--Nuclear database for astrophysics--
Experimental activities at Hokkaido University

Ayano Makinaga
Hokkaido University
Meme media Lab.

AASPP Workshop- The 2nd Asian Nuclear Reaction Database Development Workshop
2011.Sep.5-8 @ Beijing, China

- **NRDF/A database**
- **Experimental activities at Hokkaido University.**

NRDF/A(2006~ @JCPRG)

北海道大学 HOKKAIDO UNIVERSITY

Nuclear Reaction Data File For Astrophysics

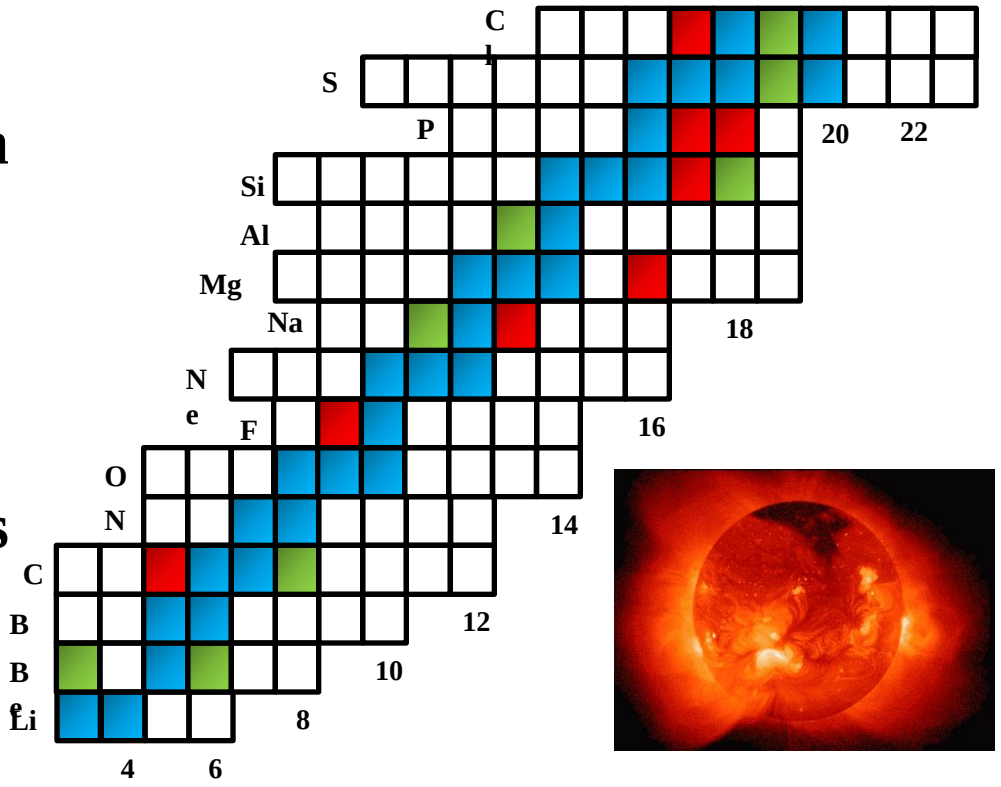
I. Theoretical evaluations for astrophysical reactions

II. Bibliographic information

III. NRDF/A file compilation
   I. S-factor
   II. Reaction rate
   III. Resonance parameters
   IV. Nuclear structure

IV. Database system

Nucleosynthesis of light emelent



From Riken Workshop 2010

NRDF/A(2006~ @JCPRG)

北海道大学 HOKKAIDO UNIVERSITY

NRDF/A bibliographic database（2008～）

World Bibliographic web service

- CINDA =>Nuclear physics publications
- Nuclear Science References (NSR) =>Nuclear physics publications
- The SAO/NASA Astrophysics Data System (ADS) =>Nuclear physics and Astrophysics and Astronomy publications

Bibliographic Database NRDF/A => Nuclear physics, Astrophysics, Astronomy and nuclear applications(medical, material, nuclear power, environmental…

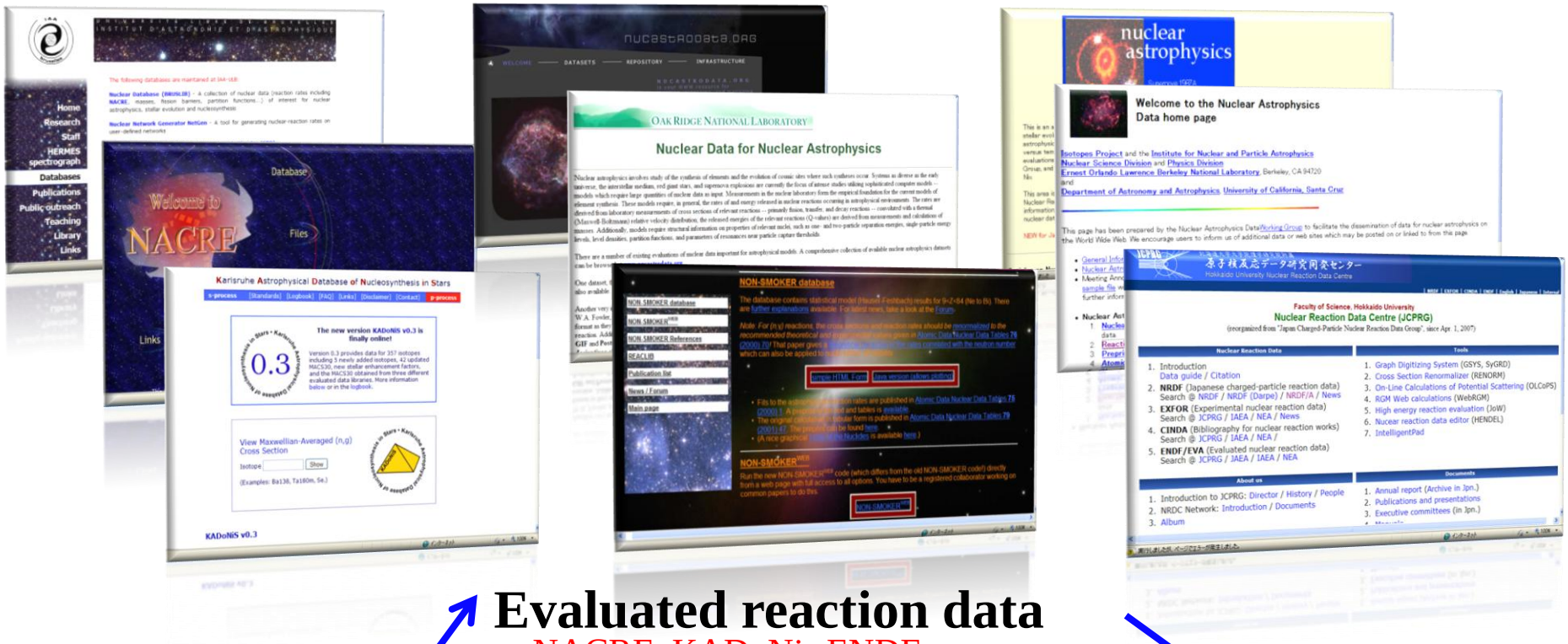
URL http://www.jcprg.org/

From Riken Workshop 2010

NRDF/A(2006~ @JCPRG)

北海道大学 HOKKAIDO UNIVERSITY

NRDF/A Nuclear Data file (2009~)



Evaluated reaction data

NACRE, KADoNis ENDF, JENDL, JEFF …

Experiment

NRDF, EXFOR

Mass evaluation

AMDC

Evaluated structure data

ENSDF

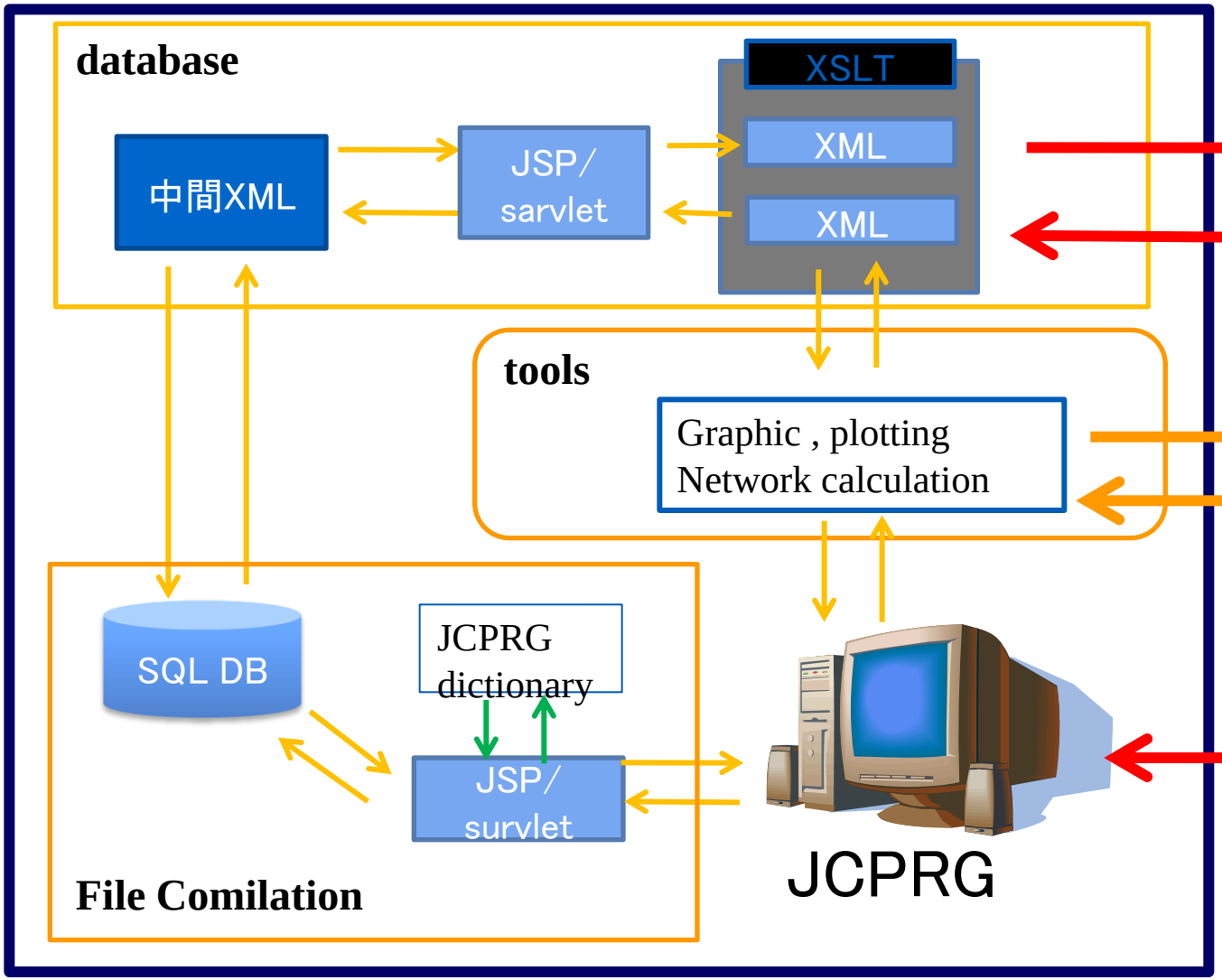
Network calculation

From Riken Workshop 2010

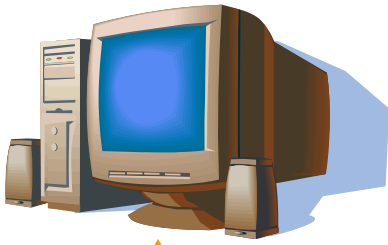
NRDF/A(2006~ @JCPRG)

北海道大学 HOKKAIDO UNIVERSITY

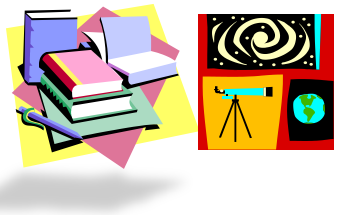
WEB System (2010～)



NRDF/A
Open Web site



Article, Experiment,
Theory

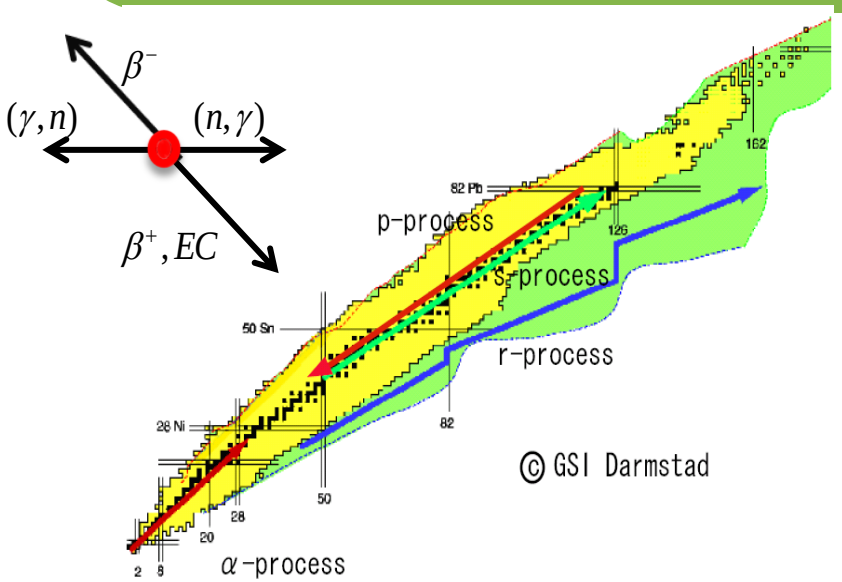


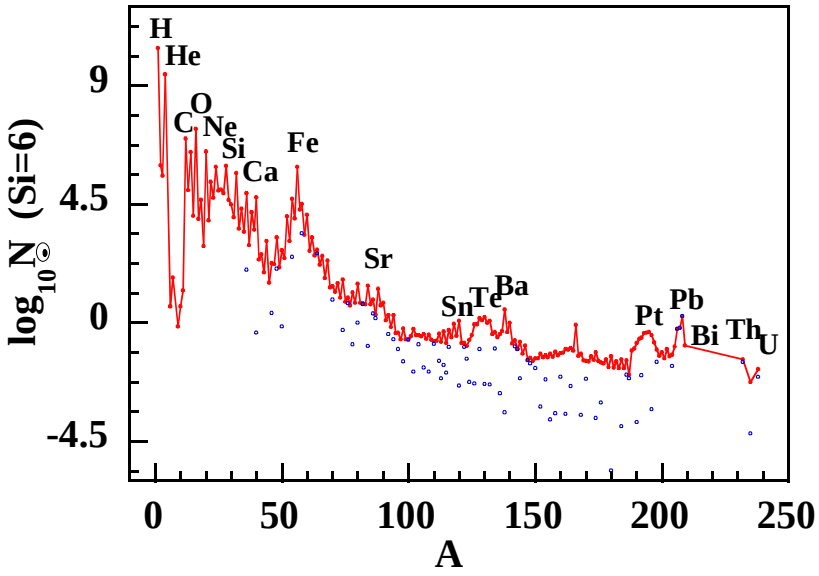
From Riken Workshop 2010

- NRDF/A database
- **Experimental activities at Hokkaido University.**

Introduction

Nucleosynthesis of the elements





- **Light element**
  - **Hydrogen burning**
  - **Helium burning**
  - **The α , e, x process**
- **Heavy element**
  - **s-process (slow)**

    β-decay rate ≫ neutron capture rate
  - **r-process (rapid)**

    β-decay rate ≪ neutron capture rate
  - **p-process**

    photodisintegration

Synthesis of the Elements in Stars (1957)

E. M. Burbidge, G. R. Burbidge, W. A. Fowler, and F. Hoyle (B^2FH)

北海道大学 HOKKAIDO UNIVERSITY

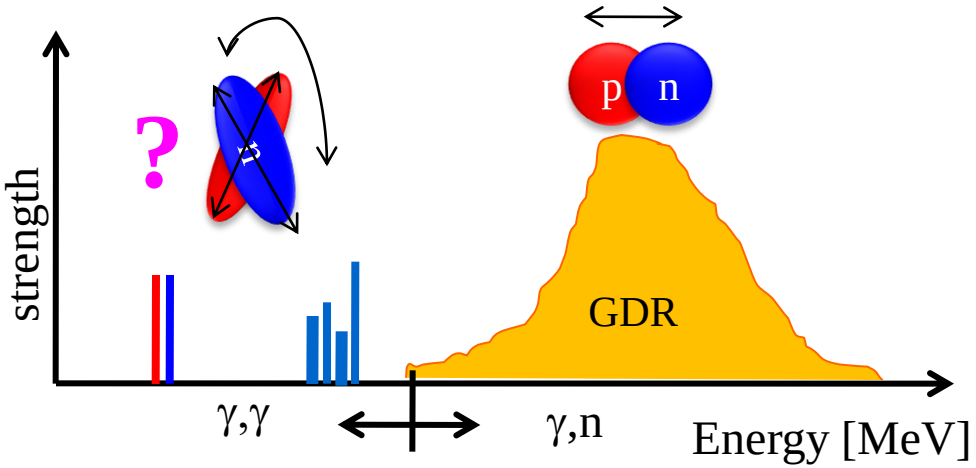
Photonuclear & neutron experiment

- Photo-neutron experiment at **AIST**
- NRF(Nuclear Resonance Fluorescence) experiment at **ELBE**&**TUNL**
- Activities of pulsed neutron experiment at **Hokkaido University**

Nuclear Data Need for Astrophysics

北海道大学 HOKKAIDO UNIVERSITY

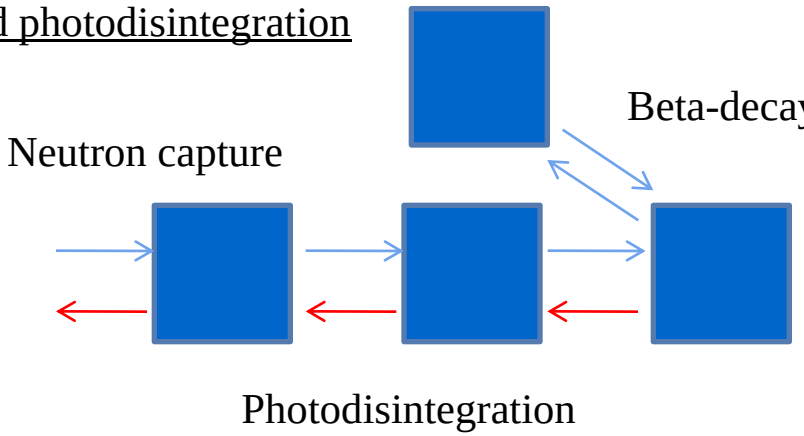
Phonuclear & neutron capture reaction



Key parameters for photonuclear reaction & Neutron capture reaction

- E1 gamma strength function
- Nuclear Level density
- Optical potential model

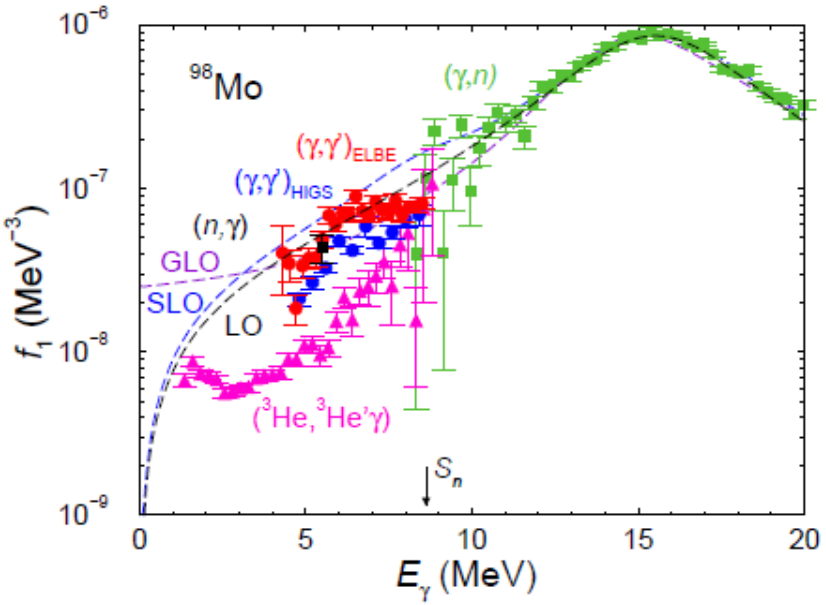
Tipical nucleosynthesis pass for the neutron capture and photodisintegration



北海道大学 HOKKAIDO UNIVERSITY

Why Gamma strength function ?

- ***Nuclear Data***
  The low-energy tail of the GDR strength is important to determine the photoneutron cross sections and their inversion(neutron capture C.S.)
- ***Nuclear Structure***
  Recent photon scattering experiment have shown extra strength below particle thereshhold. "Pygmy dipole resonance (PDR)"



R.Schwengner

Any theory can not explaine …
(TALYS etc..)

➔To understand the nucleosynthesis, we need both photo-neutron & photon-scattering cross section

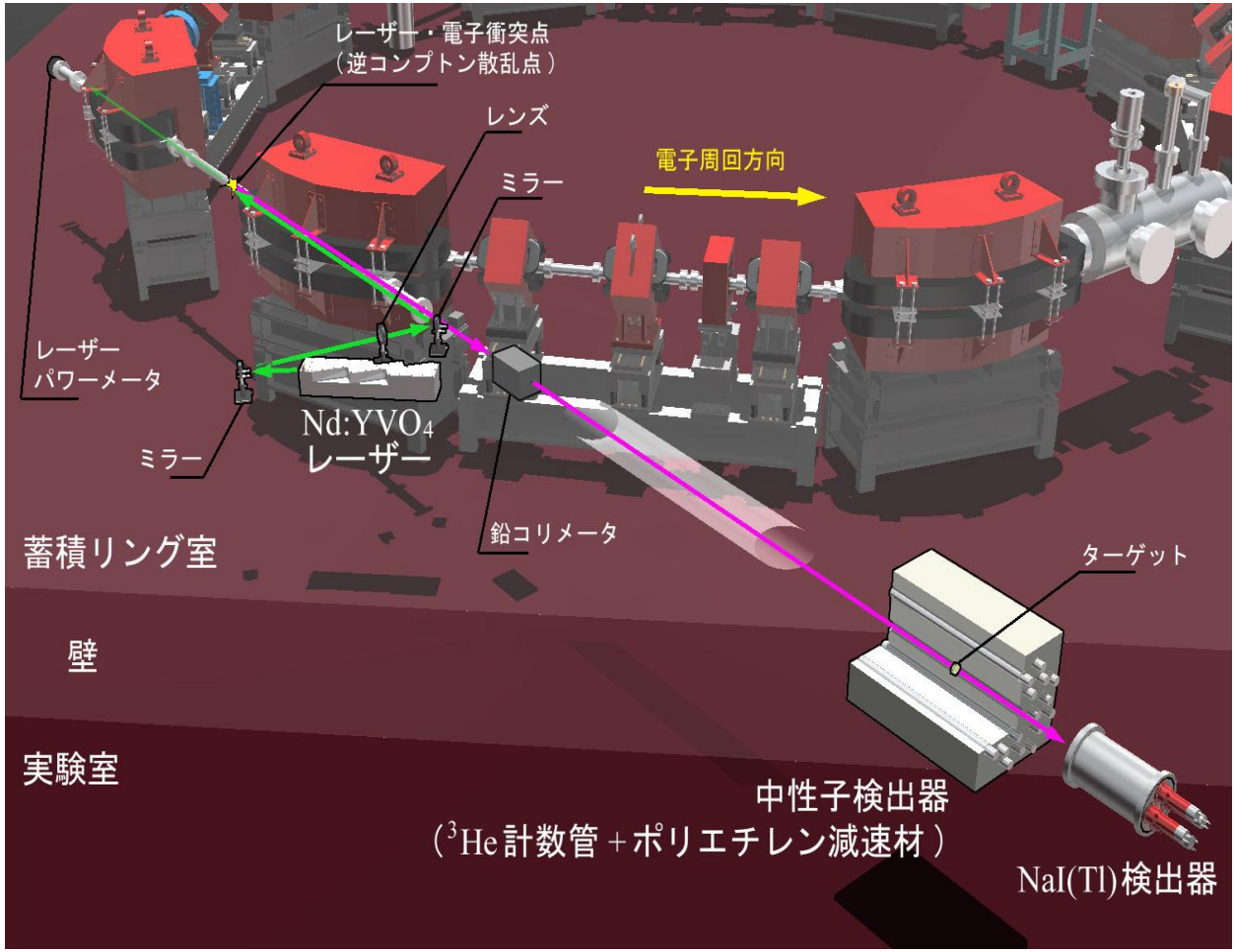
Photoneutron experiment at AIST

北海道大学 HOKKAIDO UNIVERSITY

Experimental setup

National Institute of Advanced Industrial Science and Technology(AIST) in Japan

Quasi-monochromatic γ-ray beams



Se-80濃縮率[%]	99．9
質量（Se-80以外のSe同位体含む）[mg]	1003．3
Se-80試料直径[cm]	0.8
Se-80試料厚さ[cm]	1.503
面密度[mg/cm^2]	1996

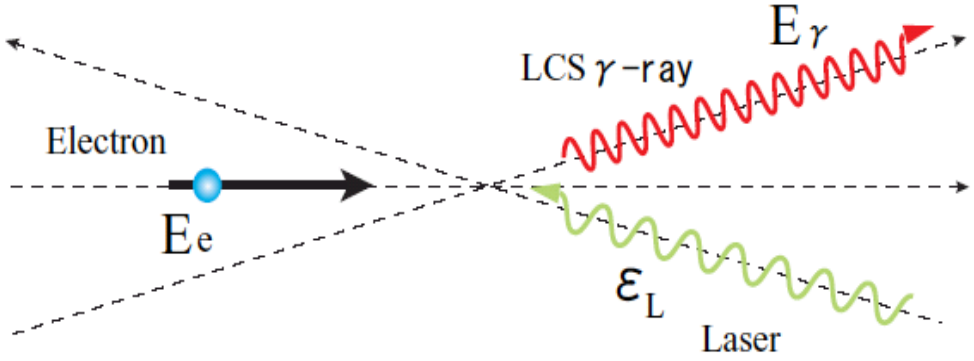
80Se標的核　holder

Photoneutron experiment at AIST

北海道大学 HOKKAIDO UNIVERSITY

LCS(Laser compton back scattering) γ-rays

Inverse Compton Scattering

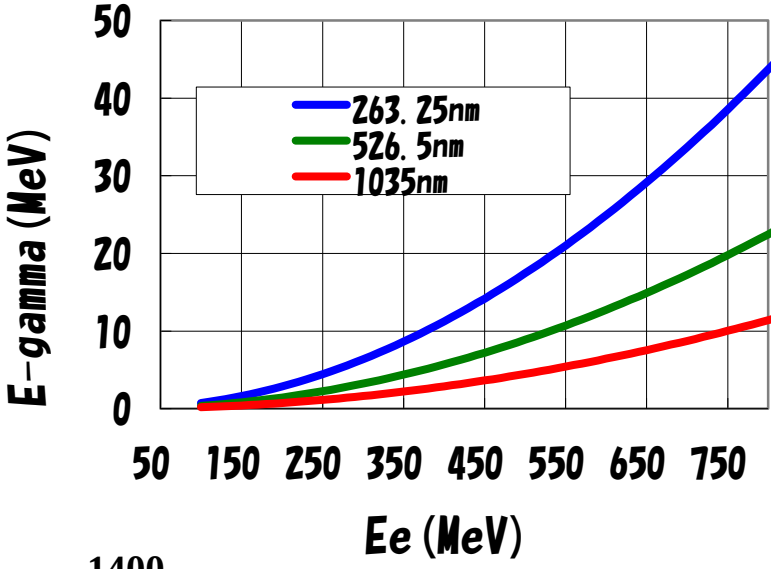


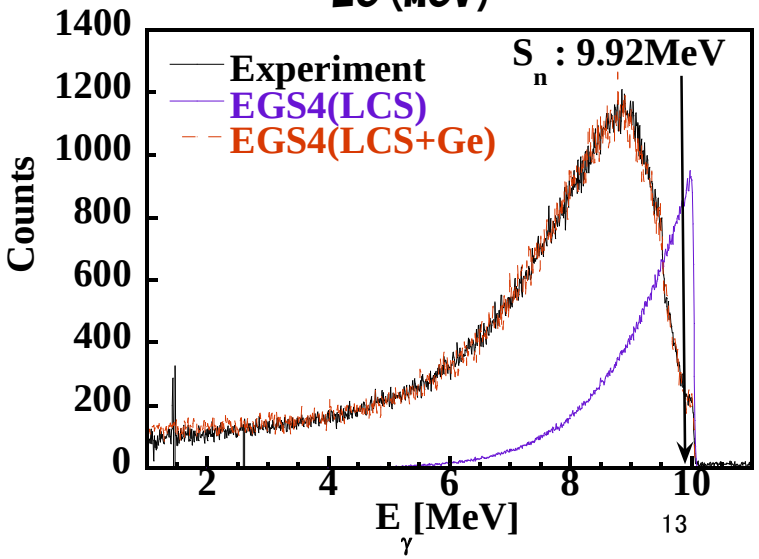
$$E_\gamma = \frac{4\gamma^2 \varepsilon_L}{1 + (\gamma\theta)^2 + 4\gamma\varepsilon_L/(mc^2)} \qquad \gamma = E_e/mc^2$$

Energy variable γ −rays

ε L: Energy of the laser (wave length)

Ee: electron energy

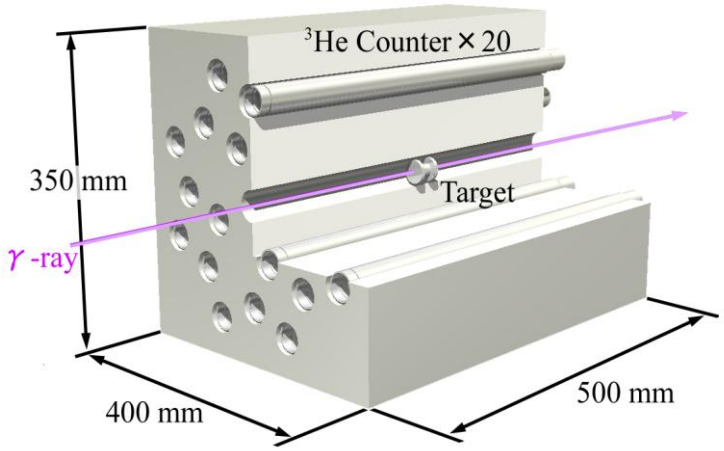


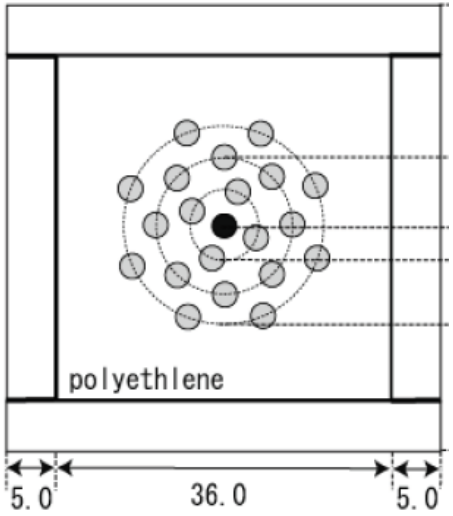


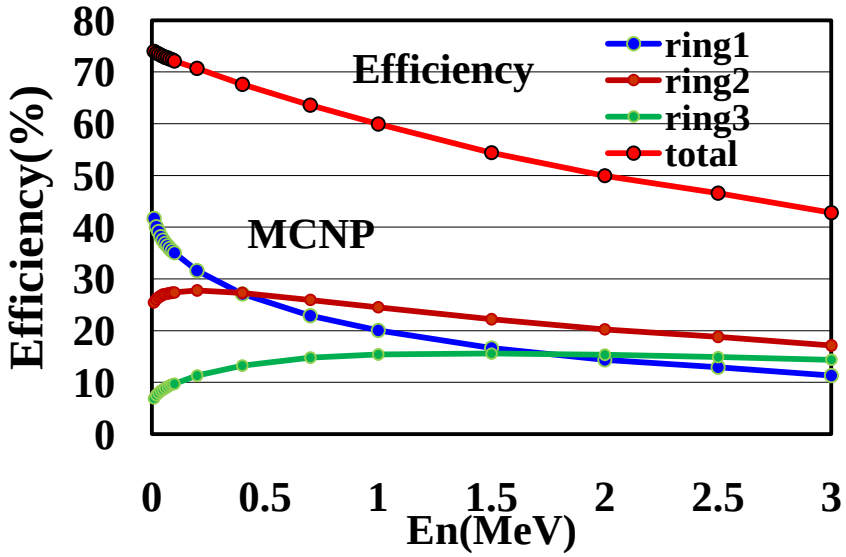
Photoneutron experiment at AIST

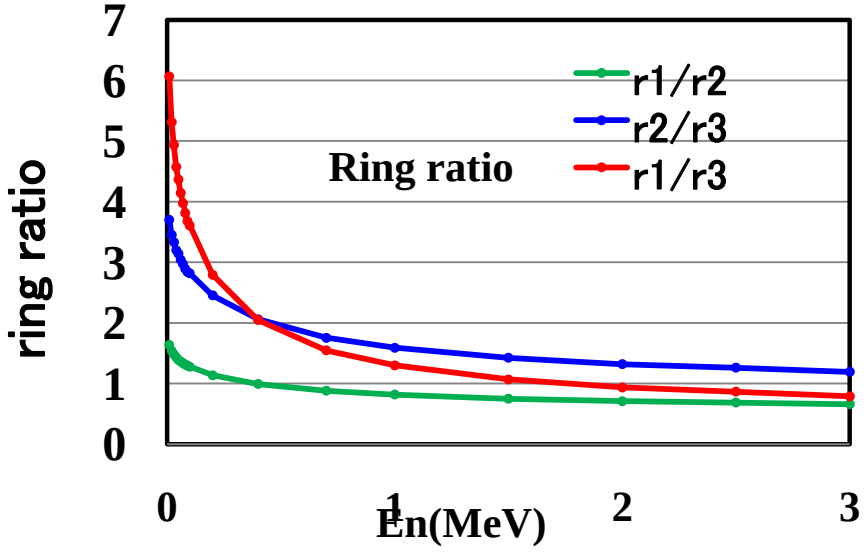
北海道大学 HOKKAIDO UNIVERSITY

Neutron detector system





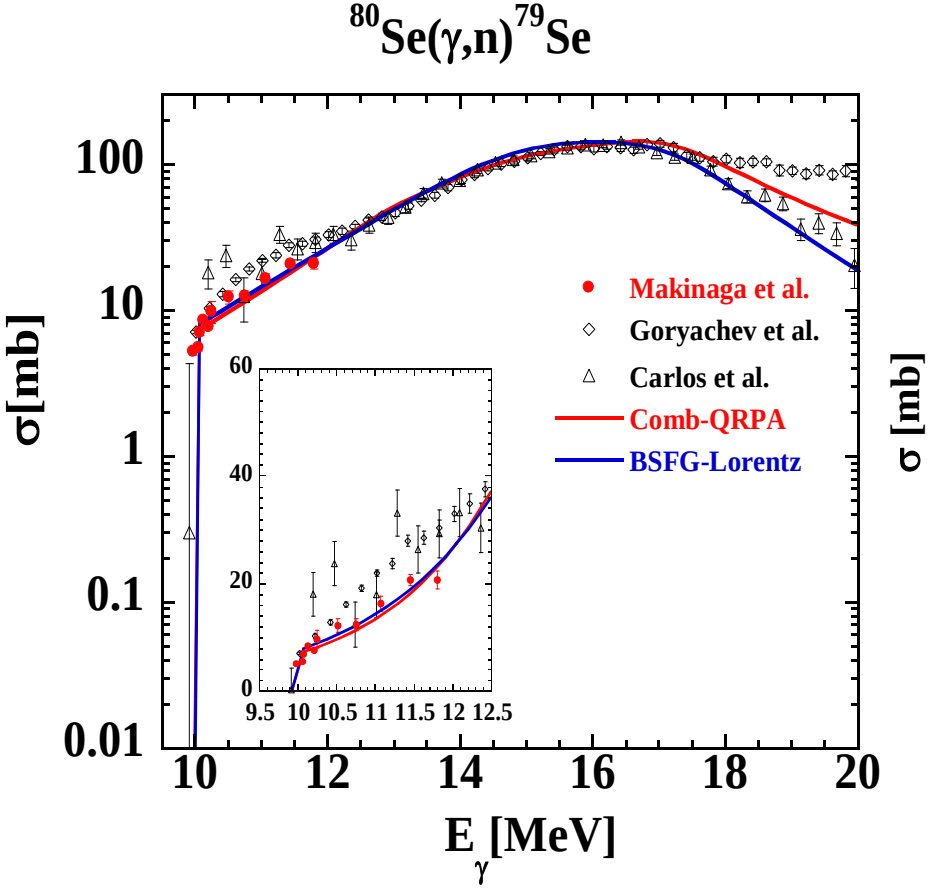




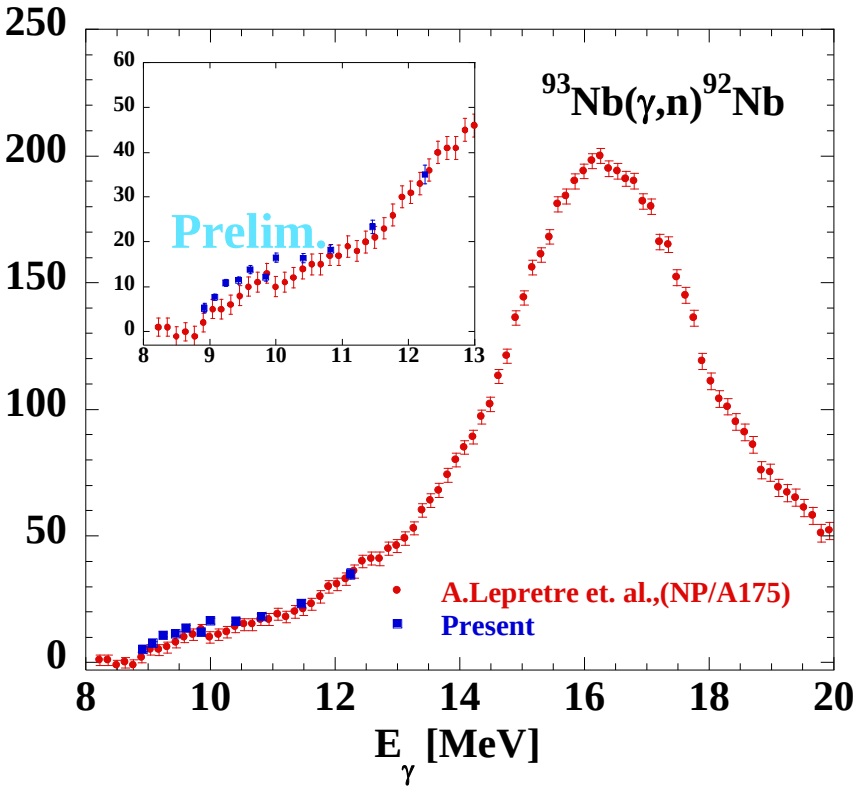
Photoneutron experiment at AIST

北海道大学 HOKKAIDO UNIVERSITY

Result



A.Makinaga et. al, PRC(2010)



=>Fix the experimental data
=>Data evaluation

Photon Scattering experiment at ELBE

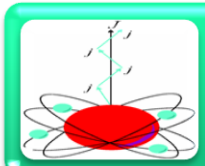
北海道大学 HOKKAIDO UNIVERSITY

Research Center Dresden Rossendorf.

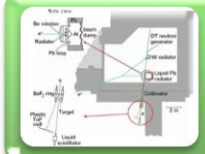
Forschungszentrum Dresden Rossendorf

Division of Nuclear Physics

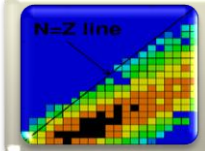
Photoactivation
>>p-process nucleosynthesis



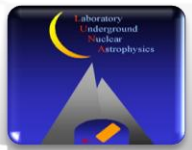
Photon Scattering
>>Nuclear structure



Neutron-Induced Reaction
>> nTOF system at nELBE



GSI and FAIR
>>structure of exotic nuclei



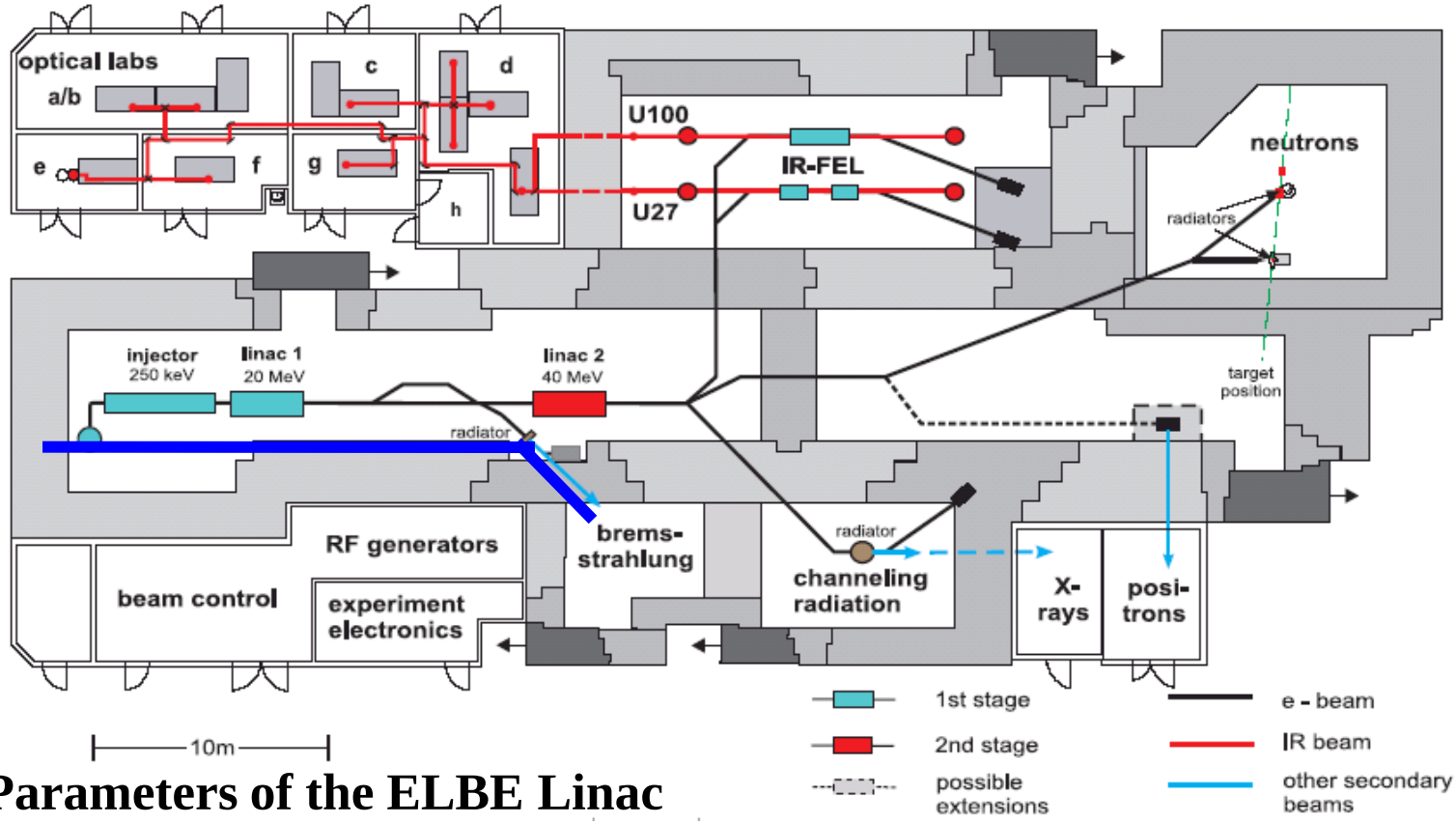
Dresden &LUNA
>>radiative-capture reactions

Photon scattering experiment at ELBE

北海道大学 HOKKAIDO UNIVERSITY

Bremsstrahlung γ-ray facility

Electron Linear accelerator of high Brilliance and low Emittance



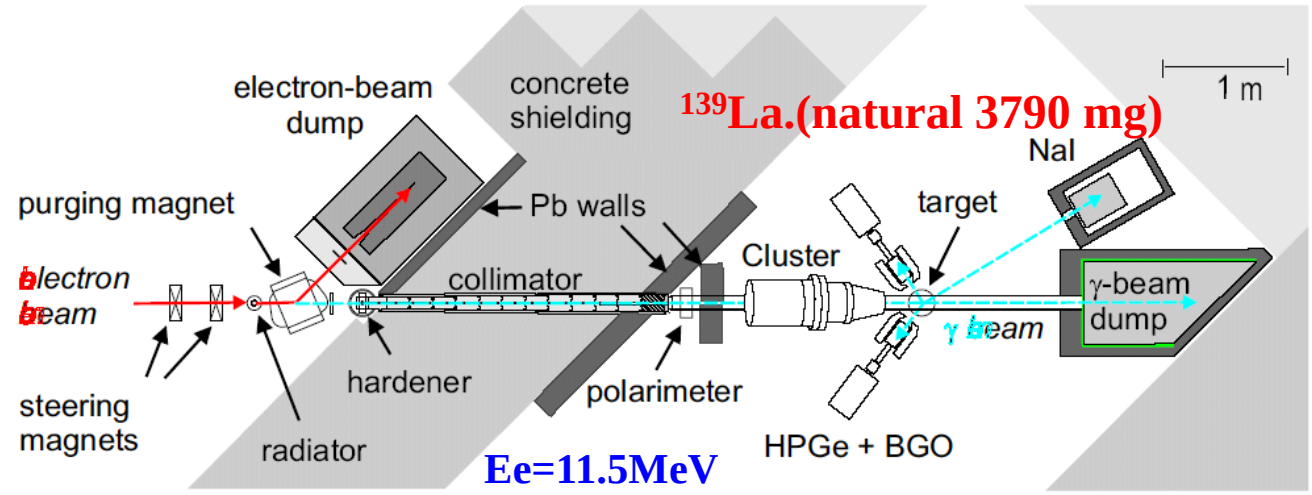
Parameters of the ELBE Linac

- Electron beam energy max 18 MeV
- Max. average beam current 1mA
- Micro-pulse rate 13 MeV
- Micro-pulse length 5ps

Photon scattering experiment at ELBE

北海道大学 HOKKAIDO UNIVERSITY

Experimental set up



R.Schwengner et. al

Ge detector system

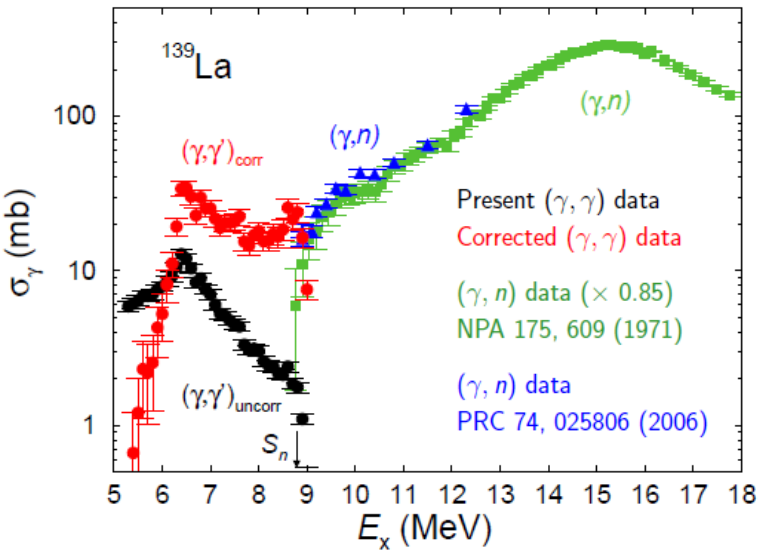
- Bremsstrahlung was produced by hitting 4μm Nb radiator
- Average currents 520μA
- Al collimator 2.6m length and 5mrad of opening angle
- 4 100%HPGe detectors with escape-suppression.
  2 detectors at 90 degrees and 2 detectors at 127 degrees:
  => angular distributions of the gamma rays

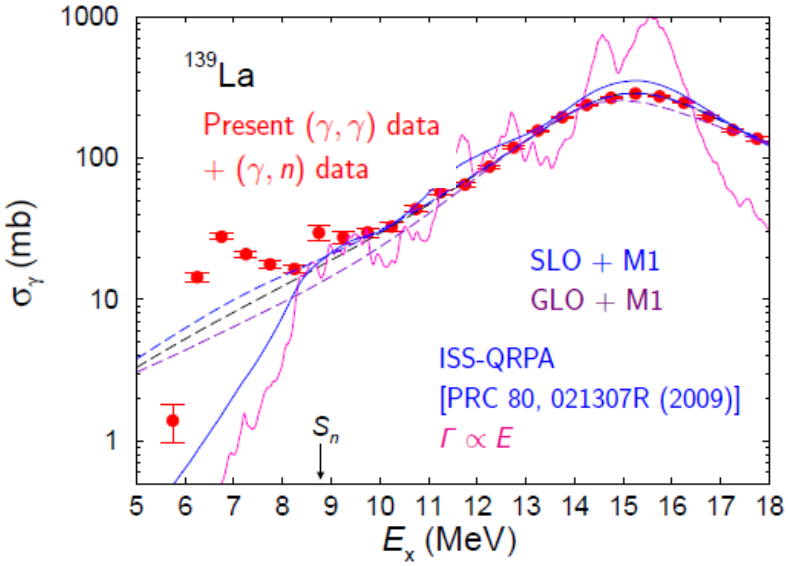
=> GEANT 4 simulation

Photon scattering experiment at ELBE

北海道大学 HOKKAIDO UNIVERSITY

Result





Lorentz curve:
$E_0 = 15.24$ MeV
$\Gamma = 4.47$ MeV
$\frac{\pi}{2}\sigma_0\Gamma = 60\ \frac{NZ}{A}$ MeV mb

A.Makinaga et. al. (2010)

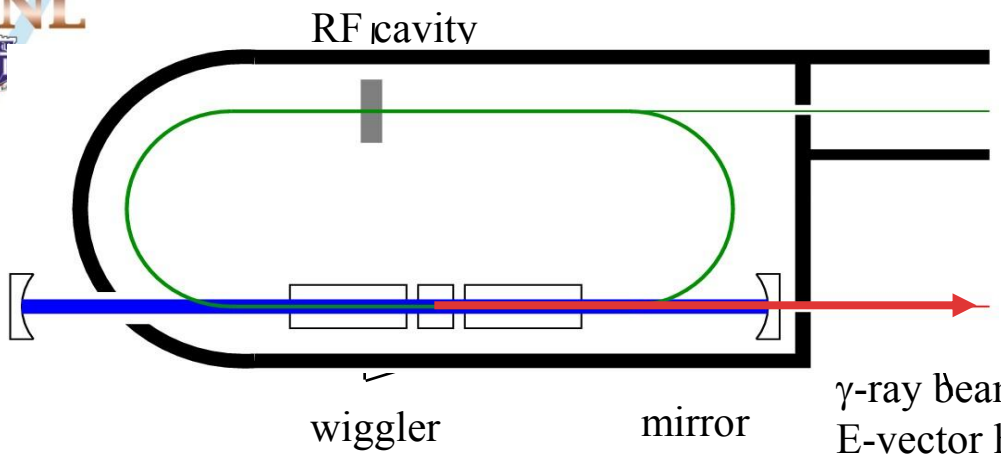
- **Photon scattering cross sections for ^{139}La below Sn were measured at ELBE at an electron kinetic energy of 11.5MeV..**
- **Extra strength is observed from about 6MeV to 8MeV (PDR) can't be explained with currently used gamma-ray strength functions.**

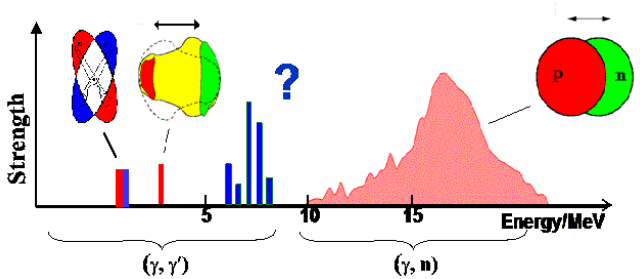
Photon scattering experiment at TUNL

北海道大学 HOKKAIDO UNIVERSITY

Triangle Universities Nuclear Laboratory

- **High Intensity γ-ray Source (HIγS)**
  - >Compton Back Scattering of FEL photons from Duke Storage Ring
- **Nearly Mono-energetic γ-rays**
- **Linearly Polarized γ-rays**
- **High Beam Intensities** >~$10^{6\sim7}$/s





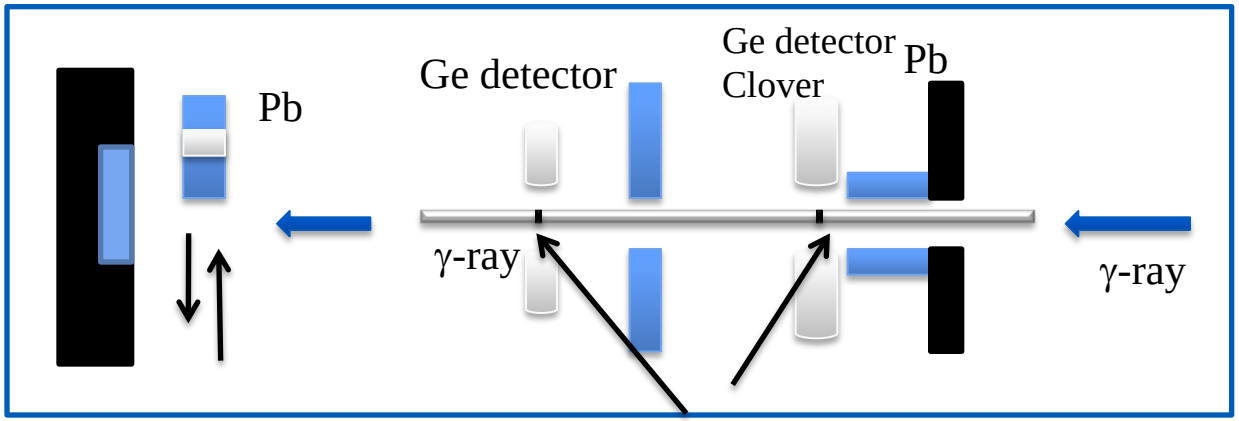
0.7–50 MeV

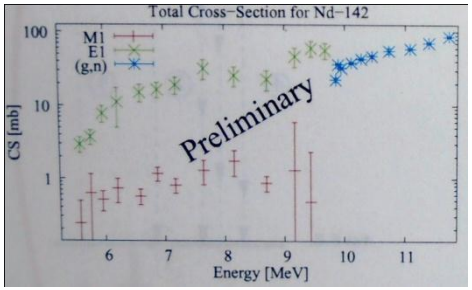
^{142,150}Nd(γ,γ')

Photon scattering experiment at TUNL

北海道大学 HOKKAIDO UNIVERSITY

Experimental set up





C.T.Angell et al
To be submitted soon

Ge detector

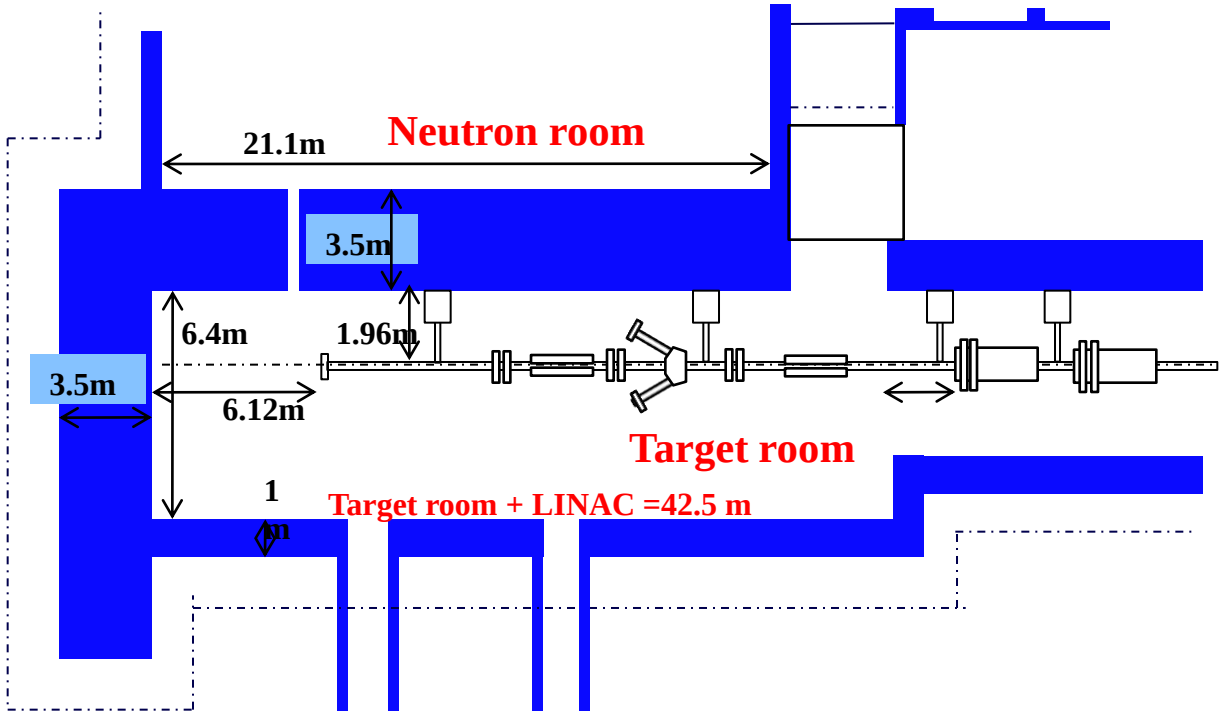
Ge detector

4 Clover Ge detector

142,150 Nd
targets

北海道大学 HOKKAIDO UNIVERSITY

Hokkaido Univ. 45MeV Electron Linac



Electron energy	~45MeV（gun current ~50mA） ~30 MeV（gun current~210mA）
Electron current	Average（example, 60μ A pulse width 3μ s）
Pulse rate	10～100p.p.s(variable、single pulse)

Pulsed neutron experiment at Hokkaido University

北海道大学 HOKKAIDO UNIVERSITY

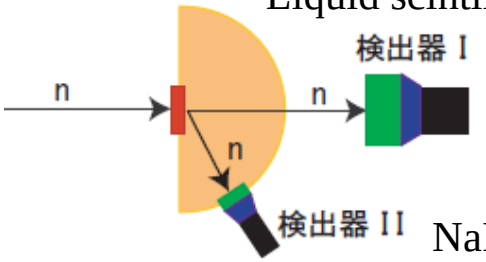
Neutron Capture experiment

This experment is supported by AASPP project (K. Kato).

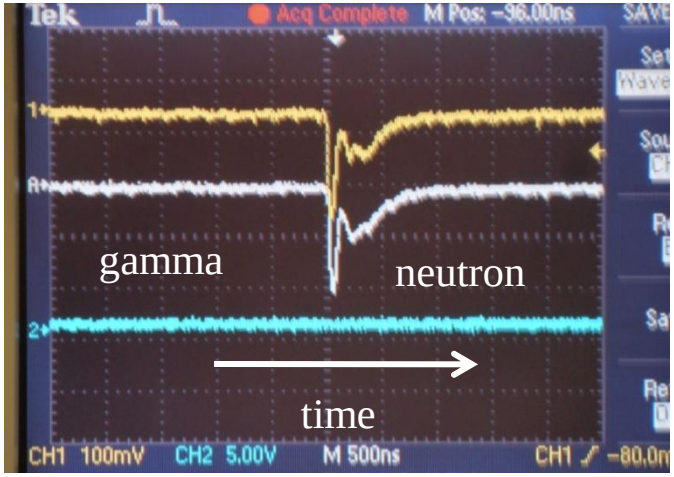
Collaborators & Advisers

A. Makinaga, T.Kamiyama, S.Goko, T.Matsumoto, M. Aikawa, K. Kato (Hokkaido Univ.)
H.Akimune(Konan Unvi.), M.Fujiwara(Osaka Univ.), S.Hohara (Kinki Univ.)
G.N.Kim (KNU)

Liquid scintillator



NaI(Tl)

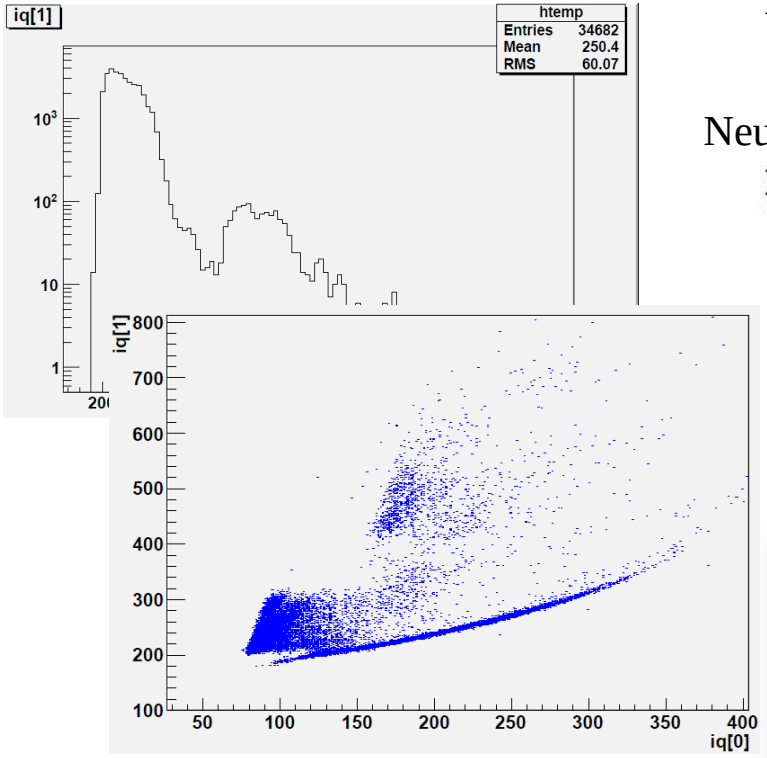


Neutron time of flight
Upper: with Cd target
Lower: without target

Electron energy ~15MeV
Electron pulse width ~0.2 μS
Electron current ~0.5 μA
Electron pulse rate 50 pps
Neutron Flight Length ~10m

北海道大学 HOKKAIDO UNIVERSITY

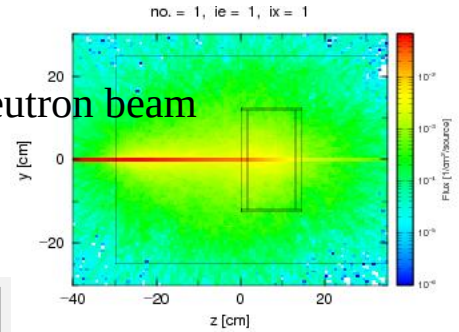
Data Analysis



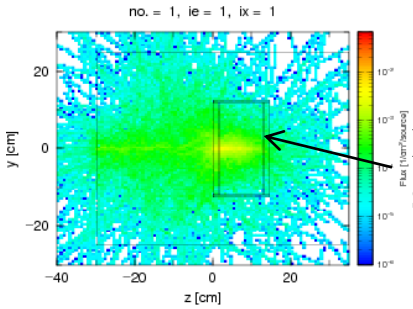
Experimental data

Example of the result of simulation with PHITS

Neutron beam



neutron



photon

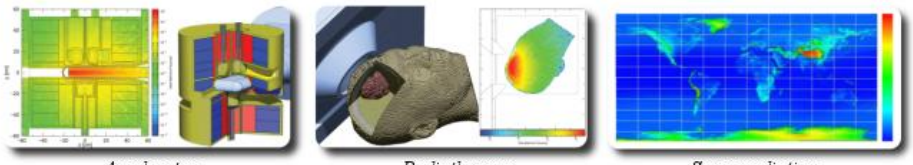
Liquid scintillator

PHITS

Particle and Heavy Ion Transport code System

What is PHITS?

PHITS (**P**article and **H**eavy **I**on **T**ransport code **S**ystem) supports your researches in the fields of accelerator technology, radiotherapy, space radiation, and in many other fields which are related to particle and heavy ion transport phenomena.



Accelerator *Radiotherapy* *Space radiation*

How to refer to PHITS?

Please refer to the following document in context of using any version of PHITS

K. Niita, N. Matsuda, Y. Iwamoto, H. Iwase, T. Sato, H. Nakashima, Y. Sakamoto and L. Sihver,

PHITS: Particle and Heavy Ion Transport code System, Version 2.23, JAEA-Data/Code 2010-022 (2010)

From JAEA WEB

Summary

- Photo-neutron experiment at AIST
- Photon-scattering experiment at ELBE&TUNL
- Activities of pulsed neutron experiment at Hokkaido University

- Further experimental and theoretical research is needed.

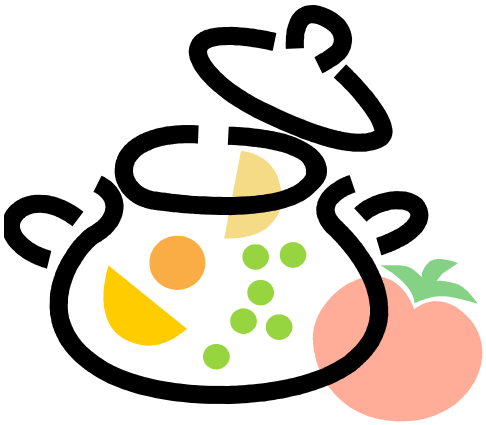
Collaborators & Advisers

- **Photoneutron experiment at AIST**
- A. Makinaga, H. Utsunomiya, T. Kaihori, T. Yamagata, H. Akimune, H. Toyokawa, T. Matsumoto, H. Harano, H. Harada, F. Kitatani, S. Goko, K. Y. Hara, S. Hohara, Y.-W. Lui, T.Hayakawa, T.Shizuma, S. Goriely
- **Photon scattering experiment at ELBE**
- A.Makinaga, G.Rusev, R.Schwengner, F.Doenau, D.Bemmerer, R.Beyer, P.Crespo, M.Erhard, A.R.Junghans, J.Klug, K.Kosev, C.Nair, K.D.Schilling, A.Wagner
- **Photon scattering experiment at TUNL**
- C.T.Angell, S.L.Hammond, H.J.Karwowski, J.H.Kelly, E.Kwan, A.Makinaga, G.Rusev, H.Utsunomiya
- **Neutron experiment at Hokaido University**

A. A. Makinaga, T.Kamiyama, S.Goko, T.Matsumoto, M. Aikawa, K. Kato (Hokkaido Univ.), H.Akimune(Konan Unvi.), M.Fujiwara(Osaka Univ.), S.Hohara (Kinki Univ.)

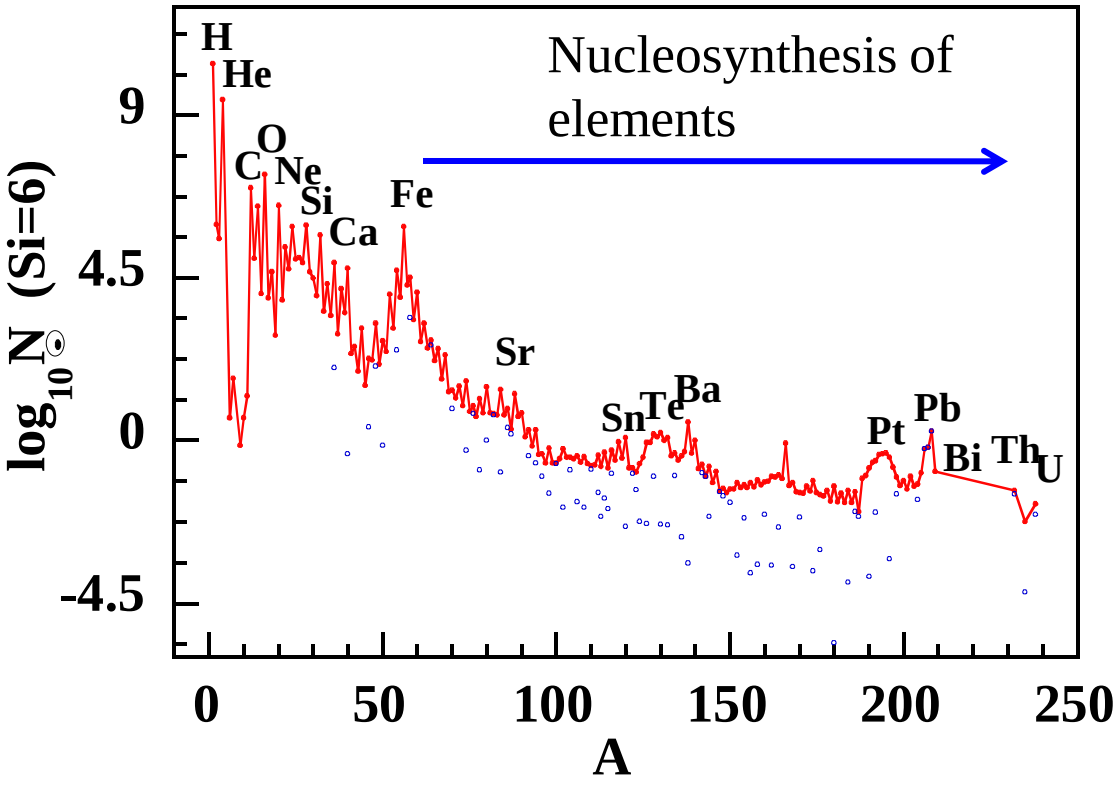
G.N.Kim (KNU)

END



北海道大学 HOKKAIDO UNIVERSITY

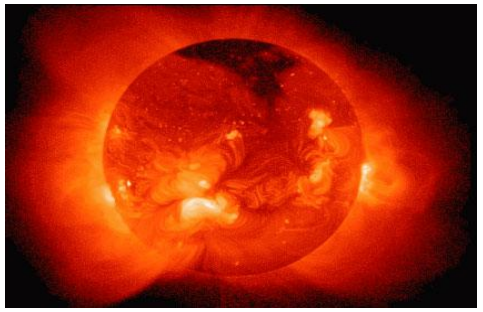
Solar system abundances



Solar system abundance

- **analysis of meteorite**

- **observation of spectrum**



➢**How and where are the isotopes produced?**