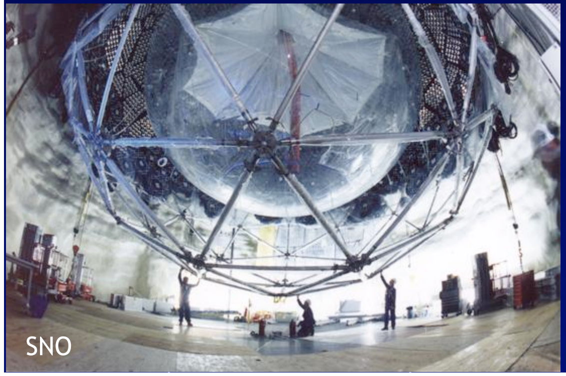

VLT (ESO)


Integral (ESA)

RIA

Opportunities for Astrophysics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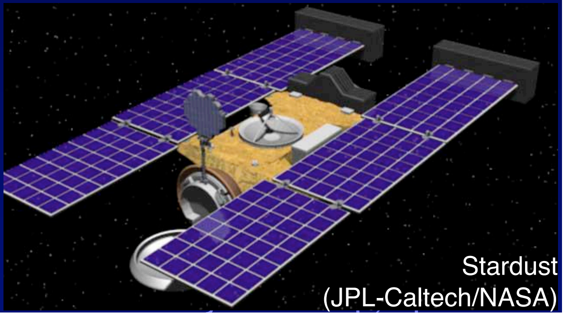
Stardust
(JPL-Caltech/NASA)


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RIA
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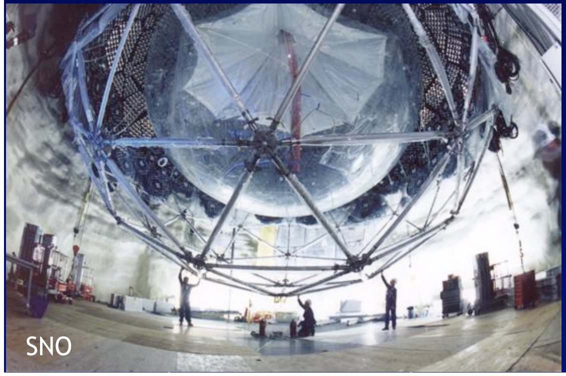
My
RIA
Wish List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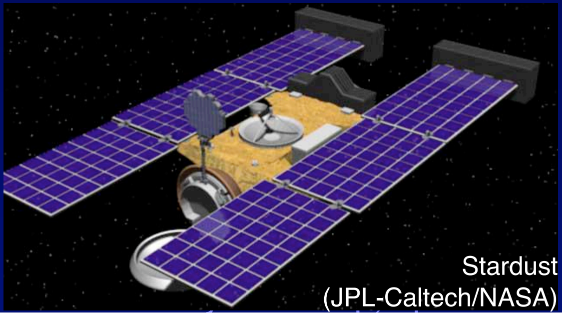
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NextGen RIB
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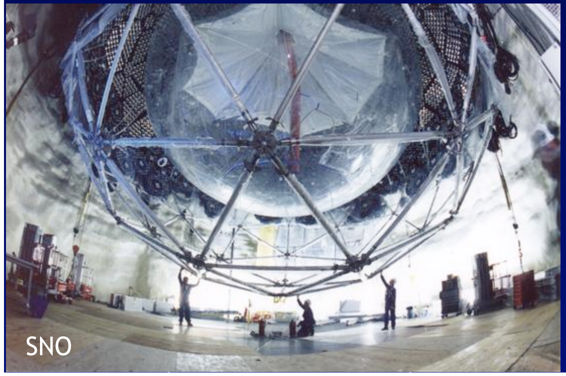
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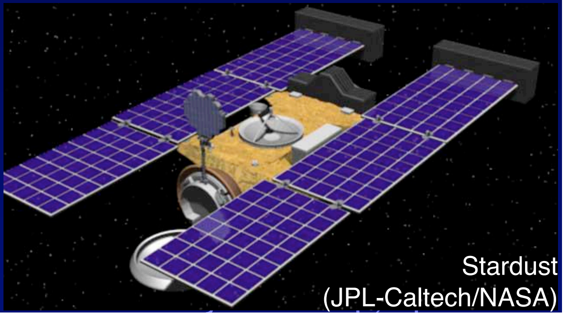

Stardust (JPL-Caltech/NASA)

Facets of RIB Interest

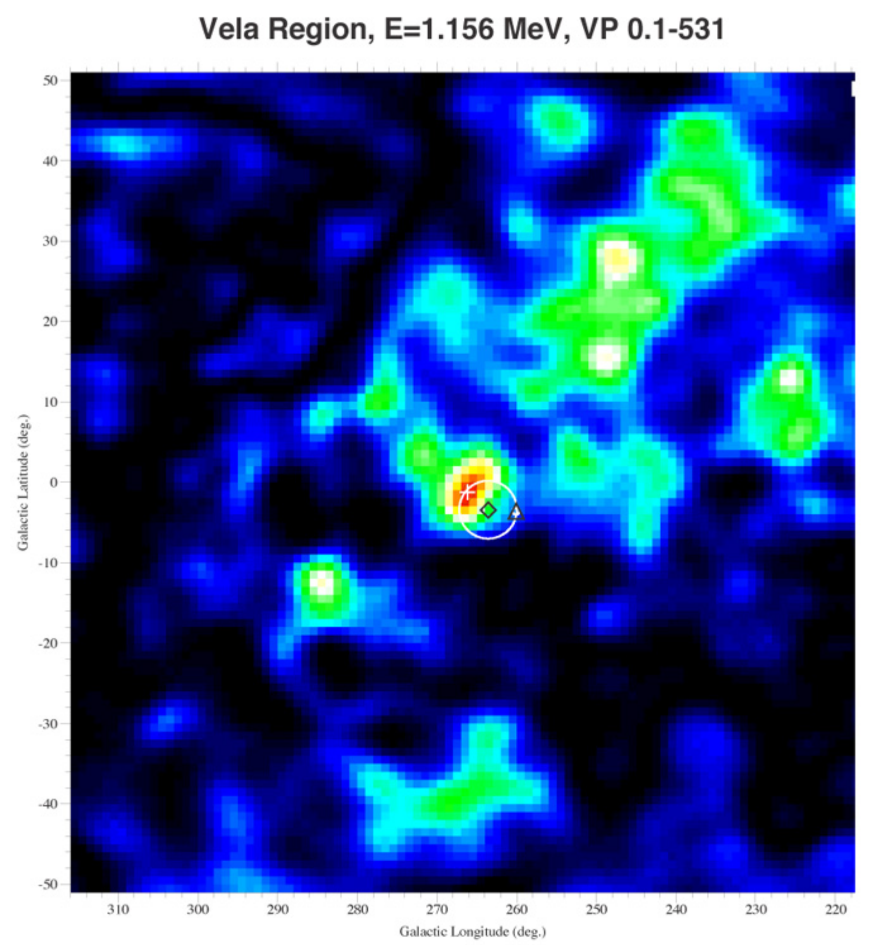
Radioactive Nuclei are involved in virtually all phase of stellar nucleosynthesis.

A few about which I can comment

- Core collapse supernovae
- Novae and X-ray bursts
- r-process

Radioactive Nuclei in Supernovae

- Core Collapse Mechanism
  - Nuclei present during collapse/above shock
  - Nuclear EOS
- Nucleosynthesis
  - Iron-peak
    - ^{56}Ni, ^{57}Ni, ^{44}Ti, etc.
  - p-process
  - r-process



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NASA, P. Challis, R. Kirshner (Harvard-Smithsonian Center for Astrophysics) and B. Sugerman (STScI)

Effects of Nuclear Electron/Neutrino Capture during Core Collapse

There are 2 separate effects.

1) Continuation of nuclear electron capture at high densities results in lower interior Y_e.

2) SMD rates result in less electron capture at low densities.

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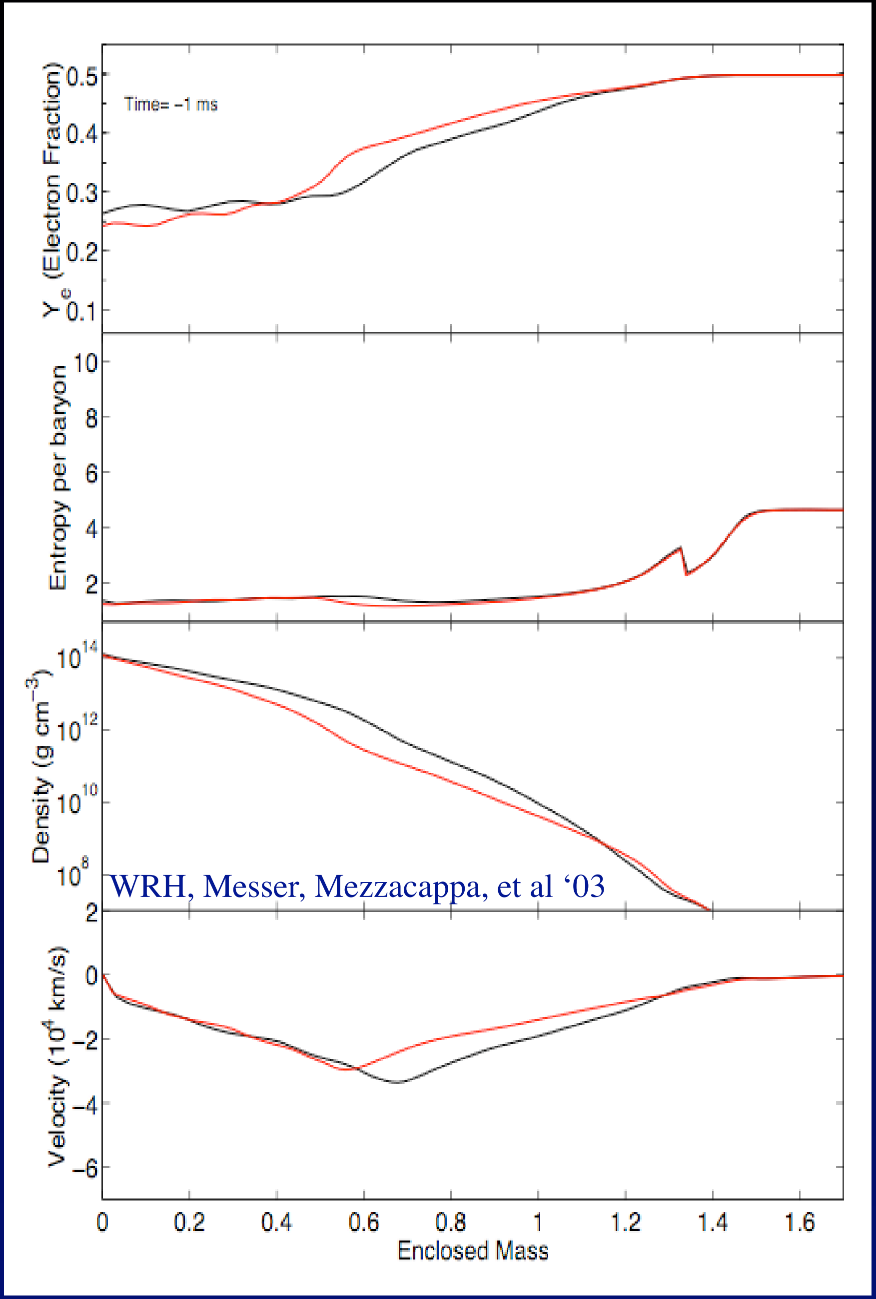

WRH, Messer, Mezzacappa, et al '03

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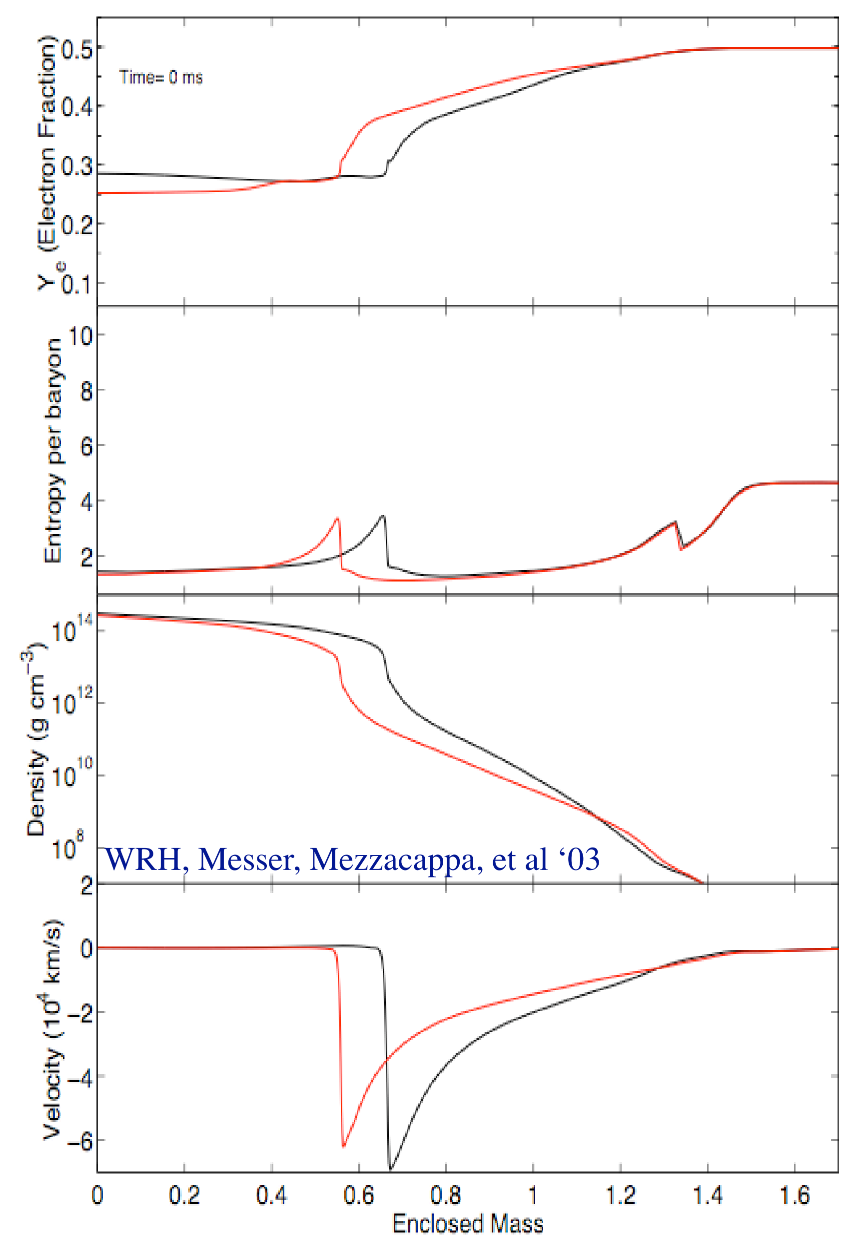

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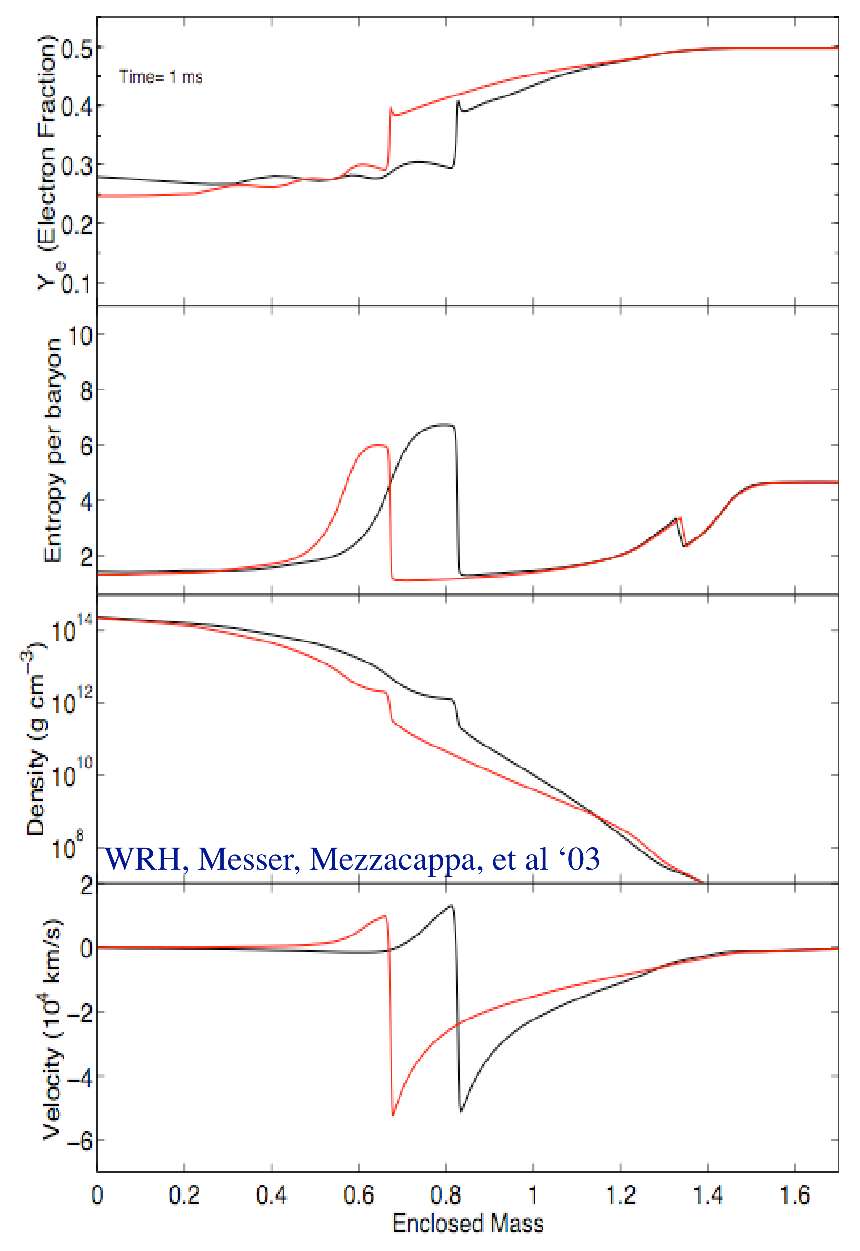

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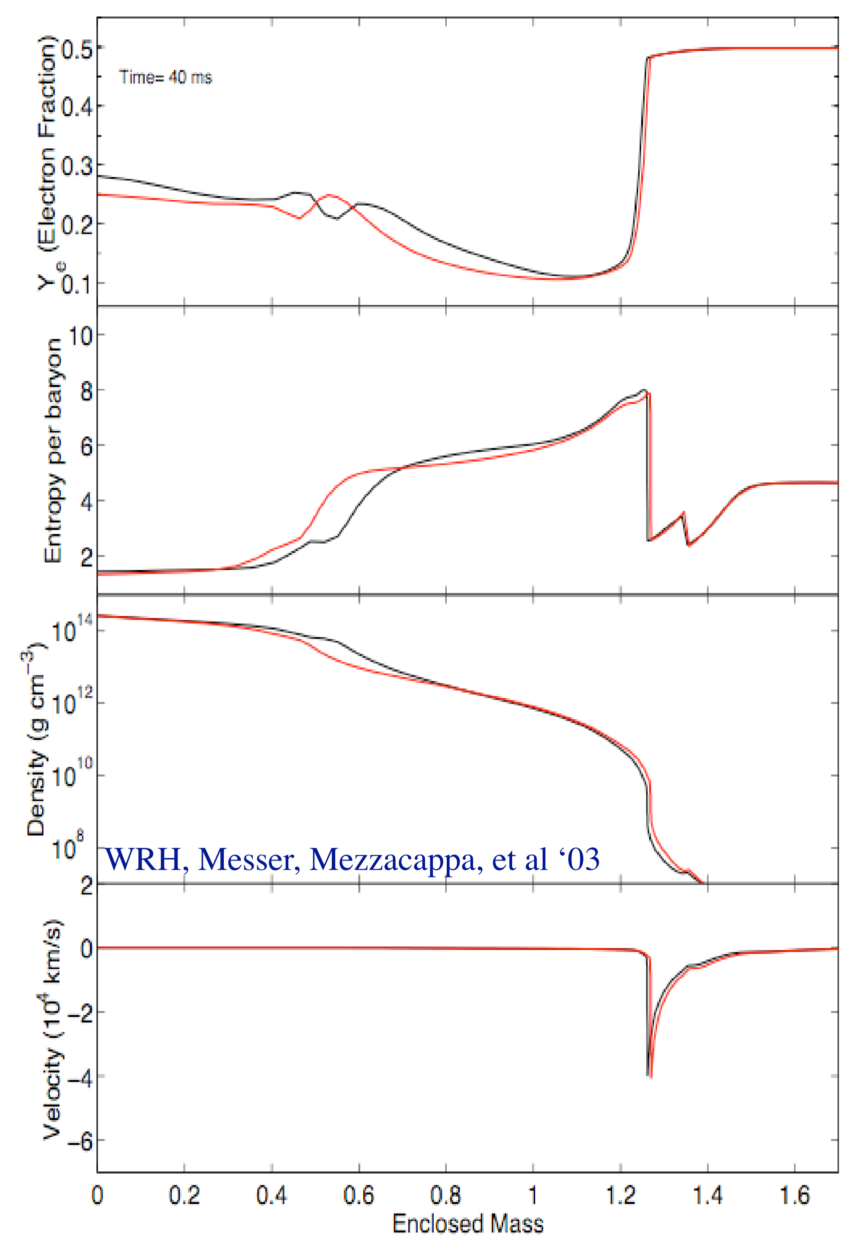


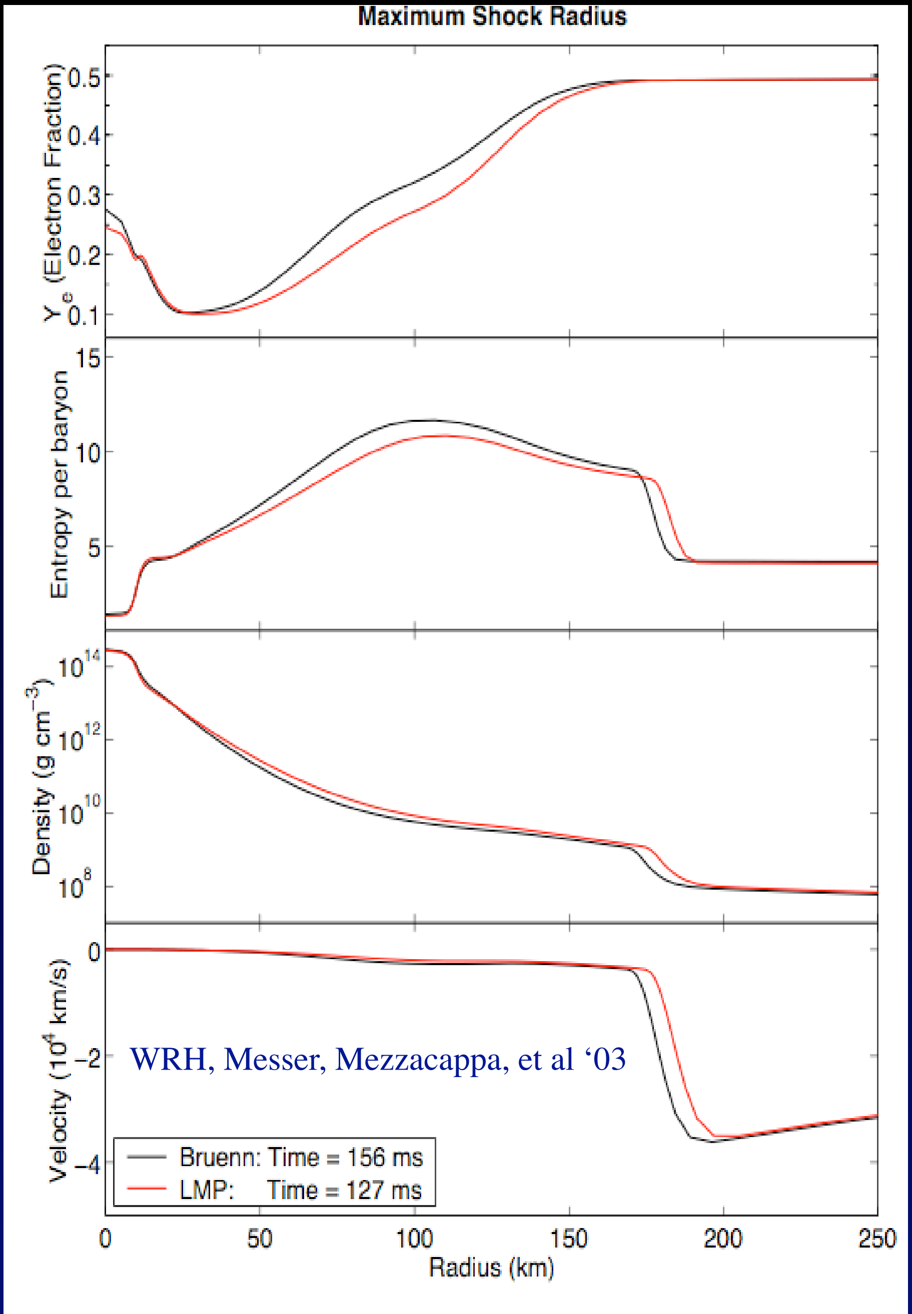
WRH, Messer, Mezzacappa, et al ‘03

Effects on Shock propagation

Gradients which drive convection are altered.

“Weaker” shock is faster.

Maximum excursion of the shock is 10 km further and 30 ms earlier.

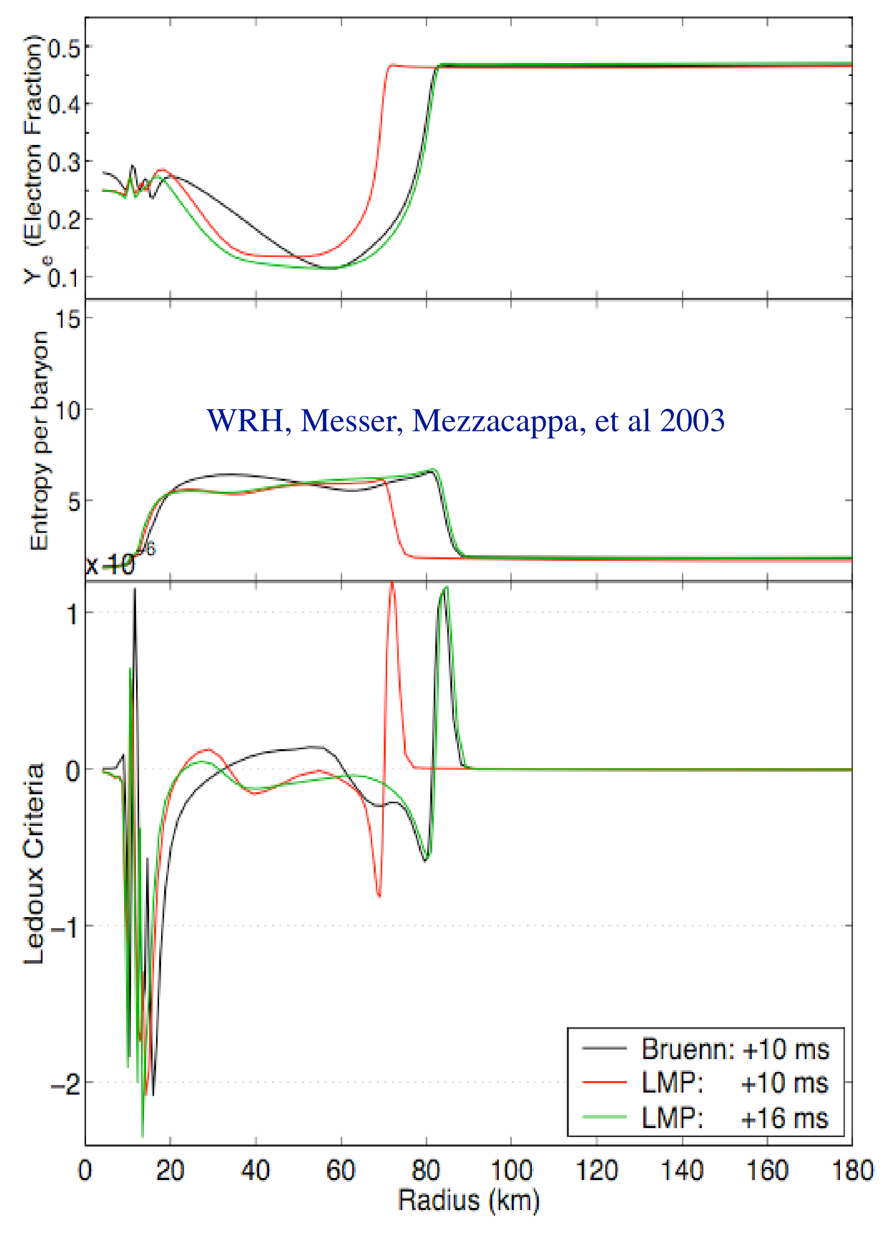


WRH, Messer, Mezzacappa, et al ‘03

PNS Convection

Fluid instabilities which drive convection result from complete neutrino radiation-hydrodynamic problem including nuclear interactions.

Updated nuclear e^-/ν capture restricts PNS convection to smaller, deeper region.

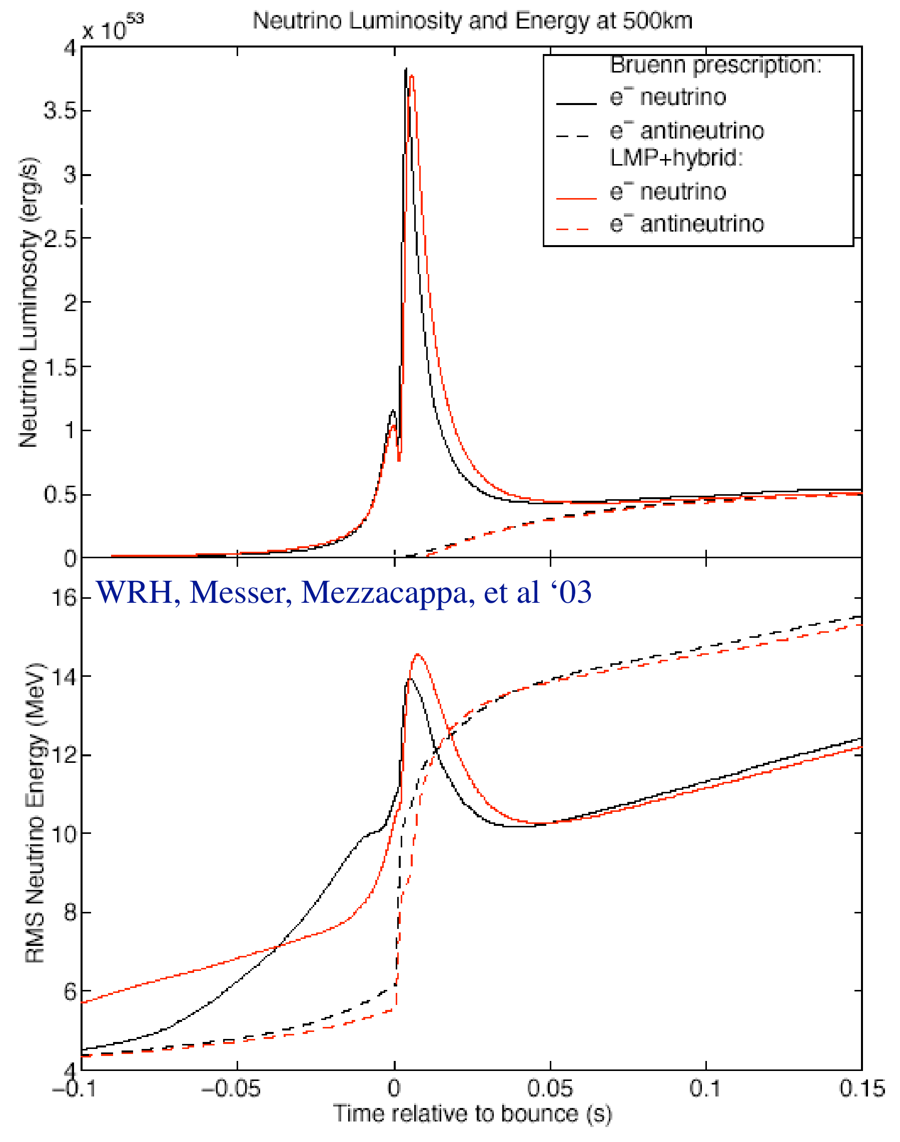


WRH, Messer, Mezzacappa, et al 2003

Changes in Neutrino Emission

ν_e burst slightly delayed and prolonged.

Other luminosities minimally affected (~1%).



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Changes in Neutrino Emission

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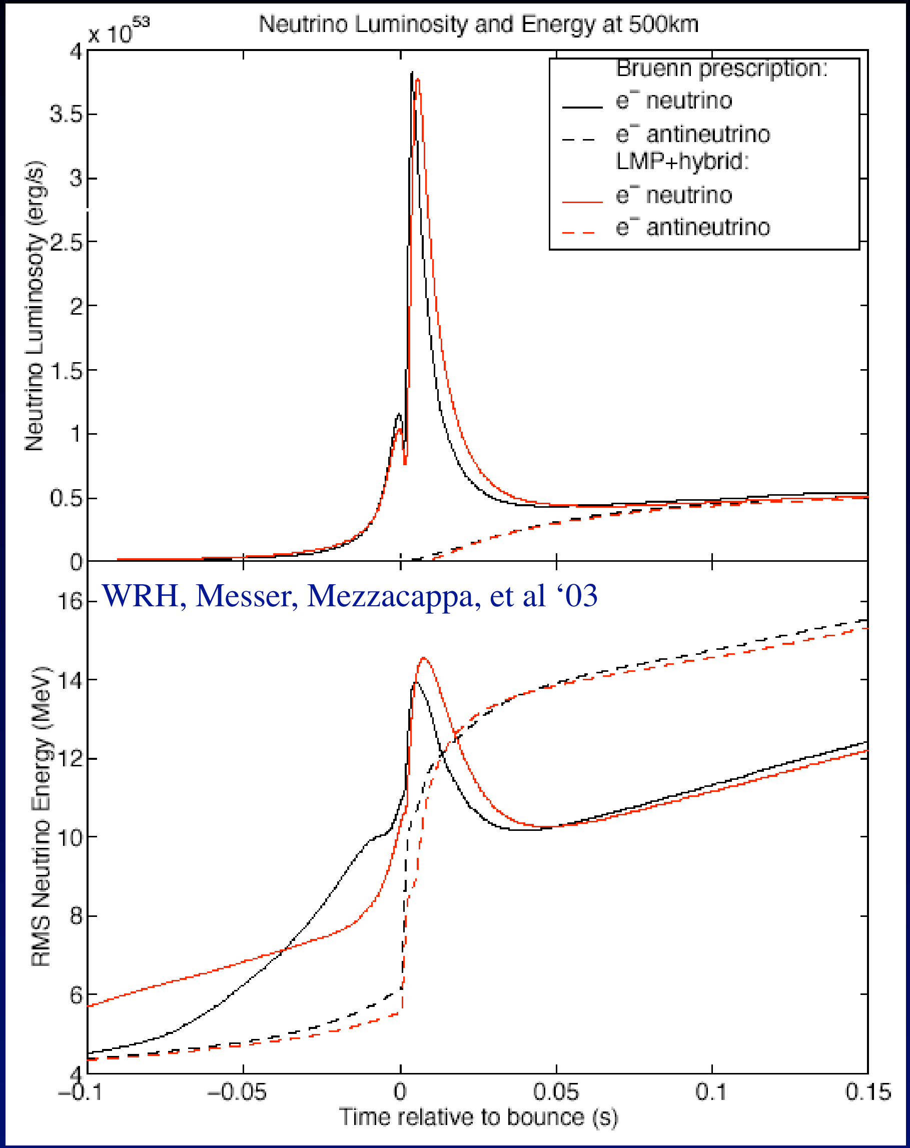
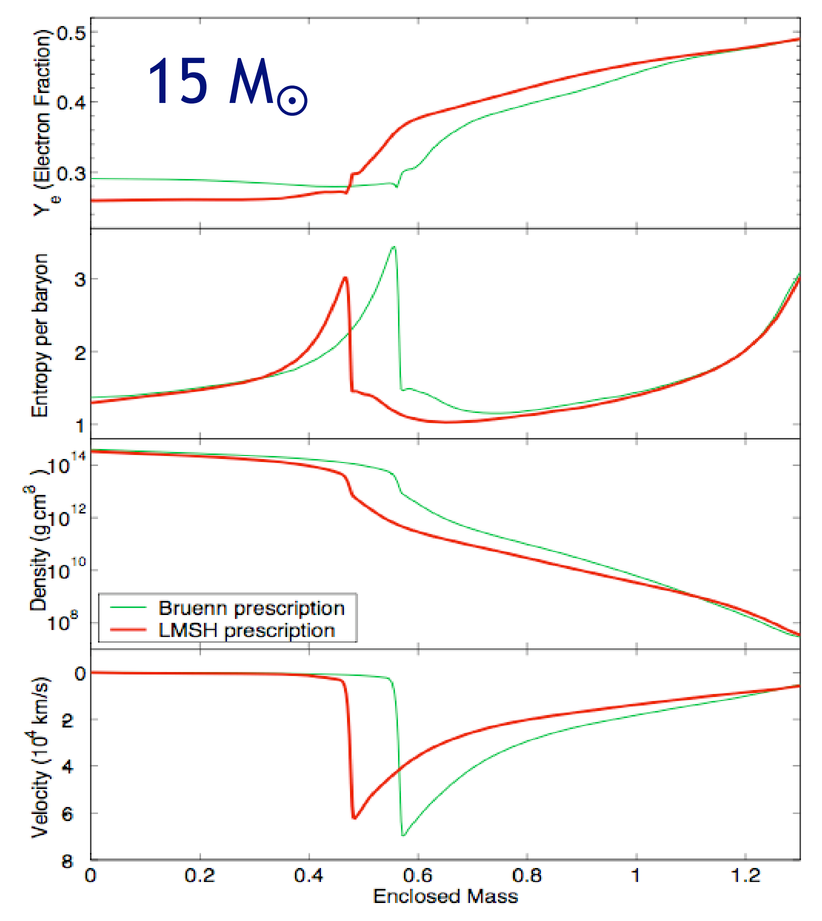
Mean ν Energy altered:

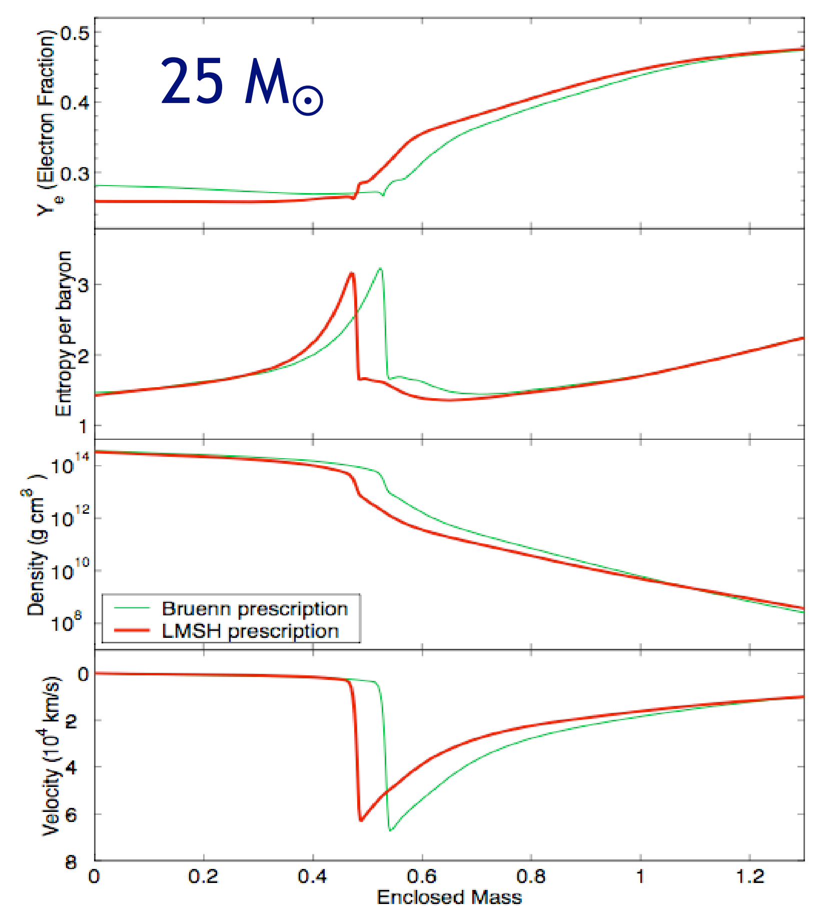
- 1-2 MeV during collapse
- ~1 MeV up to 50ms after bounce
- ~.3 MeV at late time



WRH, Messer, Mezzacappa, et al ‘03

The impact of stellar mass





Higher mass cores have higher initial entropy.

Effects of nuclear electron capture are reduced but comparable (1/2 to 2/3).

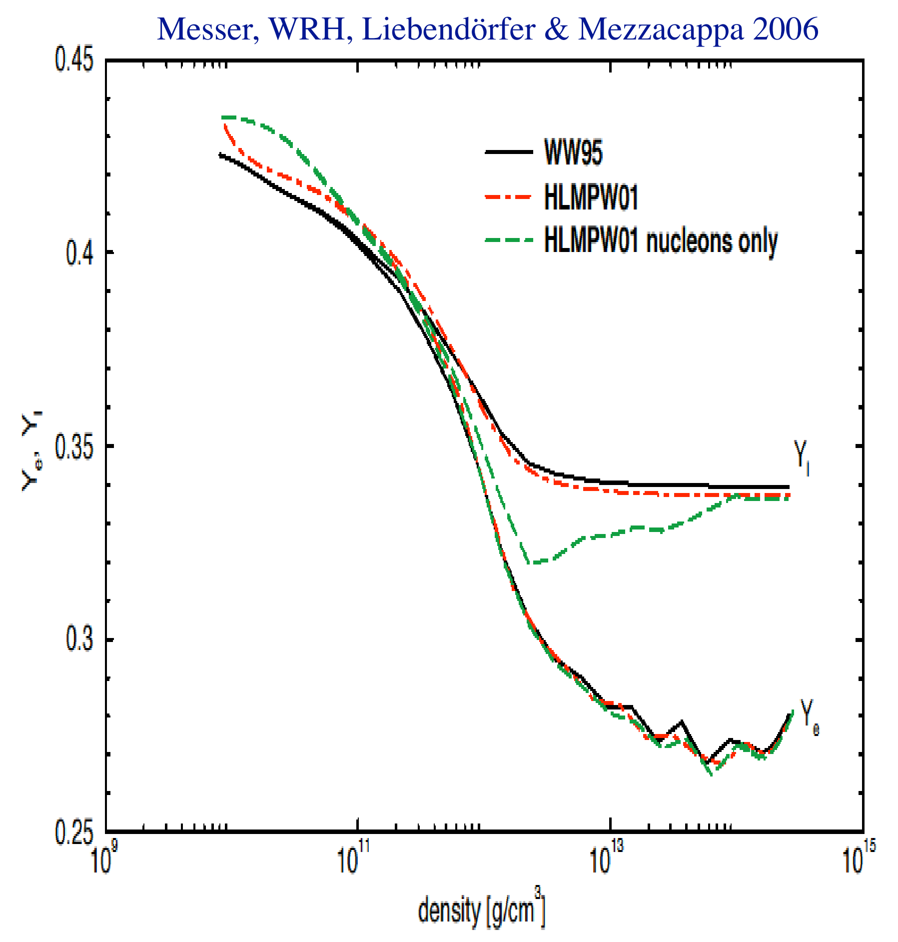
Electron Capture Feedback

Continued e^-/ν capture on nuclei not only changes the amount of capture but also breaks a feedback loop.

When e^- capture on protons dominates, there is a strong self regulation because Y_p (and therefore dY_e/dt) is a strong function of Y_e. This washes out differences in Y_e.

Example:

e^- capture on protons during collapse erases differences between progenitors with improved e^- capture rates.

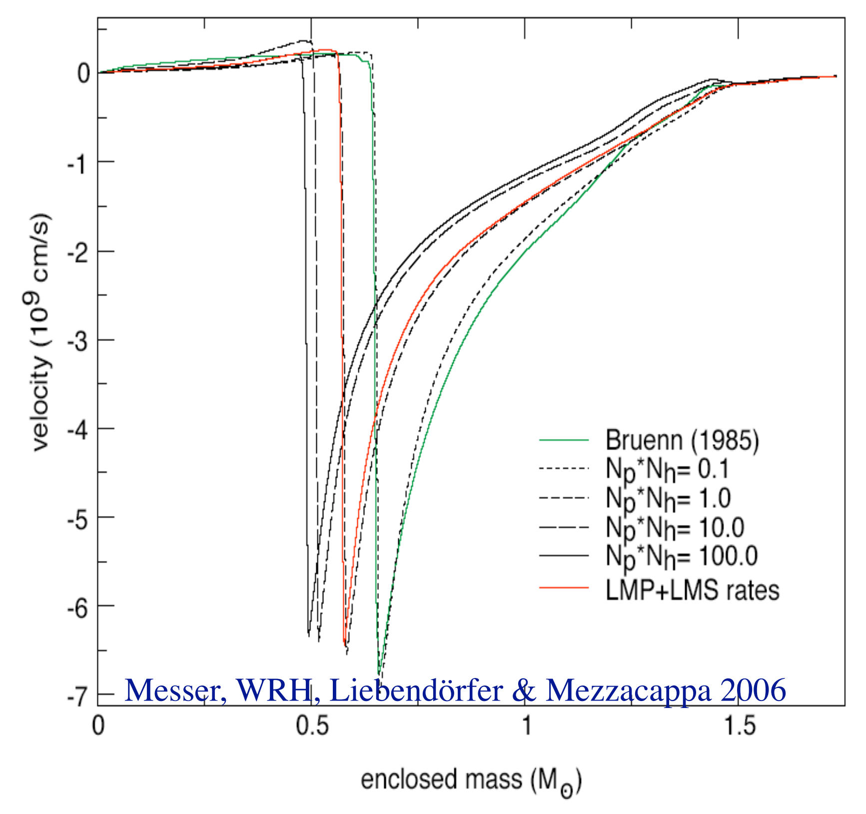

Messer, WRH, Liebendörfer & Mezzacappa 2006

Testing the Sensitivity

Used Bruenn (1985) as a reproducible starting point.

Replaced quenching term with parameter (N_pN_h) = 0.1-100

Changes from current electron capture rate of a factor of 10 move shock formation by ~0.1 solar mass.



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$$j_{nuclear} = \frac{2}{7}\frac{(2\pi)^4 G_F^2}{\pi h^4 c^4} g_A^2 \frac{\rho X_H}{m_B A} N_p(Z) N_h(N) (E+Q')^2 \left[1-\left(\frac{M_e}{E+Q'}\right)^2\right]^{1/2} F_e(E+Q'), \quad (1)$$

where

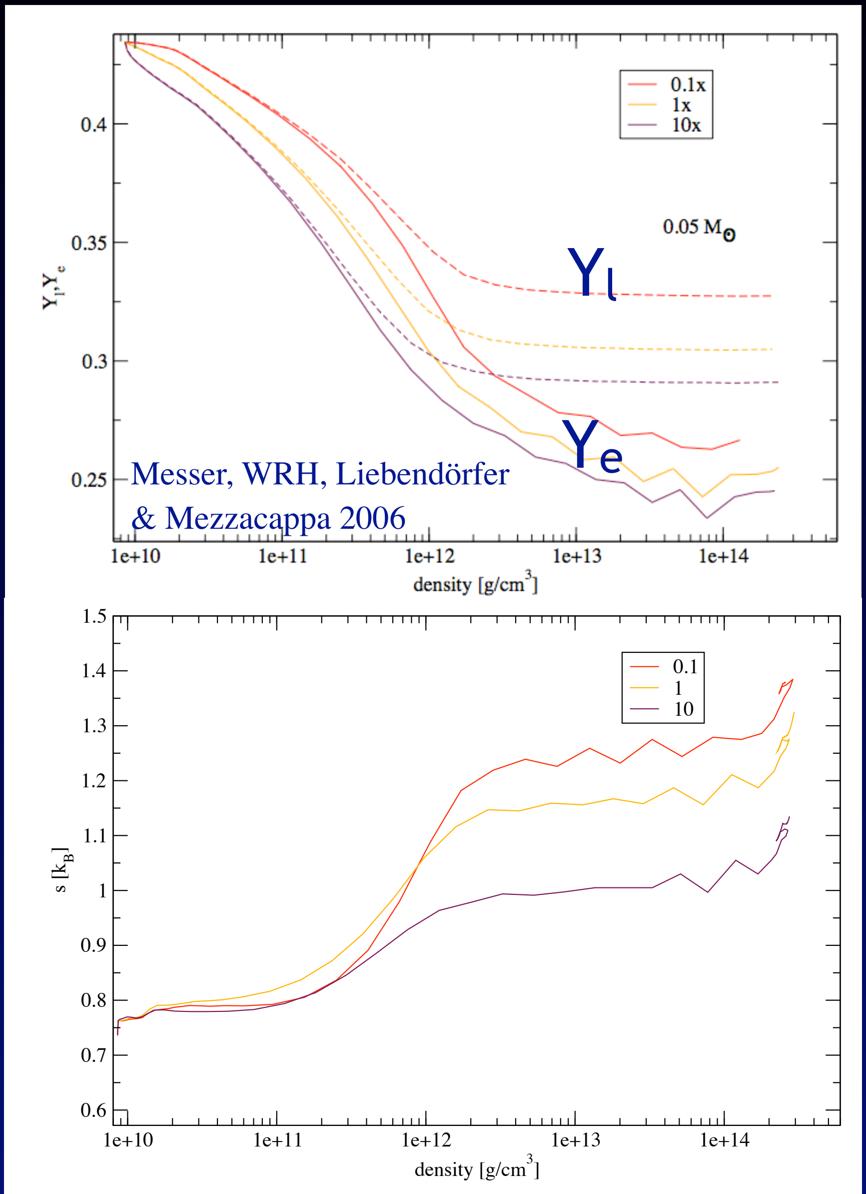
$$N_p(Z) = \begin{cases} 0 & Z < 20 \\ Z-20 & 20 < Z < 28 \\ 8 & Z > 28 \end{cases} \quad \text{and} \quad N_h(N) = \begin{cases} 6 & N < 34 \\ 40-N & 34 < N < 40 \\ 0 & N > 40\,. \end{cases} \quad (2)$$

Determining Y_e and Entropy

Change in lepton abundance ($Y_l = Y_e + Y_\nu$) occurs gradually over 2+ decades of density up to ~3×10^{12} g/cm^3.

Beyond equilibration, variations in Y_e reflect thermodynamic changes.

Entropy is flat until appreciable Y_ν is achieved allowing significant neutrino capture and heating then flattens after equilibration.



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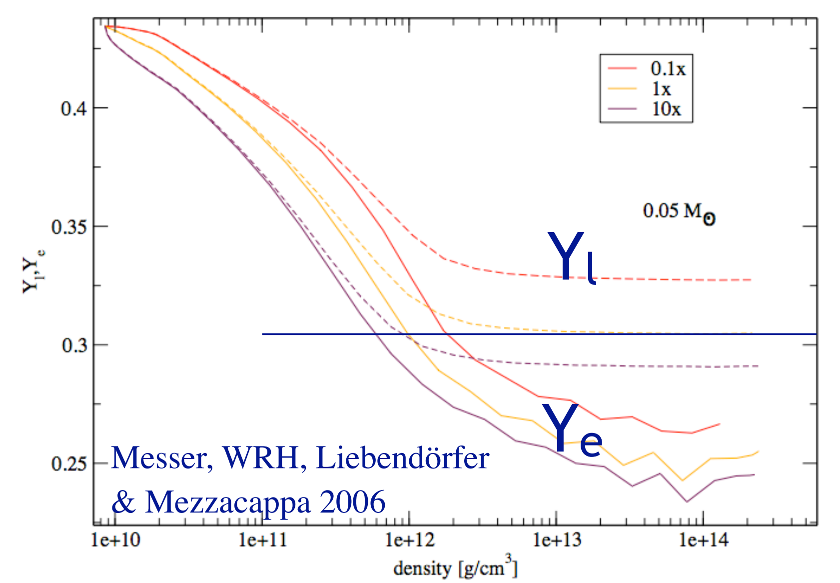

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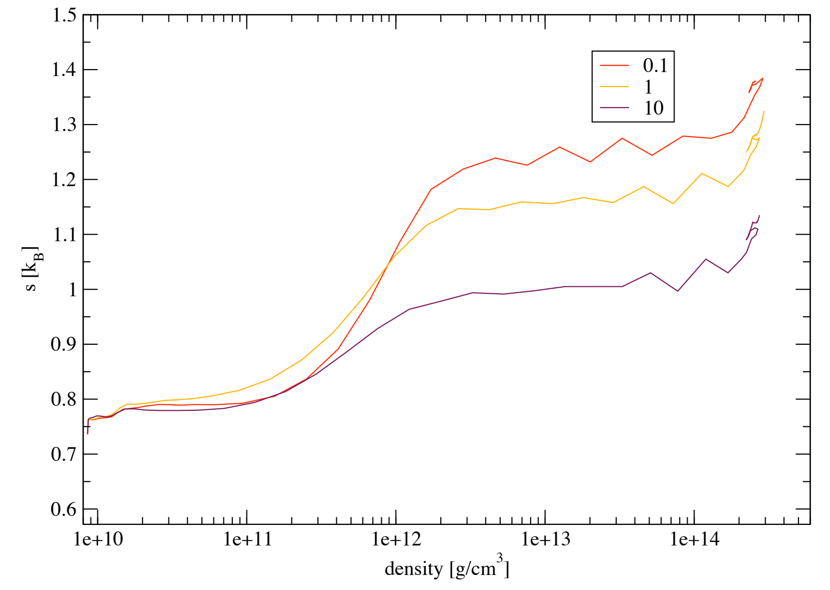
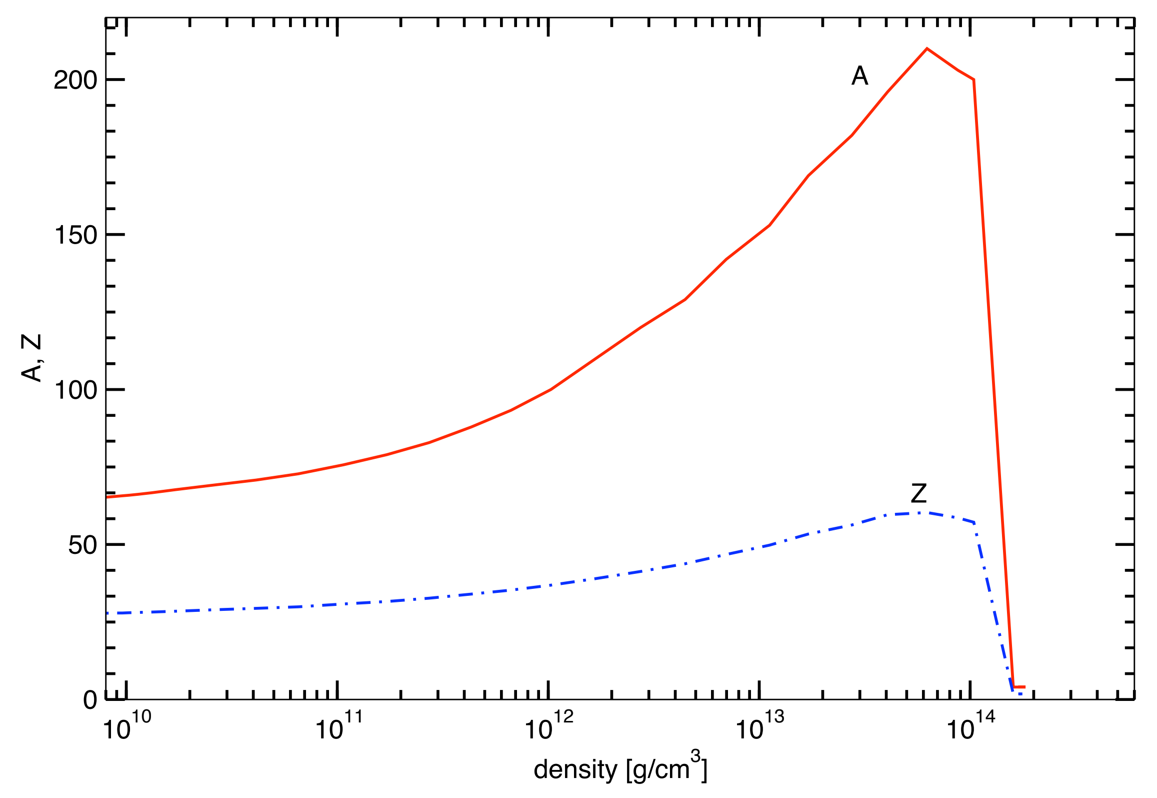


Needed Electron Capture Rates



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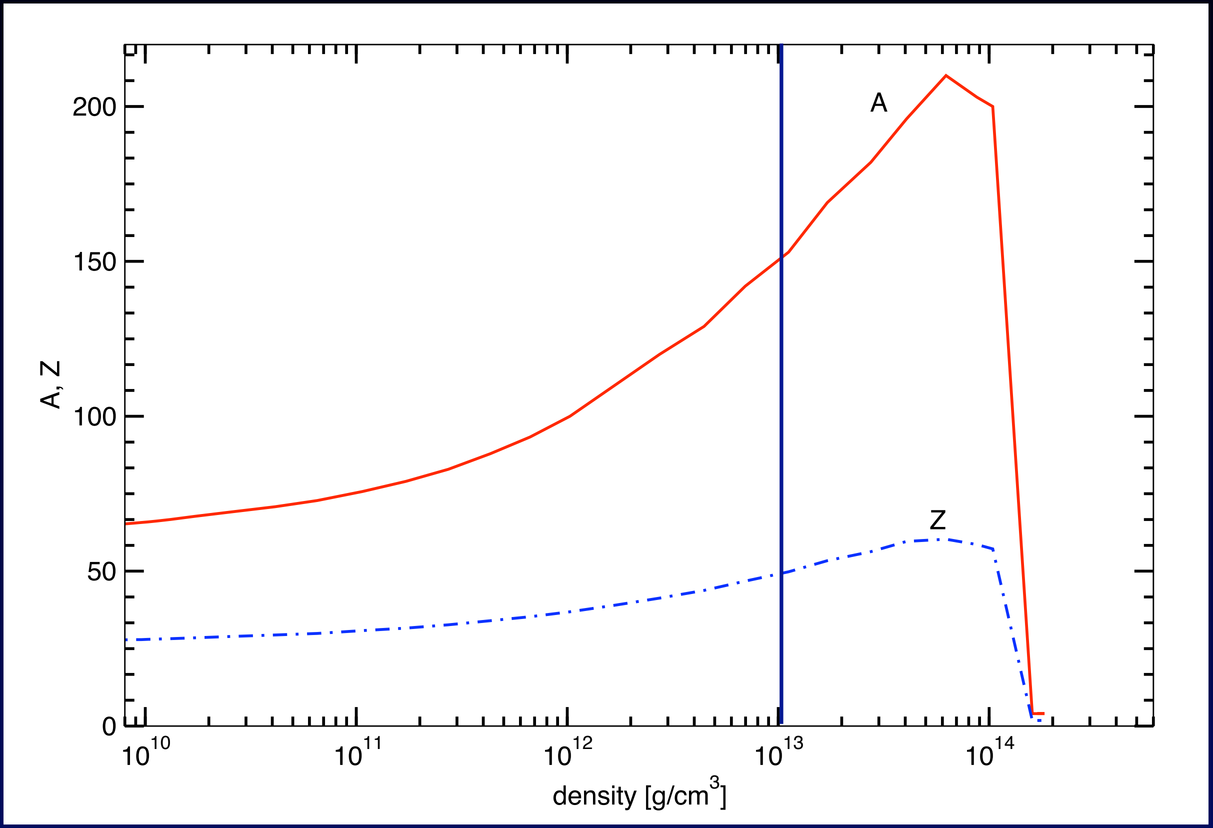

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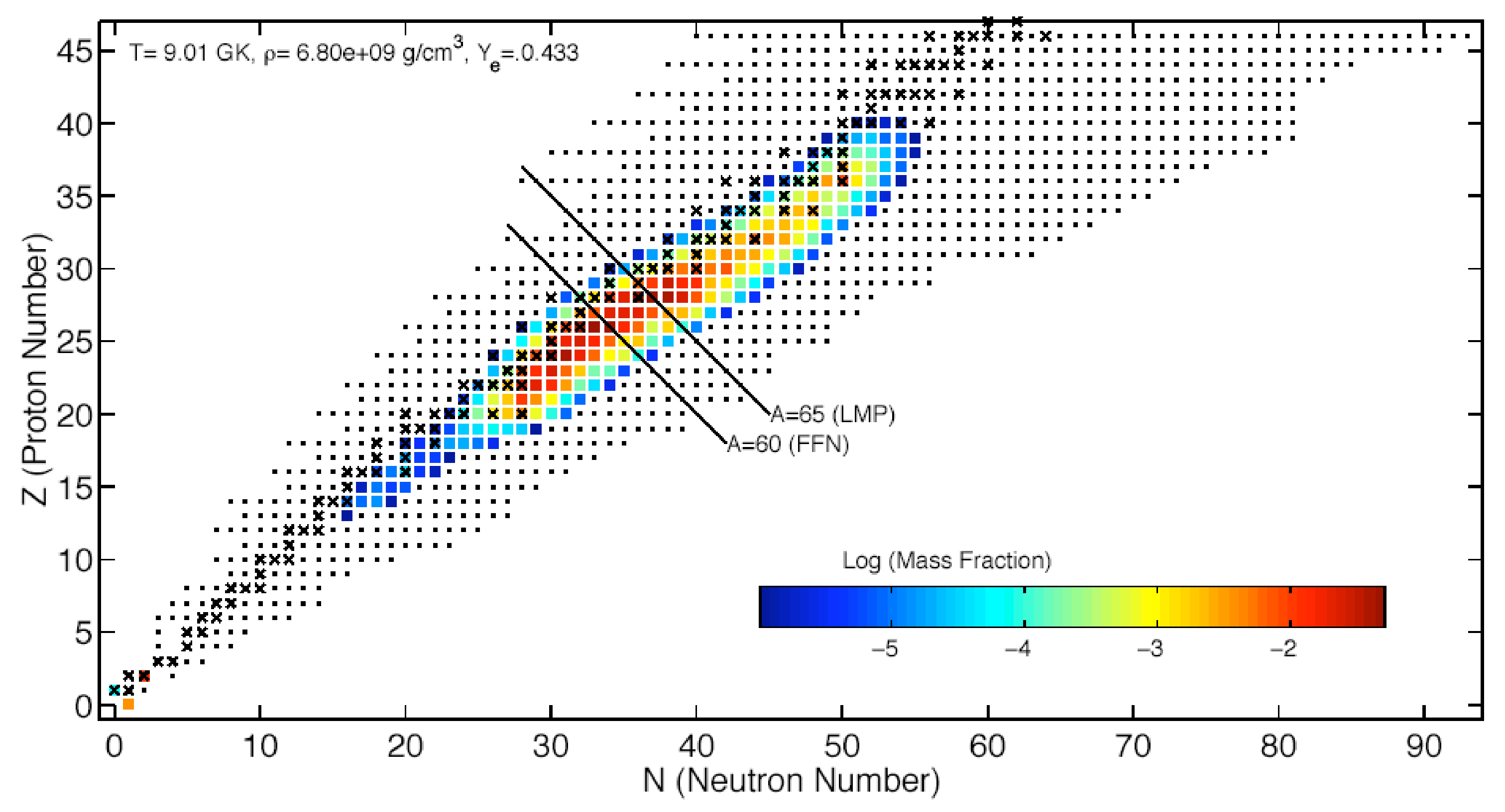

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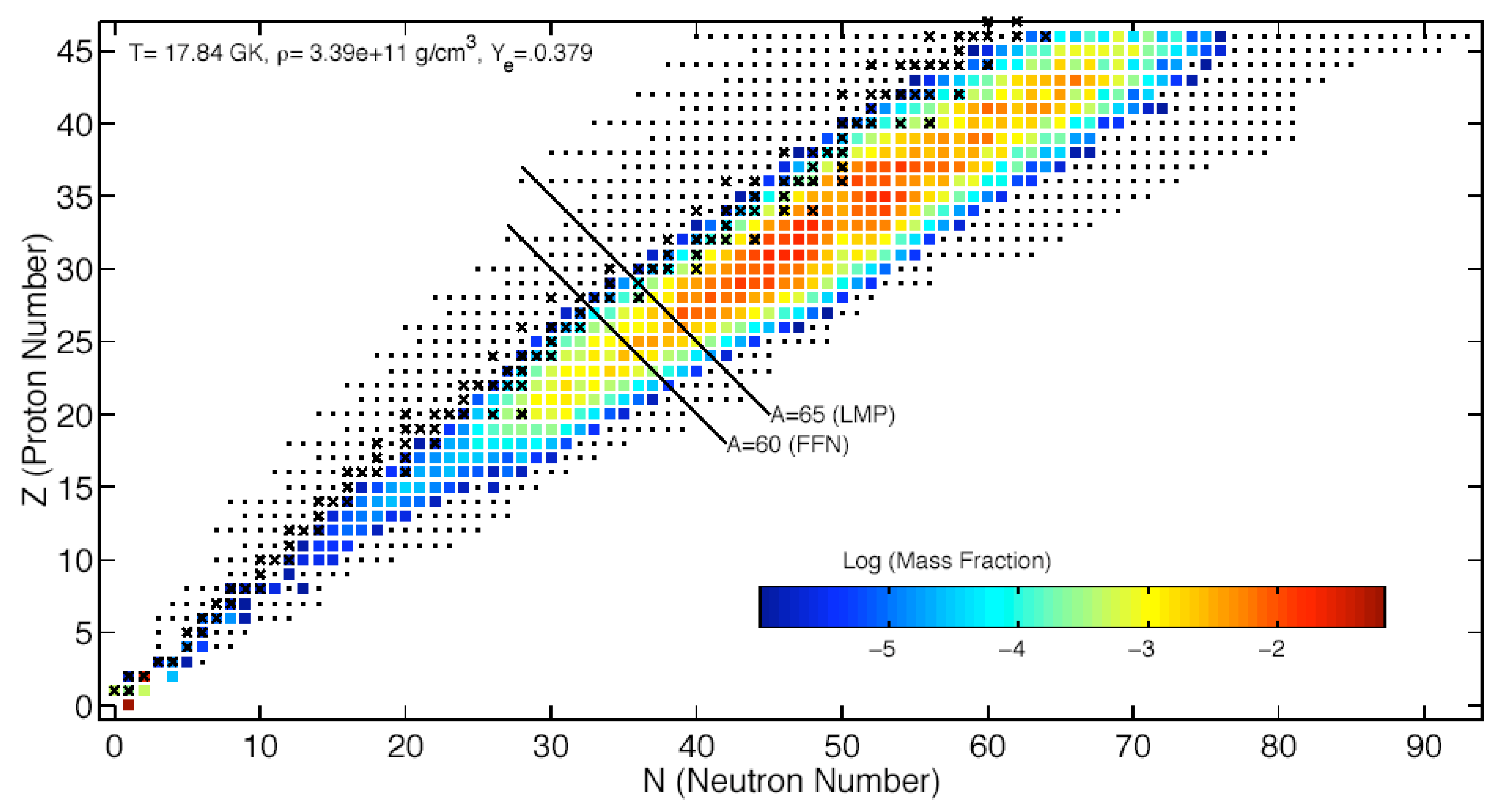


Nuclei with A < 120-150 contribute to e^-/ν capture.

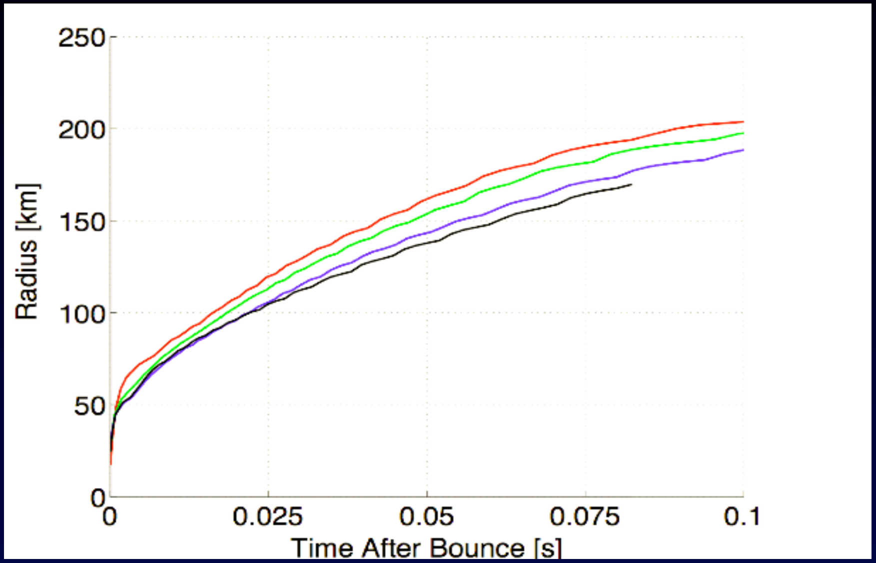
Many rates are needed, with declining quality needed with increasing mass.

Explosive Effects

Effects of electron capture on core collapse are clear.

However, collapse and explosion are separated by a "pause".

Thus the long term impact on the supernova explosion is an open question.



Changes in PNS structure and resulting changes in the neutrino luminosity and spectra seem robust.

However effects on shock propagations bridge at least part of the "pause" and are significant.

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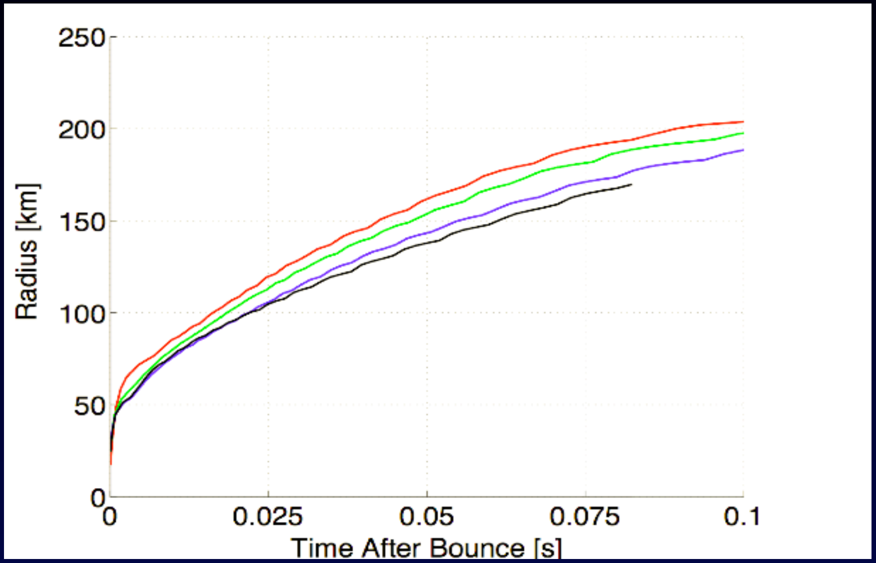

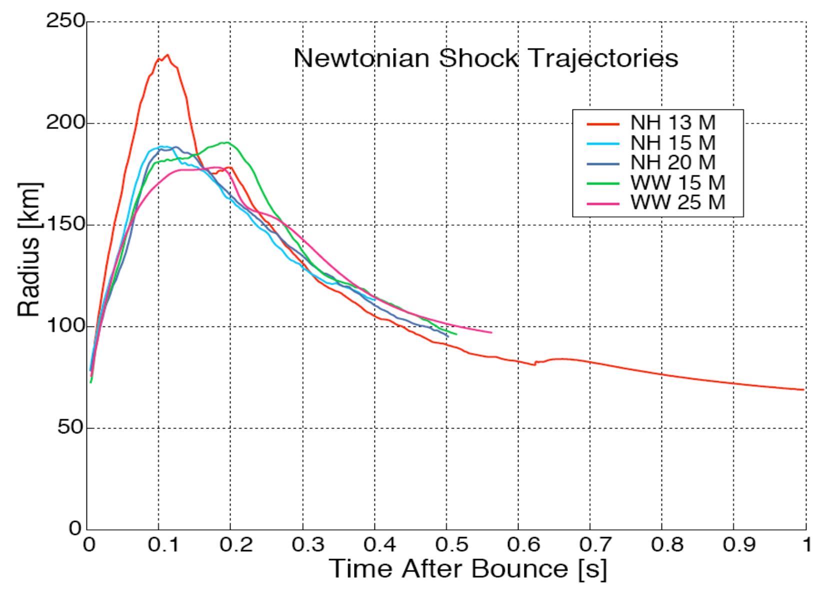

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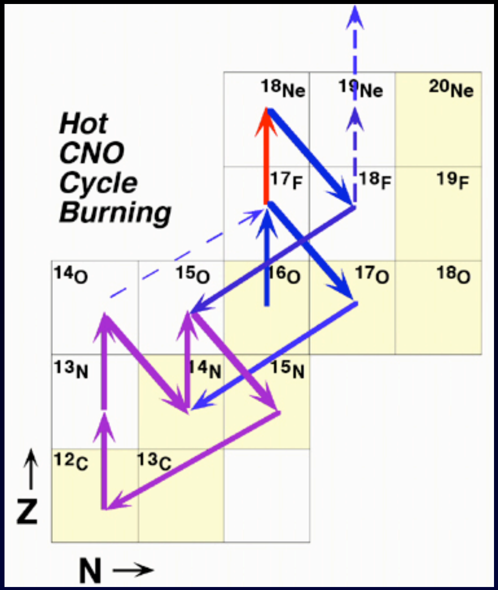
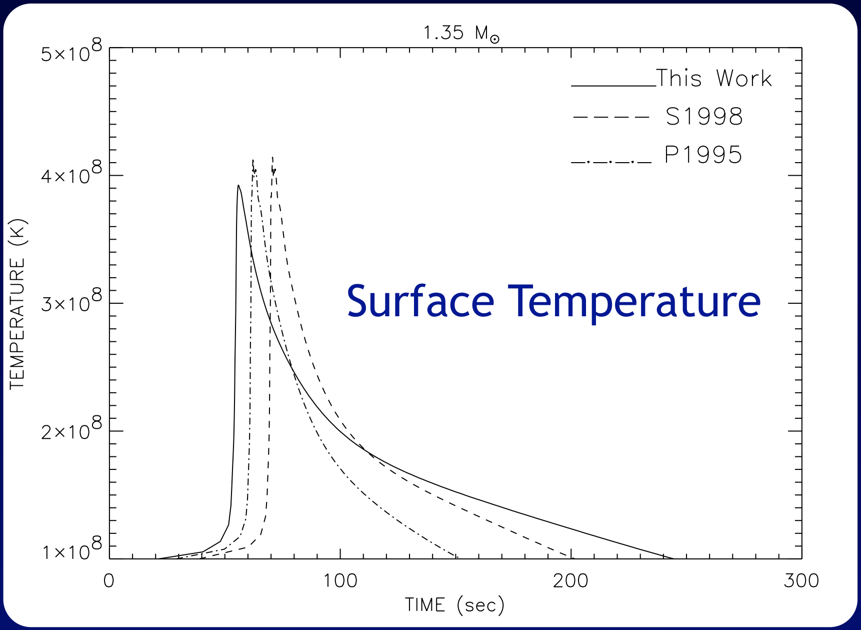
Nuclear Reactions in Novae

Hydrogen Burning in Novae occurs via the Hot CNO cycle, as well as NeNa and MgAl cycles at higher mass.

Rates for many of these reactions have been measured with RIBs in the past few years.





Starrfield, WRH & Iliadis 2006, in preparation

Models using newer rates show large variations in bulk properties, like luminosity.

Nucleosynthesis products change by factors of two or more.

For example, ^{13}C(-17%), ^{15}N (-83%), ^{17}O(-64%), ^{22}Na(-52%), ^{26}Al(+7%).

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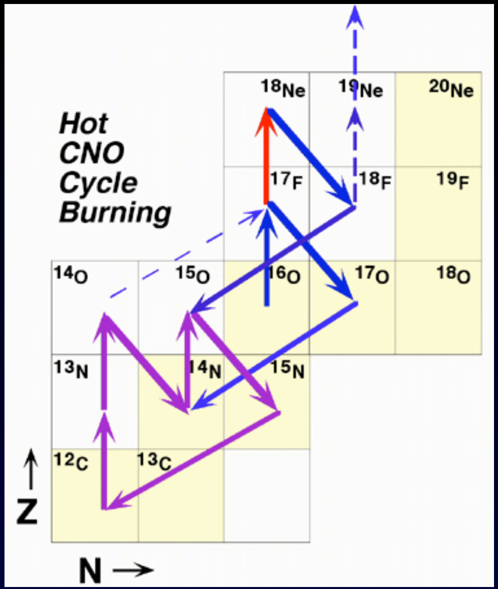

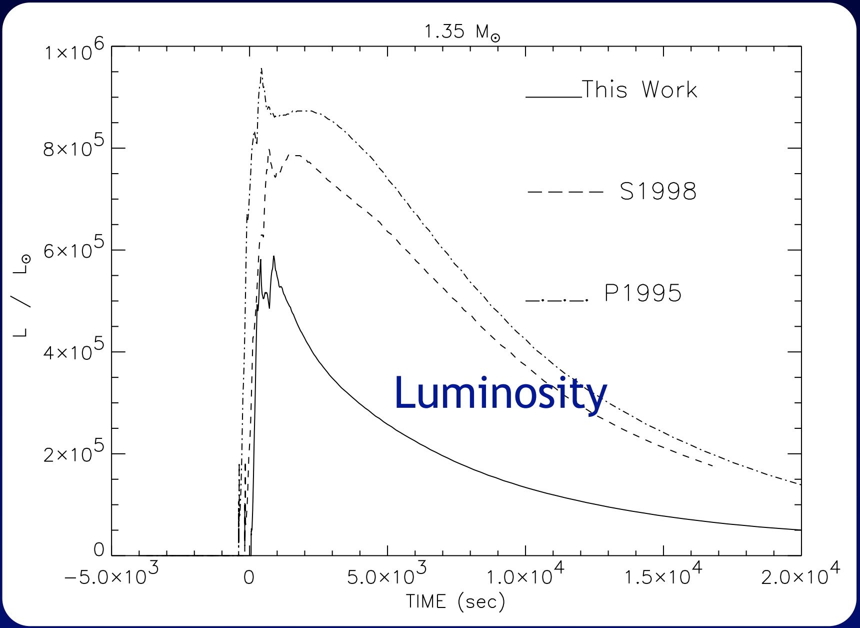

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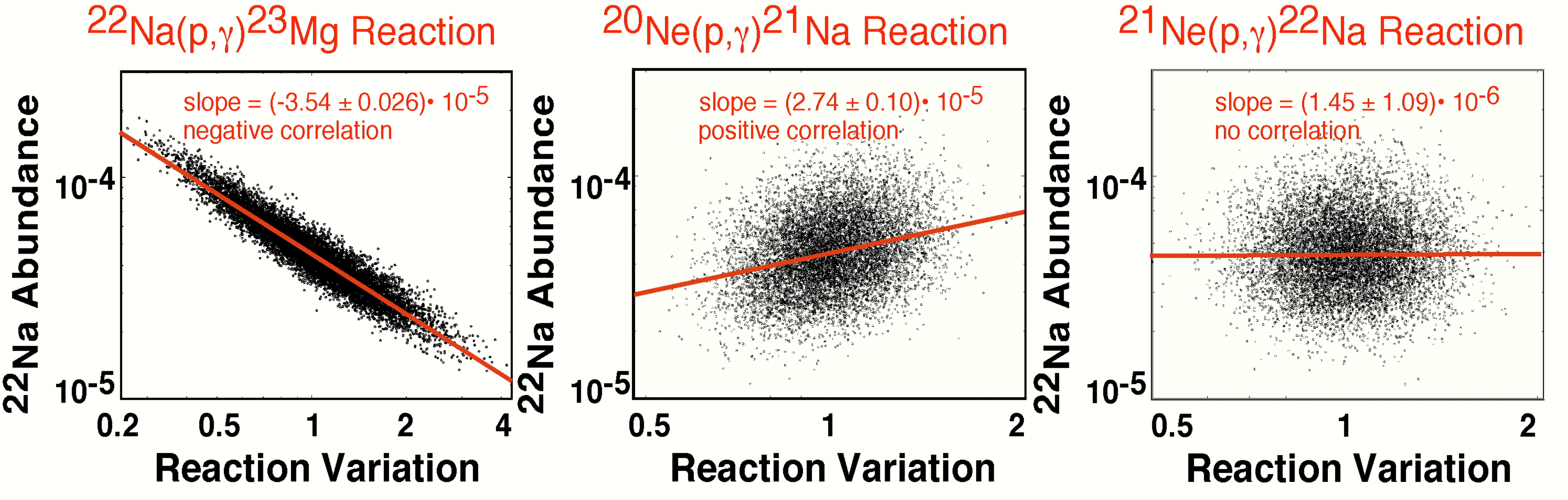
Helping to Choose Future Measurements

Sensitivity analysis studies which reaction rate rates affect energetics and nucleosynthesis.

^{22}Na is a radioactive nucleus produced in novae that could be observed by γ-ray telescopes.



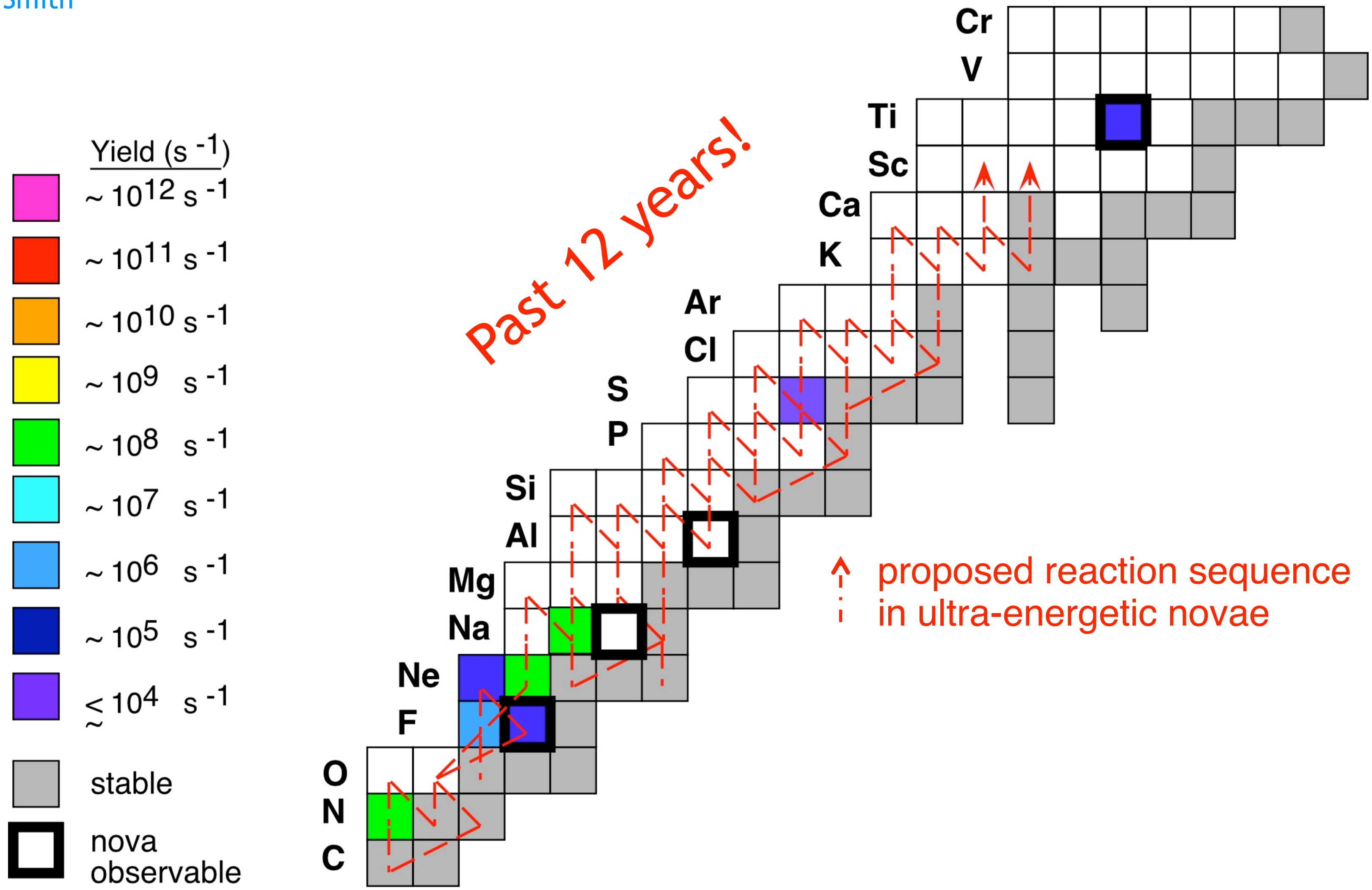
WRH, Smith, Roberts, Starfield & Smith 2006, in preparation

List of most important reactions for producing ^{22}Na:

^{22}Na(p,γ)^{23}Mg, ^{20}Ne(p,γ)^{21}Na, ^{23}Na(p,α)^{20}Ne, ^{23}Na(p,γ)^{24}Mg, ^{21}Na(p,γ)^{22}Mg.
(see also José, Coc & Hernanz 1999)

Promise of RIA: Novae & XRB Breakout

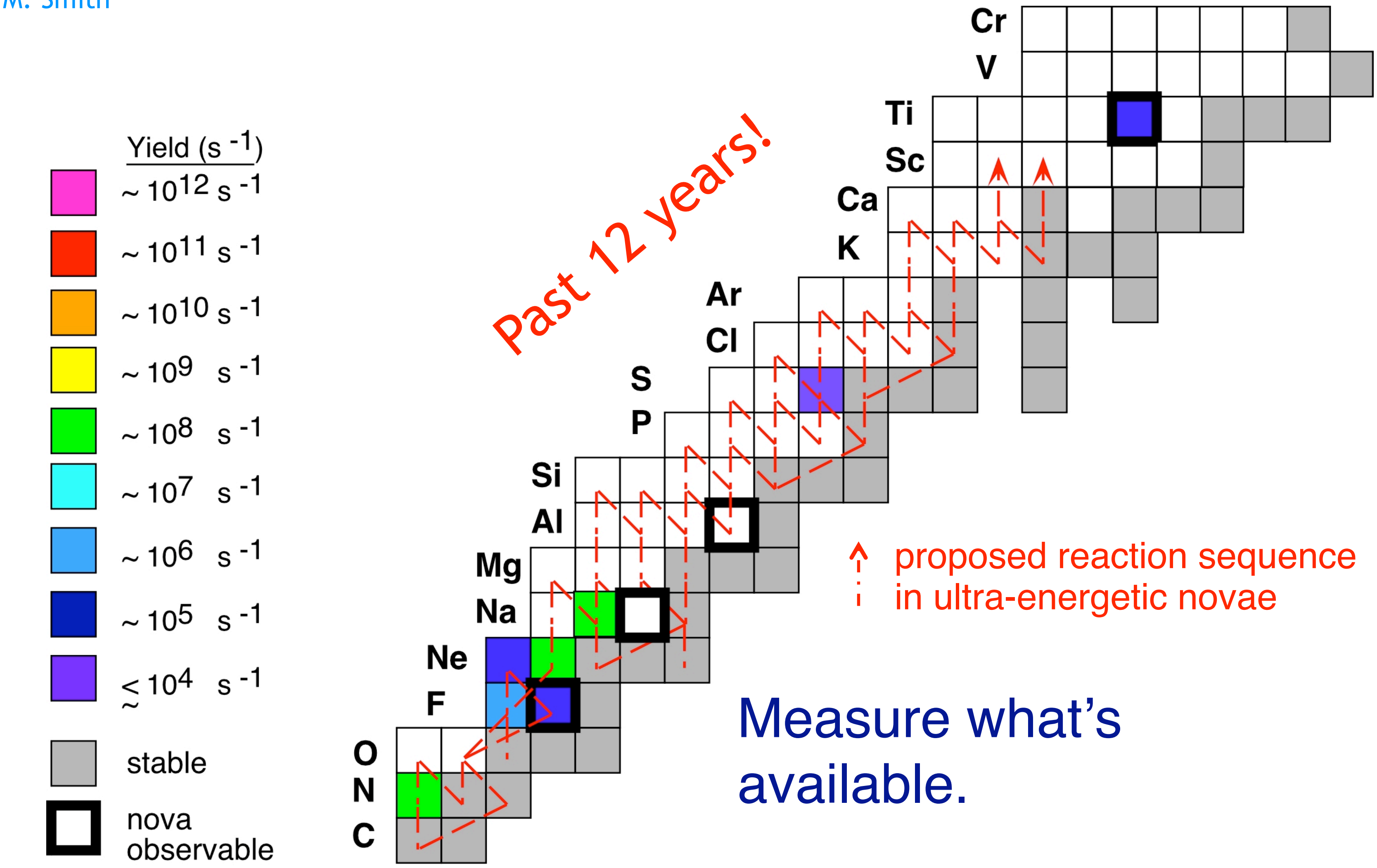
M. Smith



Past 12 years!

proposed reaction sequence in ultra-energetic novae

Promise of RIA: Novae & XRB Breakout



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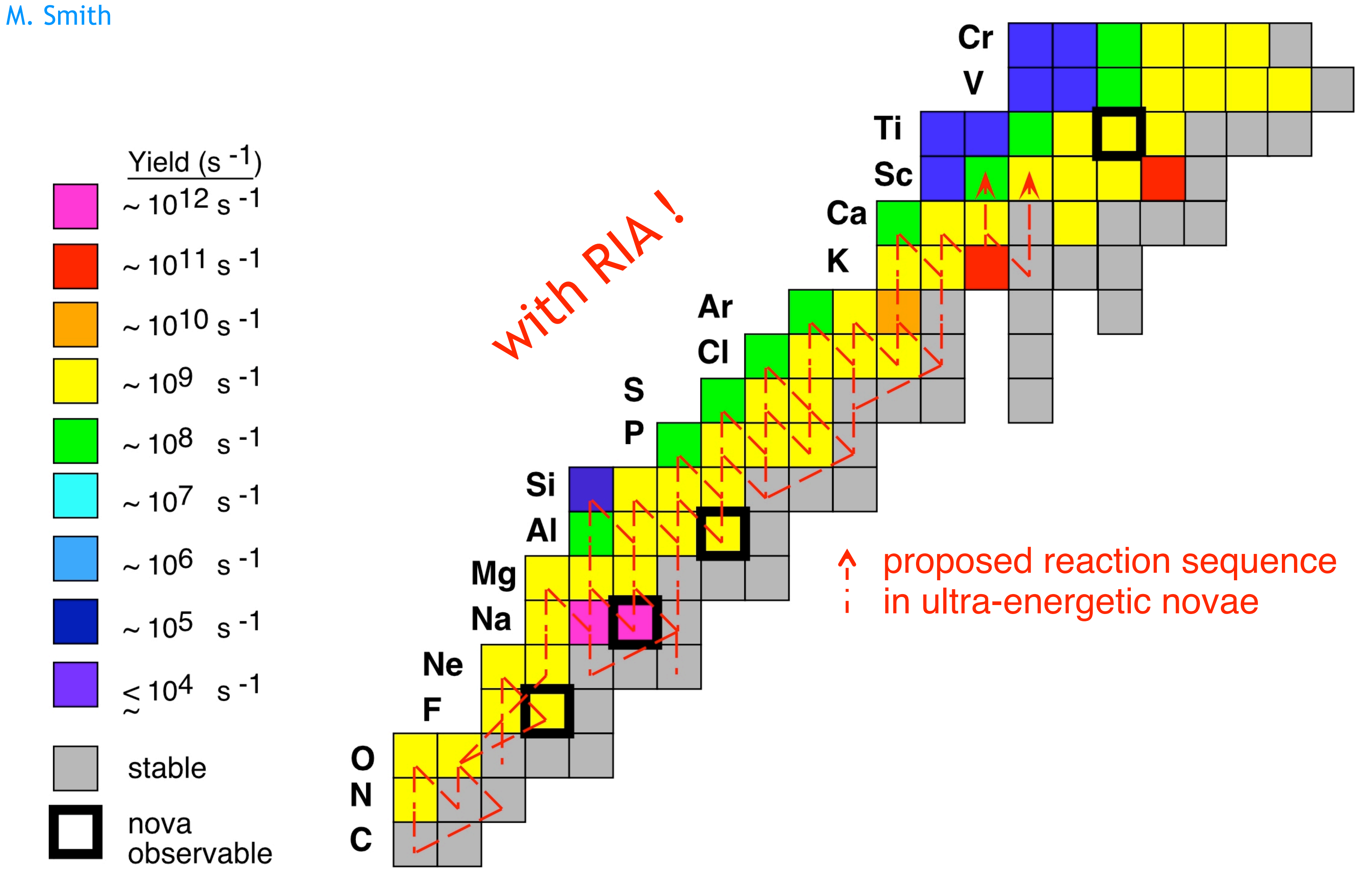
Measure what's available.

Promise of RIA: Novae & XRB Breakout

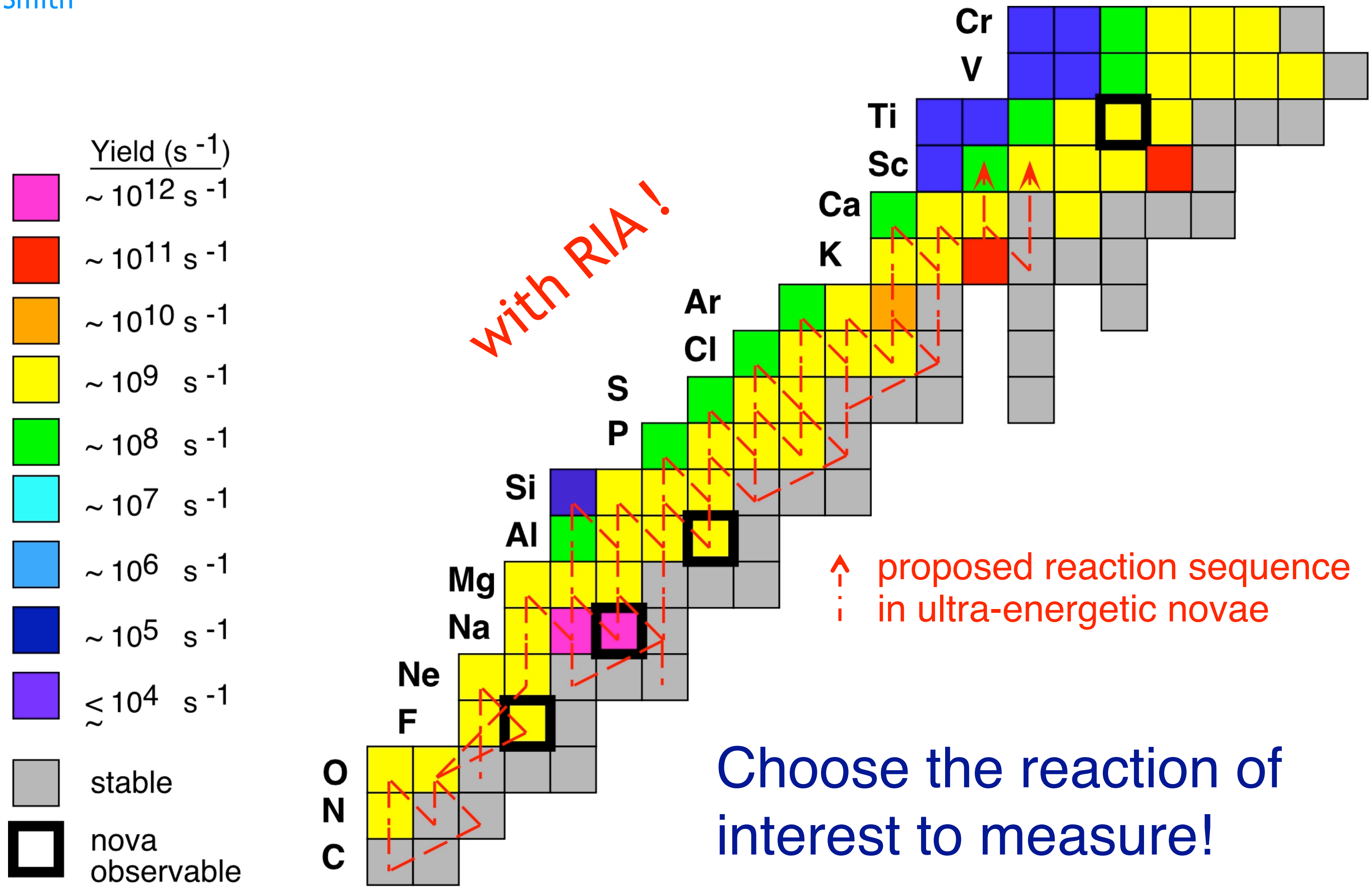

M. Smith

with RIA !

proposed reaction sequence in ultra-energetic novae

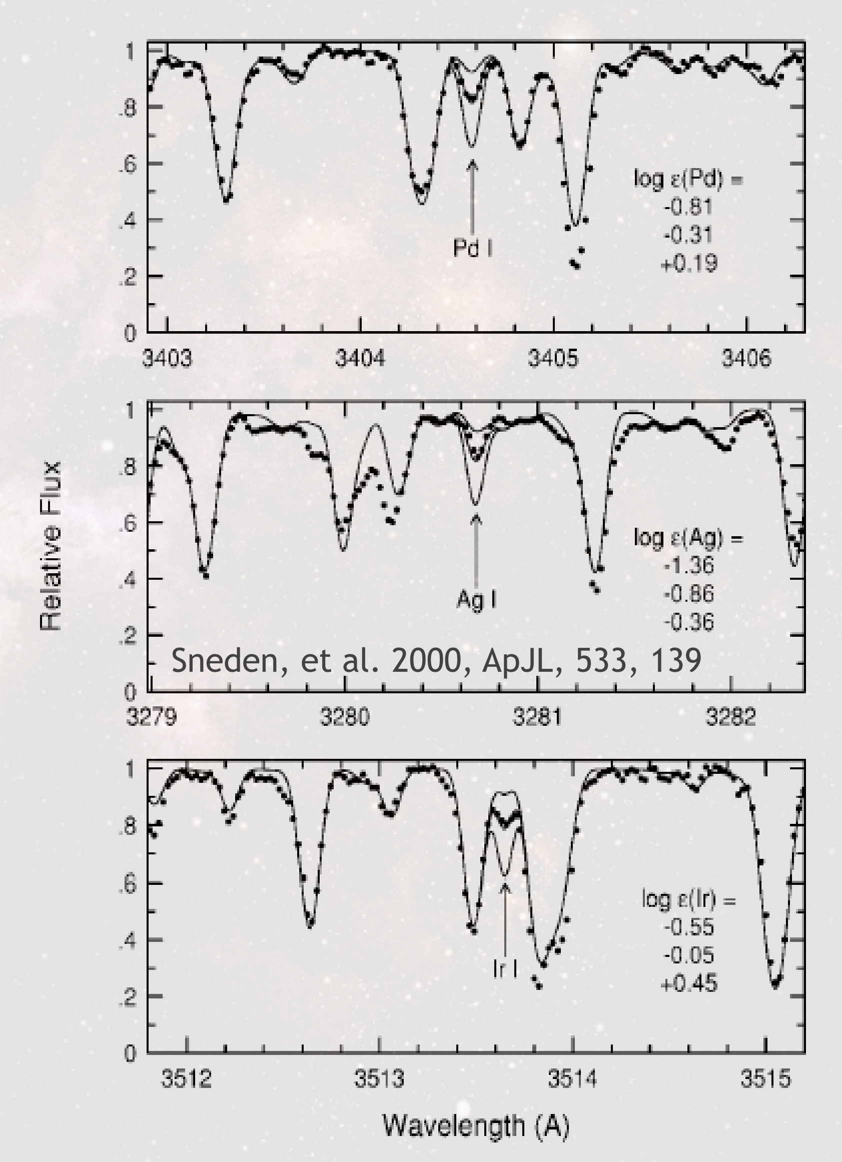
Promise of RIA: Novae & XRB Breakout

M. Smith

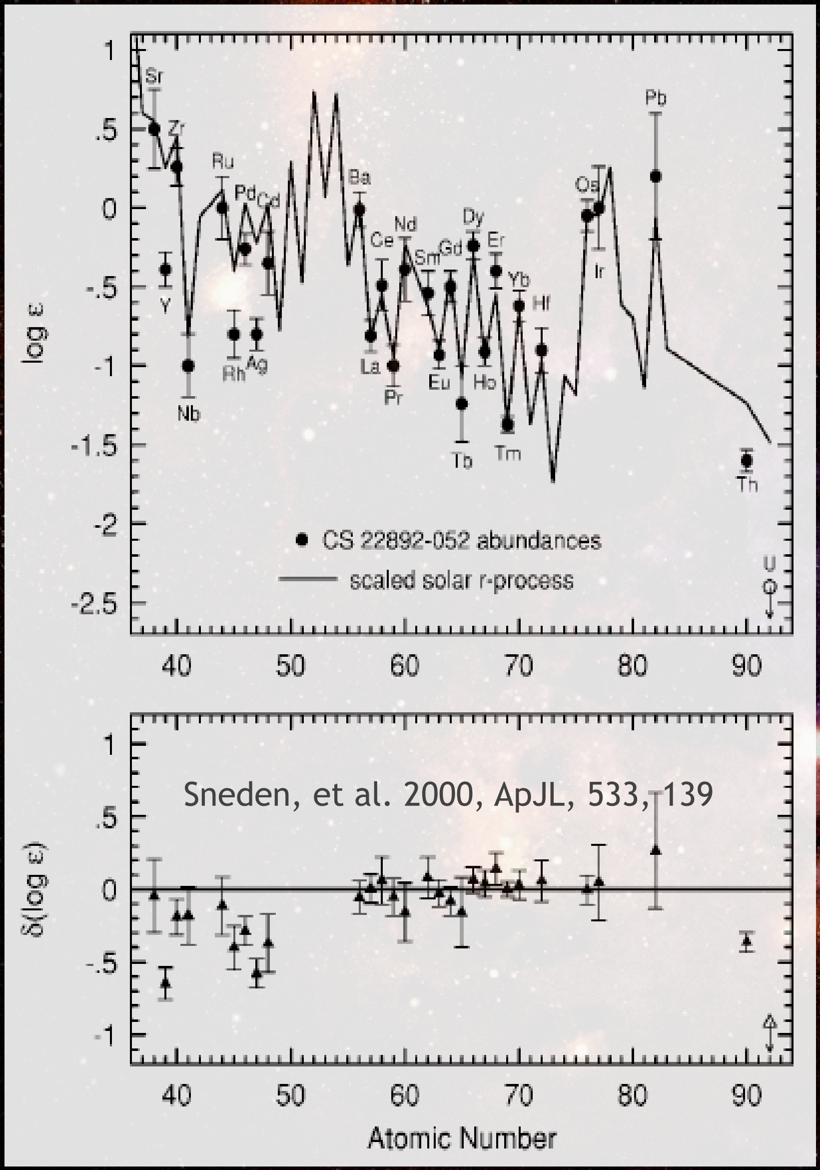


Choose the reaction of interest to measure!

Detecting the r-process in old stars



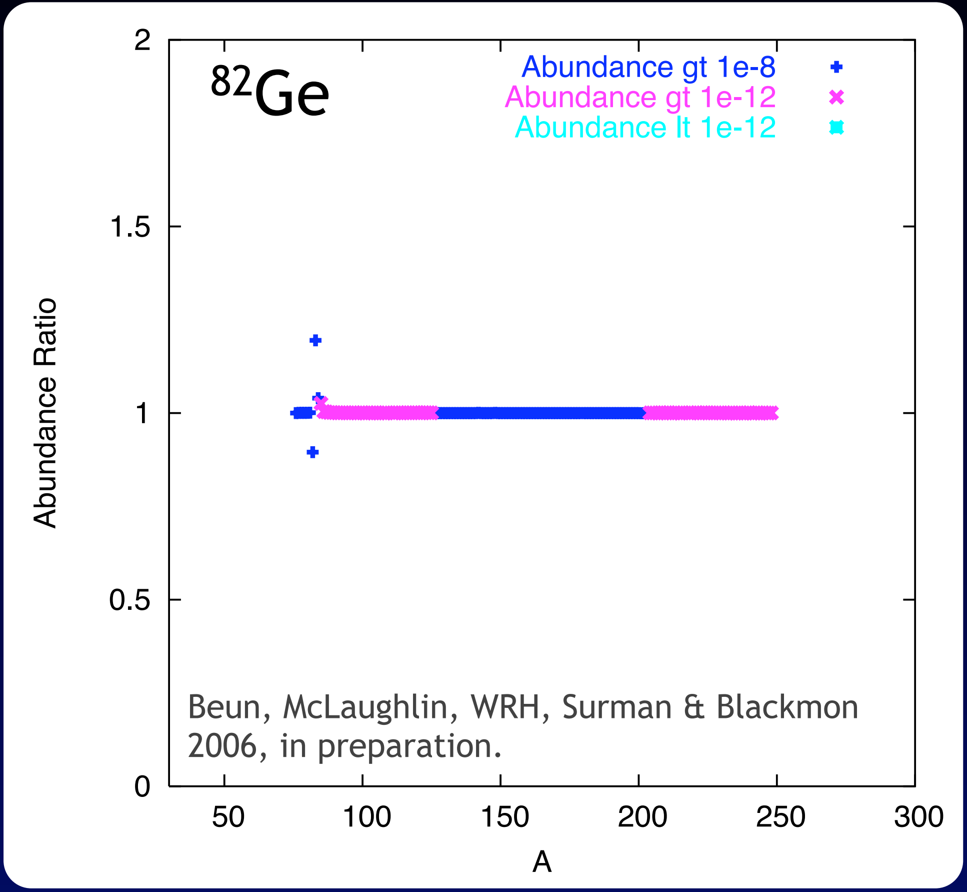
Sneden, et al. 2000, ApJL, 533, 139



Sneden, et al. 2000, ApJL, 533, 139

R-process Data

- For most of the r-process, $(n,\gamma)(\gamma,n)$ equilibrium holds.
- Much of what’s needed are masses and β–decay rates.
- (n,γ) rates matter as equilibrium breaks down.



Beun, McLaughlin, WRH, Surman & Blackmon 2006, in preparation.

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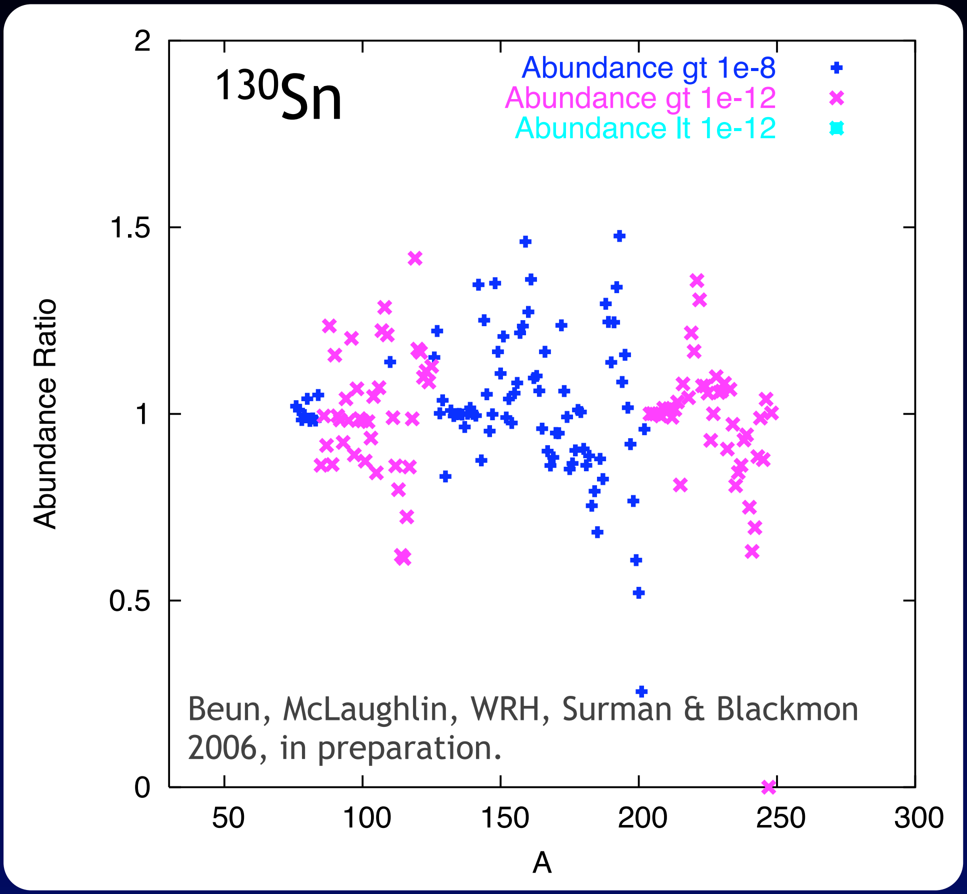

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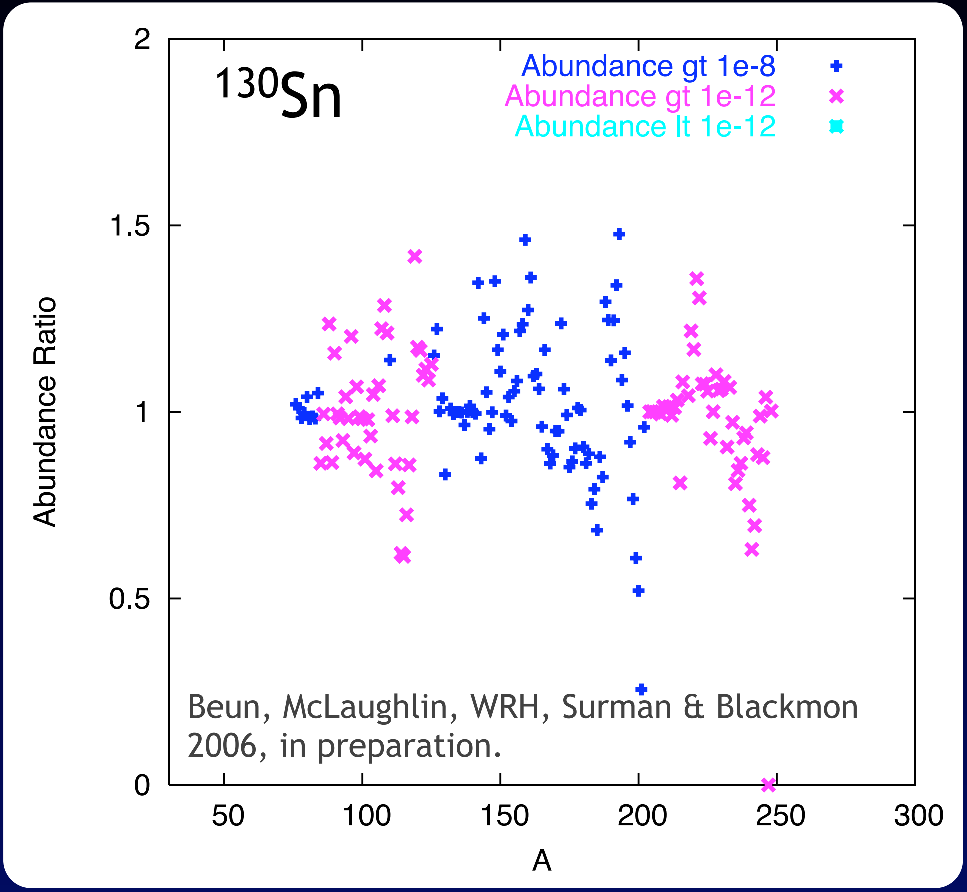

Beun, McLaughlin, WRH, Surman & Blackmon 2006, in preparation.

To achieve desired accuracy of r-process predictions will require neutron capture rates, at least near stability.

Summary

Modern treatment of nuclear electron capture significantly changes during core collapse and probably supernova evolution.

RIB experiments will guide better structure theory for the many rates that are needed.

NextGen RIB experiments will allow measurement of most of the rates of interest to novae and XRB breakout.

Comparison to r-process observations require not just masses and β-decay rates, but also selected RIB measurements of (n,γ) rates.