TRIUMF

CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada

Scientific Justification for an Electron Linear Accelerator at ISAC Part I: Nuclear Astrophysics

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TRIUMF & Simon Fraser University

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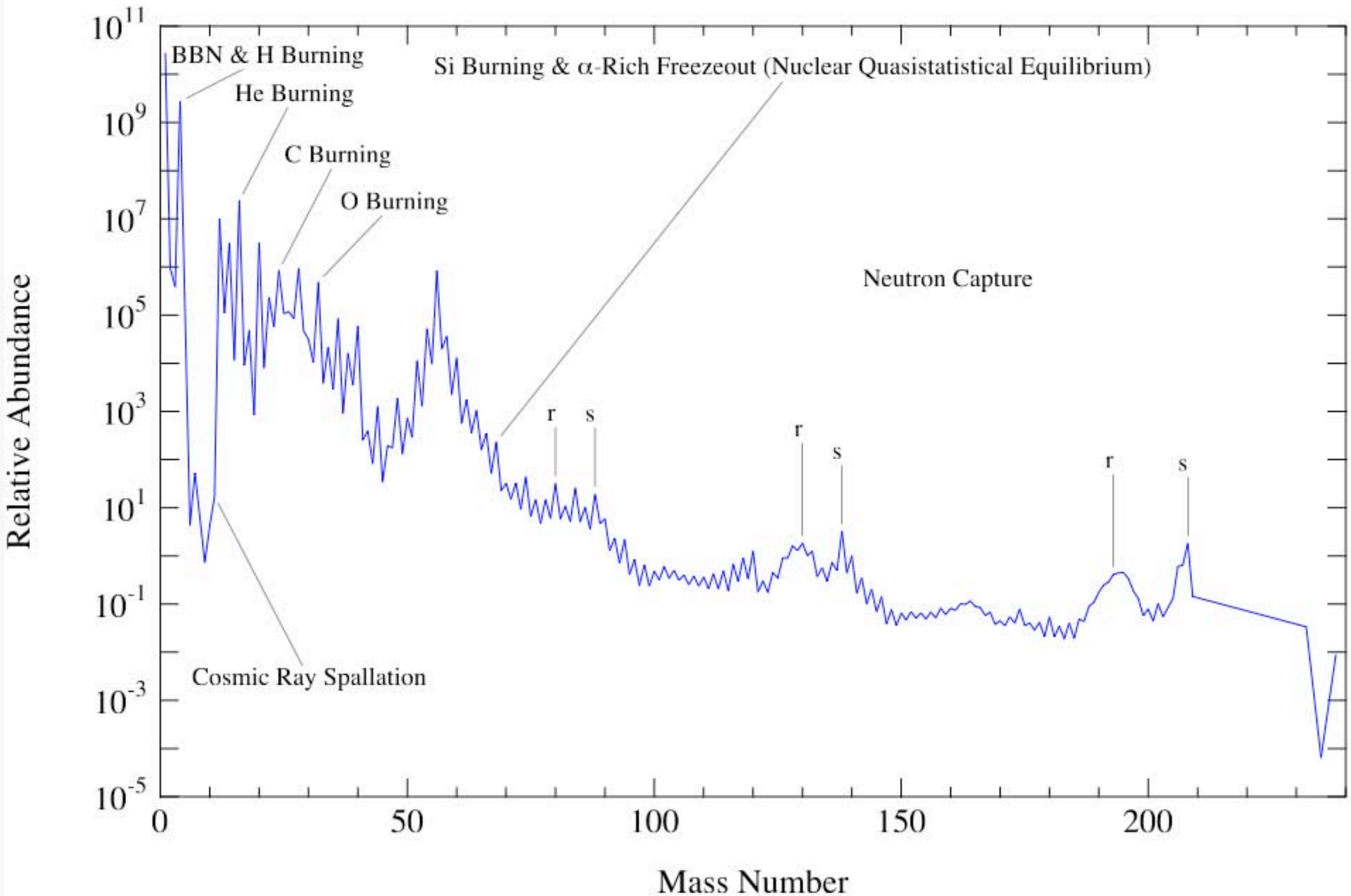
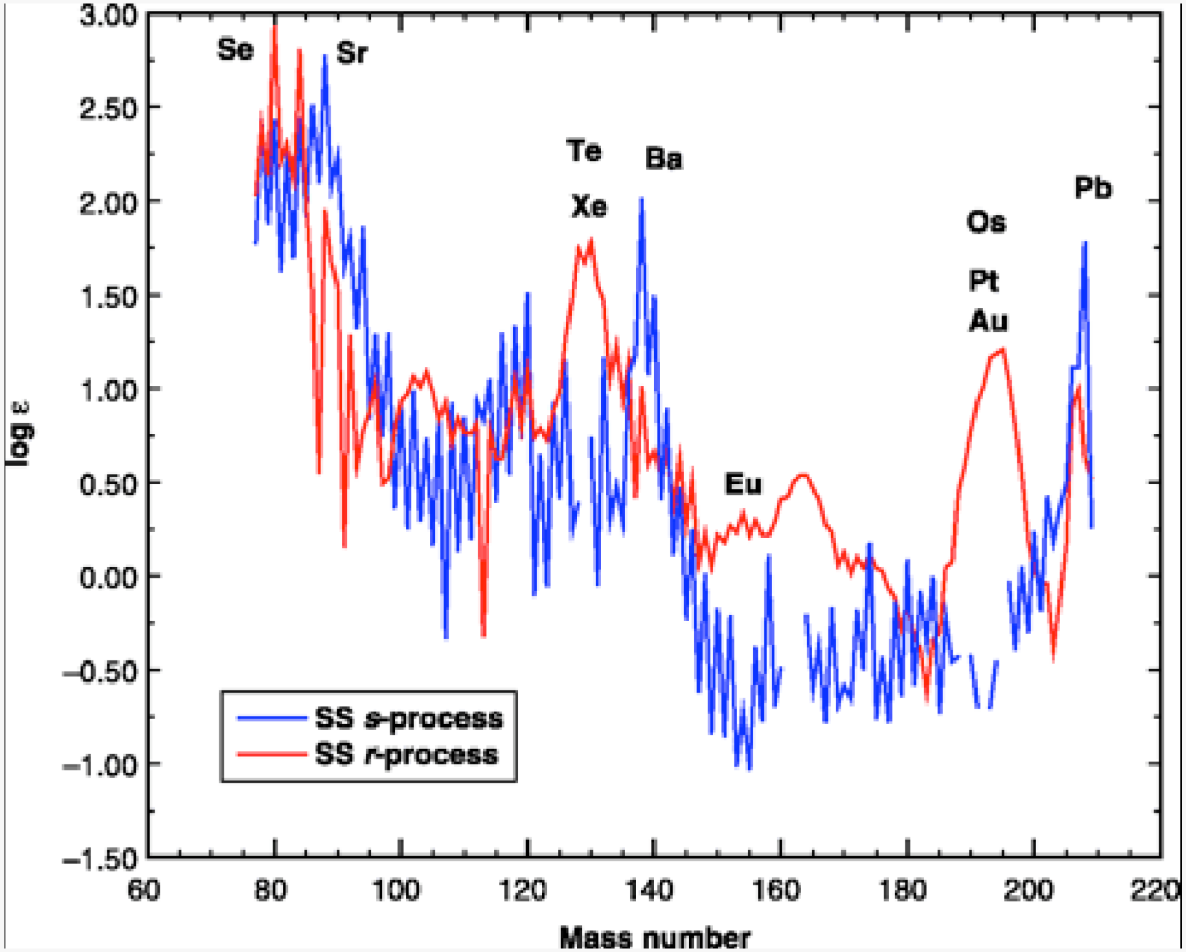
LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

Abundances and Origins of the Chemical Elements



Heavy Element Abundances



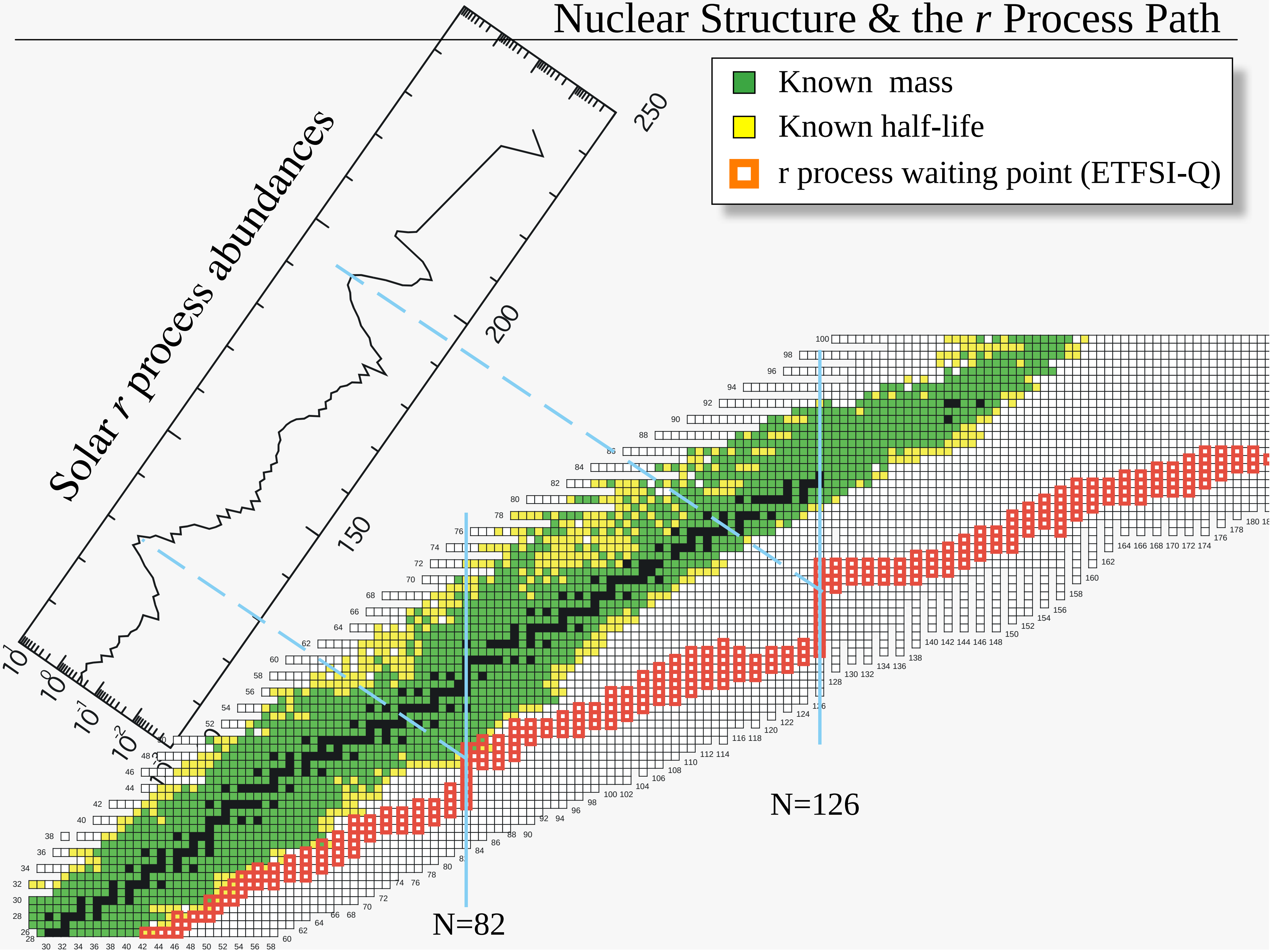
~1/2 of chemical elements w/ A > 70 produced in
r process: neutron captures on very rapid timescale (~1 s)
in a hot (GK), dense environment (>10^{20} neutrons cm^{-3})

The *r* Process Site?

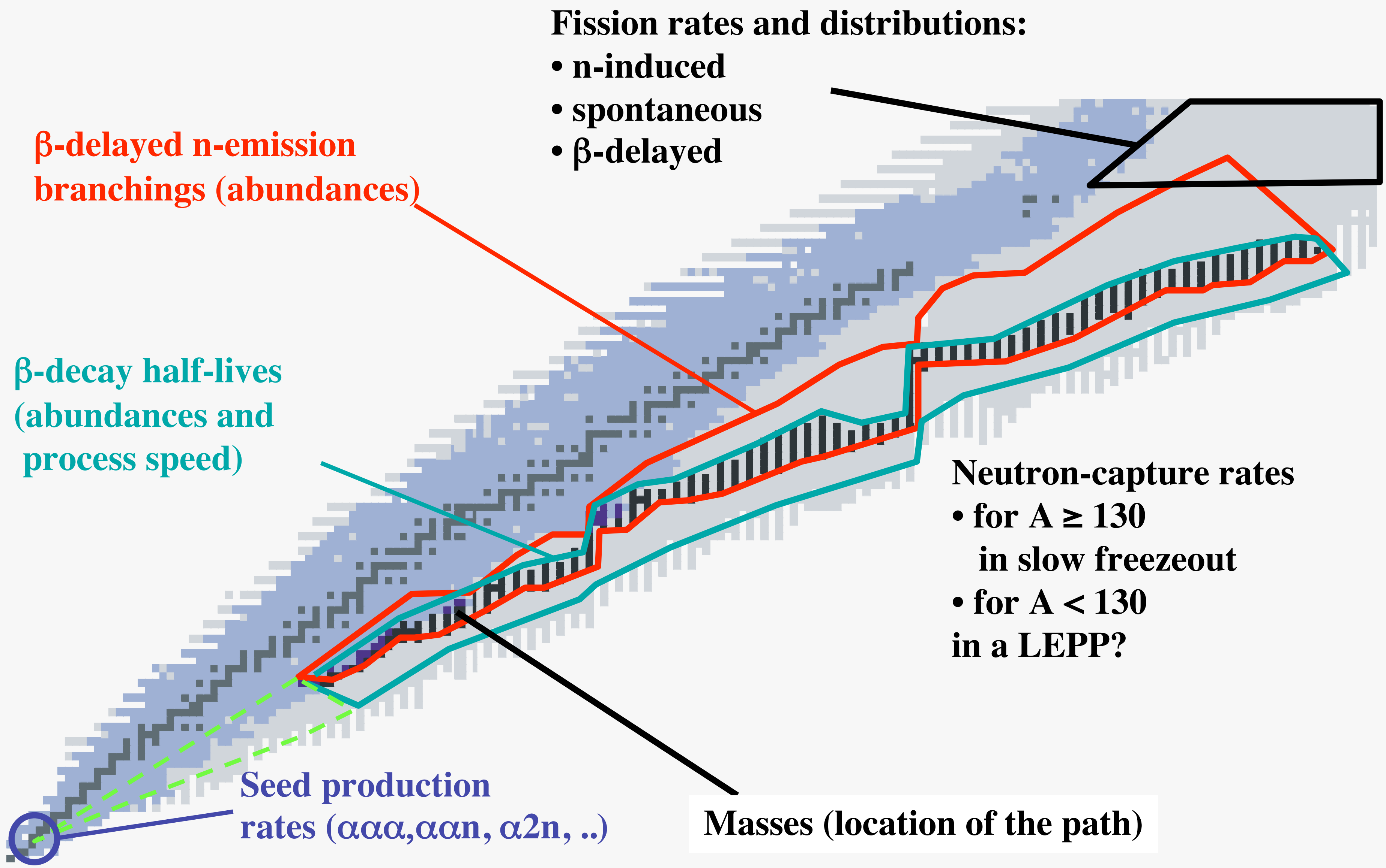
Core-collapse supernovae favoured astrophysical site; explosion liberates synthesized elements, distributes throughout interstellar medium;

Abundances of *r* process elements in old stars show consistent pattern for $Z > 47$, but variations in elements with $Z \leq 47$, implying ≥ 2 sites
Montes *et al*. 2007

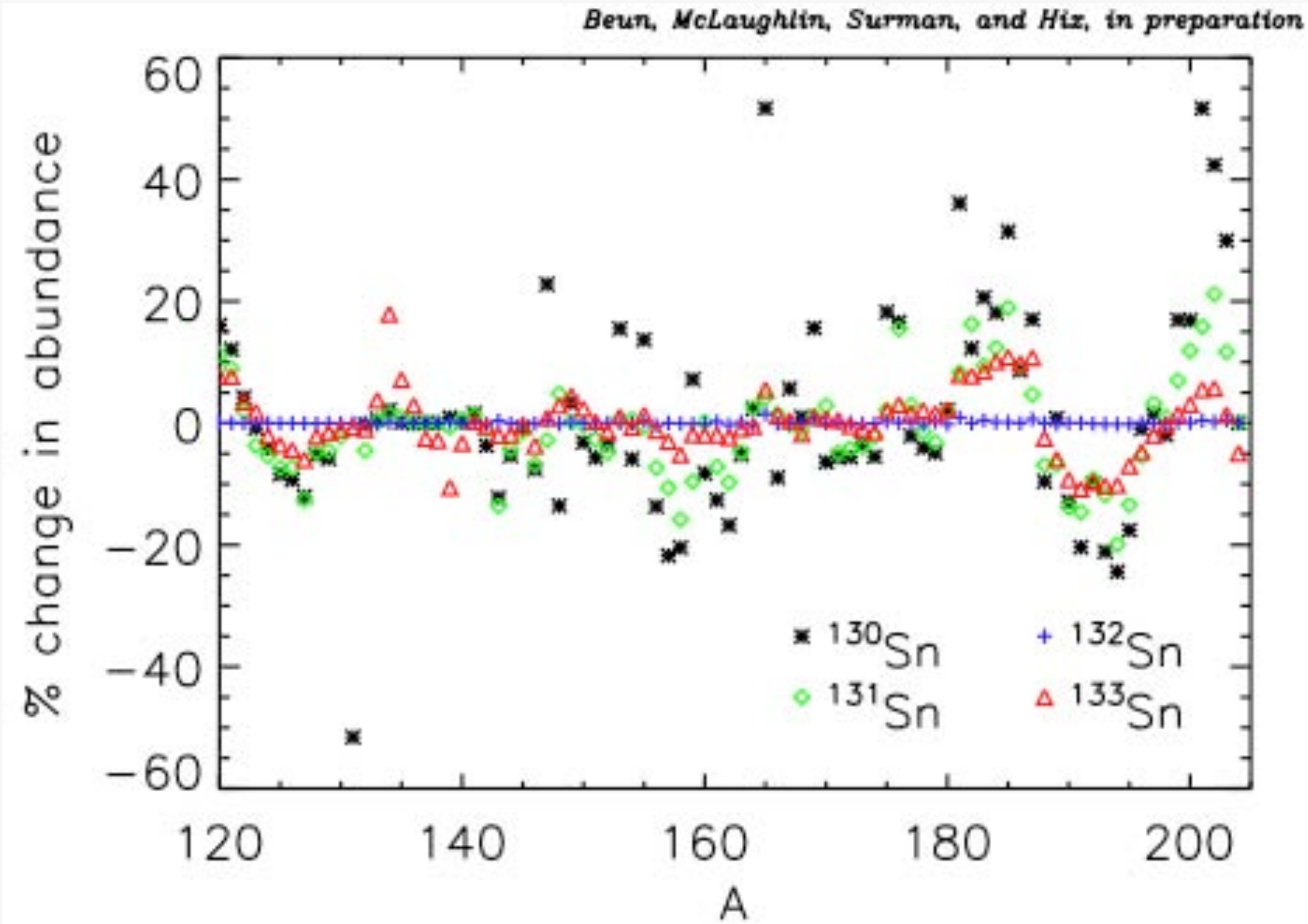
Nuclear Structure & the *r* Process Path



Nuclear Physics of the *r* Process

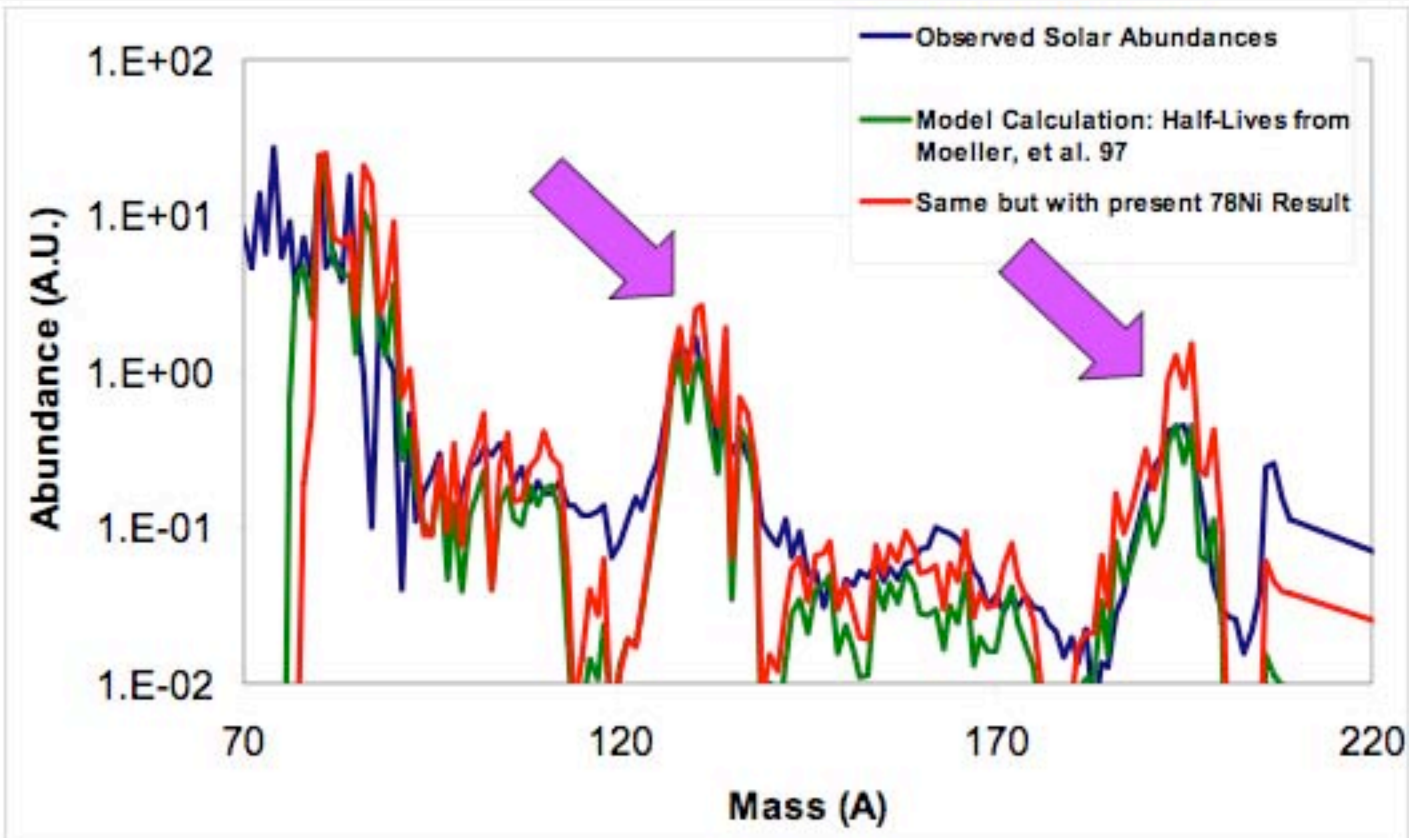


Neutron Capture Rates May "Matter"



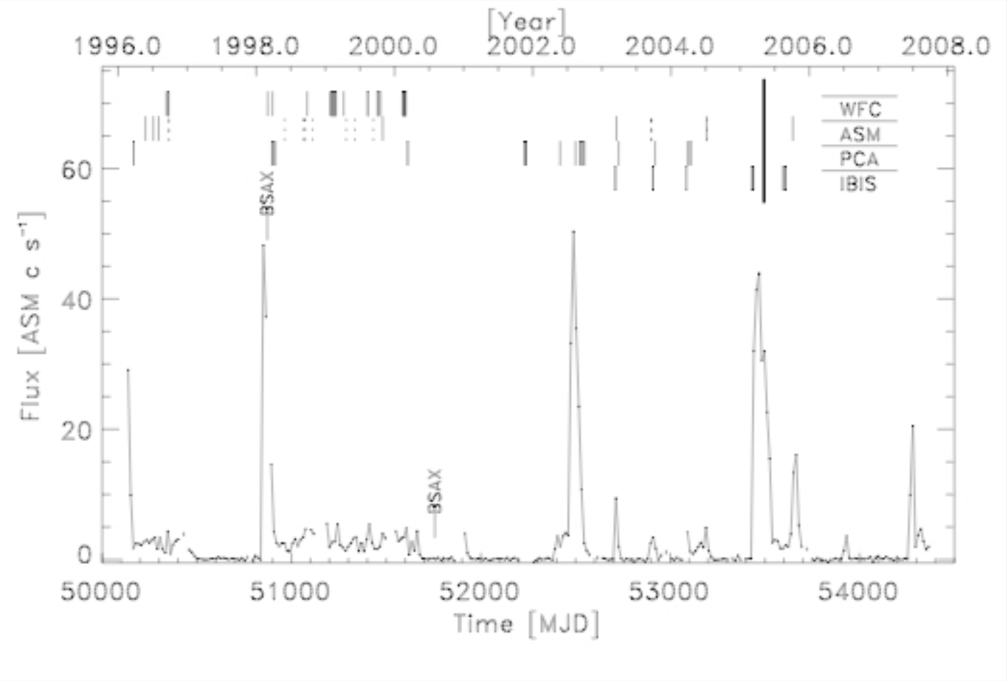
n capture rates multiplied by 100 for sensitivity study
Beun, McLaughlin, Surman, and Hix 2008

Half-Lives Influence Abundances



Hosmer, Schatz *et al*. 2005

Accreting Neutron Stars: X-Ray Bursts and Superbursts

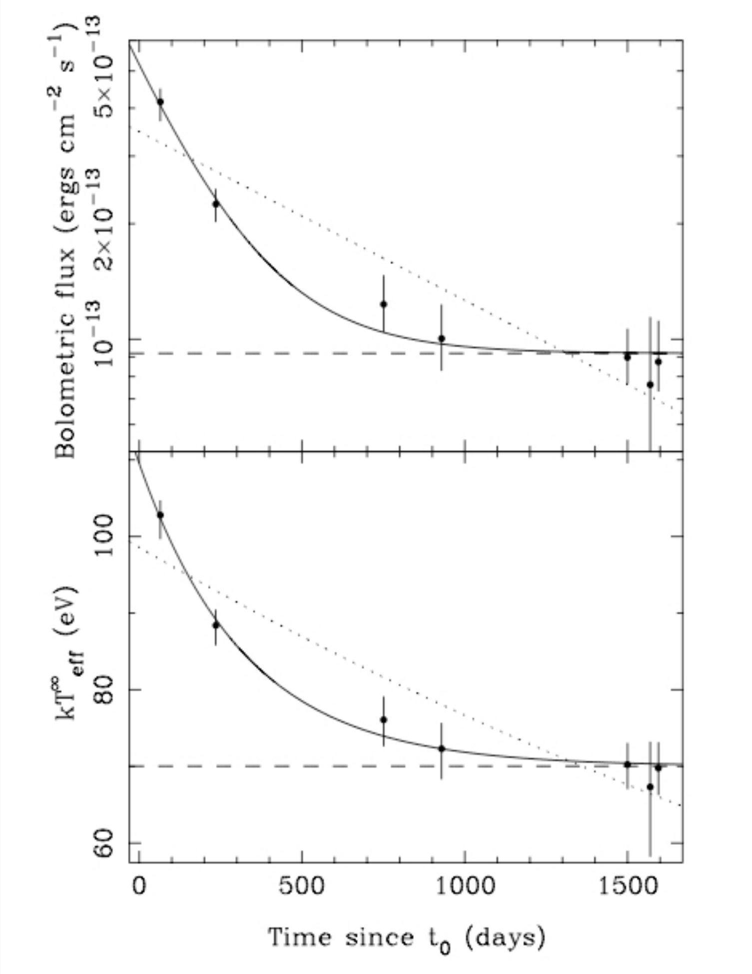


Keek *et al.* 2008

X-ray burst: accreted H and He from low mass companion lands on NS surface, layer builds up; thermonuclear runaway ensues

Superbursts may result from explosive C burning at greater depth, sensitive to thermal properties of crust

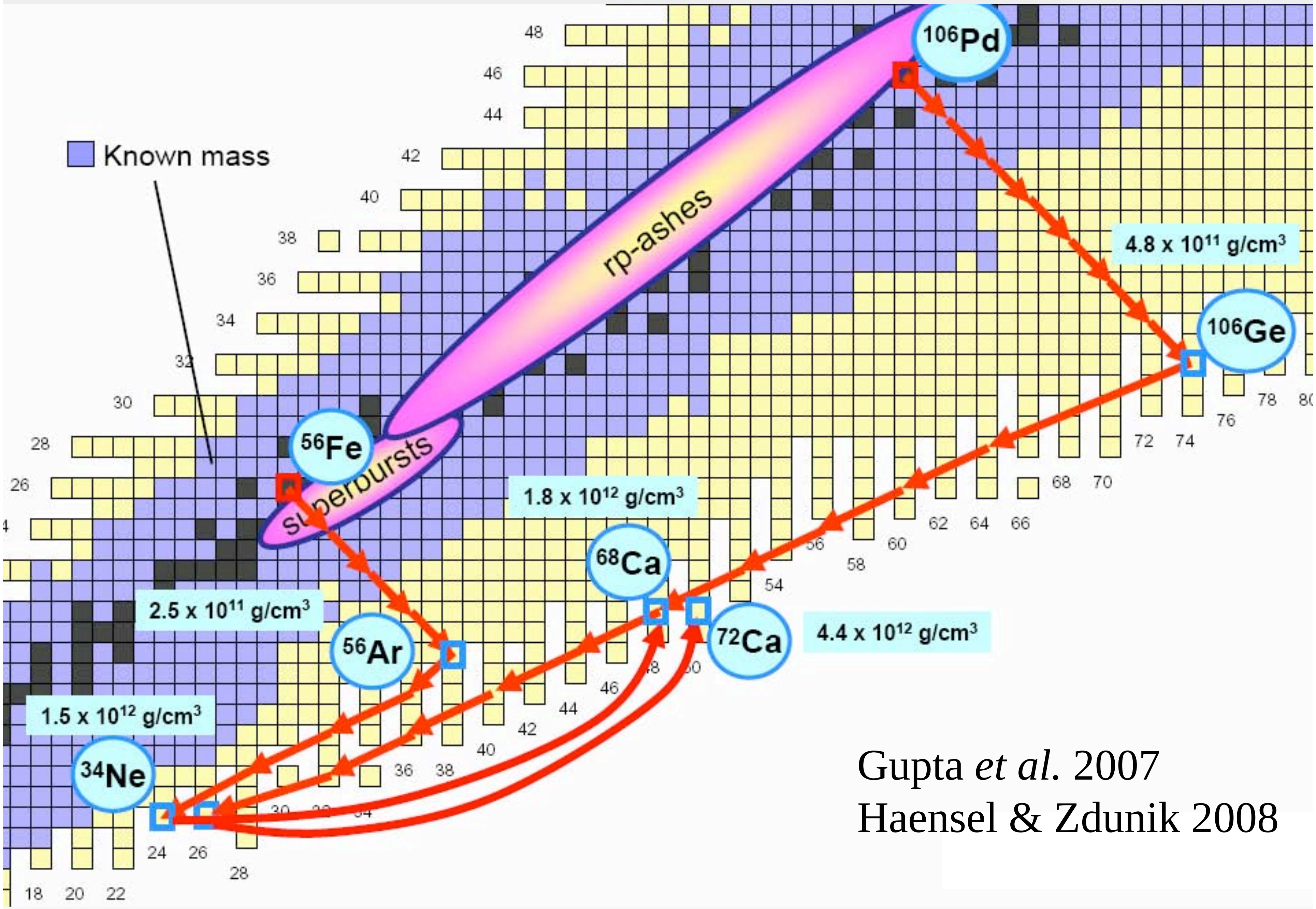
Precise X-Ray Observations of Accreting Neutron Stars



Cackett *et al.* 2006

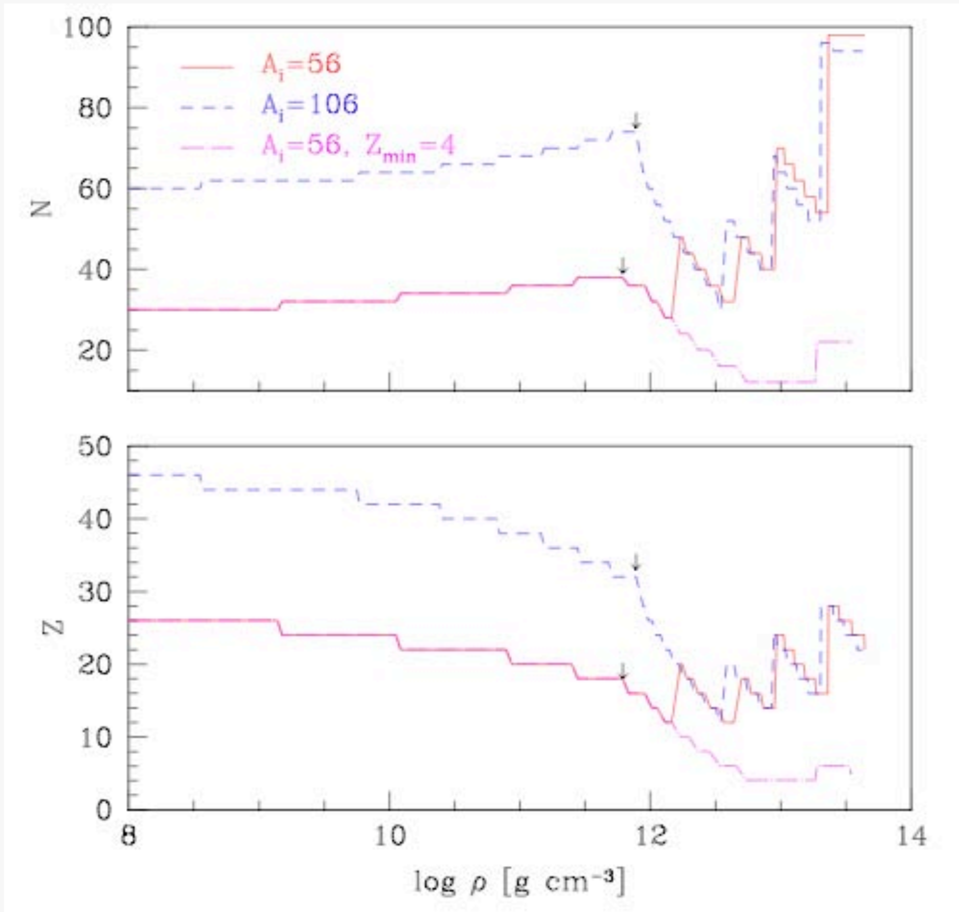
Accretion turns off after 12.5 yr; crust cooling curve depends on crust properties: thermal conductivity, thickness, heating and cooling

Neutron Star Crust Physics: Heating



Gupta *et al.* 2007
Haensel & Zdunik 2008

Descending into the Neutron Star Crust

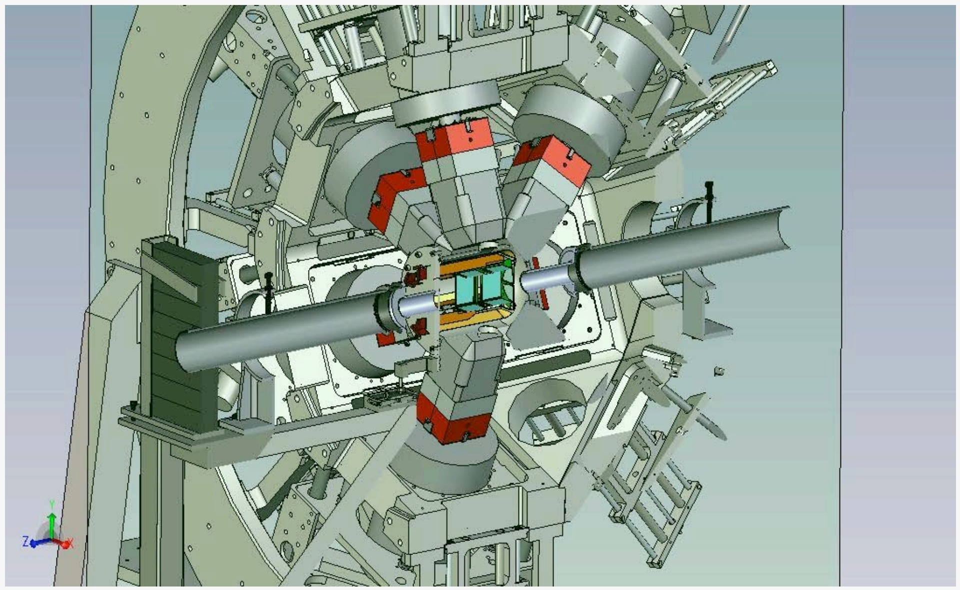


Haensel and Zdunik 2008

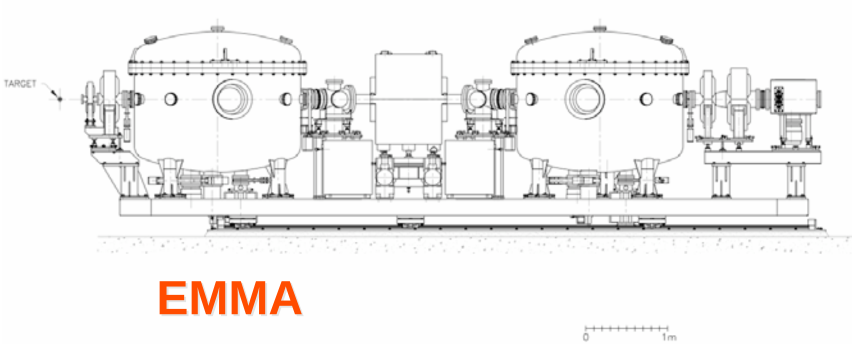
e^- capture to neutron drip, neutron emission, pycnonuclear reactions

Some Measurements in Nuclear Astrophysics Enabled by the Proposed Facility

β-decay half-lives: 8π / EMMA + TIGRESS
β-delayed n emission probabilities: DESCANT + EMMA
Masses: TITAN
(d,p) reactions: EMMA + SHARC Si array + TIGRESS



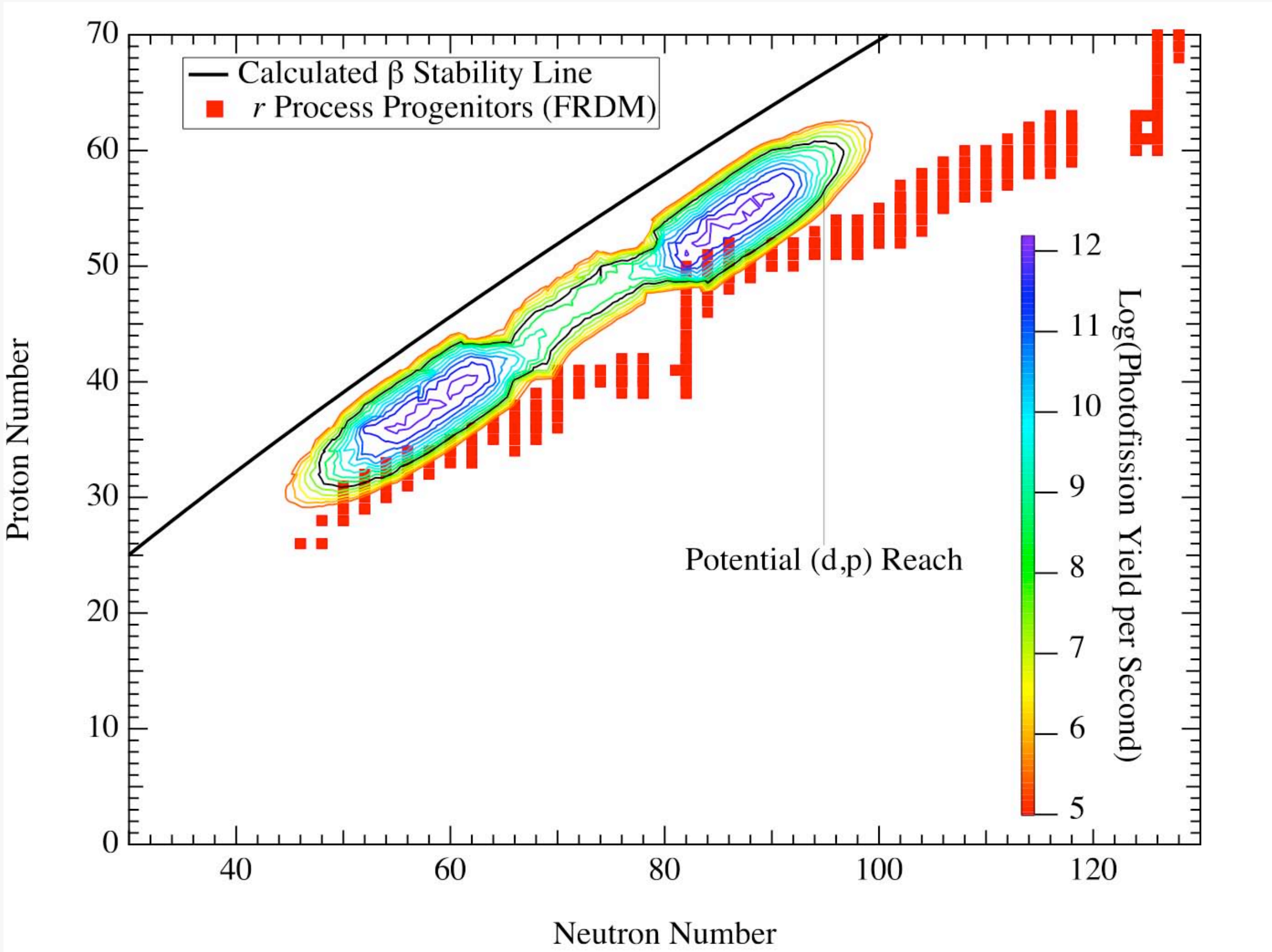
TIGRESS + SHARC



EMMA

TITAN

r Process Reach of the Electron Linac

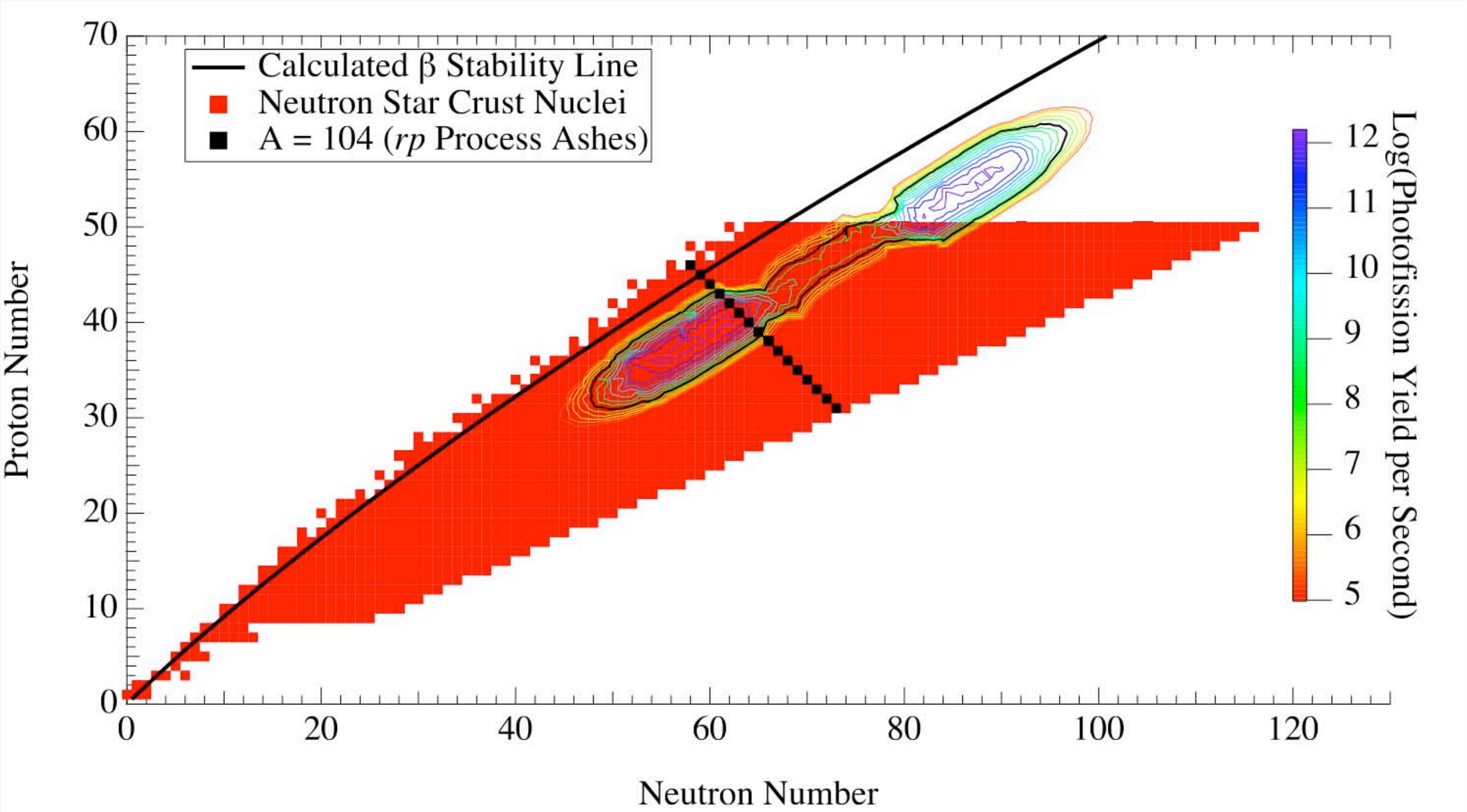


Photofission produces only neutron-rich nuclei w/ A > 70

Overlaps *r* process progenitors, notably 50 ≤ N ≤ 62 and 82 ≤ N ≤ 90;

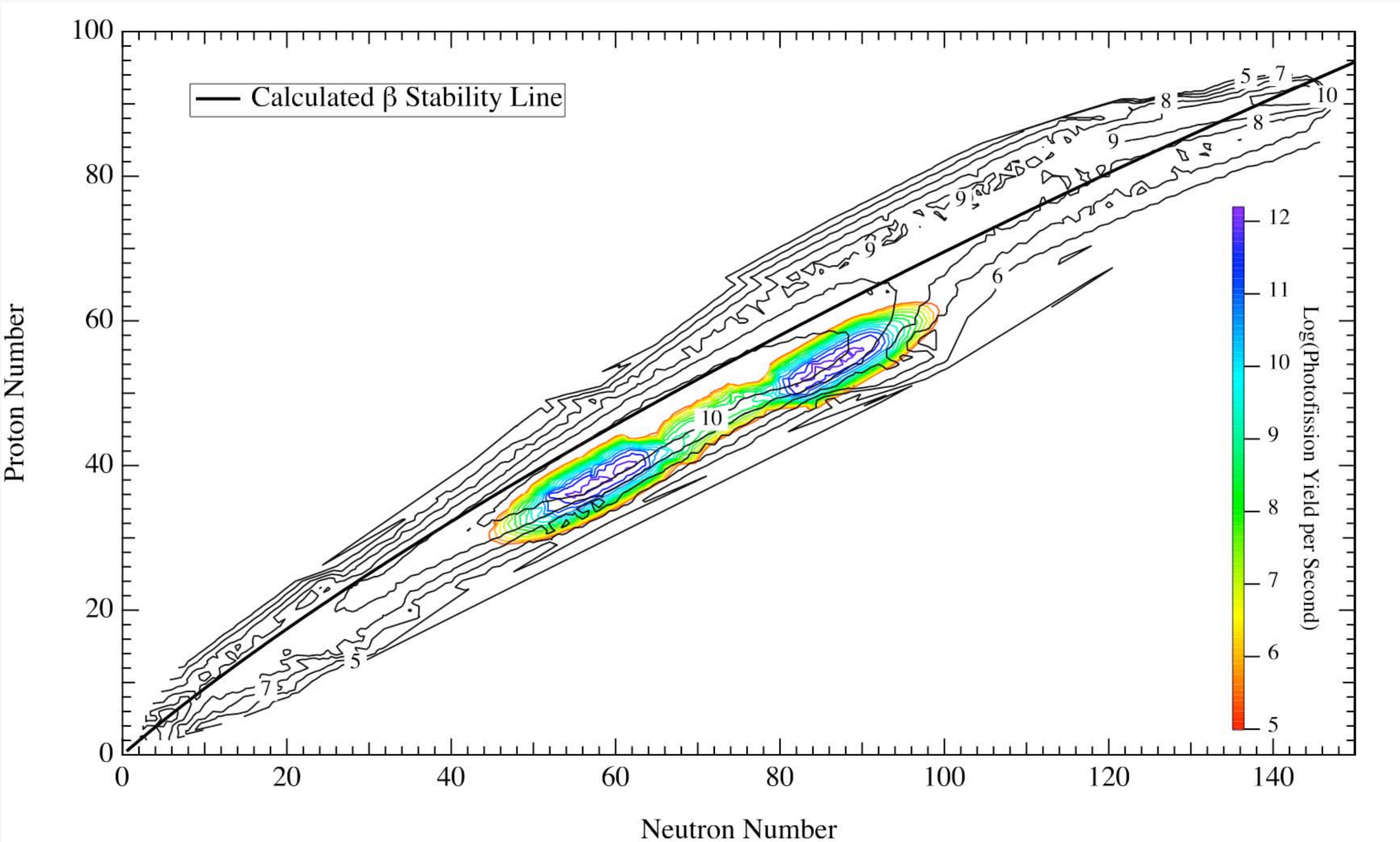
E.g., mass measurements of ^{136}Sn, ^{139}Sb, ^{142}Te

Neutron Star Crust Reach



For crust heating via e^- capture, need masses and E_x of low-lying states
E.g., mass measurements of ^{104}Zr, ^{104}Y, ^{104}Sr

Photofission vs. (p, X) Yields



50 MeV electron photofission vs. 10 μA of 500 MeV protons
Photofission: much cleaner n-rich beams with higher peak intensity

Summary

- Neutron-rich nuclei are of primary importance in the *r* process, which created roughly half of the nuclei with A > 70, and in the crusts of neutron stars, whose thermal properties can be inferred from x-ray transient and superburst observations
- Nuclear theory is insufficiently advanced to predict the properties of these nuclei *a priori*
- Experimental measurements of nuclear masses, β decay lifetimes, β-delayed neutron emission probabilities, neutron capture rates, and excitation energies are needed to constrain astrophysical models & determine *r* process site(s)
- The proposed electron linac would provide copious amounts of these nuclei relatively cleanly
- With a ^{9}Be target, the electron linac would also provide enough ^{8}Li to supply the β NMR and NQR research efforts

Acknowledments

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