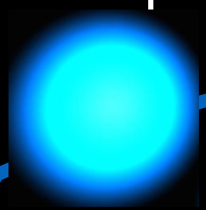
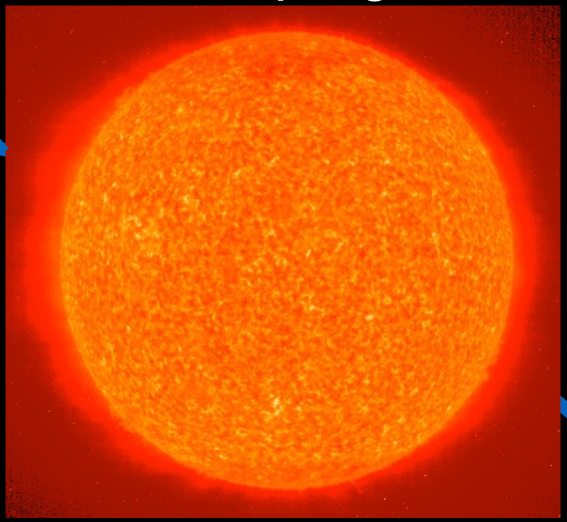
Main Sequence Star



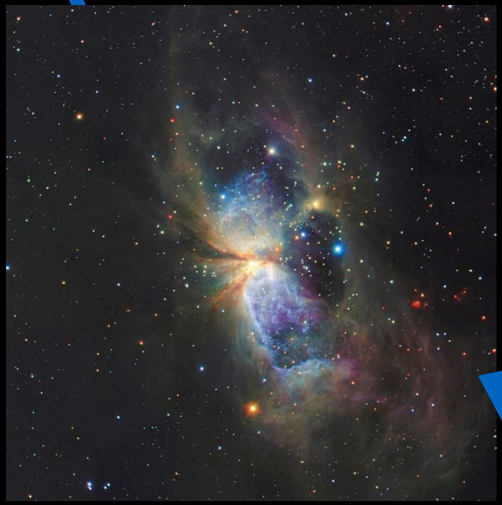
Red Supergiant



Neutrons in Nuclear Astrophysics

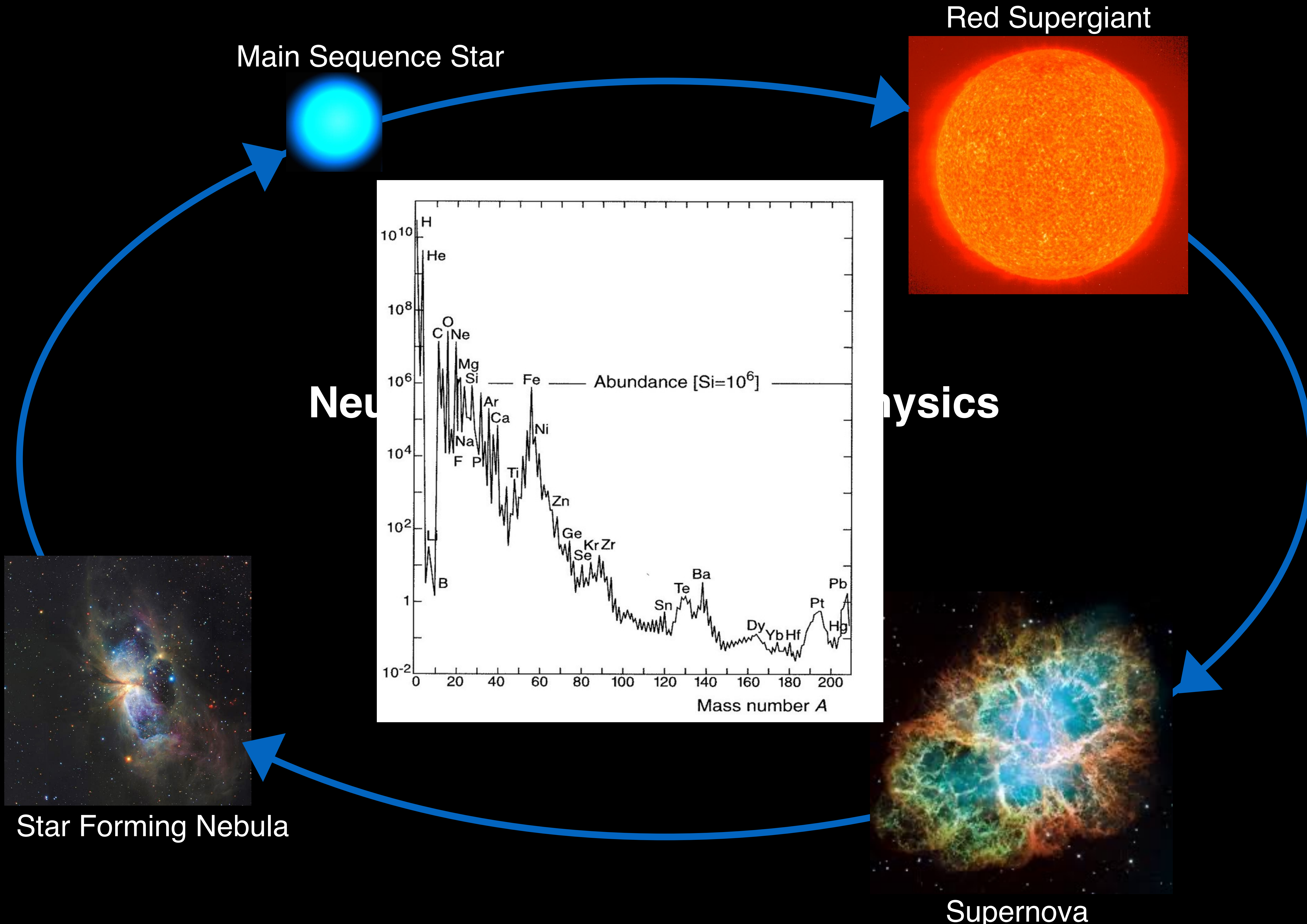
Claudia Lederer-Woods
University of Edinburgh

22 November 2021

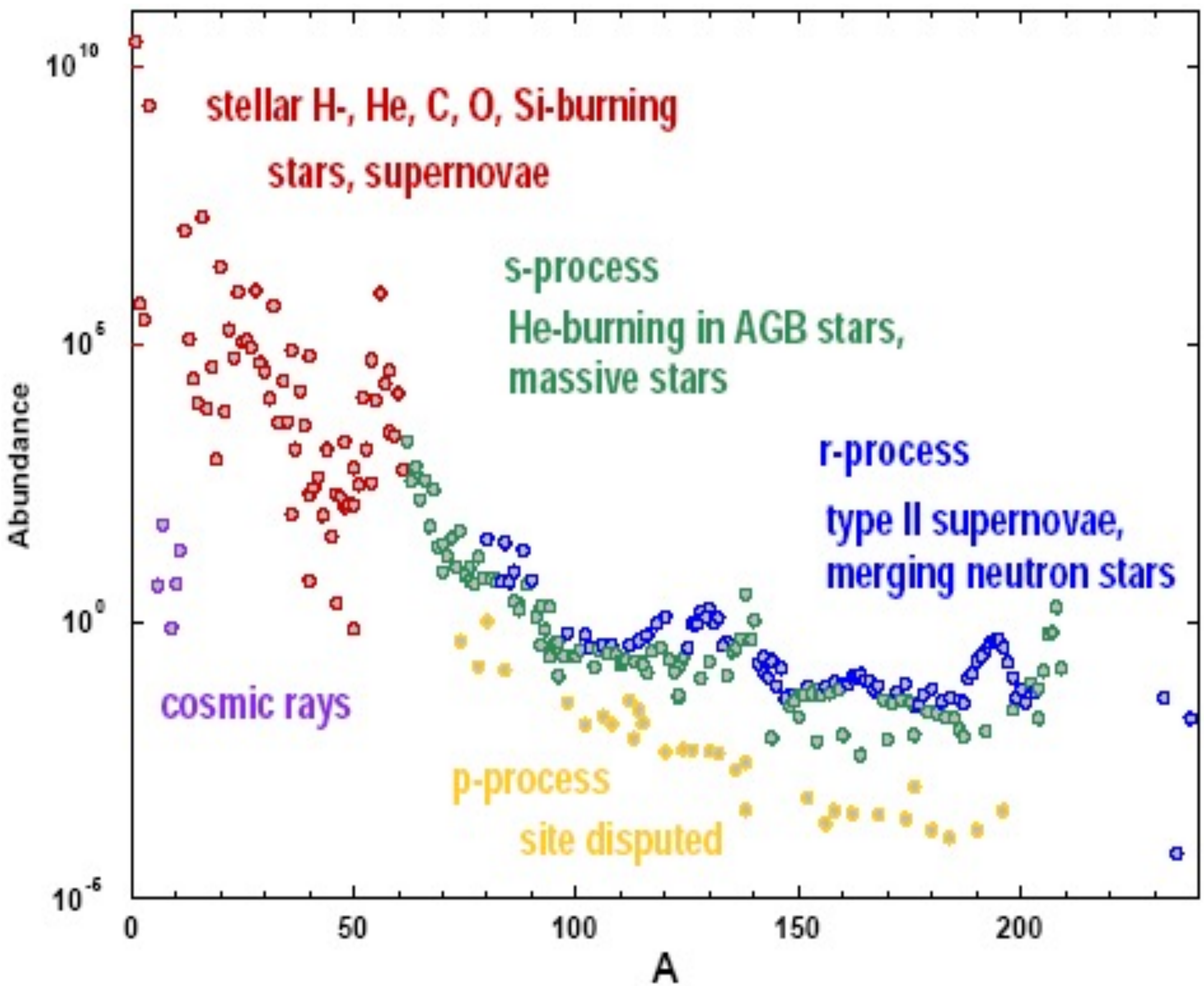


Star Forming Nebula

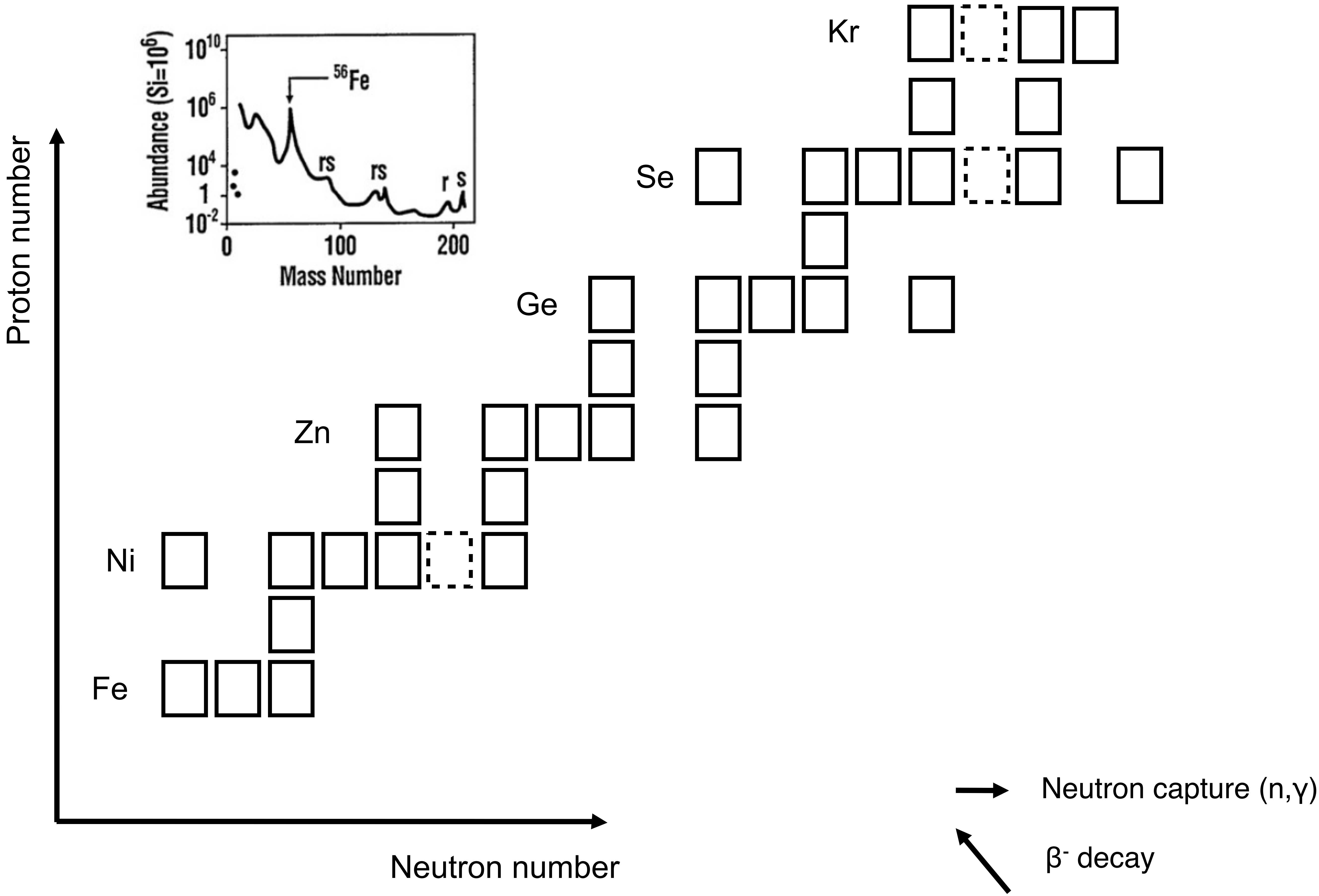
Supernova


Main Sequence Star
Red Supergiant
Supernova
Star Forming Nebula
Neu
ysics
Abundance [Si=10^6]
Mass number A
H
He
C
O
Ne
Mg
Si
Na
F
P
Ar
Ca
Ti
Fe
Ni
Zn
Ge
Se
Kr
Zr
Li
B
Sn
Te
Ba
Dy
Yb
Hf
Pt
Pb
Hg

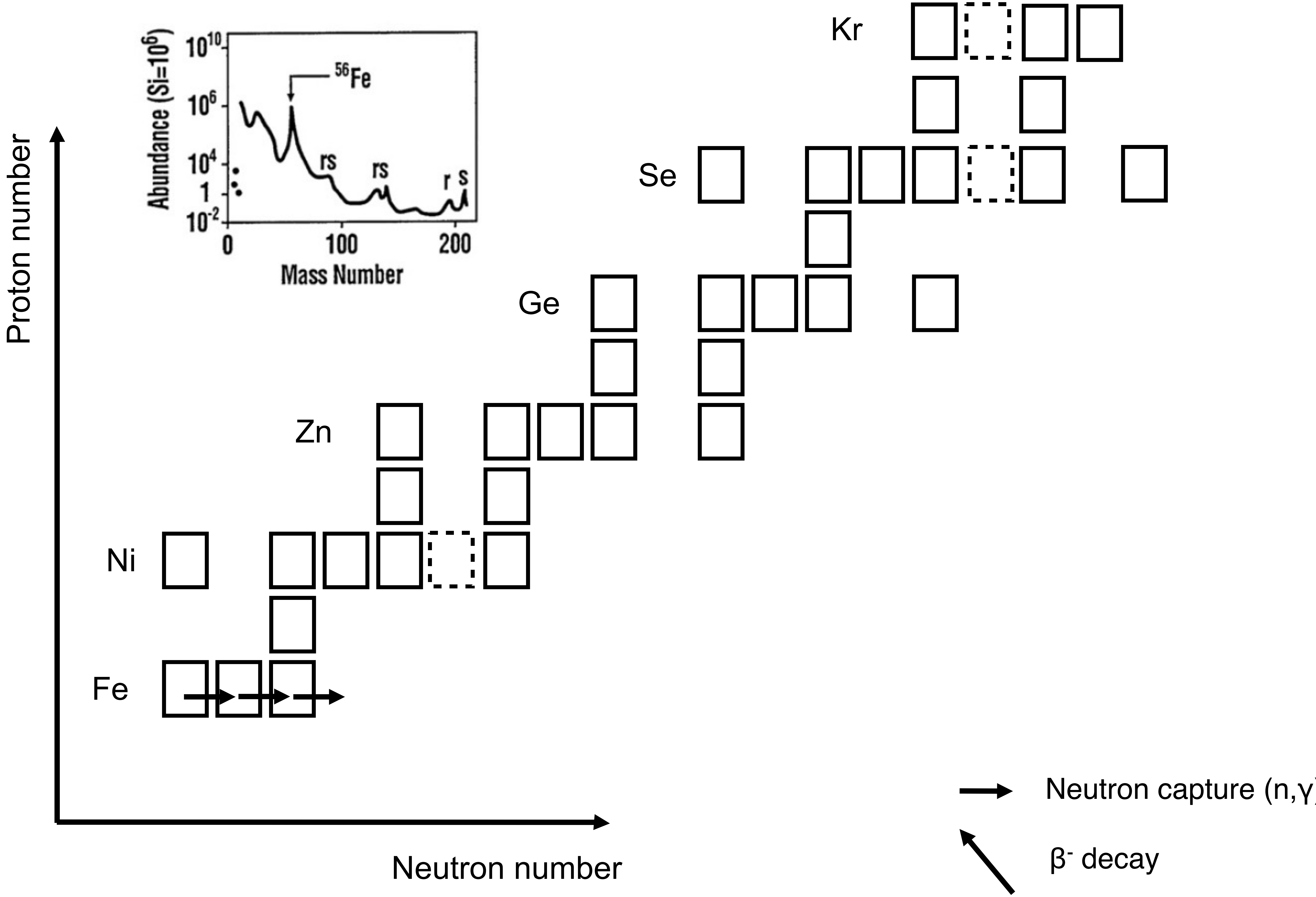
Solar system isotopic abundances



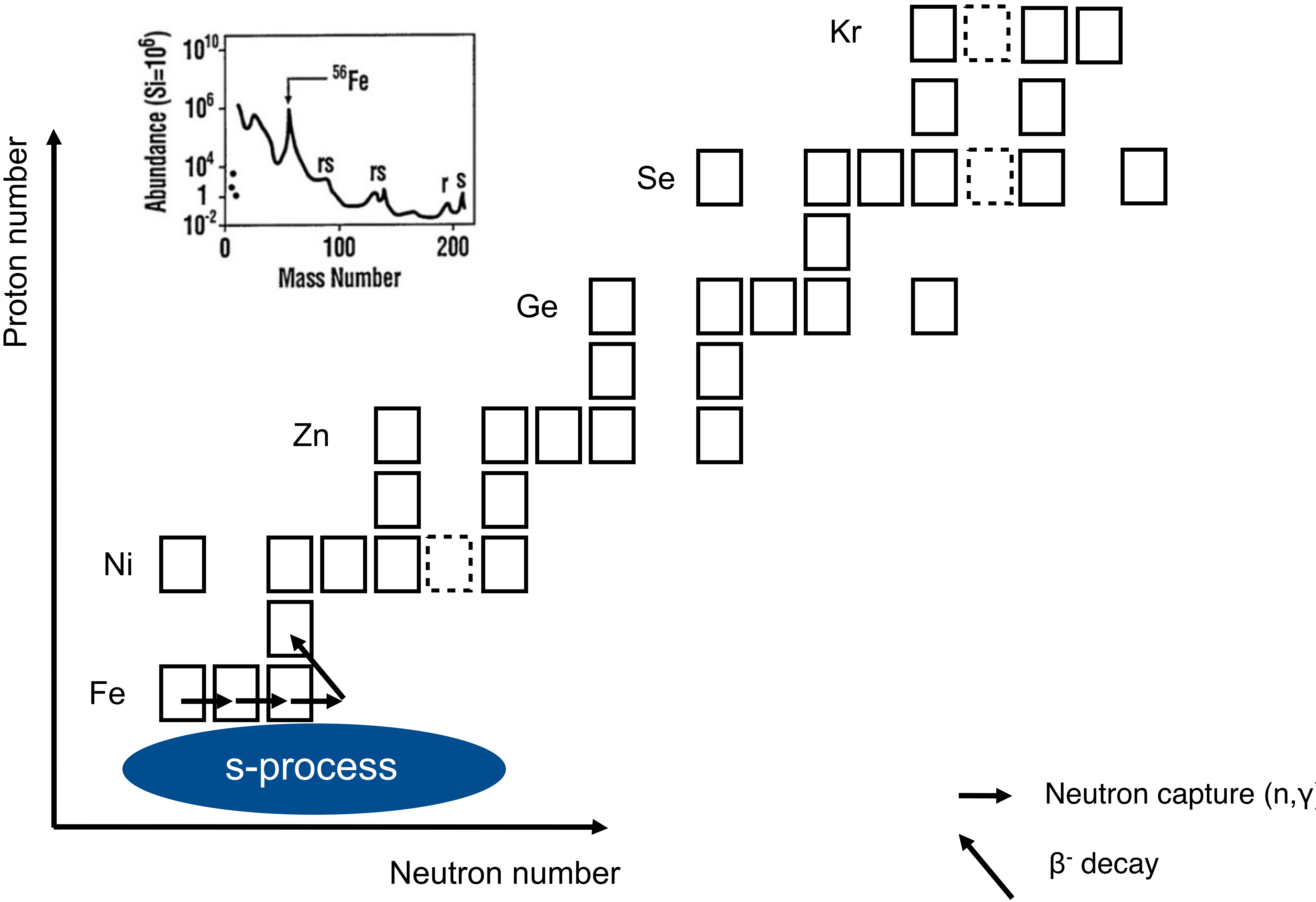
Nucleosynthesis of the heavy elements



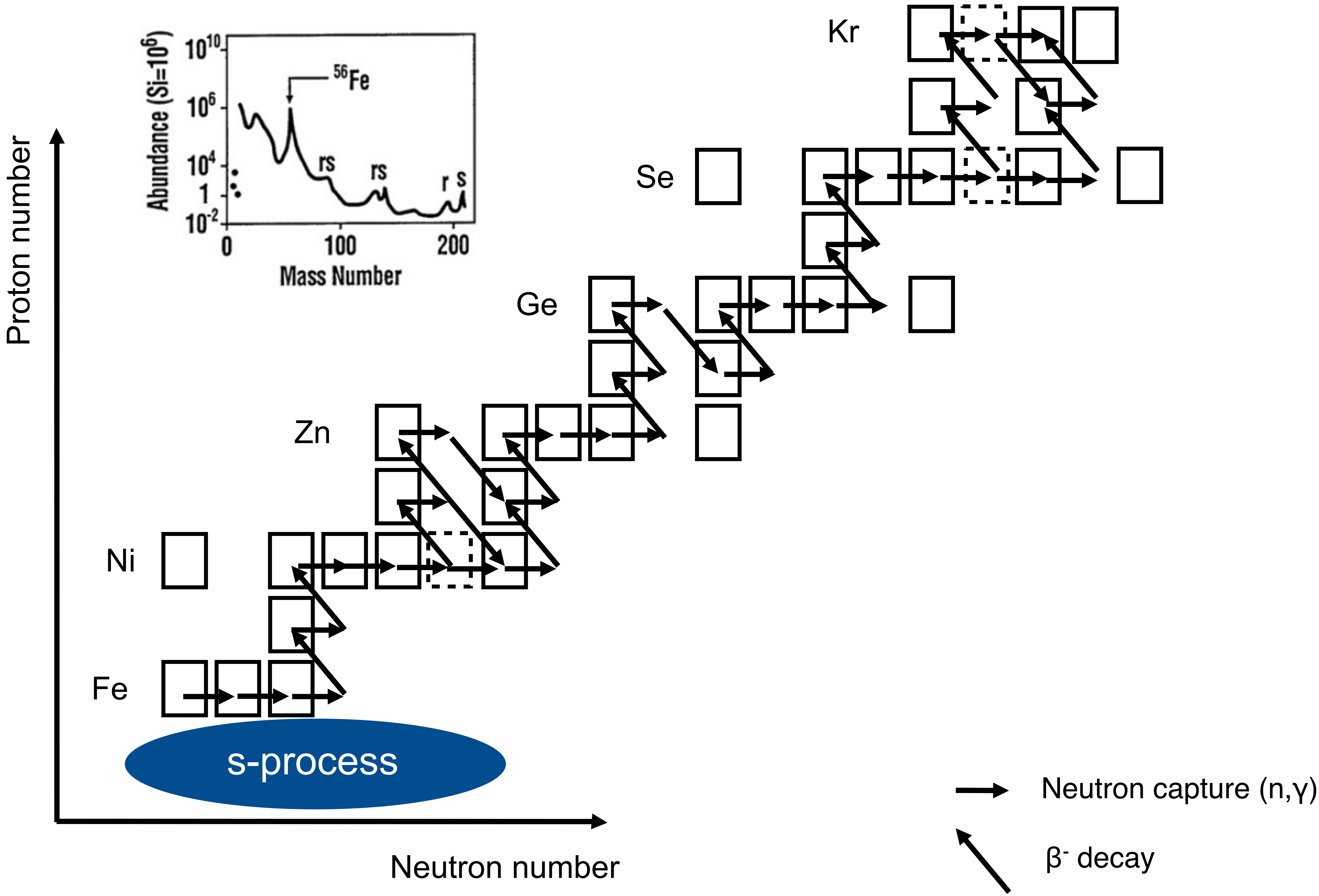
Nucleosynthesis of the heavy elements



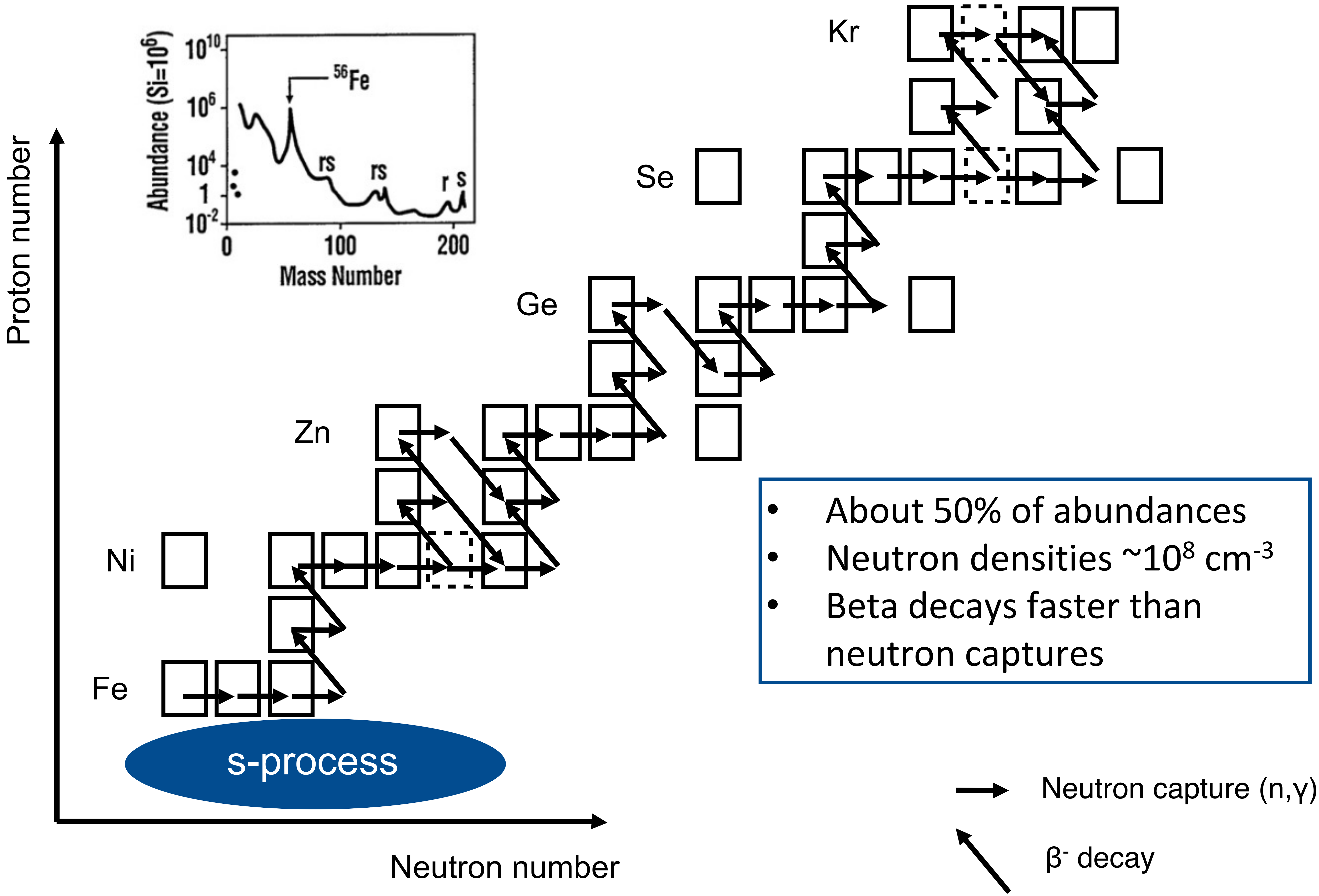
Slow neutron capture



Slow neutron capture



Slow neutron capture

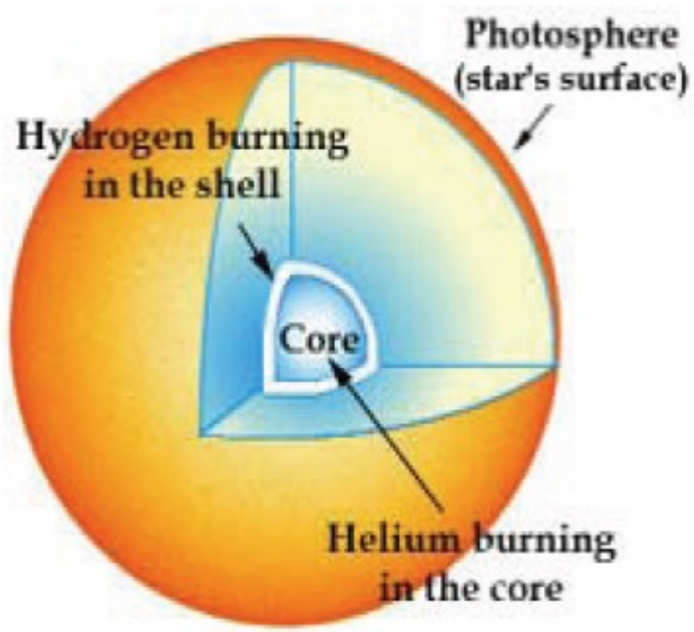


- About 50% of abundances
- Neutron densities ~10^8 cm^{-3}
- Beta decays faster than neutron captures

s-process sites

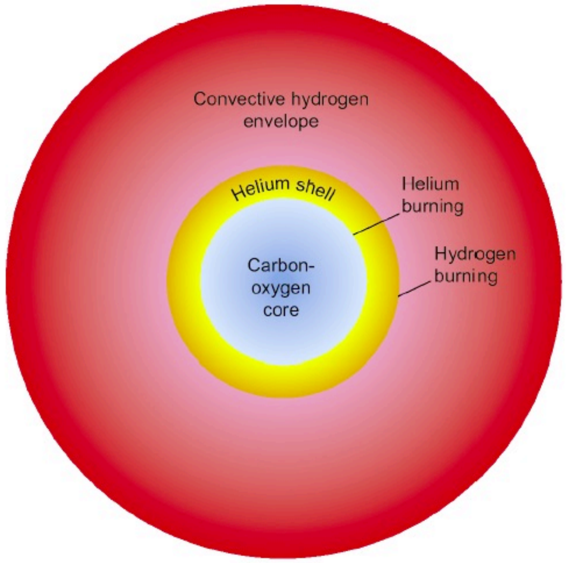
Massive Stars

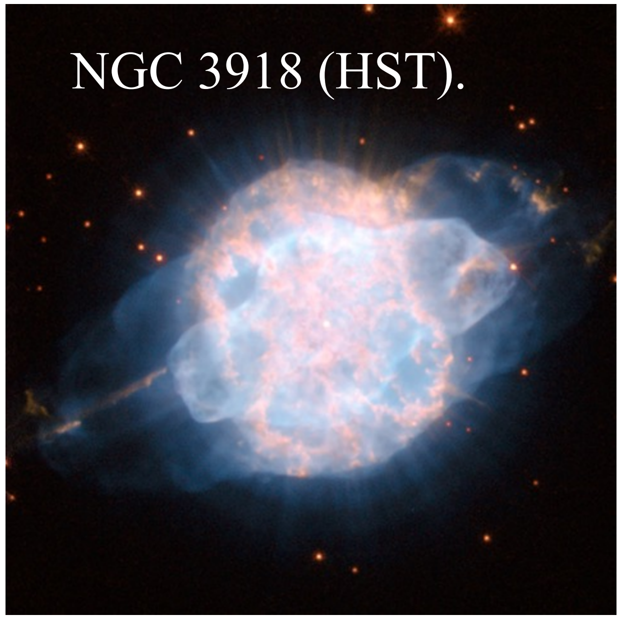
He core & C shell
Production of Fe to Zr



Low mass red giants

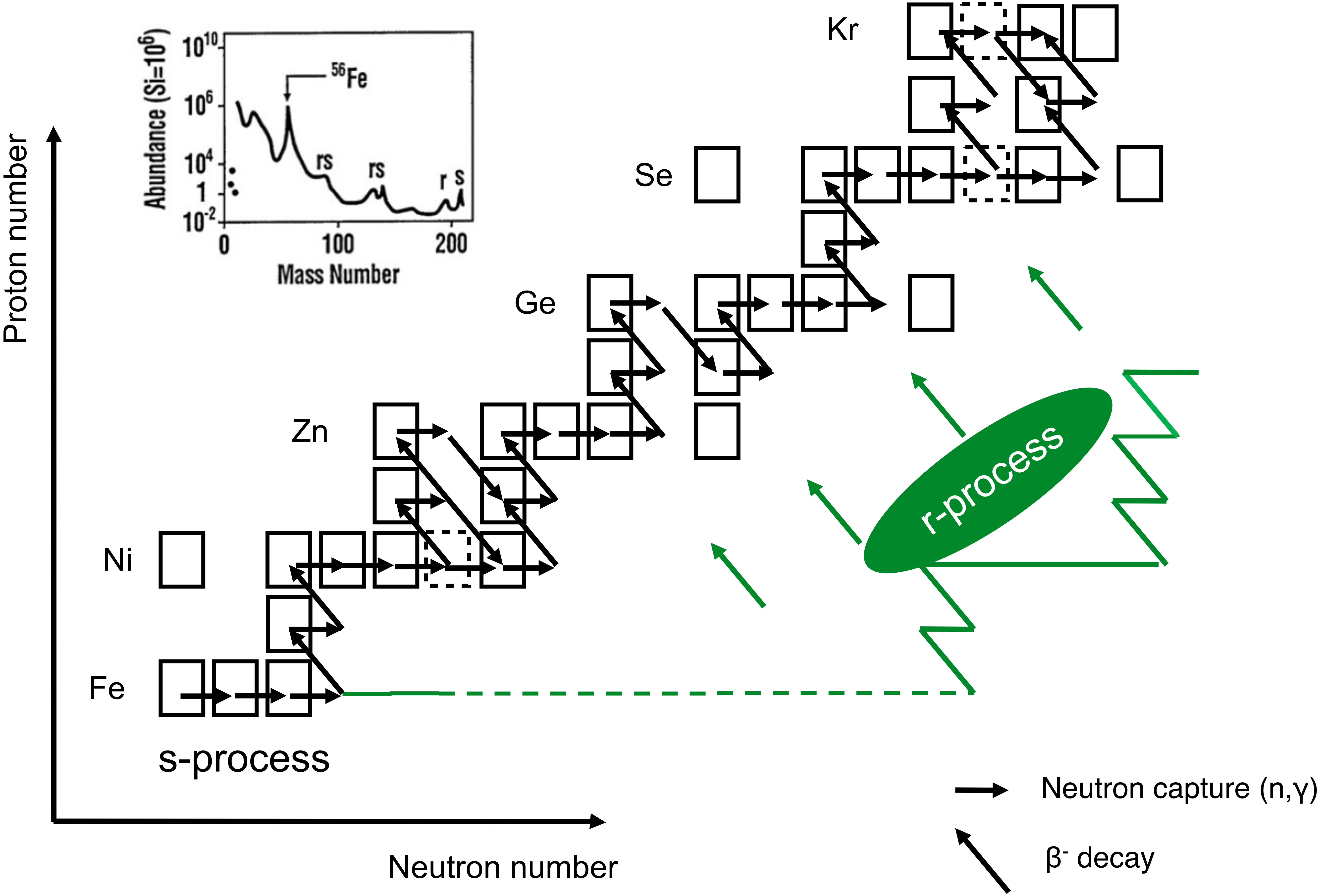
AGB phase (H shell / He shell)
Production of Zr to Pb



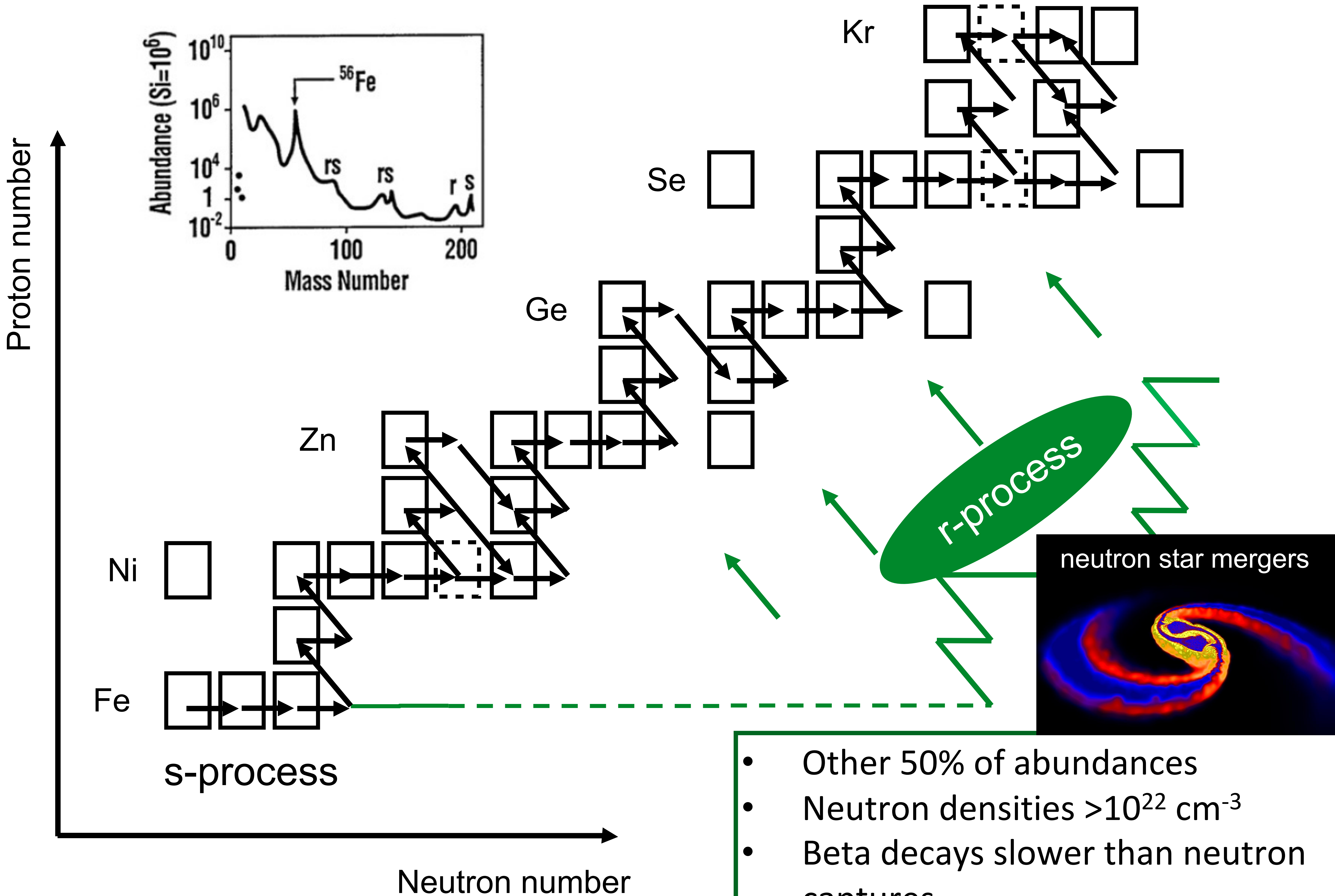


Key nuclear physics input: neutron capture cross sections

Rapid neutron capture



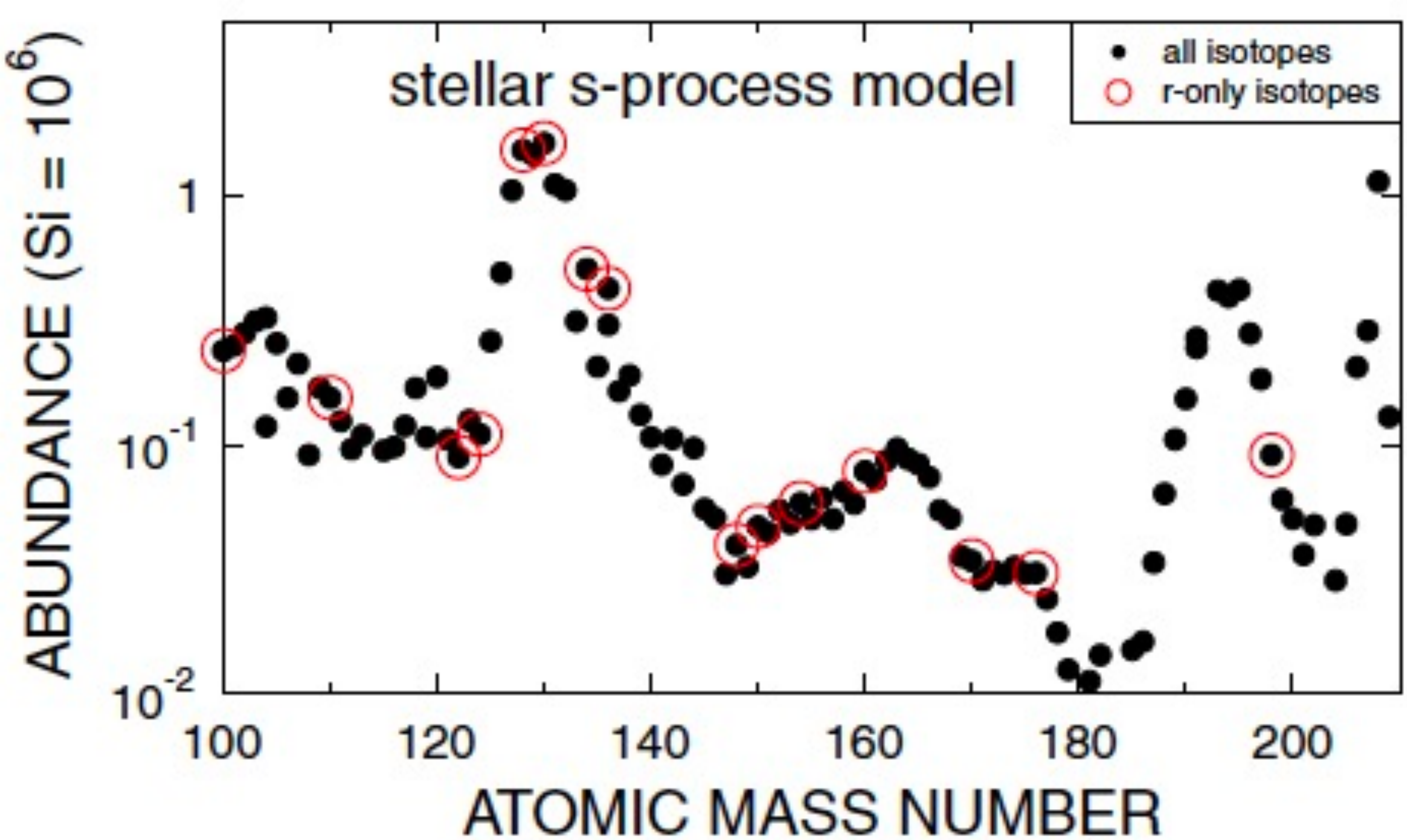
Rapid neutron capture



- Other 50% of abundances
- Neutron densities $>10^{22}$ cm^{-3}
- Beta decays slower than neutron captures

Information on neutron reactions allows to calculate the explosive contribution

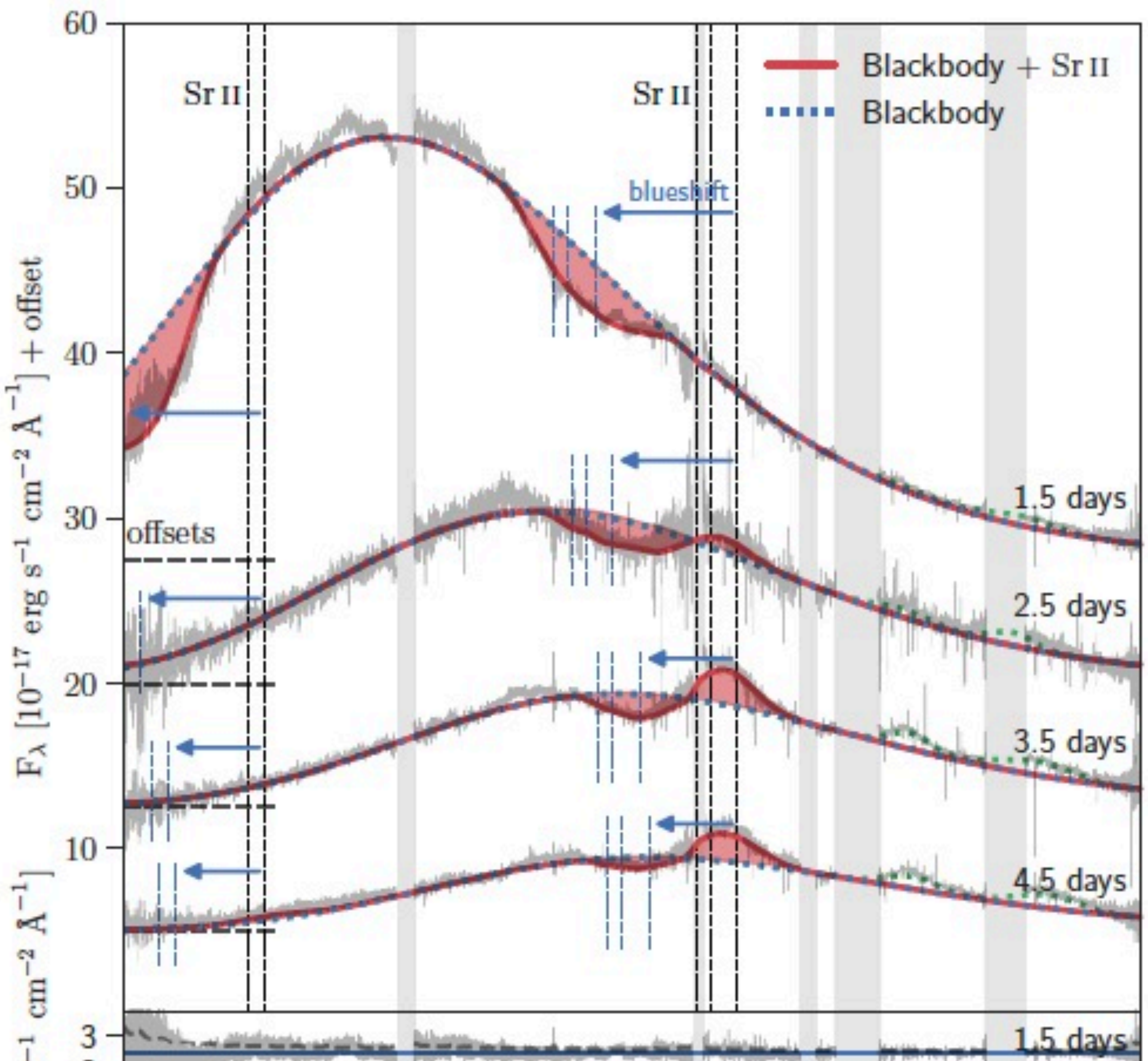
$$N_{RAPID}=N_{SUN}-N_{SLOW}$$



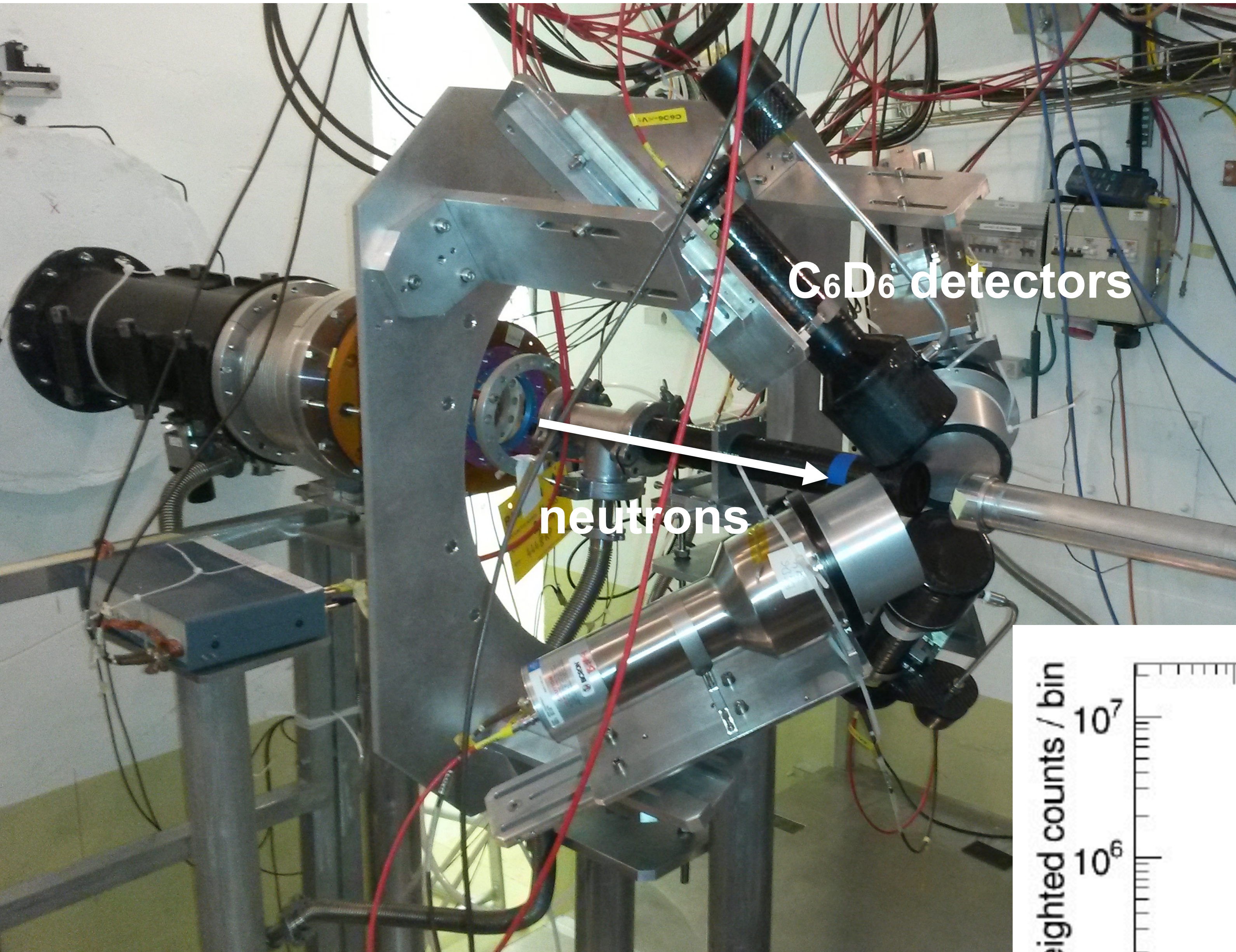
Identification of strontium in the merger of two neutron stars

Darach Watson[1,2], Camilla J. Hansen[3,*], Jonatan Selsing[1,2,*], Andreas Koch[4], Daniele B. Malesani[1,2,5], Anja C. Andersen[1], Johan P. U. Fynbo[1,2], Almudena Arcones[6,7], Andreas Bauswein[7,8], Stefano Covino[9], Aniello Grado[10], Kasper E. Heintz[1,2,11], Leslie Hunt[12], Chryssa Kouveliotou[13,14] Giorgos Leloudas[1,5], Andrew Levan[15,16], Paolo Mazzali[17,18], Elena Pian[19] [See end for affiliations]

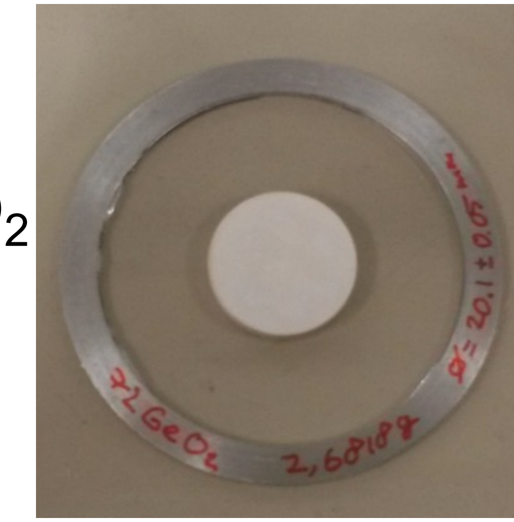
Nature 2019

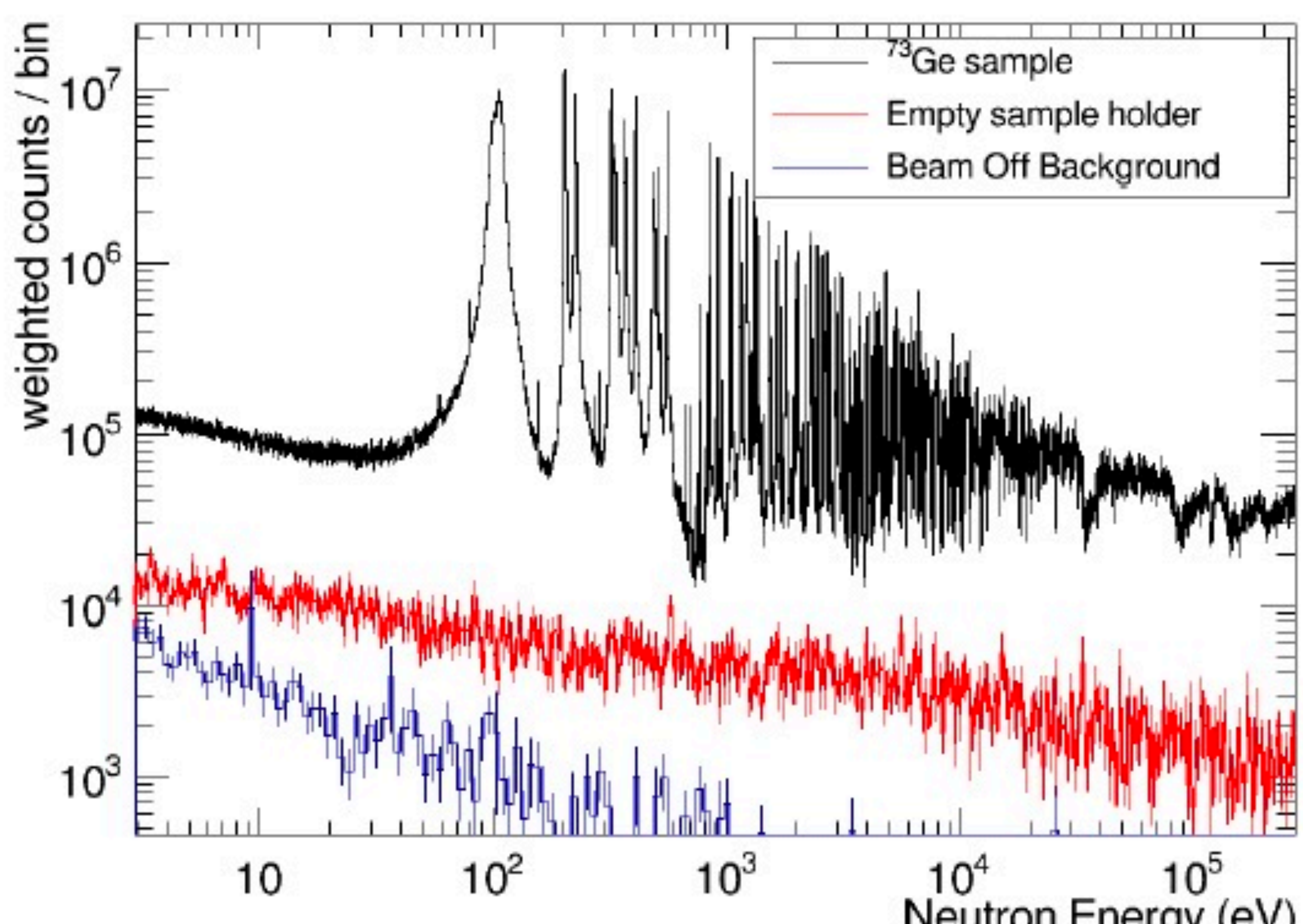


Neutron Capture Measurements at n_TOF/EAR-1: ^{73}Ge



Isotopically enriched GeO_2 sample

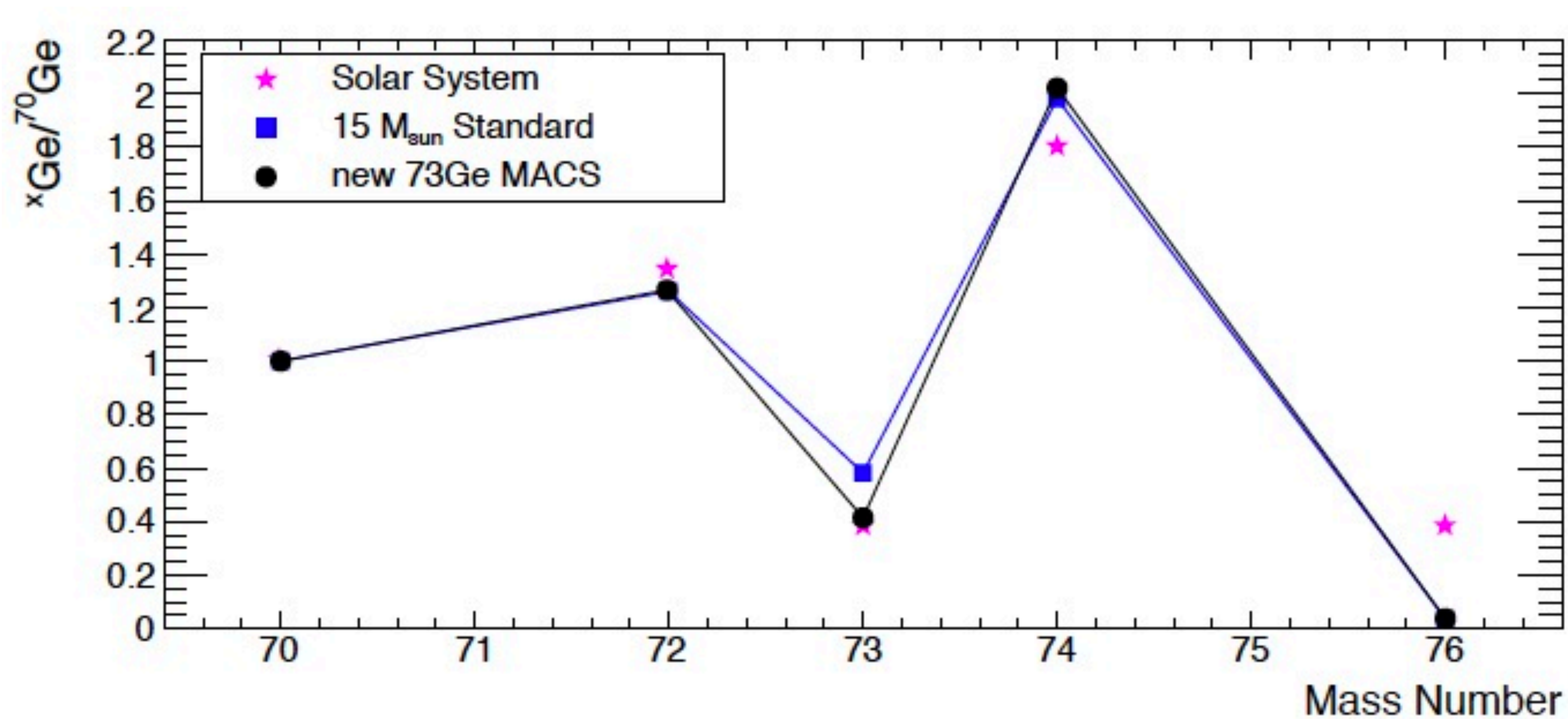




nTOF

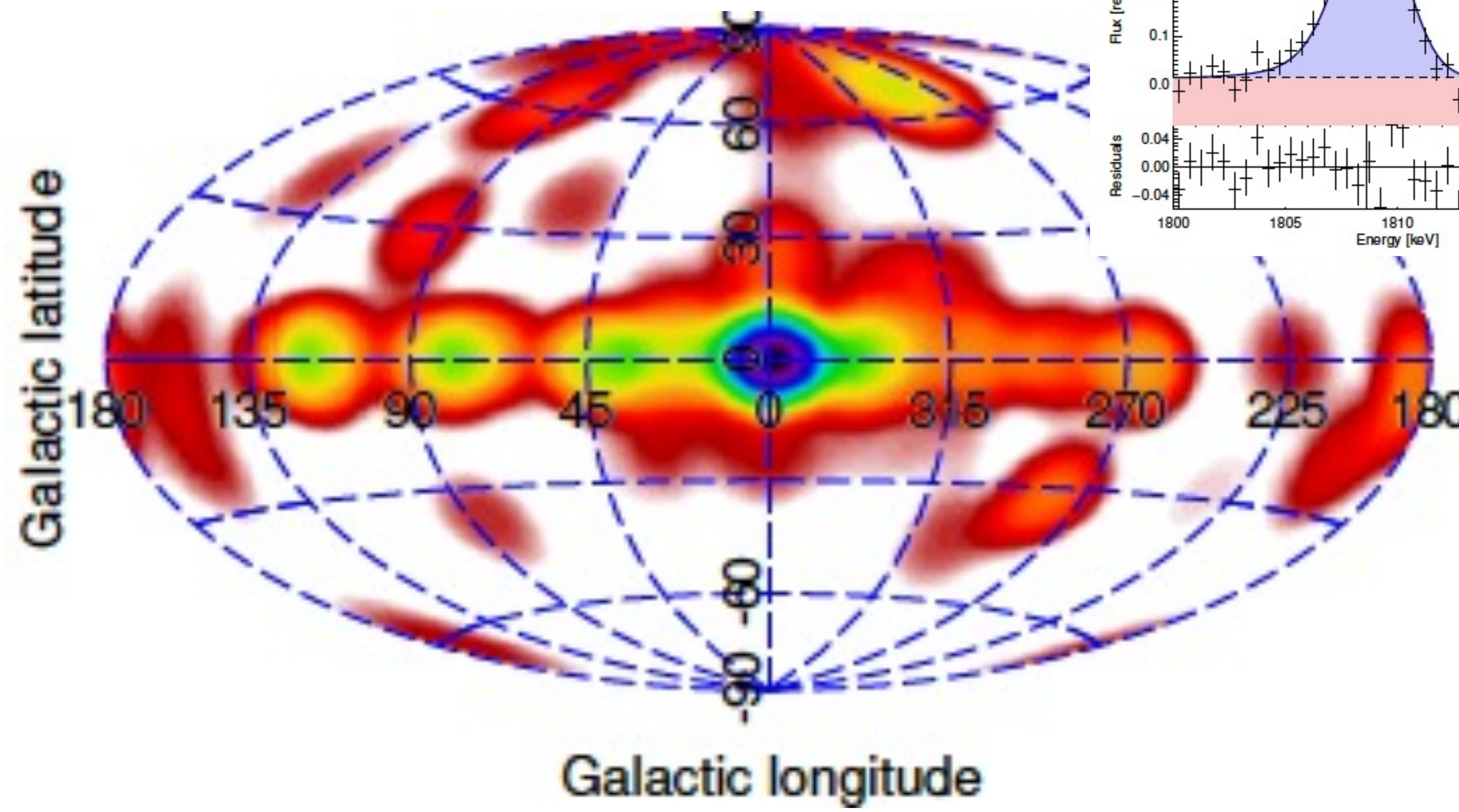
Adolf Messer Stiftung

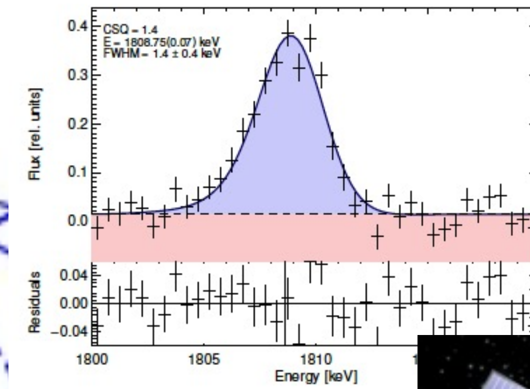
New ^{73}Ge(n,γ) cross section decreases ^{73}Ge production in massive stars, more consistent with solar system abundances (~80% of germanium comes from s process in massive stars)



Physics Letters B 790 (2019) 458–465

Cosmic γ-ray emitter ^{26}Al



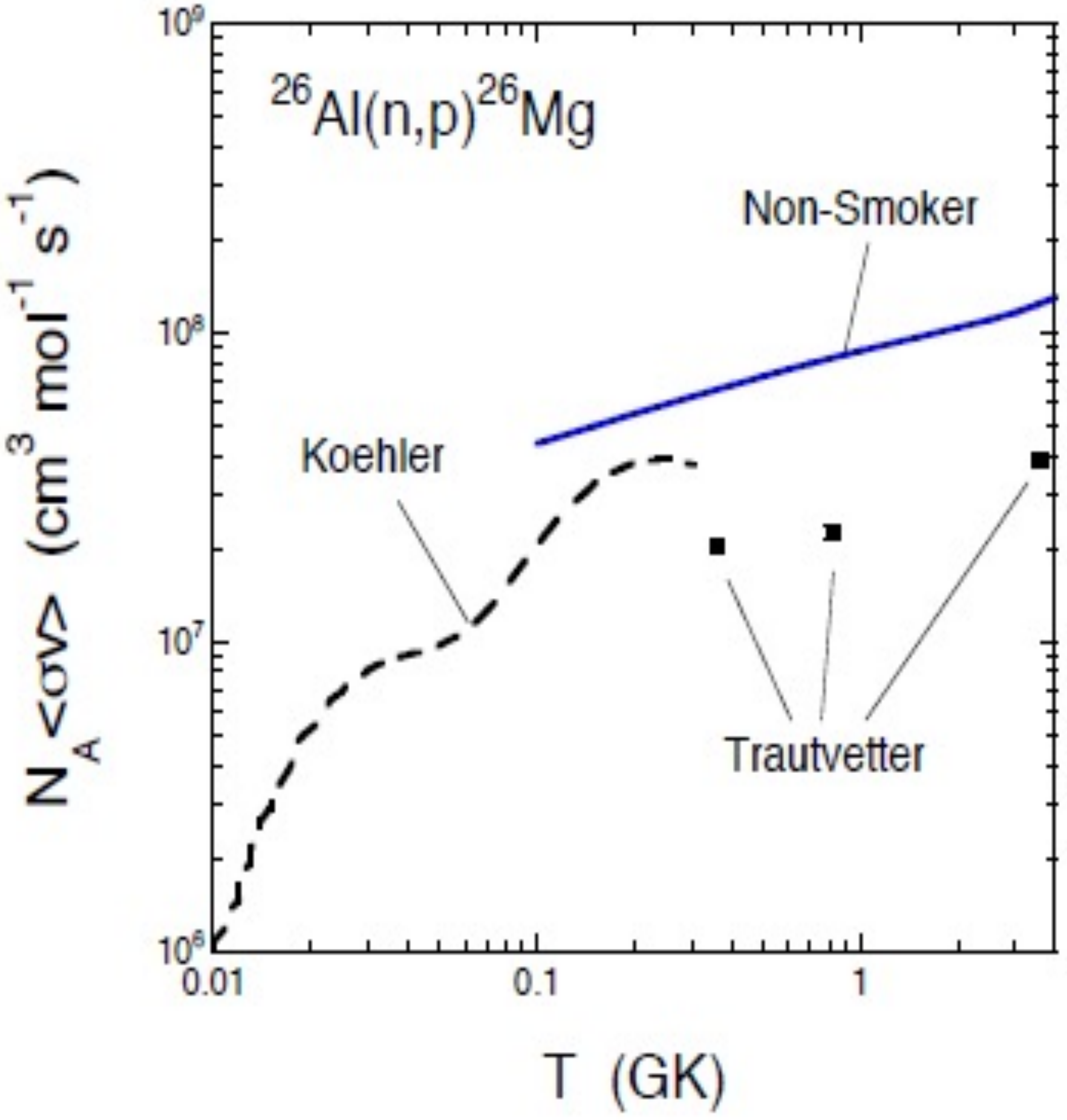


Main Origin of ^{26}Al in massive stars (Diehl et al, Nature 439 (2006))

Key uncertainties for theoretical predictions of abundances: **^{26}Al(n,p)** and **^{26}Al(n,α)** reaction rates [Iliadis et al., Astrophys. J. Supp. 193, 16 (2011)]

Also produced in **AGB stars**, which may have polluted early solar system with ^{26}Al

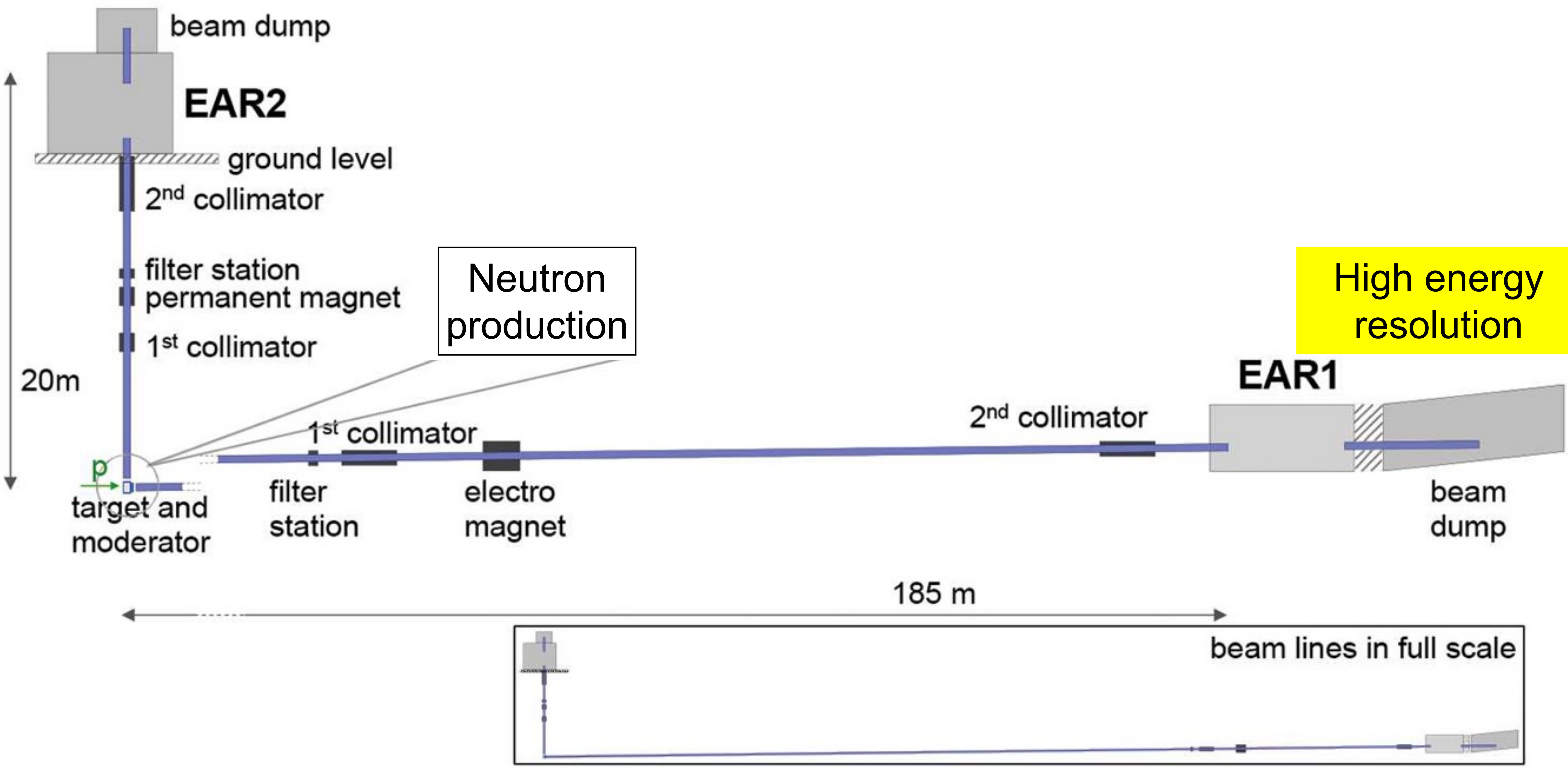
^{26}Al +n reactivities from previous measurements



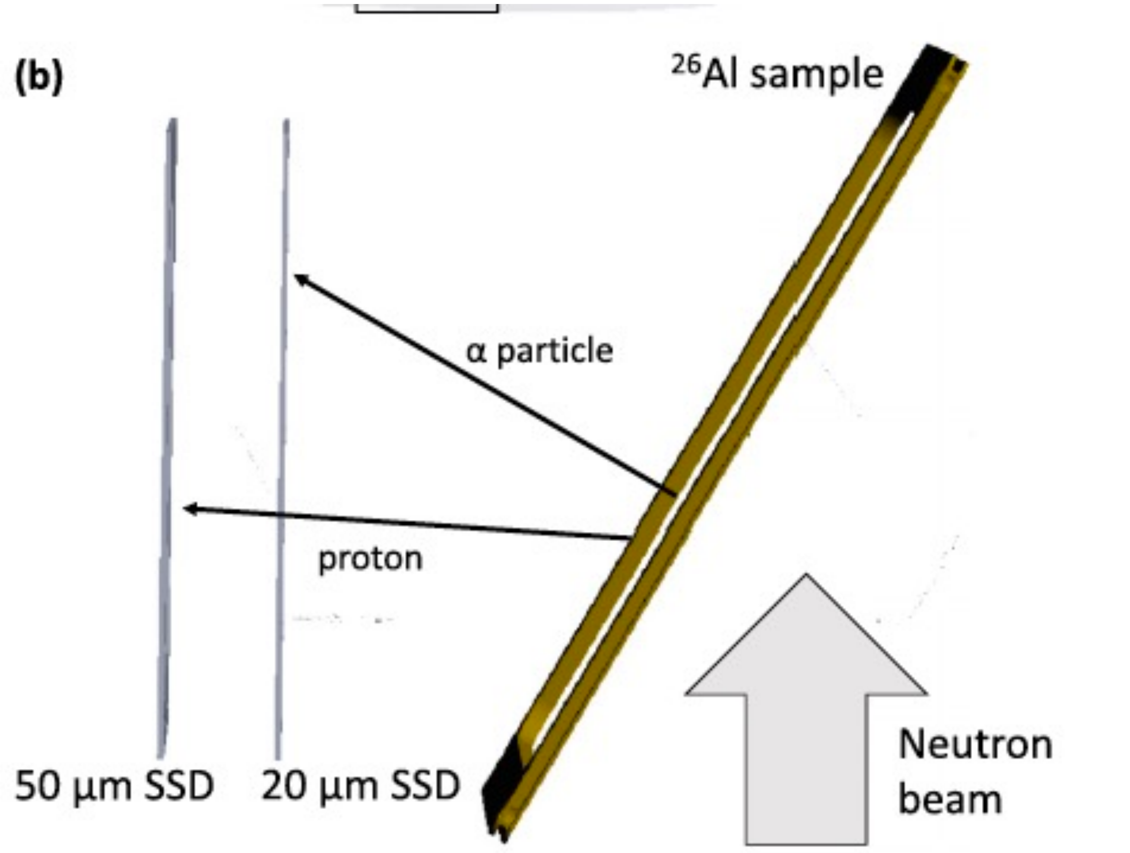
C Iliadis et al., Ast. J. Supp. 193, 16 (2011)

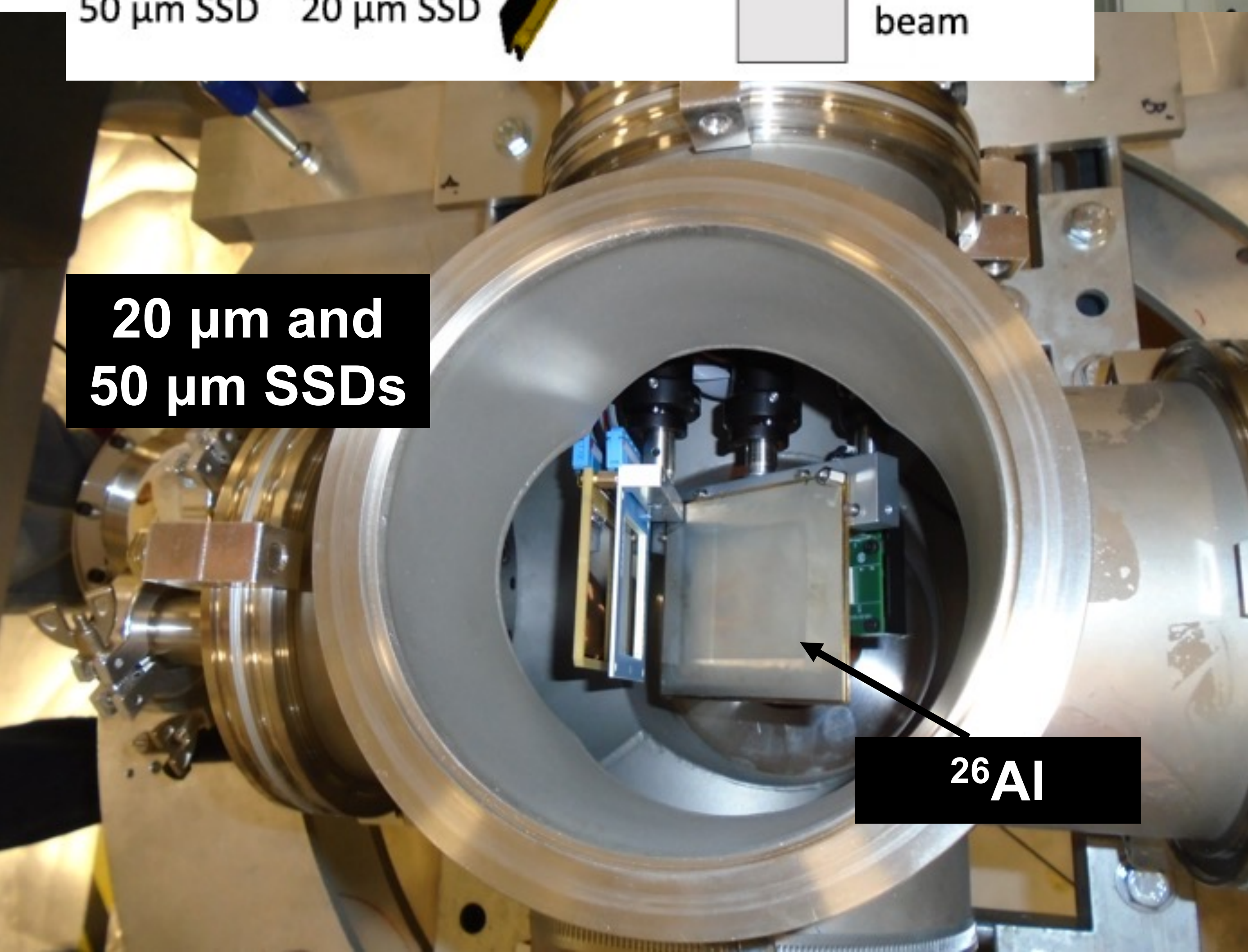
n_TOF EAR-2

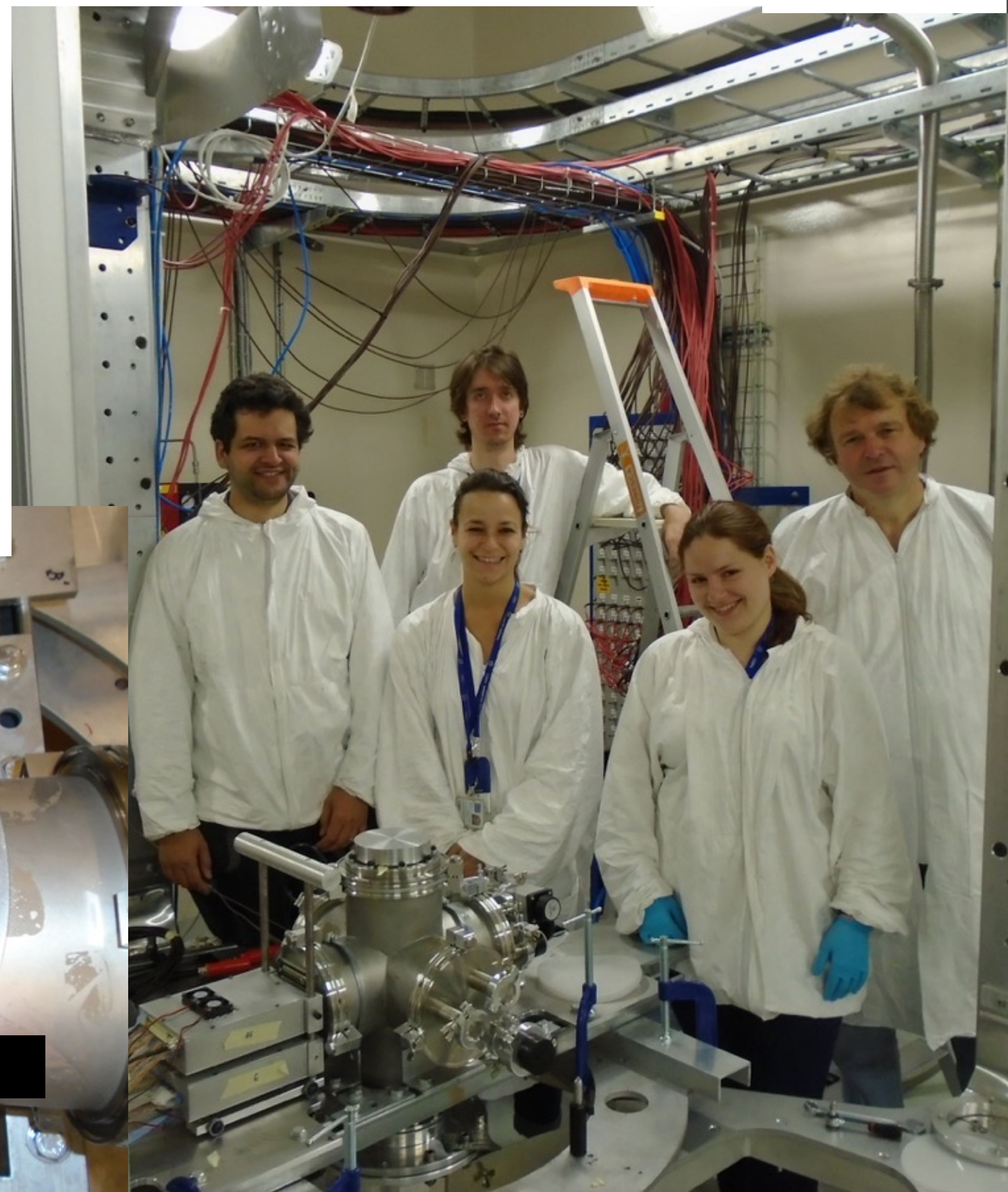
High neutron flux



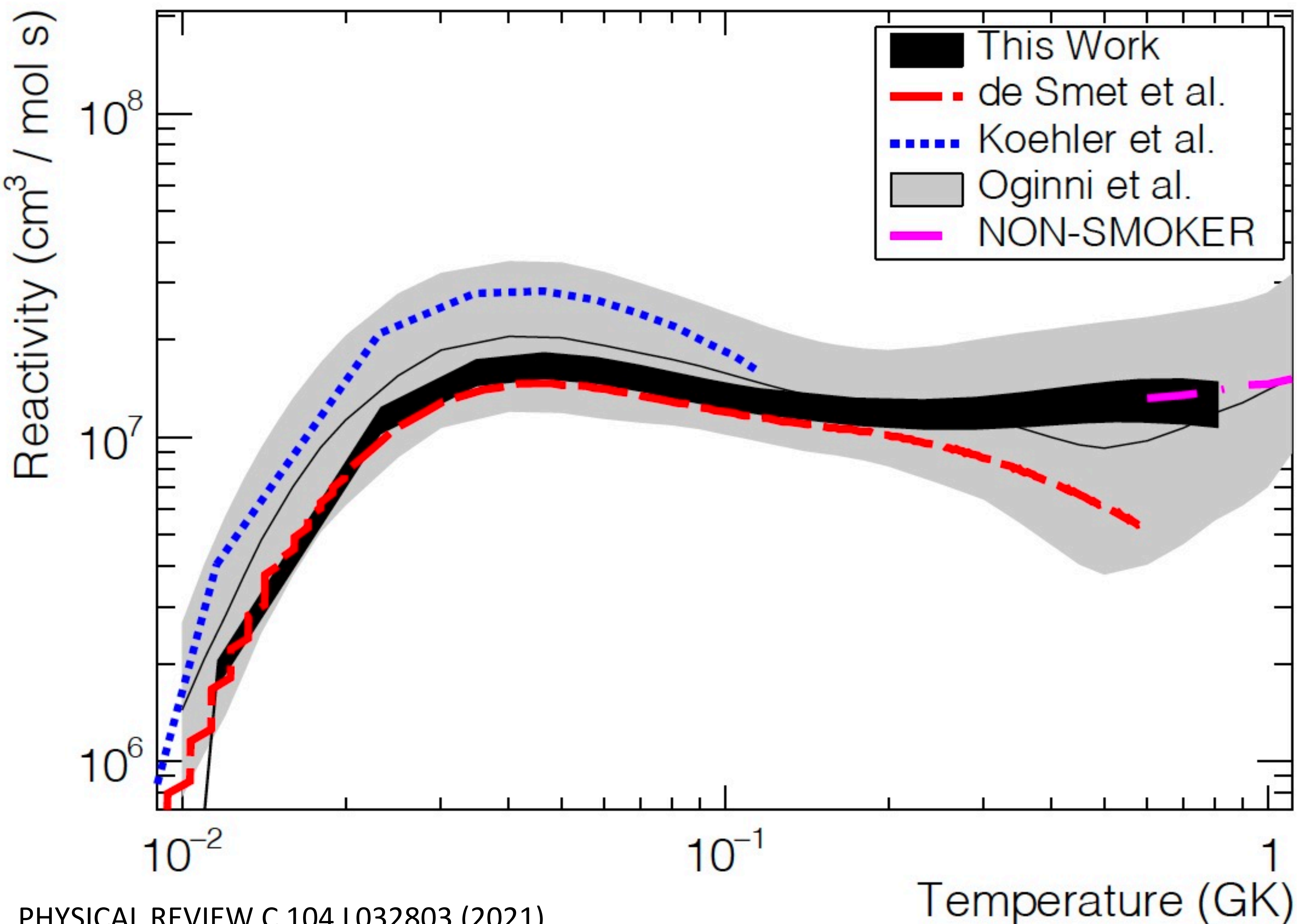
^{26}Al(n,α/p) at n_TOF EAR-2: New Silicon detection setup





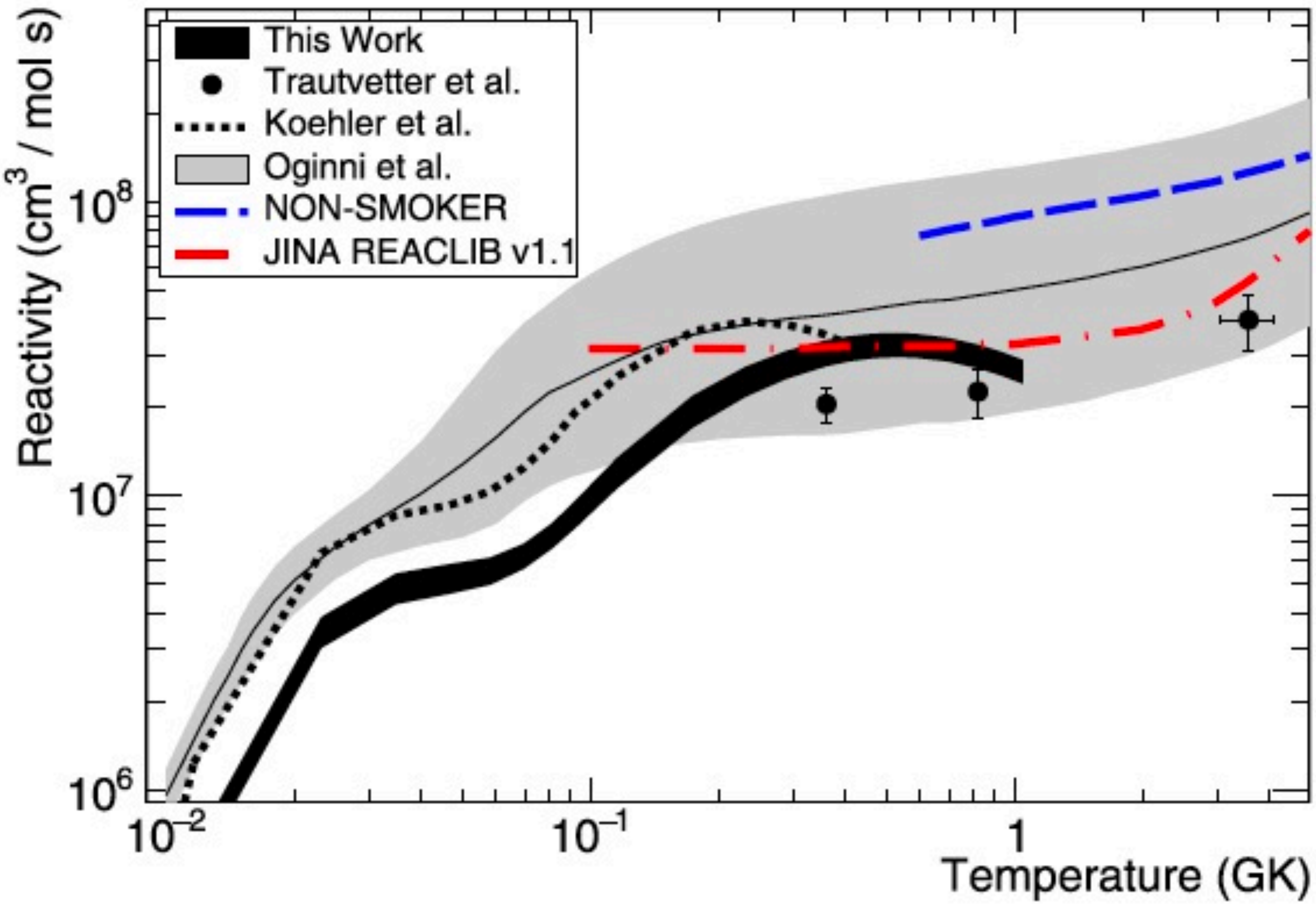


$^{26}Al(n,\alpha)$ stellar reactivities (n_TOF & GELINA)



PHYSICAL REVIEW C 104 L032803 (2021)

n_TOF ^{26}Al(n,p) stellar reactivities



PHYSICAL REVIEW C 104, L022803 (2021)

Summary and Outlook

- Neutron capture cross sections on heavy isotopes required with high accuracy to study heavy element synthesis
- Target uncertainty ~5% in stellar cross section – many successful measurements performed at n_TOF → but still more work to do (for example new data on Se isotopes and ^{68}Zn on the way!)
- Measurements on radioactive targets need high fluxes due to low quantities of sample material → high flux beam line EAR-2 well suited
- Neutron destruction of ^{26}Al successfully measured at n_TOF EAR-2 → next step is to extend neutron energy range to cover full range of interest for massive stars


The End