$^{17,18}O(p,\alpha)^{14,15}N$ cross sections measurements…

Marialuisa Aliotta
School of Physics and Astronomy - University of Edinburgh, UK
Scottish Universities Physics Alliance

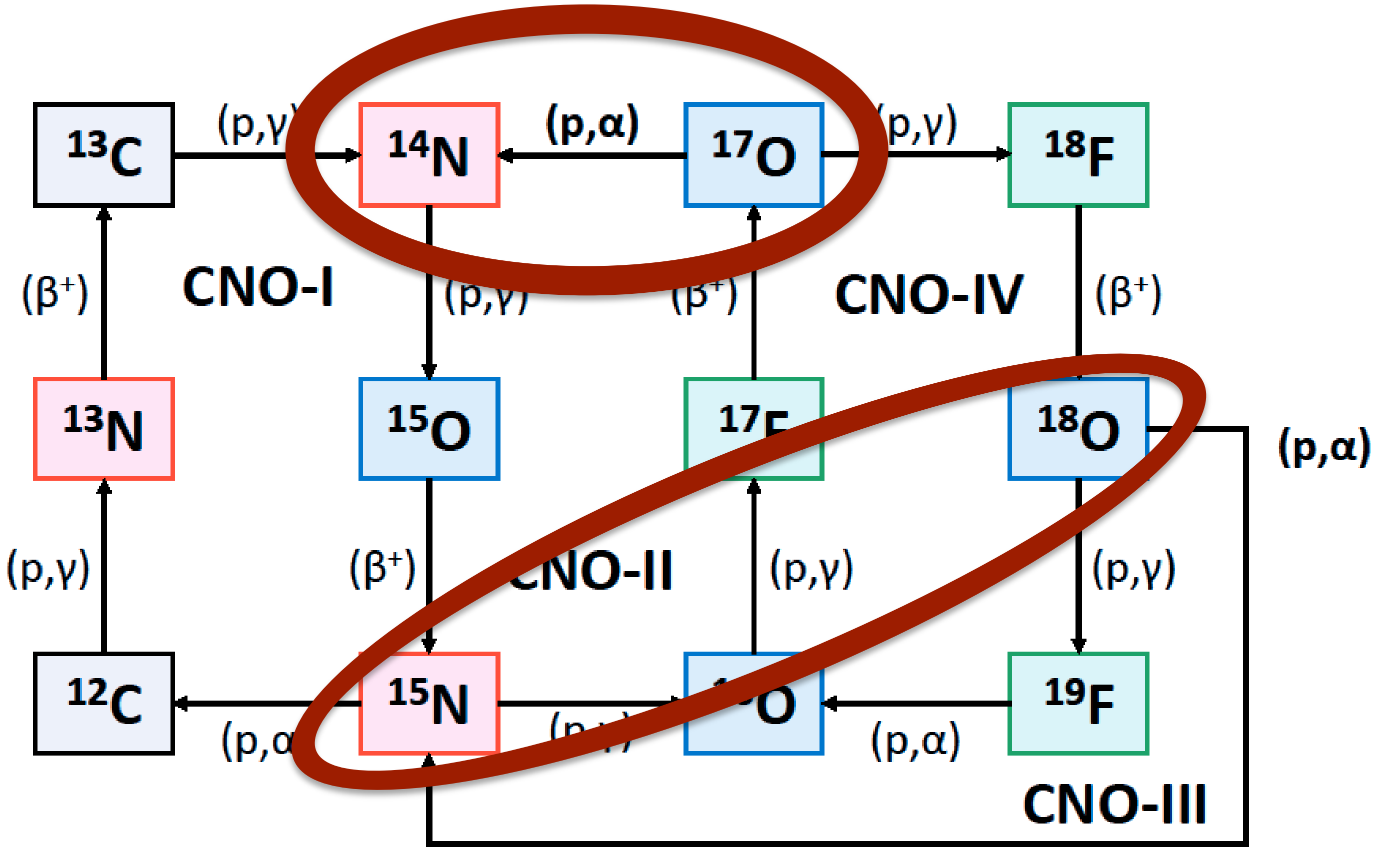
27 June 2017 – Felsenkeller Workshop Dresden

Astrophysical Motivation

Hydrogen burning in:

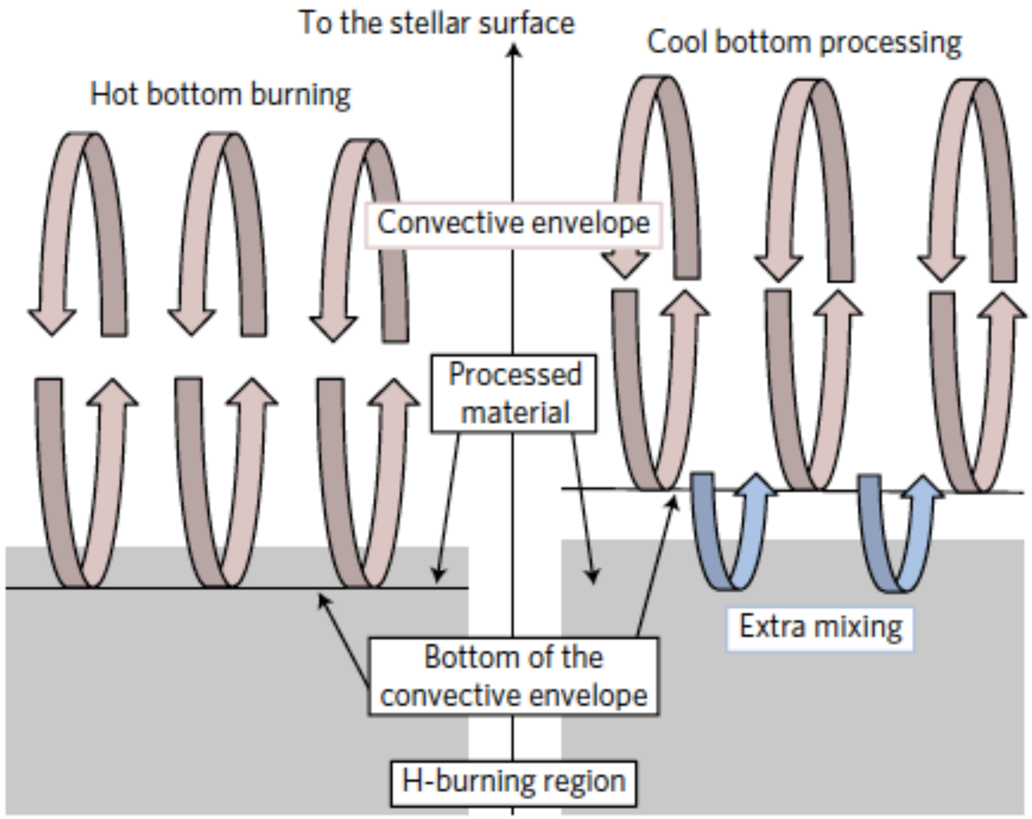
- red giants, AGB stars, massive stars and classical novae
- CNO cycles
- re-circulation processes (mixing, convection, …)
- isotopic abundances (^{15}N, $^{17,18}O$, ^{18}F, ^{19}F, …)
- pre-solar grains composition

CNO cycles


13C
14N
(p,α)
17O
(p,γ)
18F
(β+)
CNO-I
CNO-IV
13N
15O
18O
(p,α)
(p,γ)
(β+)
12C
15N
19F
(p,α)
CNO-III

Mixing processes in AGB stars

massive AGB stars
Hot Bottom
Burning



low-mass AGB stars
Cool Bottom
Processing

$^{17,18}O$ isotopes believed to be ideal tracers for HBB and CBP

their abundances can provide clues to physical conditions and mixing

Aims

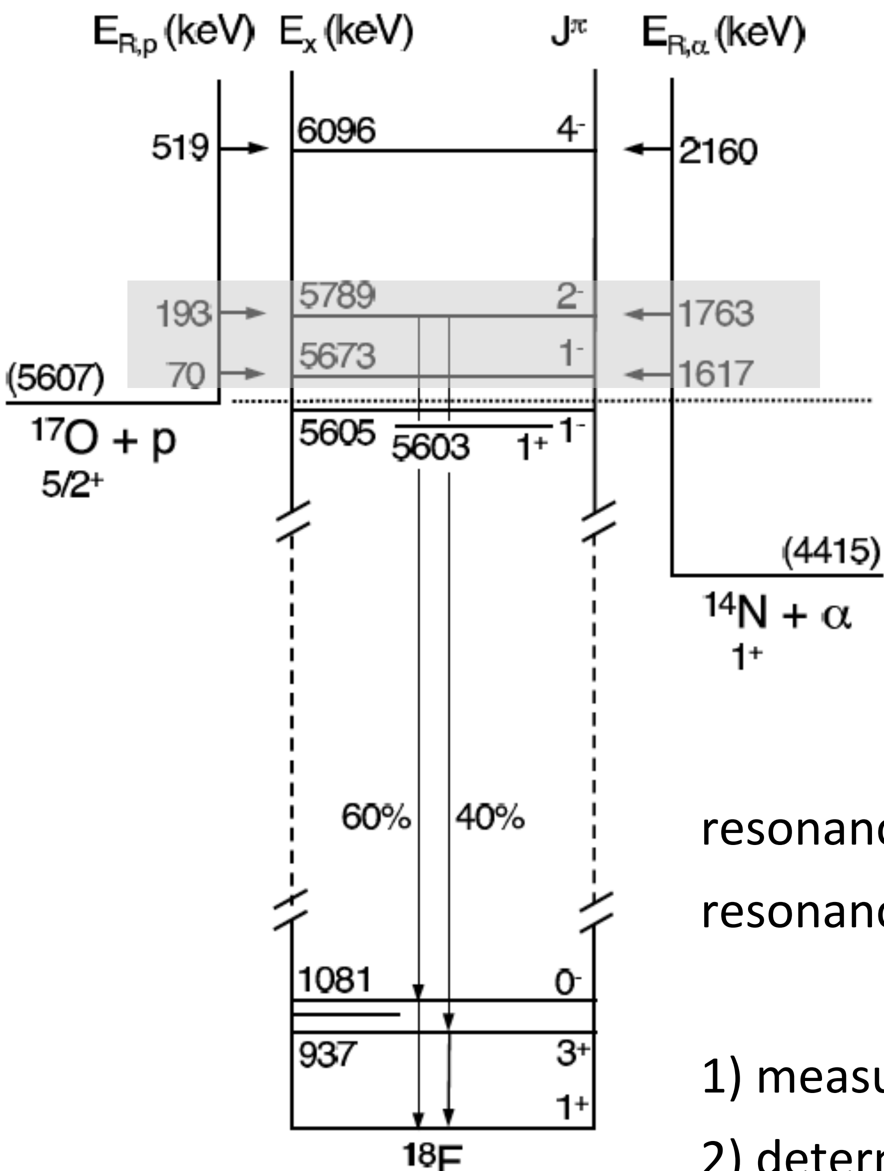
- Stellar models are affected by uncertainties in $^{17}O/^{16}O$ and $^{18}O/^{16}O$ isotopic ratios
- Uncertainties come primarily from **destruction** rate of the two isotopes

$^{17}O(p,\alpha)^{14}N$ and **$^{18}O(p,\alpha)^{15}N$**

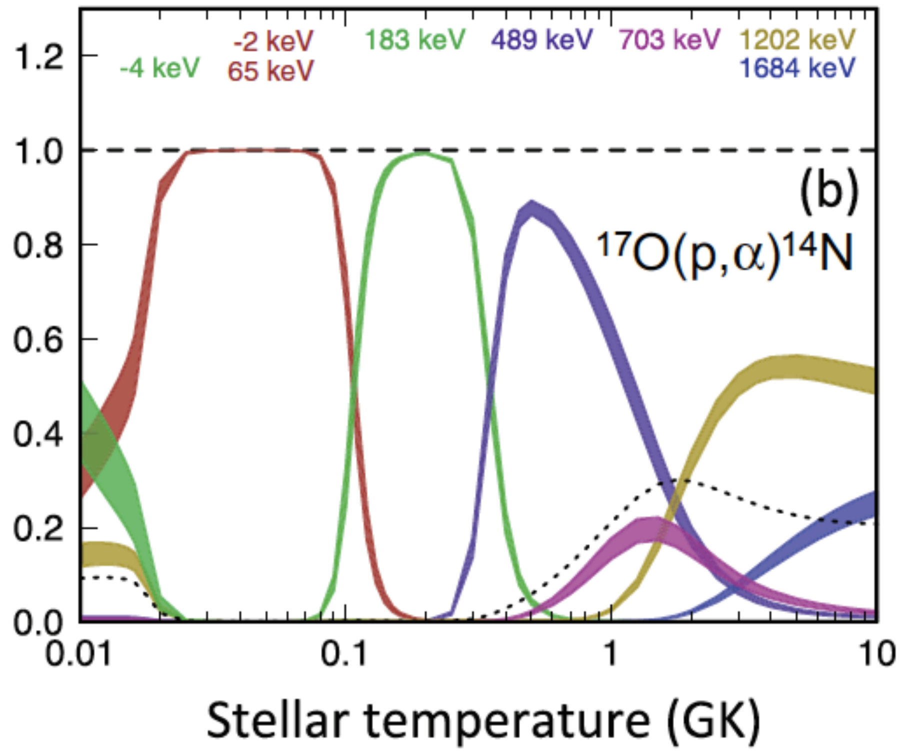
- **Our aim**: study both reactions at relevant energies to reduce the uncertainties in $^{17,18}O$ isotopic abundances
- Very low cross-sections: 10^{-9} to 10^{-12} barn
- Very low counting rates expected: ~1 count/h
- Natural background can be critical → Need for underground measurements

State of Affairs
(before our measurements)

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



Buckner et al, PRC 91 (2015) 015812



resonance strength of 193keV state well known

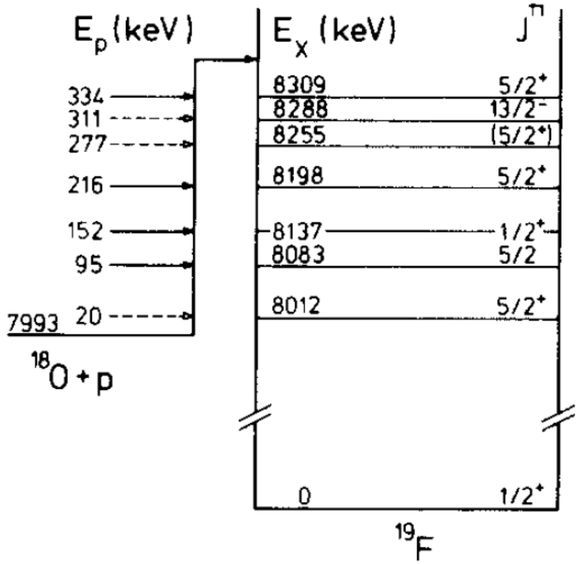
resonance strength of 70keV state largely uncertain

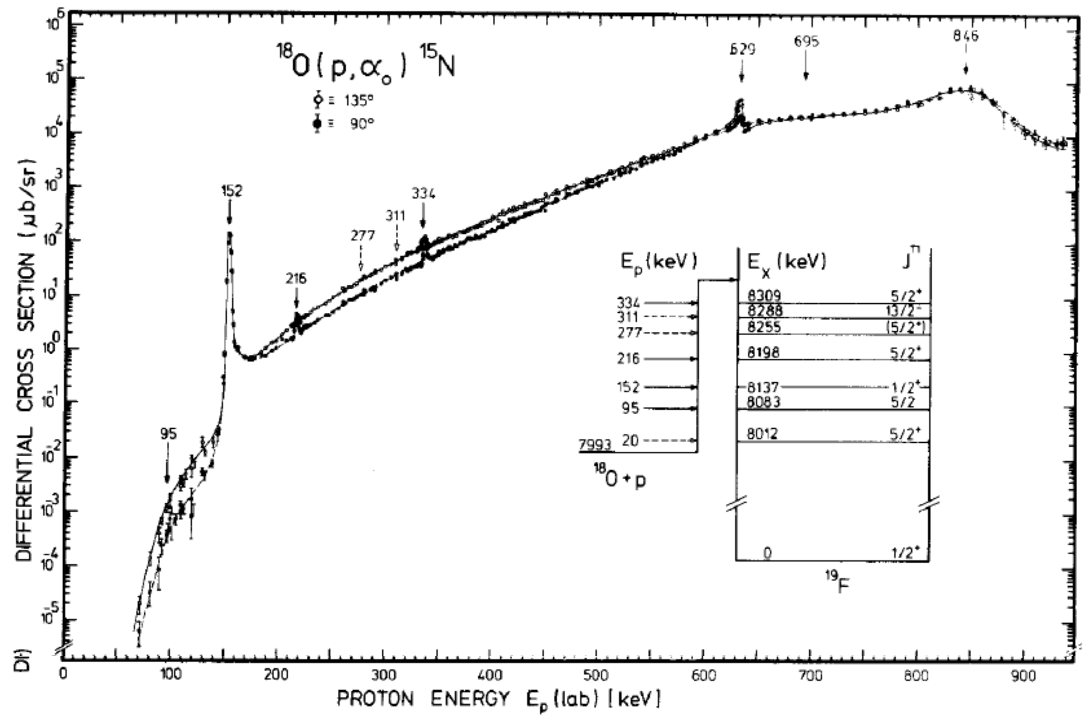
AIMS:

1) measure resonance strength of 70keV state

2) determine new reaction rate

The $^{18}O(p,\alpha)^{15}N$ reaction





Lorenz-Wirzba, NPA 313 (1979) 346

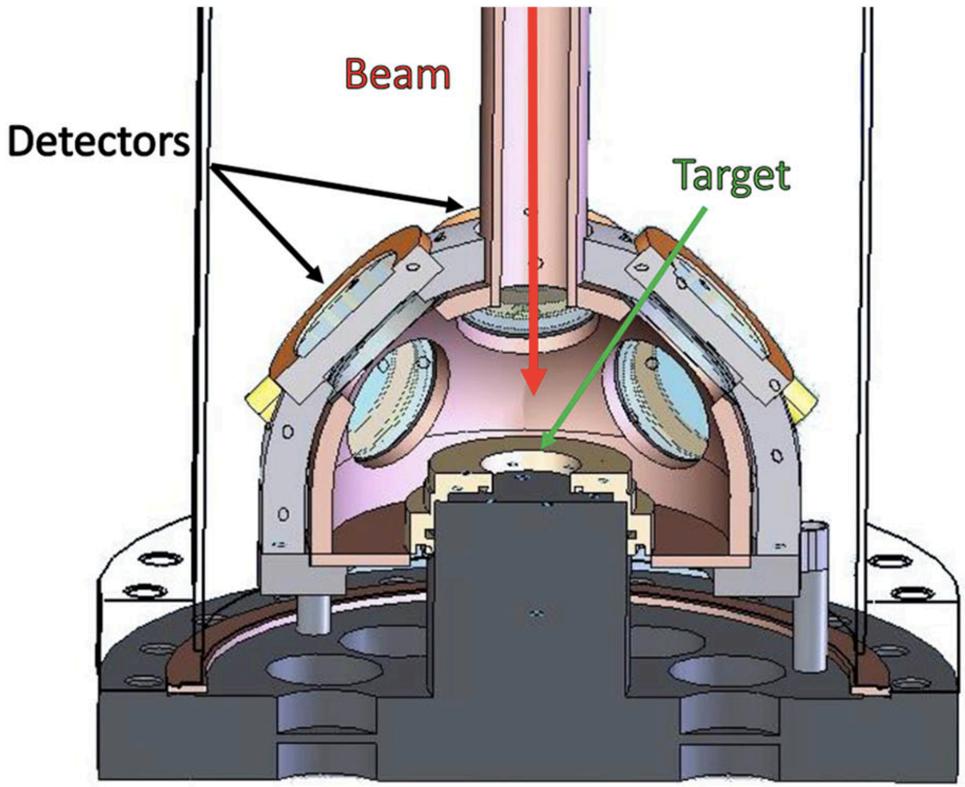
- Reaction rate (at T = 0.05-2.5 GK) dominated by 152 keV resonance, with contributions from interference between higher-energy states
- contribution from 95 keV resonance questioned (Fortune, PRC 88 (2013) 015801)

AIMS

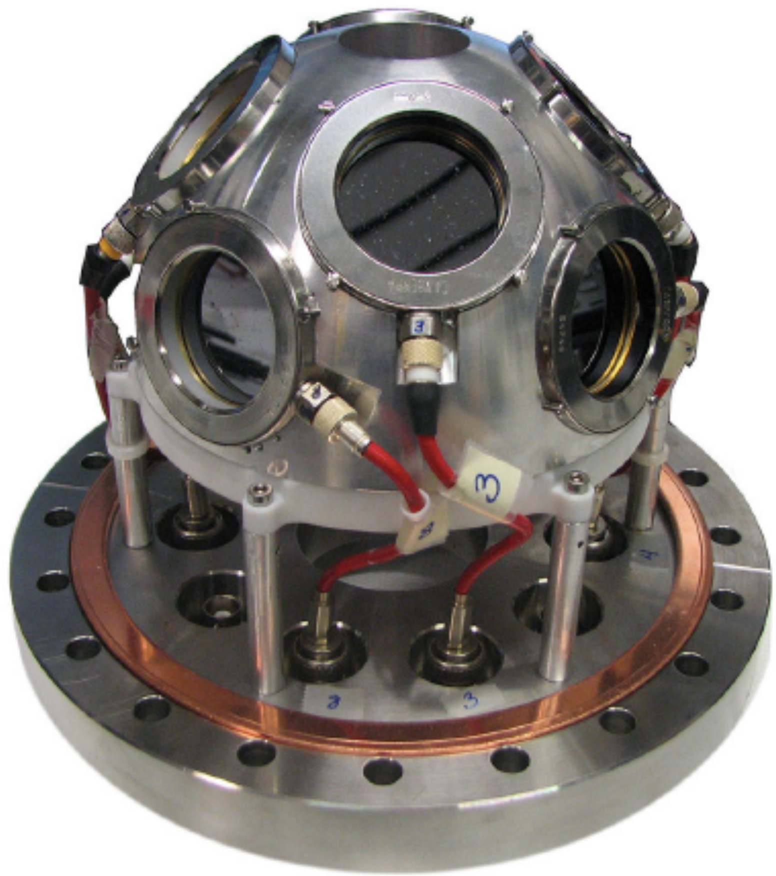
1) measure full excitation function to lowest accessible energy
2) check resonance energy of 95keV state
3) R-matrix fit to cross section → reaction rate

Our Measurements at LUNA

Purpose-built scattering chamber to host array of 8 silicon detectors

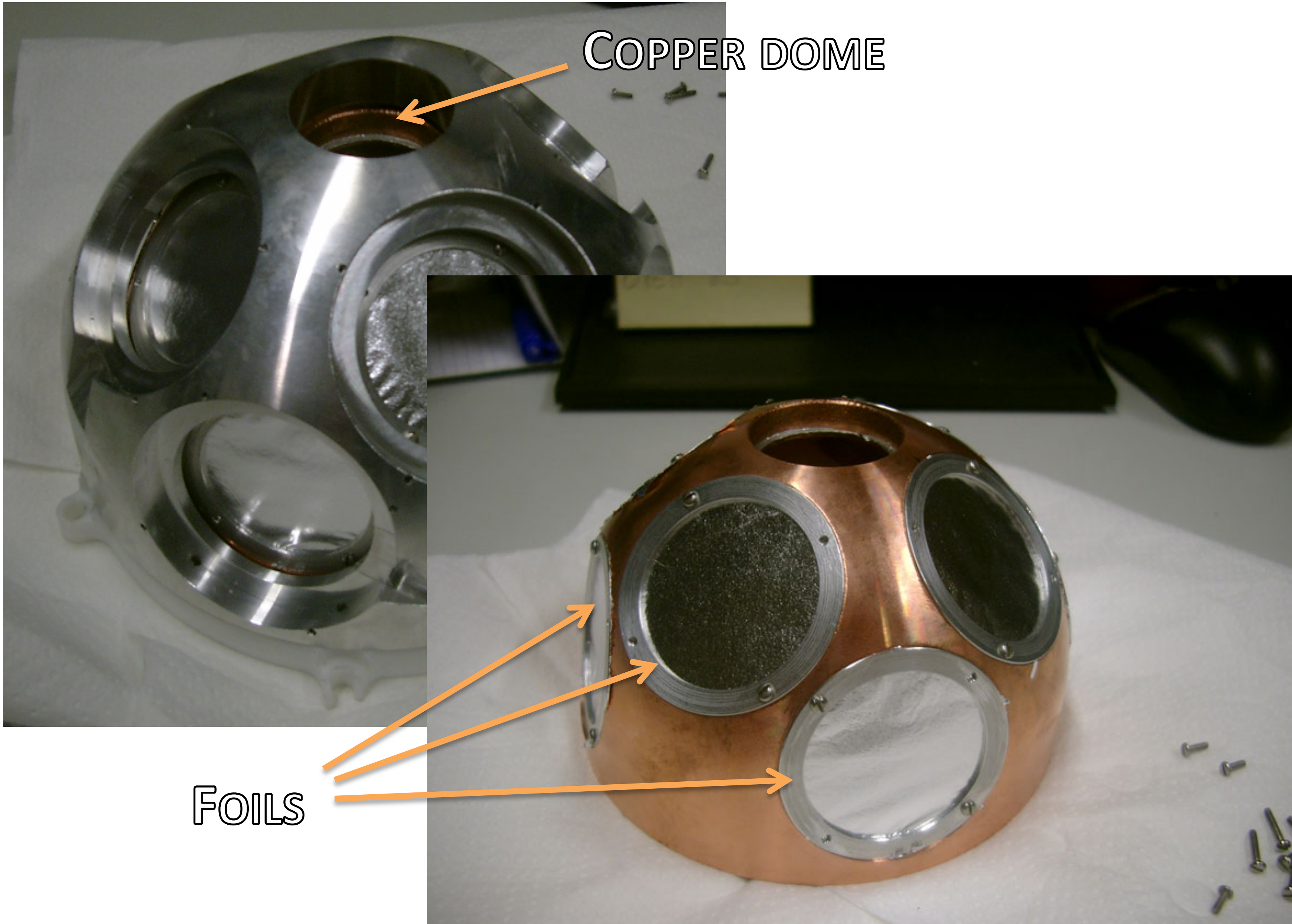


Bruno et al EJPA 51 (2015) 94



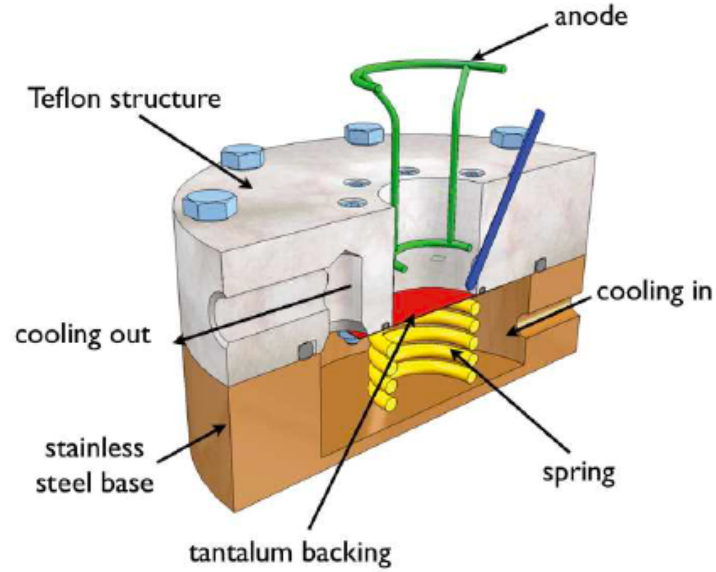
- protective aluminized Mylar foils (2.4 μm) before each detector
- expected alpha particle energy E ~ 200 keV (from 70 keV resonance in $^{17}O(p,\alpha)^{14}N$)

Setup Details



Isotopically Enriched Targets

- 95% enriched in ^{17}O or ^{18}O
- 5-15 keV thick (E_p = 200 keV)
- capable to sustain up to 20C (accumulated charge)



Eur. Phys. J. A (2012) 48: 144
DOI 10.1140/epja/i2012-12144-0

THE EUROPEAN PHYSICAL JOURNAL A

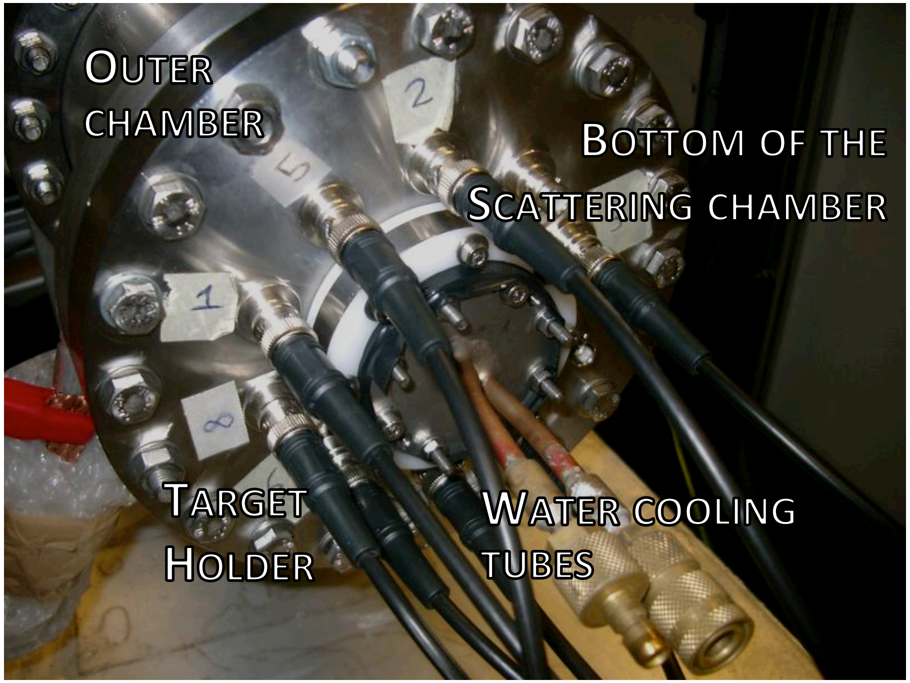
Regular Article – Experimental Physics

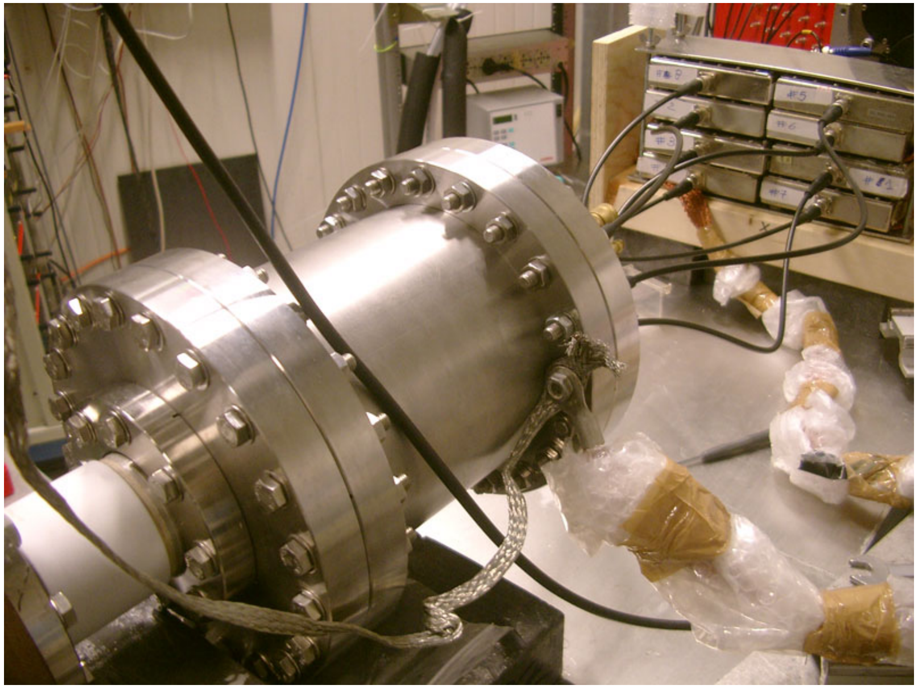
Preparation and characterisation of isotopically enriched Ta_2O_5 targets for nuclear astrophysics studies

LUNA Collaboration

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

Scattering Chamber for the $^{17,18}O(p,\alpha)^{14,15}N$ reactions at LUNA

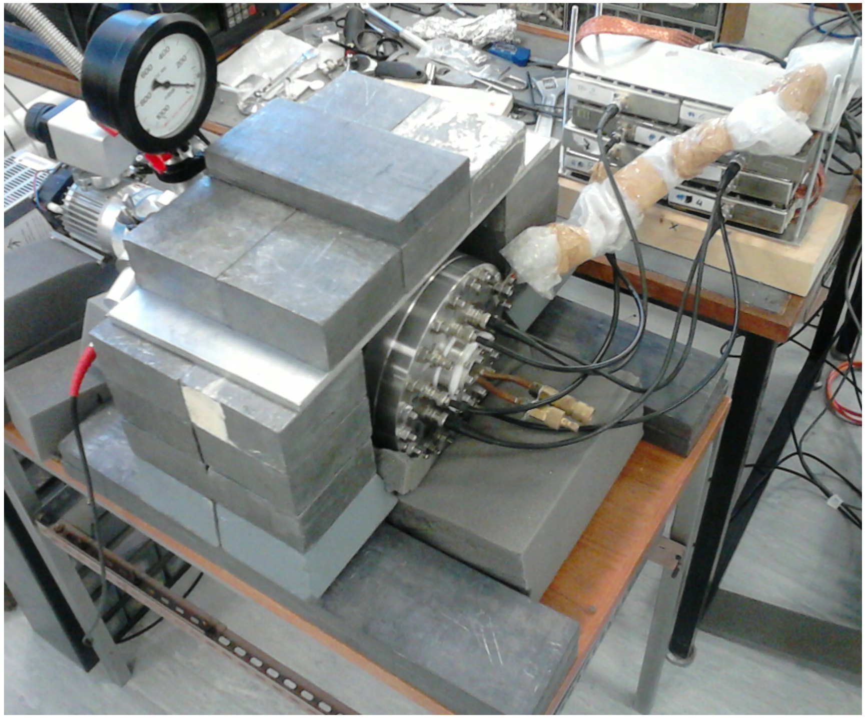




Commissioning Phase

- background measurements above- and under-ground; with and without lead shield
- detector calibration with concurrent measurement of foils thickness
- detection efficiency by two independent simulations of experimental setup and comparison with measurements

Edinburgh



Gran Sasso

Eur. Phys. J. A (2015) 51: 94
DOI 10.1140/epja/i2015-15094-y

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Experimental Physics

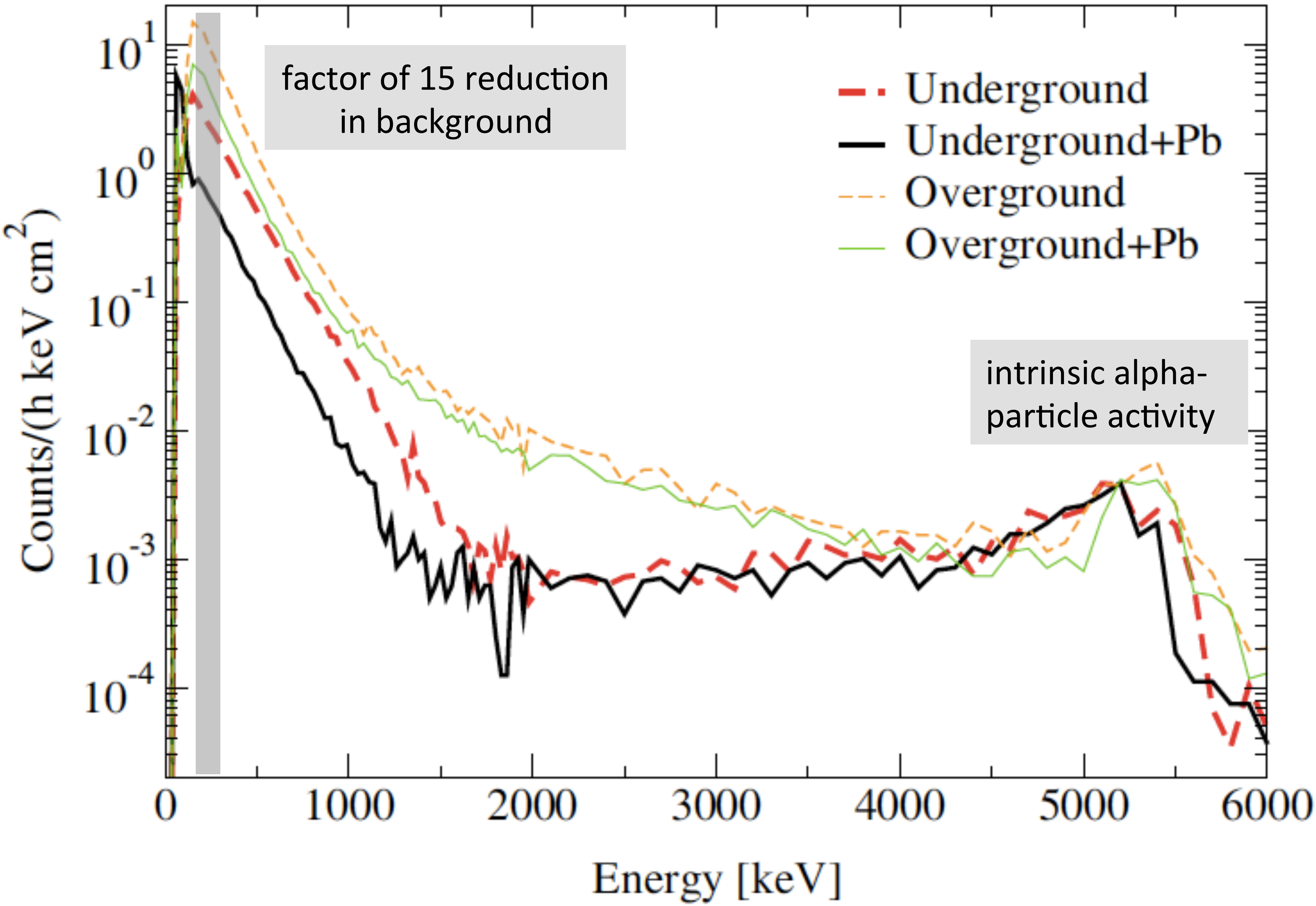
Resonance strengths in the $^{17,18}O(p,\alpha)^{14,15}N$ reactions and background suppression underground

Commissioning of a new setup for charged-particle detection at LUNA

LUNA Collaboration

C.G. Bruno[1], D.A. Scott[1], A. Formicola[2], M. Aliotta[1,a], T. Davinson[1], M. Anders[3], A. Best[2], D. Bemmerer[3], C. Broggini[4], A. Caciolli[4,5], F. Cavanna[6], P. Corvisiero[6], R. Depalo[4,5], A. Di Leva[7], Z. Elekes[8], Zs. Fülöp[8], G. Gervino[9], C.J. Griffin[1], A. Guglielmetti[10], C. Gustavino[11], Gy. Gyürky[8], G. Imbriani[7], M. Junker[2], R. Menegazzo[4], E. Napolitani[5], P. Prati[6], E. Somorjai[8], O. Straniero[2,12], F. Strieder[13], T. Szücs[3], and D. Trezzi[10]

Background Suppression

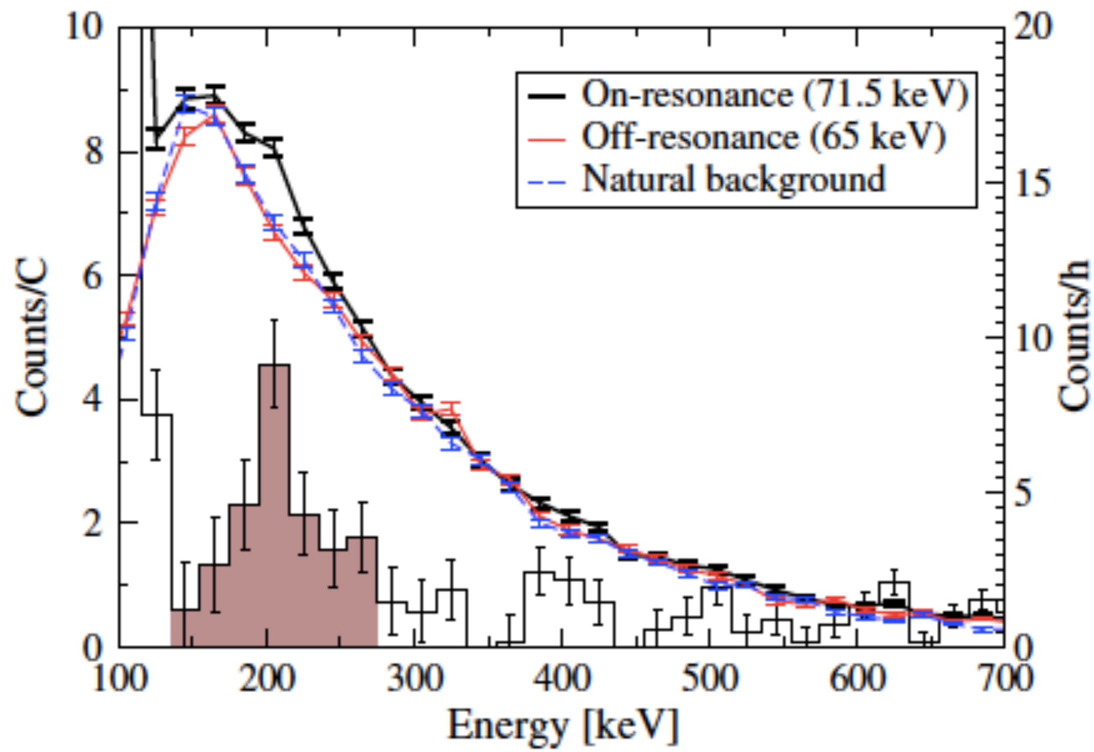


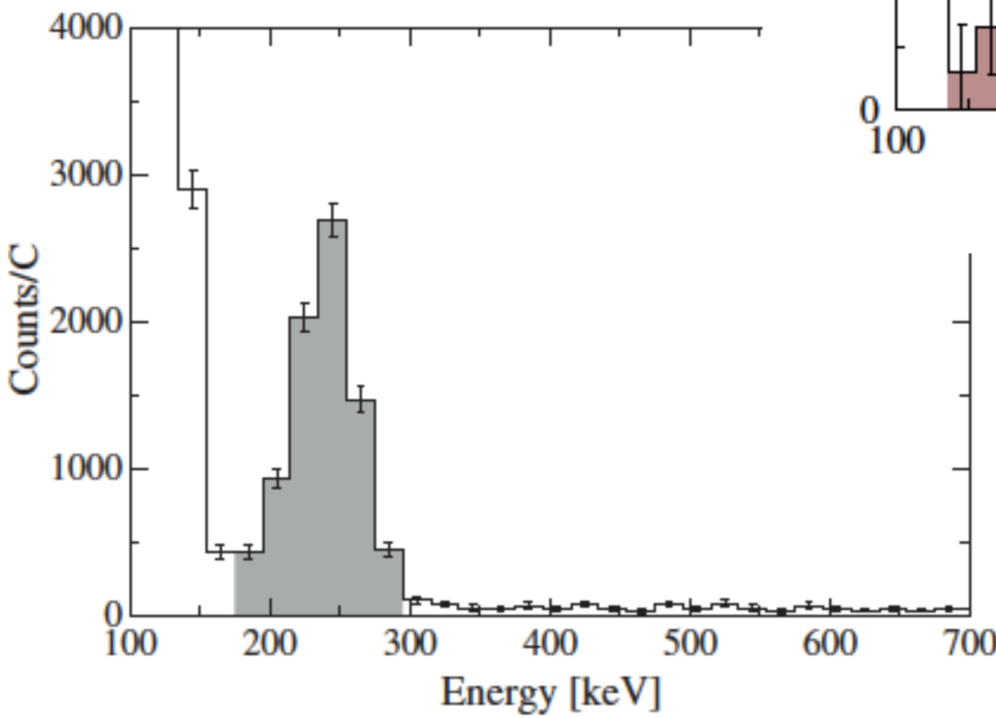
Results

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

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

use stronger 193keV resonance to identify ROI for expected alpha particles from 70keV state





$\omega\gamma$ = 10.0 ± 1.4 (stat) ± 0.7 (sys) neV

most accurate result to date

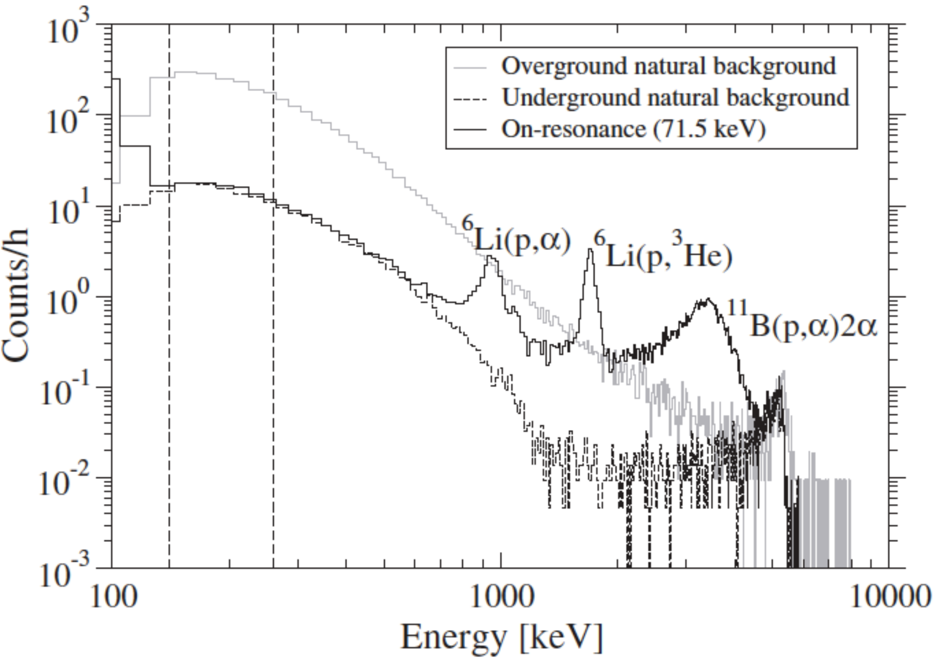
$^{17}O(p,\alpha)^{14}N$ Results

PRL 117, 142502 (2016) PHYSICAL REVIEW LETTERS week ending 30 SEPTEMBER 2016

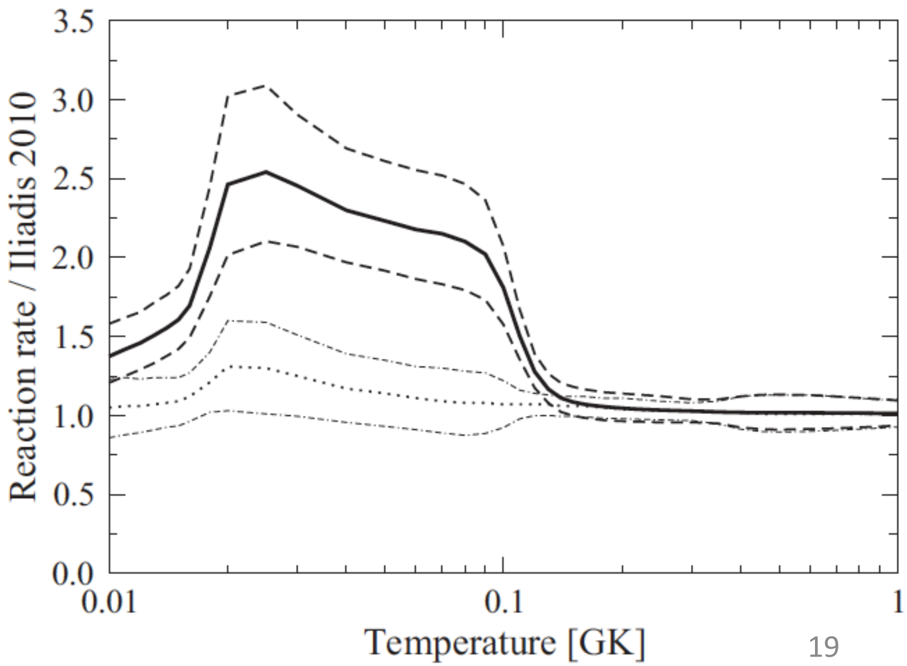
Improved Direct Measurement of the 64.5 keV Resonance Strength in the $^{17}O(p,\alpha)^{14}N$ Reaction at LUNA

C. G. Bruno,[1,*] D. A. Scott,[1] M. Aliotta,[1,†] A. Formicola,[2] A. Best,[3] A. Boeltzig,[4] D. Bemmerer,[5] C. Broggini,[6] A. Caciolli,[7] F. Cavanna,[8] G. F. Ciani,[4] P. Corvisiero,[8] T. Davinson,[1] R. Depalo,[7] A. Di Leva,[3] Z. Elekes,[9] F. Ferraro,[8] Zs. Fülöp,[9] G. Gervino,[10] A. Guglielmetti,[11] C. Gustavino,[12] Gy. Gyürky,[9] G. Imbriani,[3] M. Junker,[2] R. Menegazzo,[6] V. Mossa,[13] F. R. Pantaleo,[13] D. Piatti,[7] P. Prati,[8] E. Somorjai,[9] O. Straniero,[14] F. Strieder,[15] T. Szücs,[5] M. P. Takács,[5] and D. Trezzi[11]

15x background reduction in ROI
+ improved experimental conditions



reaction rate ~ 2-2.5x higher
than previously assumed



Astrophysical Implications

^{17}O yield from 2-10 M_{sun} stars is 15-40% smaller than previously thought

Astronomy & Astrophysics manuscript no. oiso_3
November 1, 2016
©ESO 2016

The impact of the revised $^{17}O(p,\alpha)^{14}N$ reaction rate on ^{17}O stellar abundances and yields

O. Straniero[1,2], C.G.Bruno[5], M. Aliotta[5], A. Best[6], A. Boeltzig[3], D. Bemmerer[4], C. Broggini[7], A. Caciolli[7,8], F. Cavanna[9], G.F. Ciani[3], P. Corvisiero[9], S. Cristallo[1,16], T. Davinson[5], R. Depalo[7,8], A. Di Leva[6], Z. Elekes[10], F. Ferraro[9], A. Formicola[2], Zs. Fülöp[10], G. Gervino[11], A. Guglielmetti[12], C. Gustavino[13], G. Gyürky[10], G. Imbriani[6], M. Junker[2], R. Menegazzo[7], V. Mossa[14], F.R. Pantaleo[14], D. Piatti[7,8], L. Piersanti[1,16], P. Prati[9], E. Samorjai[10], F. Strieder[15], T. Sz"ucs[4], M.P. Takács[4], and D. Trezzi[11]

$^{17}O/^{16}O$ composition and origin of pre-solar grains revisited

nature astronomy

LETTERS

PUBLISHED: 30 JANUARY 2017 | VOLUME: 1 | ARTICLE NUMBER: 0027

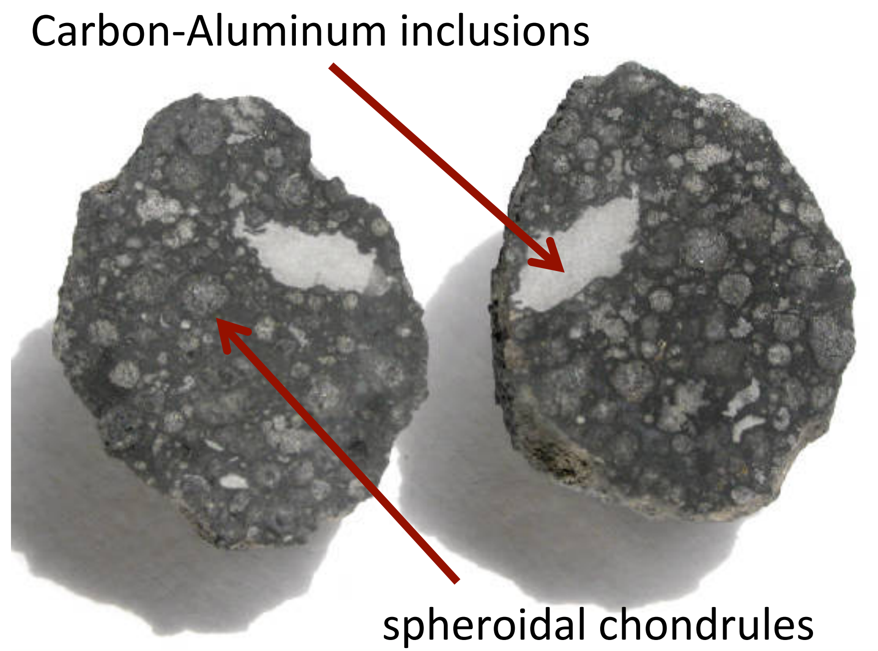
Origin of meteoritic stardust unveiled by a revised proton-capture rate of ^{17}O

M. Lugaro[1,2*], A. I. Karakas[2-4], C. G. Bruno[5], M. Aliotta[5], L. R. Nittler[6], D. Bemmerer[7], A. Best[8], A. Boeltzig[9], C. Broggini[10], A. Caciolli[11], F. Cavanna[12], G. F. Ciani[9], P. Corvisiero[12], T. Davinson[5], R. Depalo[11], A. Di Leva[8], Z. Elekes[13], F. Ferraro[12], A. Formicola[14], Zs. Fülöp[13], G. Gervino[15], A. Guglielmetti[16], C. Gustavino[17], Gy. Gyürky[13], G. Imbriani[8], M. Junker[14], R. Menegazzo[10], V. Mossa[18], F. R. Pantaleo[18], D. Piatti[11], P. Prati[12], D. A. Scott[5,†], O. Straniero[14,19], F. Strieder[20], T. Szücs[13], M. P. Takács[7] and D. Trezzi[16]

Rocks from Space: the Importance of Meteorites

fragment of Allende Meteorite
(named after nearest post office)
8 February 1969 – Mexico

- best known and most studied meteorite in history



isotopic anomalies compared to solar abundances provide evidence for processes that occurred in other stars before Solar System formed

http://www.marmet-meteorites.com/id46.html

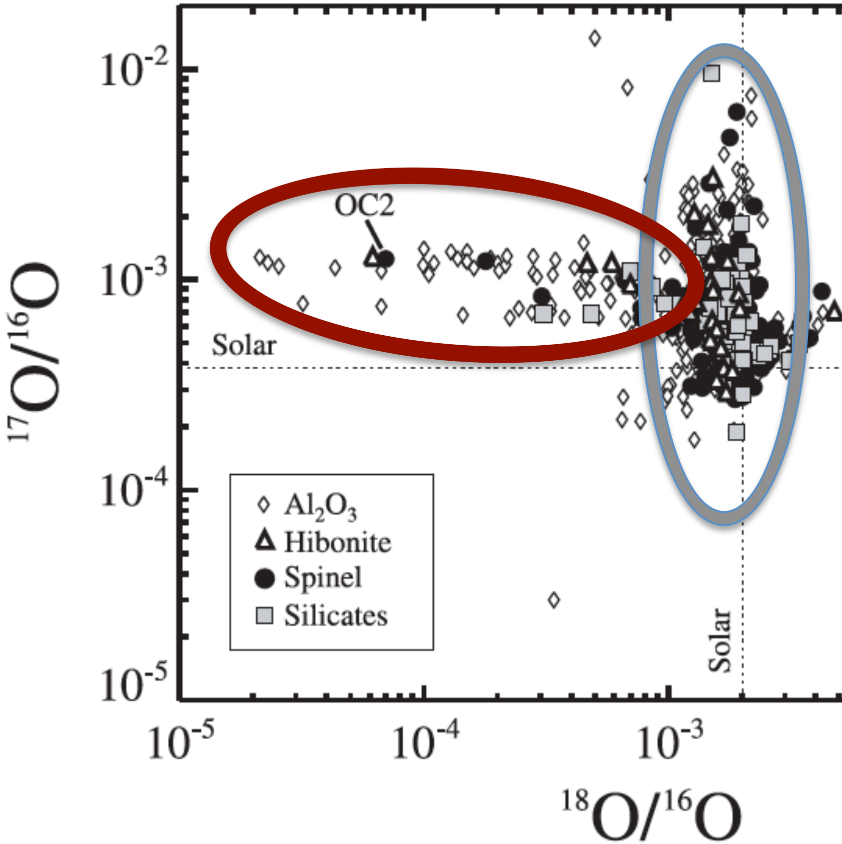
Pre-solar grains in meteorites

- Carbon-rich (diamond, graphite, silicon carbide)

- Oxygen-rich (silicates, Al-rich oxides, …)

Group I (about 75%): show excess in ^{17}O compared to solar values;
origin well-understood: red giants (1-3 $M_\odot$)

Group II (about 10%): excess in ^{17}O, but depleted in ^{18}O (up to 2 o.o.m. less than in solar system)
origin highly debated!

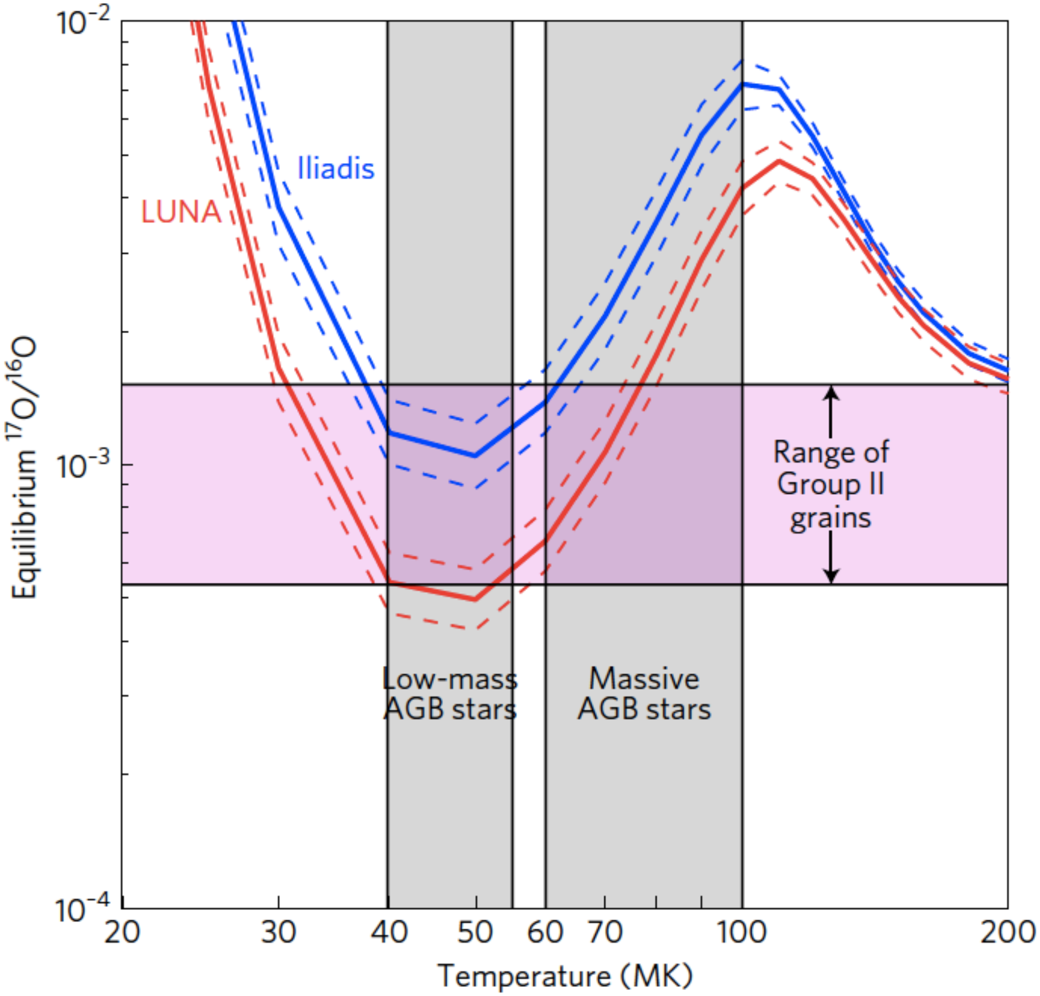


Massive (4-8 $M_\odot$) AGB stars expected to produce large amounts of dust through stellar winds…

BUT…

previous rates of $^{17}O(p,\alpha)^{14}N$ reaction could not account for observed abundances

On the origin of Group II grains



with previous $^{17}O(p,\alpha)^{14}N$ reaction rate (Iliadis, 2010):

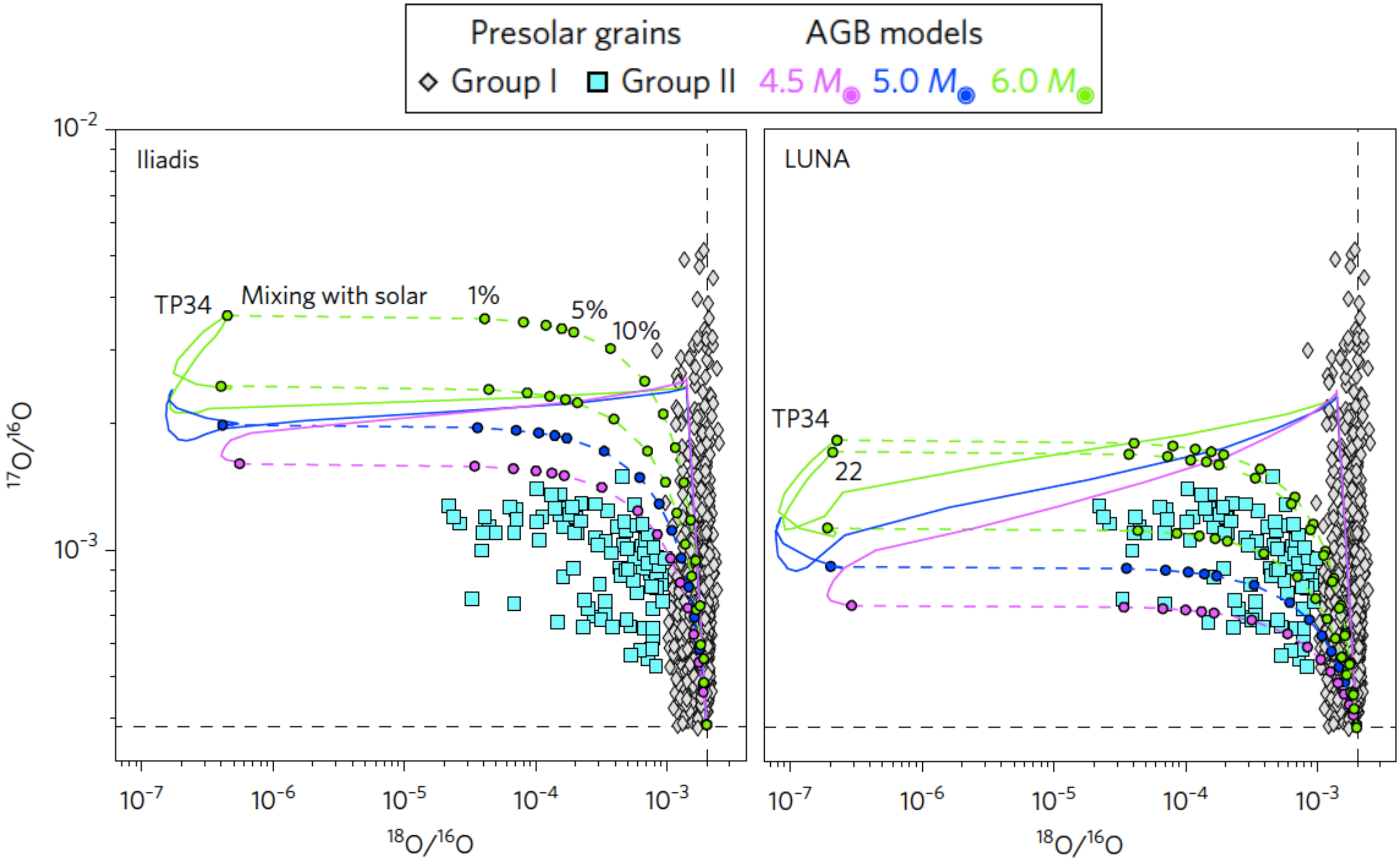
- massive AGB stars excluded as possible sites of origin
- low-mass AGB stars can be a possible site, but extra mixing process unclear

with new reaction rate (LUNA , 2016):

- massive AGB stars become likely site of origin (as expected)
- no need to invoke "extra mixing"

M Lugaro et al., Nature Astronomy 1 (2017) 0027

On the origin of Group II grains



M Lugaro et al., Nature Astronomy 1 (2017) 0027

Results
$^{18}O(p,\alpha)^{15}N$ reaction

slides remove because results not published yet

Astrophysical Implications

Reaction Rate

- ^{18}O is destroyed very efficiently
- Probably less critical than for $^{17}O(p,\alpha)$
- May still be interesting lower mass AGB stars
- Work in progress …

Laboratori Nazionali del Gran Sasso, INFN, ASSERGI, Italy/*GSSI, L'AQUILA, Italy

A. Boeltzig*, L. Csedreki, A. Formicola, G.F. Ciani*, M. Junker, I. Kochanek, A. Razeto

Università degli Studi di Bari and INFN, BARI, Italy

G. D'Erasmo, E.M. Fiore, V. Mossa, F. Pantaleo, V. Paticchio, L. Schiavulli

Konkoly Observatory, Hungarian Academy of Sciences, BUDAPEST, Hungary

M. Lugaro

Institute of Nuclear Research (ATOMKI), DEBRECEN, Hungary

Z. Elekes, Zs. Fülöp, Gy. Gyürky, T. Szücs,

Helmholtz-Zentrum Dresden-Rossendorf, DRESDEN, Germany

D. Bemmerer, K. Stoeckel, M. Takács

University of Edinburgh, EDINBURGH, United Kingdom

M. Aliotta, C.G. Bruno, T. Davinson

Università degli Studi di Genova and INFN, GENOVA, Italy

F. Cavanna, P. Corvisiero, F. Ferraro, P. Prati, S. Zavatarelli

INFN Lecce, LECCE, Italy

R. Perrino

Università degli Studi di Milano and INFN, MILANO, Italy

A. Guglielmetti, D. Trezzi

Università degli Studi di Napoli "Federico II" and INFN, NAPOLI, Italy

A. Best, A. Di Leva, G. Imbriani

Università degli Studi di Padova and INFN, PADOVA, Italy

C. Broggini, A. Caciolli, R. Depalo, P. Marigo, R. Menegazzo, D. Piatti

INFN Roma, ROMA, Italy

C. Gustavino

Osservatorio Astronomico di Collurania, TERAMO and INFN LNGS, Italy

O. Straniero

Università di Torino and INFN, TORINO, Italy

G. Gervino

with special thanks to
Carlo Bruno (PhD)