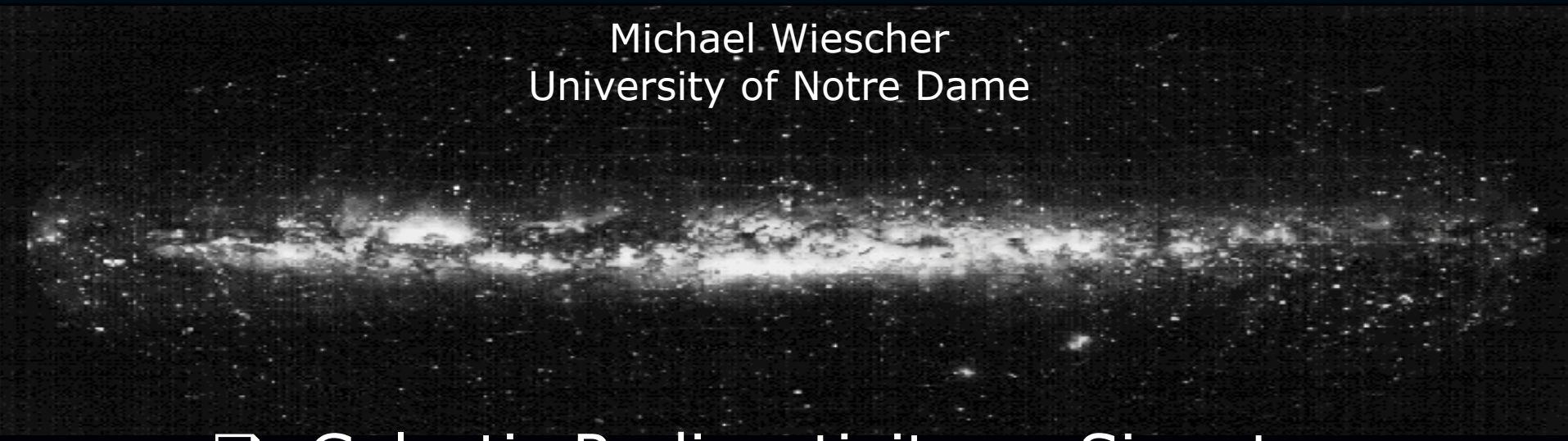
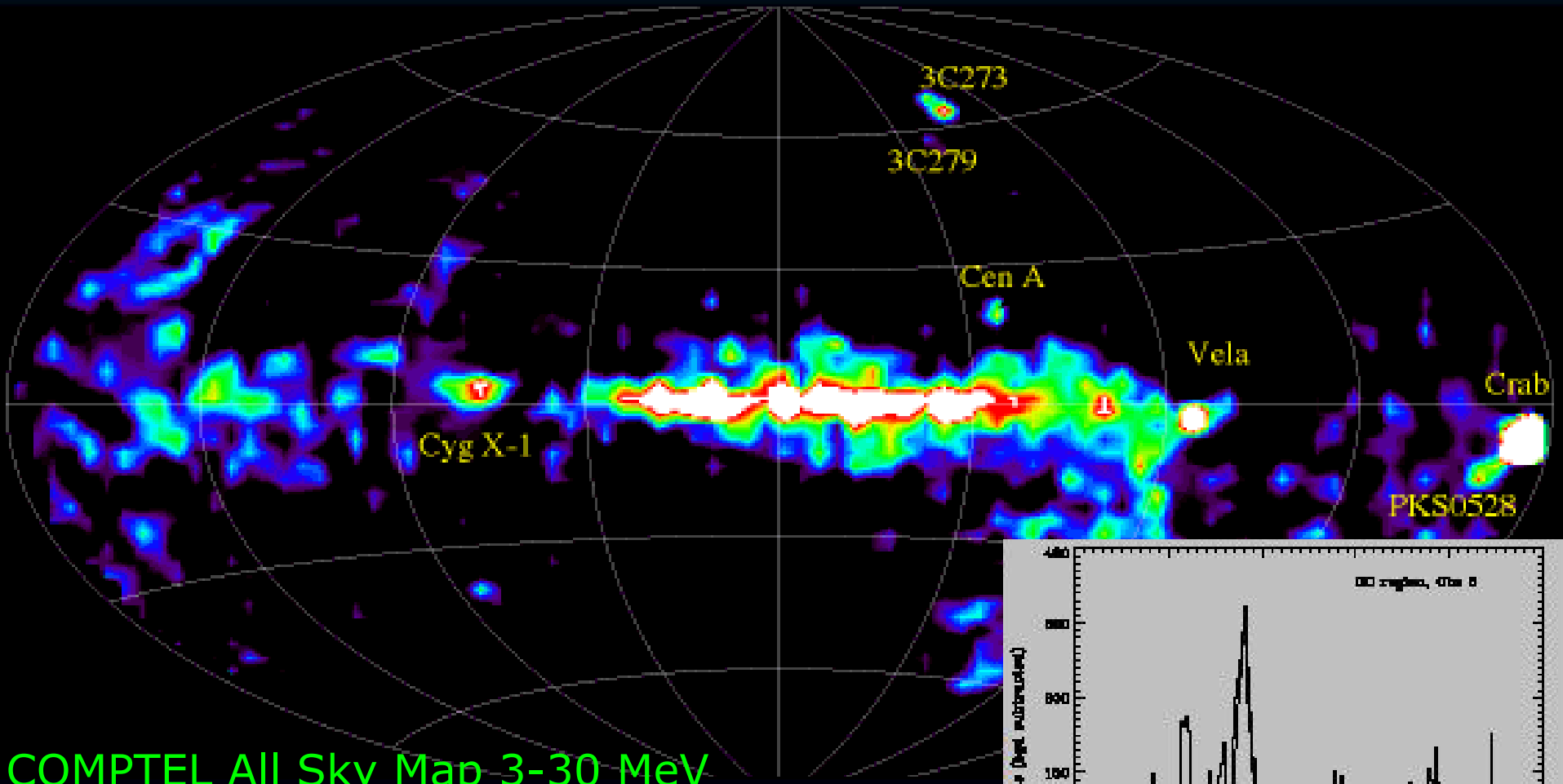
Cosmic Signatures for Nuclear Decay

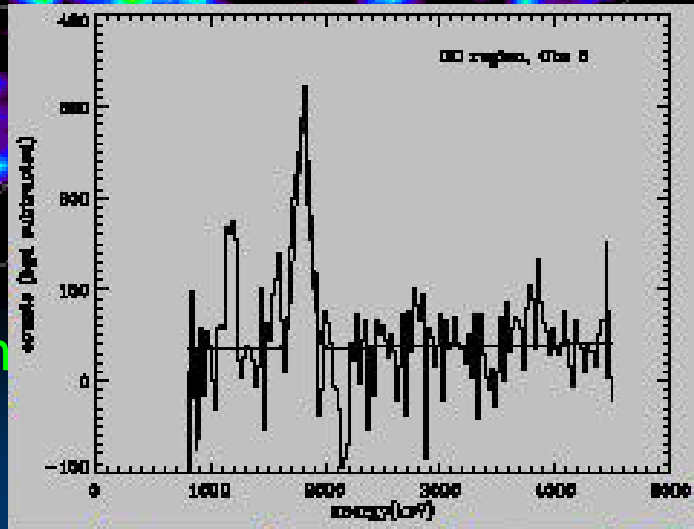
Michael Wiescher
University of Notre Dame



- Galactic Radioactivity as Signature
- Type II-SN Light Curves
- Type II-SN Models & Nucleosynthesis
- Type I-XRB Light Curves
- Type I-XRB Models & Nucleosynthesis

Galactic Radioactivity

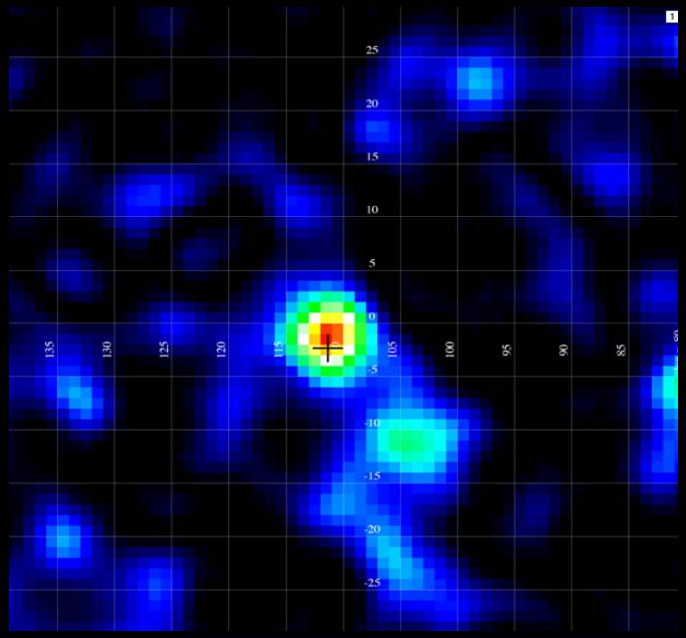




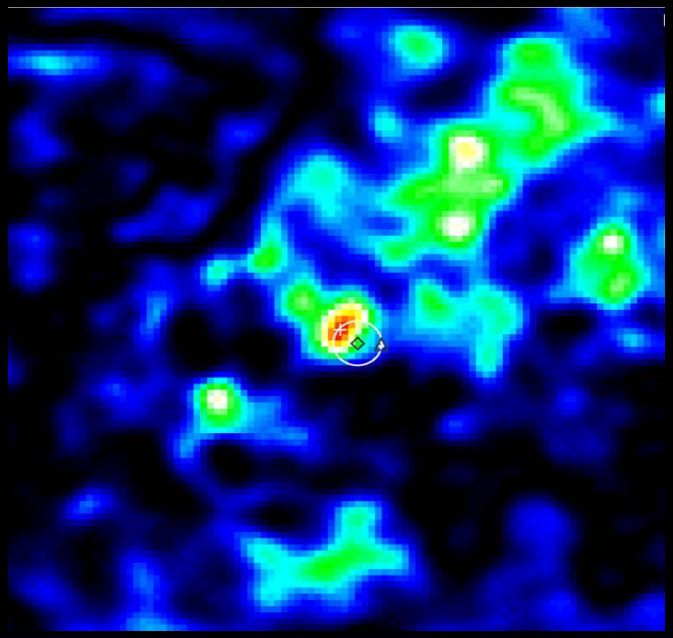
COMPTEL All Sky Map 3-30 MeV
Corresponds closely with 511 keV distribution
And 1.8 MeV ^{26}Al distribution

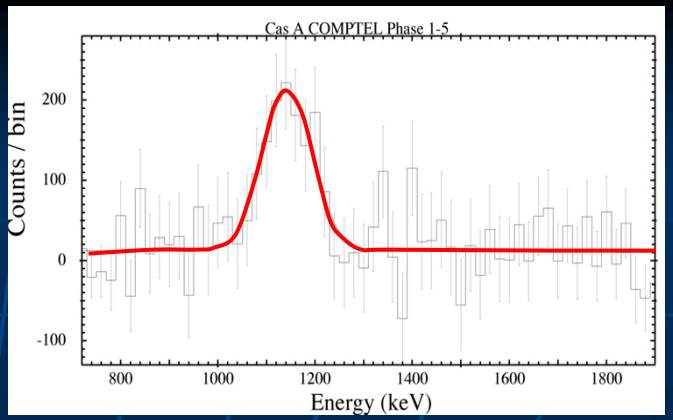
Supernova related γ-Activity

CAS A SN remnant



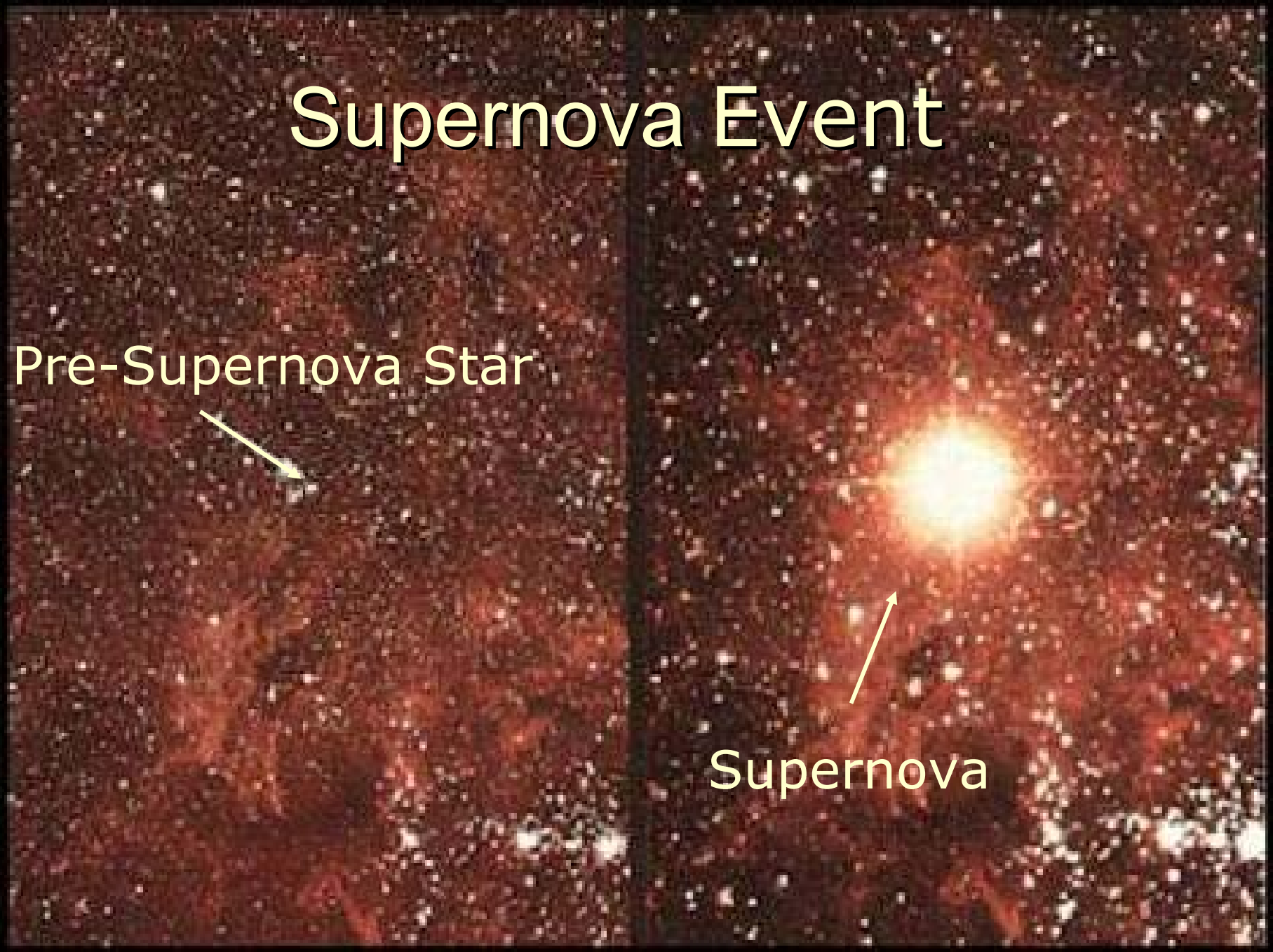
VELA SN Remnant



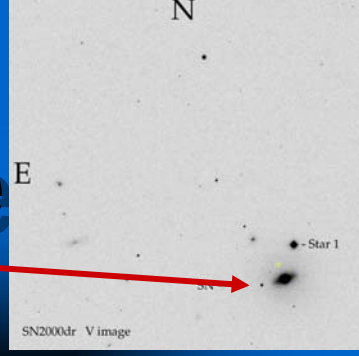


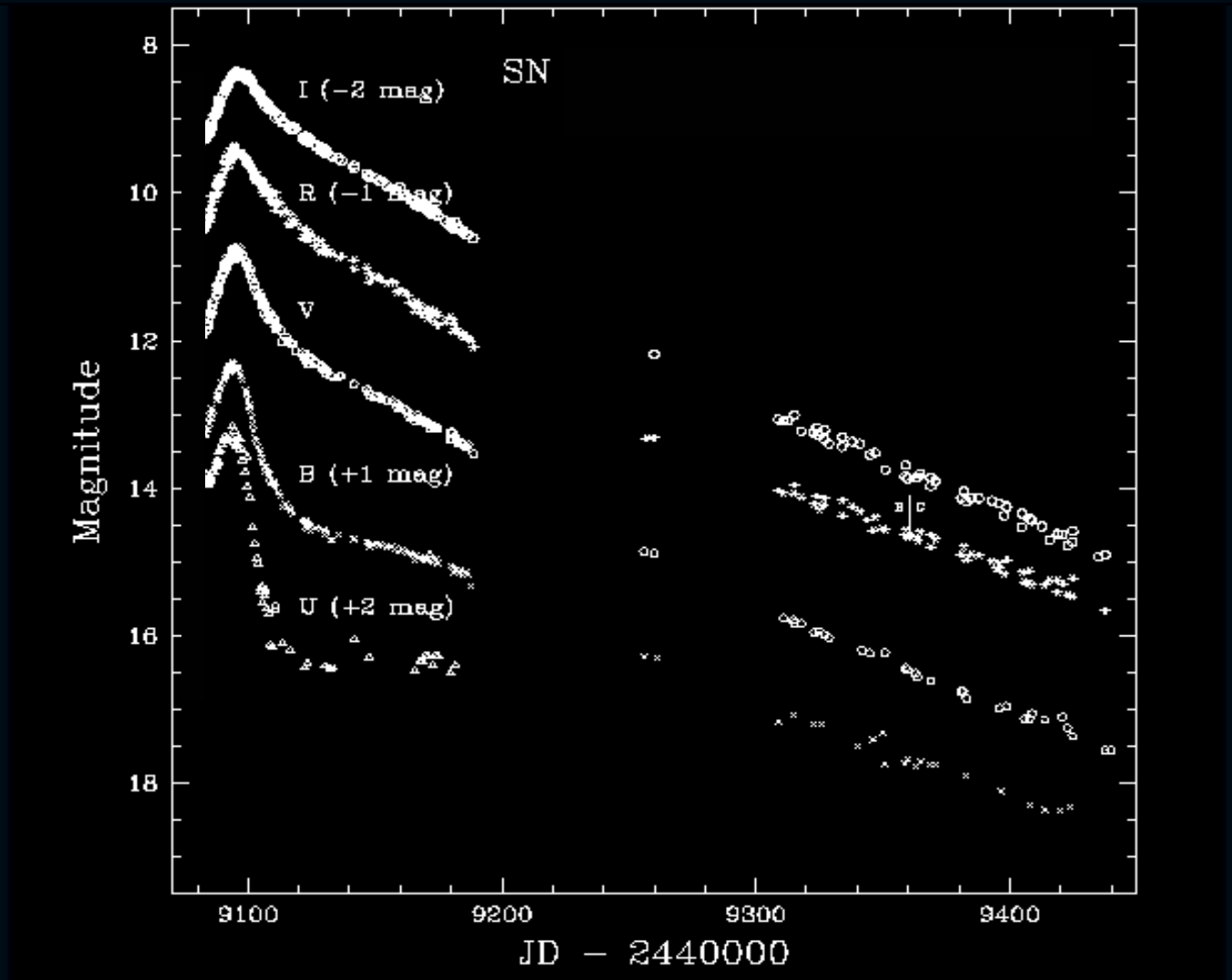
1.156 MeV from ^{44}Ti with COMPTEL

Supernova Event

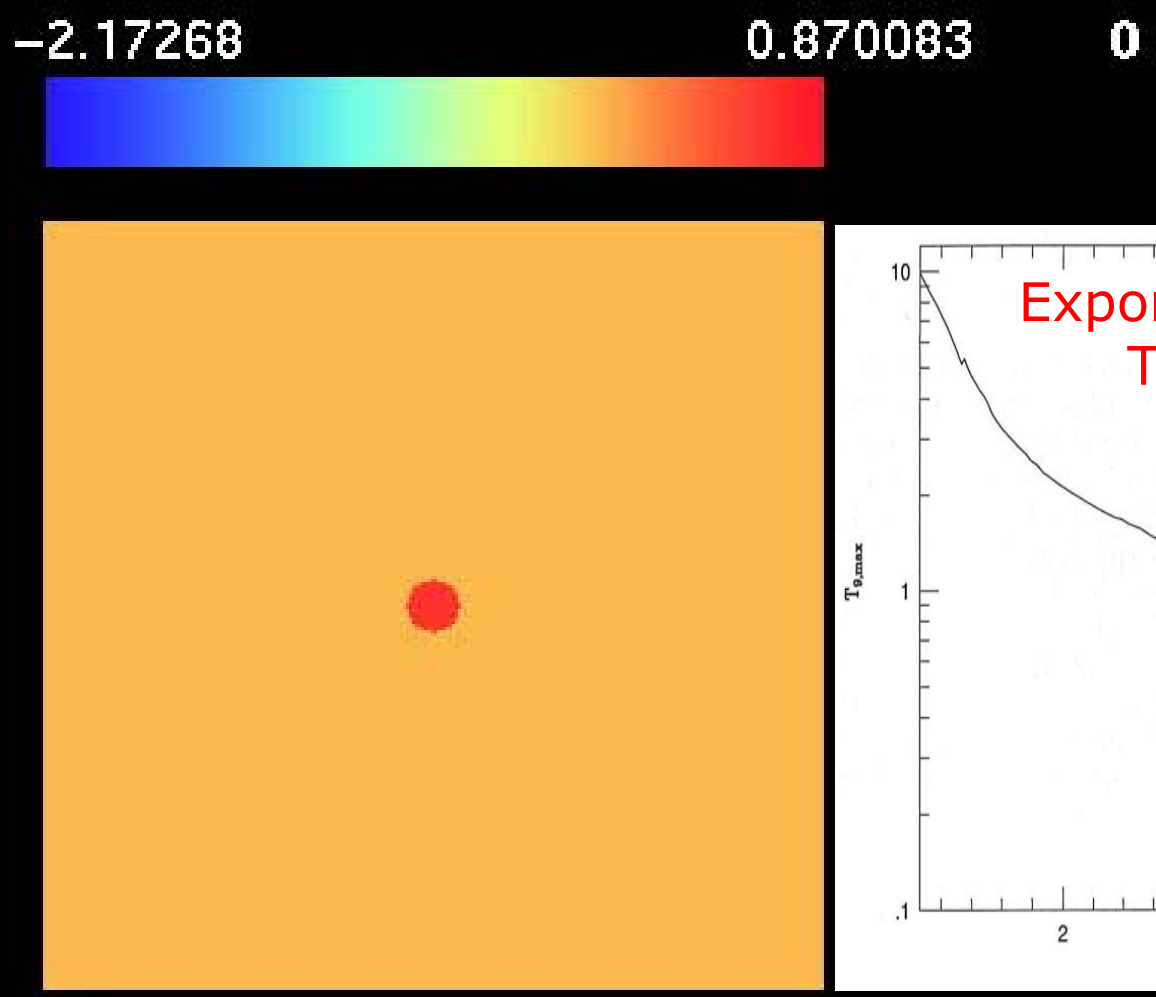


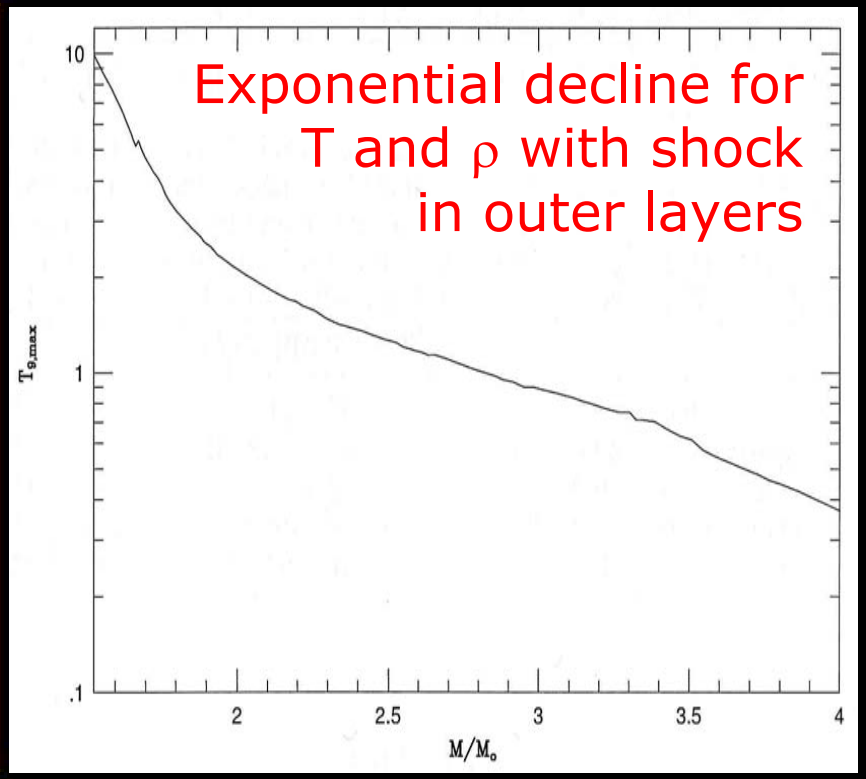
Supernova Light Curve





Shock front simulation

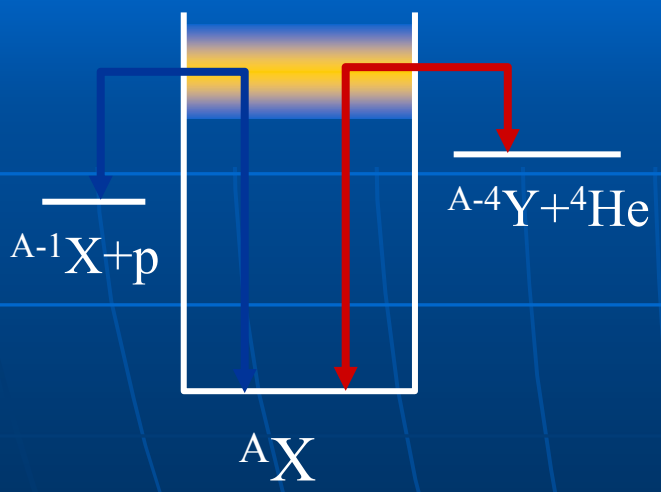




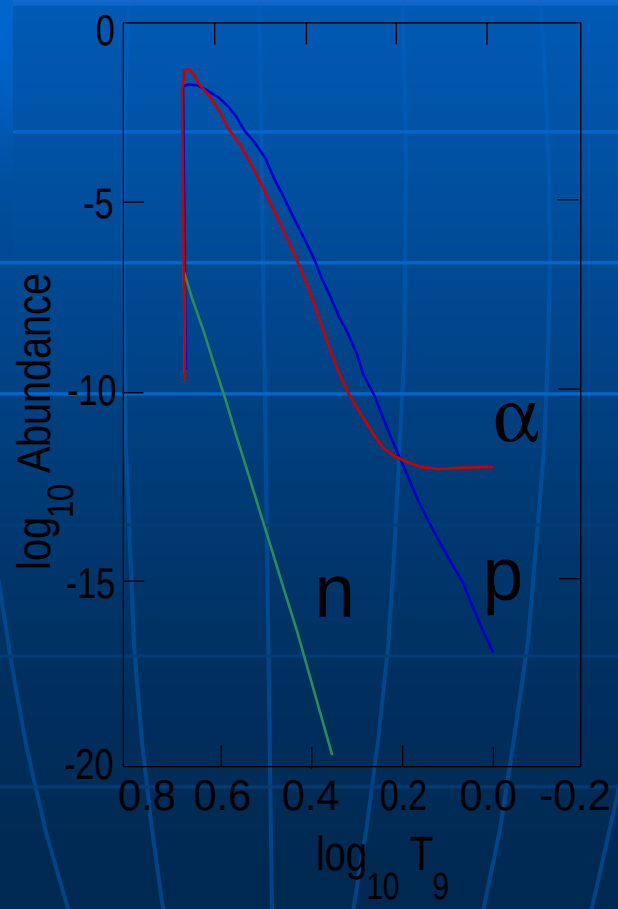
Abundance conditions in equilibrium

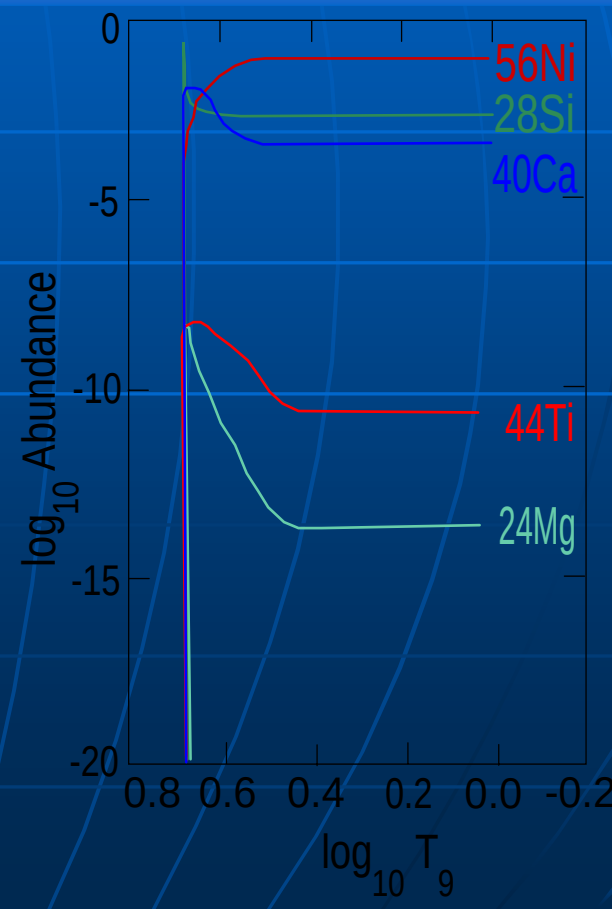
$$Y_{Z,N} = G_{Z,N} \cdot (\rho \cdot N_A)^{A-1} \cdot \left(\frac{2\pi \cdot \hbar^2}{m_u \cdot kT} \right)^{\frac{3}{2}\cdot(A-1)} \cdot e^{-\frac{B_{Z,N}}{kT}} \cdot Y_n^N \cdot Y_p^Z$$

NSE in Si-Burning

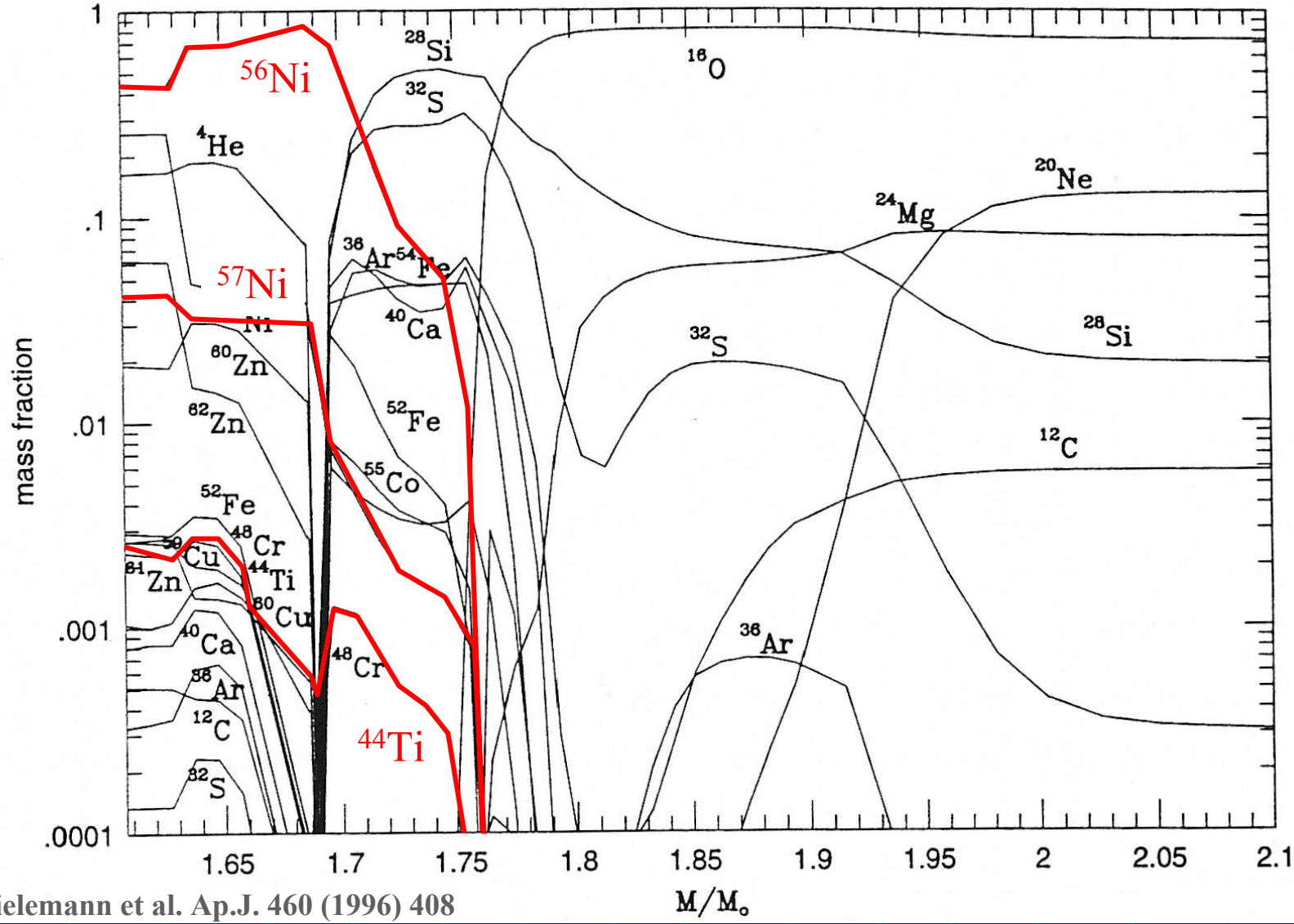


High T: light nuclei
Low T: High B nuclei



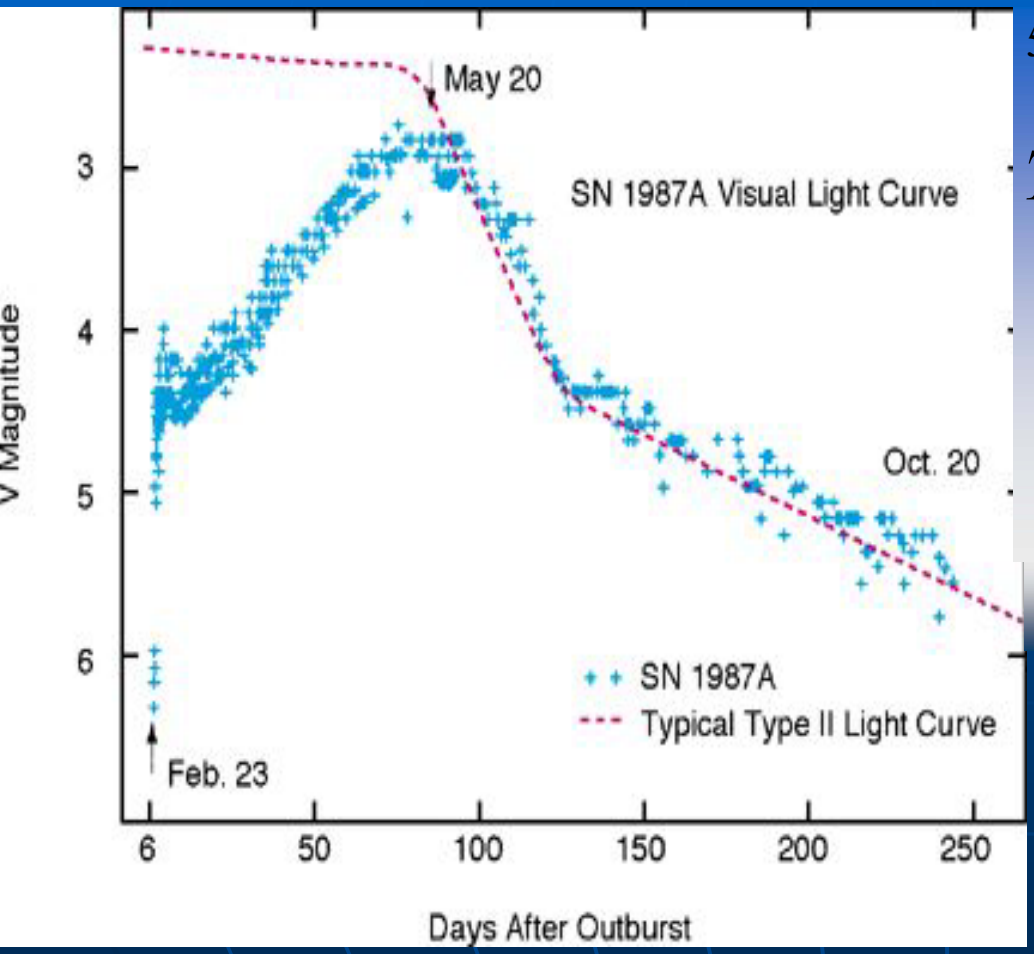


SN-Type II nucleosynthesis



Thielemann et al. Ap.J. 460 (1996) 408

Galactic ^{56}Ni radioactivity



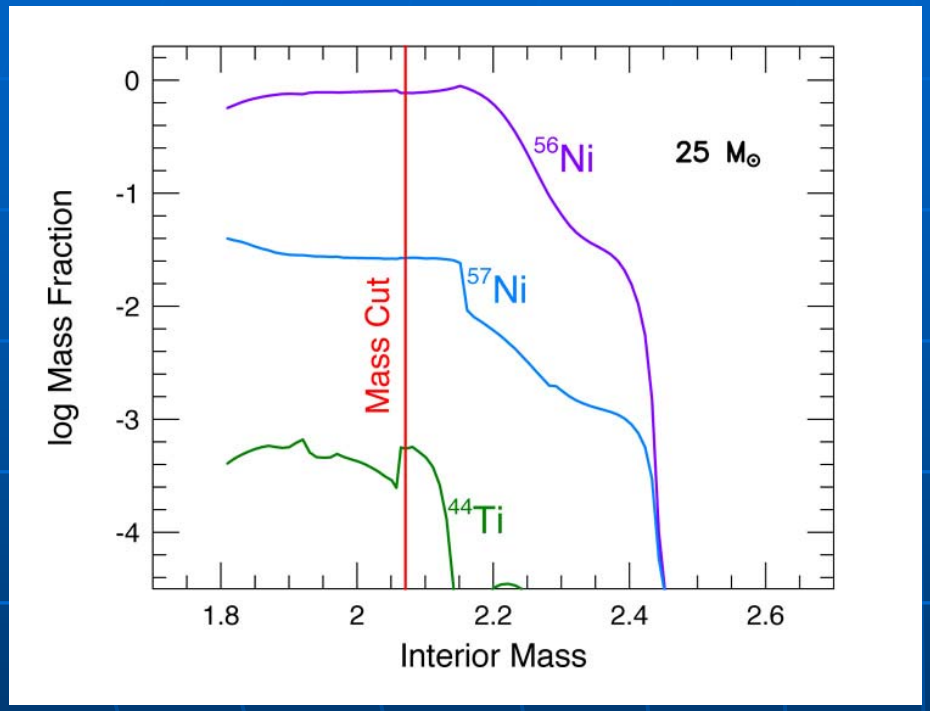
$$^{56}Ni\,(e^-,\nu)\,^{56}Co\,(\beta^+\nu)\,^{56}Fe$$

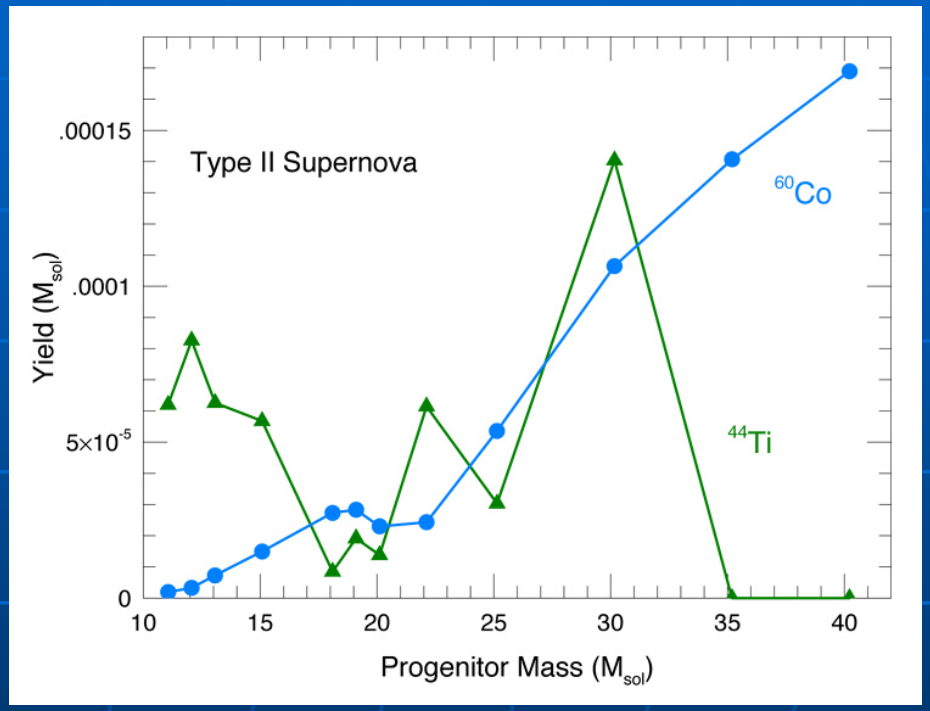
$$T_{1/2} = 6.1d \qquad T_{1/2} = 77.7d$$

$$\frac{dM_{bol}}{dt} = \frac{0.755}{T_{1/2}}$$

Rapid production of long-lived isotopes by SN-nucleosynthesis & subsequent decay; small decay rates ⇒ long cooling periods

Galactic radioactivity as SN nucleosynthesis signature

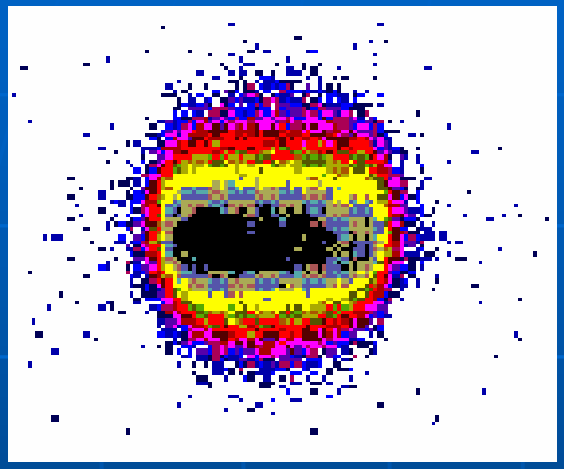


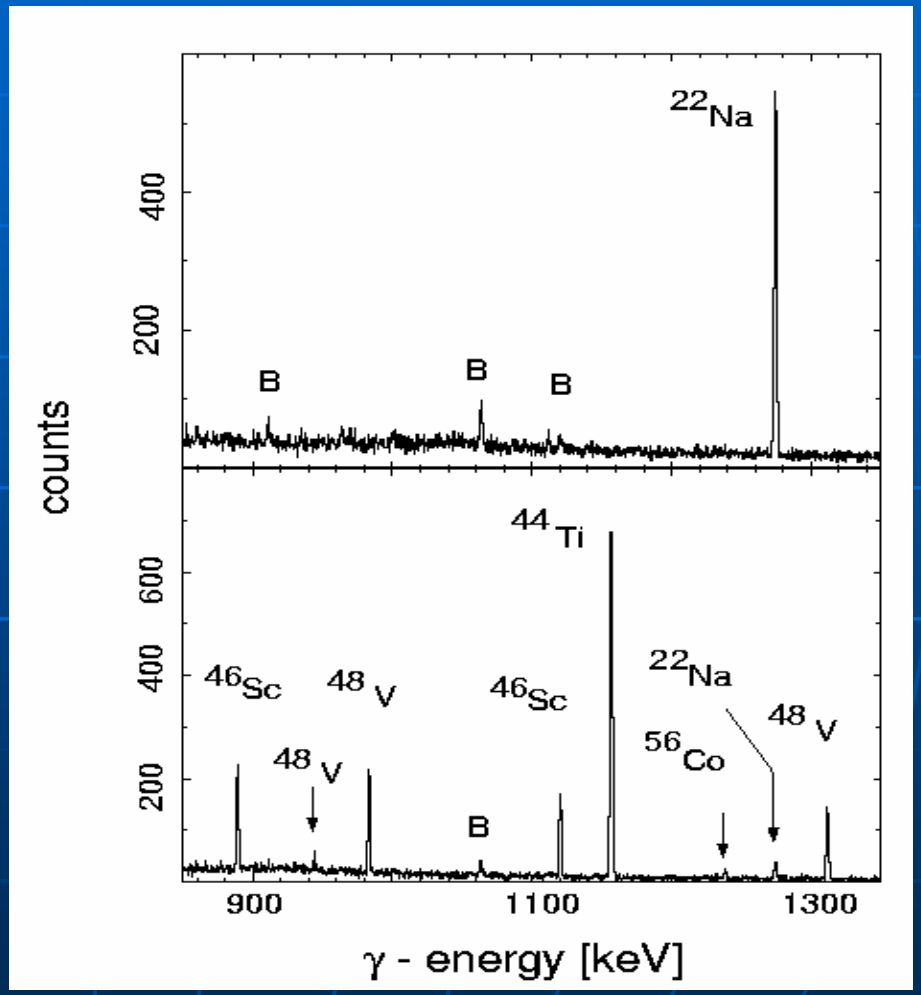


$$L_{44} = f(\kappa_{44}) \cdot \exp\left(\frac{-t}{\tau_{44}}\right) \cdot M(^{44}Ti)$$

Observed ^{44}Ti and ^{60}Co radioactivity can be used to determine mass of pre-supernova star & test ^{44}Ti abundance predictions

^{44}Ti lifetime measurement

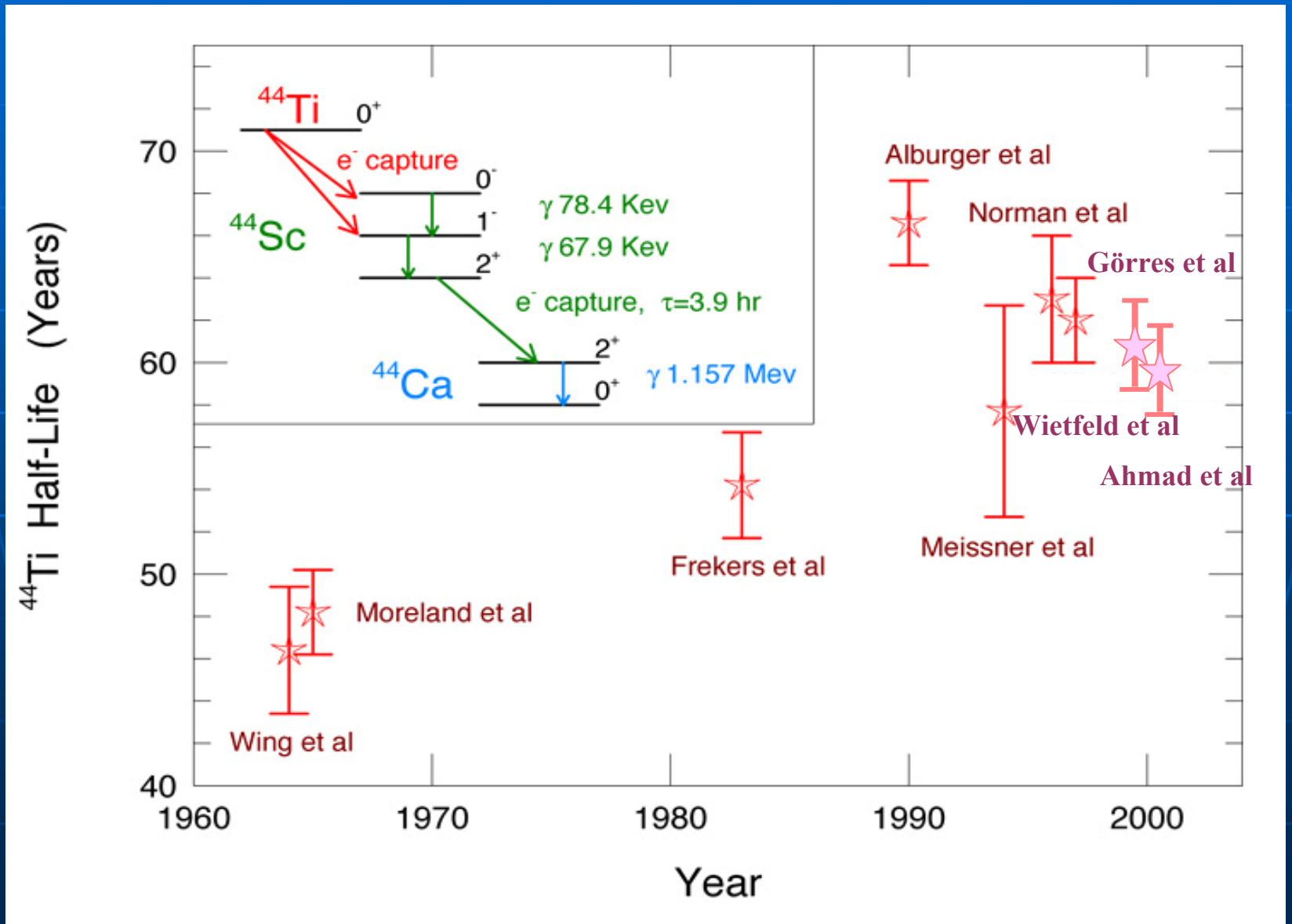




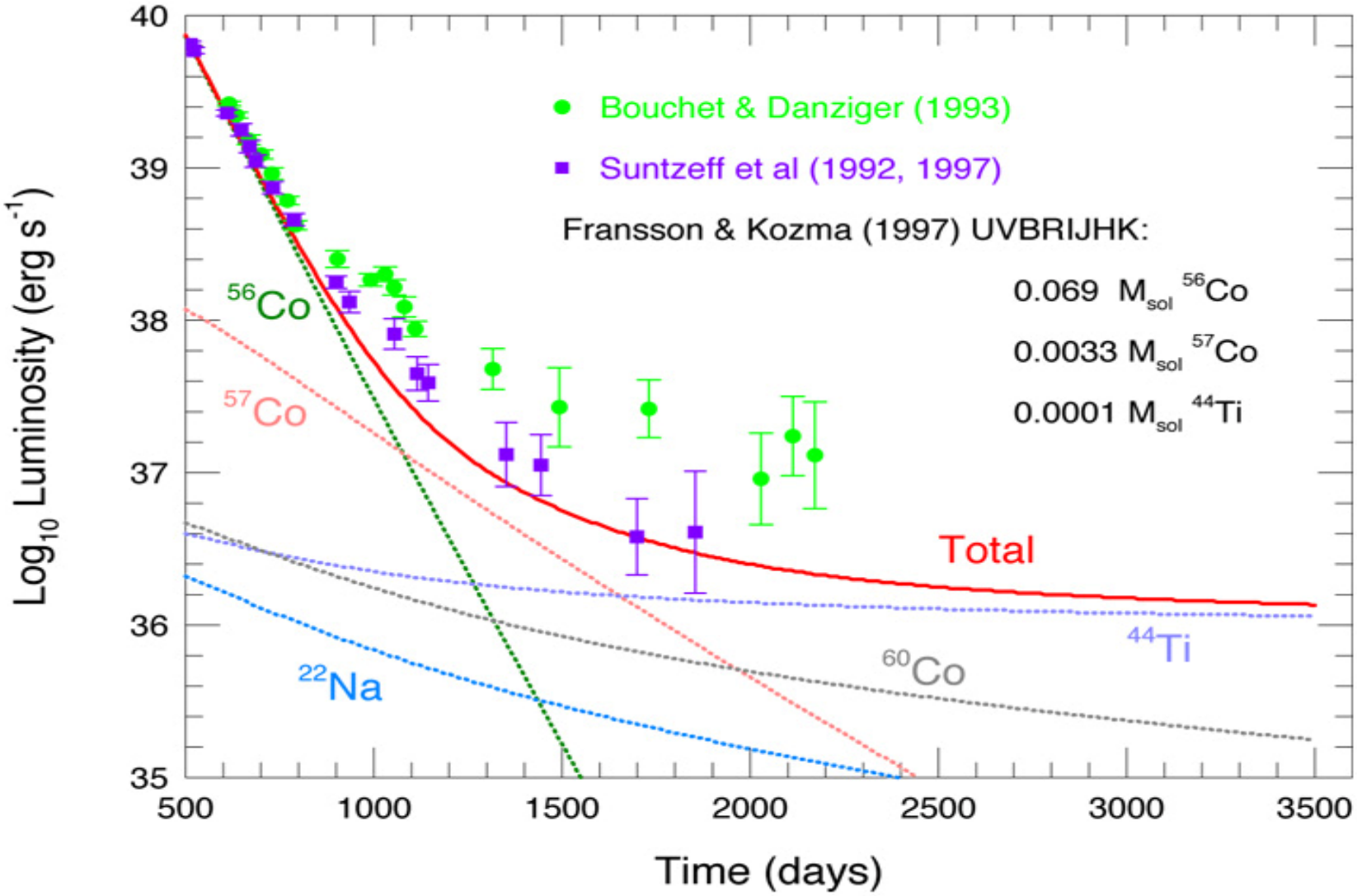
NSCL cyclotron – A1200
^{44}Ti implantation and subsequent γ-counting of characteristic 1.157 MeV line (relative to ^{22}Na)

Görres et al. PRL 80 (1998) 2554

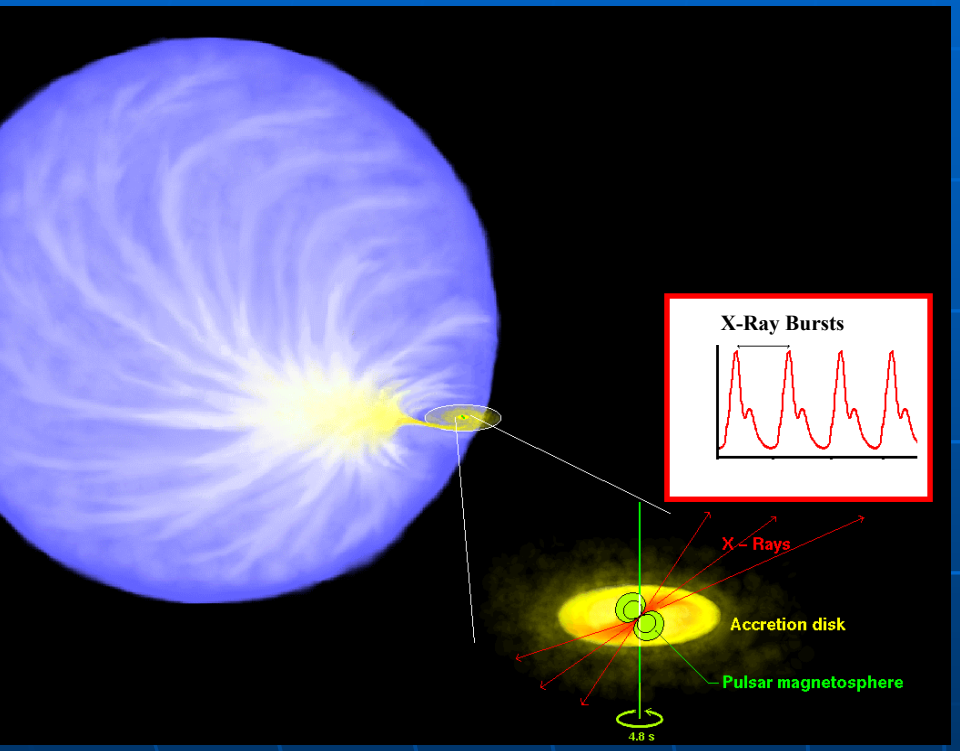
Half-life of ^{44}Ti

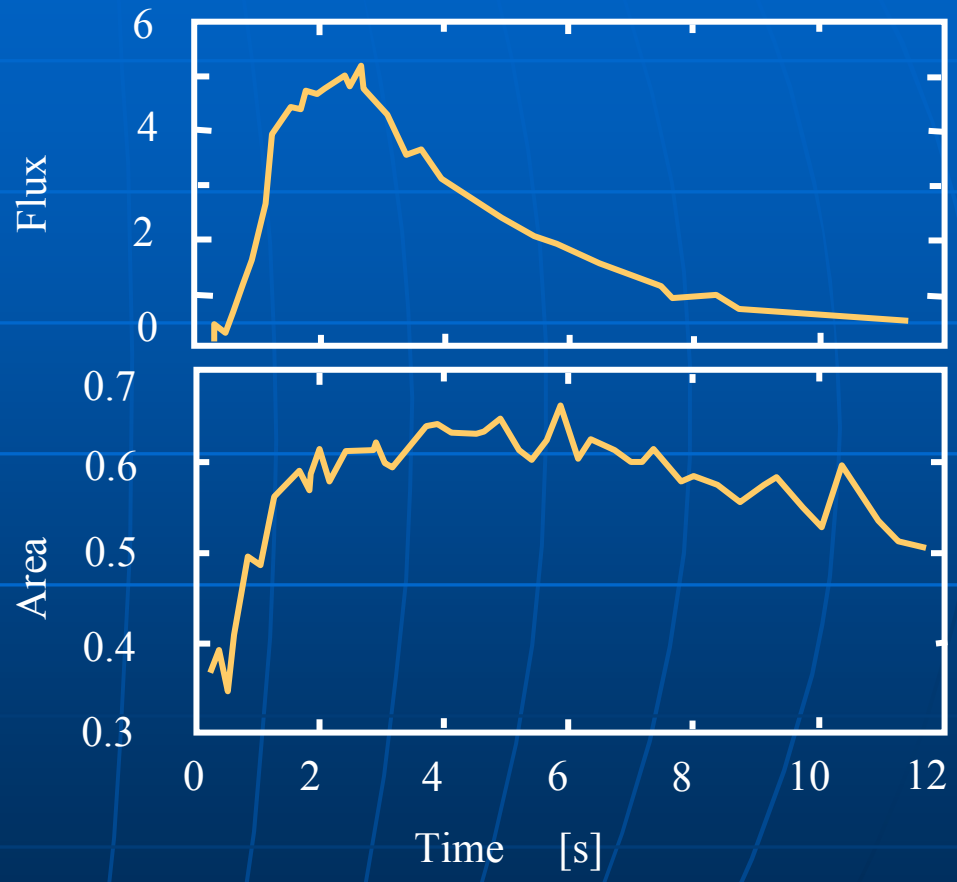


^{44}Ti & ^{60}Co in light curve of SN1987A



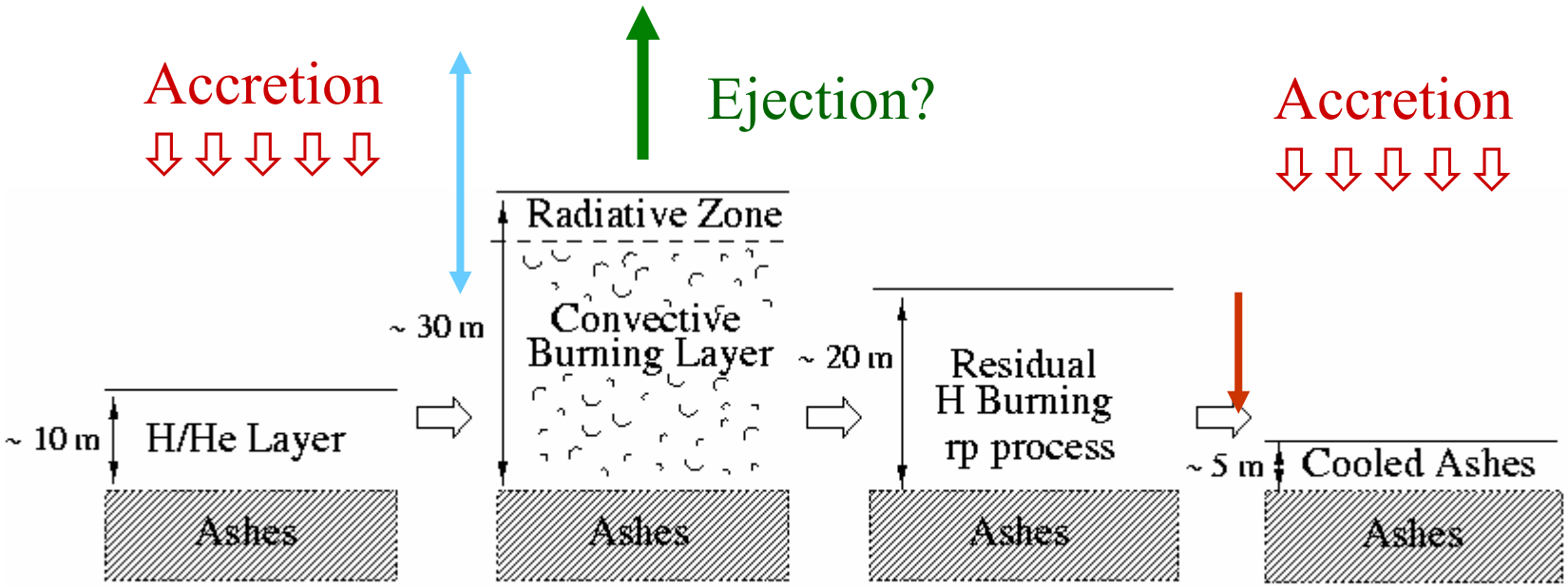
The evolution of a thermonuclear Runaway ⇒ x-ray burst





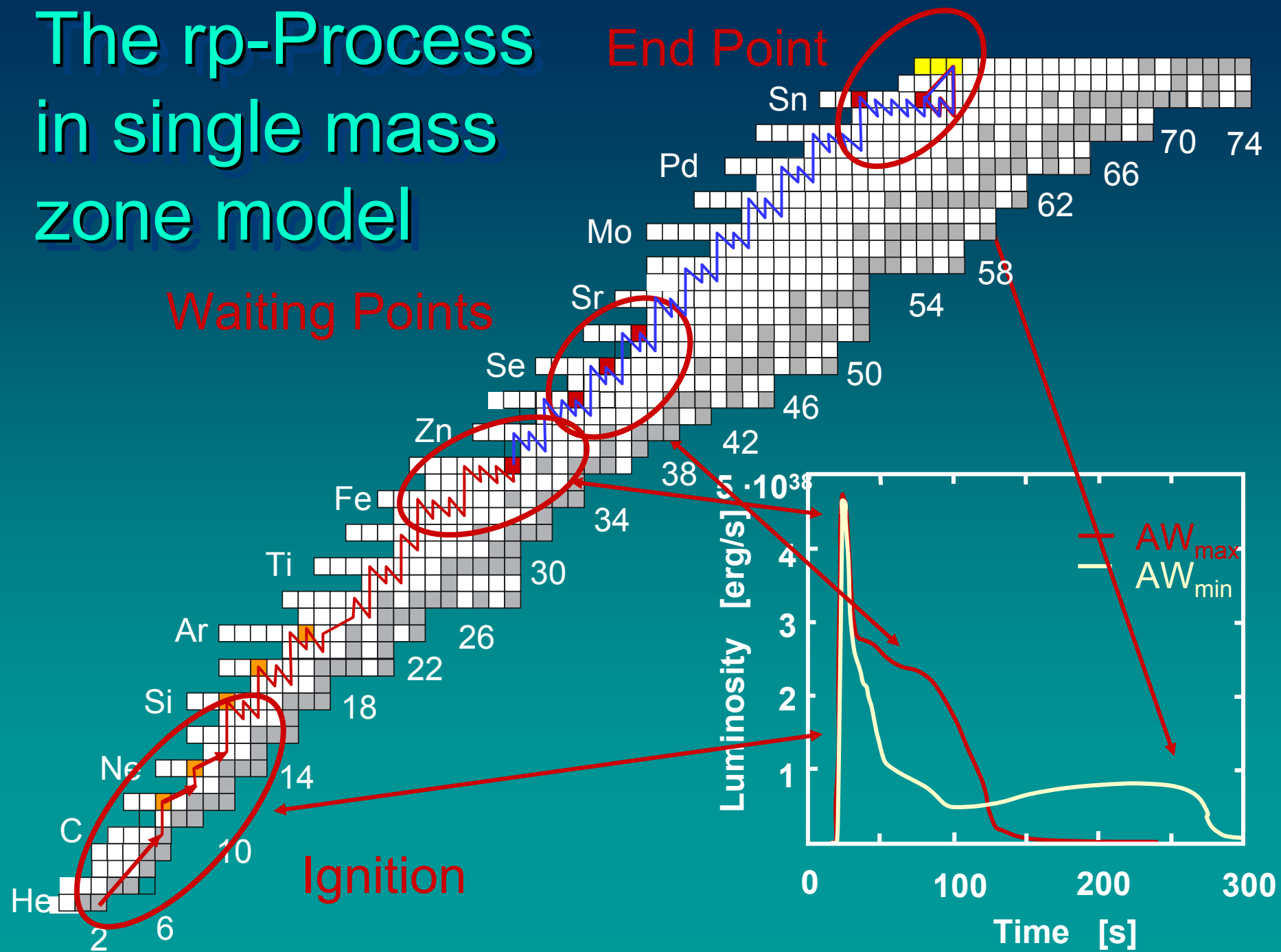
- Accretion onto neutron star
- Ignition at one location
- Thermonuclear runaway

Accretion onto Surface of a Neutron Star

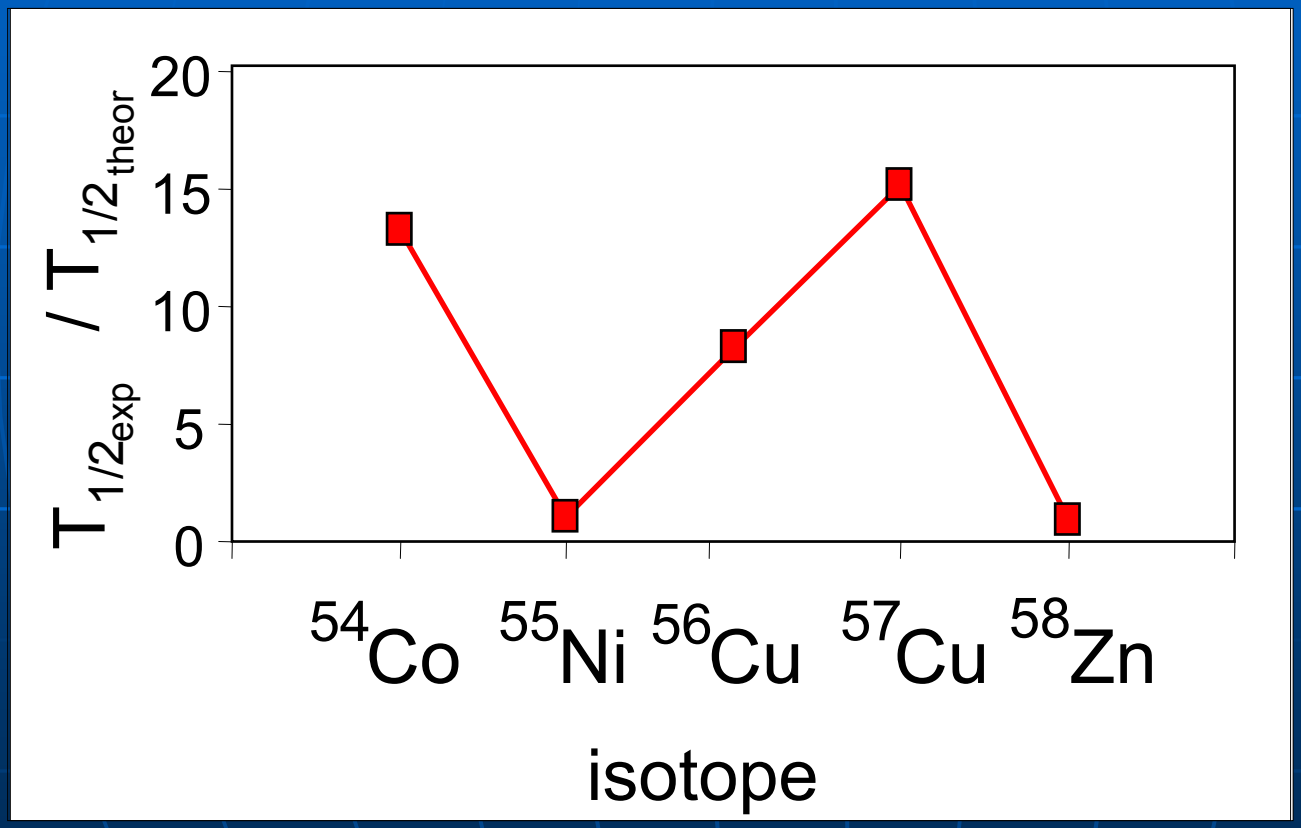


Nucleosynthesis?

The rp-Process in single mass zone model



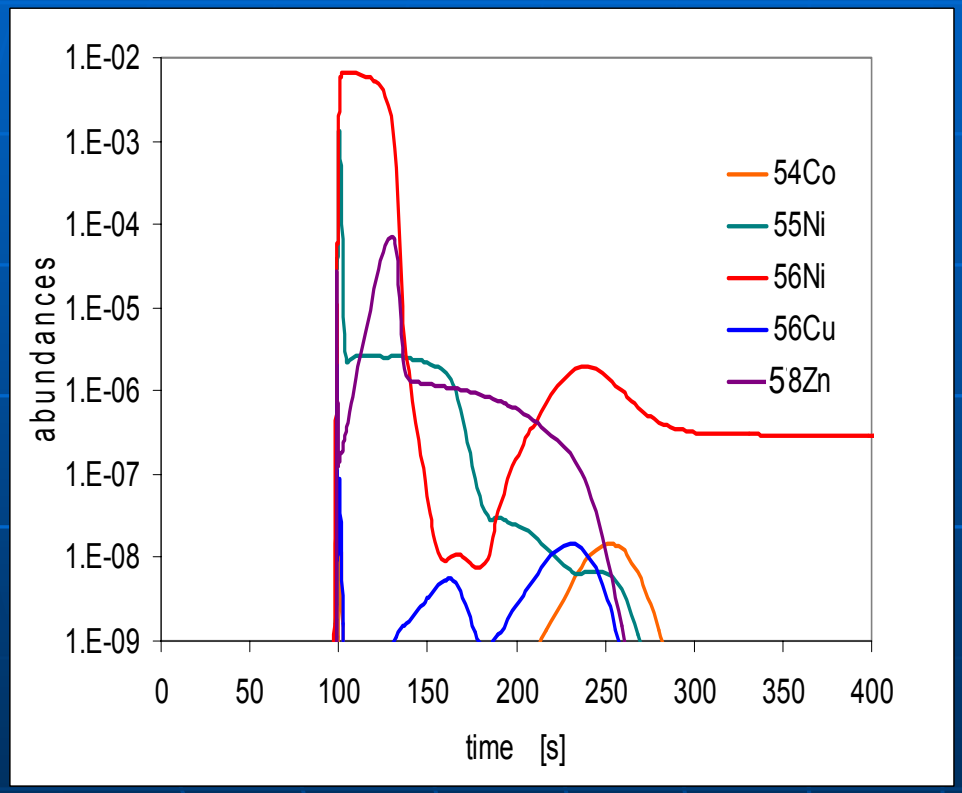
Impact of β-decay data on rp-process isotopes A=54-60

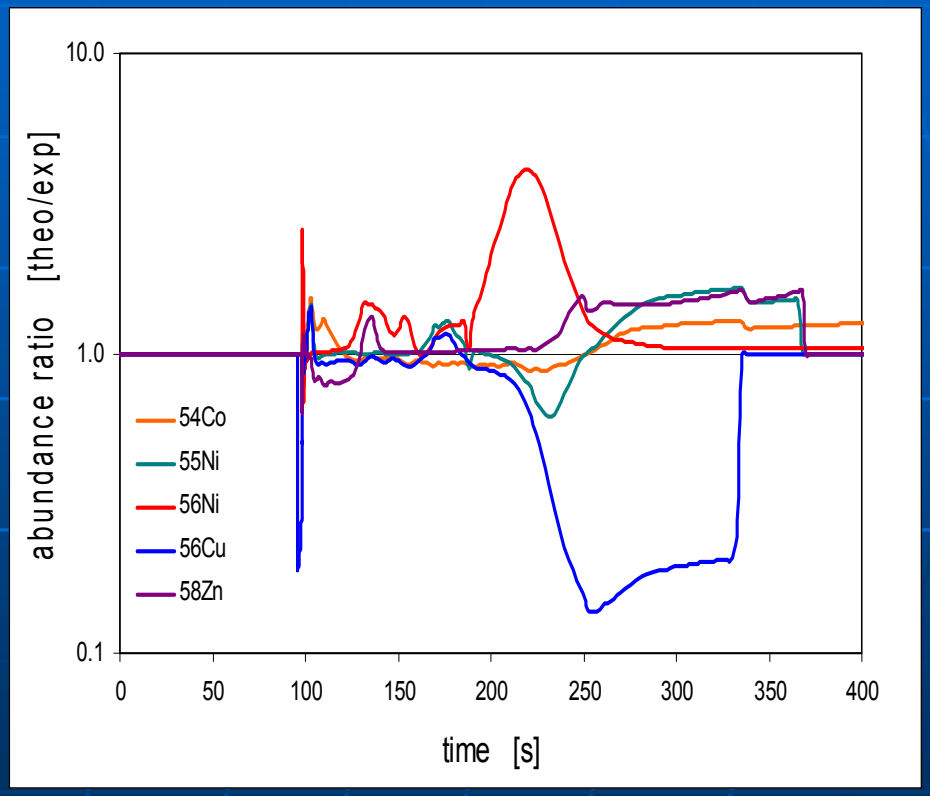


Up to one order of magnitude deviation in predicted $T_{1/2}$

Lopez Jiminez et al. PRC 66 (2002) 025803

$T_{1/2}$ dependence of abundance predictions

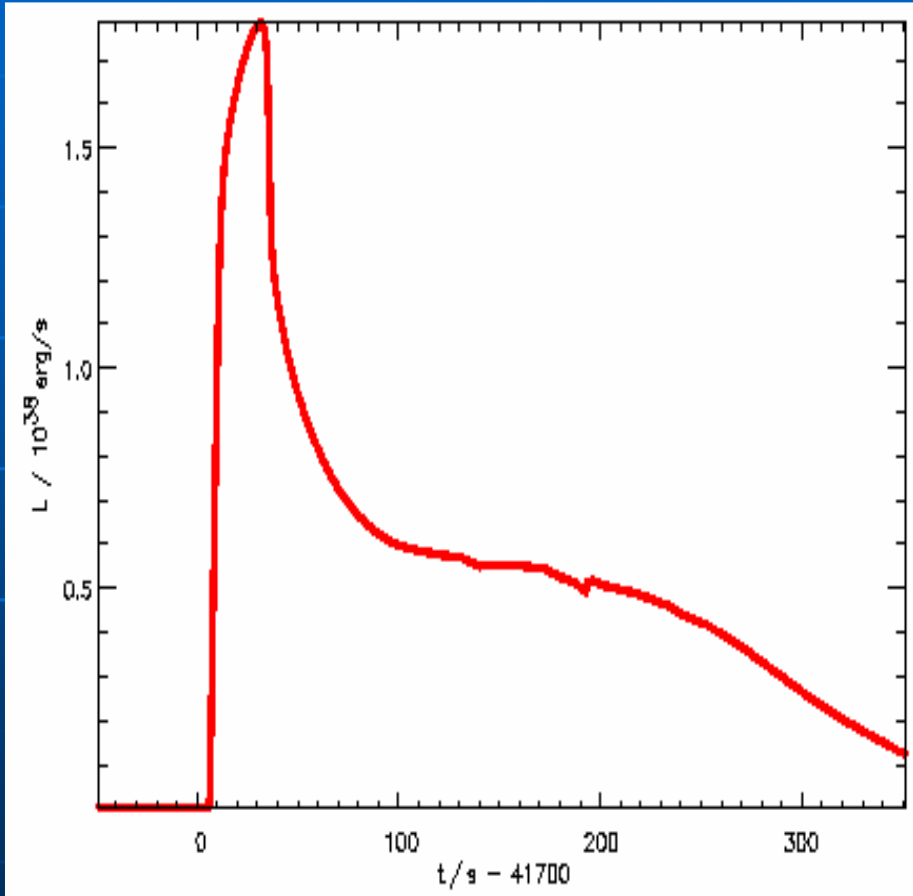


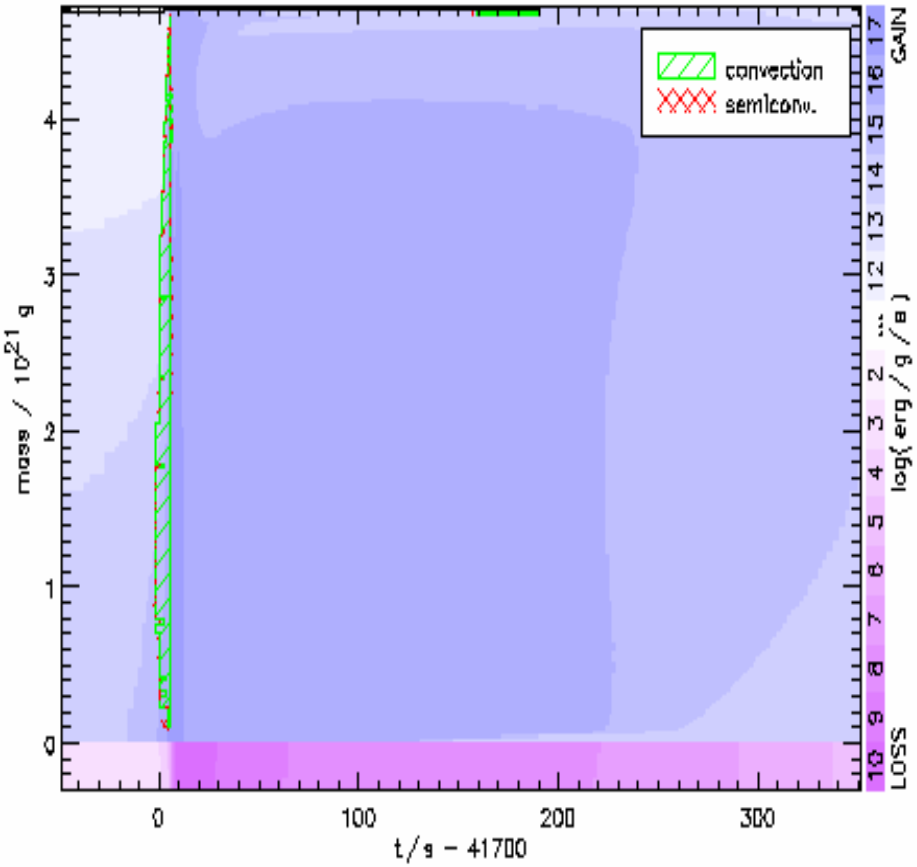


Main variation in ^{56}Ni and ^{56}Cu during cooling period

Multi-Mass-Zone Models

Woosley et al. (2003) in press

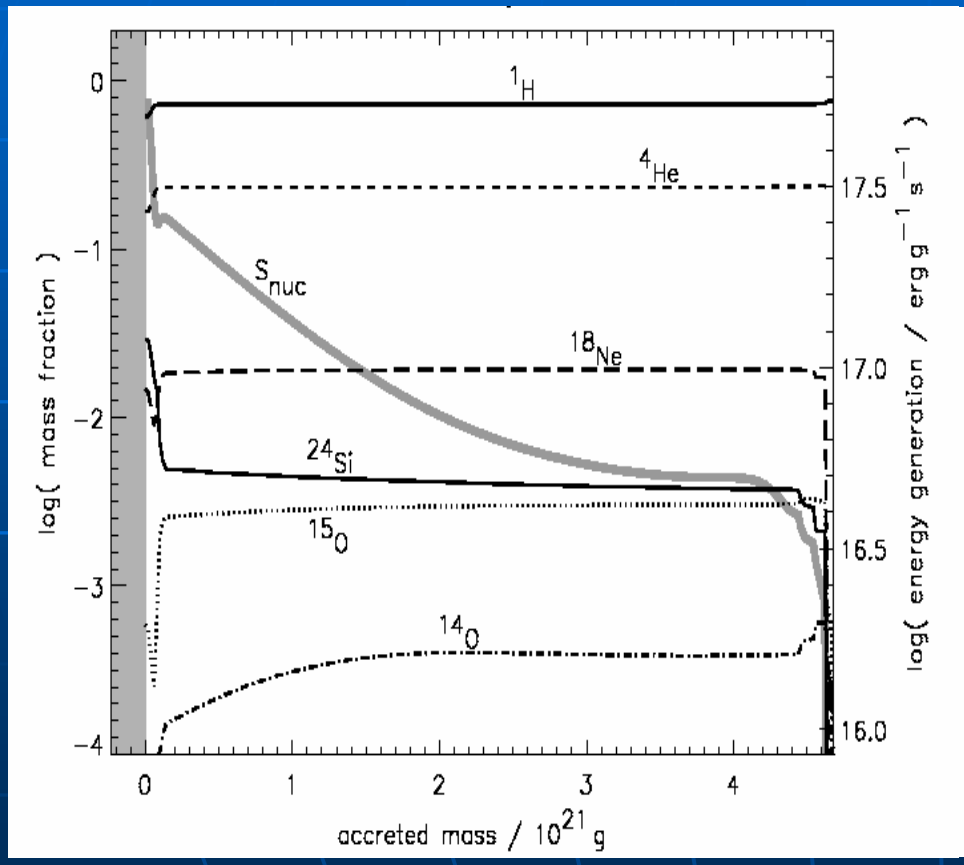


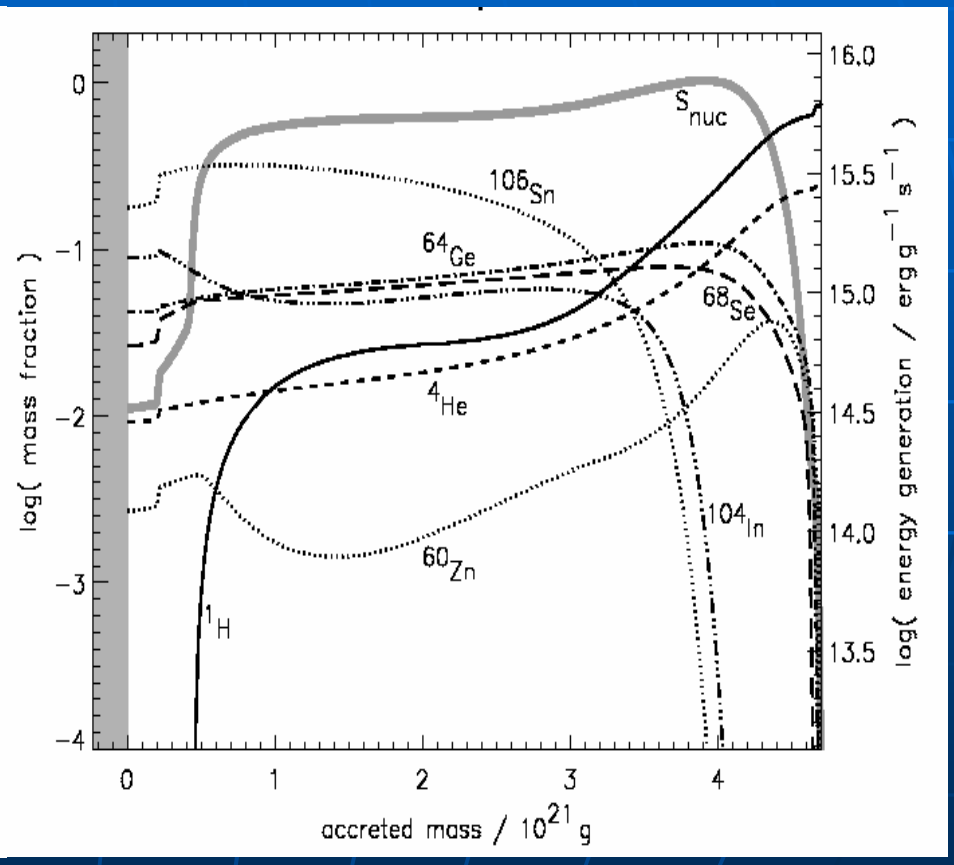


Light curve from the rp-process luminosity in all accreted layers

Light curve and convection in different accreted layers

Abundance & Energy Production in the Accreted Layers

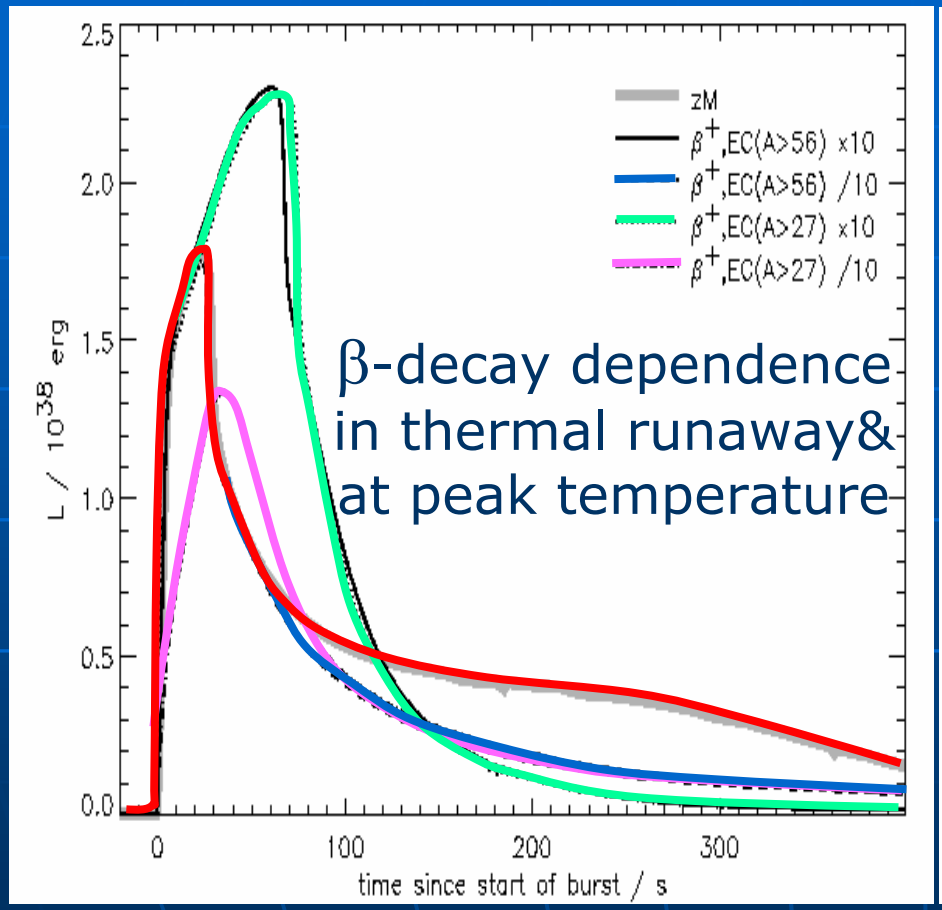


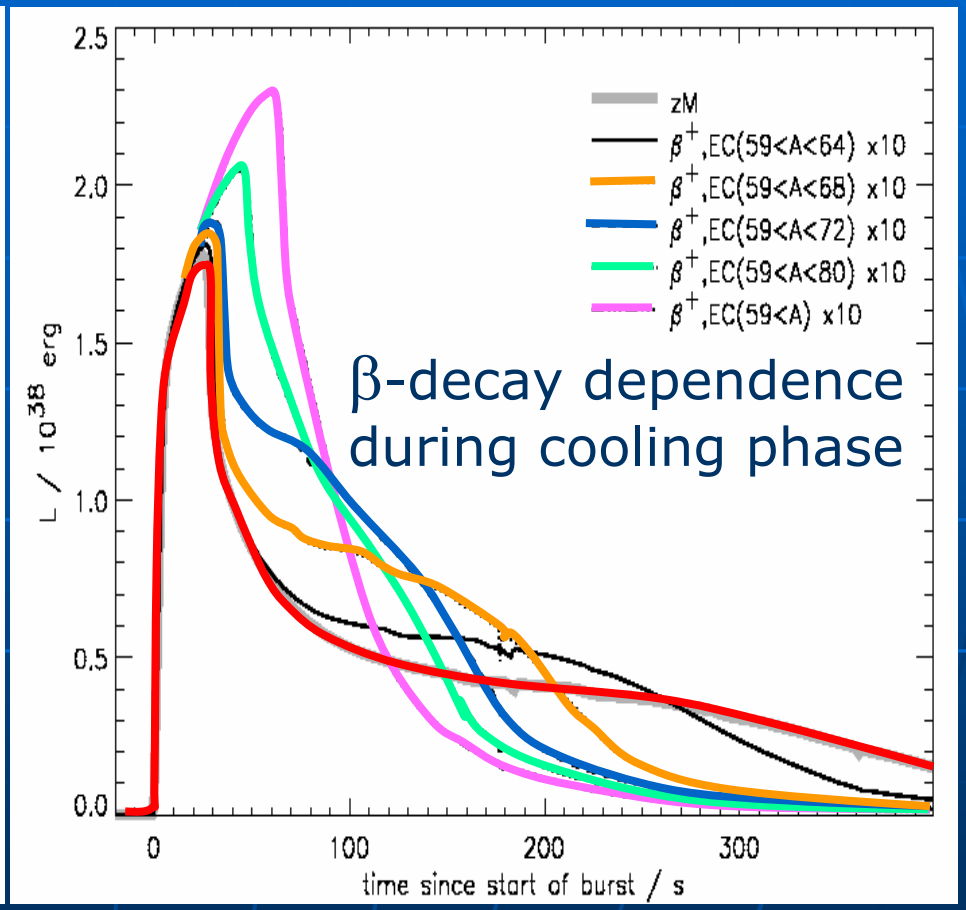


During on-set of runaway
mass stored in hot CNO

During cooling period
mass in waiting points

Parameter study: β^+/EC-decay rates





delay of cooling by larger decay rates ⇒ faster energy release

Changes in β^+/EC rates due to:

- insufficient experimental data

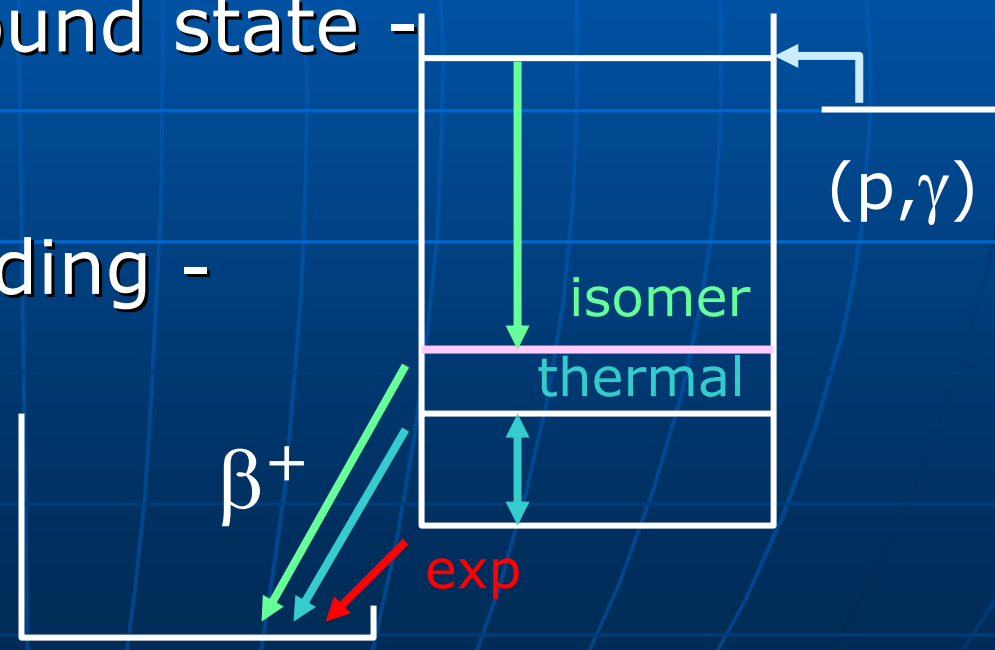
- shell model or QRPA model predictions -

- β^+ decay of thermally excited states

- in equilibrium with ground state -

- β^+ decay of isomers

- populated by (p,γ) feeding -



Conclusion

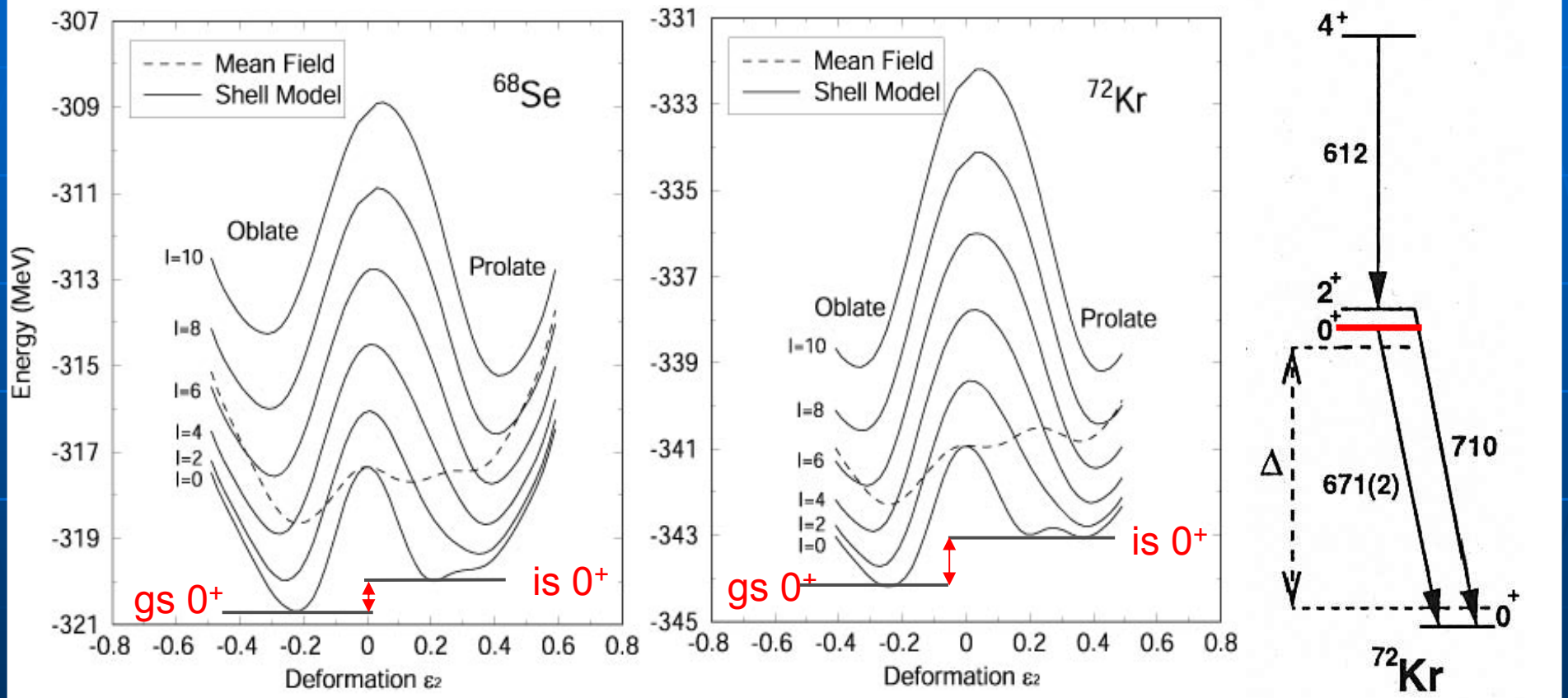
- decay processes determine luminosity
  - light curve as reflection of radioactive decay –

- decay processes determine timescales
  - slowest processes in explosive burning –

- decay processes determine storage
  - fast transport of radioactivity in convection –

- Astronomical observation may give indication on nuclear decay patterns along reaction path?

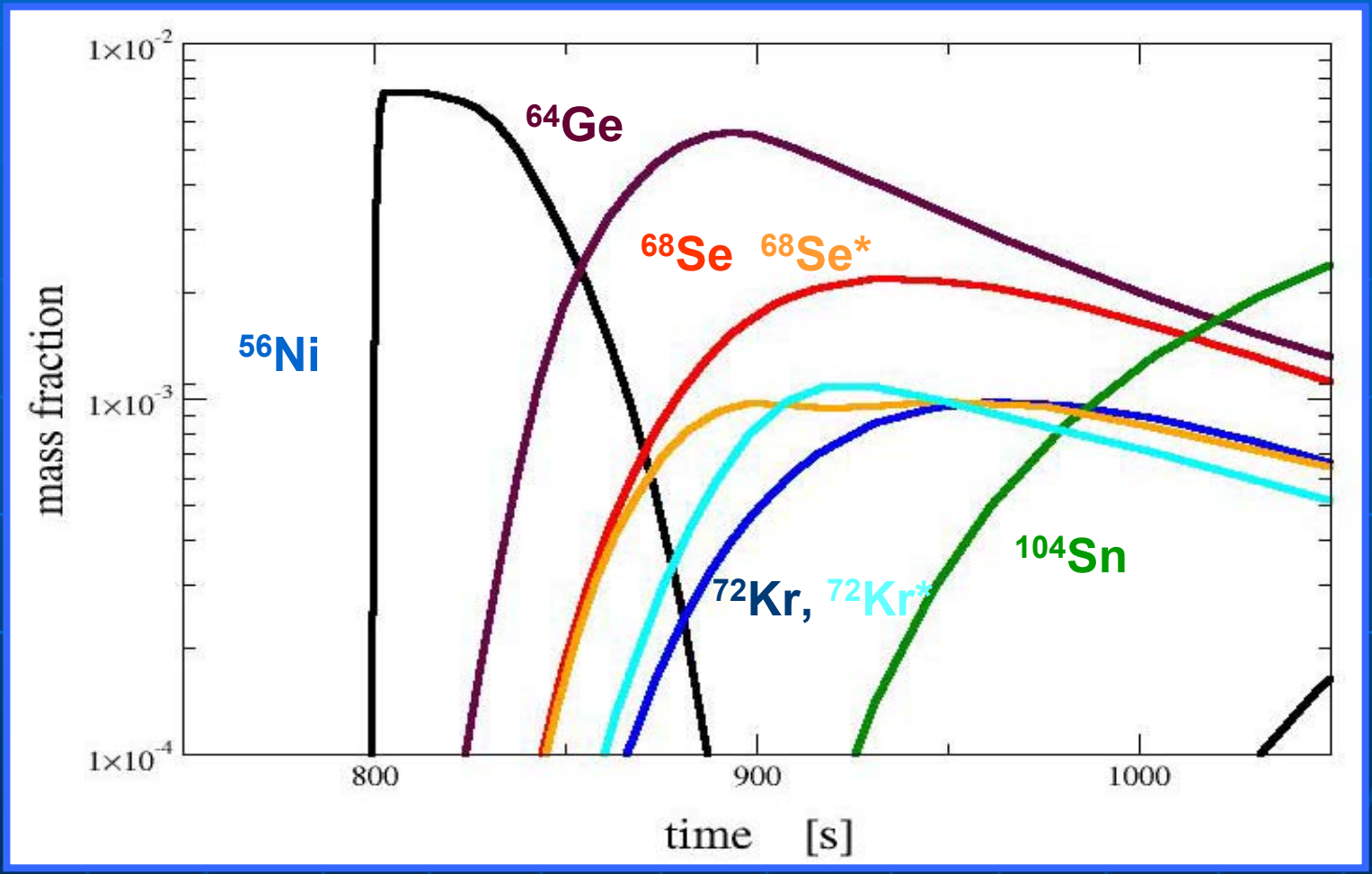
Example: Shape Isomers



(Bouchez et al. PRL 90I, 2003)

New theoretical predictions of shape isomers for A=68,72 N=Z Nuclei using the projected shell model approach. (Yang Sun, 2003)

Abundances



Proton capture on shape-isomer states increases the reaction flow and reduces the timescale for rp-process nucleosynthesis during cooling phase.