

~~Study of the alpha-nucleus optical potential through (α, n) reactions in the mass range relevant to the γ -process~~

Accelerator-based experiments for the p-process from Vravron to Budapest and beyond

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Institute of Nuclear Research (Atomki)

Debrecen, Hungary



8th p-process workshop 2024



ESF/PESC Exploratory Workshop on p-Process Nucleosynthesis

Vravron, Attika, Greece, April 18-21, 2002

Some speakers:



Claus Rolfs



Marcel Arnould



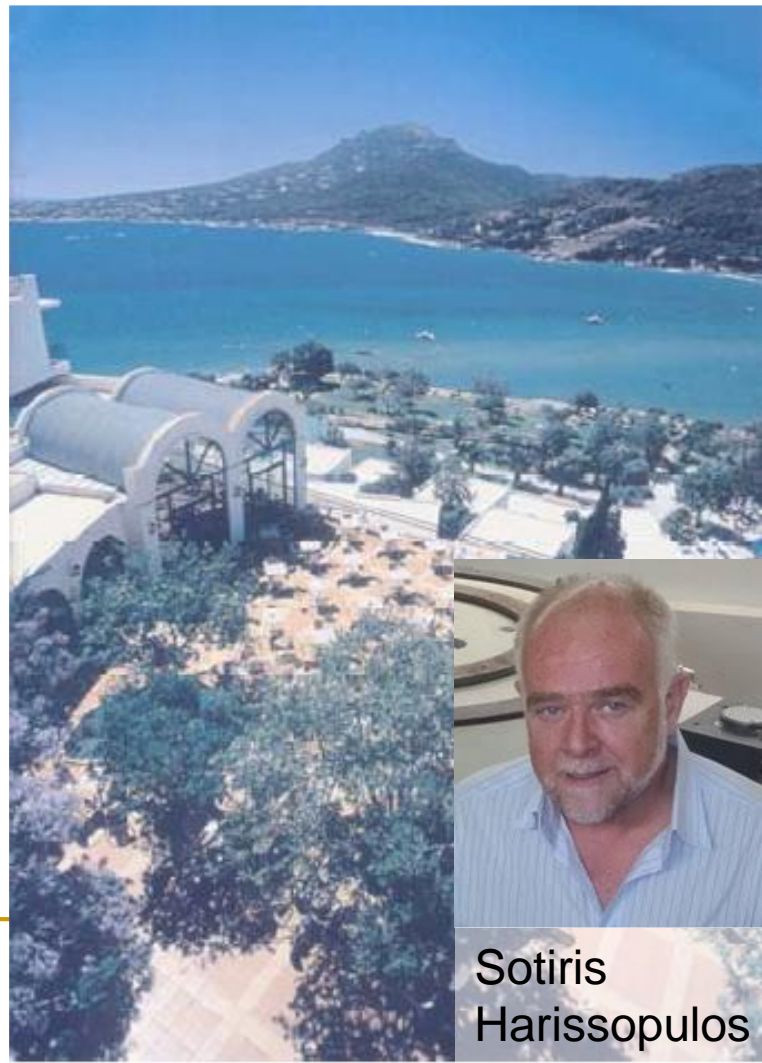
Franz Käppeler



Wolfgang Hammer



Endre Somorjai



Sotiris
Harissopulos

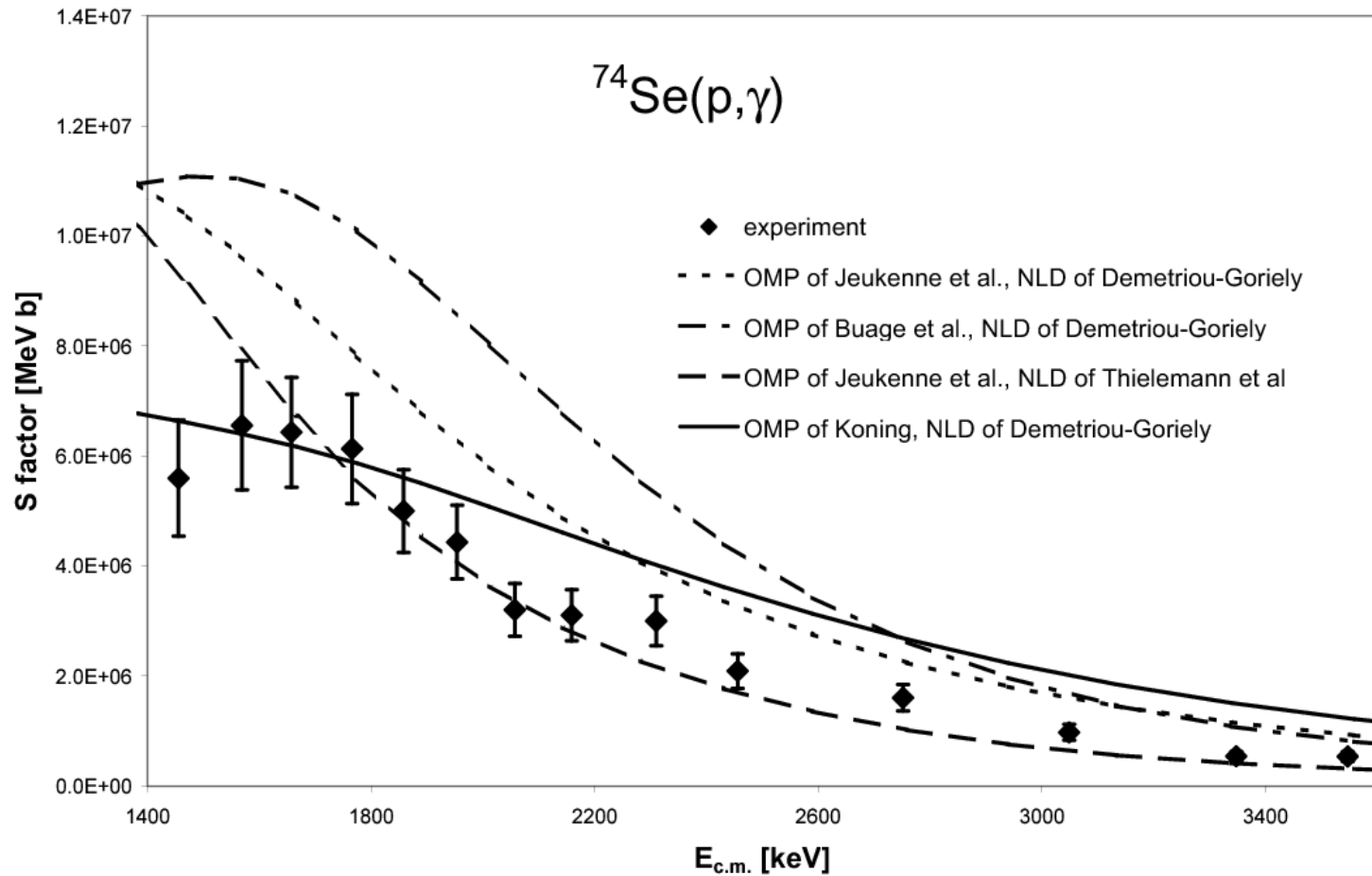
Some experimental (and related) topics

- Gamma-induced reactions
- New α -OMP (P. Demetriou)
- Level densities, γ strength functions
- Capture reactions



ESF/PESC Exploratory Workshop on
p-Process Nucleosynthesis
Vravron, Attika, Greece, April 18-21, 2002

From Atomki: p-induced reactions with activation



The p-process workshop

Garching, 10.-11.9.2009

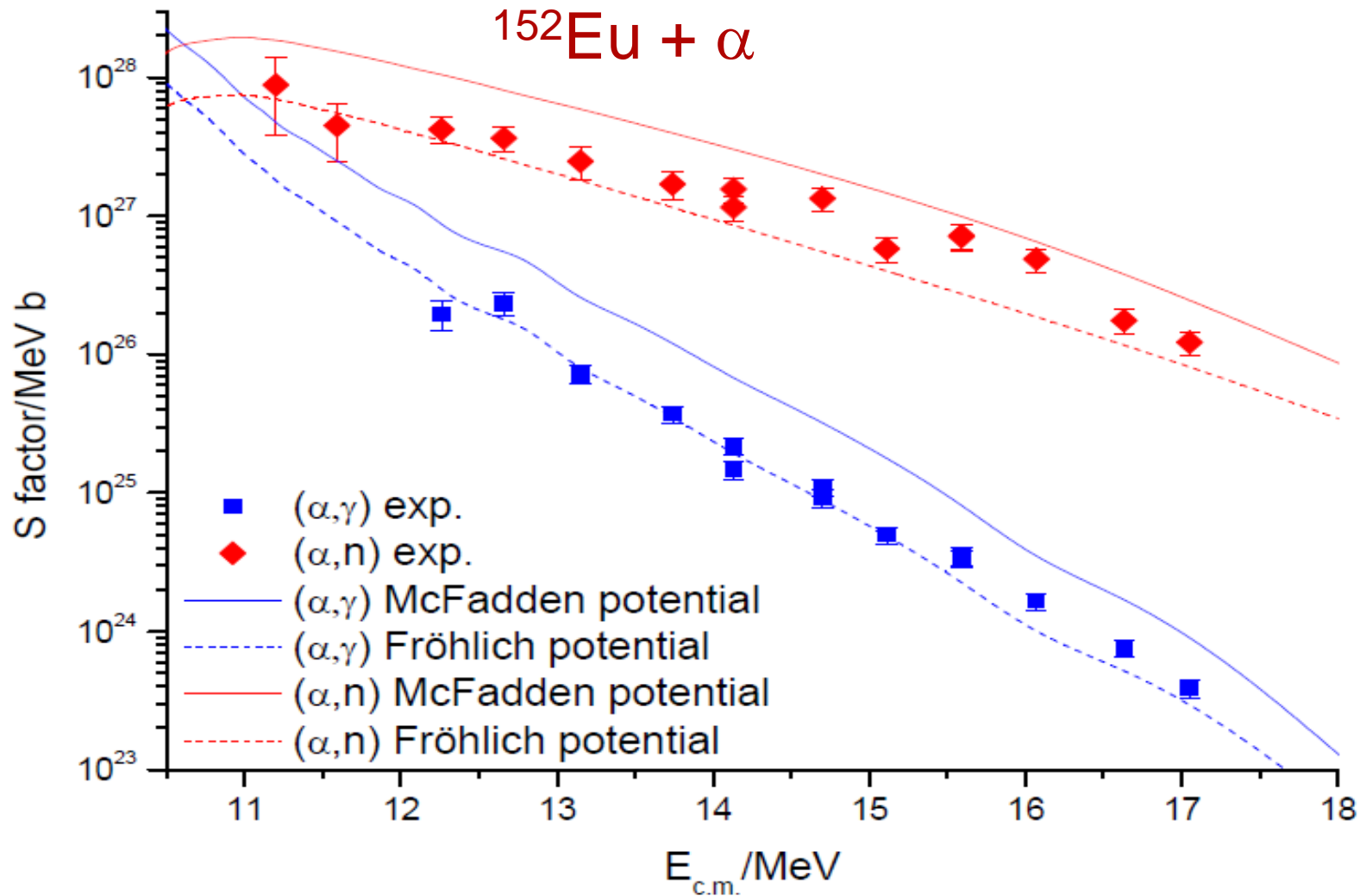


- (n, γ) cross sections
- AMS
- RIB (inverse kinematics)
- Dawn of storage ring
- rp-process
- vp-process



Iris Dillmann

From Atomki: α -induced reactions



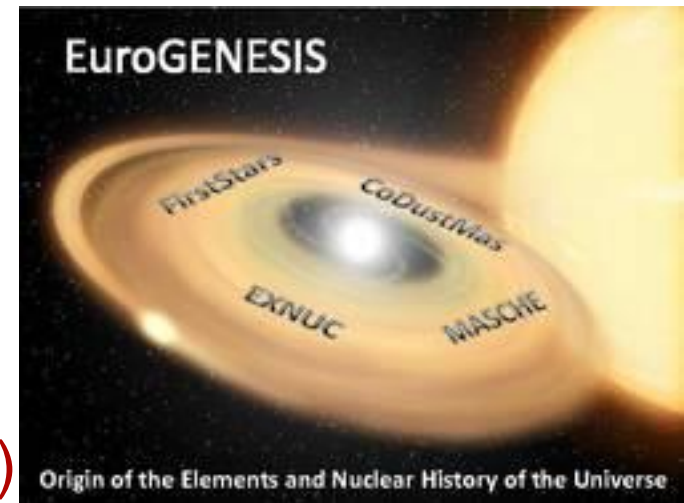
p-process: present status and outlook

Workshop

25-27 May 2011 - The Armada Hotel - Istanbul, TURKEY



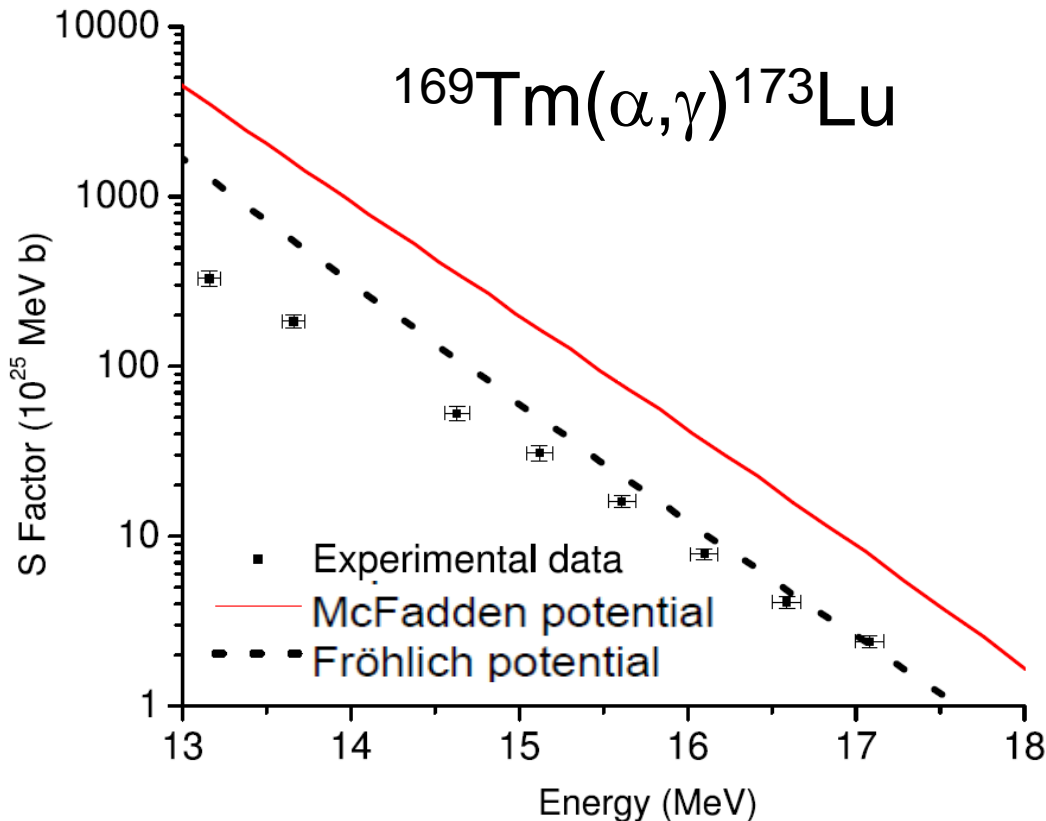
- p-process nucleosynthesis (γ -process, rp-process, vp-process, v-process)
- Nuclear structure aspects
- Experimental situation: increasing interest (DRAGON@TFIUMF, Cologne)
- Hauser-Feshbach and reaction rates
- p-process data evaluation (Kadonis)



Nalan Özkan

From Atomki: extension of activation, growing database

characteristic X-ray detection

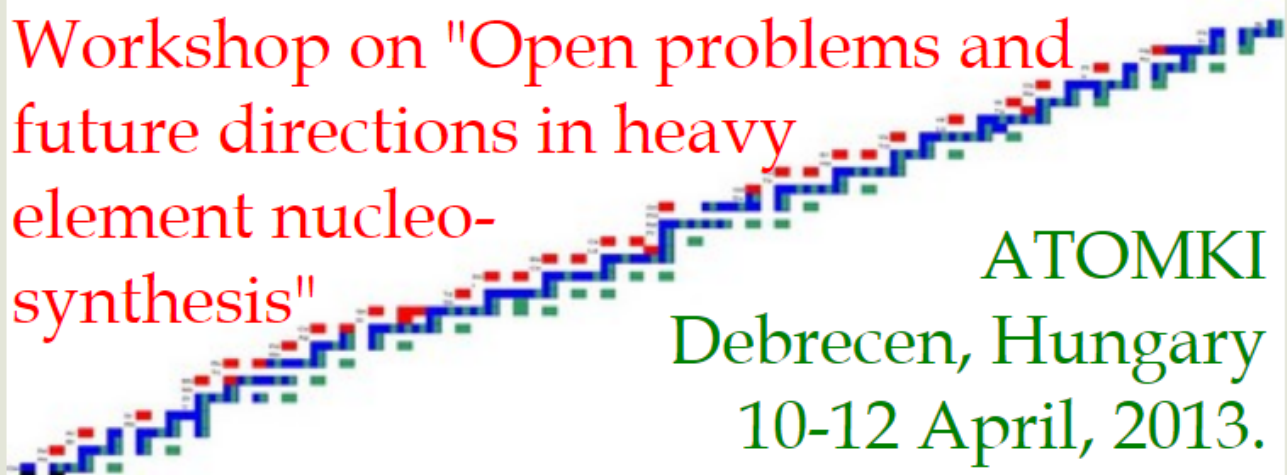


Summary of measured reactions

proton induced reactions	alpha induced reaction
$^{84}\text{Sr}(p, \gamma)^{85}\text{Y}$	$^{70}\text{Ge}(\alpha, \gamma)^{74}\text{Se}$
$^{86}\text{Sr}(p, \gamma)^{87}\text{Y}$	$^{106}\text{Cd}(\alpha, \gamma)^{110}\text{Sn}$
$^{87}\text{Sr}(p, \gamma)^{88}\text{Y}$	$^{106}\text{Cd}(\alpha, n)^{109}\text{Sn}$
$^{74}\text{Se}(p, \gamma)^{75}\text{Br}$	$^{106}\text{Cd}(\alpha, p)^{109}\text{In}$
$^{76}\text{Se}(p, \gamma)^{76}\text{Br}$	$^{113}\text{In}(\alpha, \gamma)^{117}\text{Sb}$
$^{82}\text{Se}(p, n)^{82}\text{Br}$	$^{113}\text{In}(\alpha, n)^{116}\text{Sb}$
$^{106}\text{Cd}(p, \gamma)^{107}\text{In}$	$^{144}\text{Sm}(\alpha, \gamma)^{148}\text{Gd}$
$^{108}\text{Cd}(p, \gamma)^{109}\text{In}$	$^{151}\text{Eu}(\alpha, \gamma)^{155}\text{Tb}$
$^{70}\text{Ge}(p, \gamma)^{71}\text{As}$	$^{151}\text{Eu}(\alpha, n)^{154}\text{Tb}$
$^{76}\text{Ge}(p, n)^{76}\text{As}$	
$^{85}\text{Rb}(p, n)^{85}\text{Sr}$	



Workshop on "Open problems and future directions in heavy element nucleosynthesis"

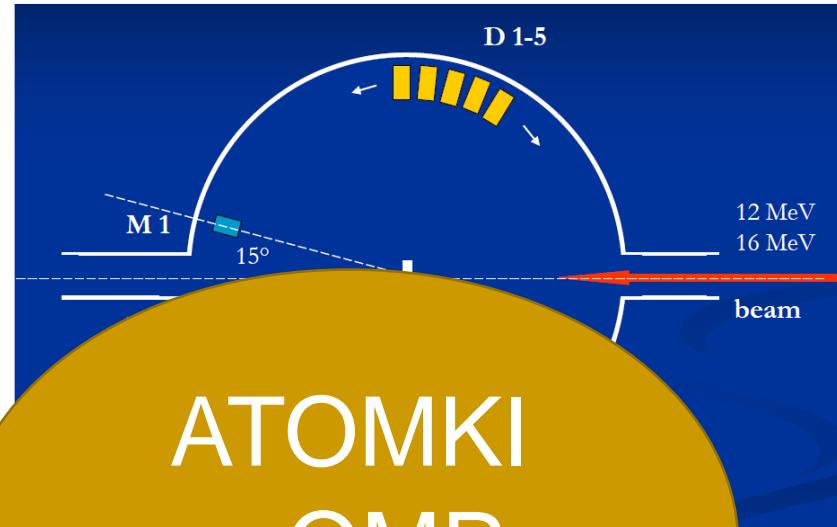


ATOMKI
Debrecen, Hungary
10-12 April, 2013.

- Astrophysical sites and processes for p-nuclide synthesis (e.g., γ -, rp-, v-, vp-, pn-processes and neutrino-winds)
- Experimental and theoretical nuclear physics for the p-nuclide production
- Open questions in nuclear physics and astrophysics for the s- and r-processes
- Observational constraints on heavy element nucleosynthesis
- Galactic chemical evolution studies for heavy element production
- Experimental techniques relevant for heavy element nucleosynthesis



From Atomki: KADoNIS-p, scattering ...



ATOMKI
 α -OMP
 version I.

Karlsruhe Astrophysical Database of Nucleosynthesis in Stars

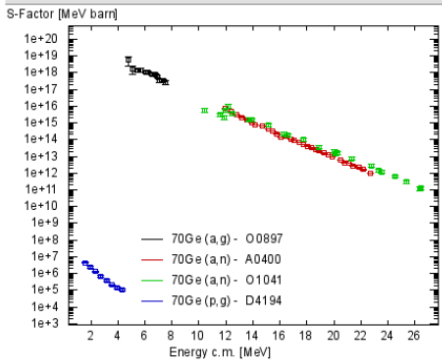
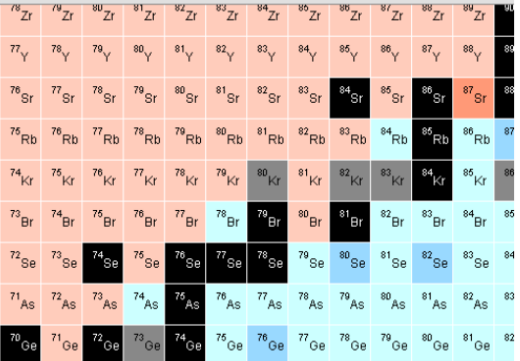
s-process [Gamow] [FAQ] [Disclaimer] [Contact us] p-process

p-process data viewer

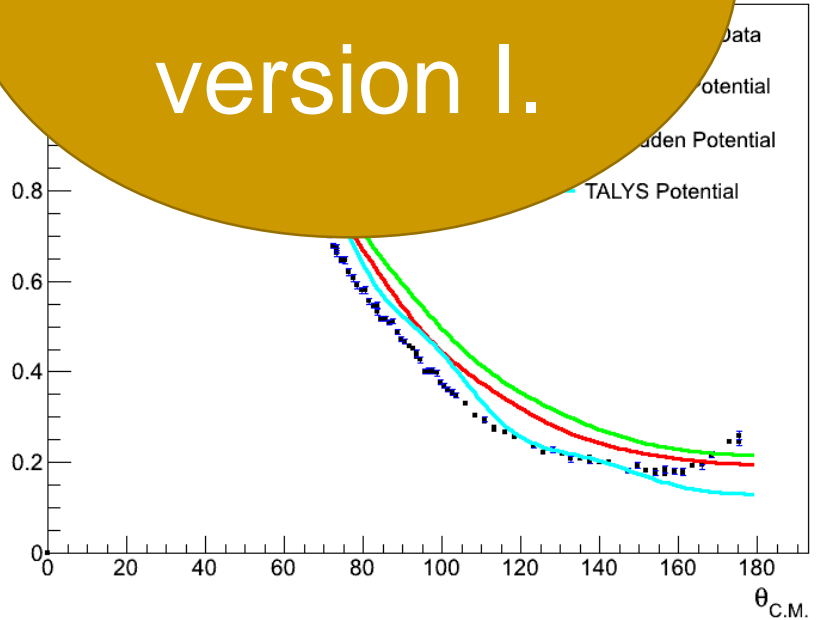
Enter your isotope of interest or click it on the chart of nuclides below (drag the chart with your mouse)

Isotope: all reactions

zoom out zoom in **70Ge**



Gamow window (T9=2-3): 3777.3 - 7807.6 MeV



p-process workshop 2015: status and outlook

June 10 – 13, 2015 at Limassol, Cyprus

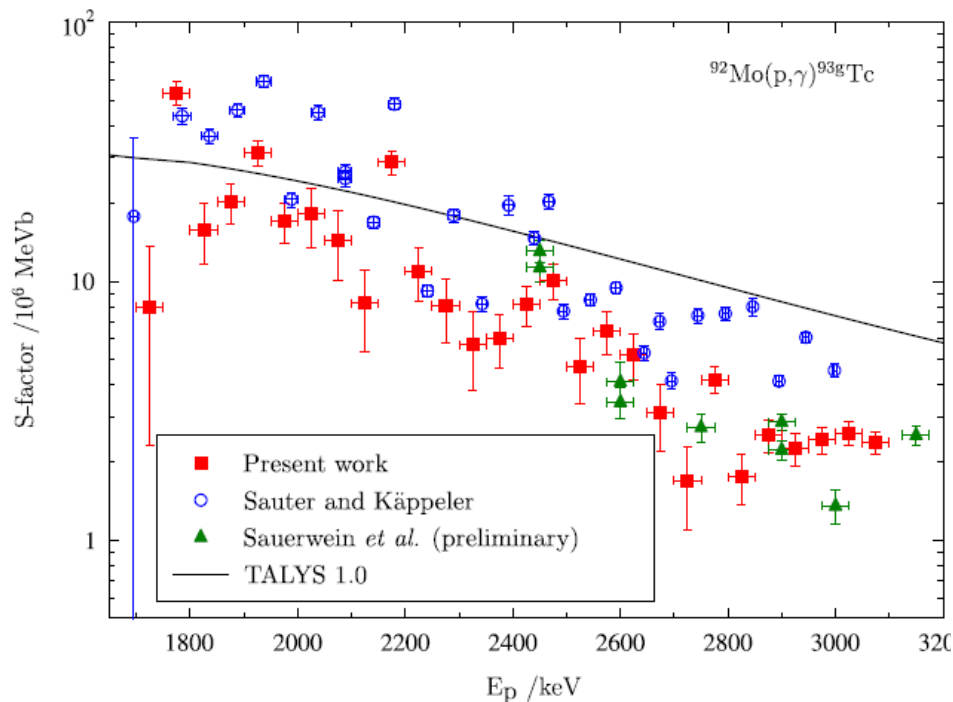
- p -process astrophysical calculations
- experimental efforts
- The νp process: production of p nuclei & related nuclear reaction sensitivities
- Calculations of reaction rates for the p process & their uncertainties
- Experimental investigations of reaction rates in **regular** and **inverse** kinematics
- ^{92}Mo region!!!



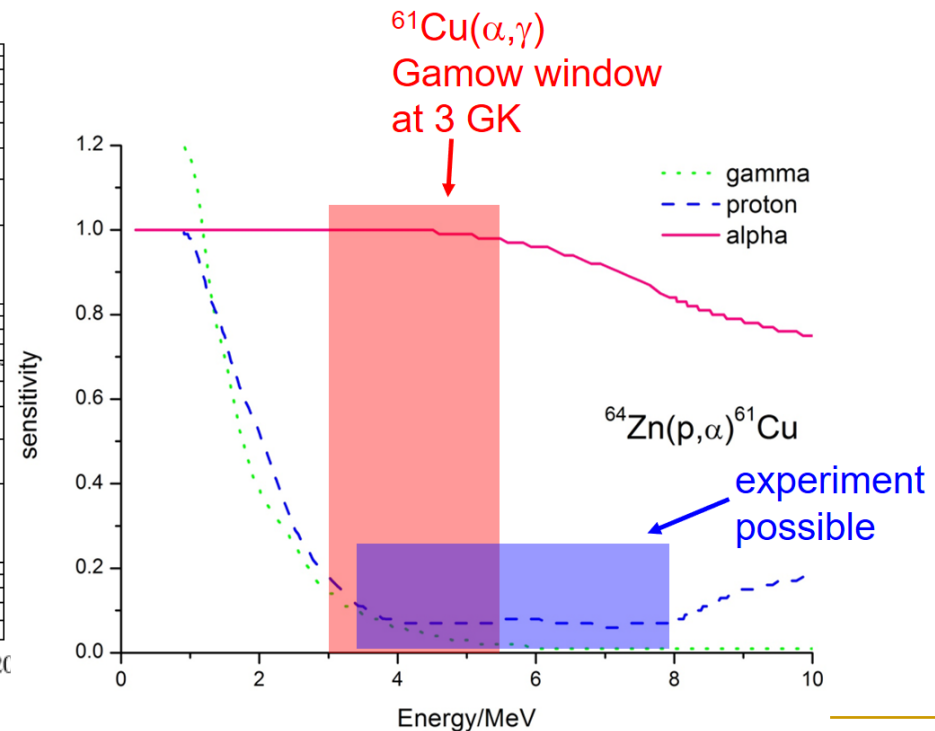
Artemis Spyrou

From Atomki: extension of activation

Thick target yield measurement
 $^{92}\text{Mo}(p,\gamma)^{93}\text{Tc}$



Study of α -OMP in
a (p,α) reaction
 $^{64}\text{Zn}(p,\alpha)^{61}\text{Cu}$



P-PROCESS WORKSHOP 2017

JUNE 29TH - JULY 1ST, 2017

UNIVERSITY OF NOTRE DAME, NOTRE DAME, IN, USA

- nuclear physics contributions (nuclear structure, Hauser-Feshbach models, cross section measurements)
- γ -induced reactions (HI γ S Facility)
- Storage ring results
- n-induced reactions (LANSCE)

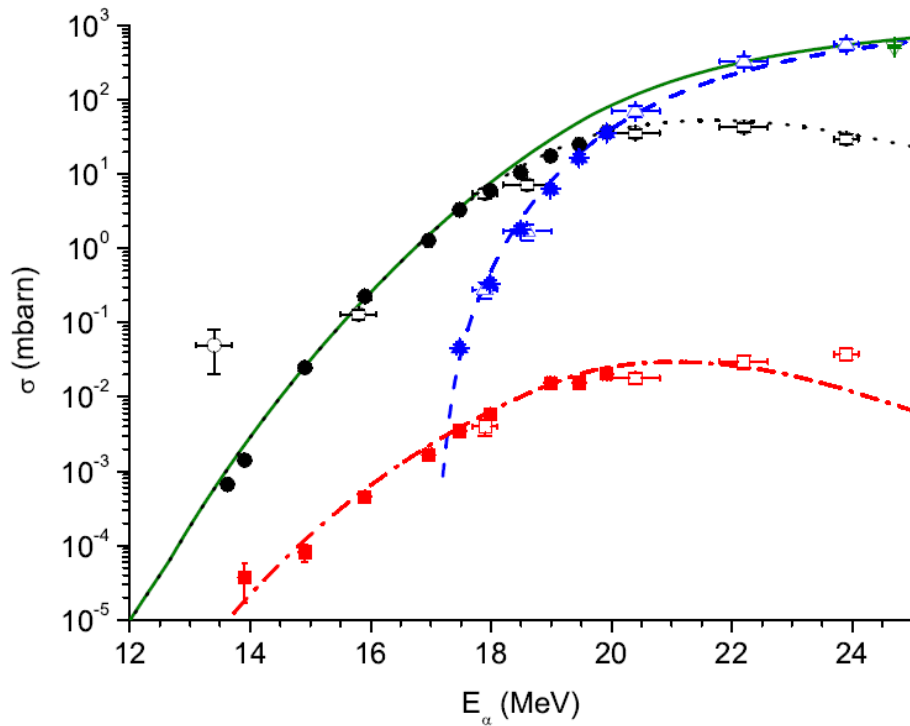


Anna Simon

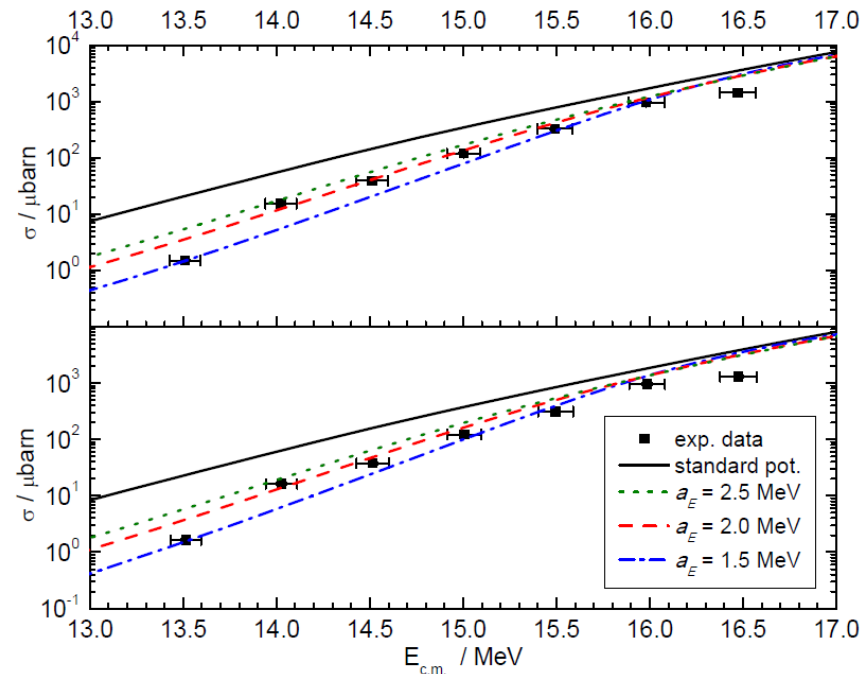


From Atomki: (α, γ) in the heaviest mass range

$^{197}\text{Au}(\alpha, \gamma)^{201}\text{Tl}$



$^{191}\text{Ir}(\alpha, \gamma)^{195}\text{Au}$



$$W(C, E_{\text{c.m.}}^\alpha) = \frac{25}{1 + e^{(0.9E_C - E_{\text{c.m.}}^\alpha)/a_E}} \text{ MeV}$$

- Nuclear physics/experiments related to p-process nucleosynthesis
- Stellar models and nucleosynthesis
- Meteorites and radioactives
- Presolar grains
- Chemical evolution
- **Nicely growing cross section database**

7th biannual p-process workshop

September 22-27, 2019

Il Boscareto Resort

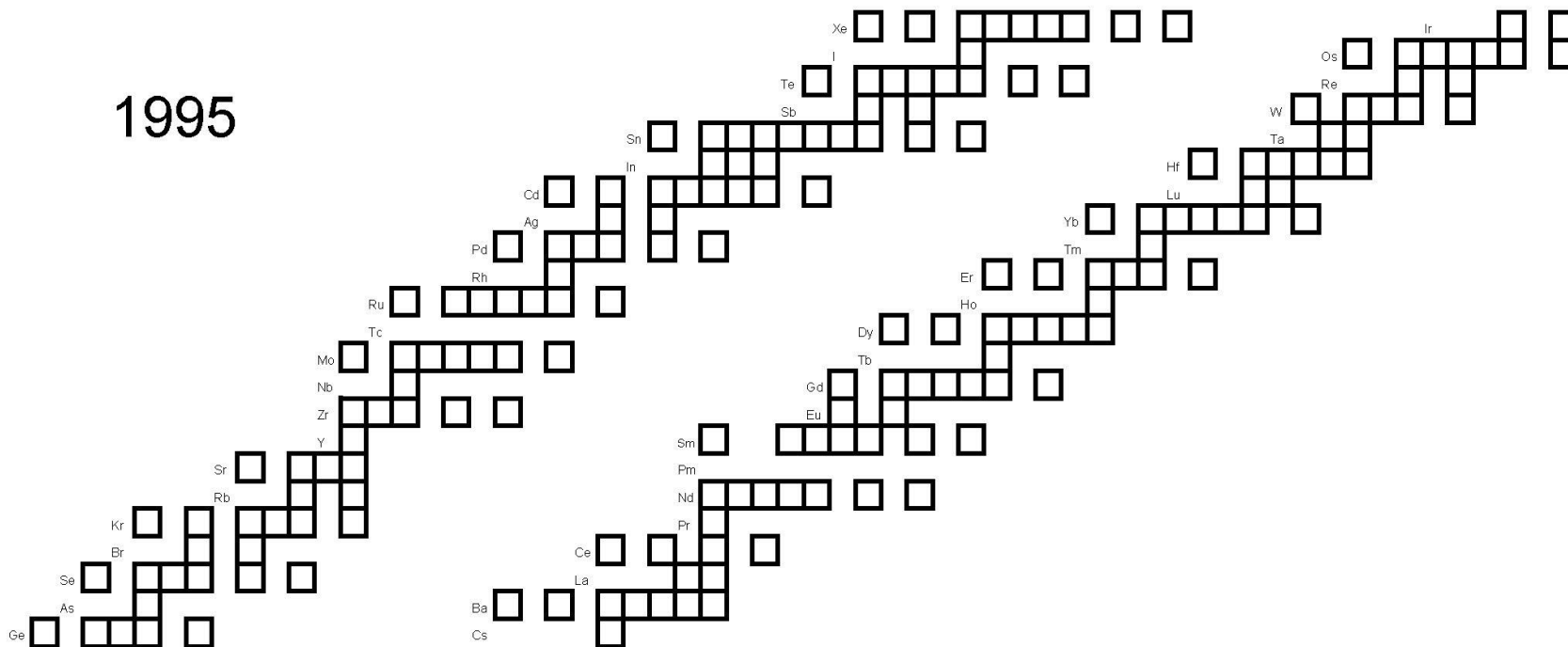
<http://www.ilboscaretoresort.it/en/>
Serralunga d'Alba (CN, Italy)



Claudia Travaglio

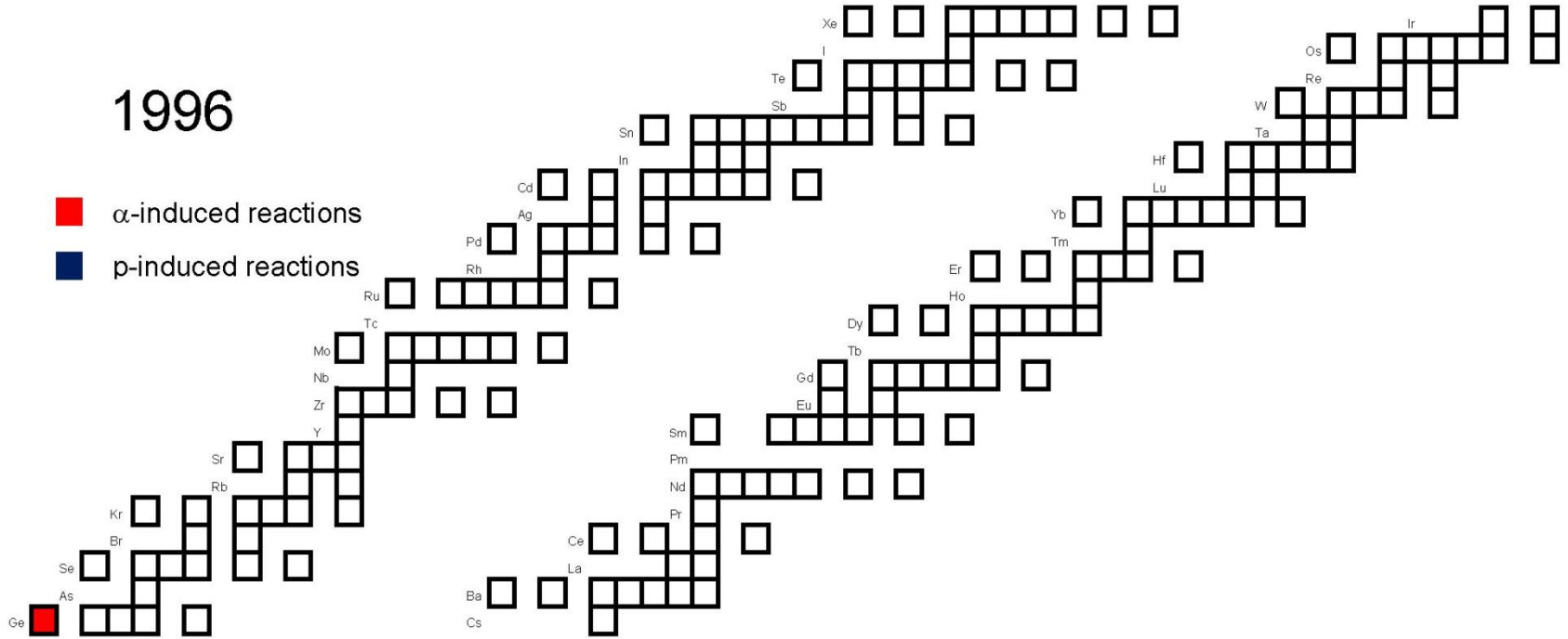


1995



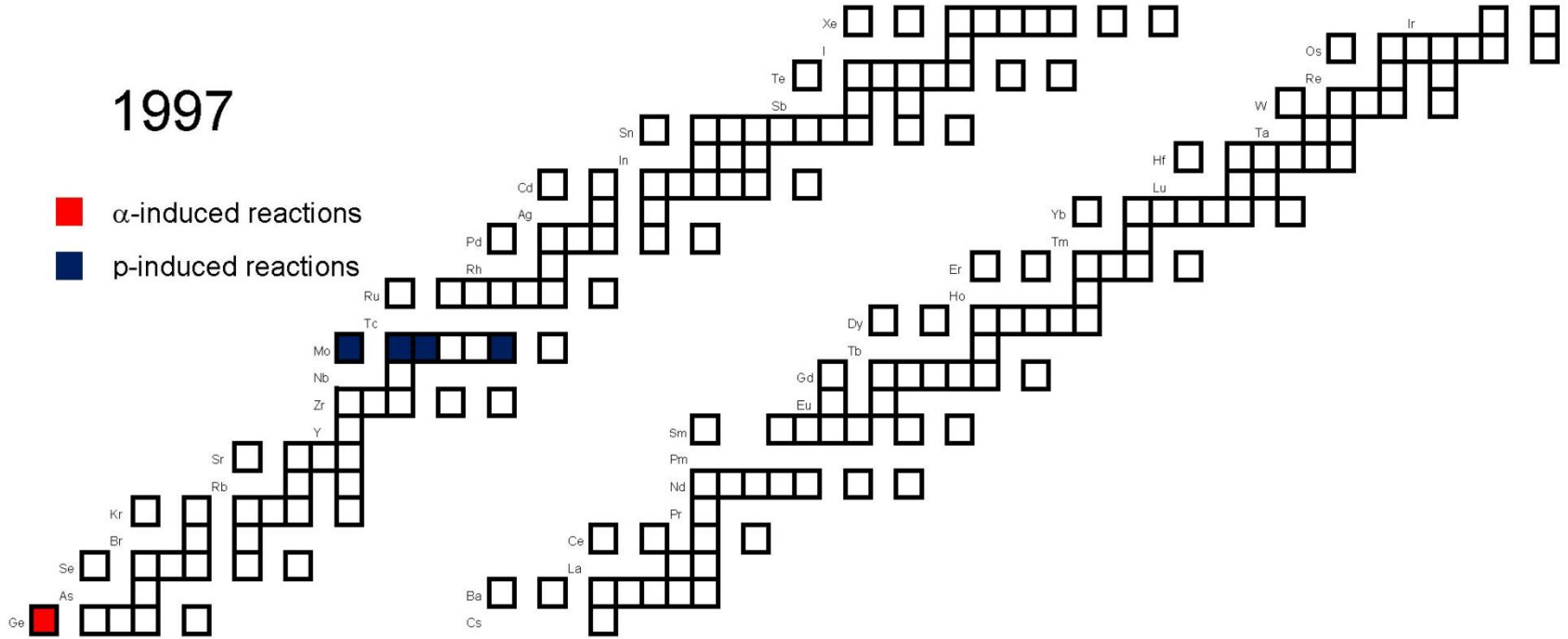
1996

- α -induced reactions
- p-induced reactions



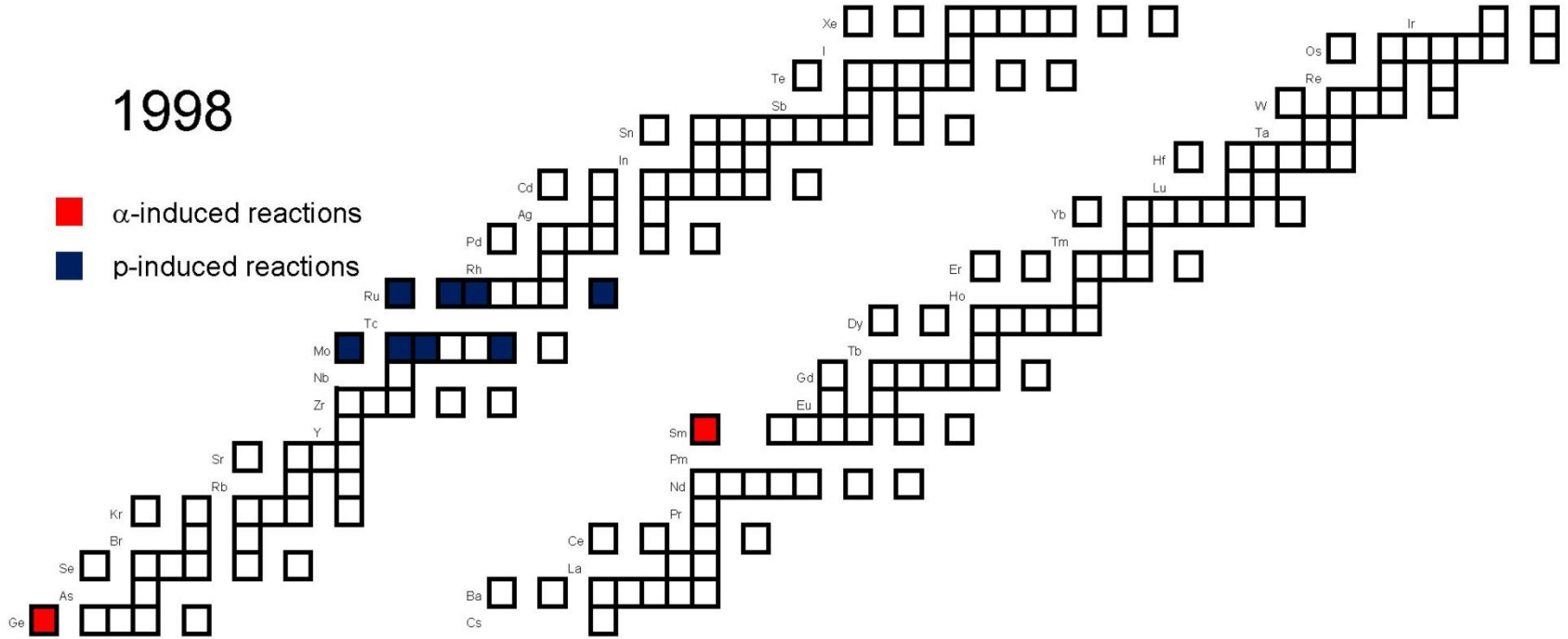
1997

- α -induced reactions
- p-induced reactions



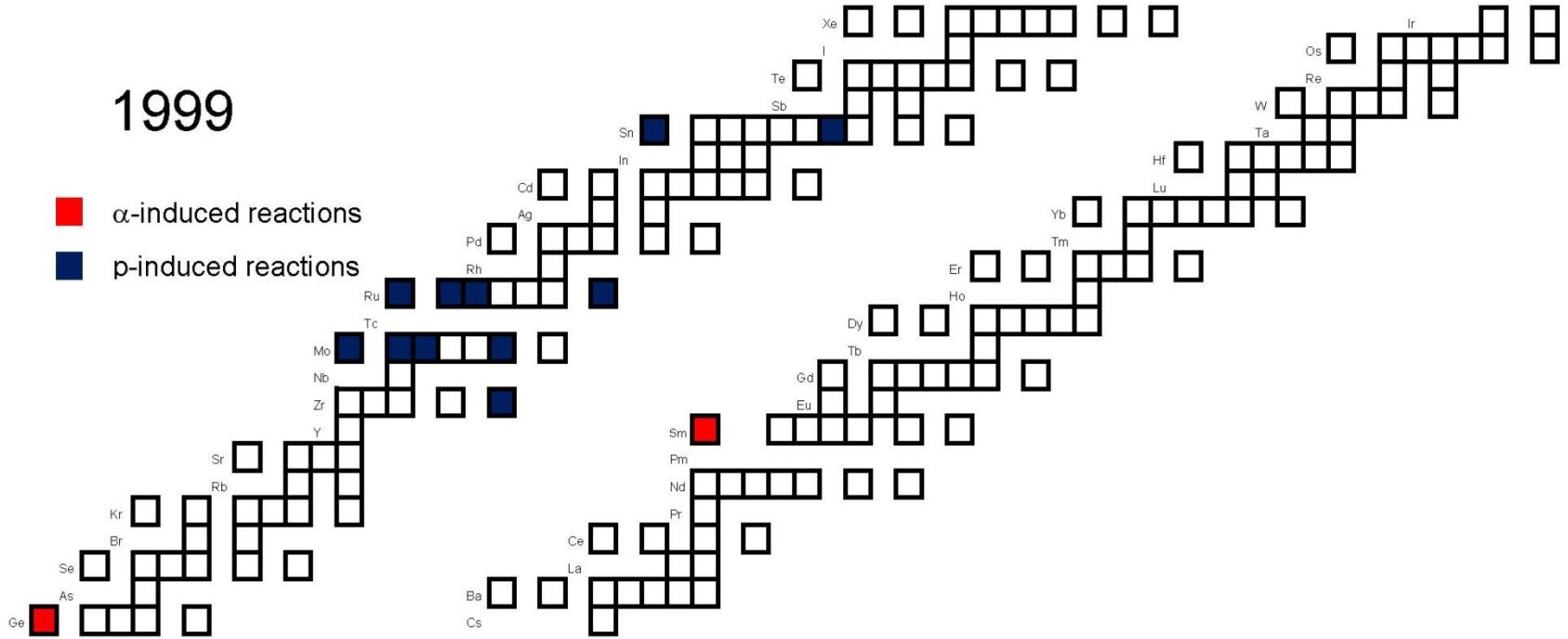
1998

- α -induced reactions
- p-induced reactions



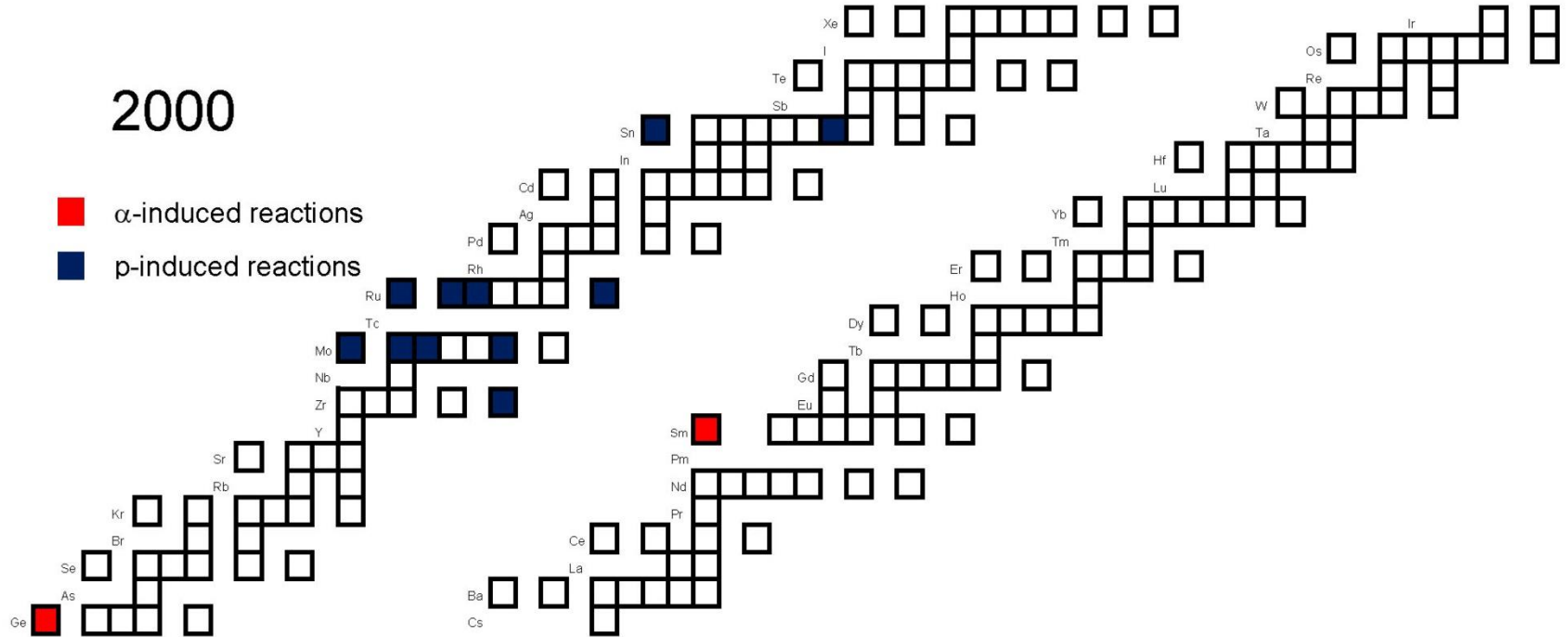
1999

- α -induced reactions
- p-induced reactions



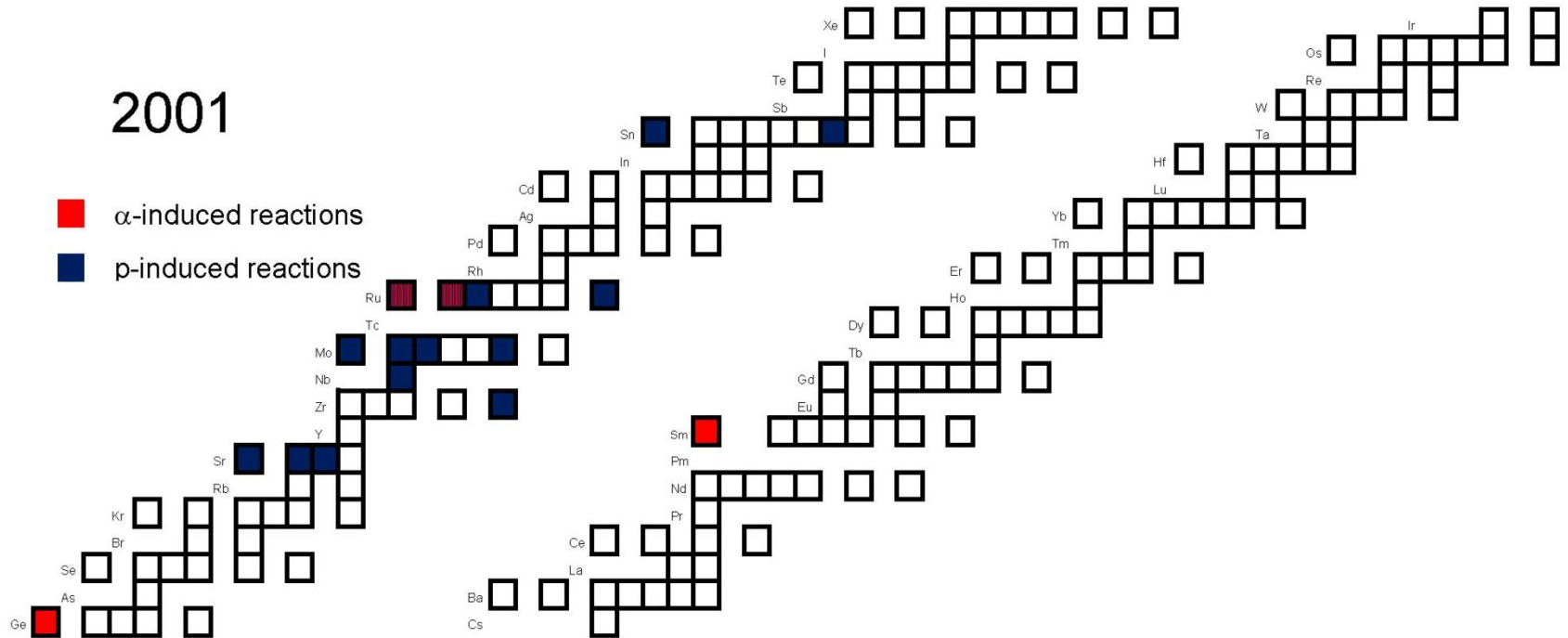
2000

- α -induced reactions
- p-induced reactions



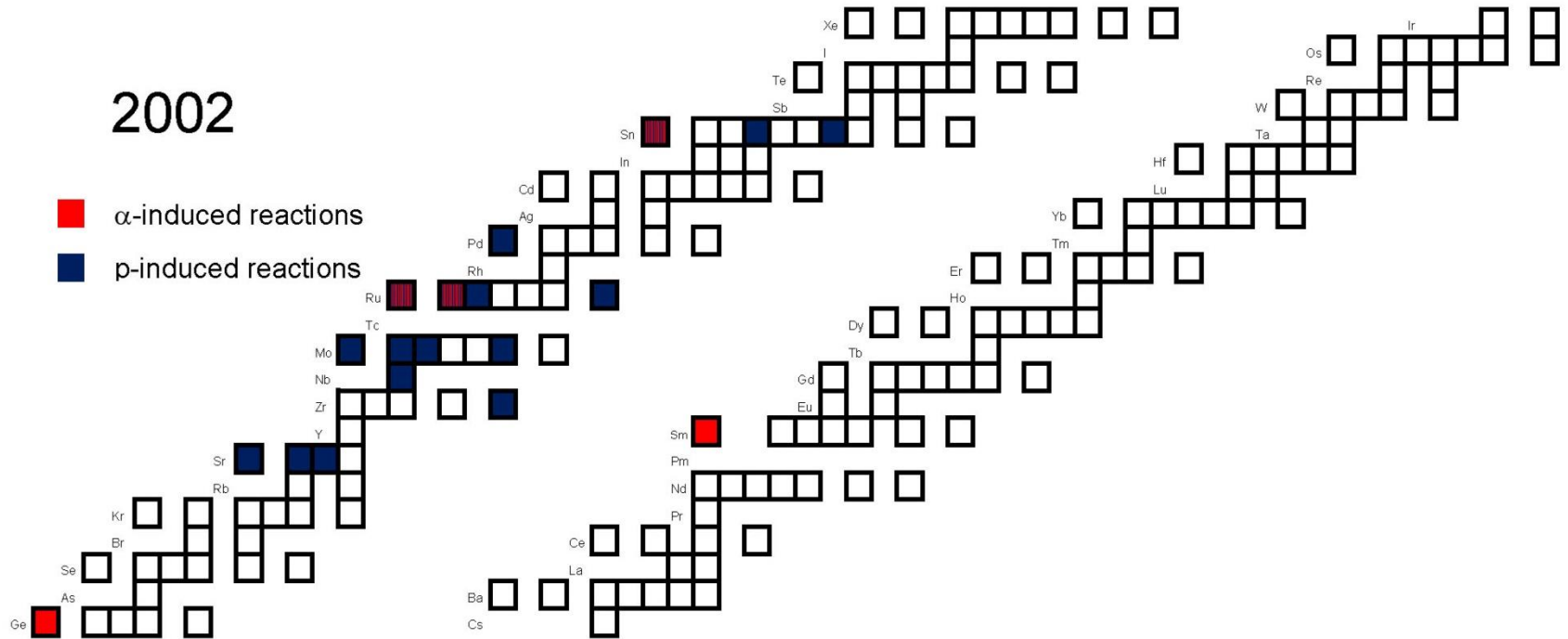
2001

- α -induced reactions
- p-induced reactions



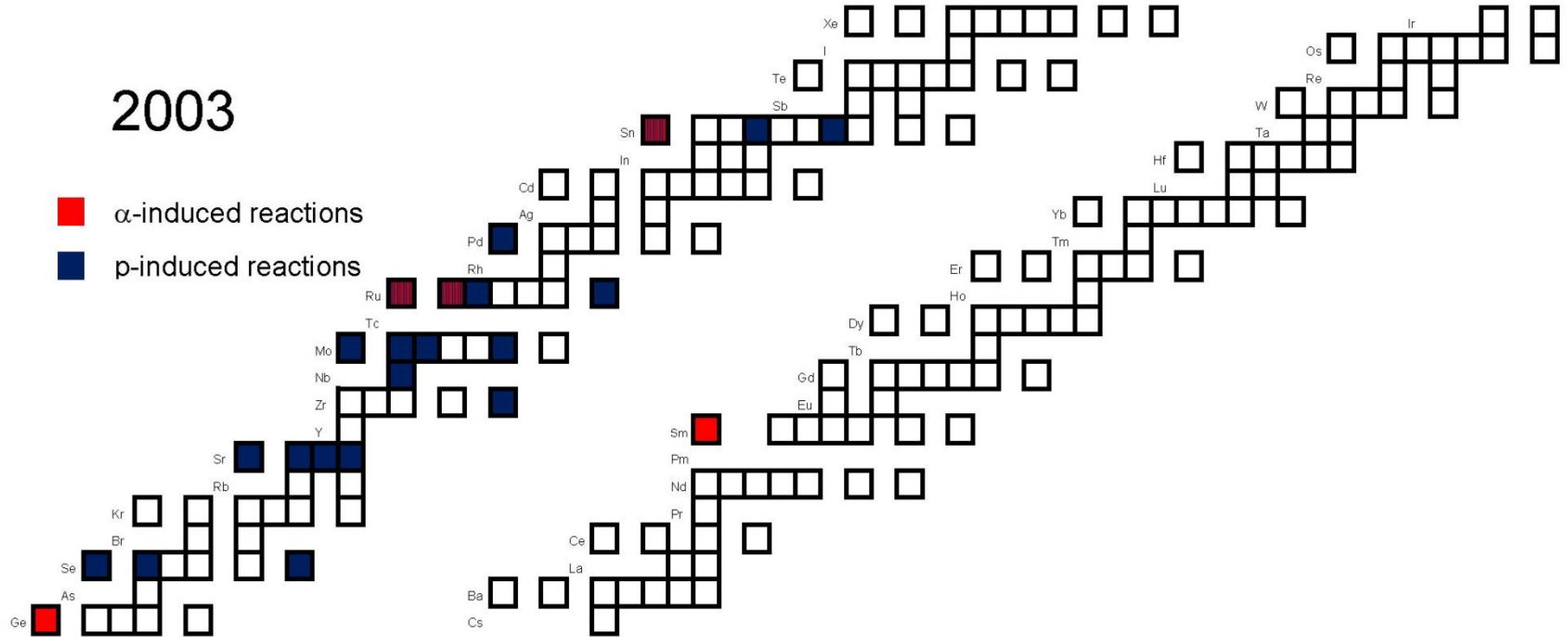
2002

- α -induced reactions
- p-induced reactions



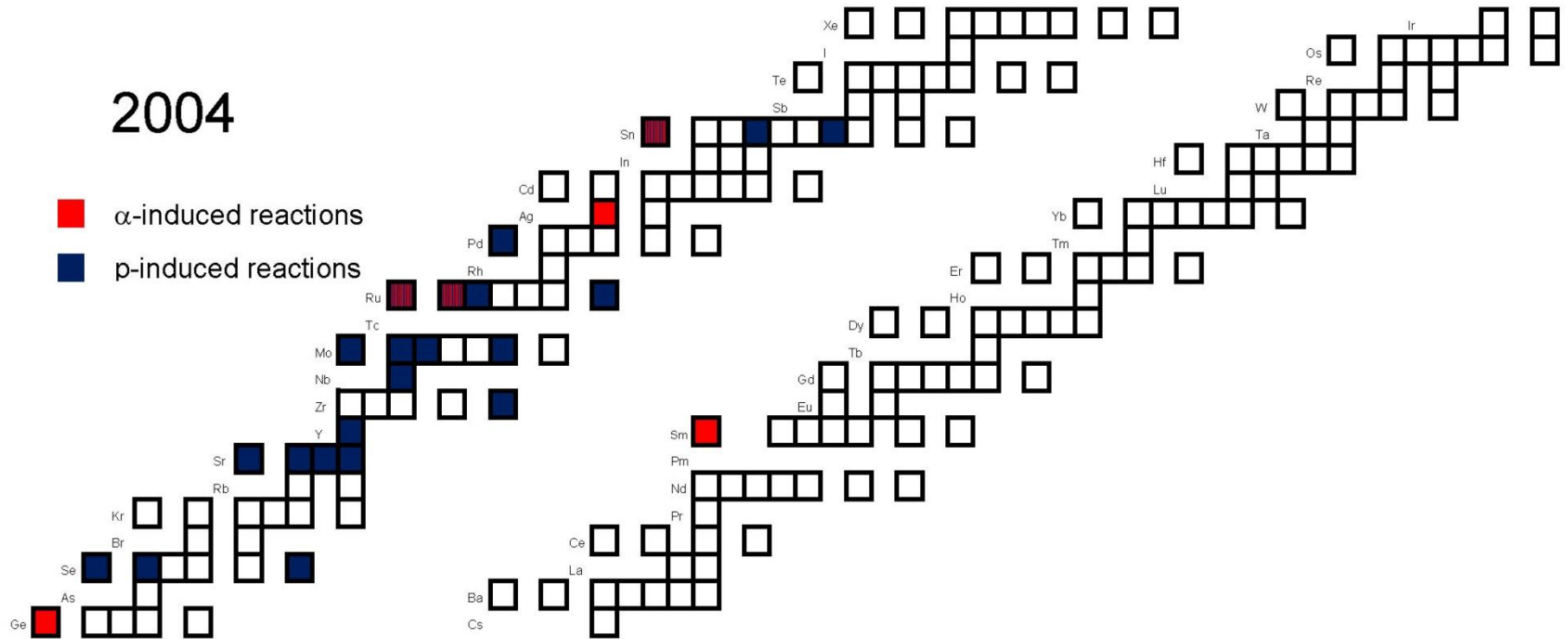
2003

- α -induced reactions
- p-induced reactions



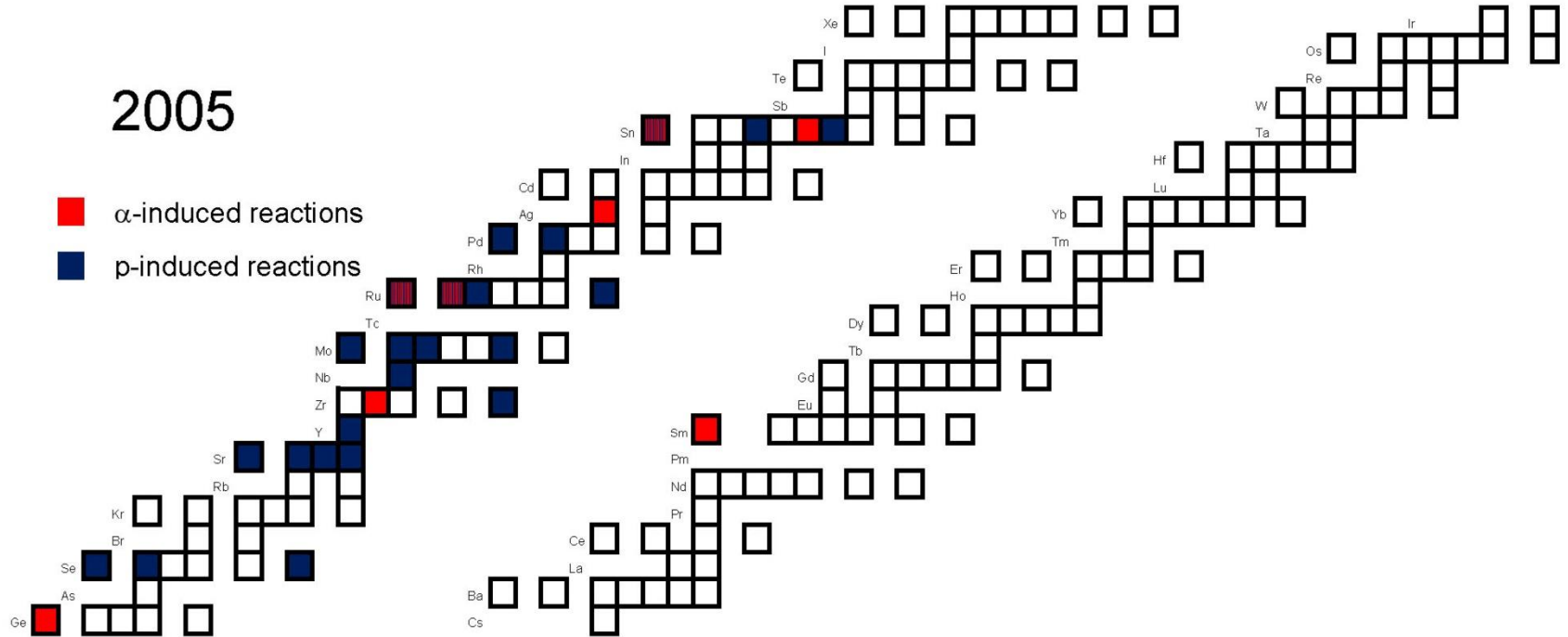
2004

- α -induced reactions
- p-induced reactions



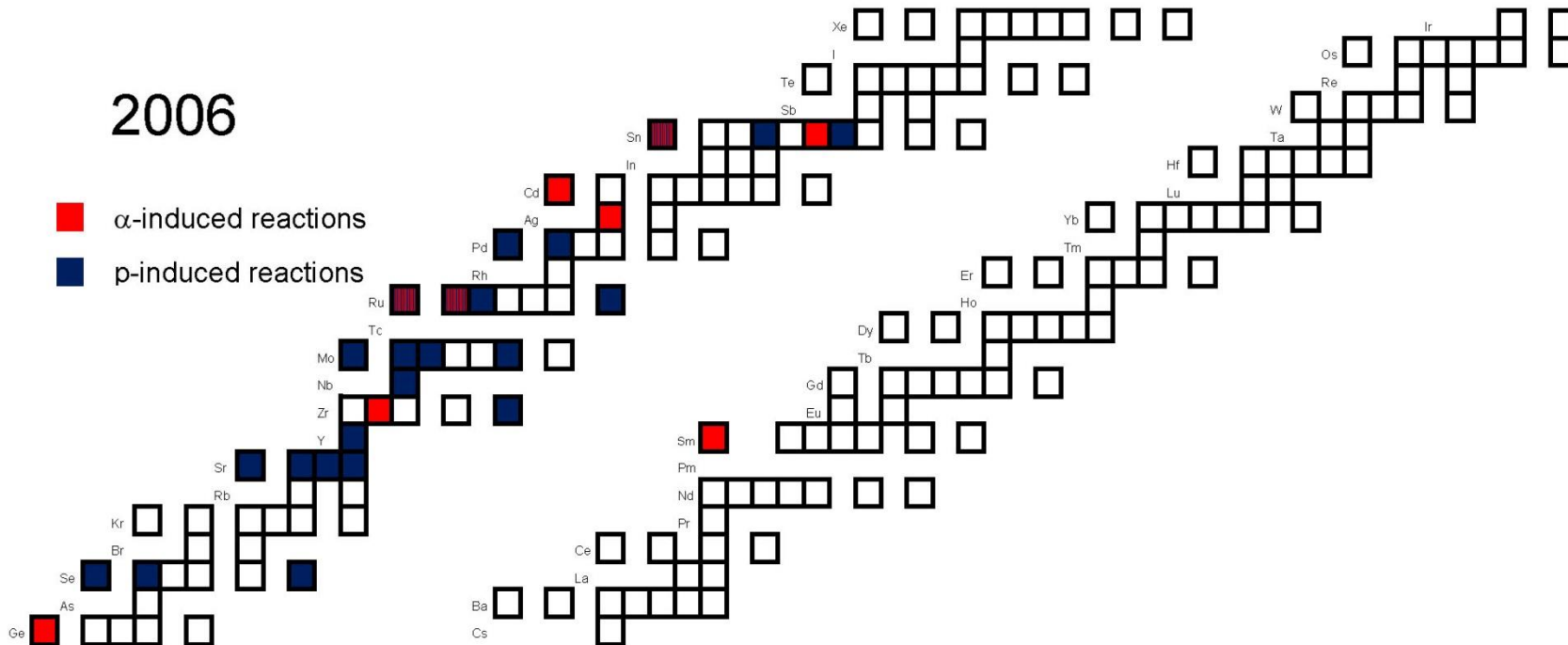
2005

- α -induced reactions
- p-induced reactions



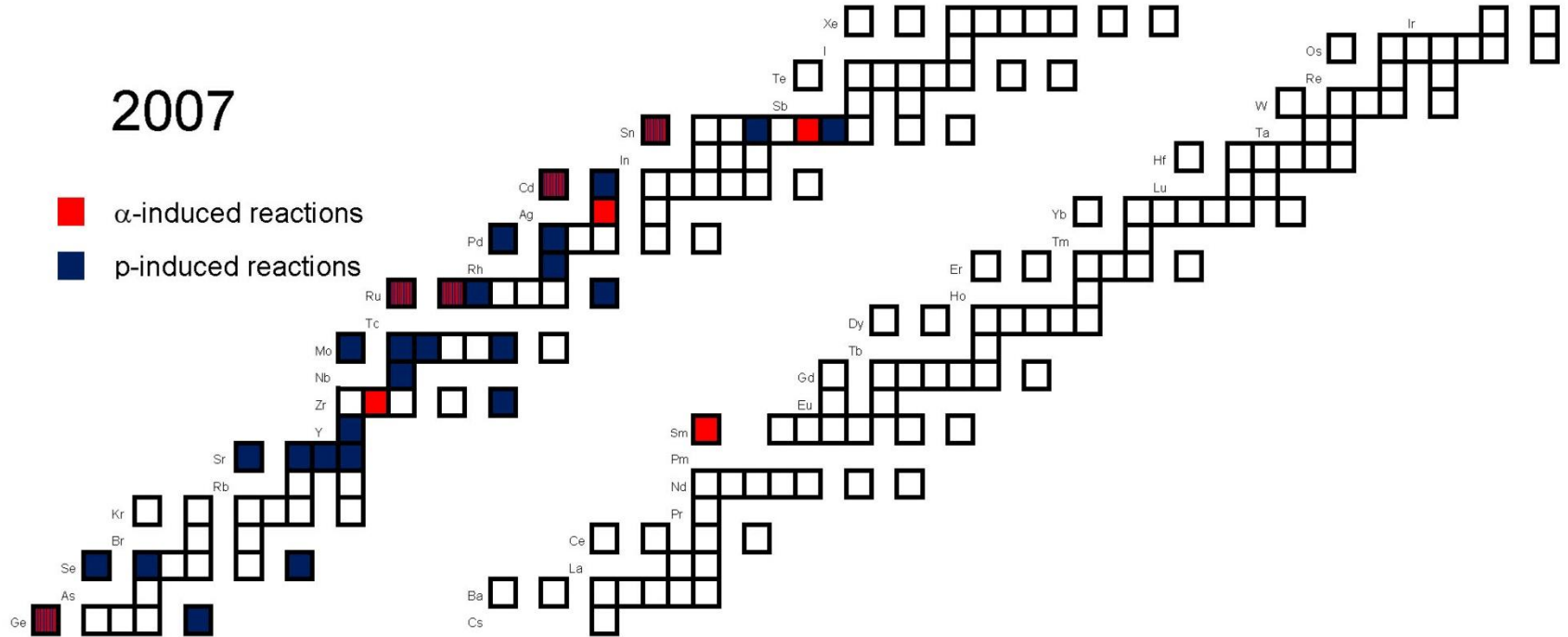
2006

- α -induced reactions
- p-induced reactions



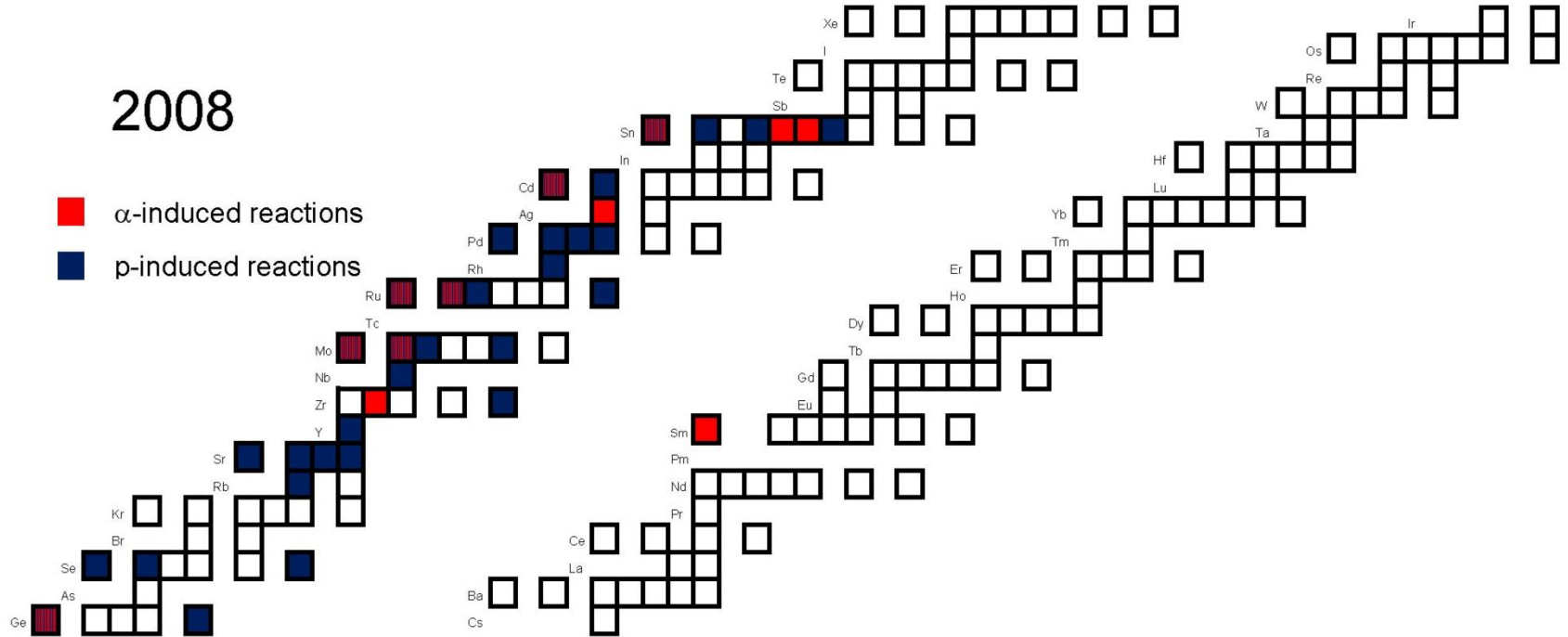
2007

- α -induced reactions
- p-induced reactions



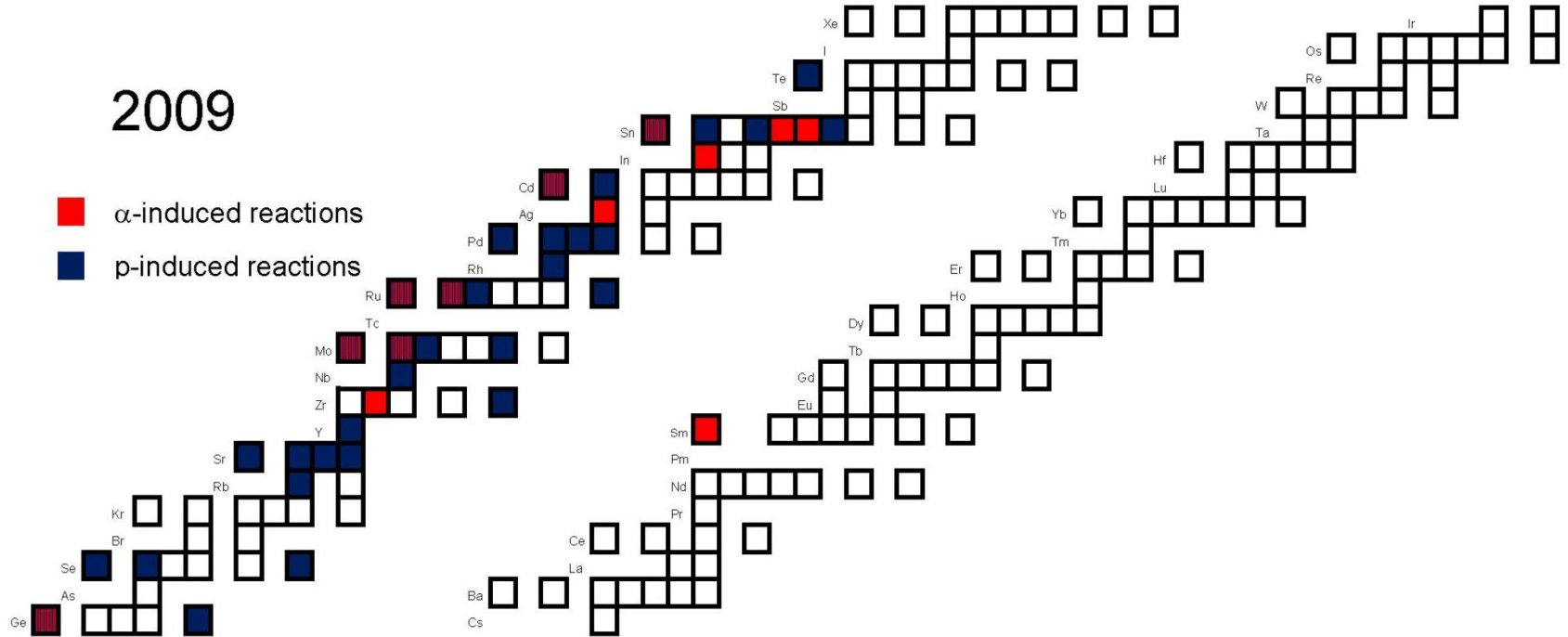
2008

- α -induced reactions
- p-induced reactions



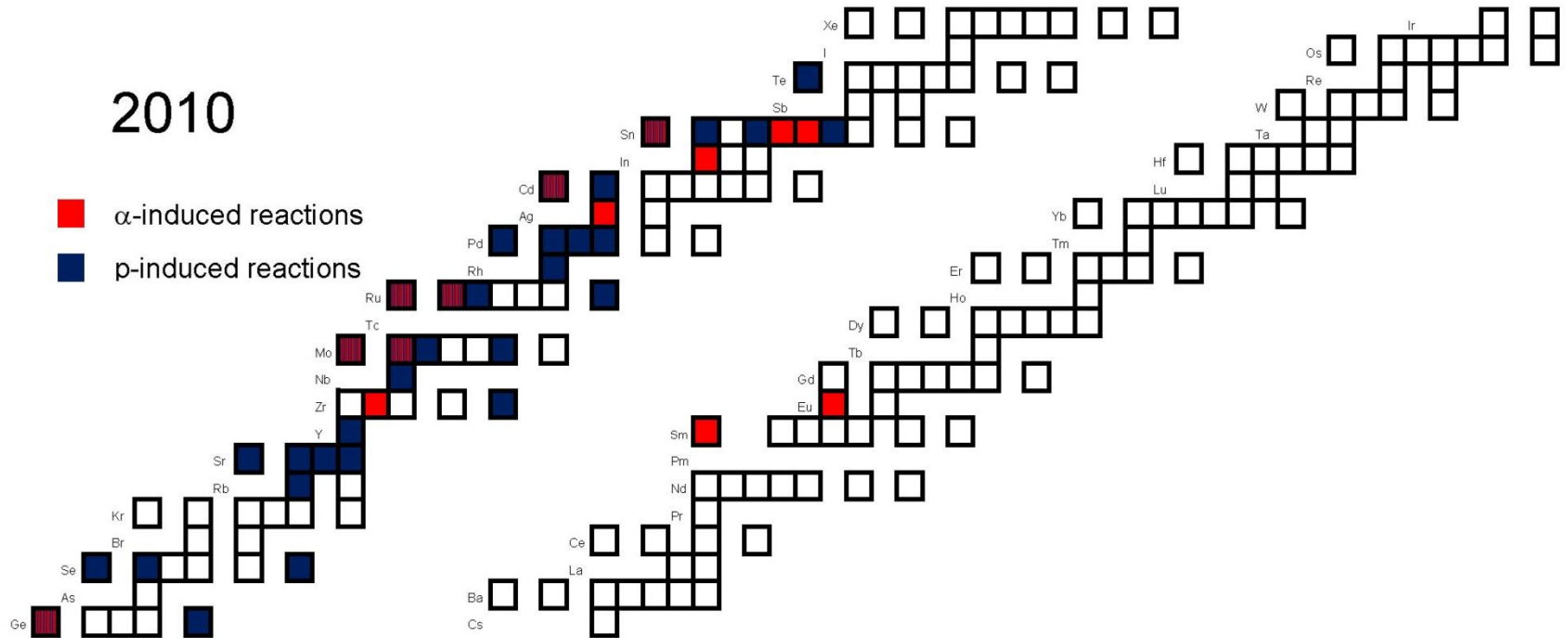
2009

- α -induced reactions
- p-induced reactions



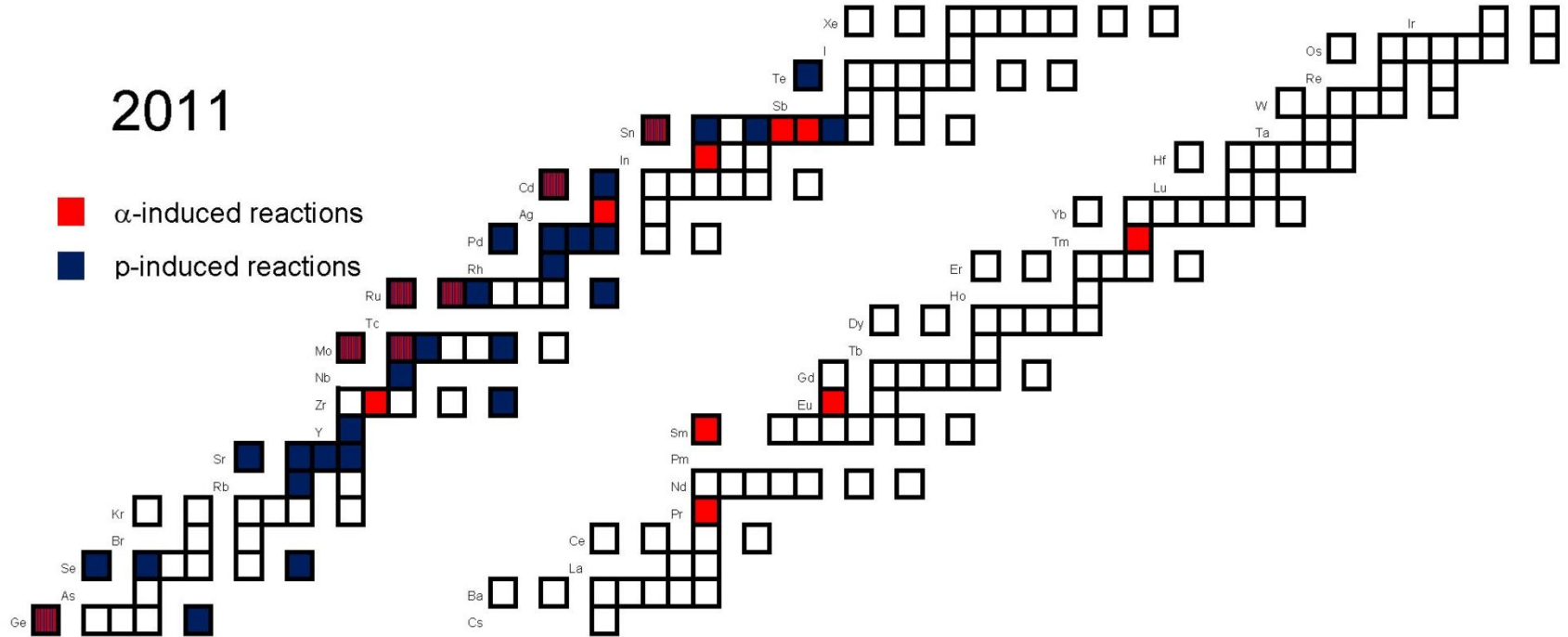
2010

- α -induced reactions
- p-induced reactions



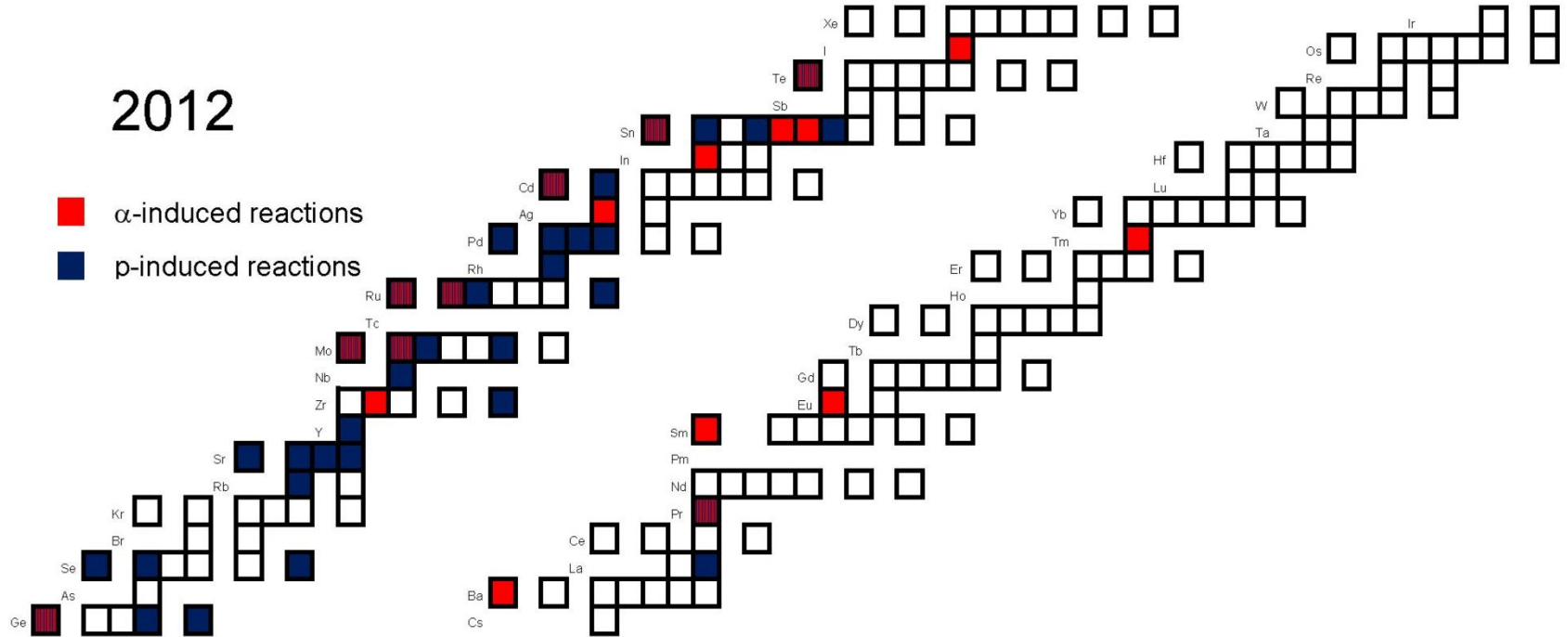
2011

- α -induced reactions
- p-induced reactions



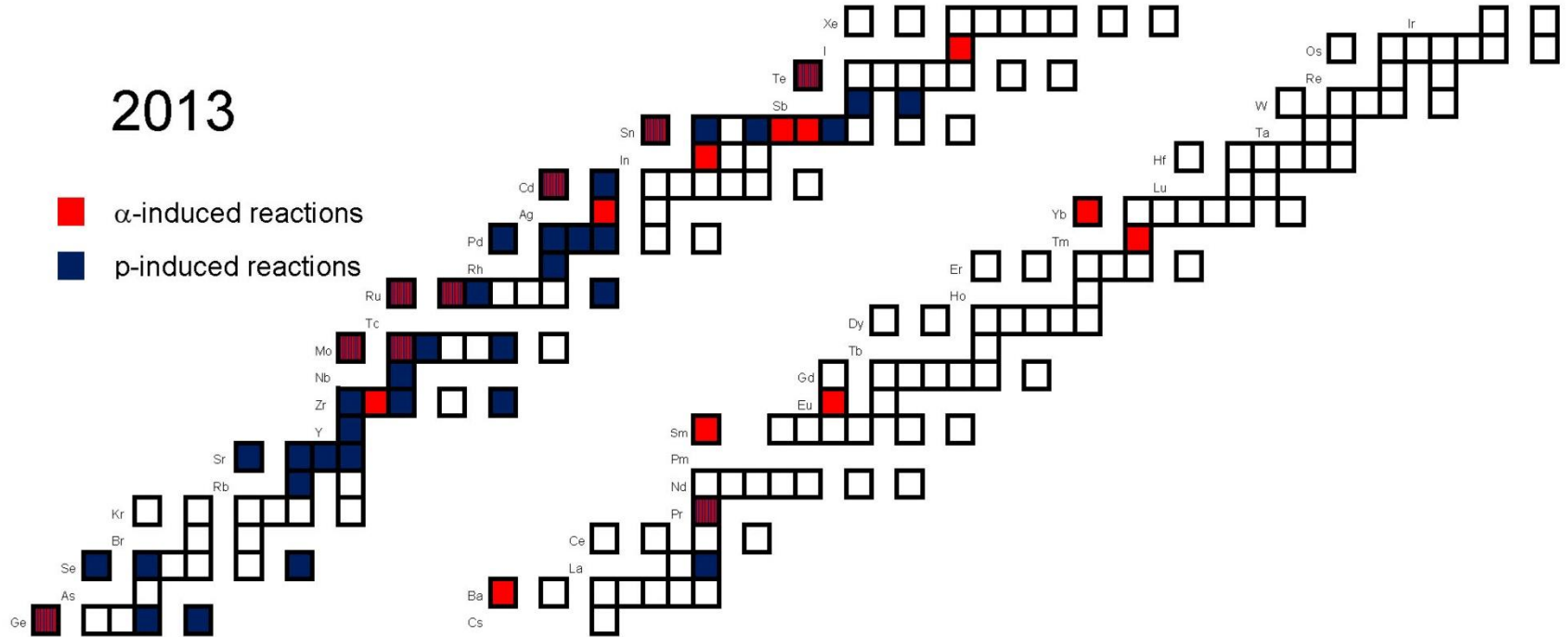
2012

- α -induced reactions
- p-induced reactions



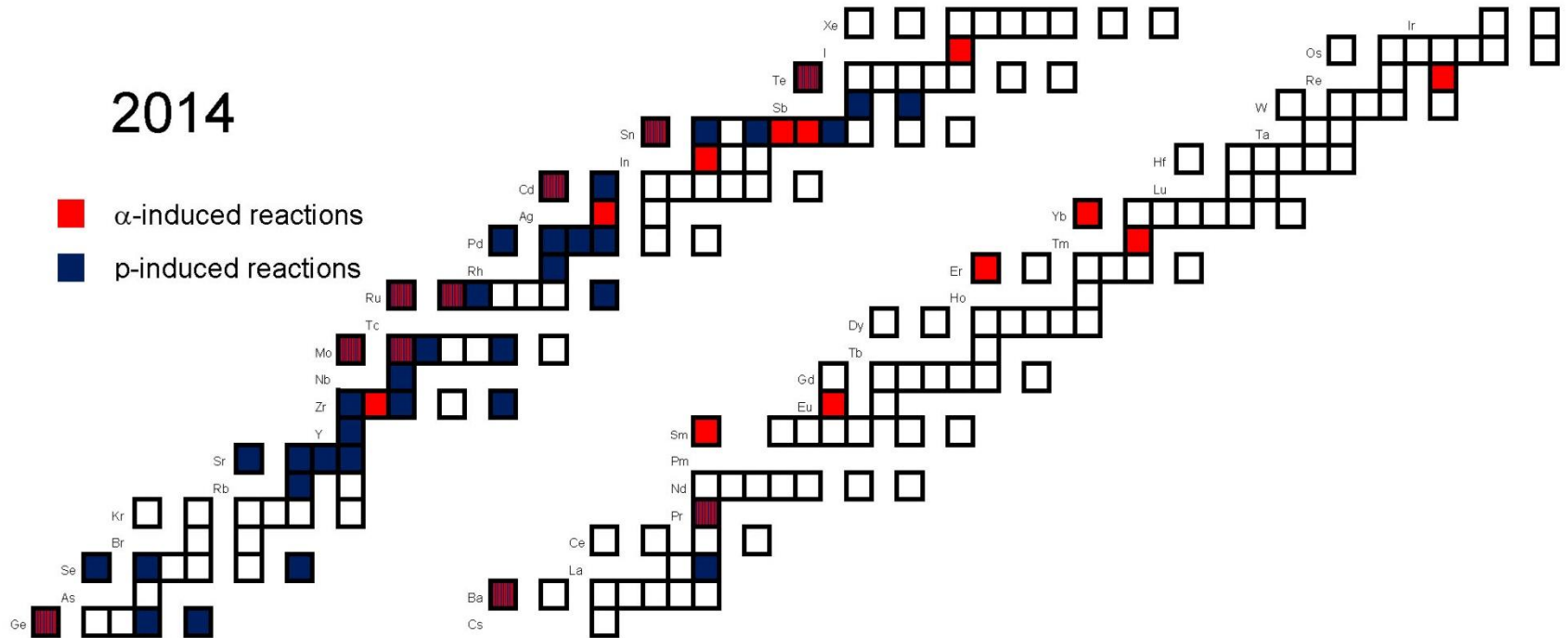
2013

- α -induced reactions
- p-induced reactions



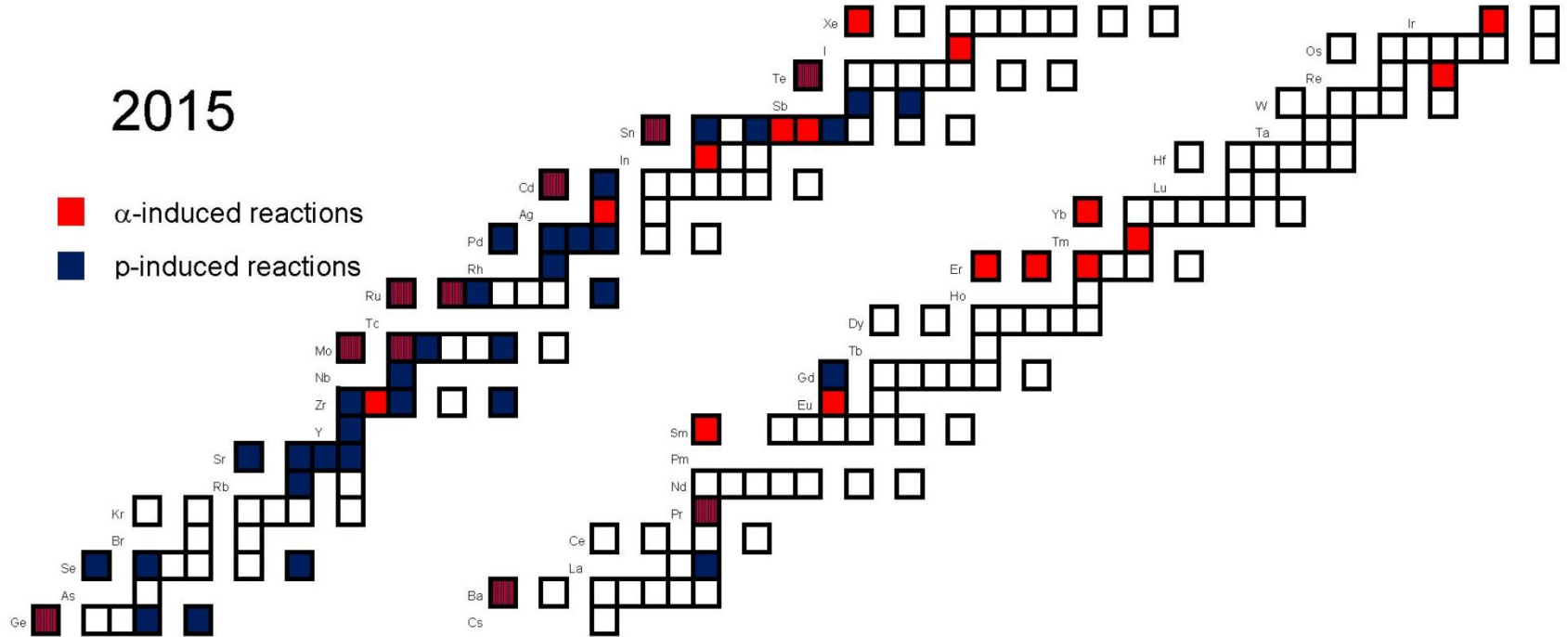
2014

- α -induced reactions
- p-induced reactions



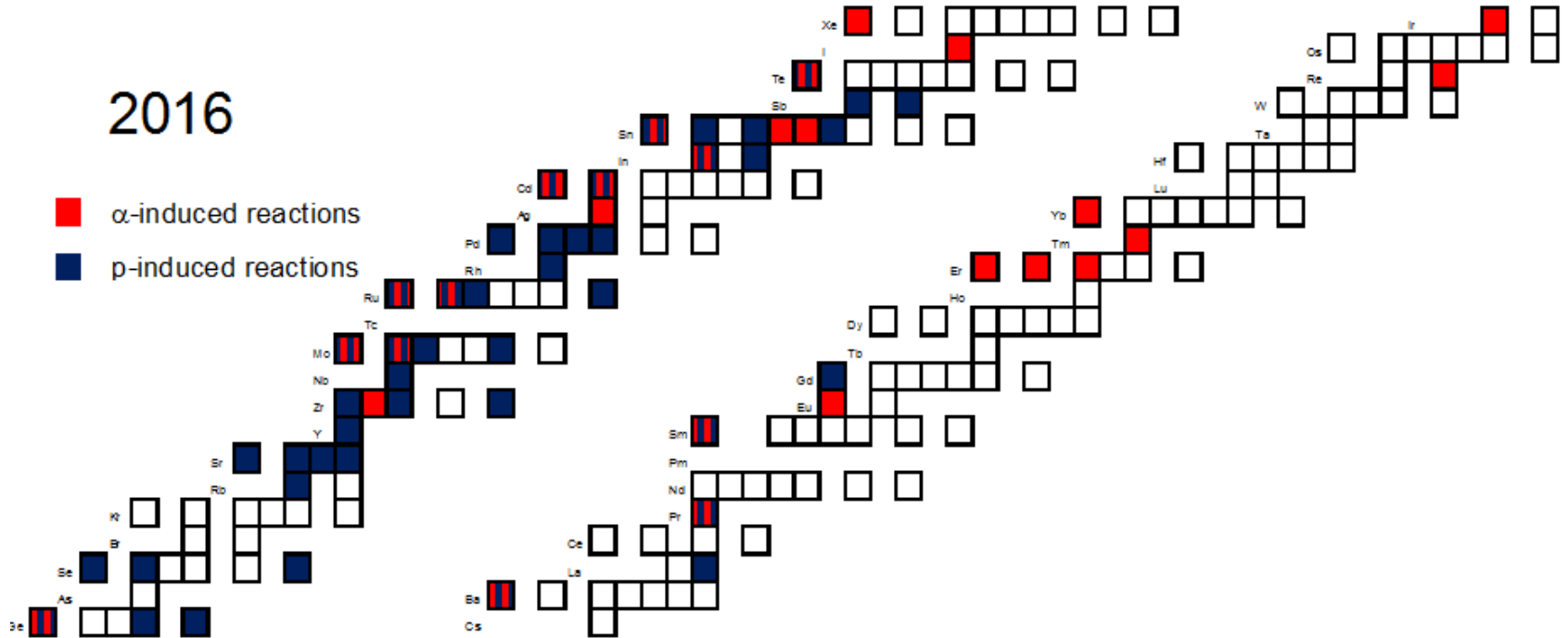
2015

- α -induced reactions
- p-induced reactions



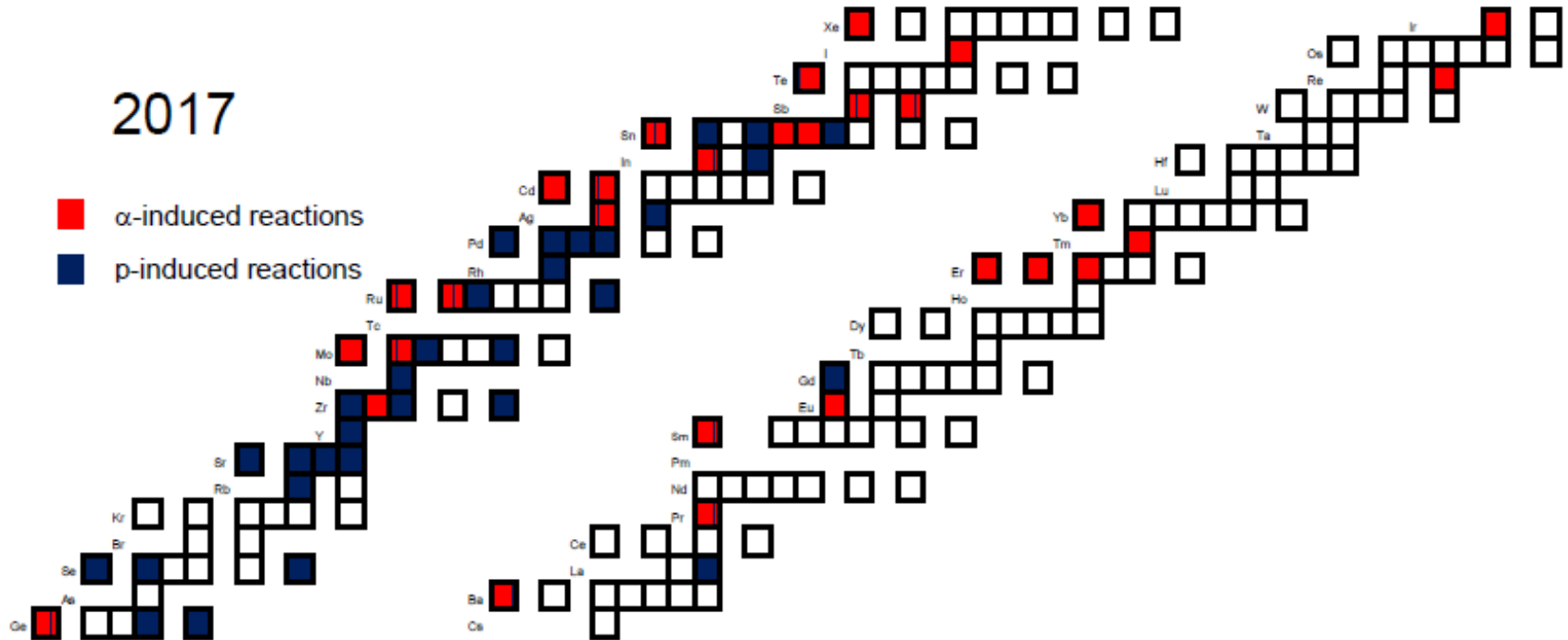
2016

■ α -induced reactions
■ p-induced reactions



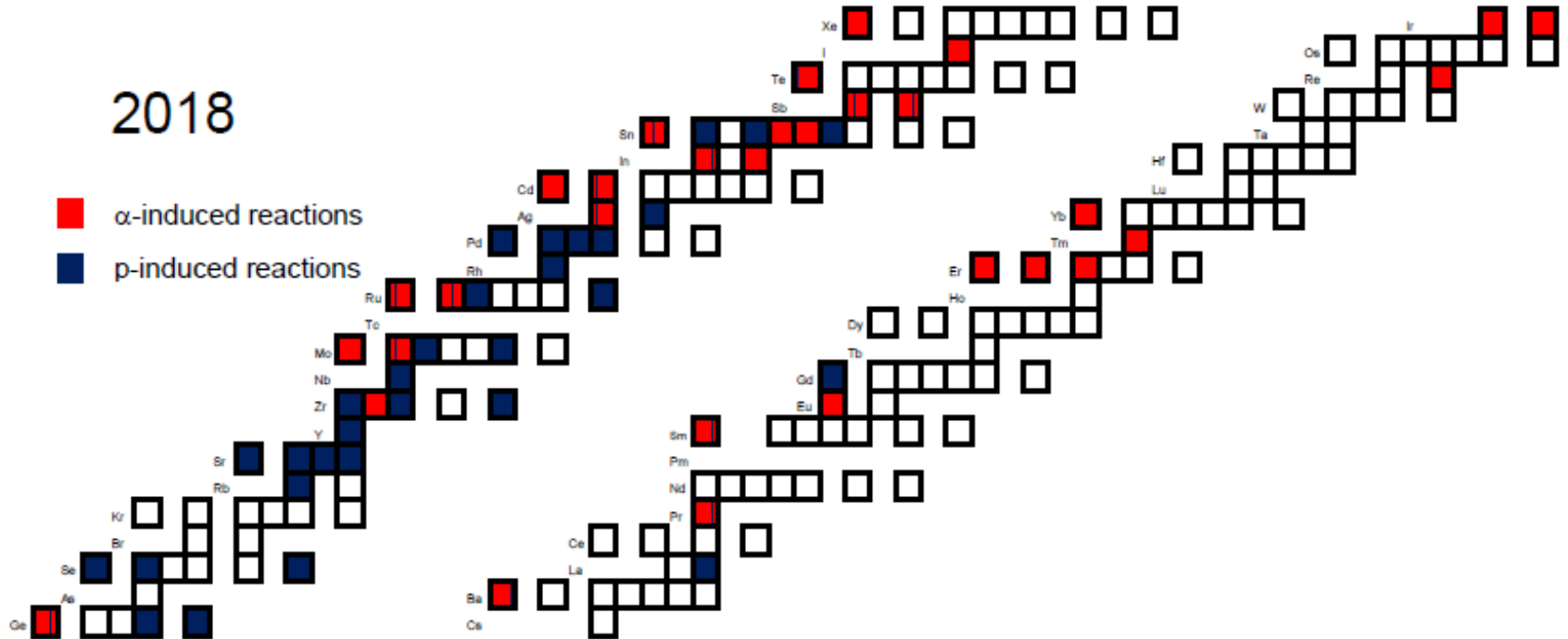
2017

■ α -induced reactions
■ p-induced reactions



2018

- α -induced reactions
- p-induced reactions



From Atomki: ATOMKI-V2 α -nucleus optical potential

- Based on reaction data
- Pure barrier transmission model
- Avoids problem with uncertain WS tail



Contents lists available at [ScienceDirect](#)

Atomic Data and Nuclear Data Tables

journal homepage: www.elsevier.com/locate/adt



Astrophysical reaction rates of α -induced reactions for nuclei with $26 \leq Z \leq 83$ from the new Atomki-V2 α -nucleus potential

P. Mohr^{a,*}, Zs. Fülöp^a, Gy. Gyürky^a, G.G. Kiss^a, T. Szücs^a, A. Arcones^{b,c}, M. Jacobi^b, A. Psaltis^b

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ABSTRACT

The new Atomki-V2 α -nucleus potential is applied to calculate astrophysical reaction rates $N_A(\sigma v)$ of intermediate mass and heavy target nuclei from iron ($Z = 26$) up to bismuth ($Z = 83$). Overall, reaction rates of α -induced reactions are provided for 4359 target nuclei, covering as well neutron-deficient as extremely neutron-rich target nuclei from the proton to the neutron dripline. Contrary to previous rate compilations, these new calculations include all relevant exit channels with the dominating (α , xn) reactions for neutron-rich target nuclei.

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And here we are in Budapest, 2024...

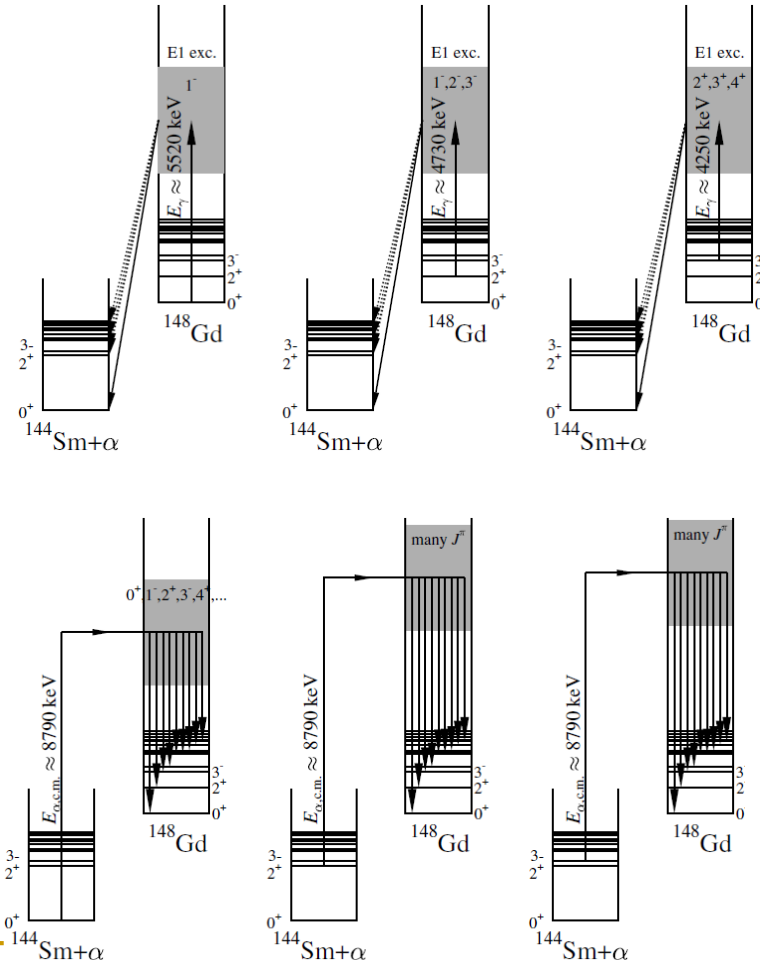
Experiments around

8th p-process workshop 2024

- γ -induced reactions
- Particle capture
- Moving away from stability
- Elastic scattering
- Key nuclear quantities

γ -induced reactions

- This is how γ -process goes...
- Technically challenging
- Thermal excitation \Rightarrow only indirect astrophysical relevance
- Provides nuclear physics information



γ -induced reactions, various approaches

PHYSICAL REVIEW C **99**, 025802 (2019)

Photon neutron reaction cross section measurements on ^{94}Mo and ^{90}Zr relevant to the p -process nucleosynthesis

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Department of Physics and Astronomy, James Madison University, Harrisonburg, Virginia 22807, USA

J. A. Silano‡ and H. J. Karwowski

*Triangle Universities Nuclear Laboratory, Durham, North Carolina 27708, USA
and University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27516, USA*

S. Goriely

HI γ S facility
See the talks of
Adriana Basu and
Dario Lattuada

Eur. Phys. J. A (2023) 59:249
<https://doi.org/10.1140/epja/s10050-023-01137-x>

THE EUROPEAN
PHYSICAL JOURNAL A



Regular Article - Experimental Physics

Measurement of the flux-weighted cross-sections for the $^{\text{nat}}\text{Yb}(\gamma, \text{xn})^{175,169,167}\text{Yb}$ reactions in the **Bremsstrahlung** end-point energies of 12–16 MeV and 60–70 MeV

H. Naik^{1,2}, G. N. Kim^{2,a} , R. Schwengner³, Wooyoung Jang⁴, T. H. Nguyen², S. G. Shin⁵, Y. Kye⁵, R. Massarczyk³, R. John³, A. Junghans³, A. Wagner³, M. H. Cho⁵

Inverse (capture) reactions in direct kinematics

- Nicely growing experimental database
- Direct relevance (detailed balance), nuclear parameters
- Activation: powerful, but limited
- In-beam: detector arrays, summing crystals

See the talks of Svenja Wilden and John McDonough

Inverse (capture) reactions in inverse kinematics

- Way to go beyond stability
- Storage rings, recoil separators, in-beam gamma-detection

See the talks of Artemis Tsantiri

Elastic alpha-scattering

- „Classical” way of studying the optical potential
- ... which turned out to be a crucial parameter
- ... and not known at astrophysical energies
- Towards radioactive isotopes in inverse kinematics!

See the talks of Daniel Galaviz,
Charles Soto and Peter Mohr

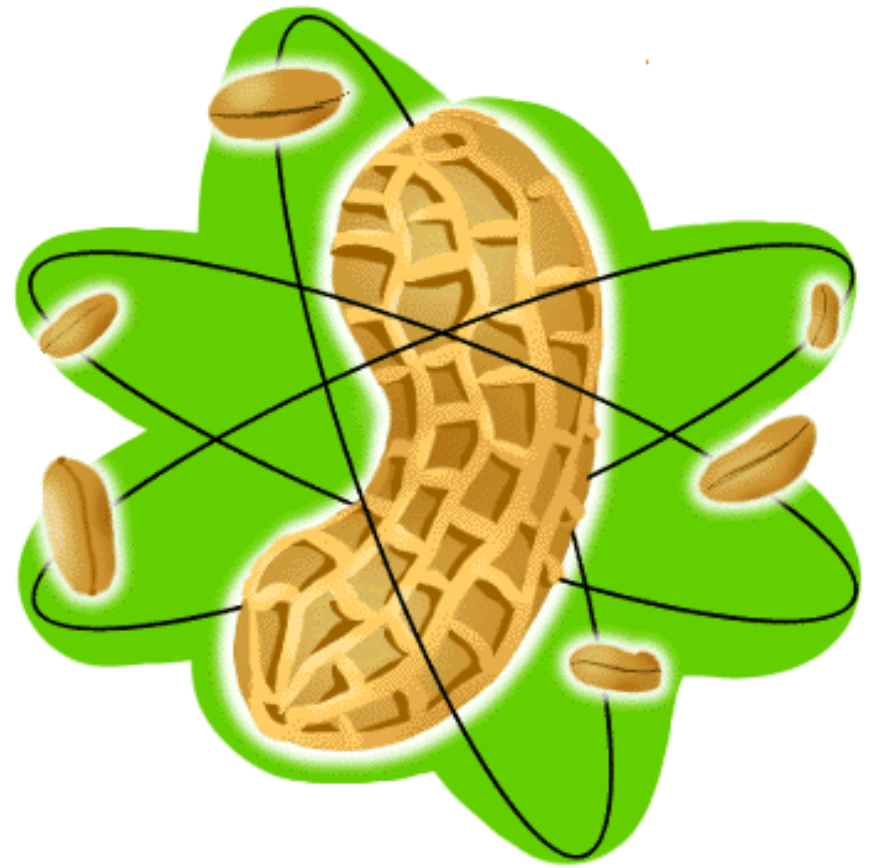
Other reaction types, like (α ,n)

- No direct p-process relevance, but
- sensitive to some nuclear parameters, like the α -OMP
- and may be relevant to e.g. the weak r-process

See the talks of Martin Müller, Zsolt Máttyus and Peter Mohr

Summary

- P-process workshops are cool
- Small community of nice people
- With new problems, exciting ideas, valuable results and steady progress



**Solar System
p-nuts**

Thank you for your attention!

