A

Start

Liverpool, June 2007

A

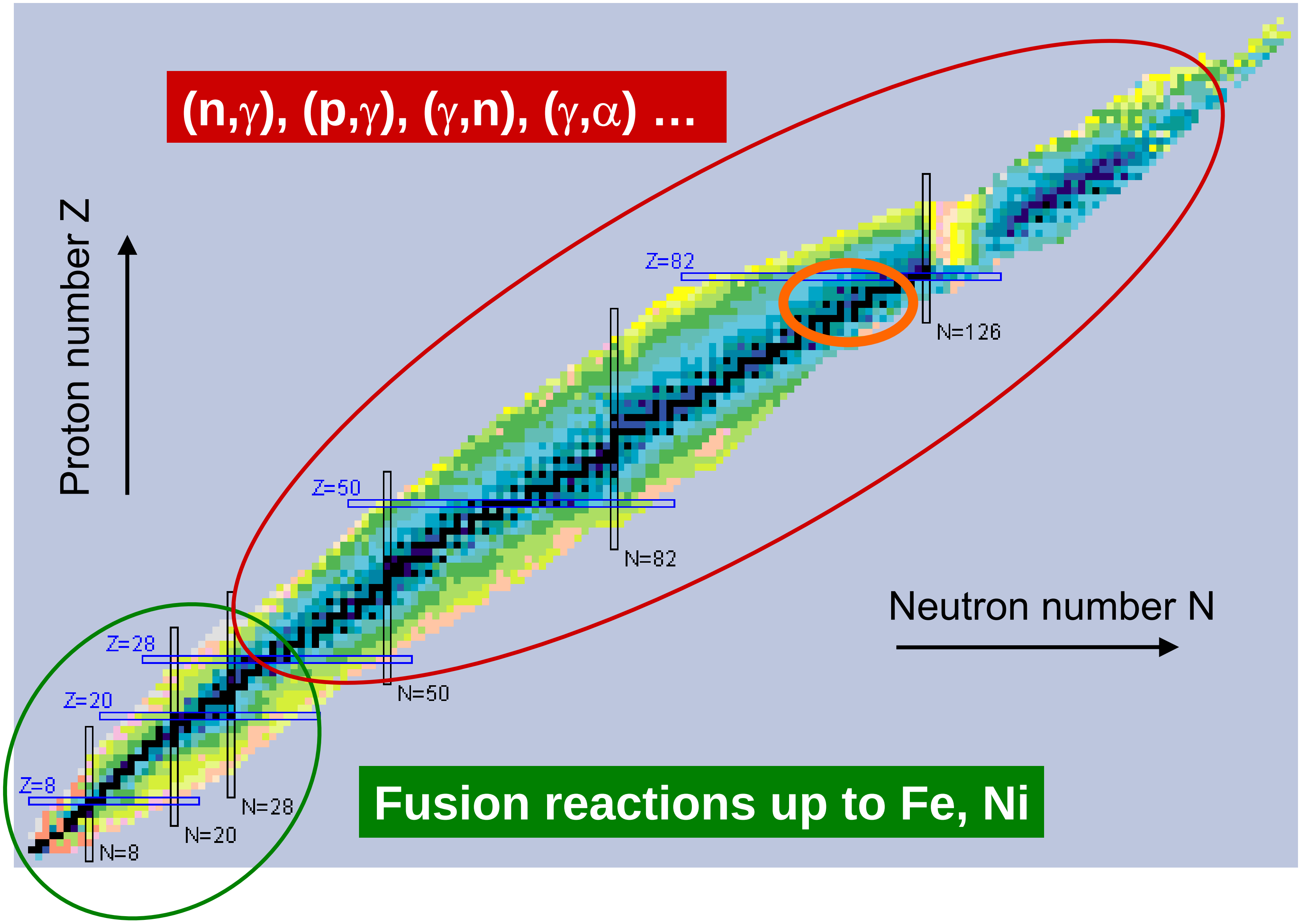
Monoenergetic photons from 4GLS and Nuclear Astrophysics

- **Synthesis of heavy nuclei**
- **Photon induced reaction rates**
- **New opportunities with 4GLS**

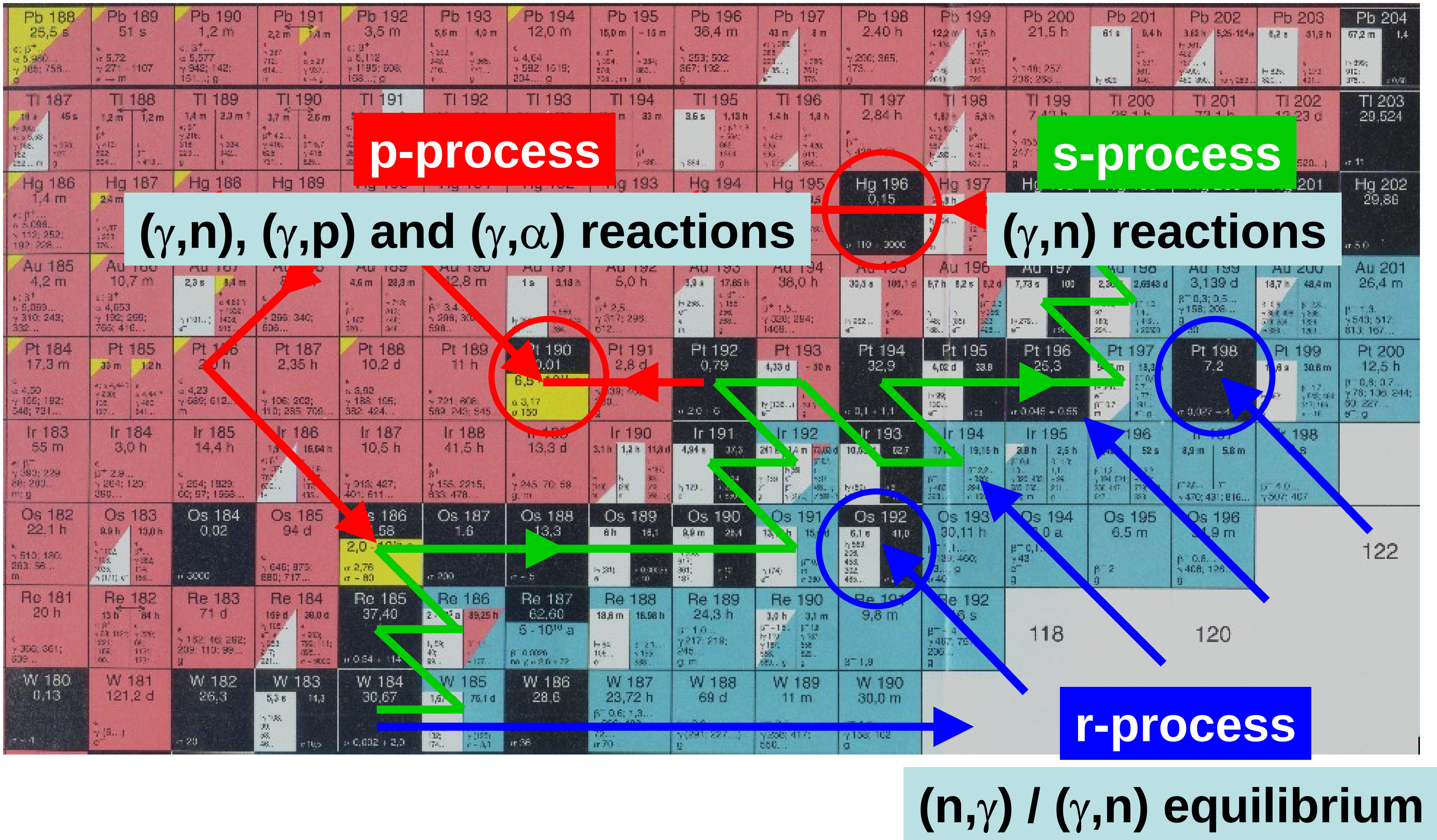
Andreas Zilges
Institut für Kernphysik
TU Darmstadt

SFB 634

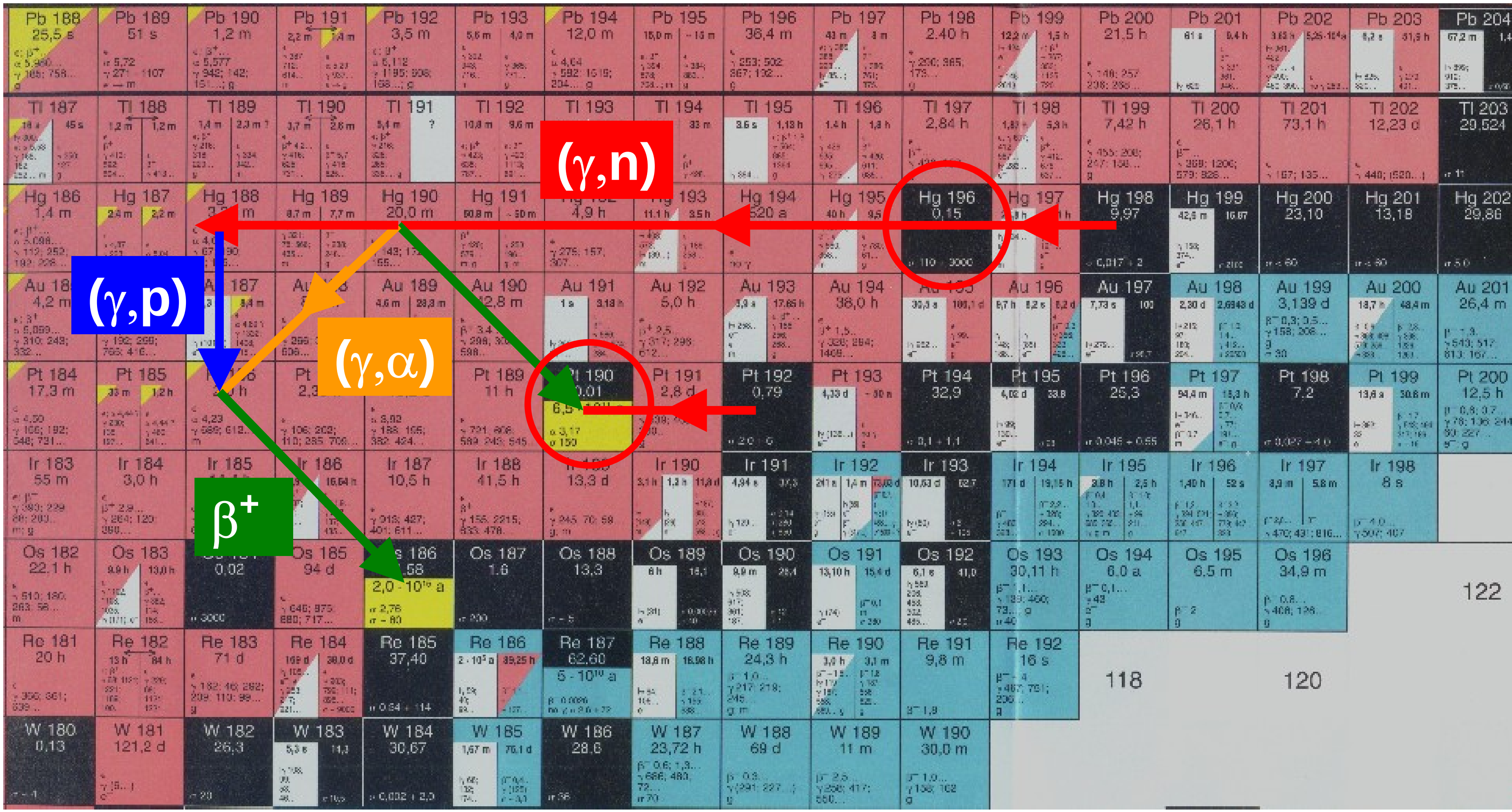
Synthesis of heavy nuclei



Synthesis of heavy nuclei

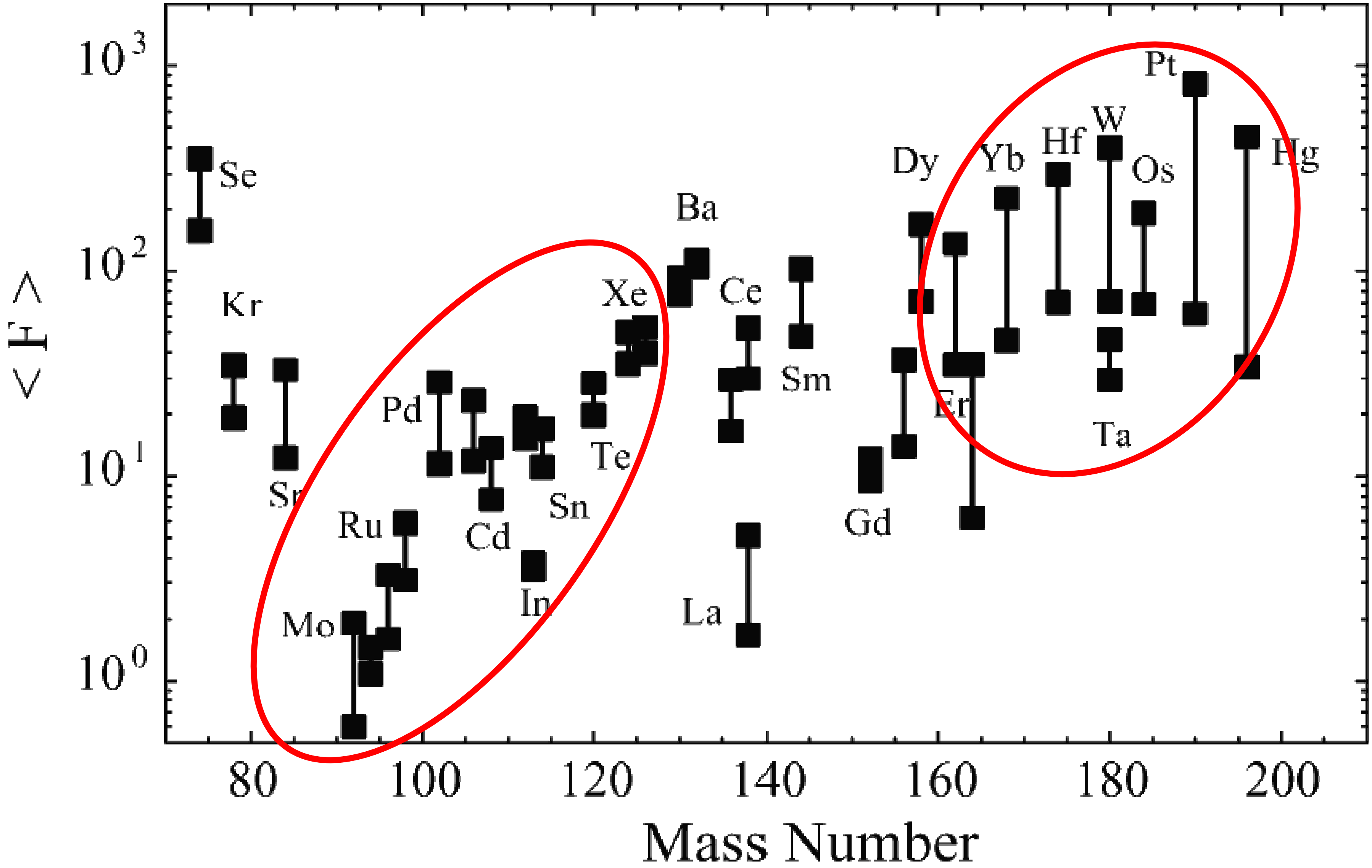


Reactions and decays in the p-process



Especially for for lighter nuclei:
Competing (n,γ), (p,γ), (α,γ)-reactions, νp-process

Abundance of p-nuclei: model vs. experiment



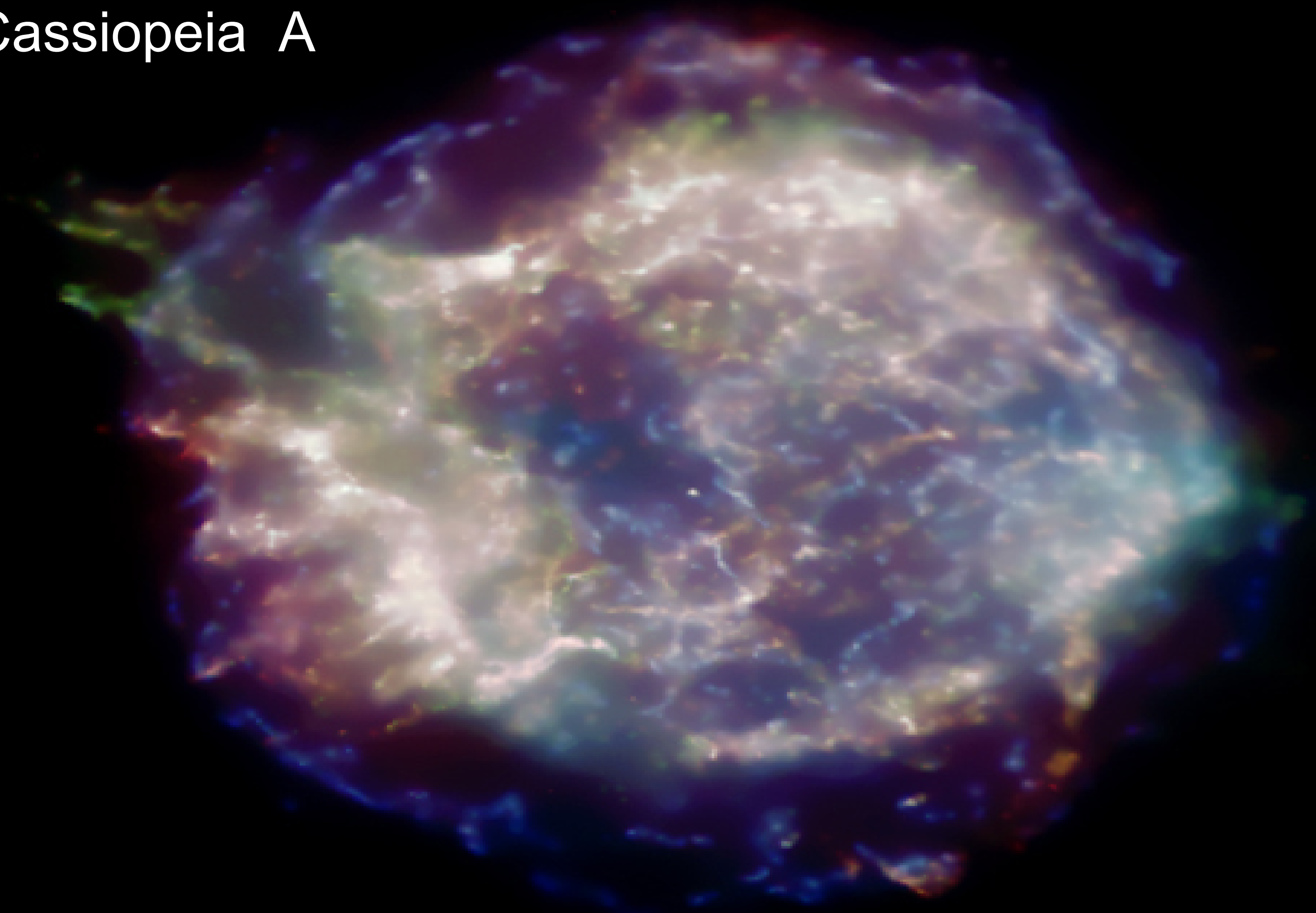
M. Arnould and S. Goriely, Phys. Rep. 384 (2003) 1

Nuclear Physics input for the p-process

- Groundstate masses
- Properties of excited states
- Level densities
- Photoresponse (γ,γ'), (γ,n), (γ,α), (γ,p)
- Optical potentials

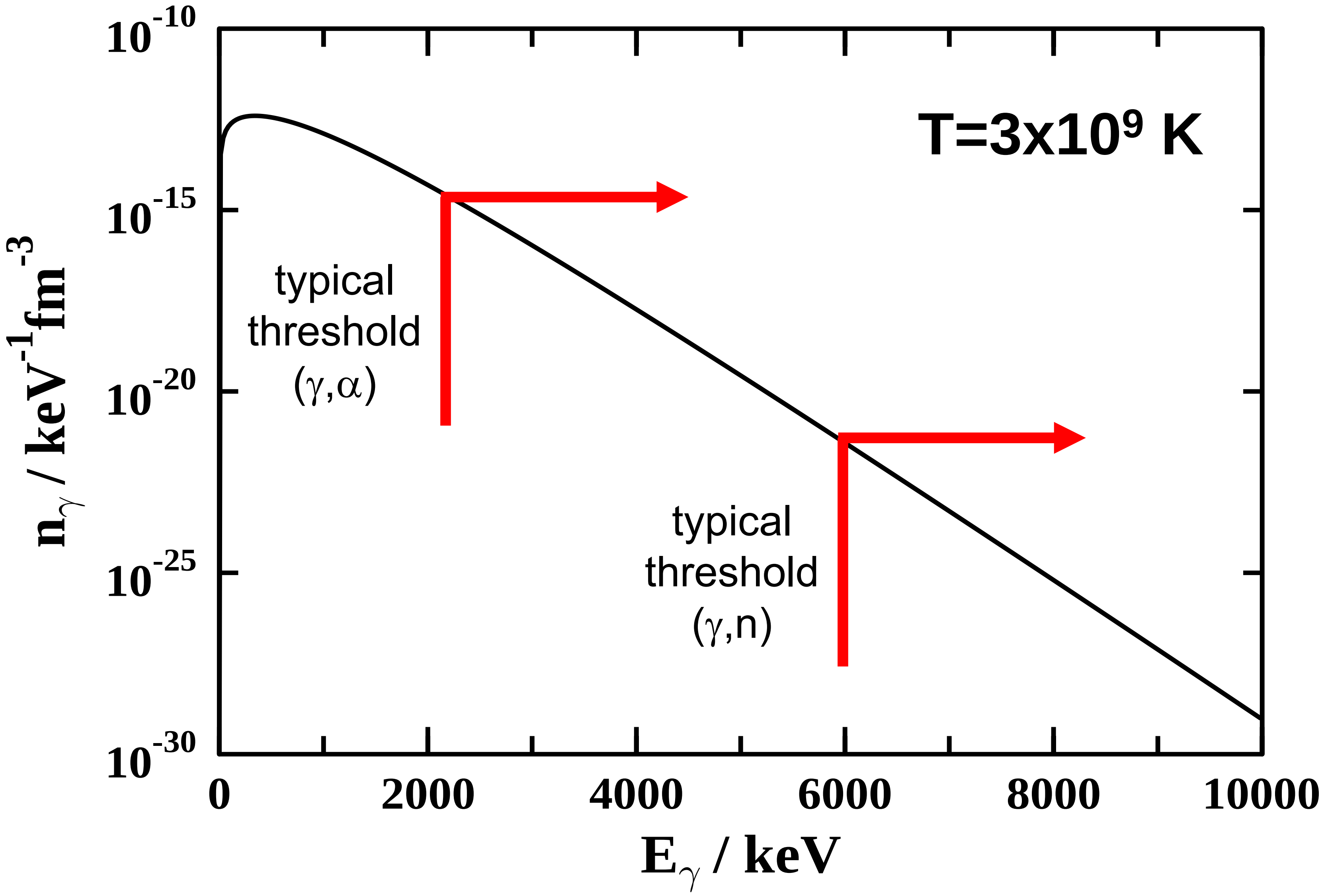
Origin of the photons

Cassiopeia A



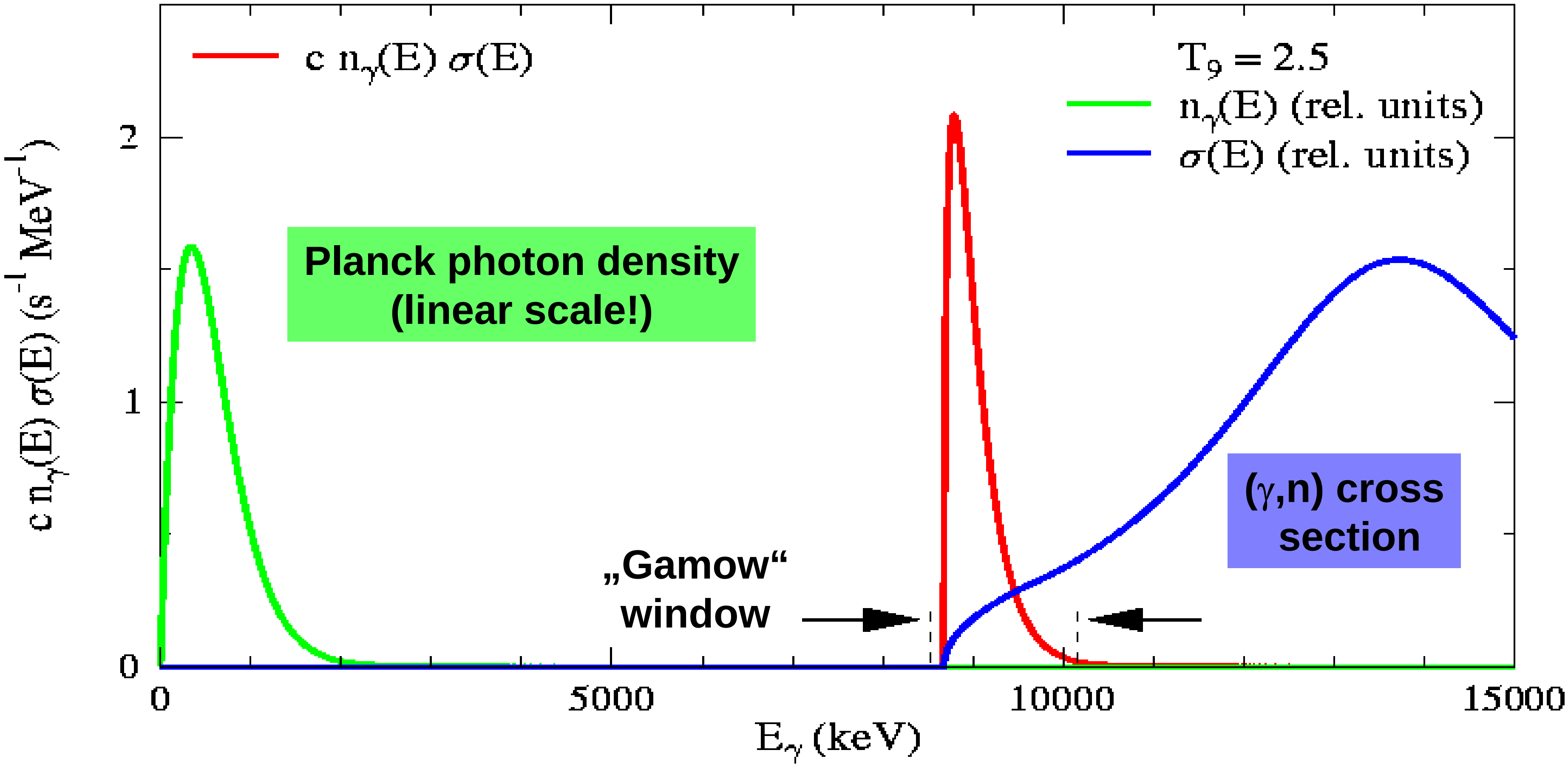
Temperatures up to $3x10^9$ K ~ 200 keV

The photon density – a Planck distribution



What is the relevant energy range ?

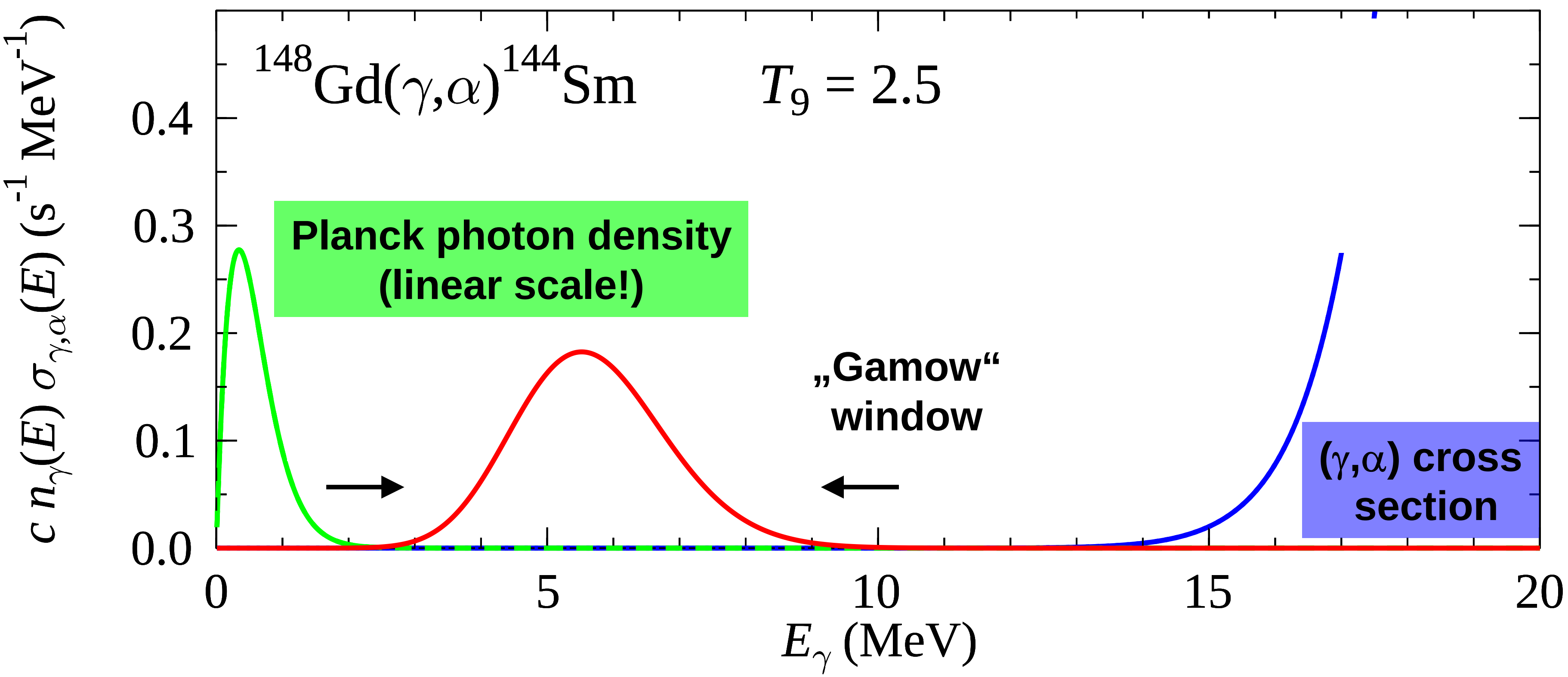
Reaction Rate: $\lambda(T) = c\int n_\gamma(E)\,\sigma(E)\,dE$



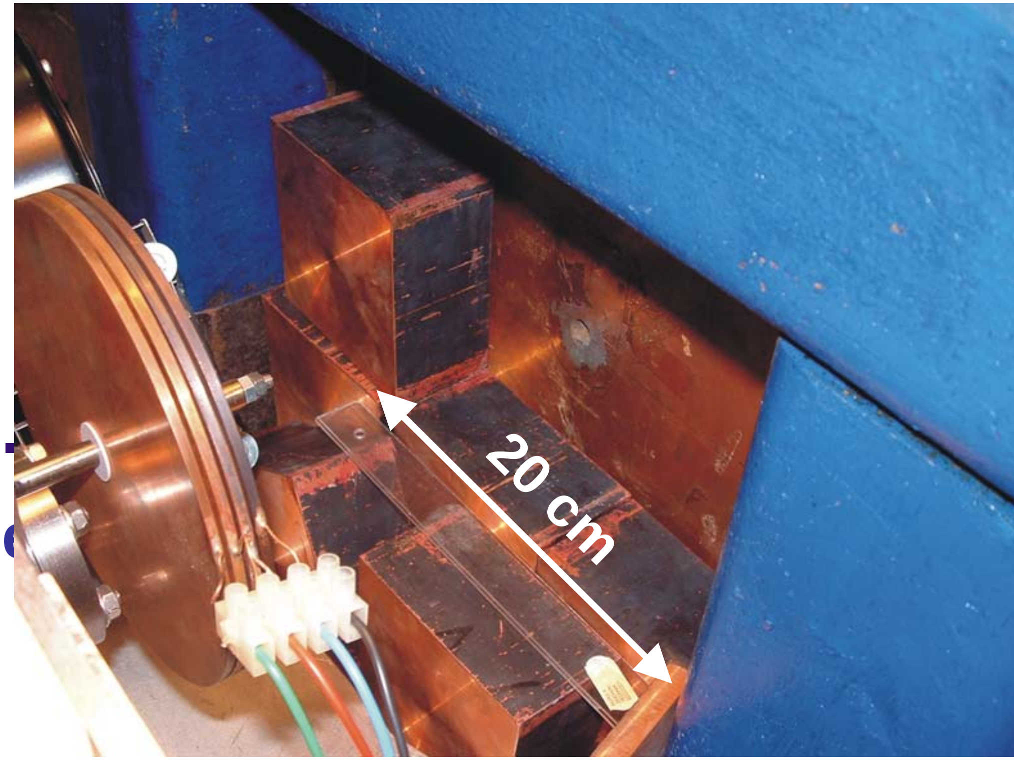
What is the relevant energy range ?

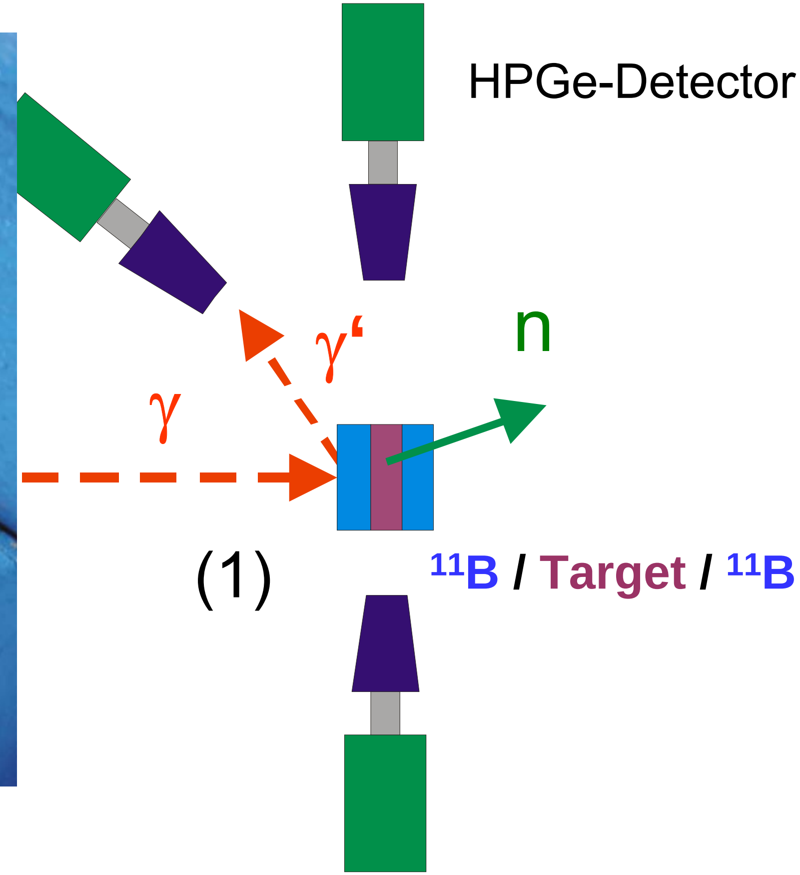
Reaction Rate: $\lambda(T) = c\int n_\gamma(E)\,\sigma(E)\,dE$

Now: σ(E) = σ(γ,α)



The photoactivation setup at S-DALINAC

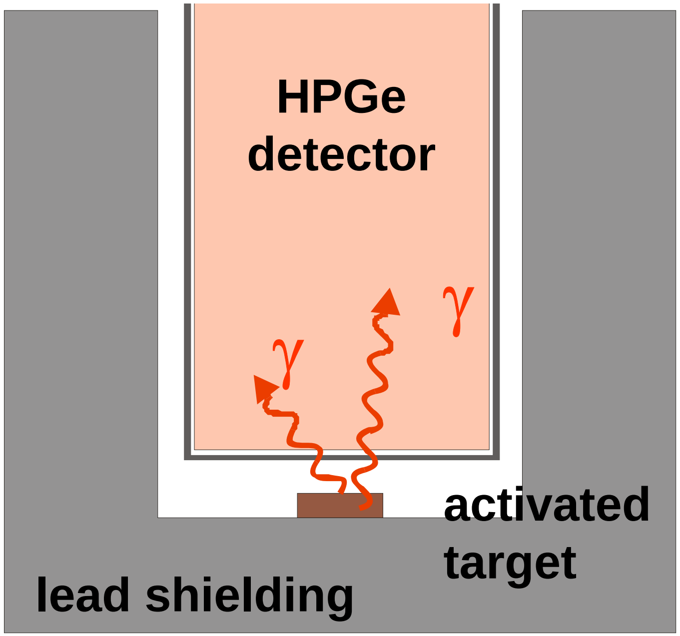


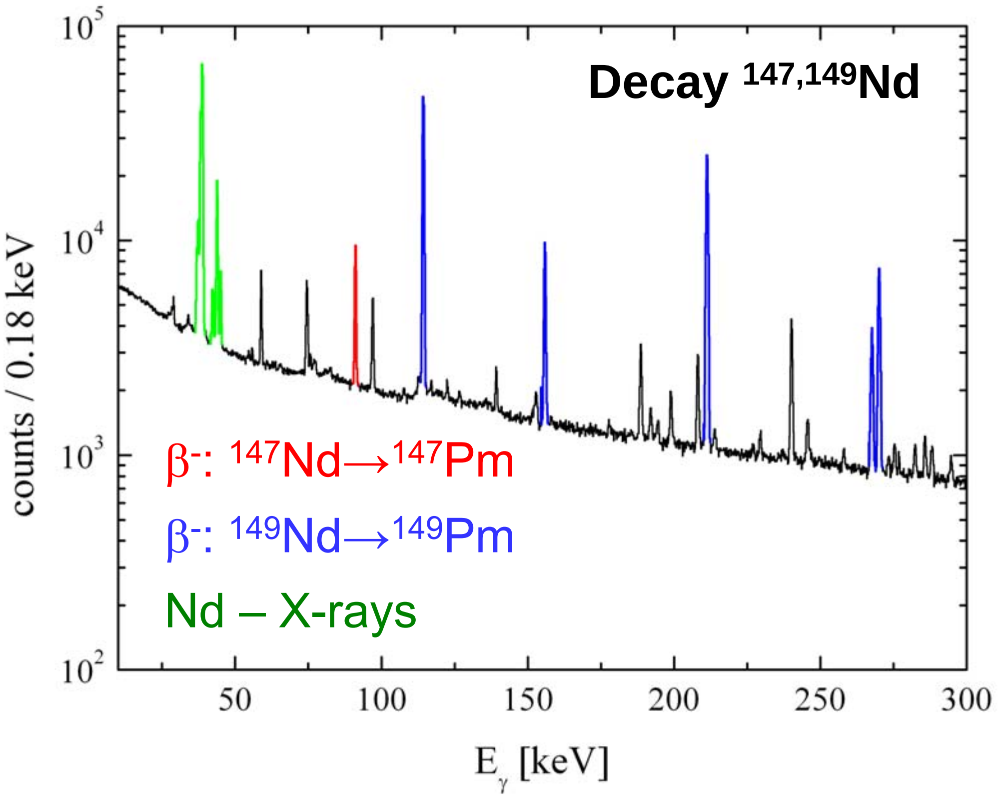


(1) Photon flux ~ 10^5 γ / (keV s cm^2)
Calibration of the photon flux via ^{11}B(γ,γ')

(2) Photon flux ~ 10^7 γ / (keV s cm^2)
Calibration of the photon flux via ^{197}Au(γ,n) and ^{187}Re(γ,n)

Determination of reaction yield





(or sample analysis with AMS)

Reaction yield: $Y \propto \int \sigma(E) n_\gamma(E) dE$

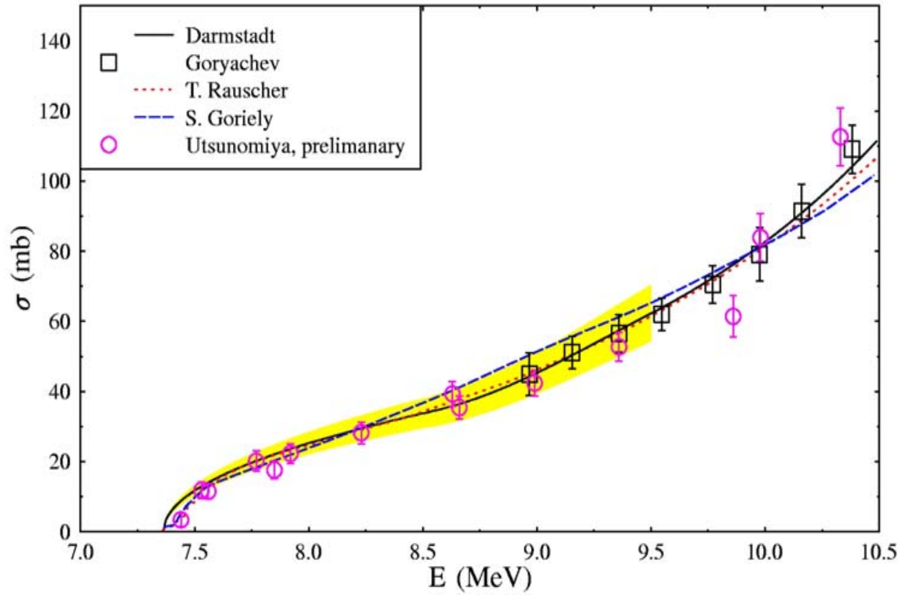
n_γ(E) is a continuous bremsstrahlung spectrum

Challenges for cross section measurements

Only integrated cross sections can be determined in conventional bremsstrahlung experiments:

$$Y \propto \int \sigma(E) n_\gamma(E) dE$$

Many informations are hidden in the energy dependence



→ Direct measurement of σ(E) !

Challenges of (γ,p) and (γ,α) measurements

Coulomb barrier for protons and α-particles:

Mass A	$E_{coul}(\alpha)$ [MeV]	$E_{coul}(p)$ [MeV]
50	12	7
100	18	11
150	27	15

Charged particles reactions are strongly suppressed in the relevant energy range

→ Very small cross sections !

4GLS for Nuclear Astrophysics

- **How to determine $\sigma(E)$ directly ?**
- **How to increase laboratory reaction rate ?**

→ A tunable γ ray source with highest intensities

→ Laser Compton Back-scattering at 4GLS

4GLS for Nuclear Astrophysics

- **Determination of small cross sections of photon induced reactions**
- **Versatile research program feasible including reaction rates of elements with A<60**
- **Complementary and/or superior to existing or planned other facilities (HIGS, AIST, ELBE, S-DALINAC, NEPTUN, SPRING 8)**
- **Broad interest from Nuclear Astrophysicists world wide**

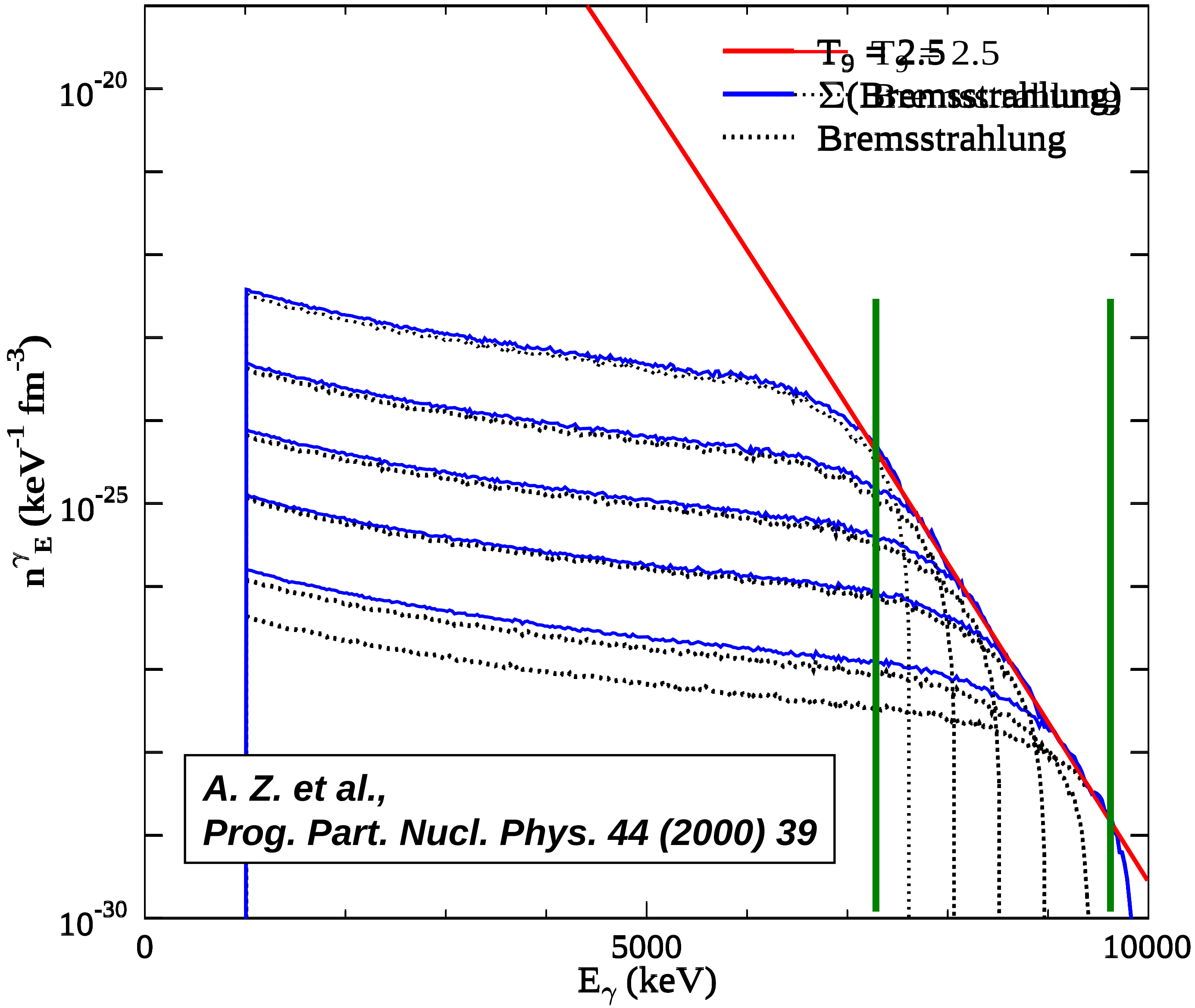
End

Groundstate (γ,n) reaction rates

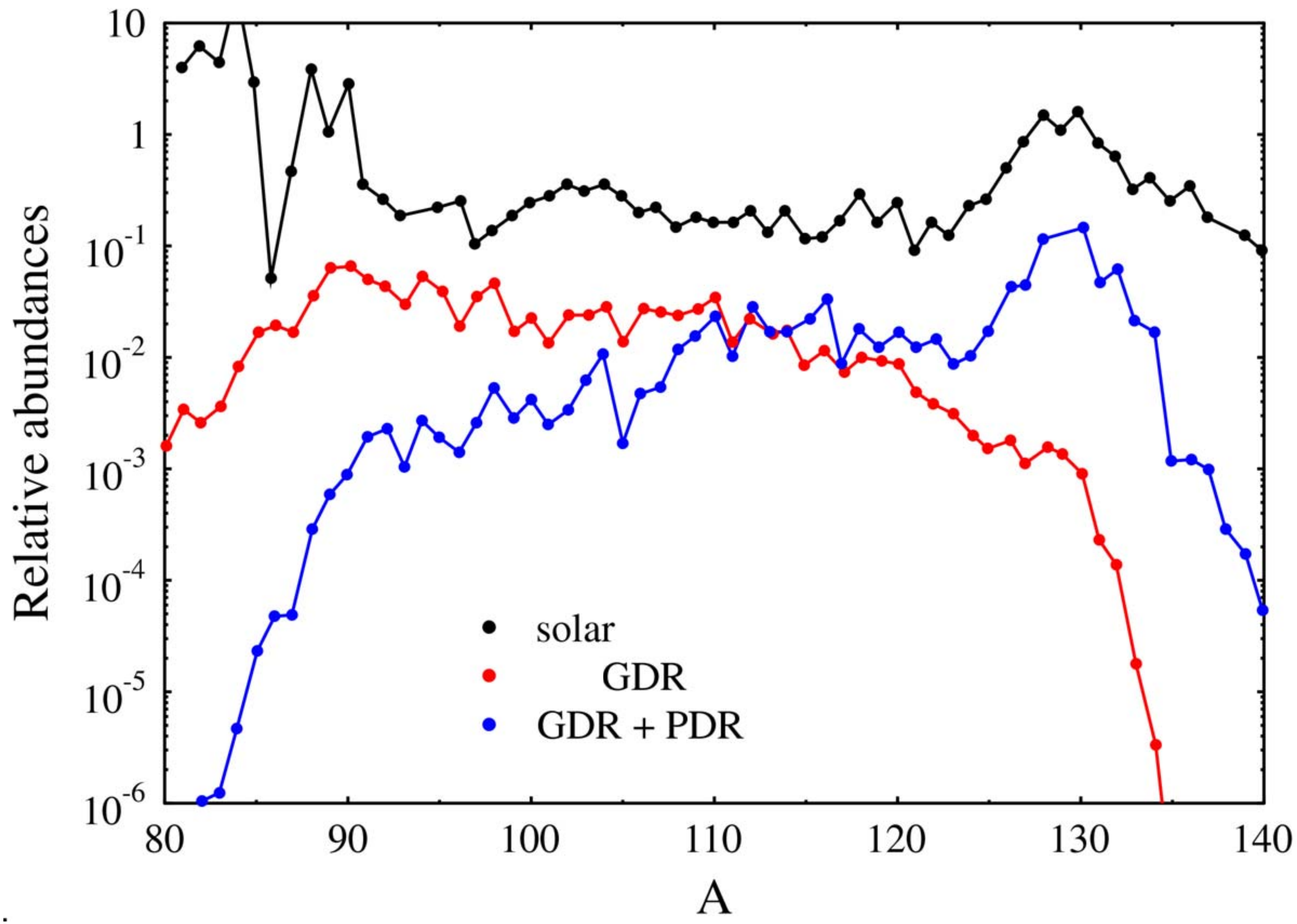
Kern	S_n (MeV)	λ_{exp} (s^{-1})
^{190}Pt	8911	0.4(2)*
^{192}Pt	8676	0.5(2)
^{198}Pt	7557	87(21)
^{197}Au	8071	6.2(8)
^{196}Hg	8840	0.42(7)*
^{198}Hg	7103	2.0(3)
^{204}Hg	7495	57(21)
^{204}Pb	8394	1.9(3)

Temperature: $T=2.5\times10^{9}$ K

Simulation of a Planck spectrum



Abundance of r-nuclei: Influcence of photoresponse



S. Goriely, Phys. Lett. B **436** (1998) 10

Modelling the *s*-process nucleosynthesis

Stellar Evolution

- **Evolutionary models** (O.Straniero and R. Gallino, NPA 777 (2006) 311)
- **Spectral observations** (M. Busso et al., Annu. Rev. Astron. Astrophys. 37 (1999) 239)

Galactic Evolution

- **Averaging over stars with various metallicity and mass** (C. Travaglio et al., ApJ 521 (1999) 691)

s-process nucleosynthesis

Elemental Abundances

- **High-resolution spec-troscopy and investigation of meteorides** (E. Anders and N. Grevesse, Geochim. Cosmochim. Acta 53 (1989) 197)

Nuclear Physics Input

- **Neutron capture cross sections** (KADONIS online database)
- **Beta-decay rates at branching points** (K. Takahashi and K. Yokoi, ADNDT 36 (1987) 375)
- **Rates of neutron sources** (F. Käppeler et al., ApJ 437 (1994) 396)

Investigation of branching points

Branching	(n,γ) (MACS@30 keV) [mb]	(γ,n) (Normalization)	Code	Reference
^{147}Nd / ^{148}Nd	**382**	**1.03 (20)**	*NON-SMOKER (2003)*	J. Hasper, to be published
	453	**0.86 (17)**	*NON-SMOKER-Web*	
^{185}W / ^{186}W	**599**	**1.22 (17)**	*NON-SMOKER*	K. Sonnabend et al., ApJ 583 (2003) 506
	654	**0.97 (13)**	*Mengoni*	
^{95}Zr / ^{96}Zr	**126**	**1.22**	*NON-SMOKER*	K. Sonnabend, to be published
	23	**1.54**	*MOST*	
^{186}Re / ^{187}Re	**1546**	**1.15 (31)**	*NON-SMOKER*	S. Müller et al., PRC 73 (2006)
	623	**1.07 (28)**	*MOST*	