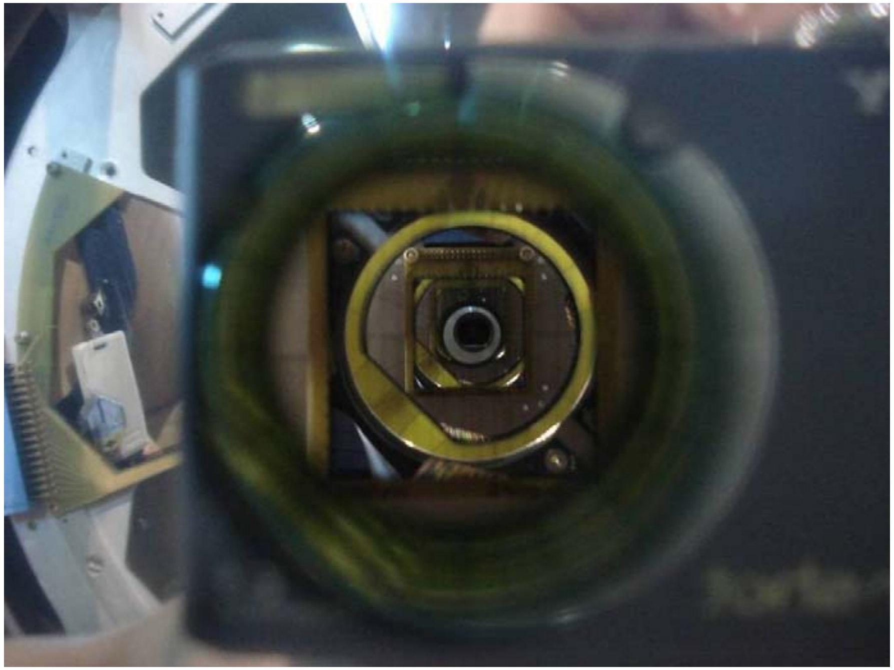
Explosive Phenomena in Astrophysics and Nuclear Reactions Studies



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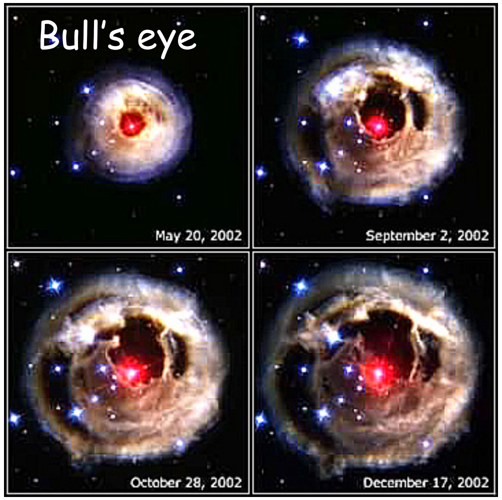
Talk's outline

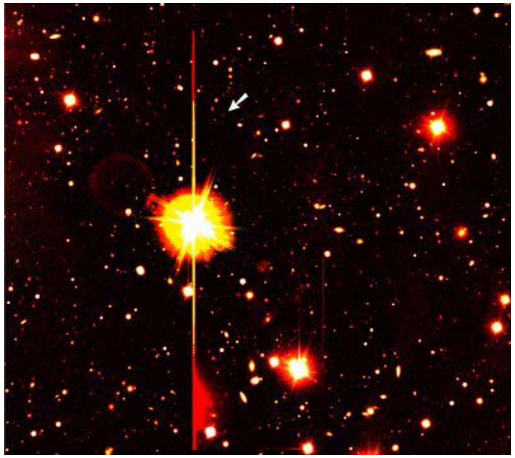
- explosive phenomena in astrophysics
- radioactive beam experiments
  - the $^{14}O(\alpha,p)^{17}F$ reaction (GANIL)
  - the $^{18}Ne(\alpha,p)^{21}Na$ reaction (TRIUMF)
- stable beam experiments
  - the $^{17}O(p,\gamma)^{18}F$ reaction (LUNA)
  - the $^{17}O(p,\alpha)^{14}N$ reaction (LUNA)
- general remarks and an announcement

Explosive phenomena

Stellar outbursts

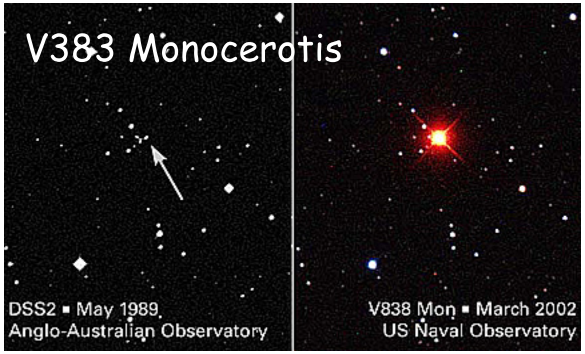


Gamma Ray Bursts



most powerful events since the Big Bang
(energy released in few seconds larger
than Sun's output over its entire lifetime)

Erupting supergiants

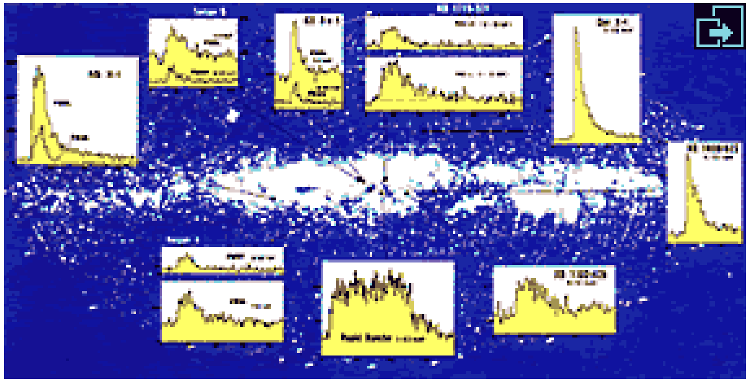


very short timescales
(seconds → hours)

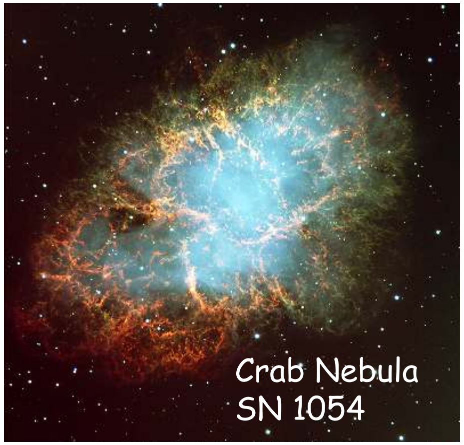
↓

nuclear reactions
with
UNSTABLE NUCLEI

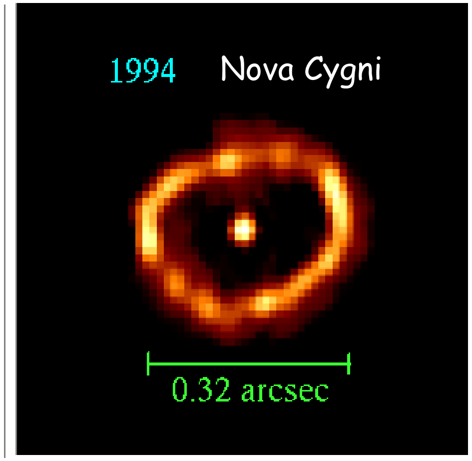
X-Ray Bursts



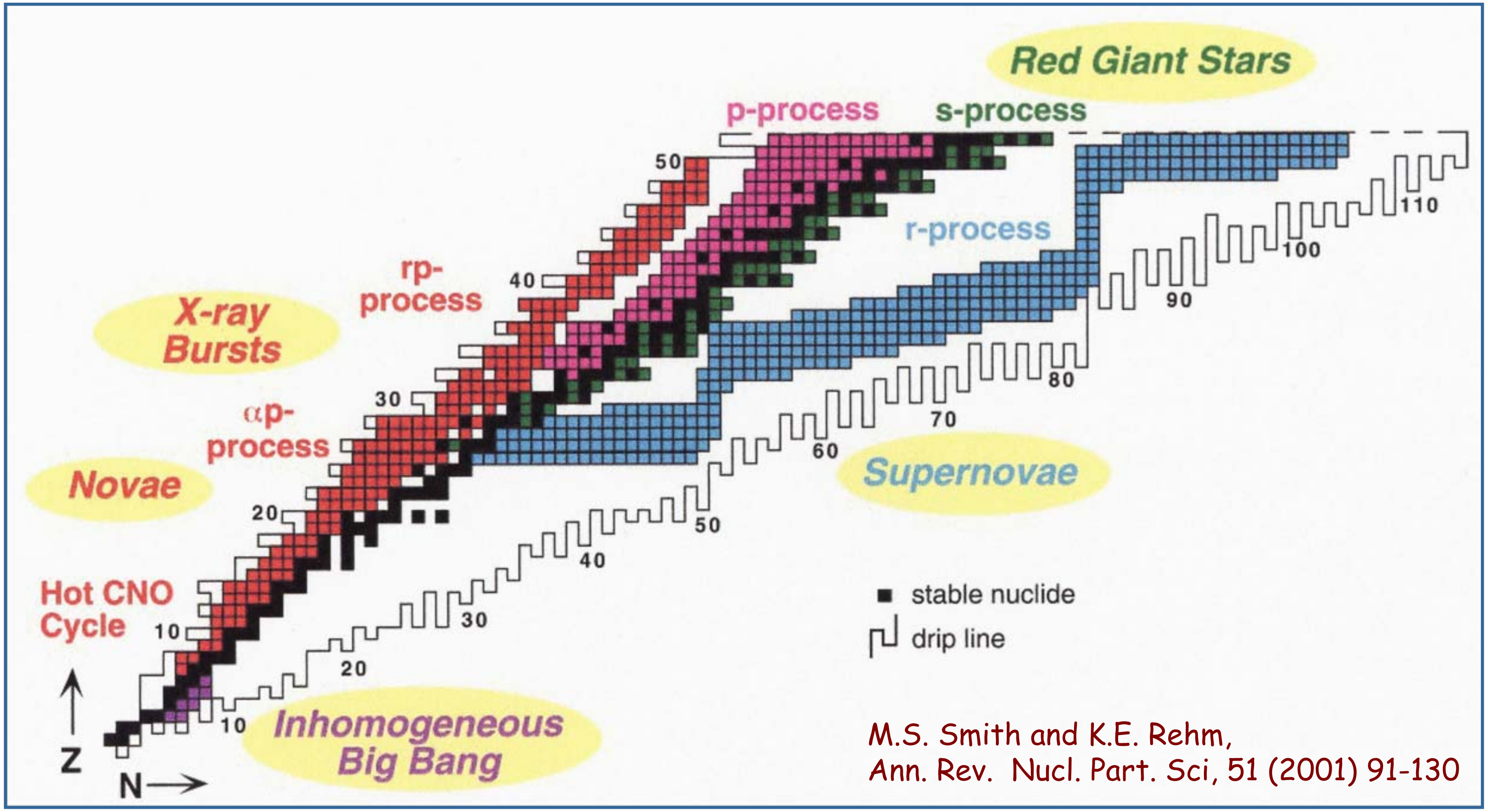
Supernovae



Novae



Overview of main nuclear processes and astrophysical sites



M.S. Smith and K.E. Rehm,
Ann. Rev. Nucl. Part. Sci, 51 (2001) 91-130

- nuclear reaction paths involve UNSTABLE species ⇒ **Radioactive Ion Beams**
- key reactions identified by sensitivity of astrophysical models to nuclear inputs

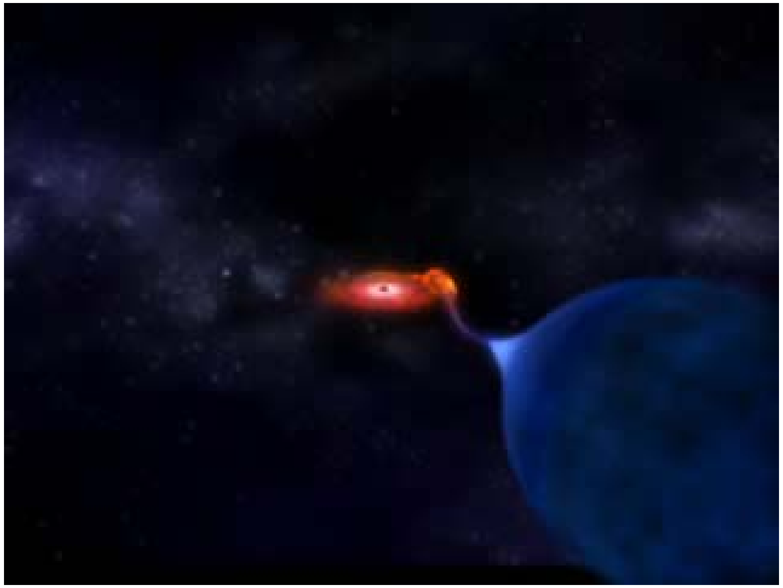
binary star systems

novae, X-ray bursts,
supernovae Type I

the model

NOVAE, X-RAY BURSTERS, SUPERNOVAE TYPE I

semi-detached binary system: compact star + less evolved star



- H and He transfer from companion
- degenerate conditions ⇒ explosive ignition
- mass ejection (novae) or strong X-rays emission
- cooling down of surface after explosion
- decay of burst profile/light curve
- if matter transfer continues process may repeat

$T \sim 10^{9}$ K

$\rho \sim 10^{6}$ g cm^{-3}

→

(α,p) and (p,γ) reactions on proton-rich nuclei

nucleosynthesis up to A ~ 80-100 mass region

nucleosynthesis path: breakout from Hot CNO, onset of rp-process

explosive hydrogen burning

Some key (α,p) reactions along the nucleosynthesis path

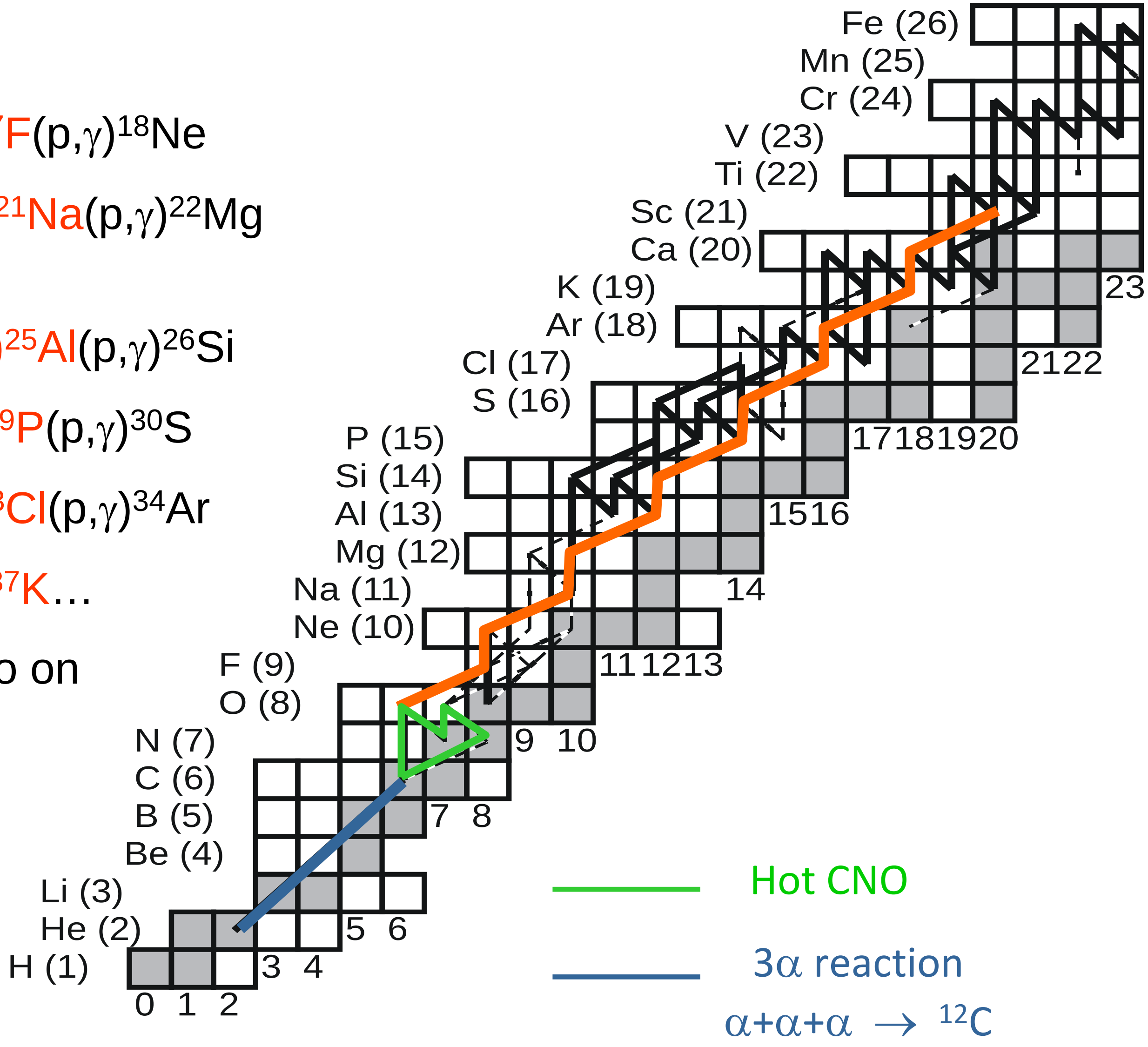
break-out from HCNO

- $^{14}O(\alpha,p)^{17}F(p,\gamma)^{18}Ne$
- $^{18}Ne(\alpha,p)^{21}Na(p,\gamma)^{22}Mg$

αp-process

- $^{22}Mg(\alpha,p)^{25}Al(p,\gamma)^{26}Si$
- $^{26}Si(\alpha,p)^{29}P(p,\gamma)^{30}S$
- $^{30}S(\alpha,p)^{33}Cl(p,\gamma)^{34}Ar$
- $^{34}Ar(\alpha,p)^{37}K$…

… and so on

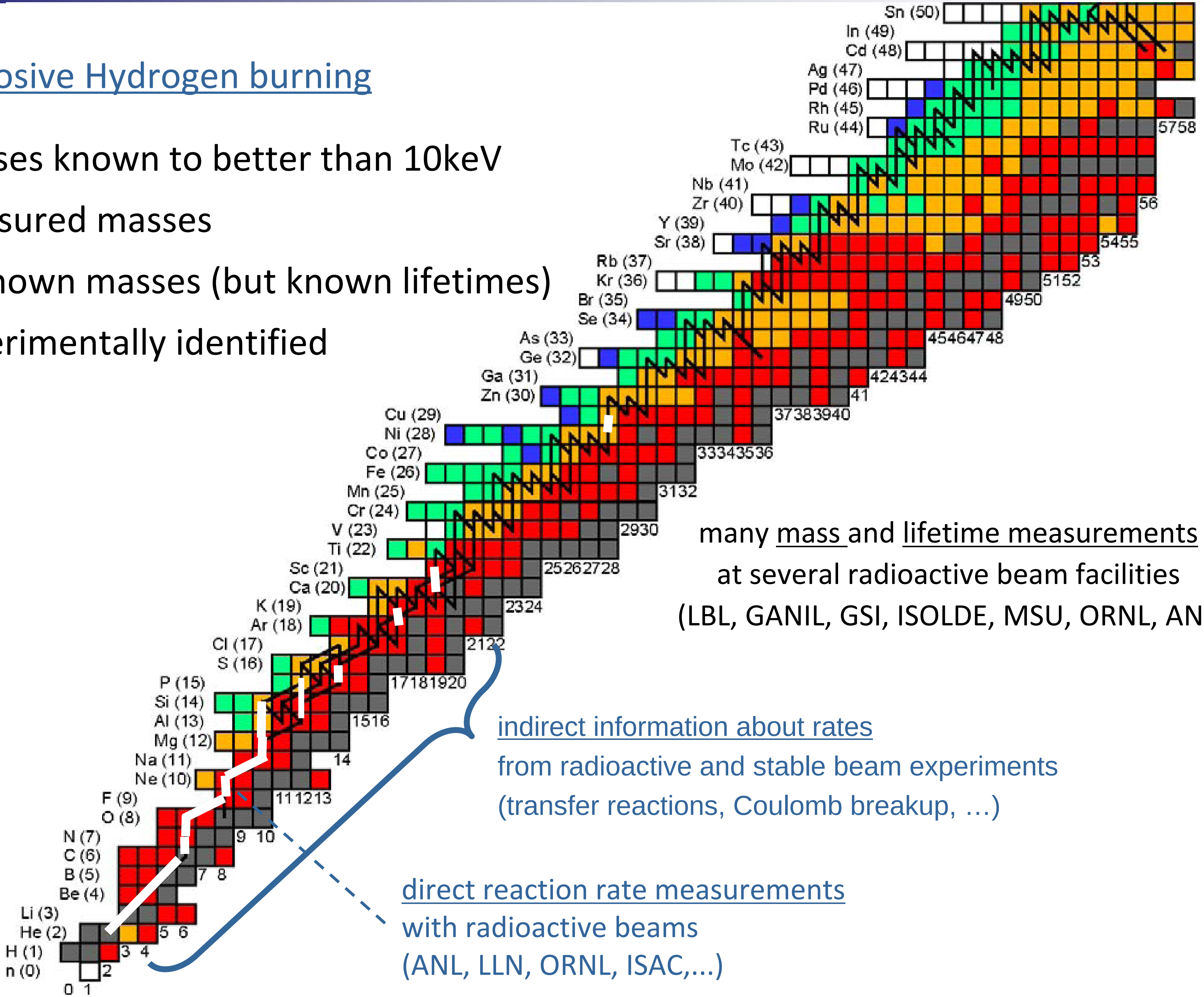


Overview

Schatz & Rehm NP A777 (2006) 601

Explosive Hydrogen burning

- 🔴 masses known to better than 10keV
- 🟠 measured masses
- 🟢 unknown masses (but known lifetimes)
- 🔵 experimentally identified



many mass and lifetime measurements

at several radioactive beam facilities

(LBL, GANIL, GSI, ISOLDE, MSU, ORNL, ANL)

indirect information about rates

from radioactive and stable beam experiments

(transfer reactions, Coulomb breakup, …)

direct reaction rate measurements

with radioactive beams

(ANL, LLN, ORNL, ISAC,...)

the $^{14}O(\alpha,p)^{17}F$ reaction

possible breakout route from HCNO cycle

LEVEL SCHEME OF ^{18}Ne

Information on ^{14}O(α,p)^{17}F reaction rate from:

- level structure of ^{18}Ne
- theoretical calculations
- inverse reaction ^{17}F(p,α)^{14}O
- some direct data

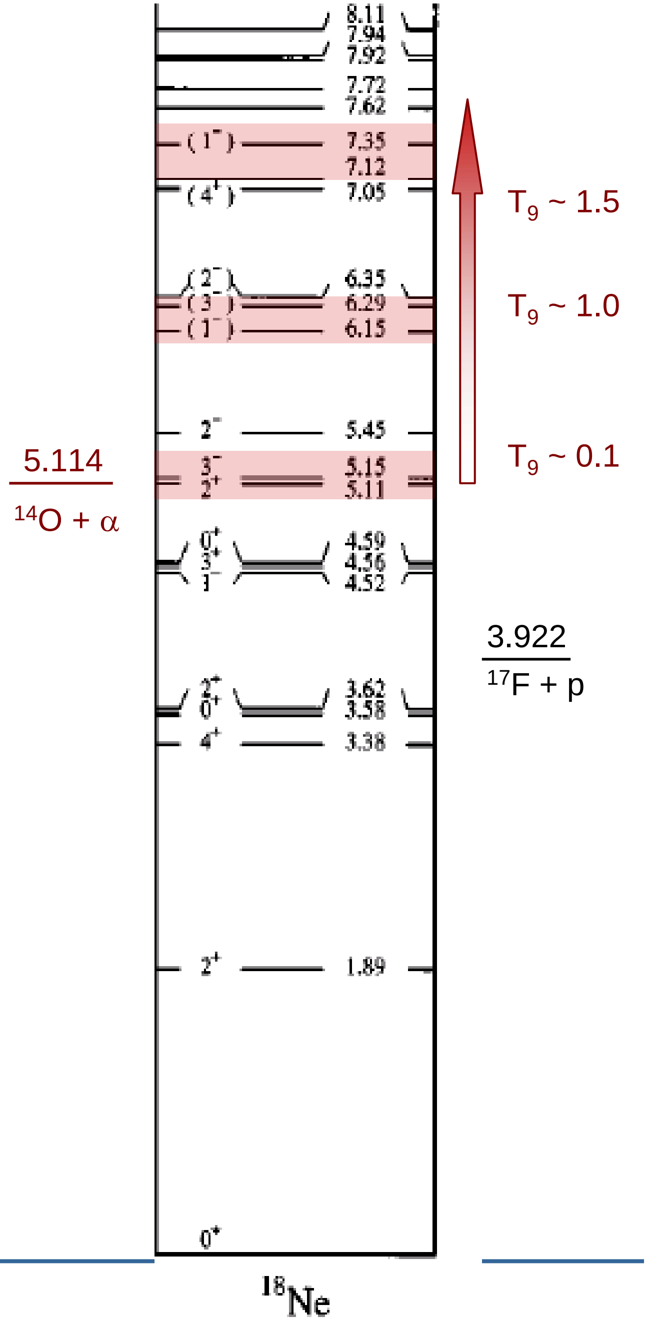
main, expected contributions to reaction rate from:

resonance at 6.15 MeV $J^{\pi} = 1^{-}$

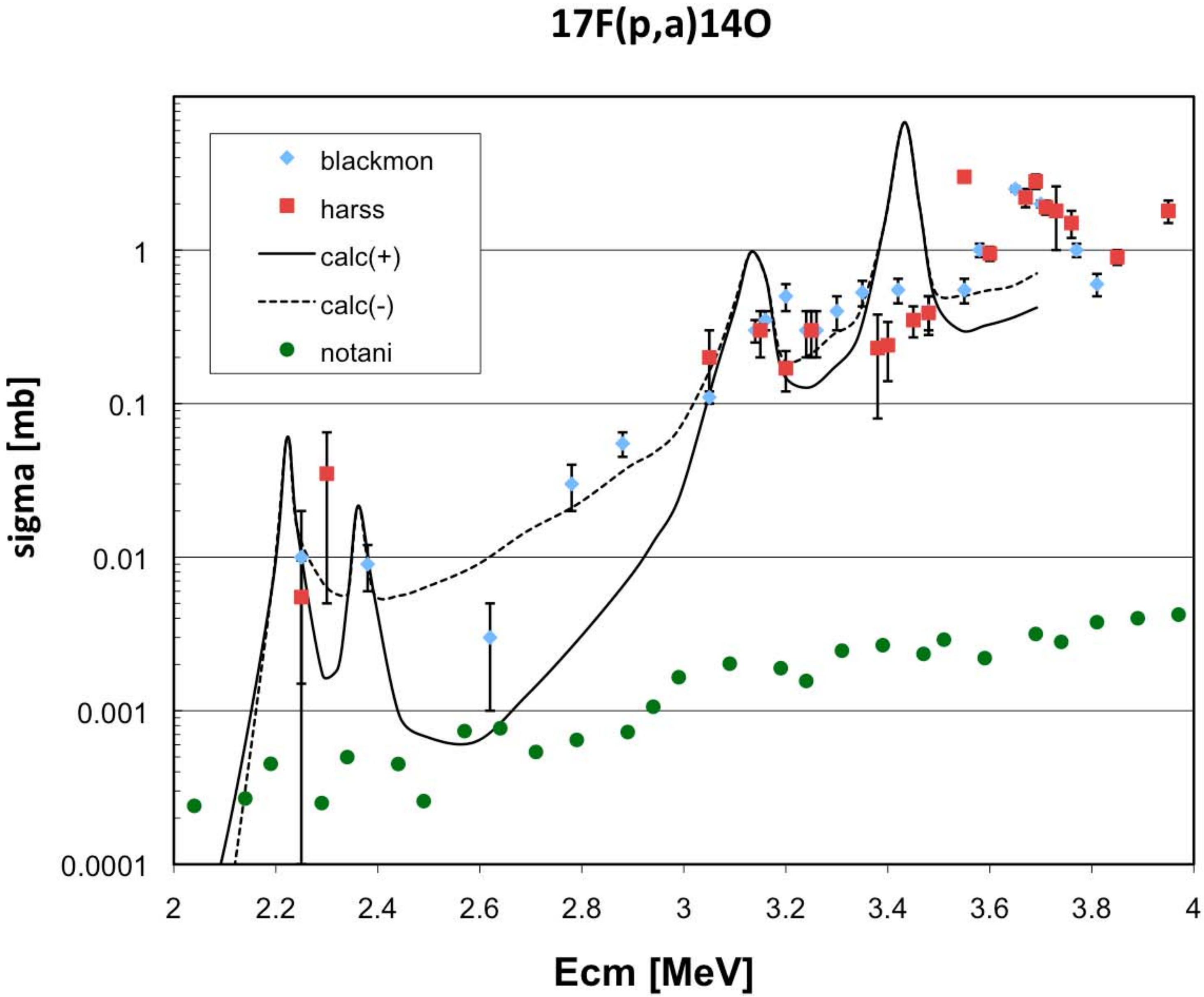
direct contribution with l =1

@ T $\leq$ 1.0x10^9 K

states at ~ 7 MeV @ T $\geq$ 1.5x10^9 K



Current status

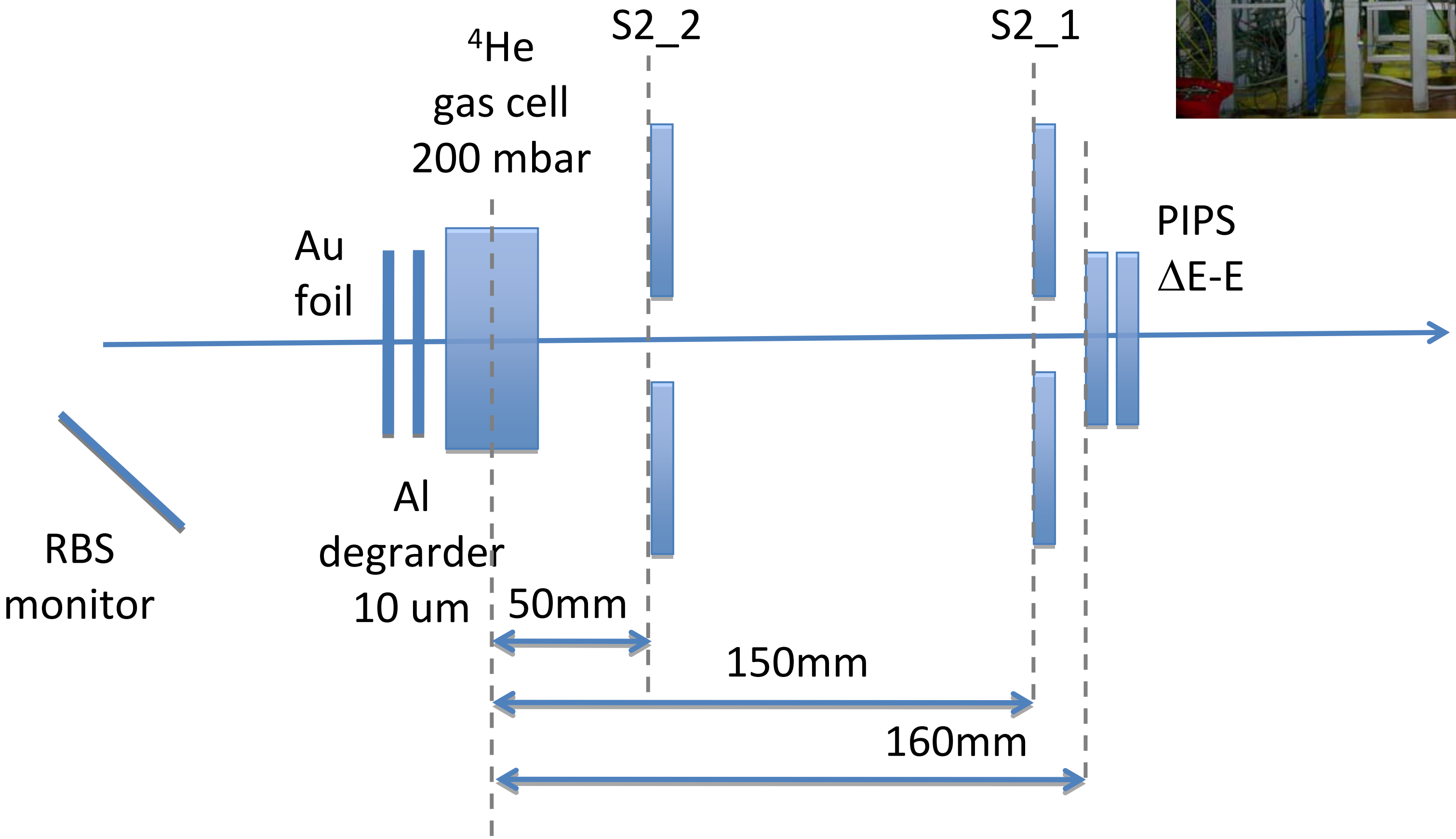


GANIL experiment (2011)

$^{14}O\ 8^{+}$ beam

E = 3.5 MeV/A

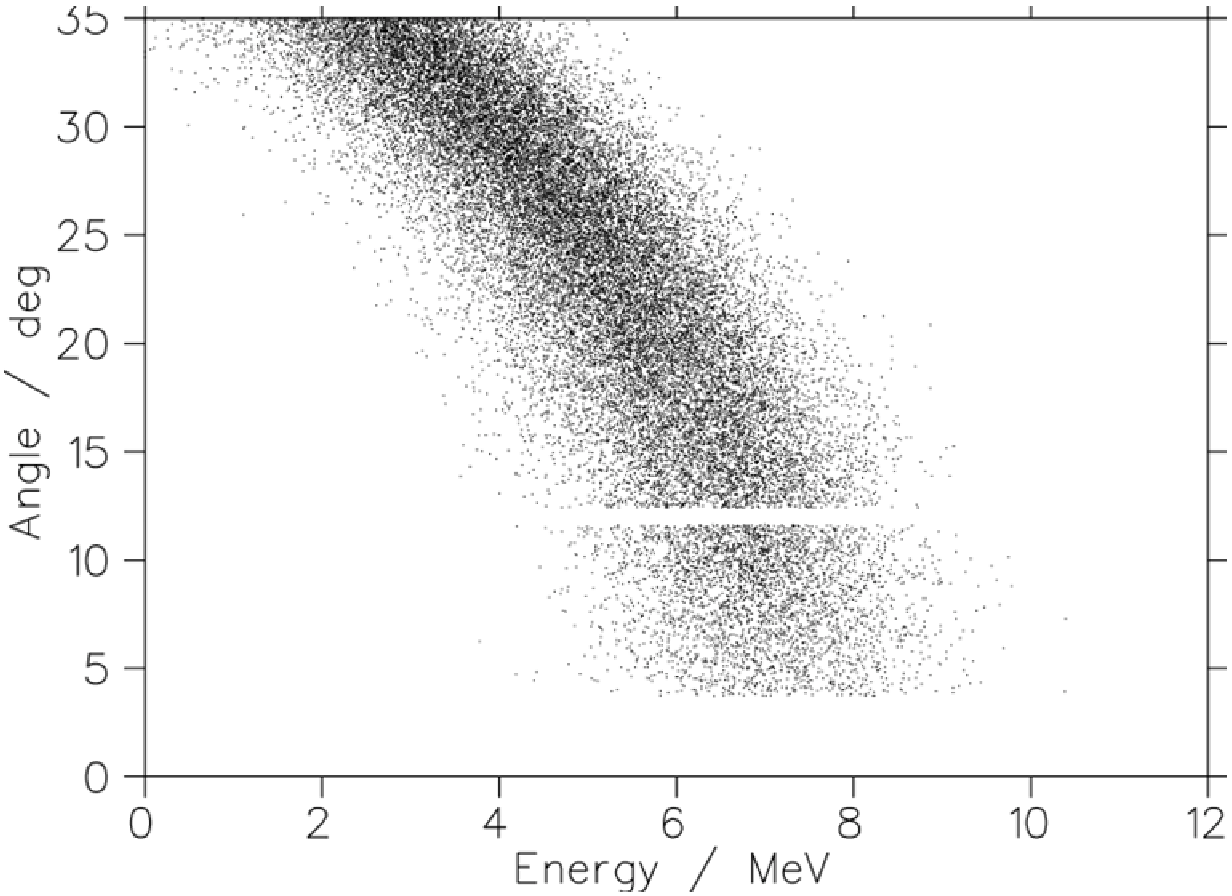
i= 10^5pps



simulations

kinematics curve for protons coming from $^{14}O(\alpha,p)^{17}F$ reaction

as seen in S2 detectors

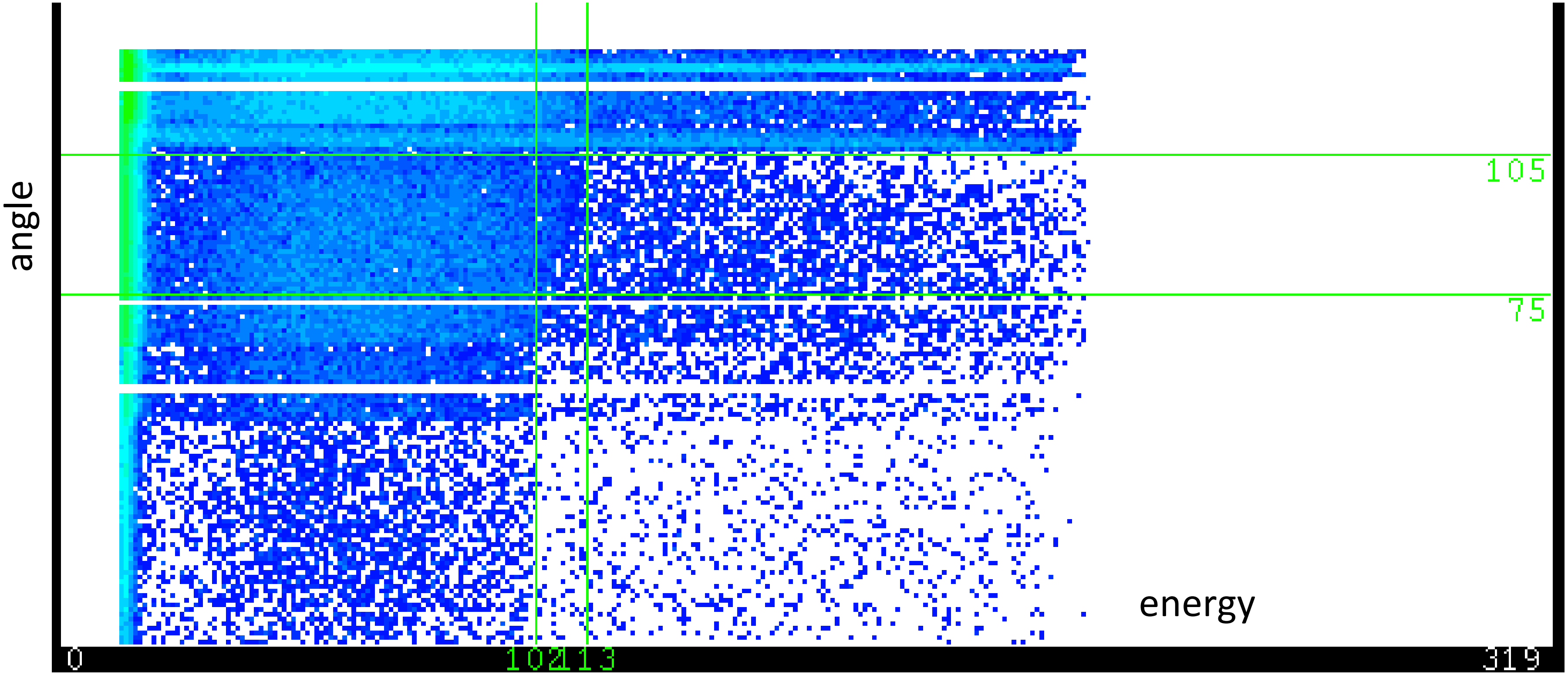


courtesy: A. Murphy

experimental data

lots of events that are NOT from $^{14}O(\alpha,p)^{17}F$ reaction

probably fusion-evaporation protons and deuterons



courtesy: A. Murphy

analysis in progress

direct studies extremely difficult because of:

- low beam intensities
- low target densities
- high background from contaminant reactions

an alternative approach

proposal to study key (α,p) reactions relevant to type I X-ray bursts by time-reversed (p,α) approach at relevant astrophysical energies

$^{18}\mathrm{Ne}(\alpha,p)^{21}\mathrm{Na}$ breakout from HCNO cycle

direct and indirect investigations exist, but uncertainties remain

$^{22}\mathrm{Mg}(\alpha,p)^{25}\mathrm{Al}$
$^{26}\mathrm{Si}(\alpha,p)^{29}\mathrm{P}$
$^{30}\mathrm{S}(\alpha,p)^{33}\mathrm{Cl}$
$^{34}\mathrm{Ar}(\alpha,p)^{37}\mathrm{K}$

possible waiting points in type I X-ray bursts

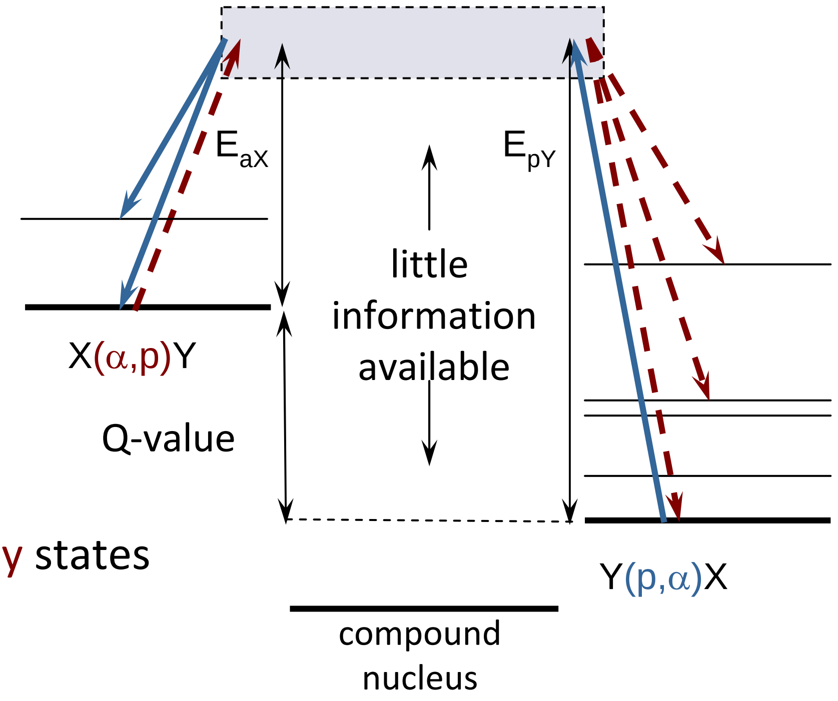
no experimental data available

the methodology

time-reversed approach: X(α,p)Y ⇔ Y(p,α)X

detailed-balance theorem

$$\frac{\sigma_{\alpha X}}{\sigma_{pY}} = \frac{m_p m_Y}{m_\alpha m_X}\,\frac{E_{pY}}{E_{\alpha X}}\,\frac{(2J_p+1)(2J_Y+1)}{(2J_\alpha+1)(2J_X+1)}$$



direct approach: spin-less particles

⇒ populate only natural parity states

indirect approach: no selectivity

However! kinematic selection on transitions between ground states

⇒ ensure only natural parity states have been populated

main limitation: only ground-state to ground-state transitions

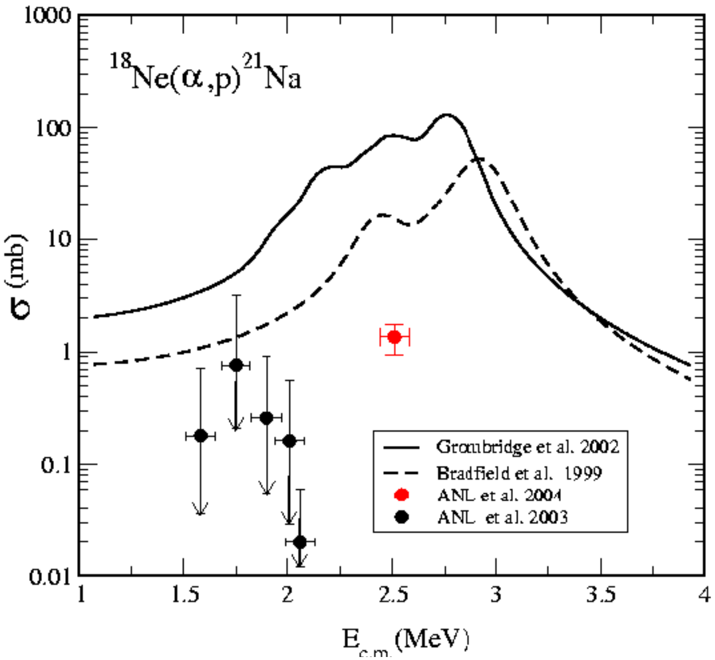
⇒ lower limit to cross section

the $^{18}Ne(\alpha,p)^{21}Na$ reaction

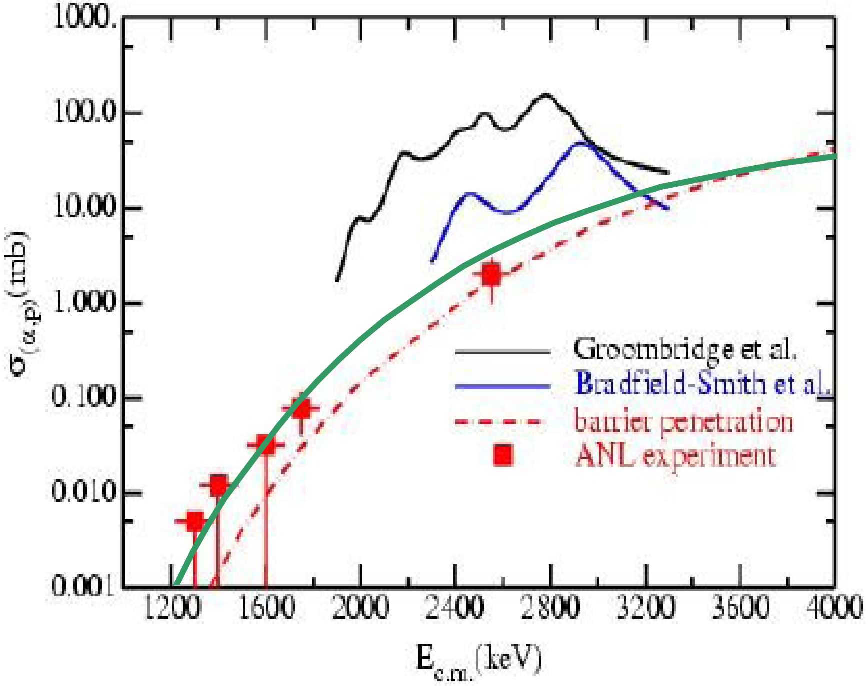
possible breakout route from HCNO cycle

^{18}Ne(a,p)^{21}Na : current status

Argonne National Laboratory
Internal Report 2004



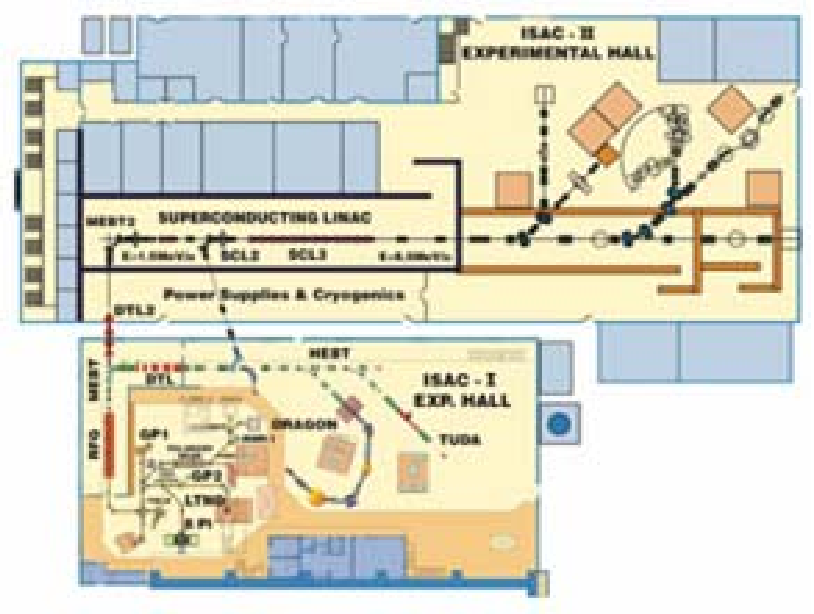
Argonne National Laboratory
Internal report 2005



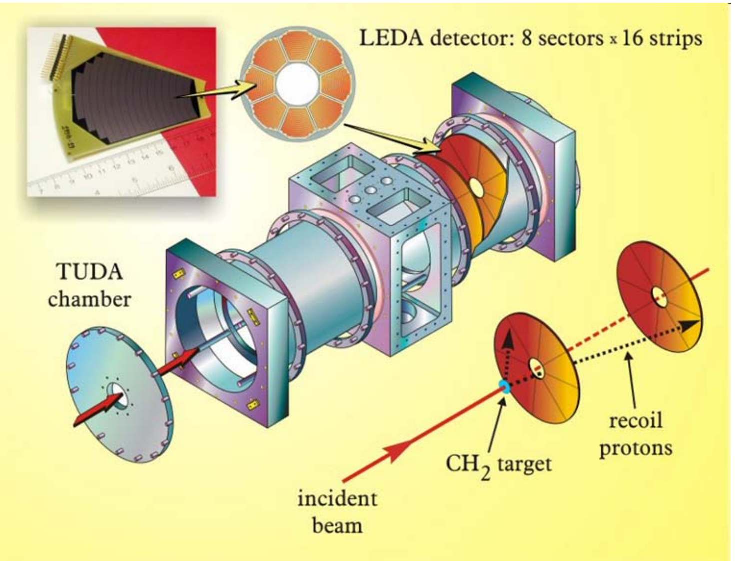
- two direct measurements
- one time-reversed measurement (unpublished)
- theoretical prediction (Hauser-Feshbach)
- large discrepancies remain
- recent studies of ^{22}Mg states (up to 12-13 MeV)
  e.g. via ^{24}Mg(p,t)^{22}Mg – Chae (2009); Matic (2009)
- resonant elastic scattering - He (2008, 2009)

^{21}Na(p,α)^{18}Ne

Experiment run in August 2009



TUDA scattering chamber



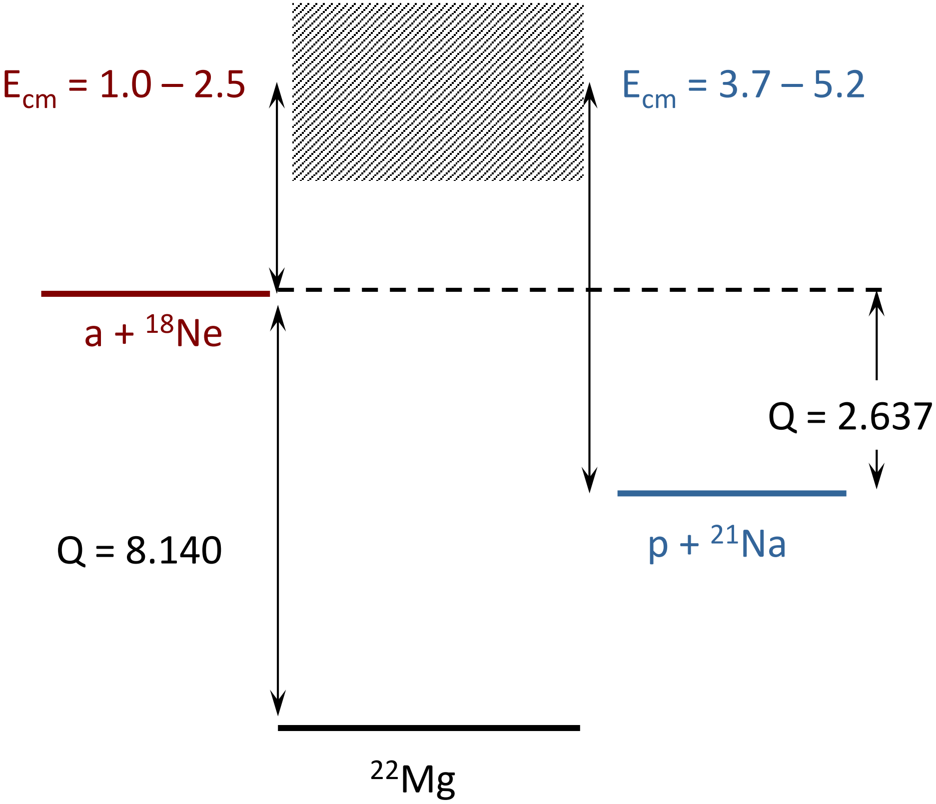
S1103 Collaboration

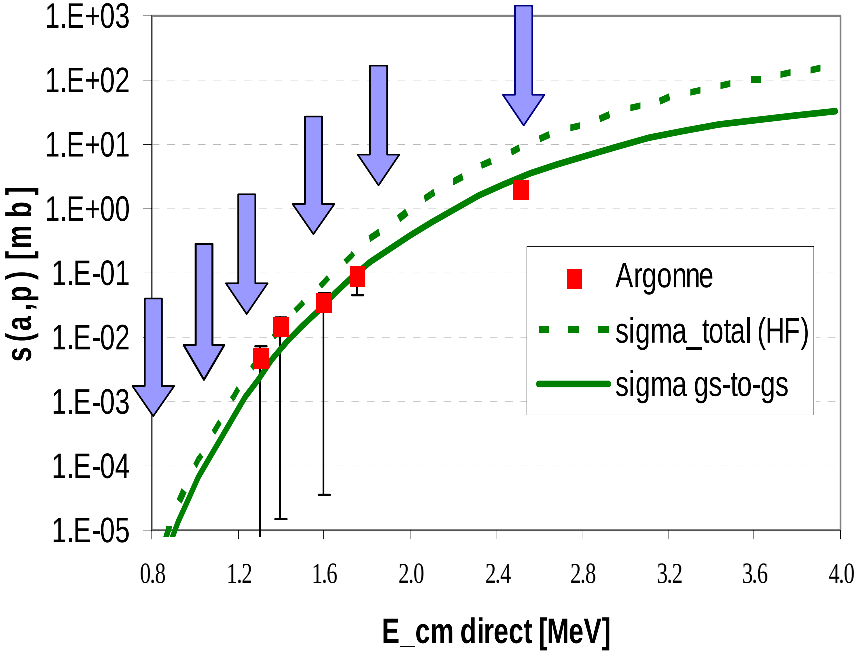
University of Edinburgh - University of York - TRIUMF

proposed experiment: ^{18}Ne(a,p)^{21}Na

Aims: 1) investigate energy range E_{cm} ~ 1.0 – 2.5 MeV
by time-reverse approach (E_{cm} ~ 3.6 – 5.2 MeV)

2) investigate resonant states in ^{22}Mg (E_r ~ 8.5 – 10.1 MeV)
by resonant elastic scattering


(all energies in MeV)



Experimental setup @ ISAC II

^{21}Na 5^{+} beam

I ~ 5x10^{6} pps

E ~ 5.5 – 3.8 MeV/u

CH$_2$ target

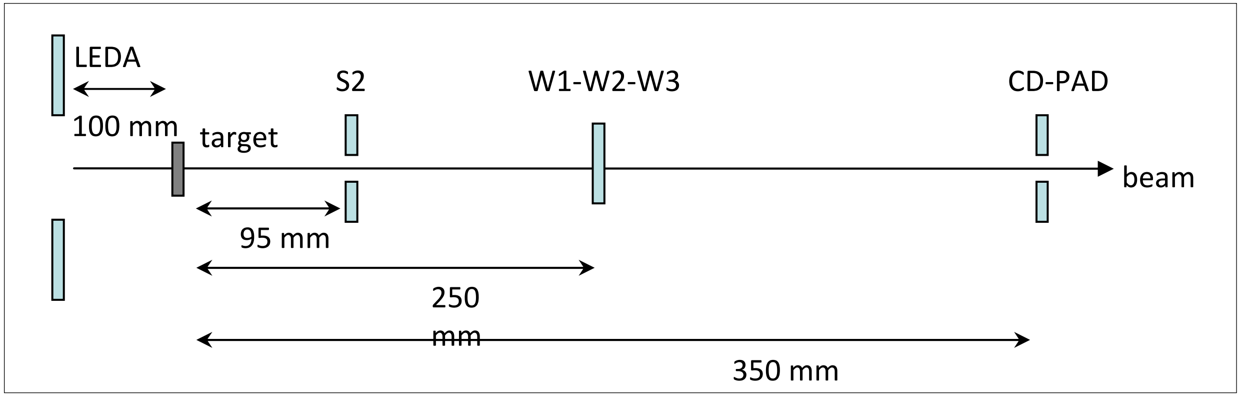
W: protons (alphas)

aim

mea nt elastic proton scattering

(thic asurement)

LEDA: RBS on Au spot



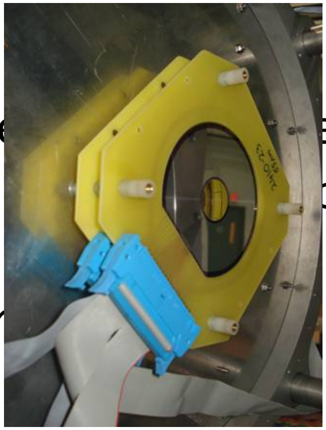
aim 1): measure eld for ^{18}Ne+alpha

particle by ΔE-E technique

(thin tar ents)

S2 detector:

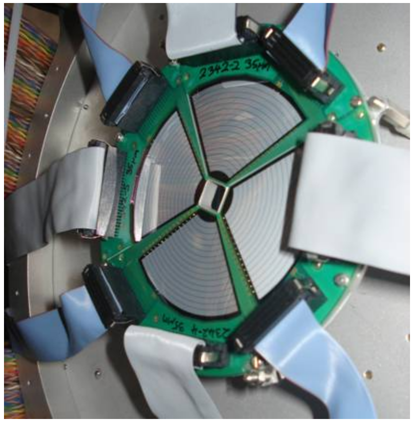
alpha particles



CD-PAD:

heavy ions

^{18}Ne, ^{21}Na

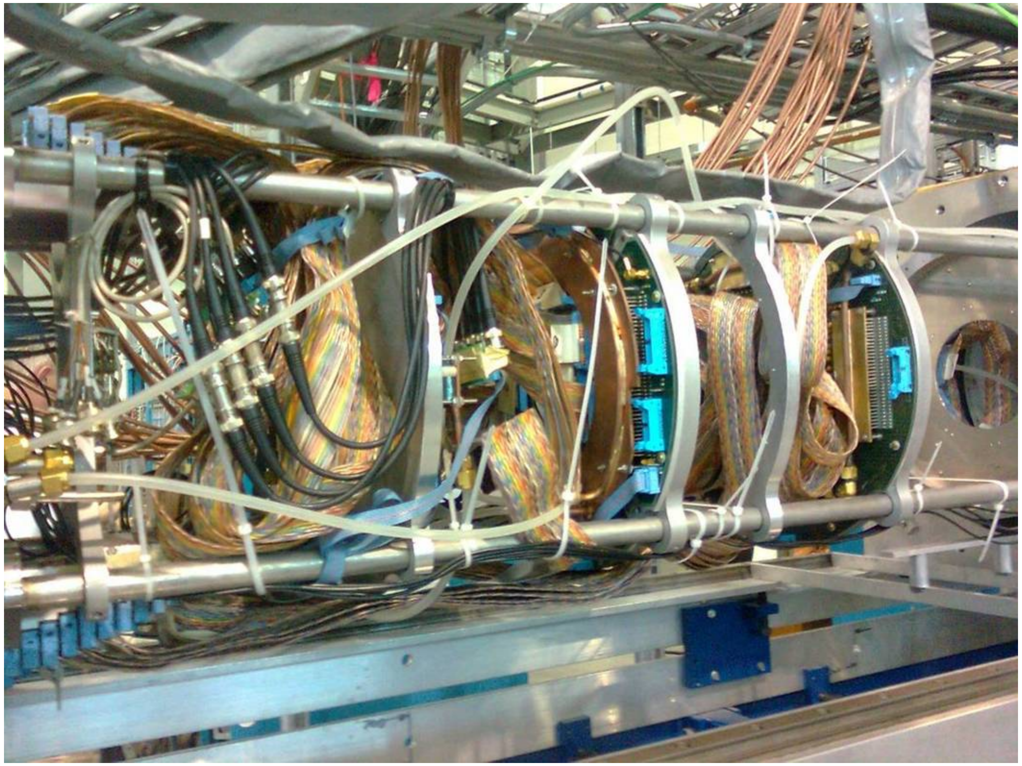


Experimental setup @ ISAC II

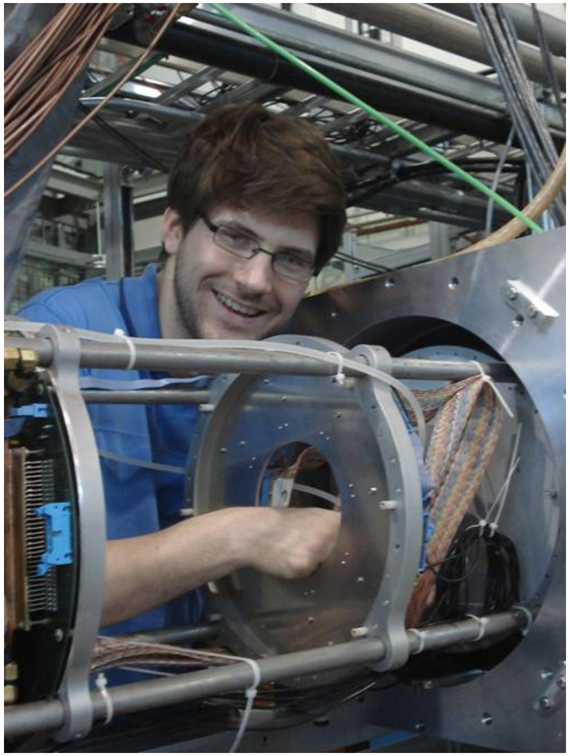
~420 individual channels

largest number ever of silicon detector channels in TUDA

a messy situation…



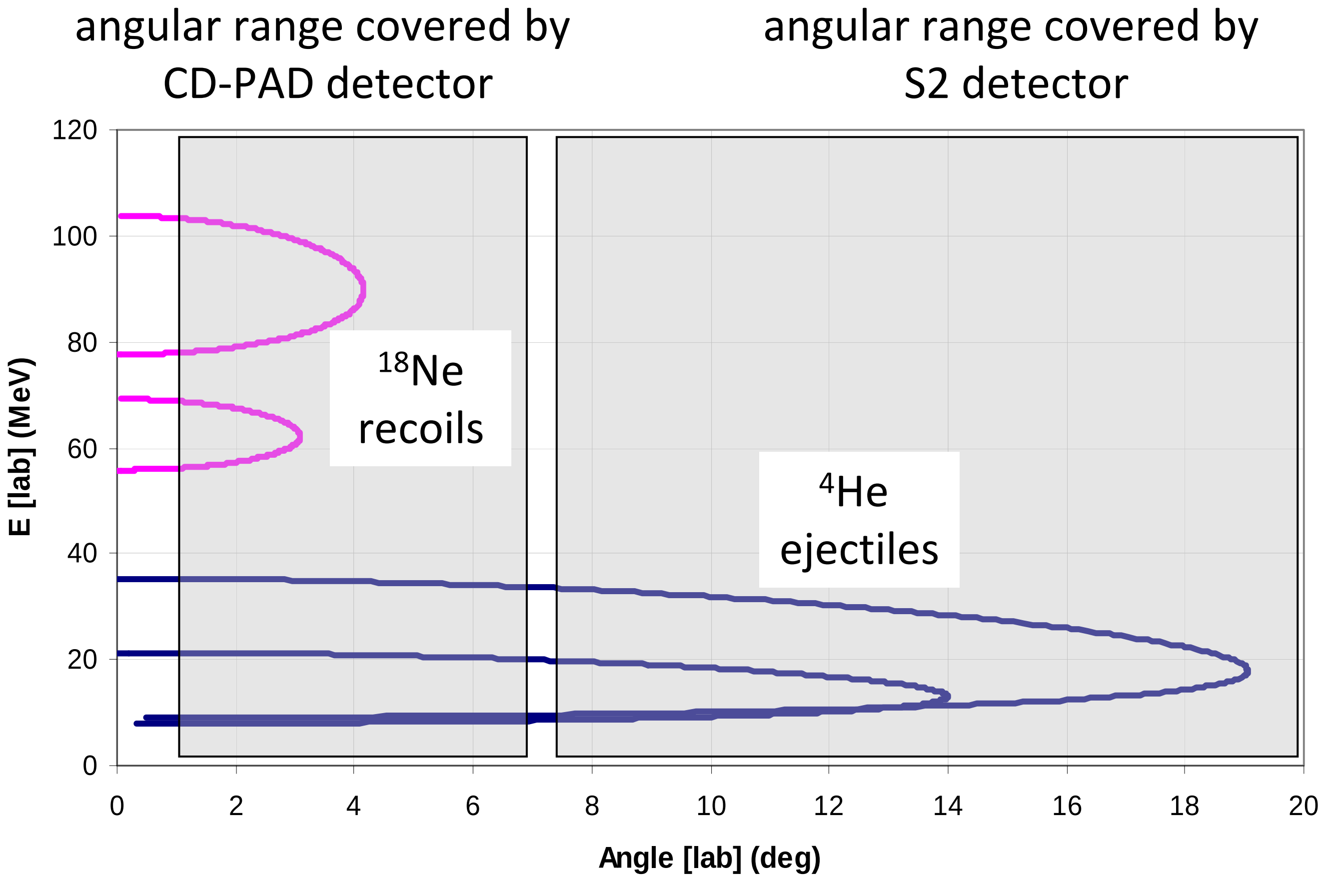
Philip Salter



kinematics curves

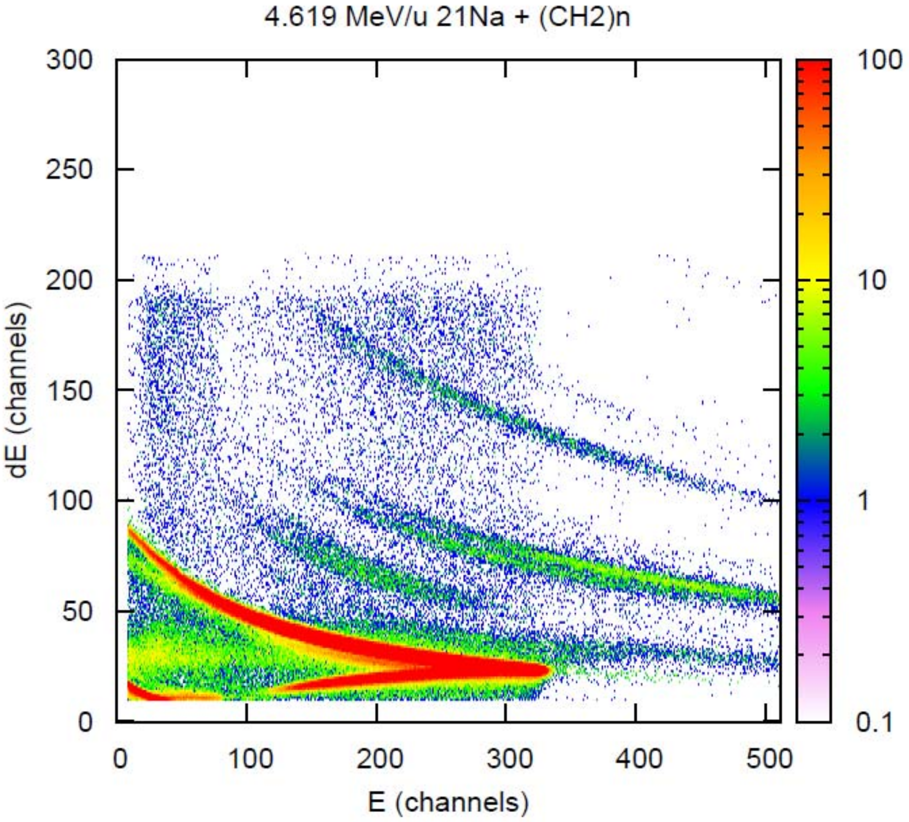
$^{21}Na(p,a)^{18}Ne$ kinematics at E_{beam} = 115 – 80 MeV

inverse kinematics ⇒ forward focussed reaction products

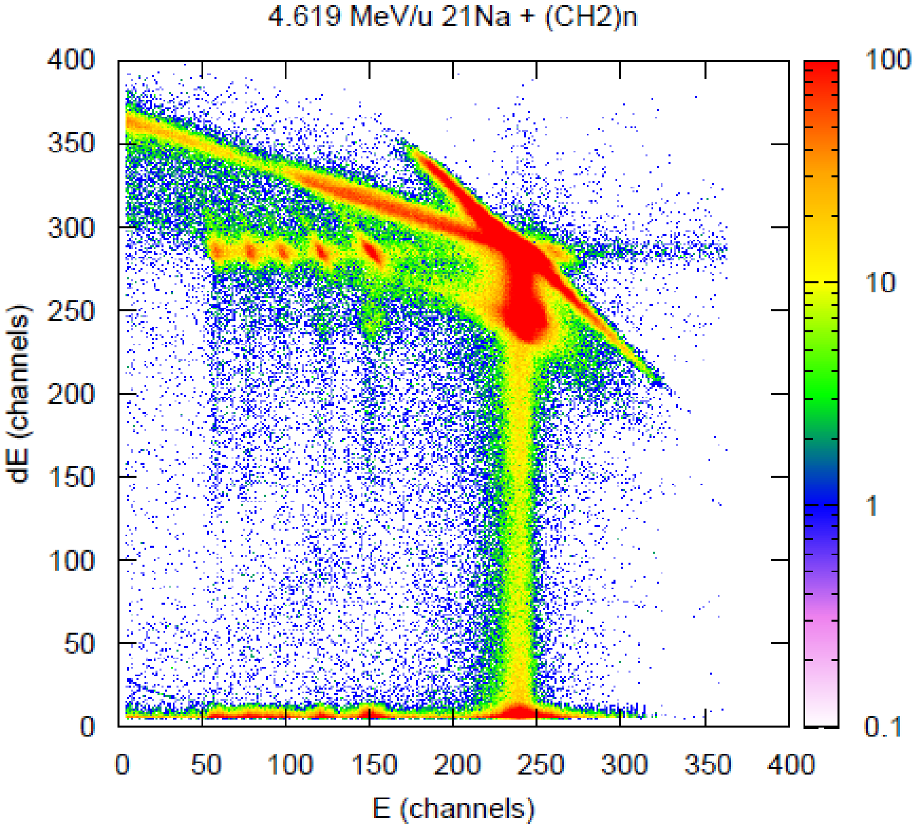


Collected data

alpha particles in S2 detector



heavy ions in CD-PAD detector

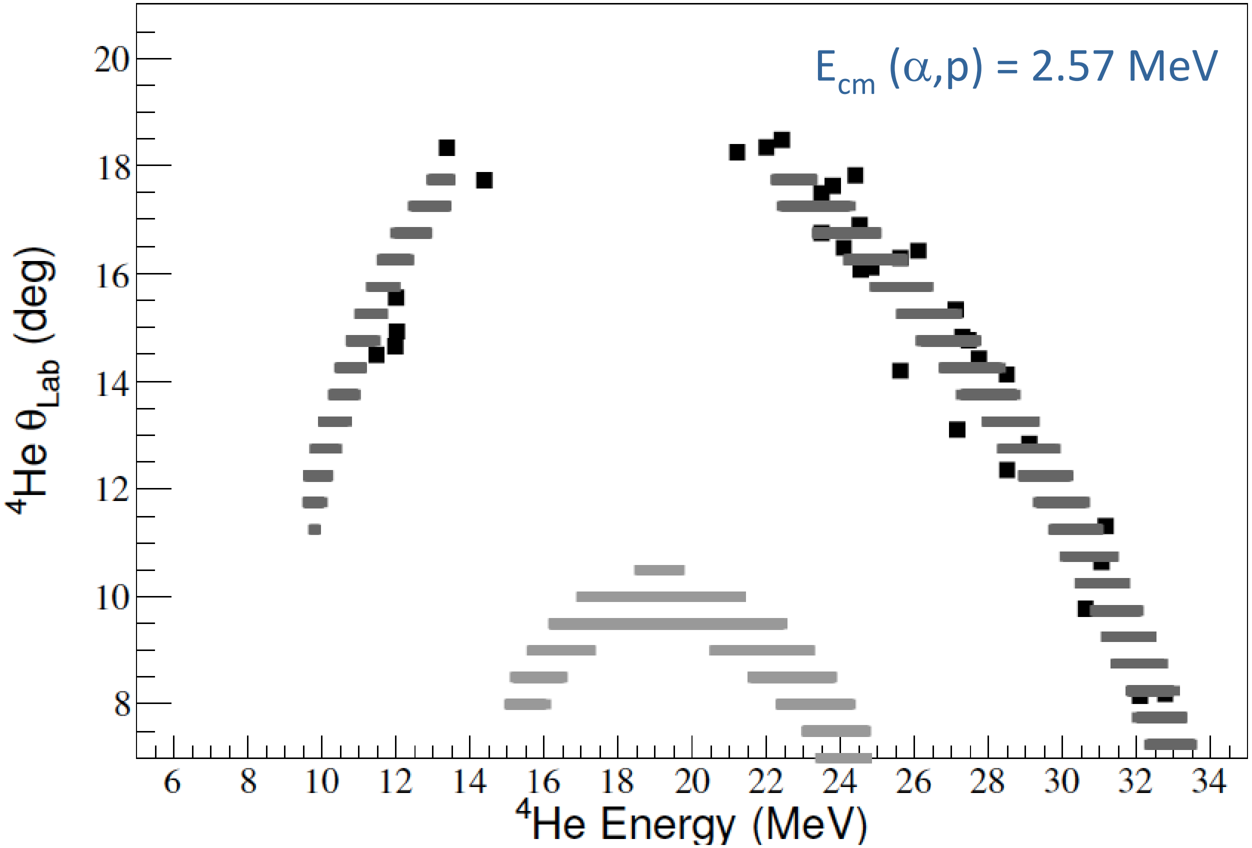


particle identification and event selection obtained by:
two-body co-planarity; ΔE-E technique; total energy reconstruction

Our Results

alpha kinematics loci (experimental and simulated)

alpha particles in coincidence with 18Ne in CD-PAD



Salter *et al*. PRL 108 (2012) 242701

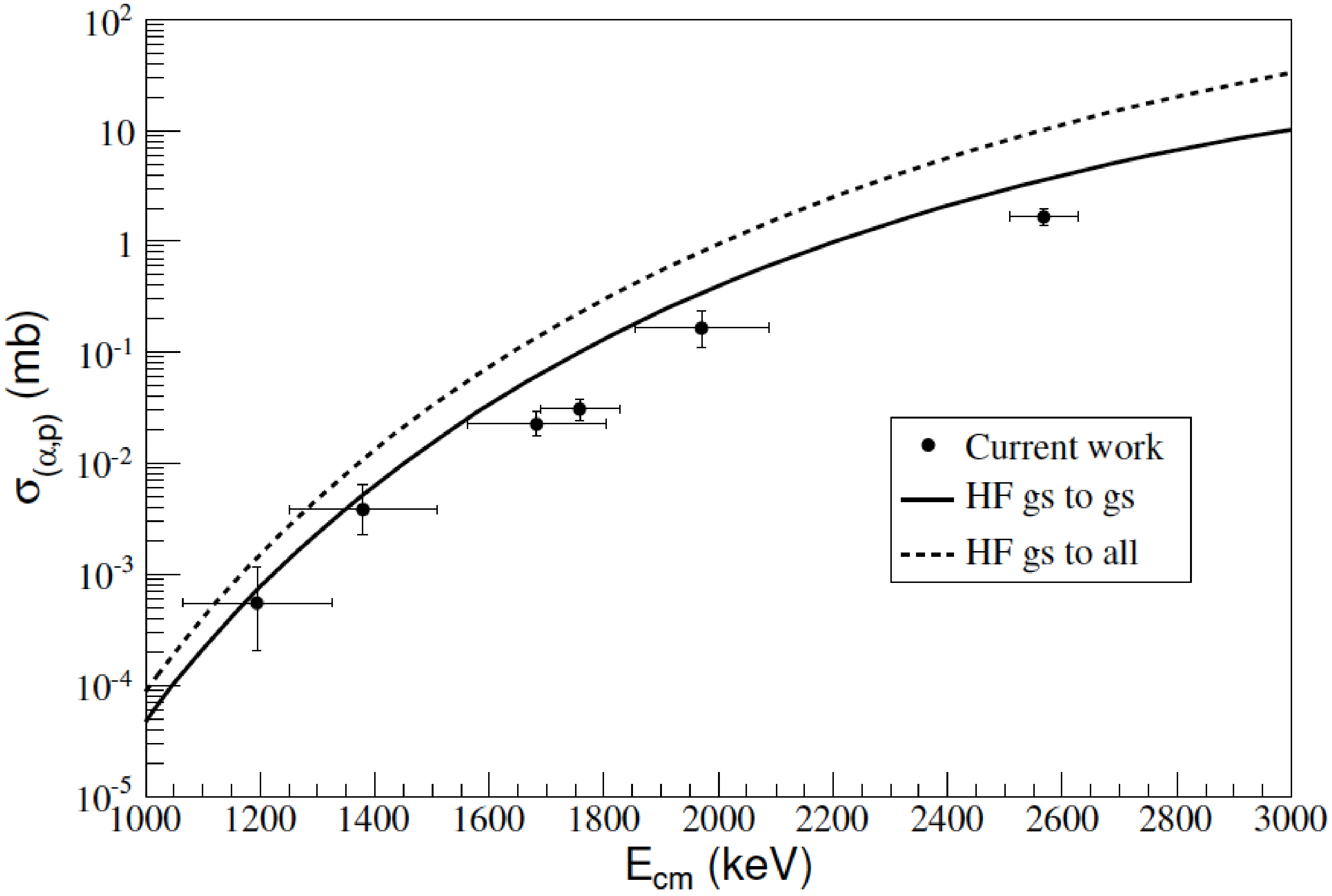
distinguish gs-gs transition from gs to 1.89 MeV in ^{18}Ne

no events observed to first excited state of 18Ne

Our Results

^{18}Ne(α,p)^{21}Na total reaction cross section

(gs transitions only)

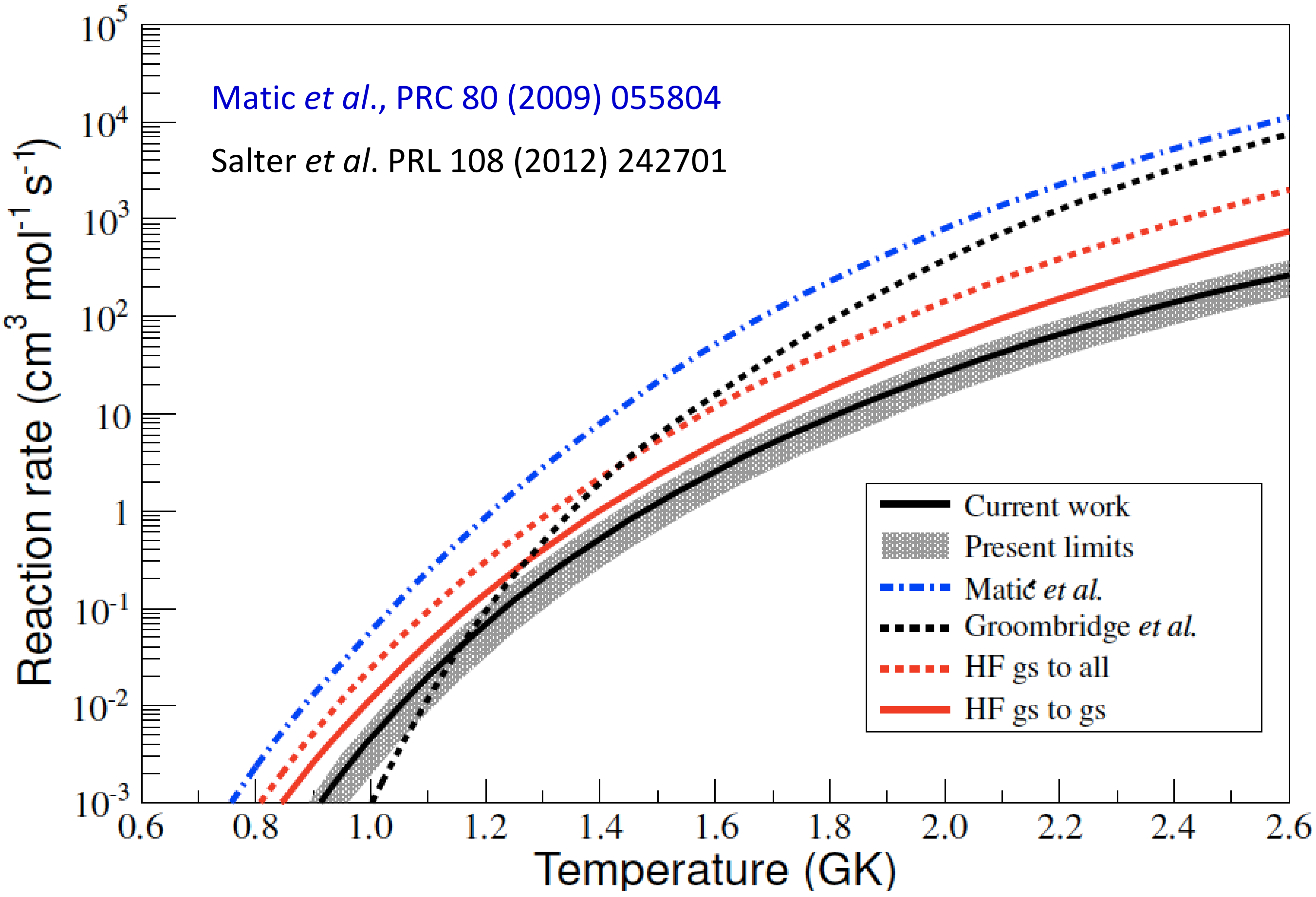


Salter *et al*. PRL 108 (2012) 242701

- good agreement with HF_{gs} at low energies
- but factor of 2-3 lower at higher energy

Our Results

Stellar reaction rate $^{18}\mathrm{Ne}(\alpha,p)^{21}\mathrm{Na}$

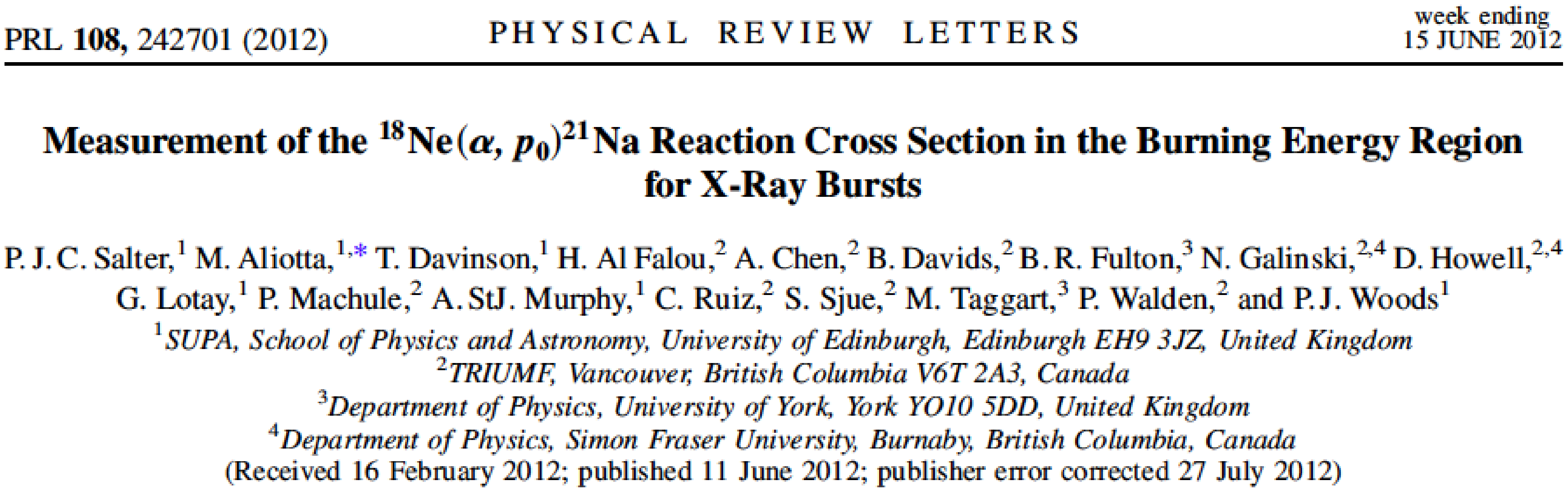


Matic *et al*., PRC 80 (2009) 055804

Salter *et al*. PRL 108 (2012) 242701

- different temperature dependence w.r.t. Groombridge rate
- up to a factor of ~25 lower than HF$_{gs}$ at T=2.4 GK
- up to a factor of ~40 lower than Matic at T=2.4 GK

Summary and Conclusions



PRL **108,** 242701 (2012) PHYSICAL REVIEW LETTERS week ending 15 JUNE 2012

Measurement of the $^{18}\mathrm{Ne}(\alpha, p_0)^{21}\mathrm{Na}$ Reaction Cross Section in the Burning Energy Region for X-Ray Bursts

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(Received 16 February 2012; published 11 June 2012; publisher error corrected 27 July 2012)

- ^{18}Ne(a,p_0)^{21}Na reaction cross section is a factor of 2-3 lower than HF$_{gs}$ calculations
- lowest energy measurement to date into Gamow peak (T =1.5-2.0 GK) of X-ray bursts
- reaction rate up to factor 40 lower than previous (indirect) studies
- expect breakout from HCNO to occur at higher temperatures
- need for detailed hydrodynamic calculations

with special thanks also to:

H Al Falou, A Chen, B Davids, B Fulton, N Galinski, D Howell,
A StJ Murphy, C Ruiz, S Sjue, M Taggart, P Walden, PJ Woods

Remarks

Remarks & Outlook

- direct measurements with RIBs are difficult (RIBs availability & intensities)
- time-reversal approach promising technique for (α,p) reactions
- results for ^{18}Ne(α,p)^{21}Na reaction

Future

- ^{37}K(p,α)^{34}Ar proposal accepted at TRIUMF (December 2009)

  + proposal at CERN (October 2012)

  + LoI at Texas A&M College Station (October 2011)

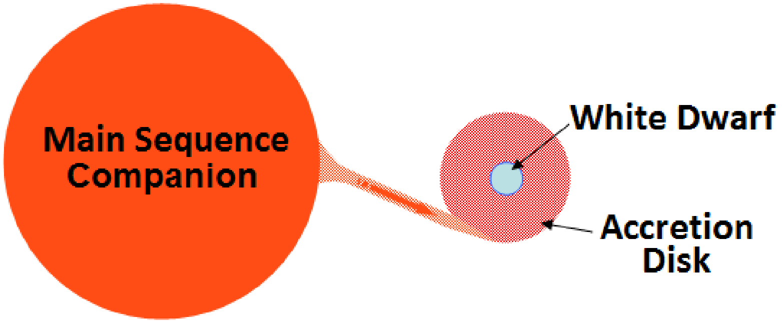
- ^{29}P(p,α)^{26}Si and ^{33}Cl(p,α)^{30}S LoI at GANIL (January 2010) and CERN (October 2010)

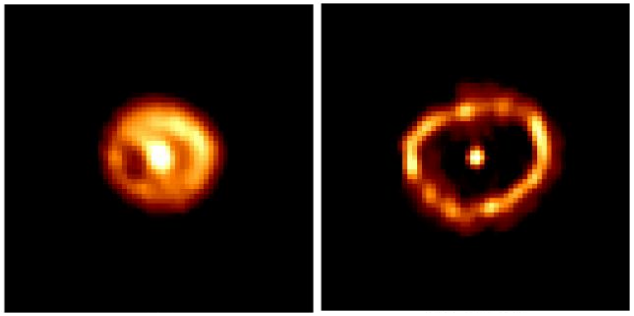
the $^{17}O(p,\gamma)^{18}F$ reaction

source of 18F in Novae

Astrophysical Motivation

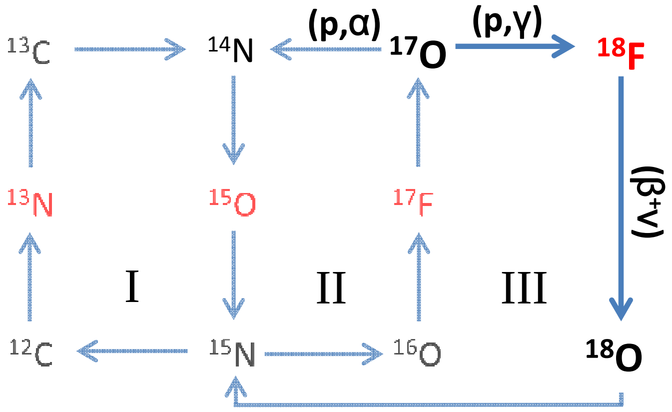
- **Classical Novae**





(Cygni 1992)

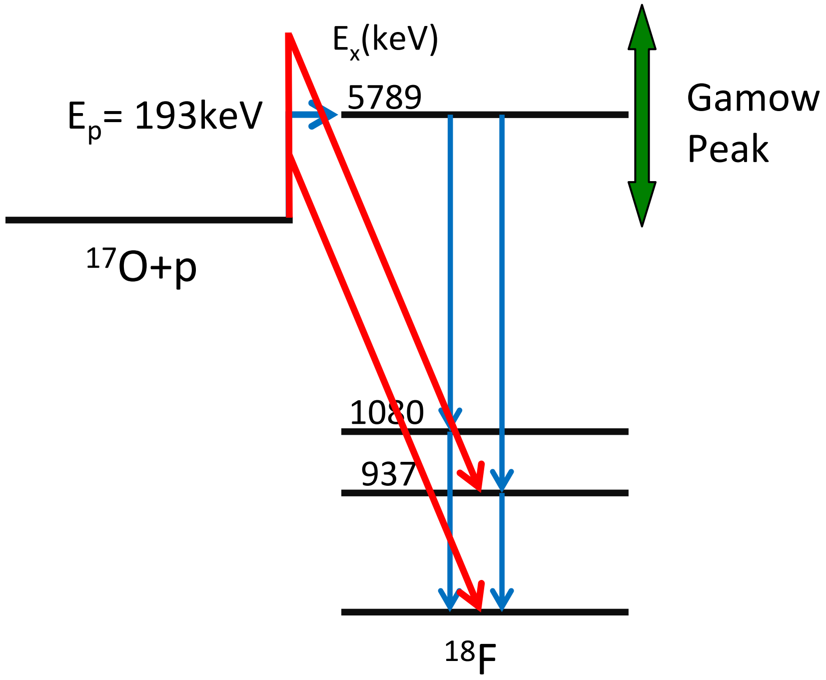
- Significant source of ^{17}O, ^{15}N and ^{13}C
- Reactions: **^{17}O(p,γ)^{18}F** and **^{17}O(p,α)^{14}N**



- **Annihilation 511 keV gamma-rays** following β^{+} decay of ^{18}F ($t_{1/2}$=110 mins)
- Potential **constraints on current novae models**

The $^{17}O(p,\gamma)^{18}F$ Reaction in Novae

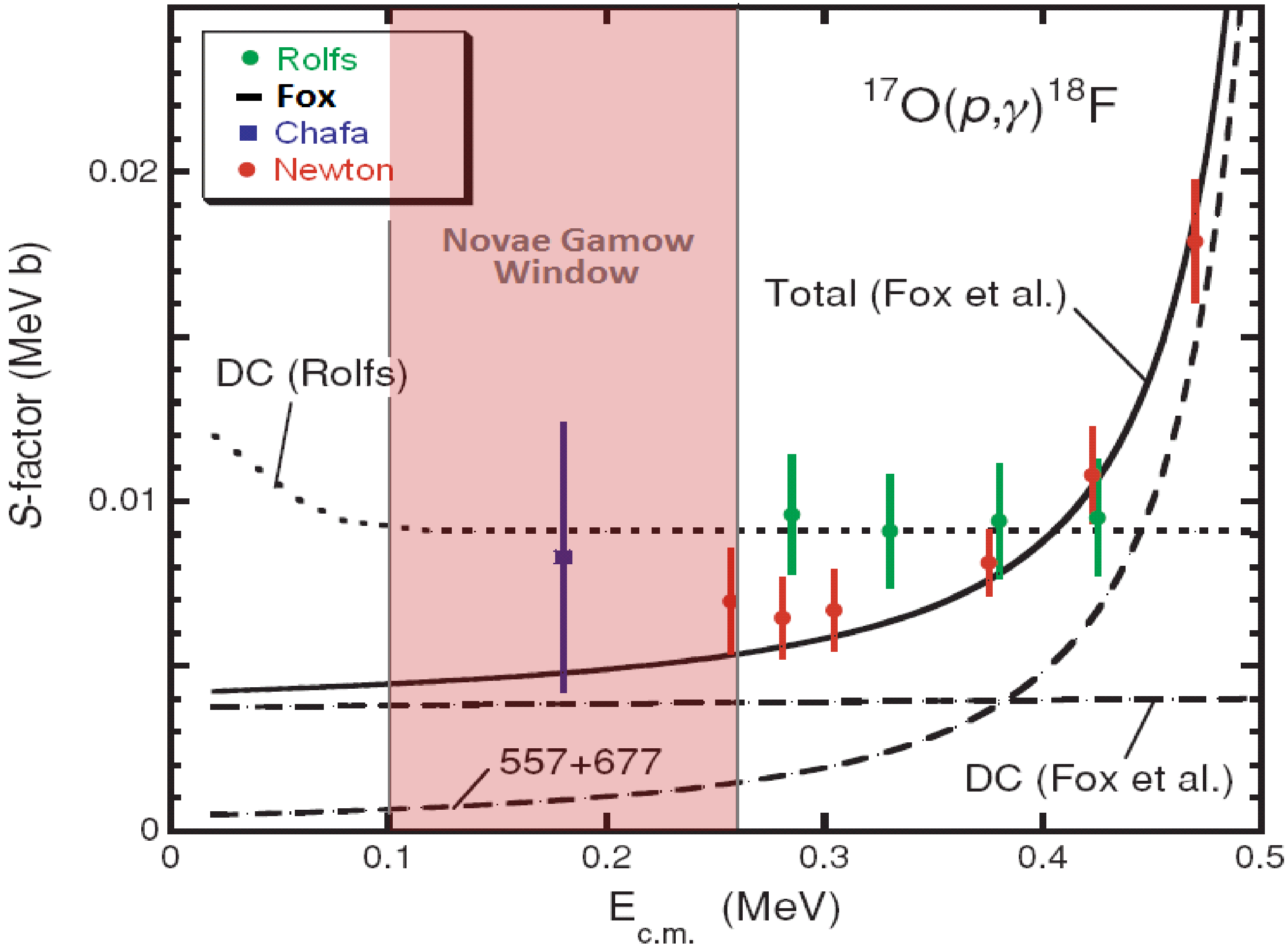
- T=0.1-0.4 GK
  E_0= 100 – 260 keV
- resonant contribution
  E_p = 193 keV
- non-resonant contributions
  DC + low-energy tails from broad high-energy resonances



$\omega\gamma_{193}$= (1.2±0.2)×10^{-6} eV [Fox *et al.* Phys. Rev. C 71, 055801 (2005)]
$\omega\gamma_{193}$= (2.2±0.4)×10^{-6} eV [Chafa *et al.* Phys. Rev. C 75, 033810 (2007)]

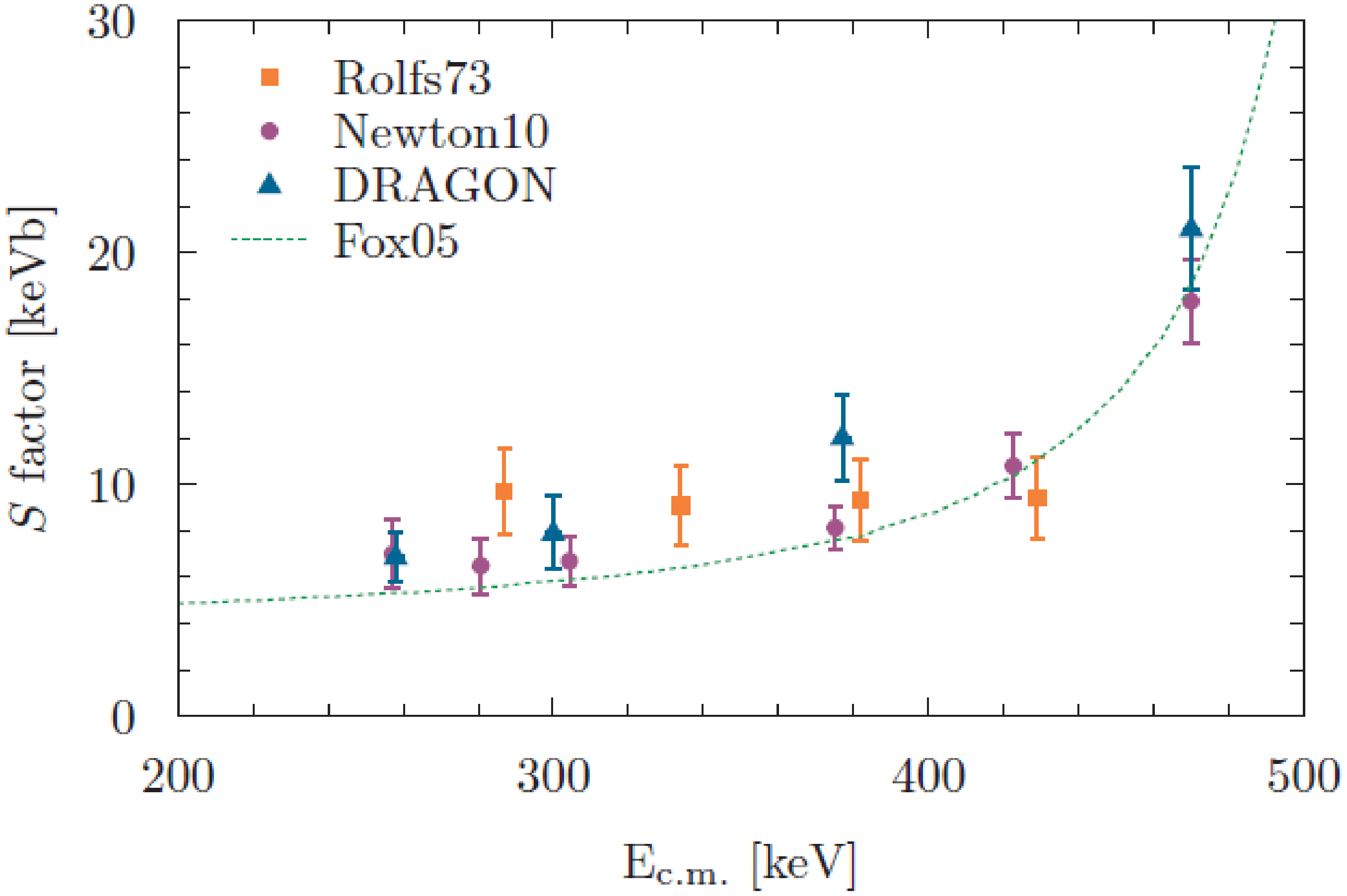
factor ~2 discrepancy

The $^{17}O(p,\gamma)^{18}F$ Reaction S-factor



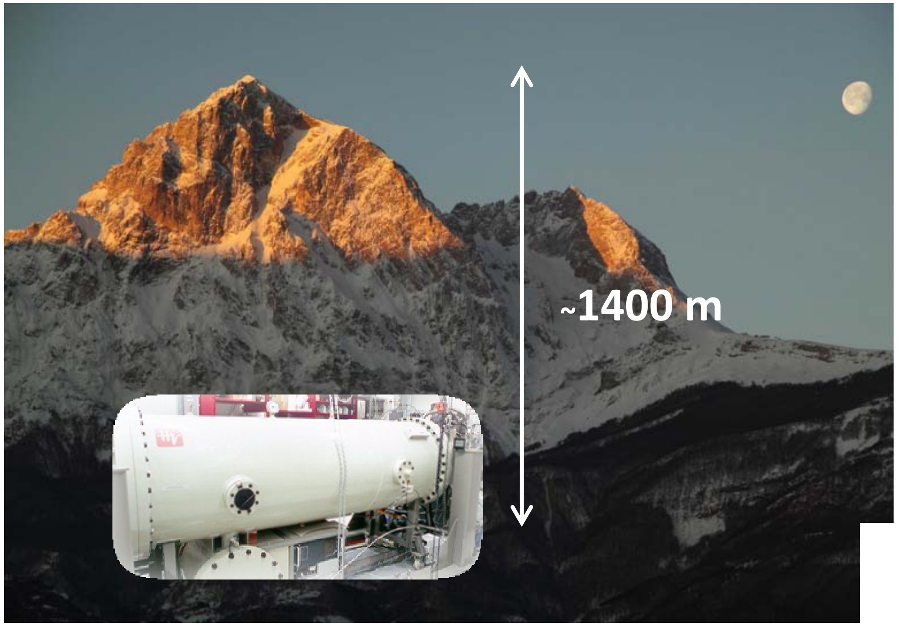
- Rolfs *et al.* Nuc. Phys. A217 29-70 (1973)
- Fox *et al.* Phys. Rev. C 71, 055801 (2005)
- Chafa *et al.* Phys. Rev. C 75, 033810 (2007) (activation measurement)
- Newton *et al.* Phys. Rev. C 81, 045801 (**2010**) (E_{cm} = 257 – 470 keV measurement)

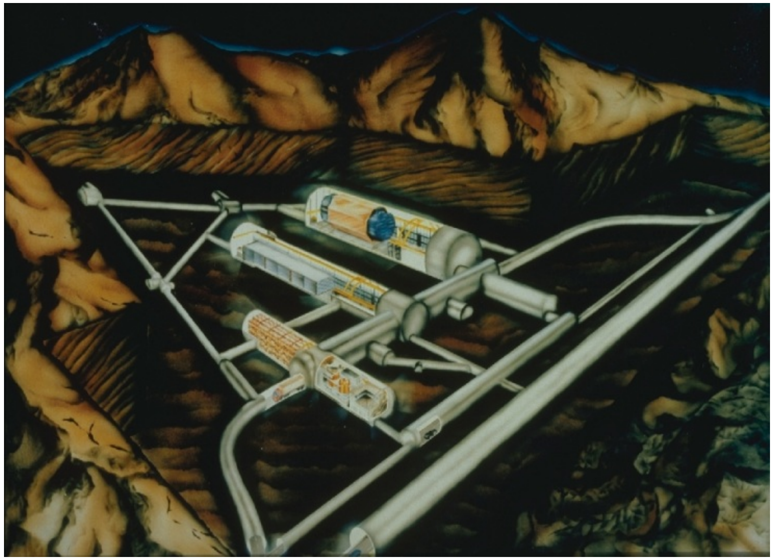
The $^{17}O(p,\gamma)^{18}F$ Reaction S-factor

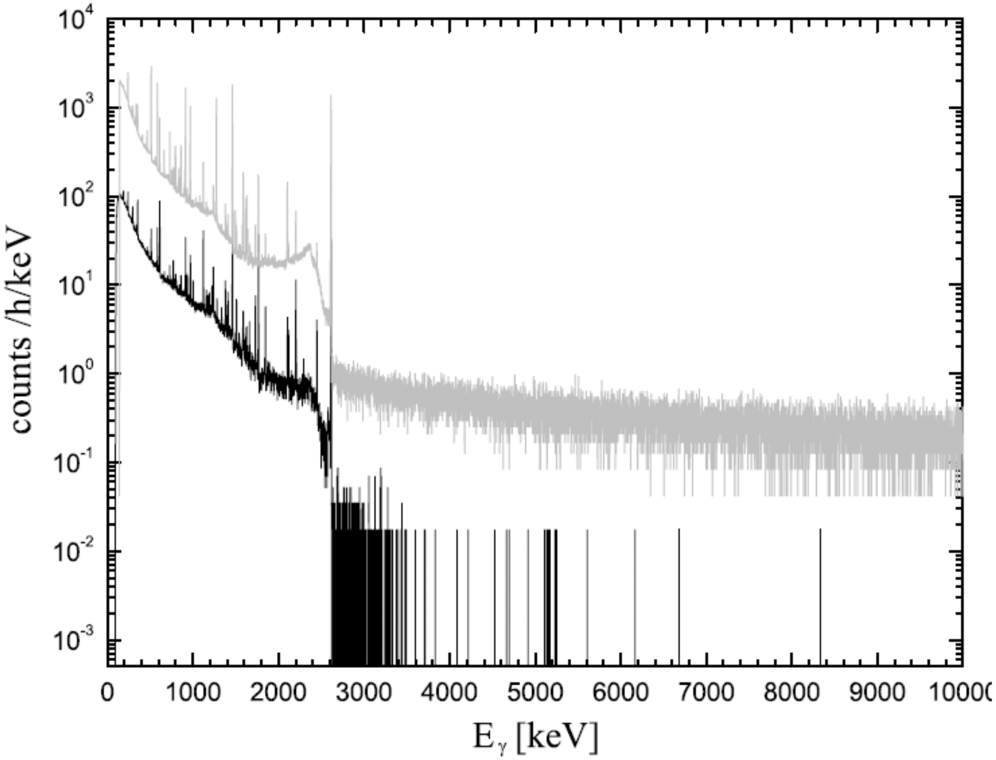


Hager *et al.* Phys. Rev. C 85, 035803 (2012) (Inverse kinematics at DRAGON)

The LUNA Accelerator at Gran Sasso





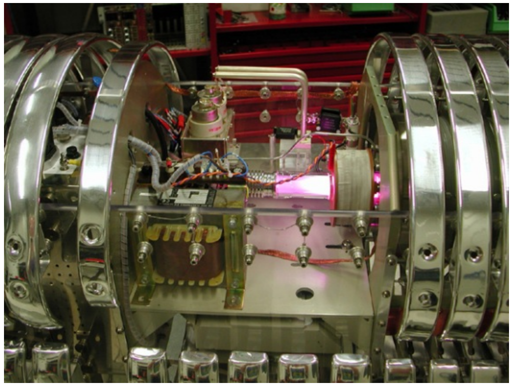


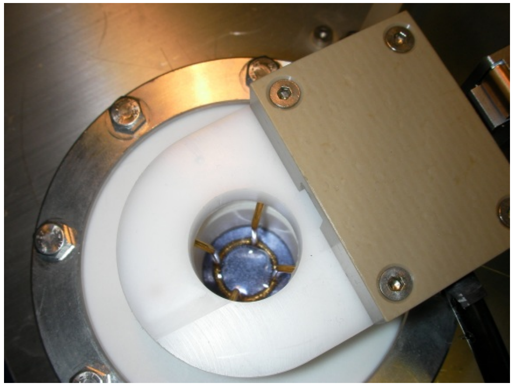
Experimental approach and setup

activation measurement
prompt-gamma detection

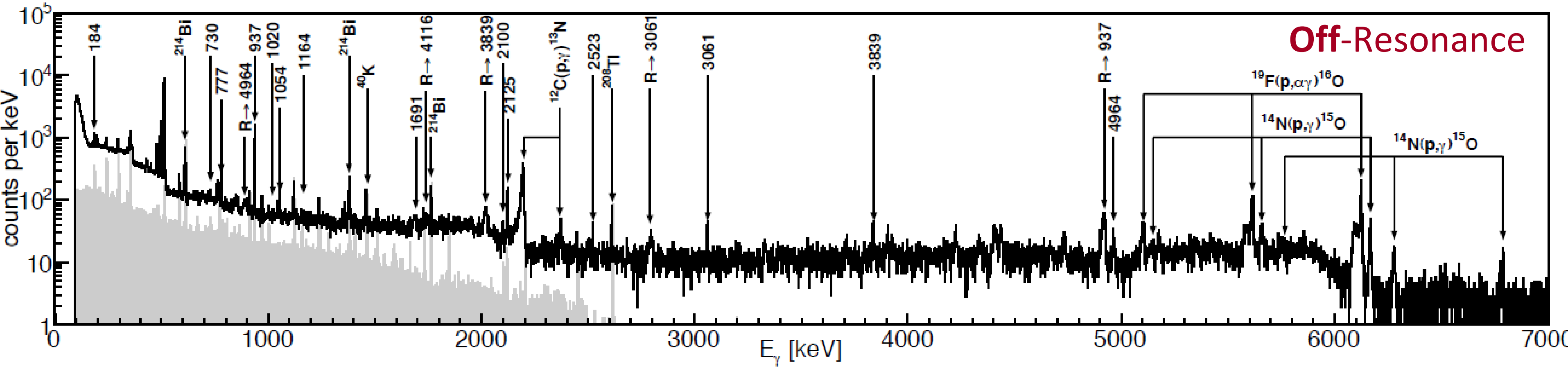
resonant and non-resonant contributions

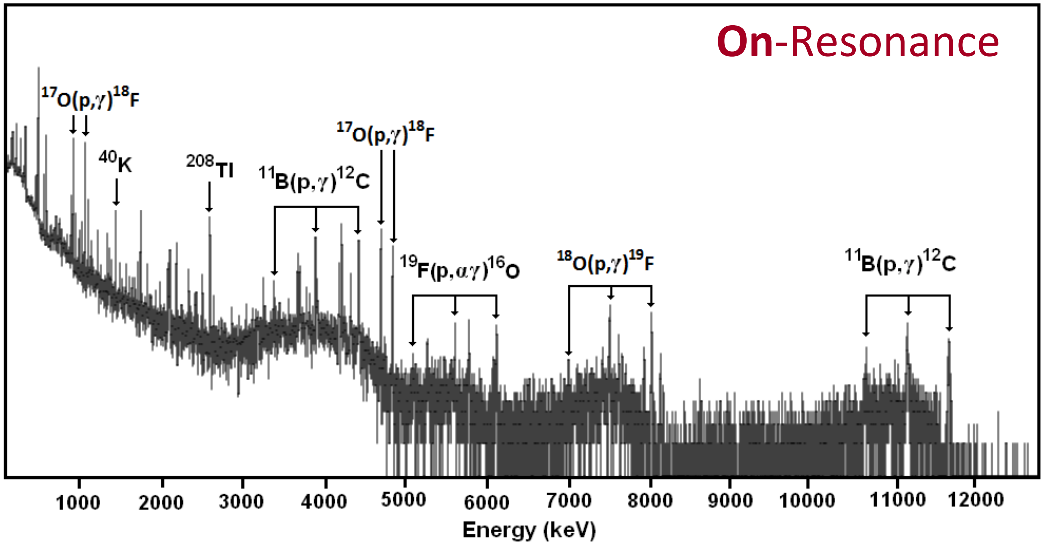
- 400 kV electrostatic accelerator
- up to **400 keV protons** with a **maximum current ~400 μA**
- **70% Enriched ^{17}O targets** on tantalum backings (prepared via anodization)
- ~5cm of **lead shielding** surrounding detector

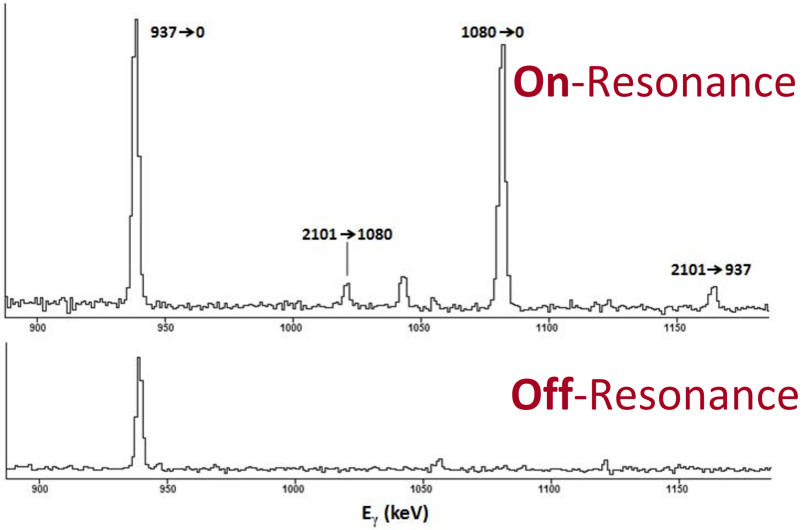




On and Off Resonance Spectra

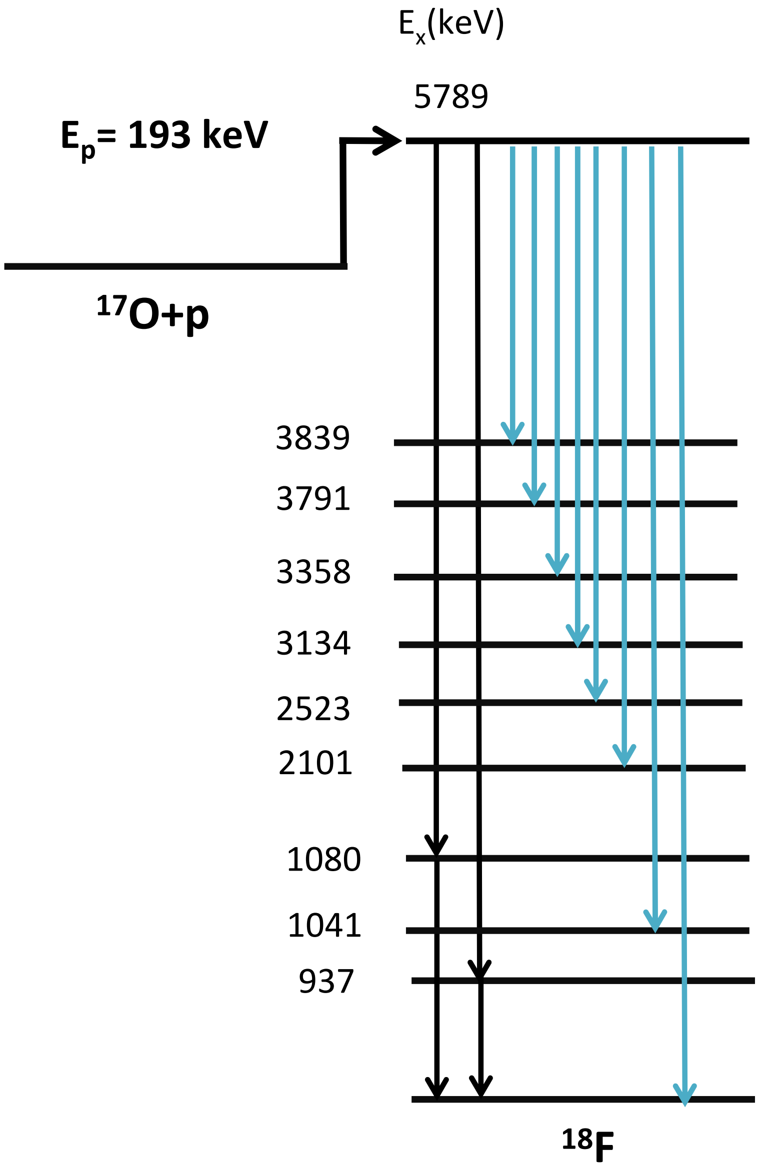






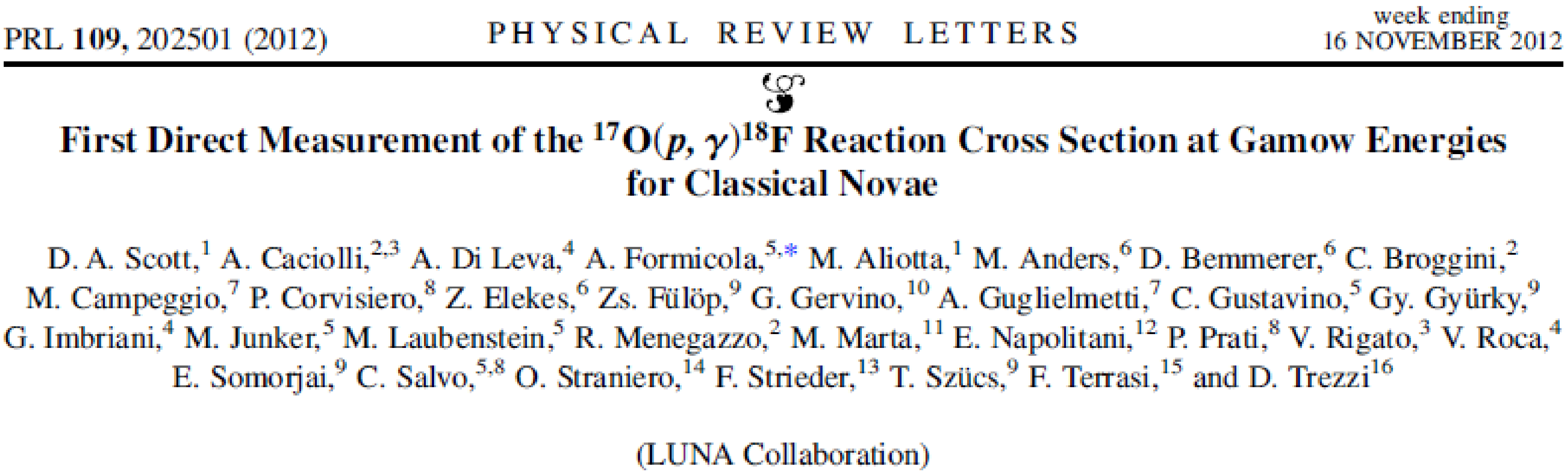
Courtesy: D.A. Scott

New Transitions Observed



Black = Previously Observed

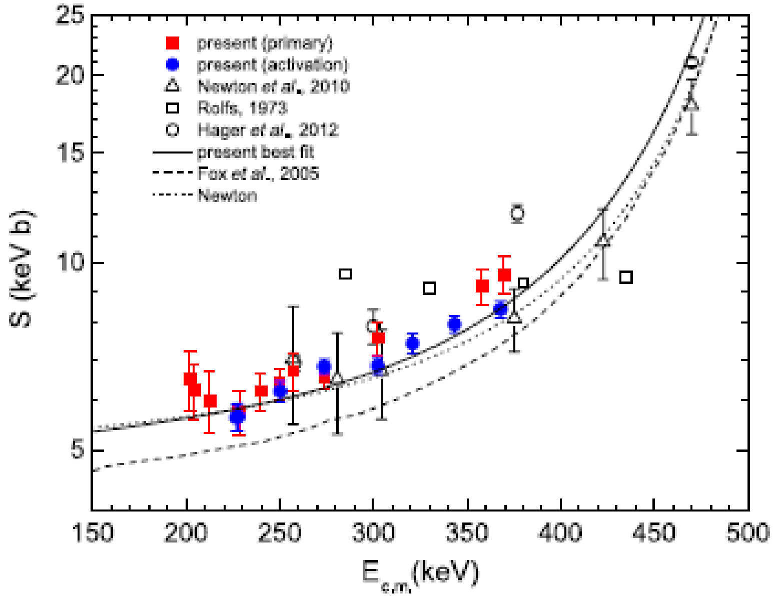
Blue = First Observation

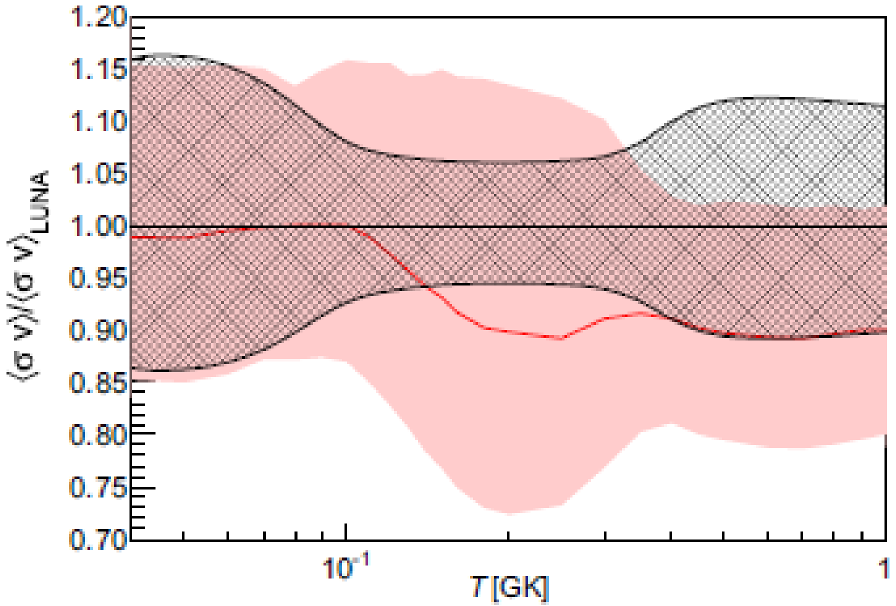

PRL 109, 202501 (2012) PHYSICAL REVIEW LETTERS week ending 16 NOVEMBER 2012

First Direct Measurement of the $^{17}O(p,\gamma)^{18}F$ Reaction Cross Section at Gamow Energies for Classical Novae

D. A. Scott,[1] A. Caciolli,[2,3] A. Di Leva,[4] A. Formicola,[5,*] M. Aliotta,[1] M. Anders,[6] D. Bemmerer,[6] C. Broggini,[2] M. Campeggio,[7] P. Corvisiero,[8] Z. Elekes,[6] Zs. Fülöp,[9] G. Gervino,[10] A. Guglielmetti,[7] C. Gustavino,[5] Gy. Gyürky,[9] G. Imbriani,[4] M. Junker,[5] M. Laubenstein,[5] R. Menegazzo,[2] M. Marta,[11] E. Napolitani,[12] P. Prati,[8] V. Rigato,[3] V. Roca,[4] E. Somorjai,[9] C. Salvo,[5,8] O. Straniero,[14] F. Strieder,[13] T. Szücs,[9] F. Terrasi,[15] and D. Trezzi[16]

(LUNA Collaboration)

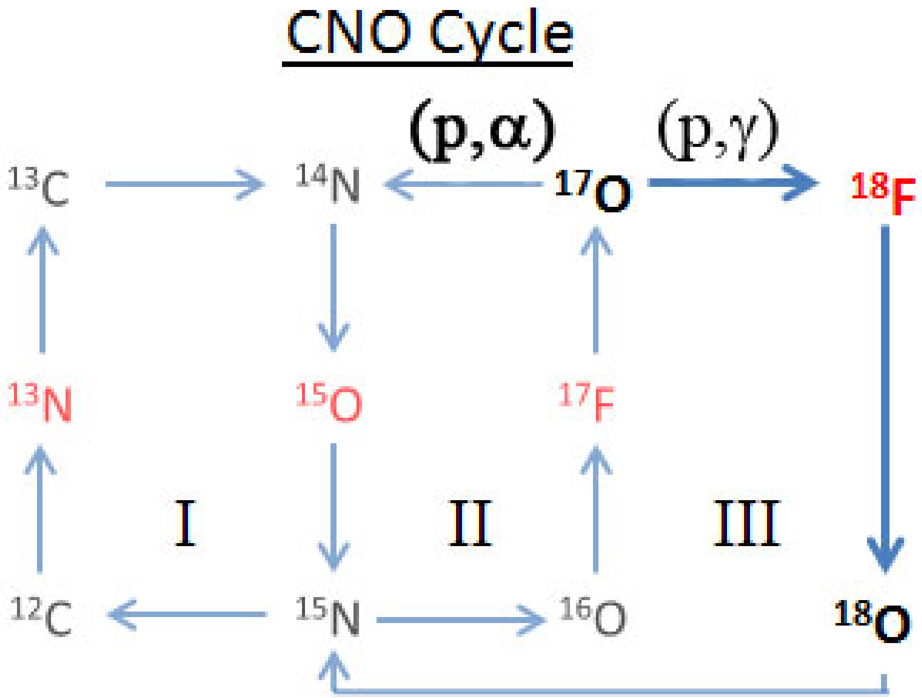




E_{cm} = 200-370 keV (lowest to date)
$\omega\gamma$ = 1.67 ± 0.12 μeV (most precise to date)

factor 4 reduction in reaction rate uncertainty at novae temperatures

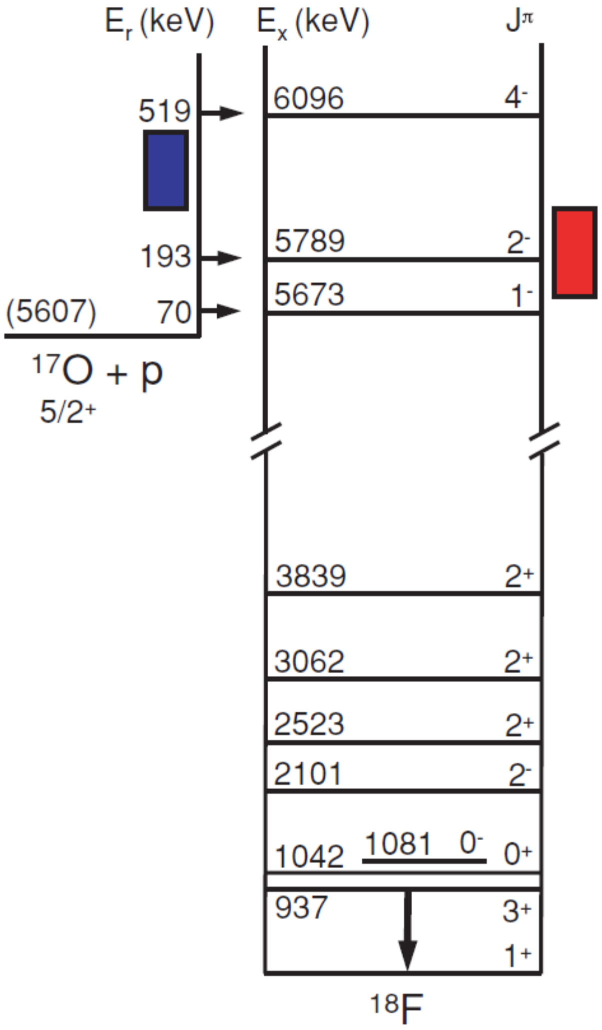
the $^{17}O(p,\alpha)^{14}N$ reaction



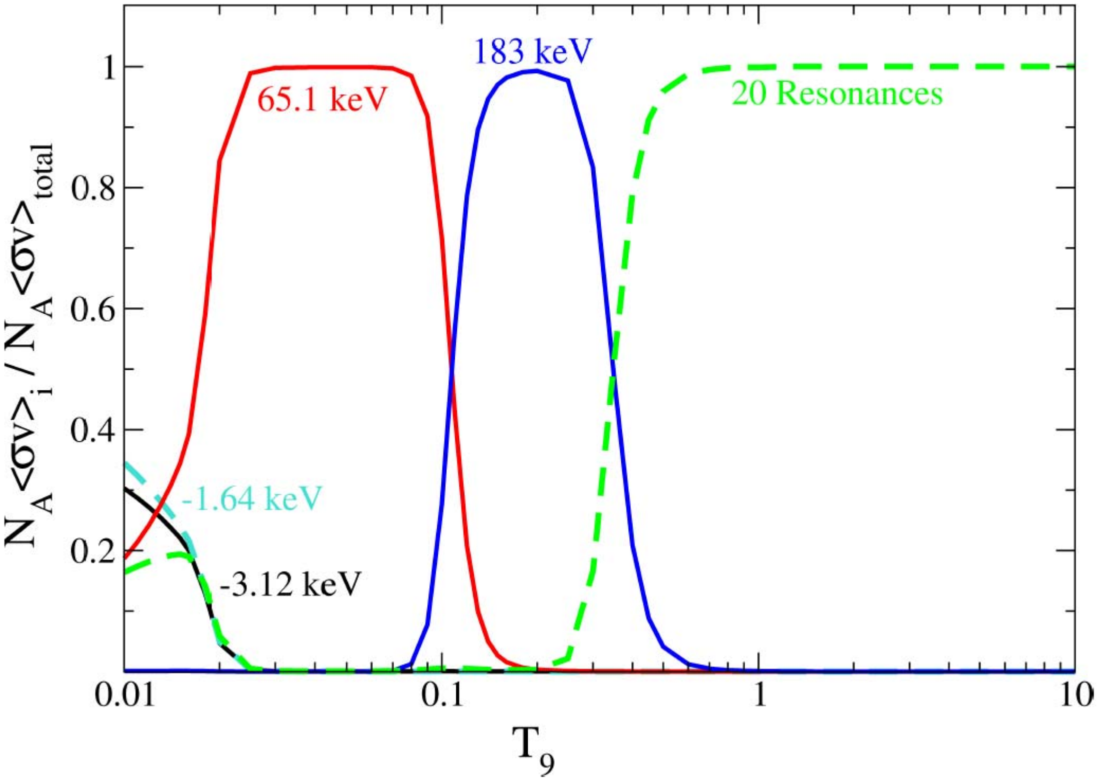
- branching point between CNO-II and CNO-III
- competition with (p,γ) channel
- critical for ^{17}O / ^{16}O and ^{18}F abundances
- important in a variety of scenarios (AGB stars, classical Novae…)

$^{17}O(p,\alpha)^{14}N$ generalities

- two resonances: 70 and 193 keV (lab)
- 70 keV dominant at AGB-stars temperatures (0.03-0.1 GK)



J.Newton, PhD thesis (2010)



J.Newton et al. Phys.Rev.C 81 (2010)

$^{17}O(p,\alpha)^{14}N$ reaction: current status

- 193 keV resonance:

Authors	**Resonance strength**	**Approach**
Chafa (2005-07)	$(1.6 \pm 0.2) \times 10^{-3}$ eV	Indirect (activation)
Moazen (2007)	$(1.70 \pm 0.15) \times 10^{-3}$ eV	Indirect (inverse kinematics)
Newton (2007-10)	$(1.66 \pm 0.17) \times 10^{-3}$ eV	Direct

- 70 keV resonance: **no direct measurement so far**

Berheide (1992)	$< 8 \times 10^{-10}$ eV	Direct (upper limit)
Sergi (2010)	$4.21^{+0.87}_{-0.73} \times 10^{-9}$ eV	Indirect (Trojan horse)
Sergi (2010)	$3.66^{+0.76}_{-0.64} \times 10^{-9}$ eV	Indirect (Trojan horse)

measuring this resonance at LUNA is our final goal

Experimental Setup

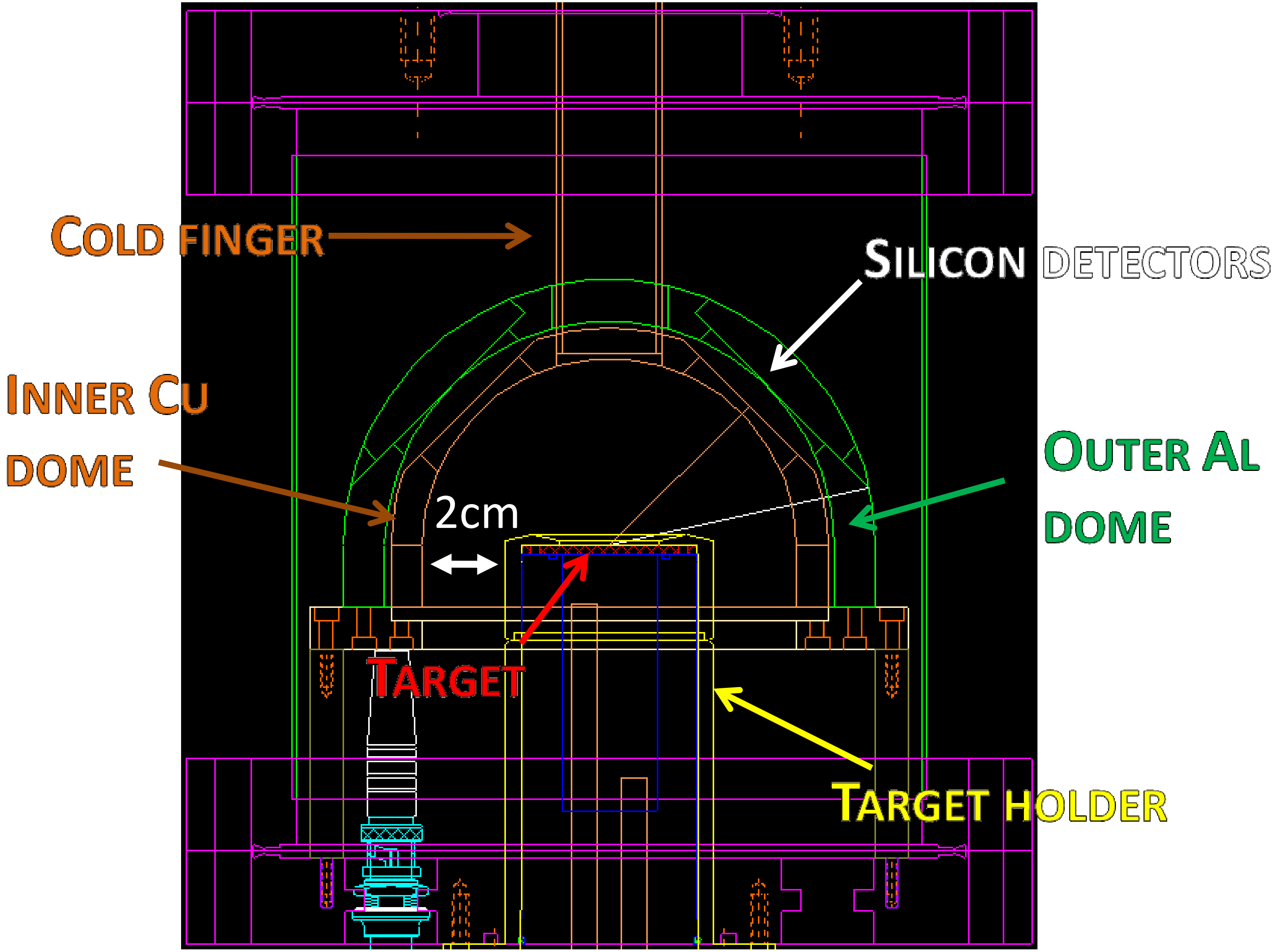
- eight ($9cm^2$ area) silicon detectors in semi-spherical geometry approximately 0.6π coverage (~15% efficiency)

- protective Al-Mylar foils (2.4um) to stop elastic protons

- 95%-enriched ^{17}O targets (anodisation)

- approximately 2 counts/hour expected for 70 keV resonance (assuming 100 μA beam current and 95% ^{17}O enriched targets)

scattering chamber



COLD FINGER

SILICON DETECTORS

INNER CU DOME

OUTER AL DOME

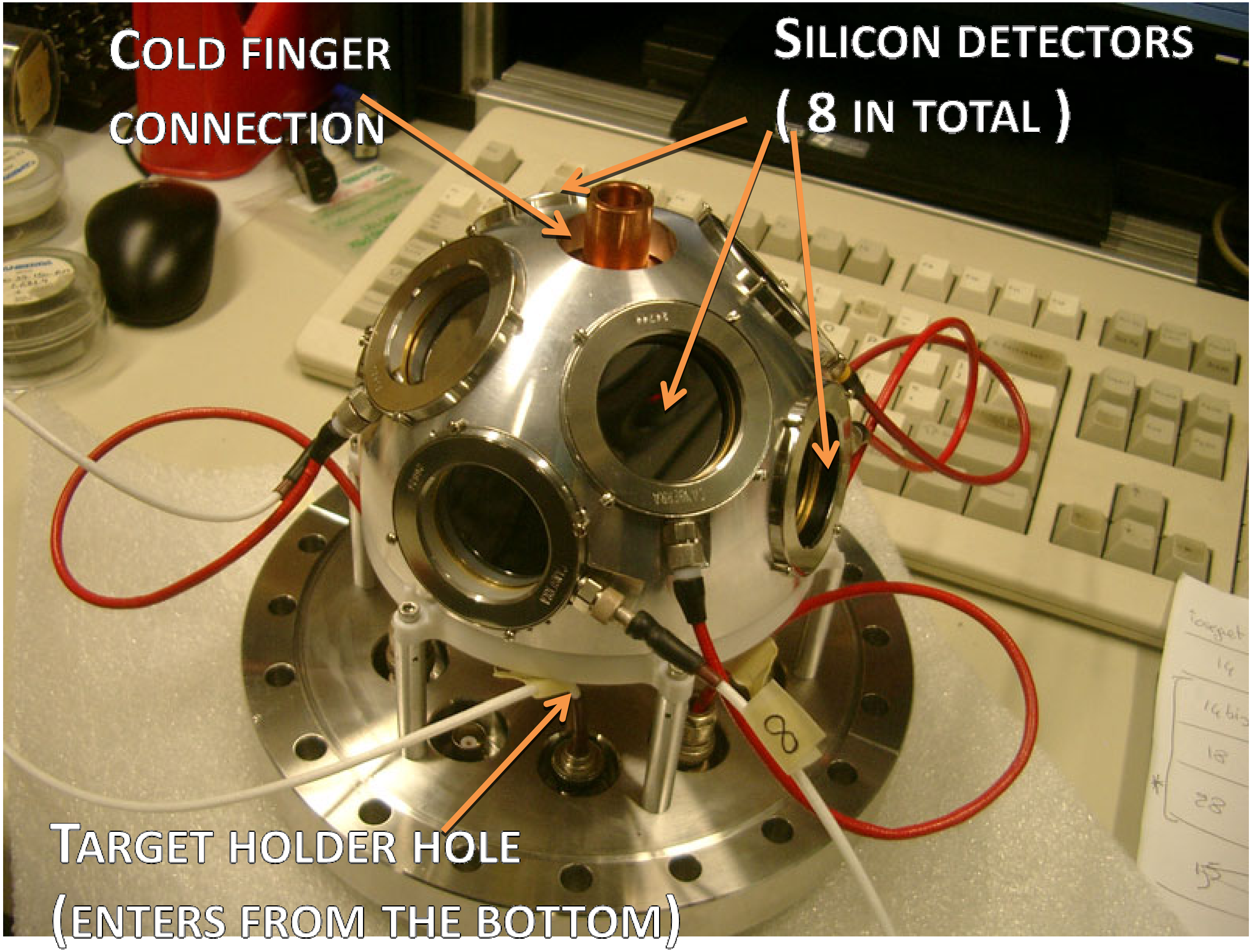
2cm

TARGET

TARGET HOLDER

Courtesy: Carlo Bruno

Experimental Setup



COLD FINGER CONNECTION

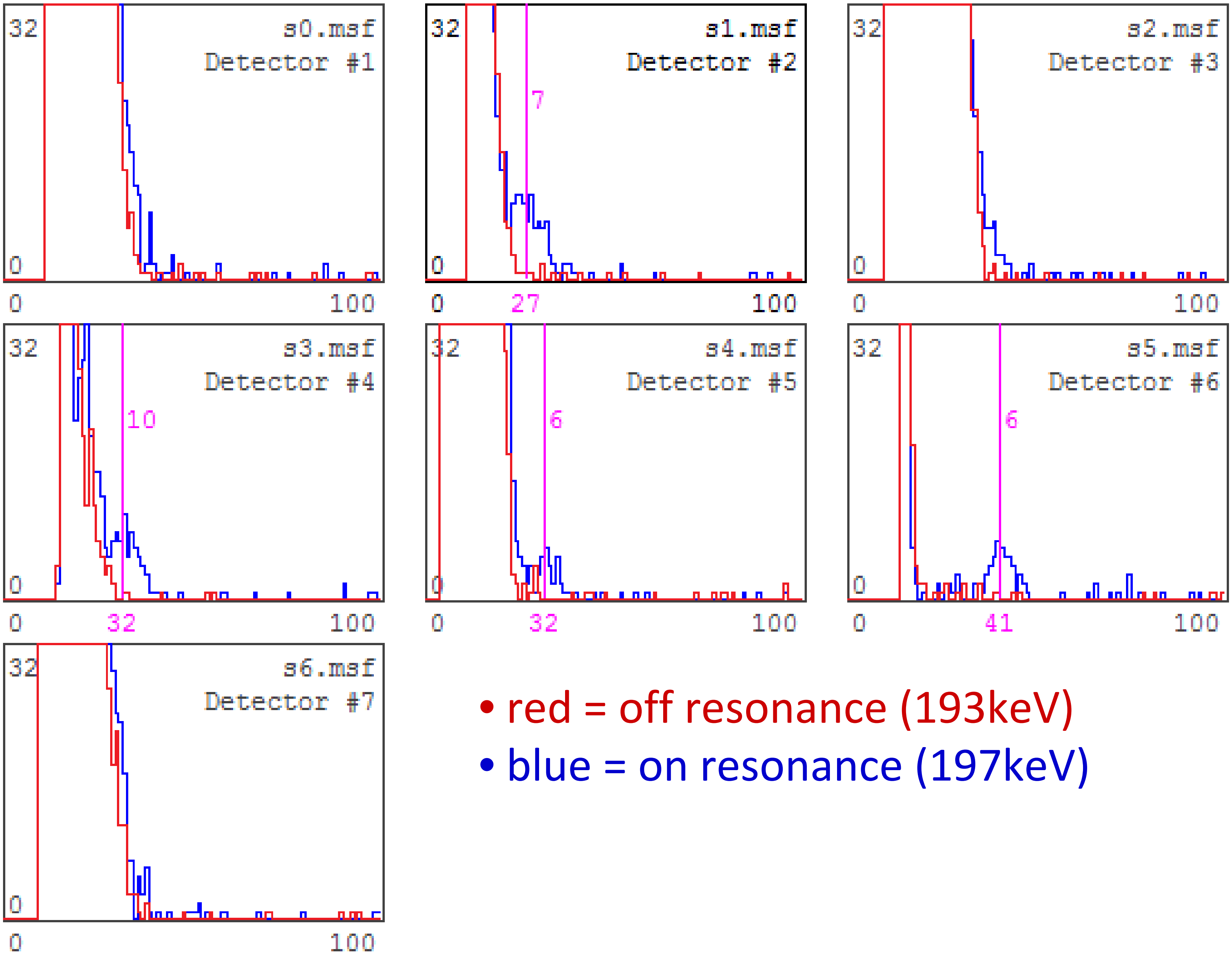
SILICON DETECTORS (8 IN TOTAL)

TARGET HOLDER HOLE (ENTERS FROM THE BOTTOM)

Courtesy: Carlo Bruno

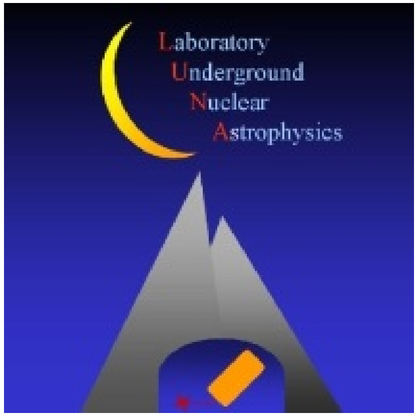
Courtesy: Carlo Bruno

^{17}O 193keV spectra



- red = off resonance (193keV)
- blue = on resonance (197keV)

The Luna Collaboration



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Zs. Fülöp, Gy. Gyurky, T. Szucs, E. Somorjai Institute of Nuclear Research (ATOMKI), Debrecen, Hungary

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G. Imbriani, V. Roca Università di Napoli ''Federico II'', and INFN, Napoli, Italy

G. Gervino Università di Torino and INFN, Torino, Italy explosive scenarios provide unique conditions for nuclear reactions involving both exotic and stable nuclei

new, improved RIB facilities will open up opportunities for further advances in Nuclear Astrophysics

HOWEVER

much remains to be done also with stable nuclei

INFN
Istituto Nazionale
di Fisica Nucleare

Starting up the
LUNA MV Collaboration

6-8 February 2013
Laboratori Nazionali del Gran Sasso, Italy

Goal of the workshop is to establish the LUNA MV Collaboration, define its structure, and formalize the tasks of its participating institutions.

The LUNA MV project will focus on the measurement of the key astrophysical reactions $^{3}He(\alpha,\gamma)^{7}Be$, $^{12}C(\alpha,\gamma)^{16}O$, $^{13}C(\alpha,n)^{16}O$ and $^{22}Ne(\alpha,n)^{25}Mg$ using a MV machine located in the Gran Sasso underground laboratory.

International Program Committee

C. Broggini	(INFN, Padova, Italy)
M. Busso	(Perugia University, Italy)
H. Costantini	(Aix-Marseille University, France)
Z. Fülöp	(ATOMKI Debrecen, Hungary)
L. Gialanella	(Seconda Università di Napoli, Italy)
M. Hass	(Weizmann Institute, Israel)
C. Iliadid	(University of North Caroline, US)
A. Lefebvre	(CSNSM CNRS/IN2P3, France)

Local Organizing Committee

A. Guglielmetti	(Milano University, Italy - Chair)
A. Formicola	(LNGS, Italy - Scientific Secretary)
M. Junker	(LNGS, Italy)
P. Prati	(Genova University, Italy)
F. Chiarizia	(Conference Secretary)

Registration Deadline: 31 January 2013

http://luna-mv.lngs.infn.it

MV accelerator @LNGS

science cases:

$^{3}He(\alpha,\gamma)^{7}Be$

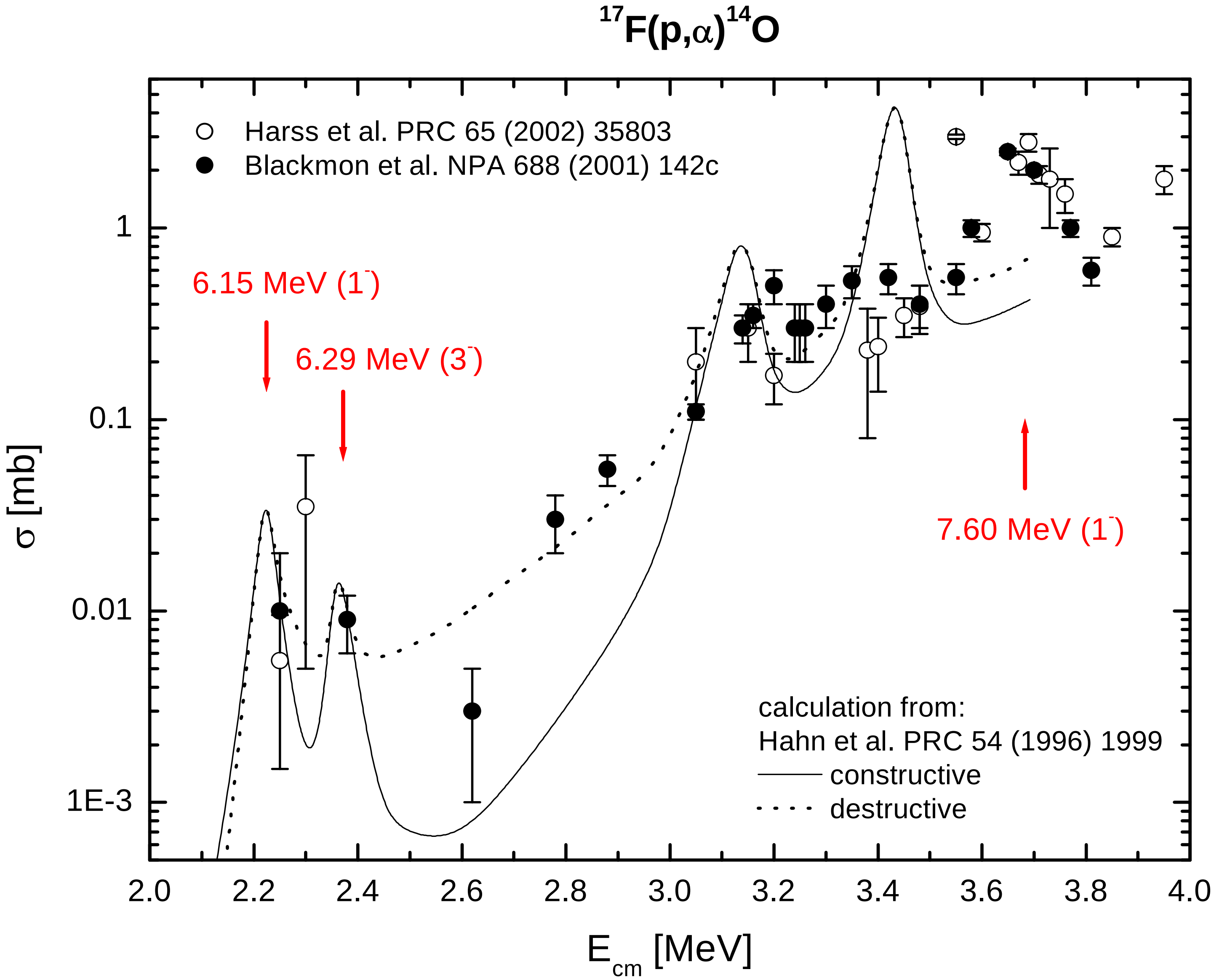
$^{12}C(\alpha,\gamma)^{16}O$

$^{13}C(\alpha,n)^{16}O$

$^{22}Ne(\alpha,n)^{25}Mg$


THANK YOU

Current status



explosive hydrogen burning

(exact path depends on given stellar conditions)

some key reactions:

$^{13}N(p,\gamma)^{14}O$ (LLN)

$^{14}O(\alpha,p)^{17}F$ (RIKEN, Oak Ridge)

$^{18}Ne(\alpha,p)^{21}Na$ (LLN, Argonne)

$^{21}Na(p,\gamma)^{22}Mg$ (TRIUMF)

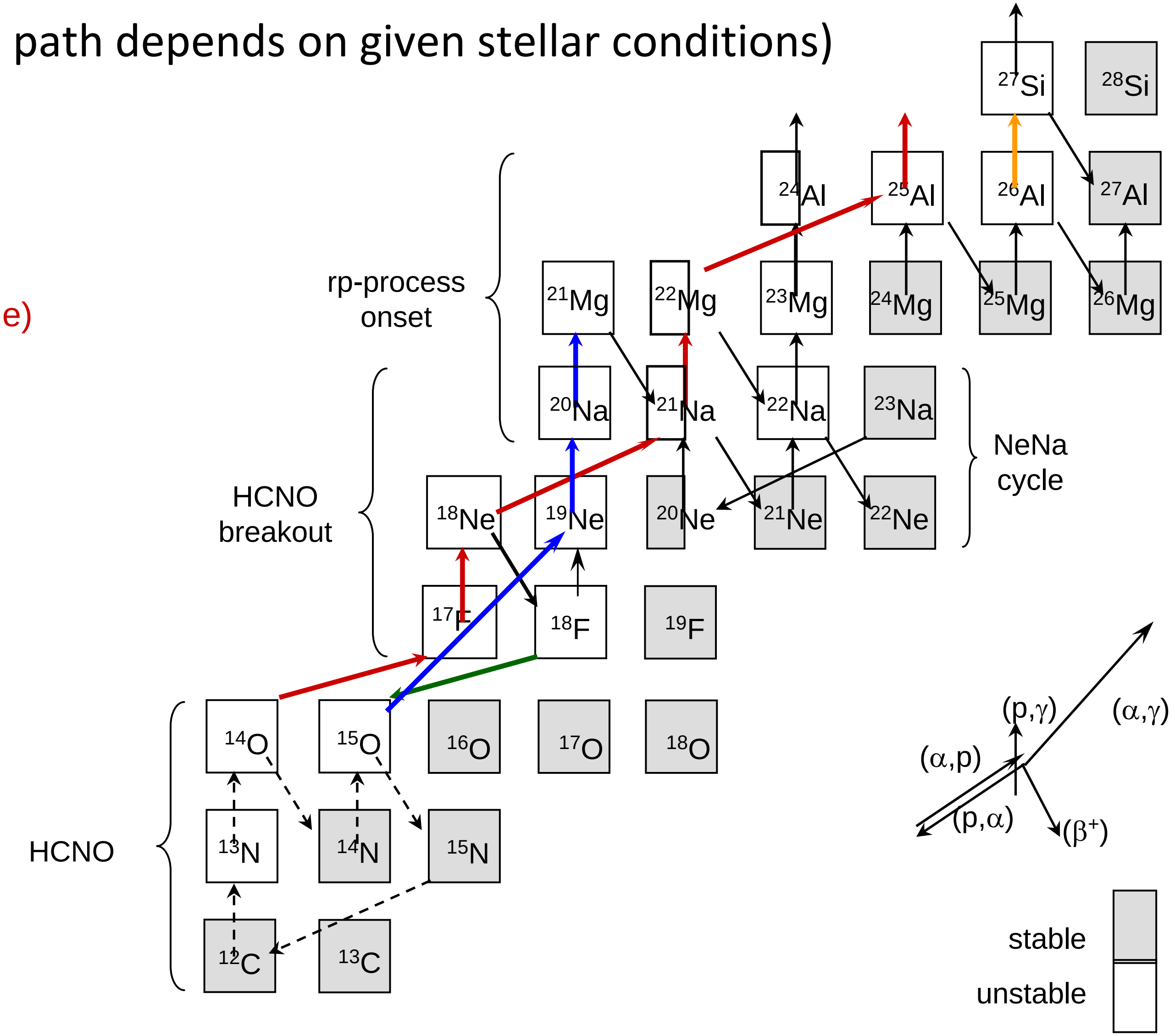
$^{15}O(\alpha,\gamma)^{19}Ne$ (indirect)

$^{19}Ne(p,\gamma)^{20}Na$ (LLN)

$^{20}Na(p,\gamma)^{21}Mg$ (TRIUMF)

$^{18}F(p,\alpha)^{15}O$ (LLN, Oak Ridge)

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



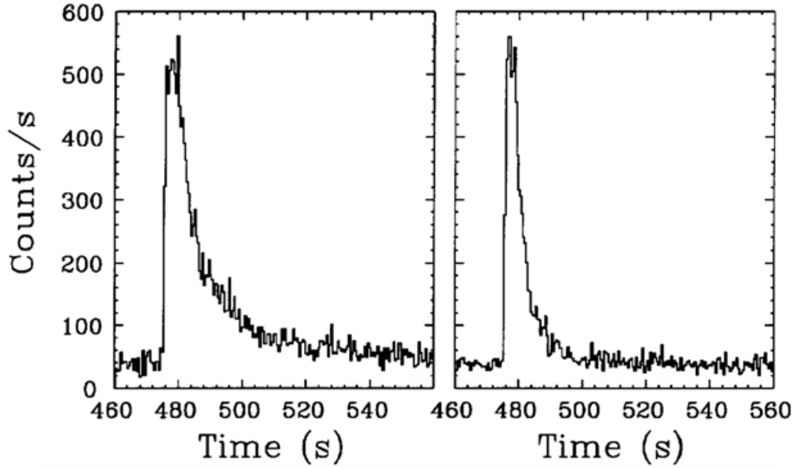
HCNO breakout required for *rp*-process onset

observational features

type I X-ray bursts

- 10^{38} - 10^{39} erg/s
- fast rise time (1-10s)
- duration (~10-100s)
- some show double peak at max
- spectral softening
- recurrence intervals (several hours)

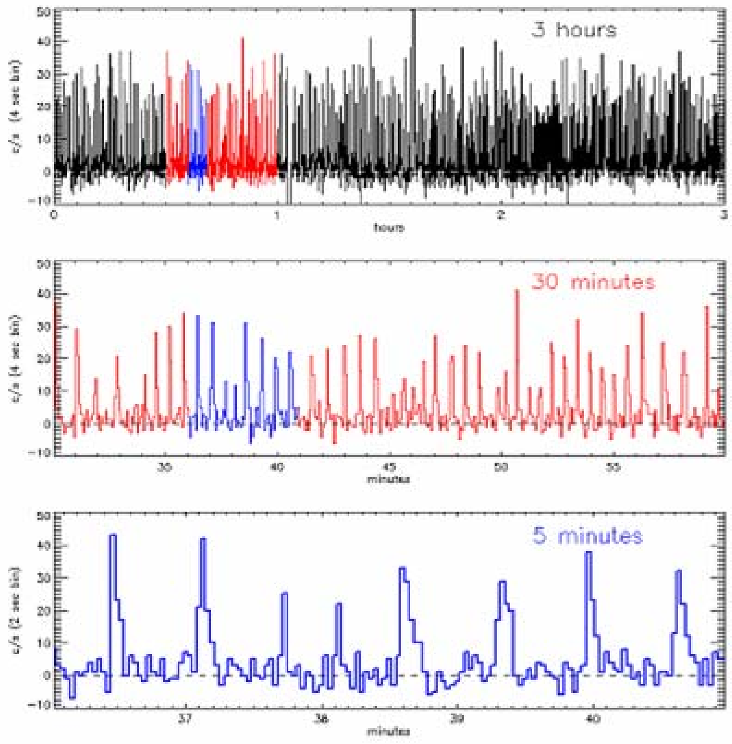
Lewin, van Paradijs, & Taam (1993) Sp Sci Rev, 62, 223



type II X-ray bursts

- rapid successions of bursts (few minutes interval)
- sudden flux drop without gradual decay from peak values
- no spectral softening in decay

total ~230 X-ray systems known



Rapid Burster (MXB 1730-335) - ESA webpage

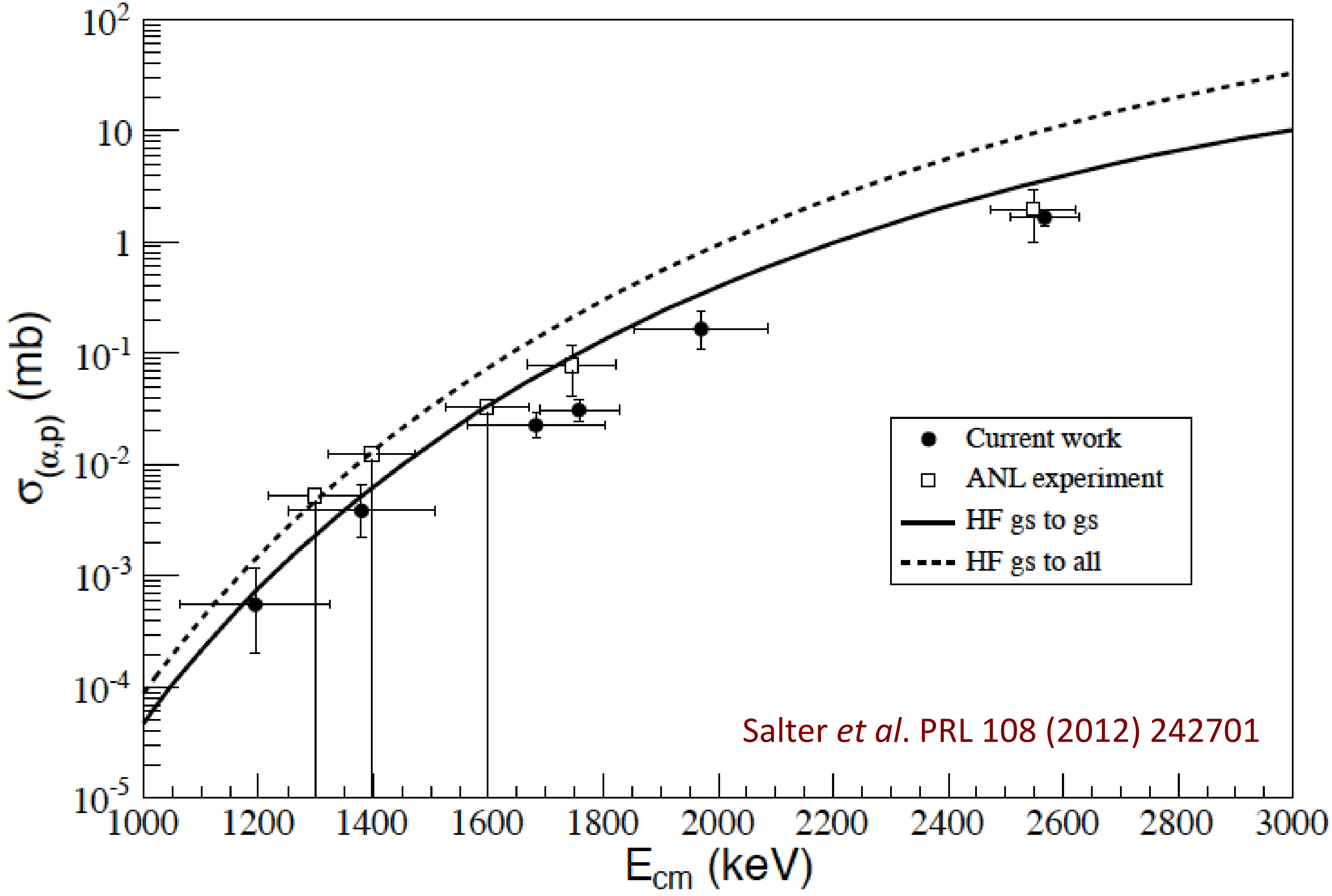
DETECTORS AND TA_2O_5 TARGET

- 8 SILICON DETECTORS FROM EDINBURGH (CANBERRA PIPS)
- SURFACE: 9 CM^2
- THICKNESS: 4X300 μm, 3X700 μm (+ 1X150 μm)
- DEAD LAYER: UNDER 100nm
- RESOLUTION: 40 keV FOR THE AM PEAK (5486 keV)

- ONLY 5-8 keV IN THICKNESS
- STABLE UNDER BEAM BOMBARDMENT (UP TO 20C)
- $H_2{}^{17}O$ WATER AVAILABLE AT ~95% ENRICHMENT
- $H_2{}^{18}O$ WATER AVAILABLE AT ~95% ENRICHMENT

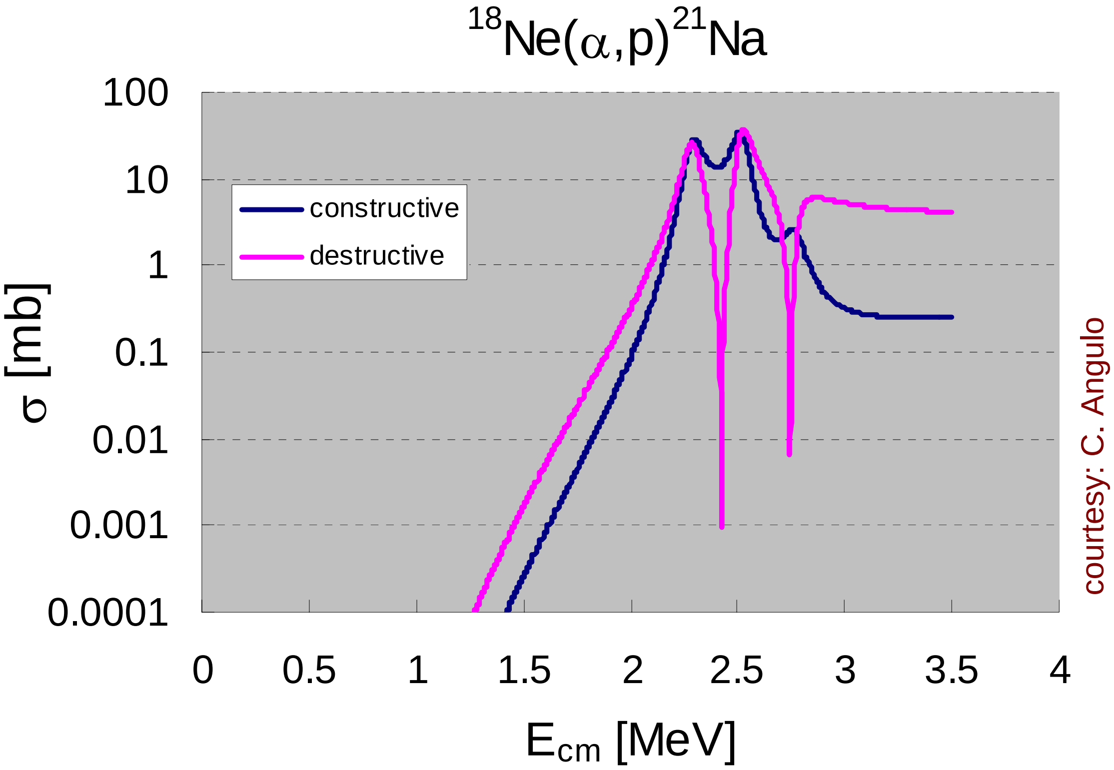
Our Results

^{18}Ne(α,p)^{21}Na total reaction cross section comparison with ANL data (unpublished)



Salter *et al*. PRL 108 (2012) 242701

R-matrix calculations



courtesy: C. Angulo

three resonances only: E_x= 2.28, 2.52, 2.78 MeV

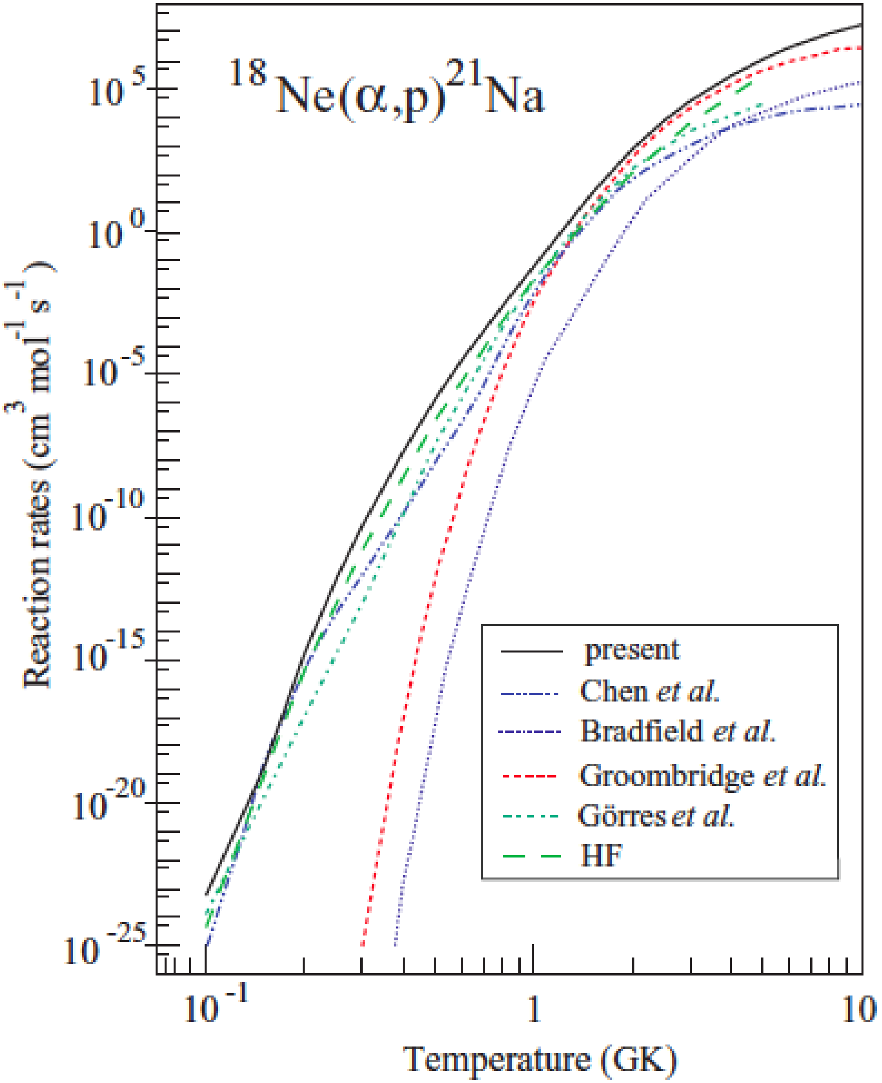
Γ = 7.3x10^{-4}, 10^{-3}, 10^{-3} MeV

(NB values differ from those quoted in Groombridge et al.)

discrepancy between direct and indirect measurements due to interference effects?

Stellar reaction rate

Matic et al, PRC 80 (2009) 055804



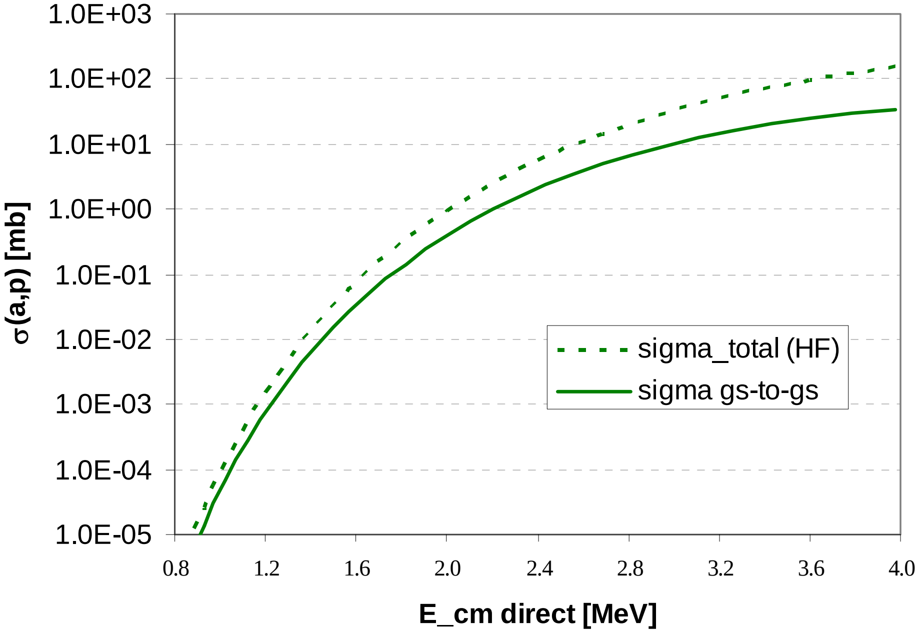
study of ^{22}Mg levels via $^{24}Mg(p,t)^{22}Mg$

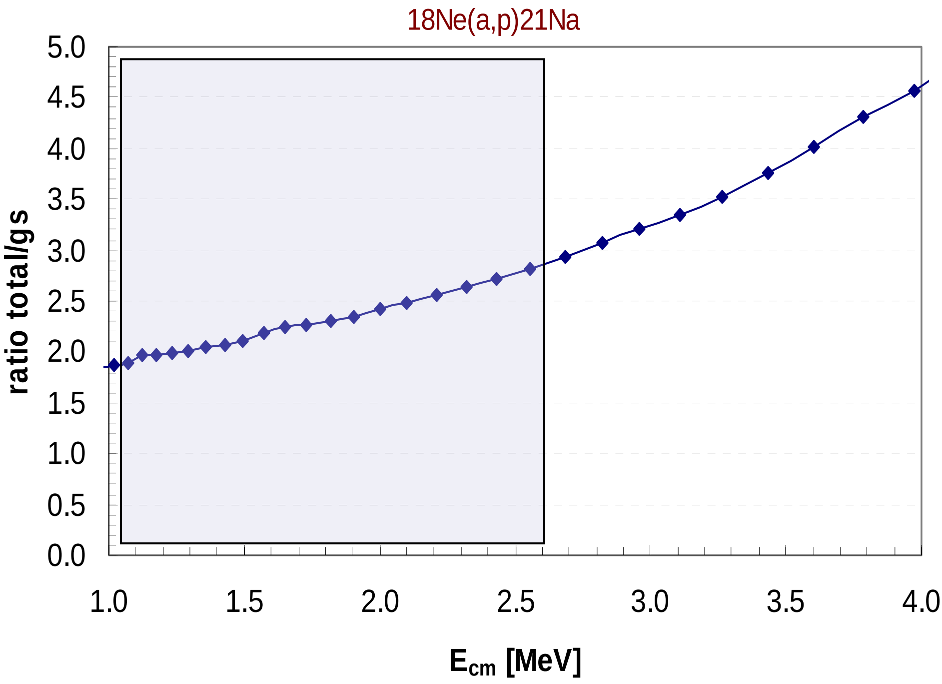
- HF from Görres PRC 51 (1995) 392 (cf. Rauscher & Thielemann, At. Data Nucl. Data Tables 79 (2001) 47)
- T = 0.3-1.0 GK HF ~5x smaller than in Matic
- T > 1.0 GK Matic in agreement with Groombridge (spectroscopic factors taken from this and other refs)
- for randomized spin values, rate ~10x different

^{18}Ne(α,p)^{21}Na theoretical predictions

what contribution from excited states? Hauser-Heshbach: ~ factor 3 difference

$$\sigma_{tot}\,(p,a) = \sigma_{gs}\,(p,a)\ HF_{tot}/HF_{gs}$$



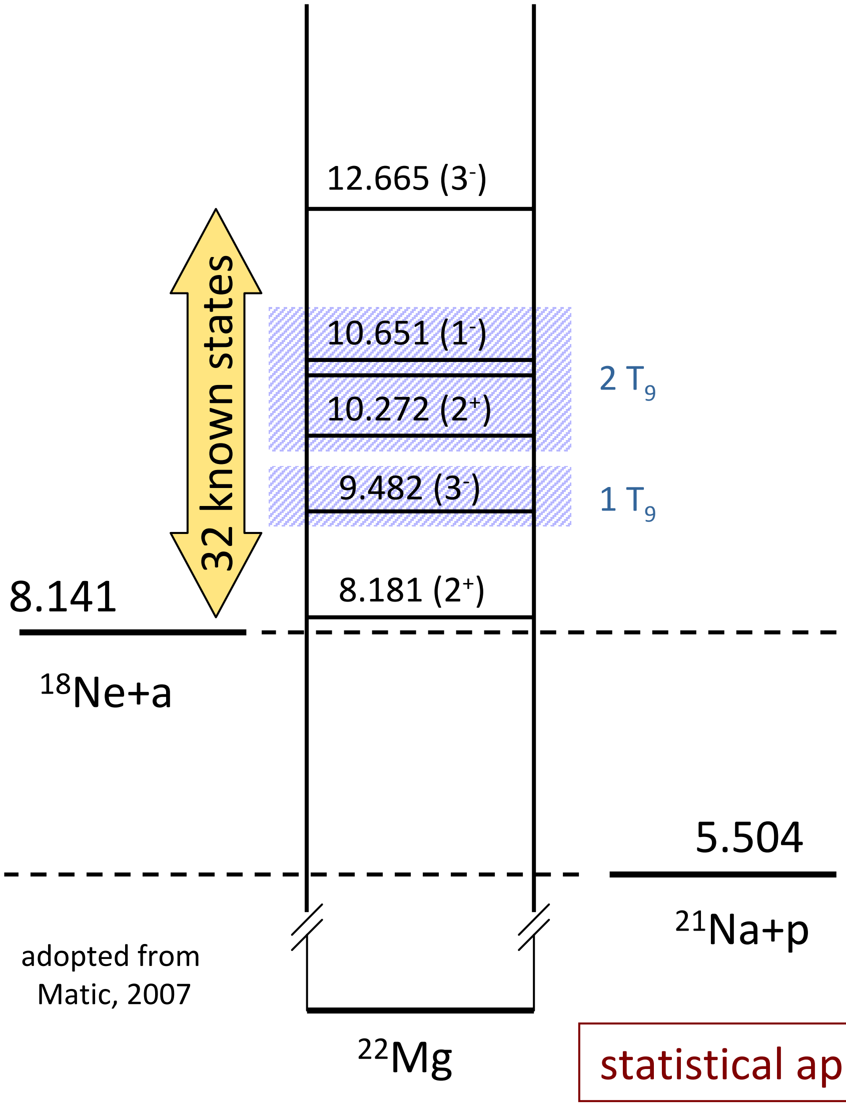


possibility to measure contribution to excited states

by comparison between proton elastic and inelastic scattering

^{18}Ne(a,p)^{21}Na

X-ray bursts, relevant temperature: **T= 1-2 GK ⇒ Gamow region E_{cm} ~ 1.3-2.1 MeV**



adopted from
Matic, 2007

Hauser-Feshbach statistical approach
generally applicable if:

$$\Delta \leq \langle\Gamma\rangle \leq \Delta E_0$$

spacing
between levels

width of
Gamow region

average
resonance width

Here: lower level density
+ natural parity states only!

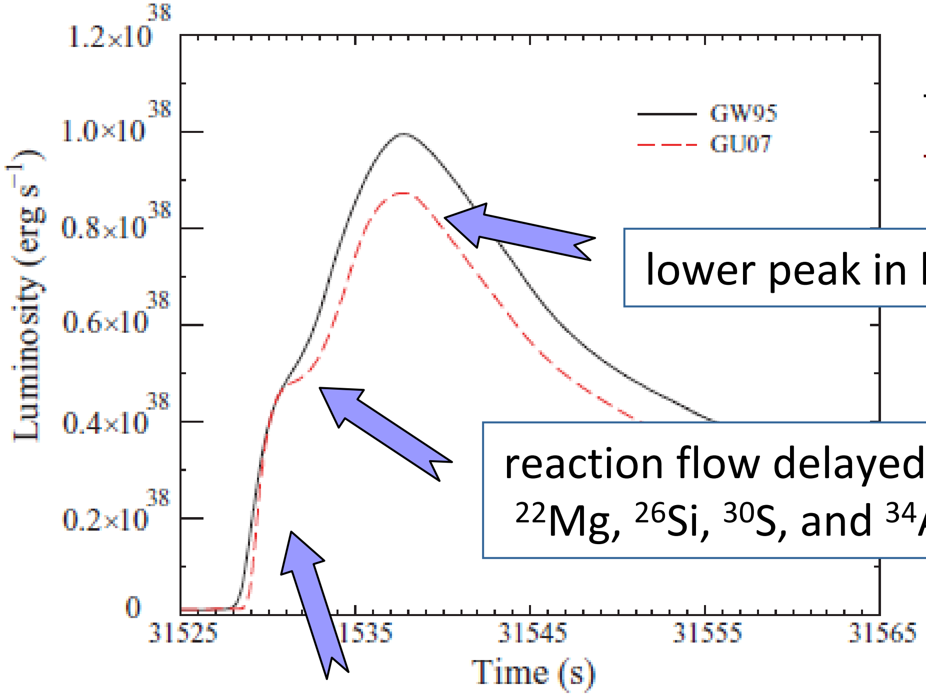
statistical approach may be uncertain by factor 10

Astrophysical implications

higher rate for ^{18}Ne(a,p)^{21}Na at T=0.4-0.8 GK

⇓

faster ap burning ⇒ faster rise in temperature and He burning



——— Görres et al PRC 51 (1995) 392

- - - - - - - Matic et al PRC 80 (2009) 055804

lower peak in luminosity curve

reaction flow delayed at ^{22}Mg, ^{26}Si, ^{30}S, and ^{34}Ar waiting points

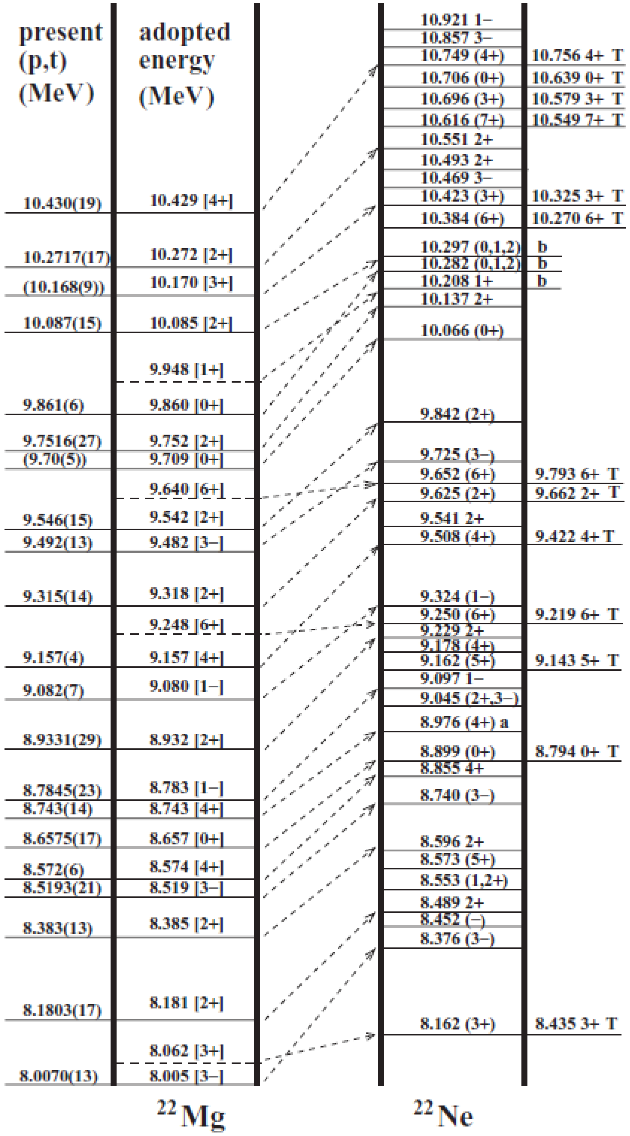
sharper rise until first waiting point reached

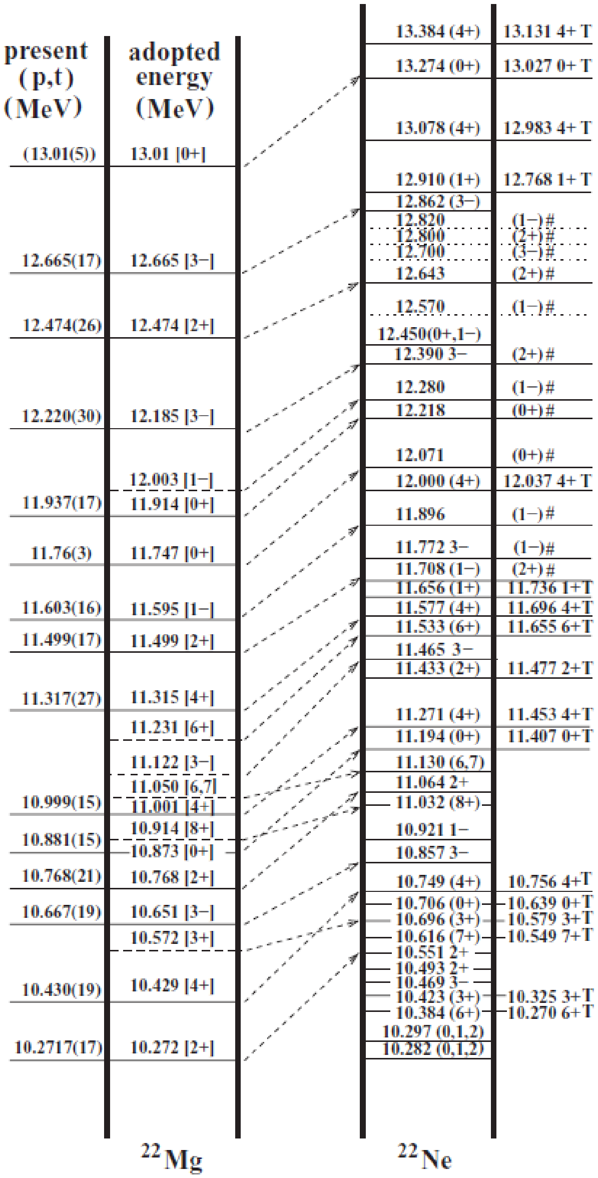
NB conclusions based on spherically symmetric simulations;
more realistic comparison need more sophisticated 2D and 3D models

^{22}Mg excited states

Matic et al, PRC 80 (2009) 055804

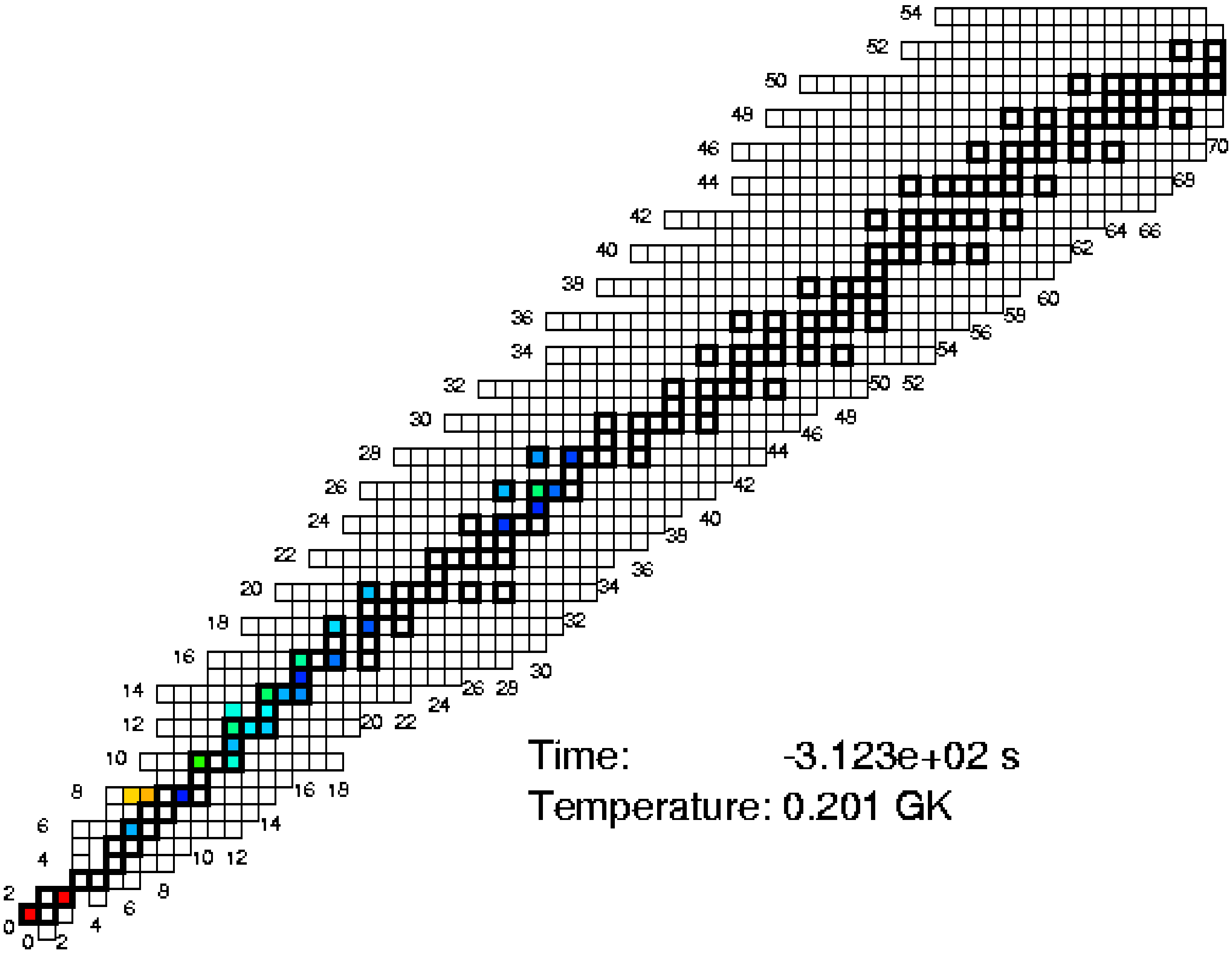
^{24}Mg(p,t)^{22}Mg





rp process during type I X-ray burst

H. Schatz, NSCL and Dept. of Physics and Astronomy, Michigan State University

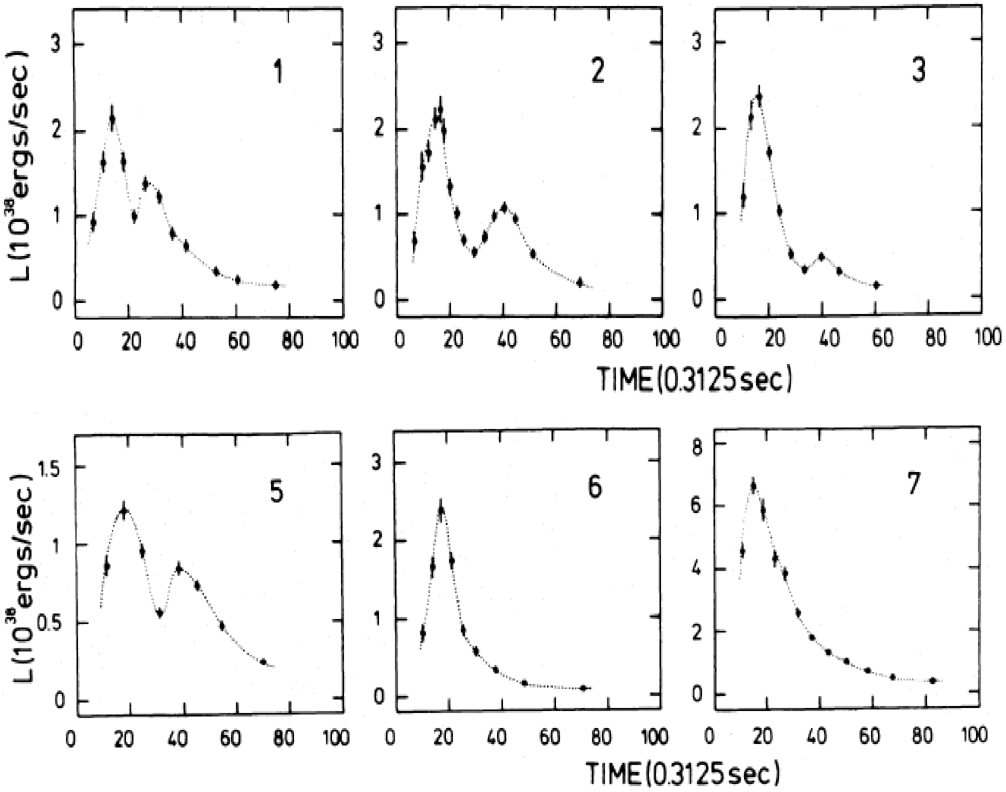


double-peak structures

some Type I X-ray bursts show double peak in luminosity separated by a few seconds

bursts from 4U/MXB 1636-53

Szatjano et al. ApJ 299 (1985) 487-495



burst from 4U 1608-52

Penninx et al. A&A 208 (1989) 146-152

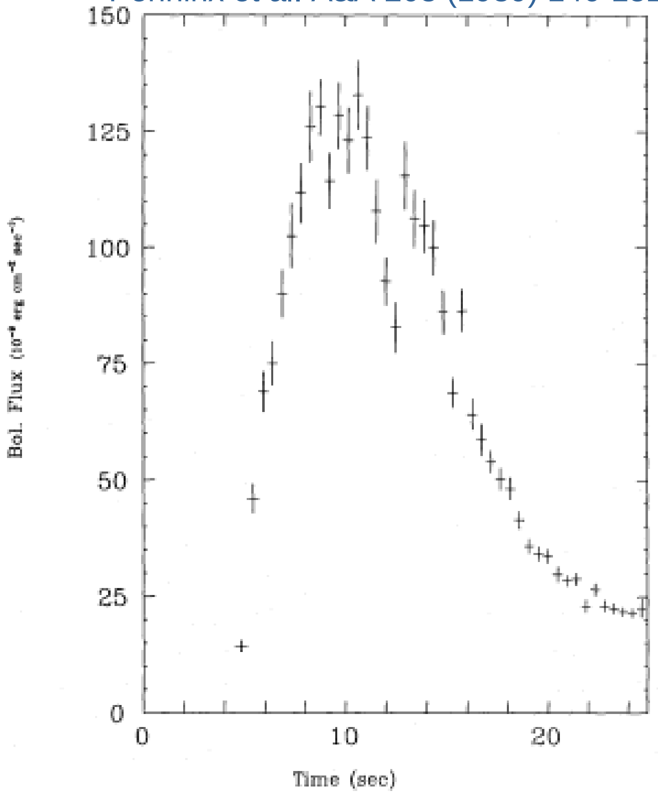


Fig. 5. Bolometric flux of the 1986 burst, notice the ~25% dip

origin of double-peak structures still controversial

Remarks

open questions

- why different types of bursters?
- what determines bursts timescales?
- do X-ray bursts contribute to galactic nucleosynthesis?

nuclear data needs

thermonuclear runway driven by αp-process and rp-process

- breakout reactions $\Rightarrow$ constraints on ignition conditions + runaway timescale
- proton-capture reactions cross sections on proton-rich nuclei

  $\Rightarrow$ influence temperature and luminosity
- masses, β-decay lifetimes, level structure, proton-separation energies