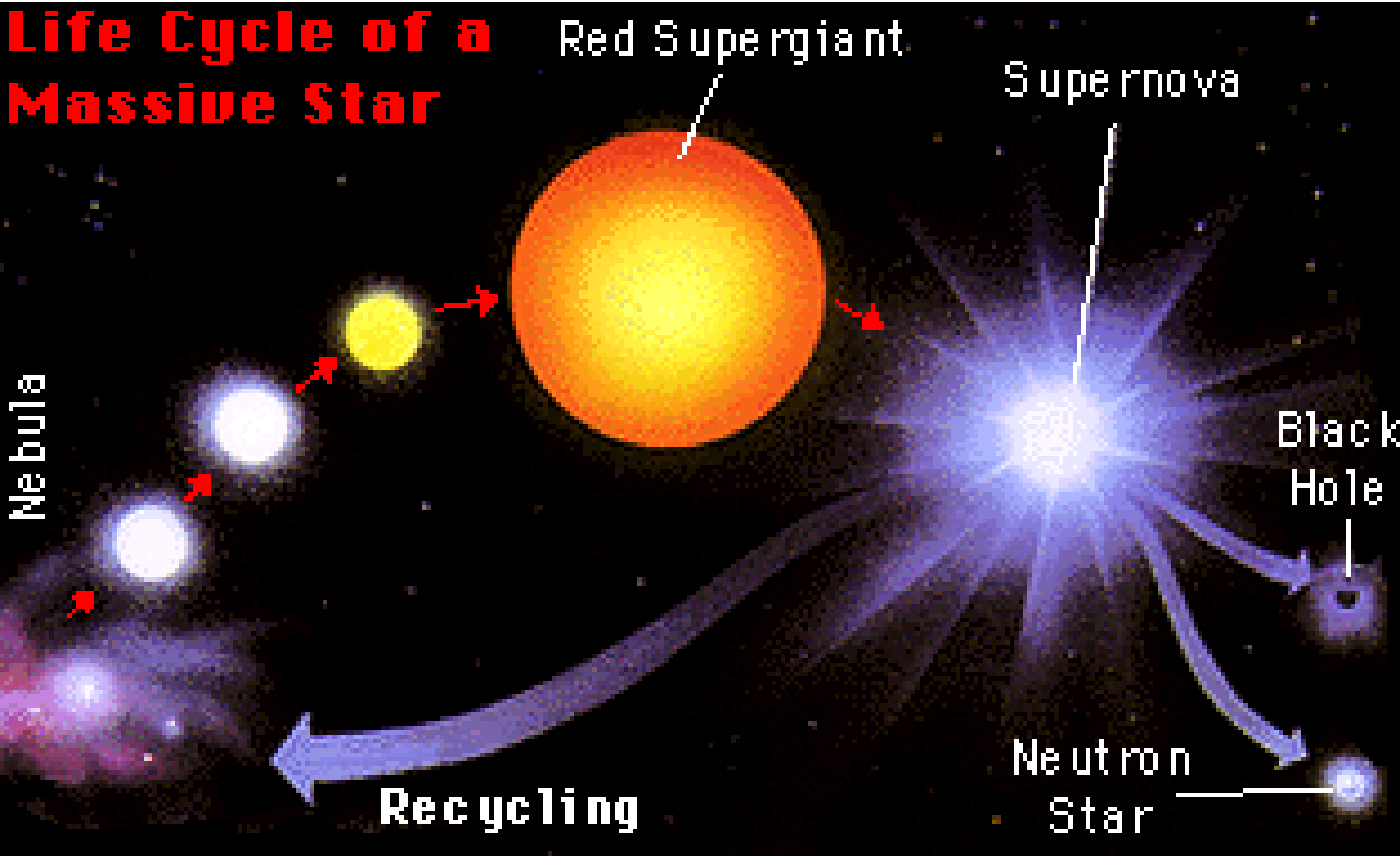
INTEGRAL satellite telescope - 2.8(8) M_{sun} of ^{26}Al in our galaxy
[R. Diehl, *Nature **439** 45(2006)*]



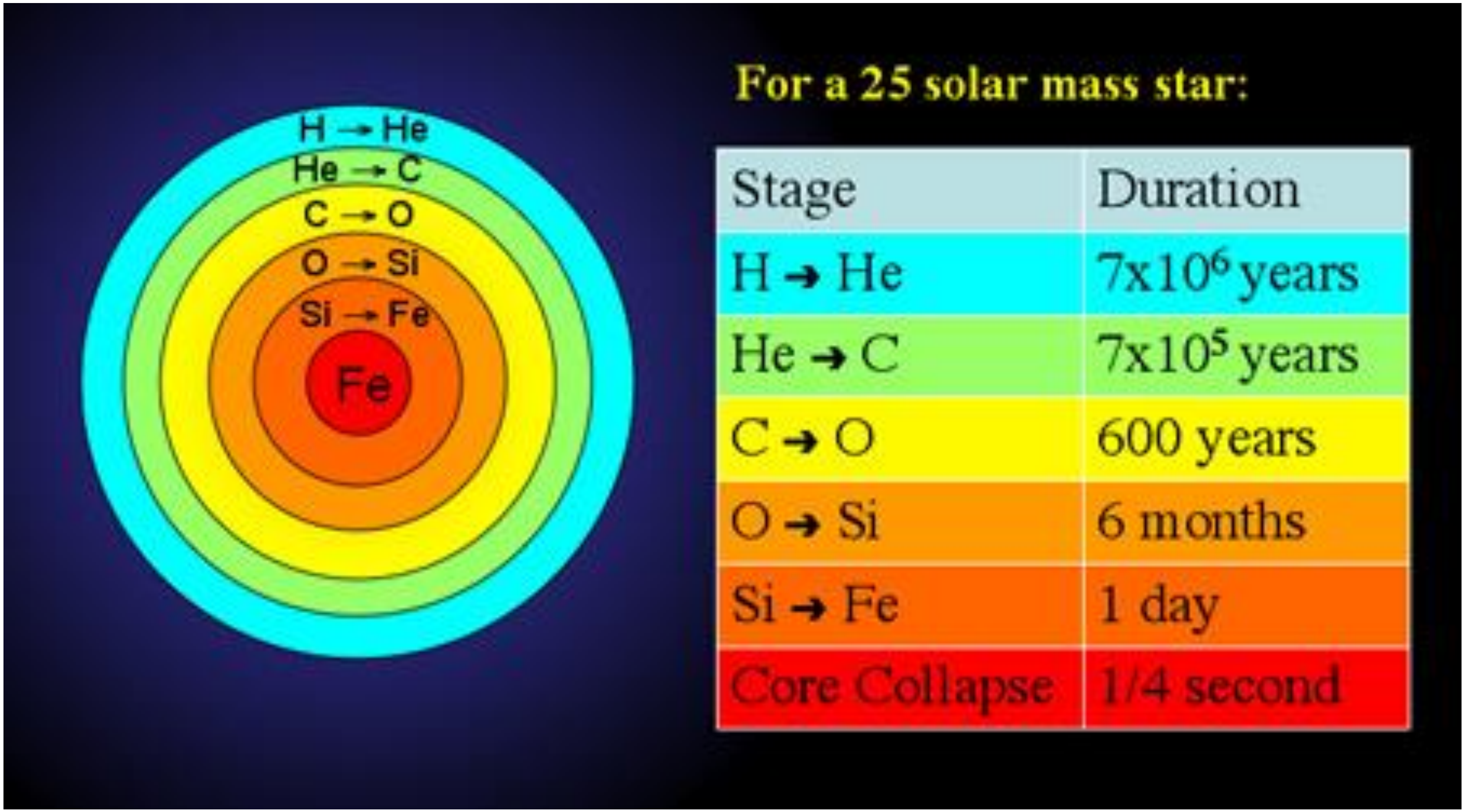




Supernova Cycle

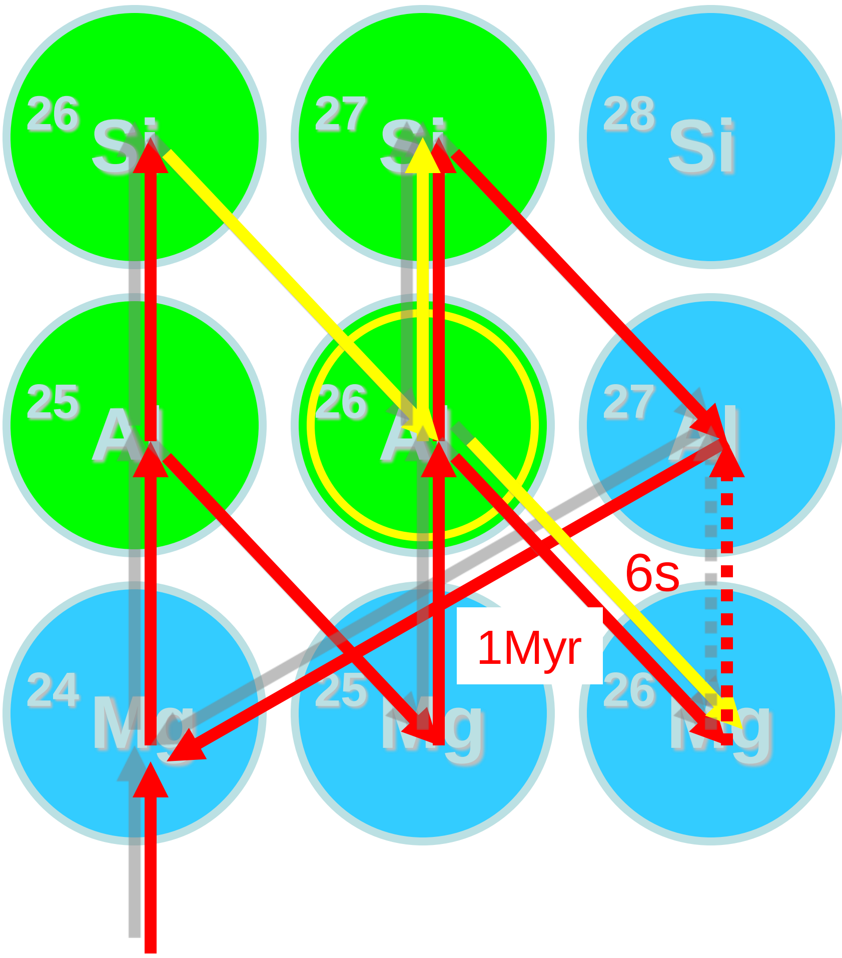


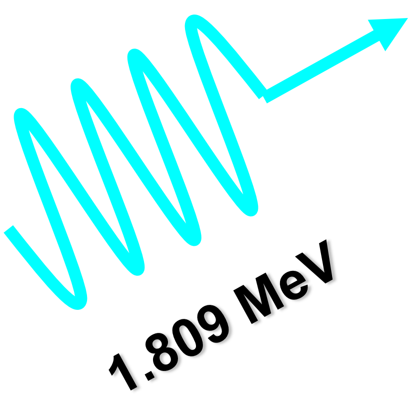
Stellar Life

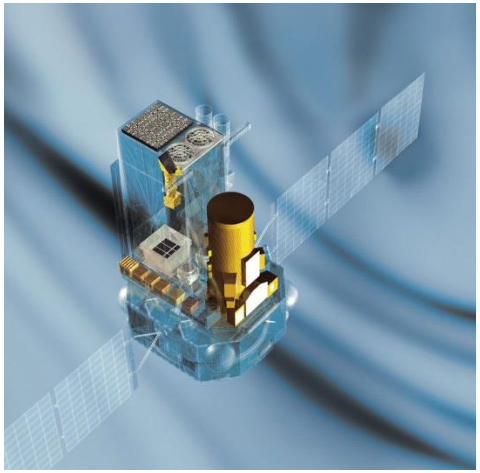


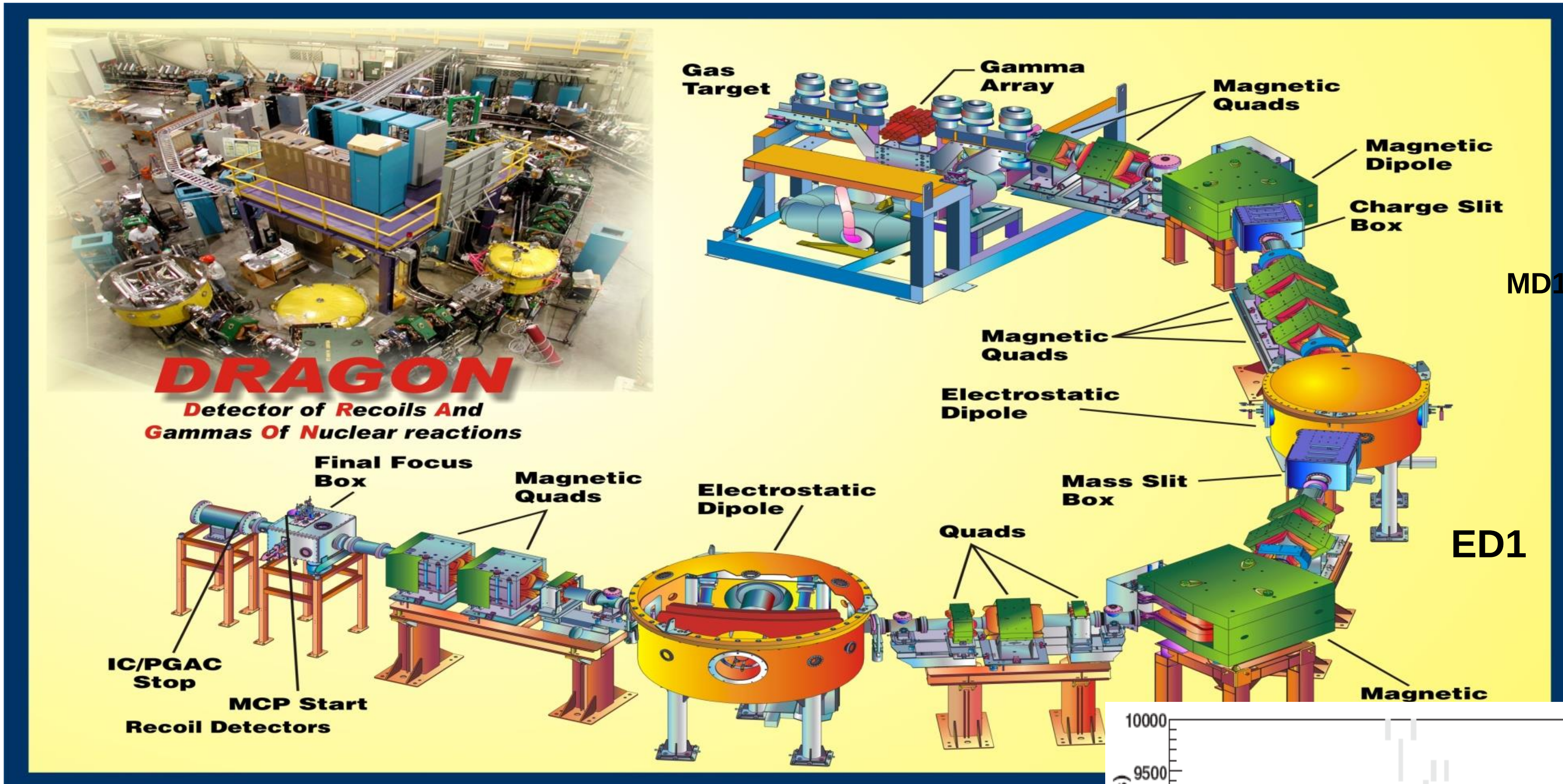
Stage	Duration
H → He	7×10^6 years
He → C	7×10^5 years
C → O	600 years
O → Si	6 months
Si → Fe	1 day
Core Collapse	1/4 second

Hydrogen burning in Mg – Al Cycle

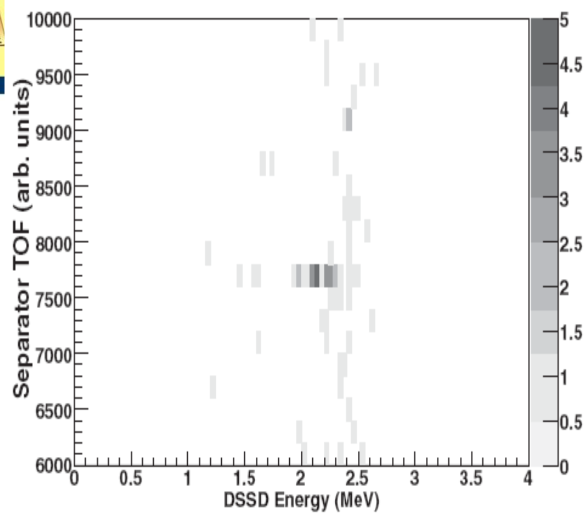








Direct measurement of $^{26g}Al(p,\gamma)^{27}Si$ reaction on 188 keV resonance, PRL 96 252501(2006)



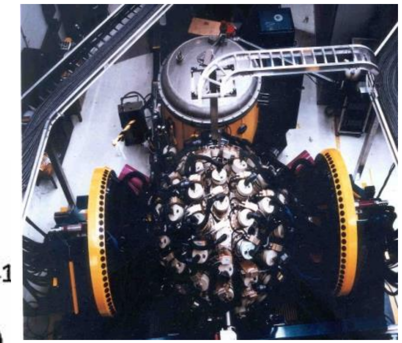
→ lower energy resonances may play dominant role for destruction of ^{26}Al burning in W-R stars?

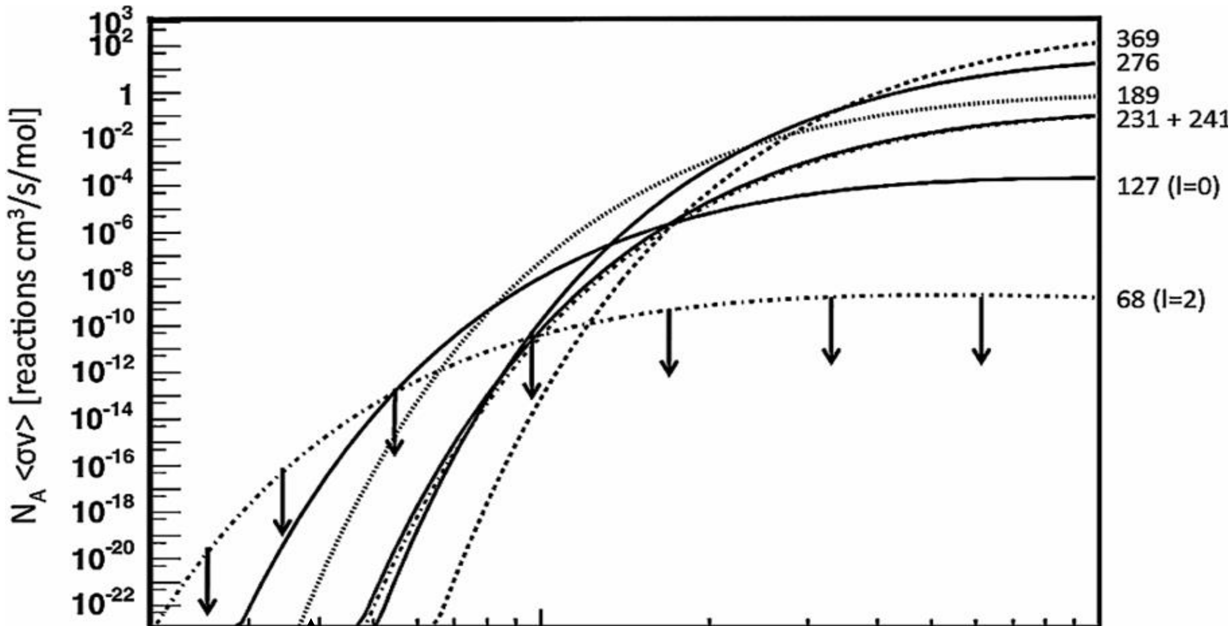
PRL 102, 162502 (2009) PHYSICAL REVIEW LETTERS week ending 24 APRIL 2009

Identification of Key Astrophysical Resonances Relevant for the $^{26g}Al(p,\gamma)^{27}Si$ Reaction in Wolf-Rayet Stars, AGB stars, and Classical Novae

G. Lotay,[1] P. J. Woods,[1] D. Seweryniak,[2] M. P. Carpenter,[2] R. V. F. Janssens,[2] and S. Zhu[2]

Factor ~ 10^4 reduction in uncertainties in estimated $^{26g}Al(p,\gamma)^{27}Si$ reaction rate





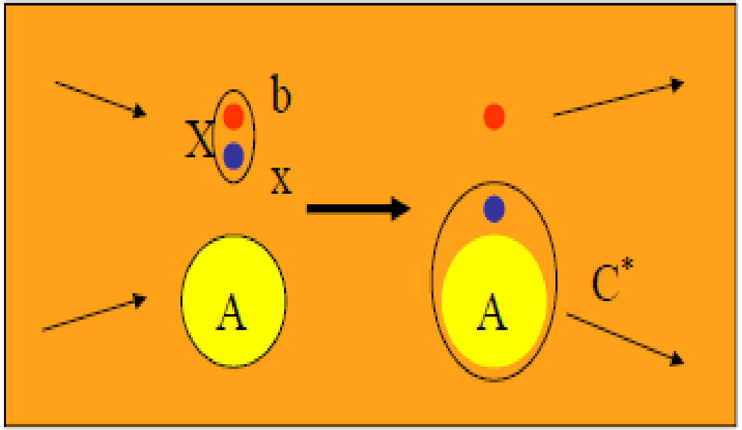
However, resonance strengths for critical low T ^{26}Al burning regime in Wolf-Rayet stars still need to be determined

$$\omega\gamma = \frac{2J+1}{(2J_1+1)(2J_T+1)}\frac{\Gamma_1\Gamma_2}{\Gamma}$$

use transfer reactions to estimate Γ_p for (p,γ) reactions

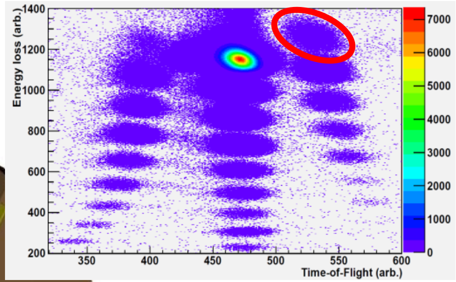
where resonance has $\Gamma_p << \Gamma_\gamma$, ω_γ is proportional to $\Gamma_{p.}$

Γ_p α P_l (barrier penetration factor) X S(spectroscopic factor)

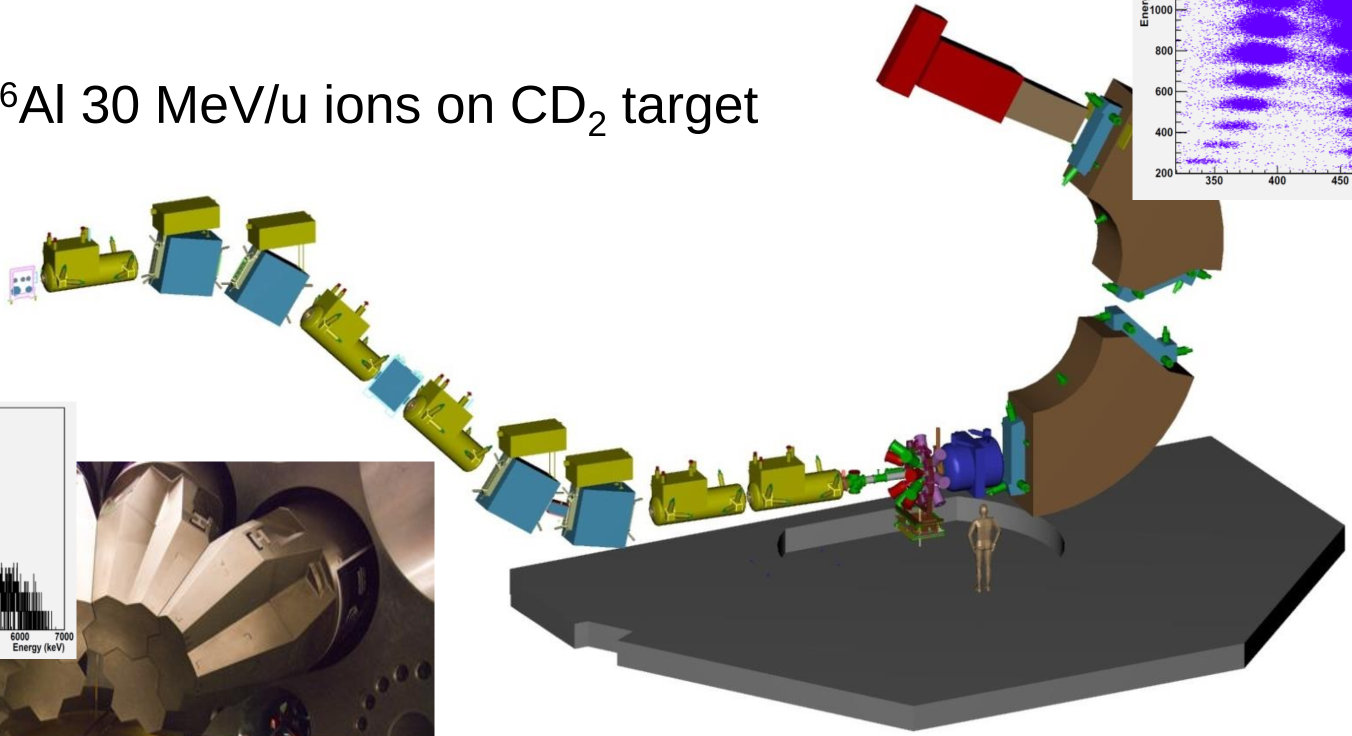


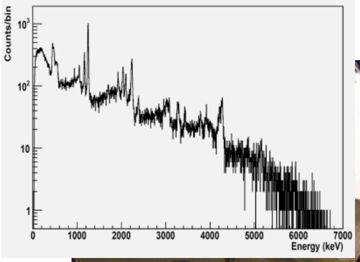
$\sigma_{transfer} = \sigma_{DWBA}$ X S

New technique for (d,n) studies of (p,γ) resonance strengths with GRETINA γ-array and S800 spectrometer
PJW, H Schatz et al., NSCL, April 2013



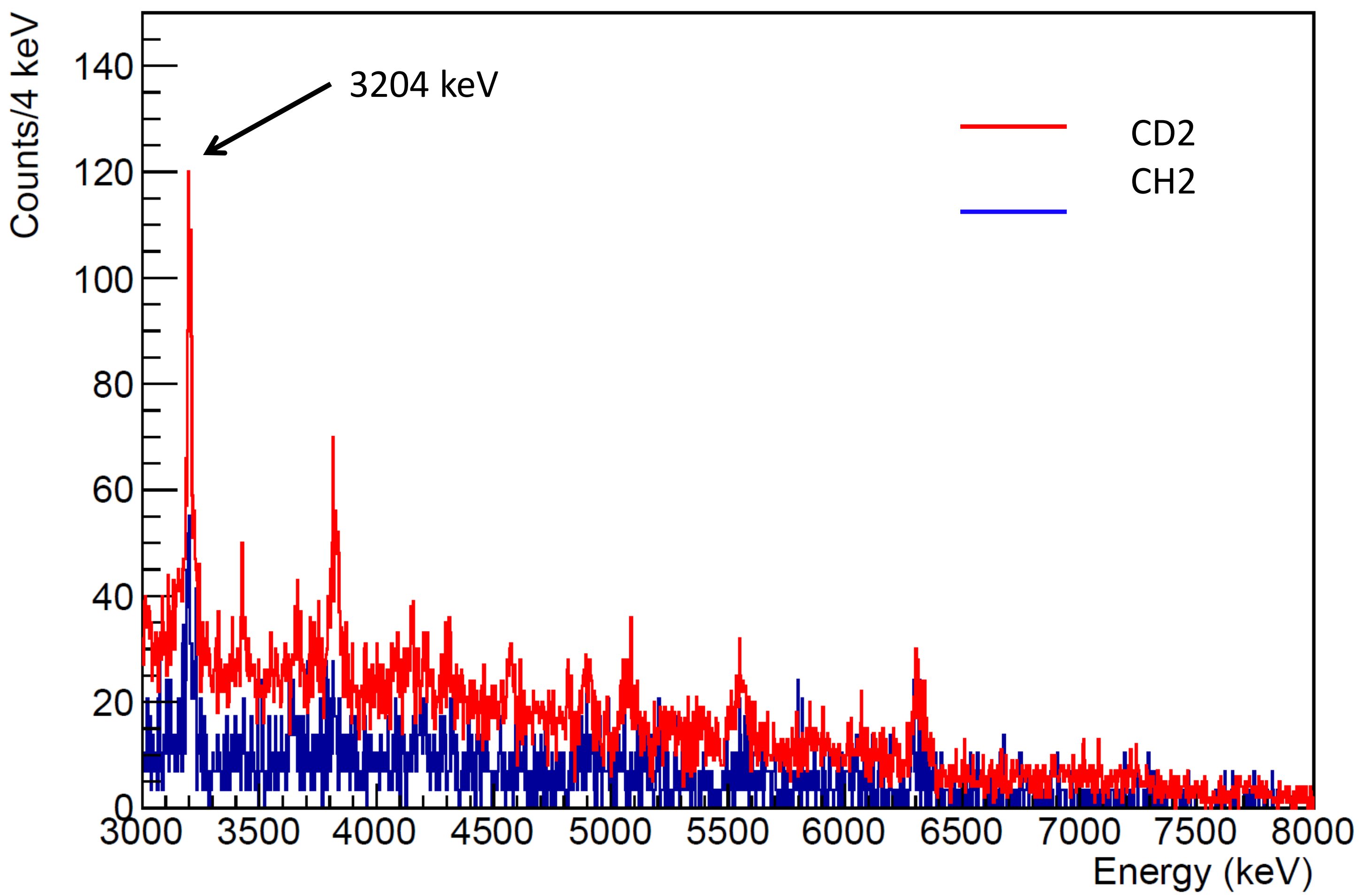
~10^6 ^{26}Al 30 MeV/u ions on CD_2 target





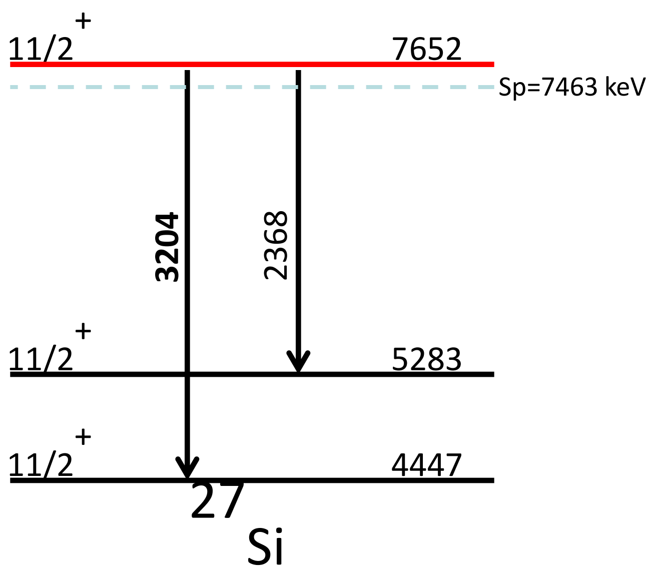
Measure $\sigma(d,n)_{INT} \rightarrow \Gamma_p$ for strong resonances

^{27}Si gamma spectrum – analysis A Kankainen



Total cross section for (d,n) transfer reaction from GRETINA γ-ray intensities

Observe transitions from the known strong single-particle state at 7652 keV!



Studied previously with:

- ^{26}Al target
  Vogelaar et al., PRC 53 (1996) 1945
- ^{26}Al beam on hydrogen target
  Ruiz et al., PRL 96 (2004) 252501

Resonance strengths:

ωγ= 55(9) μeV
PhD thesis , R Vogelaar
ωγ= 35(7) μeV
Ruiz et al., PRL 96 (2004) 252501

$$\omega\gamma = \frac{6}{11}\frac{\Gamma_\gamma \Gamma_p}{\Gamma_\gamma + \Gamma_p} \approx \frac{6}{11}\boldsymbol{\Gamma_p}$$

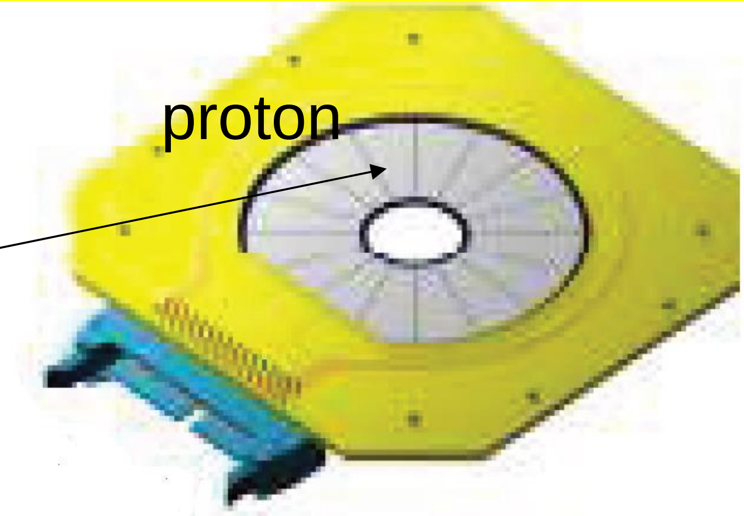
$$\Gamma_\gamma \gg \Gamma_p$$

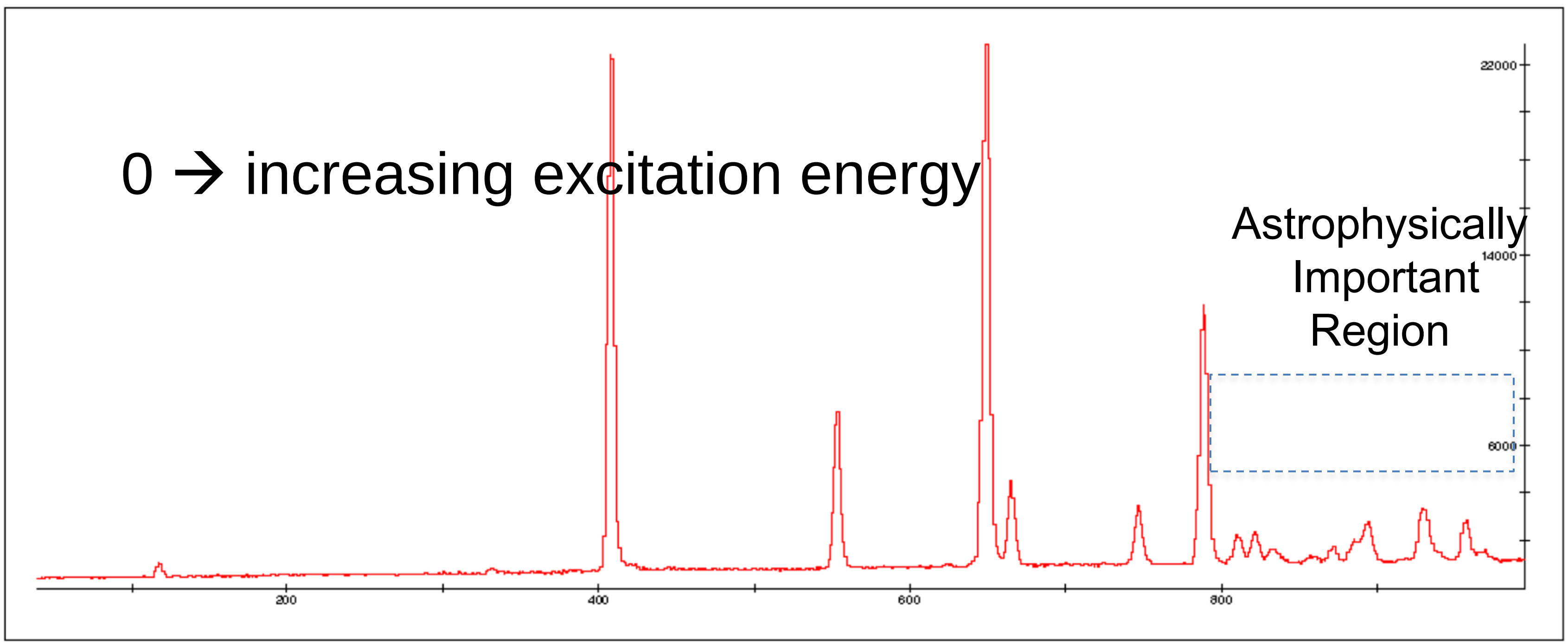
Waiting on theoretical calculations for (d,n) reactions to obtain proton widths Γp

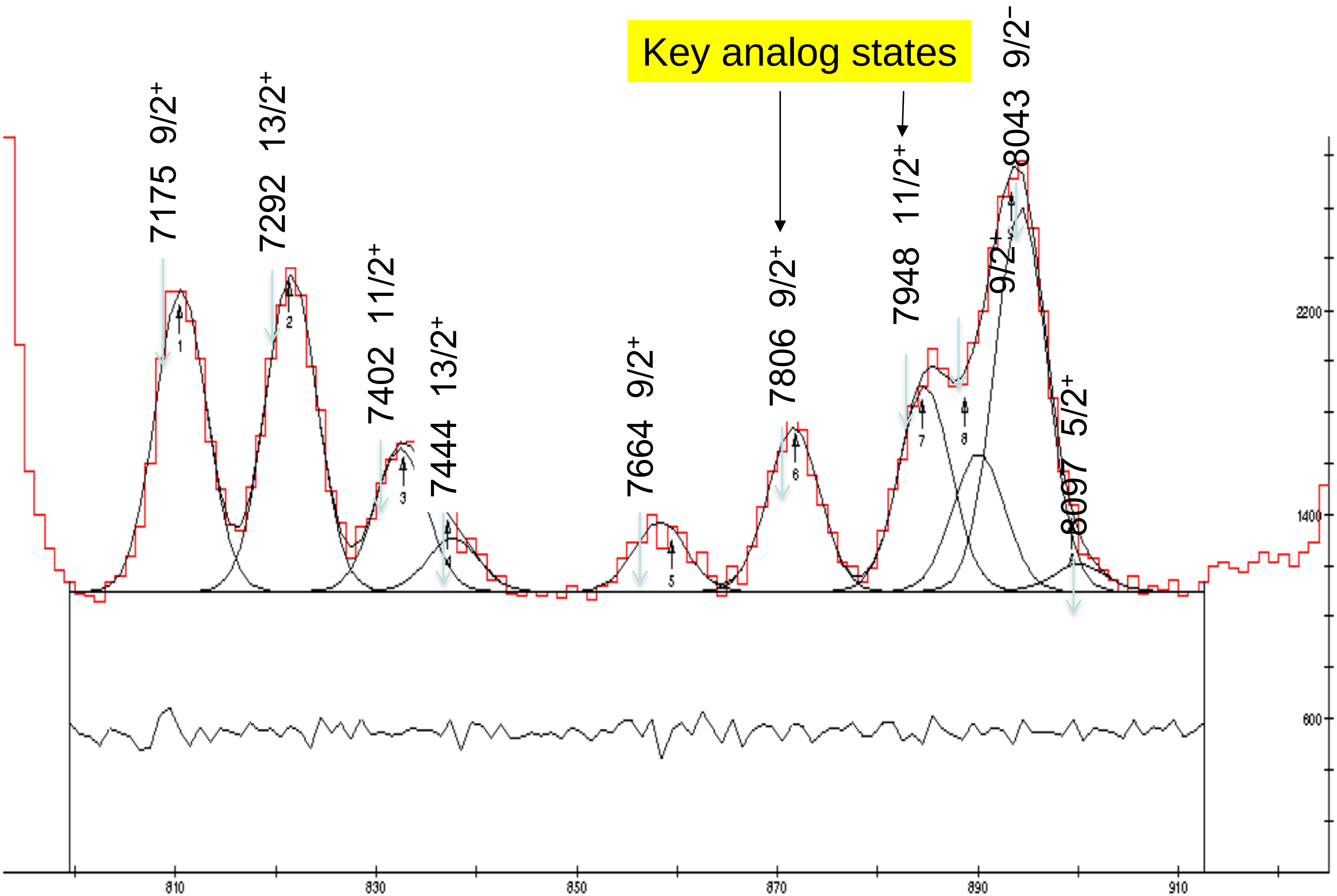
Anu Kankainen
DNP2013, October 23-26, 2013,
Newport News, VA, USA

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 → $(CD_2)_n$ target
I_{beam} ~ $5*10^8$ pps



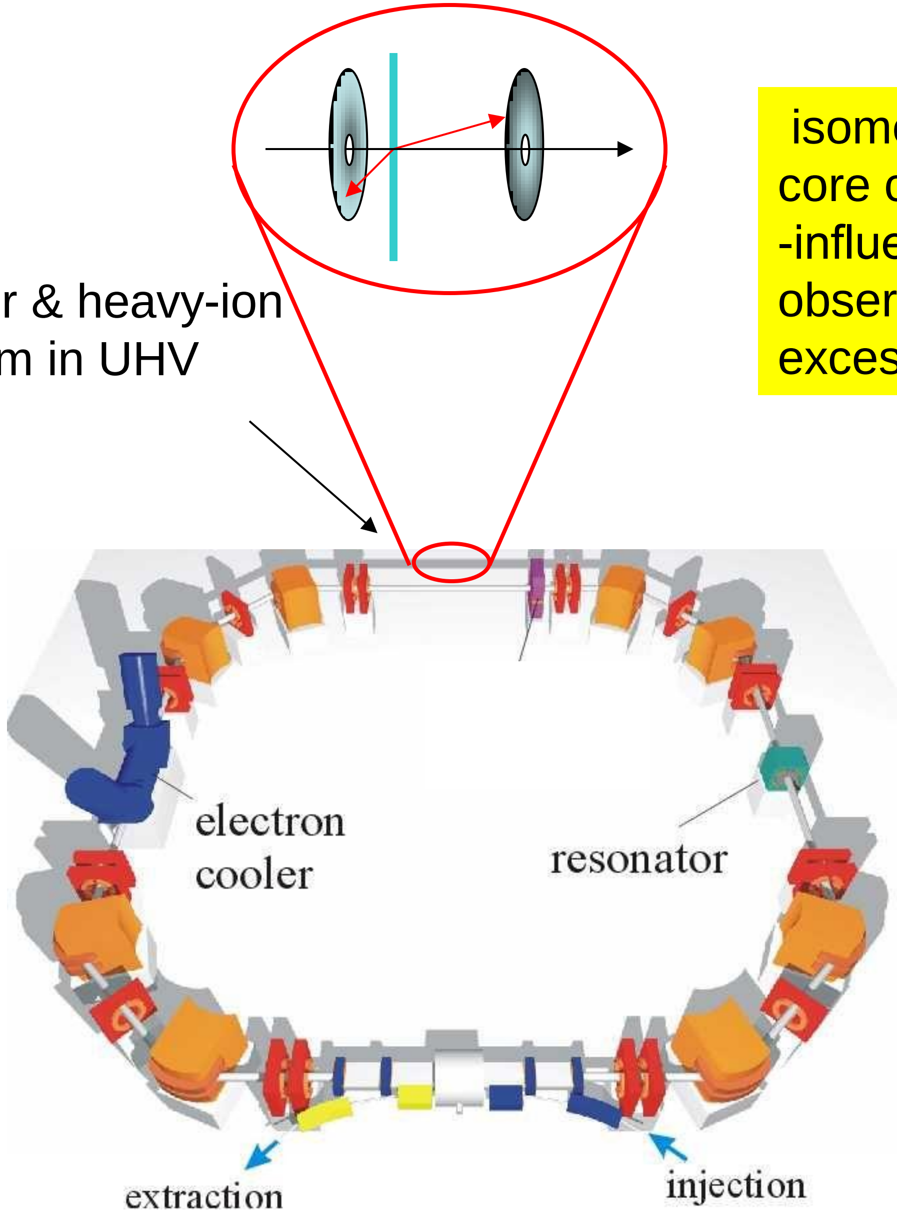




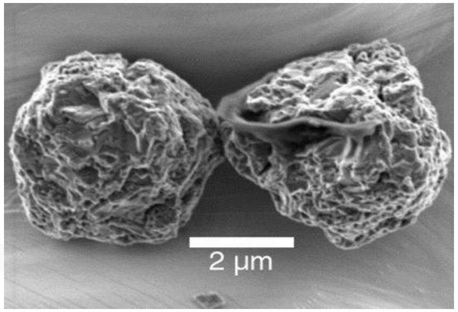
Exotic reaction since $J^{\pi} = 5^{+}$ for ^{26g}Al!

Future $^{26m}Al(d,p)^{27}Al$ study on TSR storage ring@ISOLDE

In-ring target chamber & heavy-ion recoil detection system in UHV



isomer can be excited in core collapse supernovae -influences ‘extinct’ ^{26}Al observed in meteorites as excess ^{26}Mg



In-ring DSSD System for ultra-high resolution (d,p), (p,d) and (^{3}He,d) transfer studies of astrophysical resonances

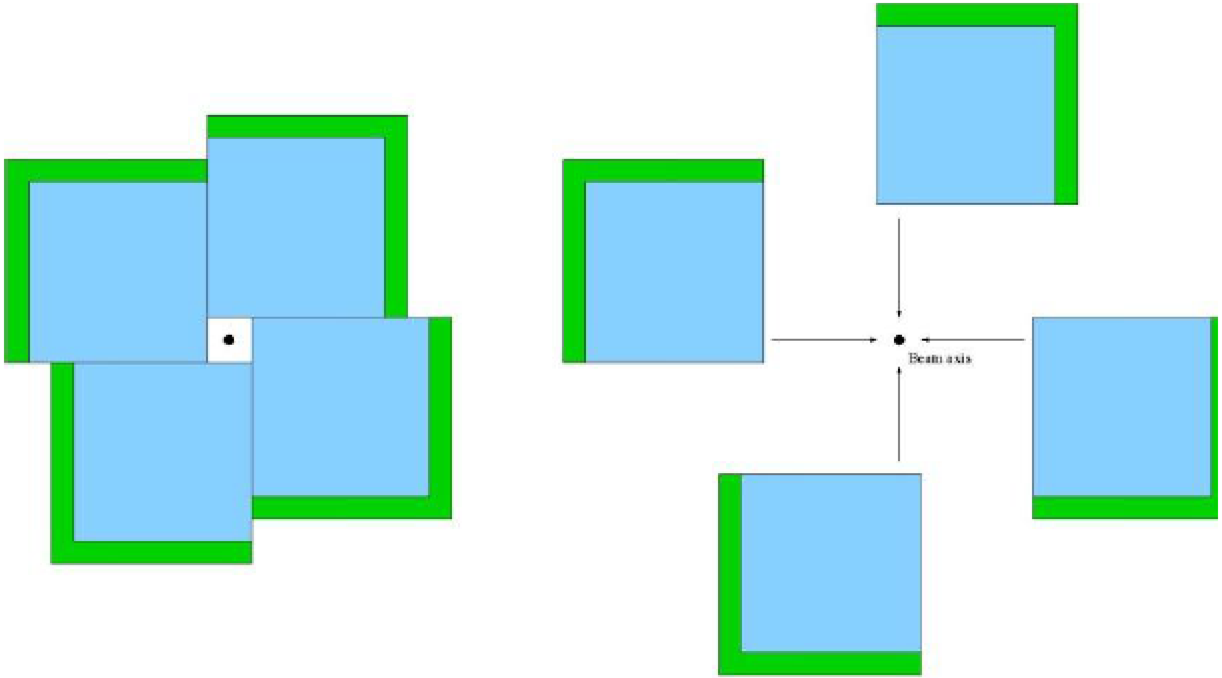
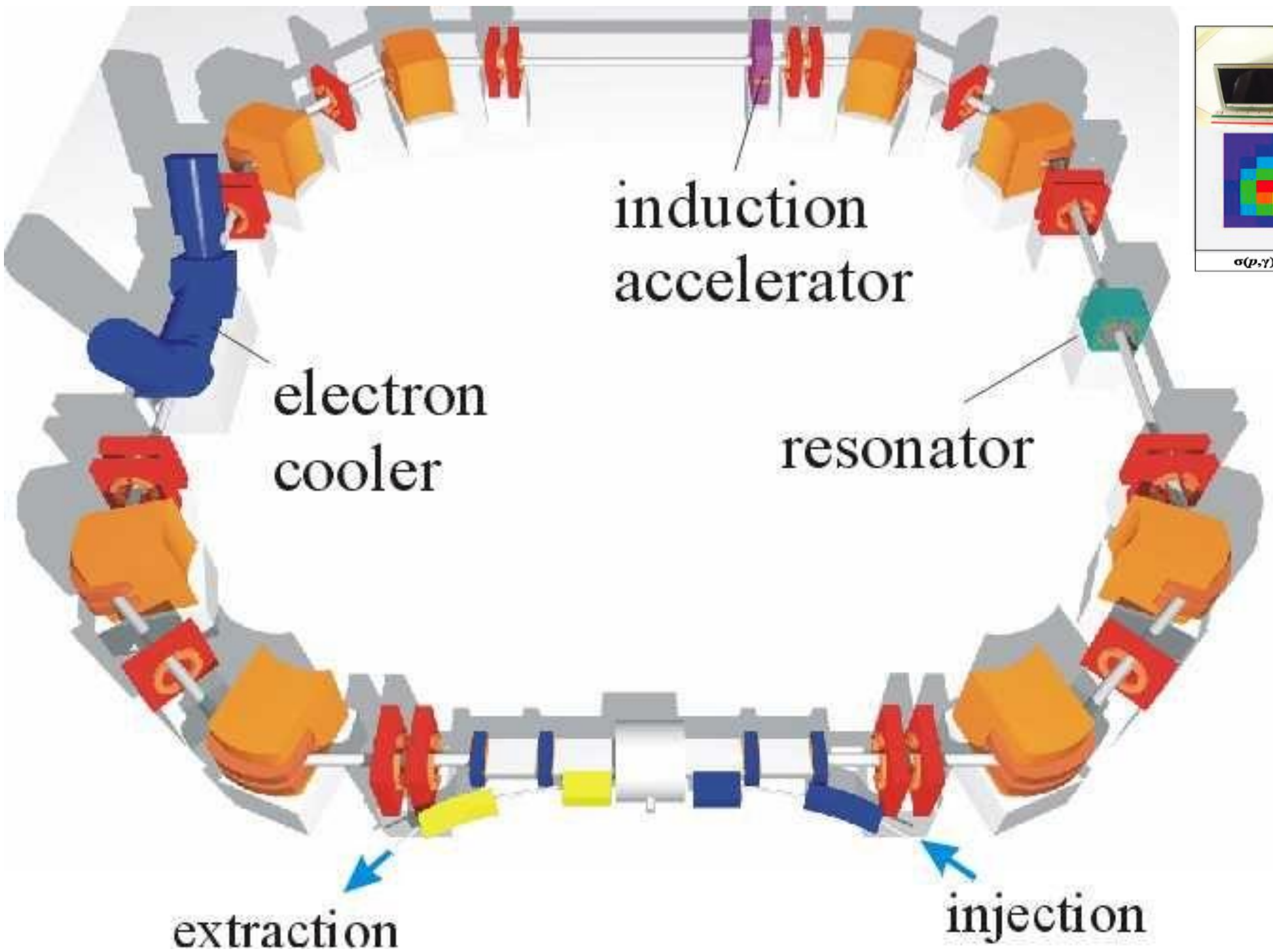


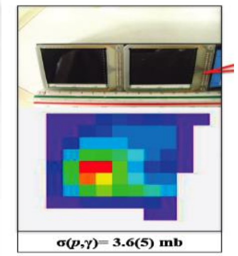
Figure 1: Illustration of upstream or downstream assembly of 4 DSSDs about beam axis

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

→ resolutions approaching 10 keV FWHM attainable   T Davinson

Recoil detector system for radiative capture measurements in UHV of astrophysical p-process → ions injected directly at energy of interest





UK ISOL-SRS Proposal

- LoI accepted
- January 2014 STFC recommend next stage of proposal submission
- Feb 28 final submission of proposal

→ Maximum funding ~5 MEuro

→ 3 M£ of new money

- April 29/30 presentaion of final proposal to STFC

Conclusion

We are in a very exciting era coupling the properties and reactions of exotic nuclei with explosive nuclear astrophysics

The TSR@ISOLDE storage ring facility can play a unique role addressing the most interesting science questions in the field.