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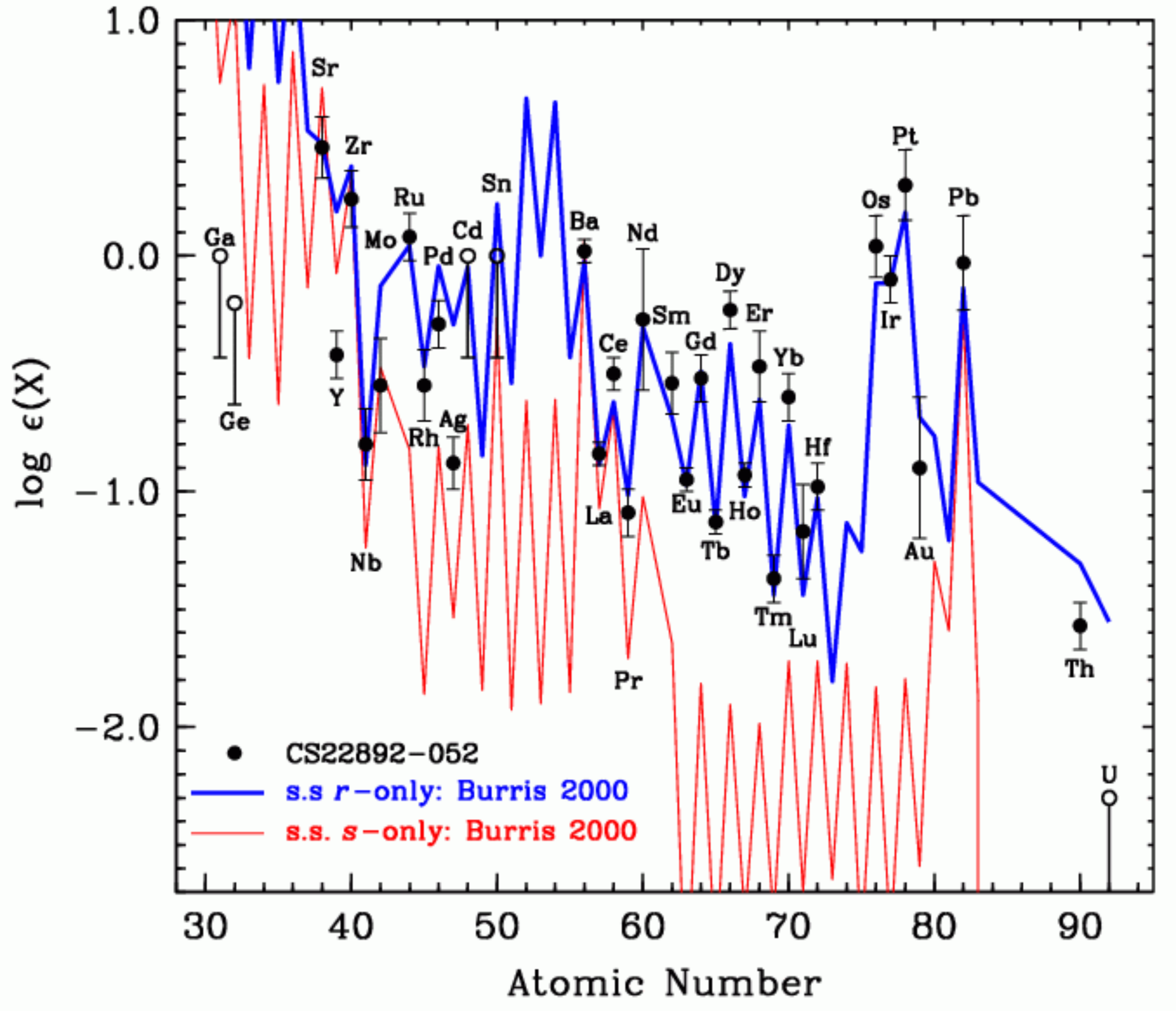
The r-Process in Metal Poor Stars and Black Hole Formation

(Work in Progress....)

Introduction

- Background: Metal Poor Halo Stars
  - CS22892-052
  - Truncated distributions
- Possible Scenario: Incomplete r-process
  - R-process incomplete due to collapse to BH
  - Black hole collapse effects
    - Neutrinos
    - Hydrodynamics
- Preliminary Calculation
  - Woosley Hydrodynamics
    - Cut off below presumed “Event Horizon”
  - Nuclear reaction network
- Results
  - Partial r-process results
  - Metal comparisons
  - Comparison to metal poor star
- Future work
  - More elaborate code: Neutrinos, event horizon, collapse dynamics
  - Asymmetric collapse

Metal Poor Stars: CS22892-052



Excellent catalog of abundance distributions.

Comparison to solar distribution.

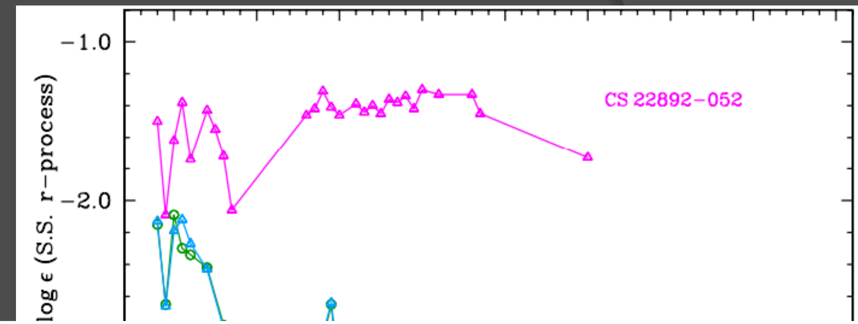
Caveat: Not all stars are as well described as CS22892-052.

Sneden, et al. (2003)

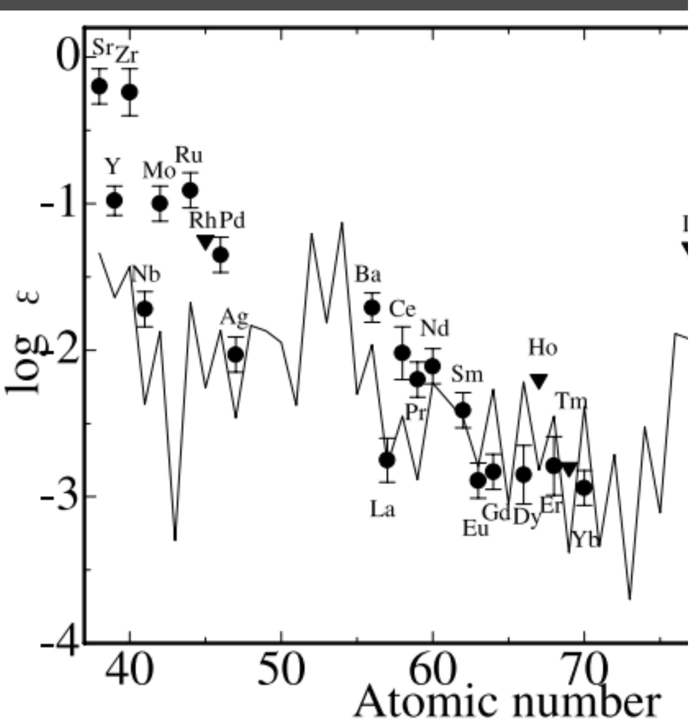
Metal Poor Stars Enriched at Low Mass

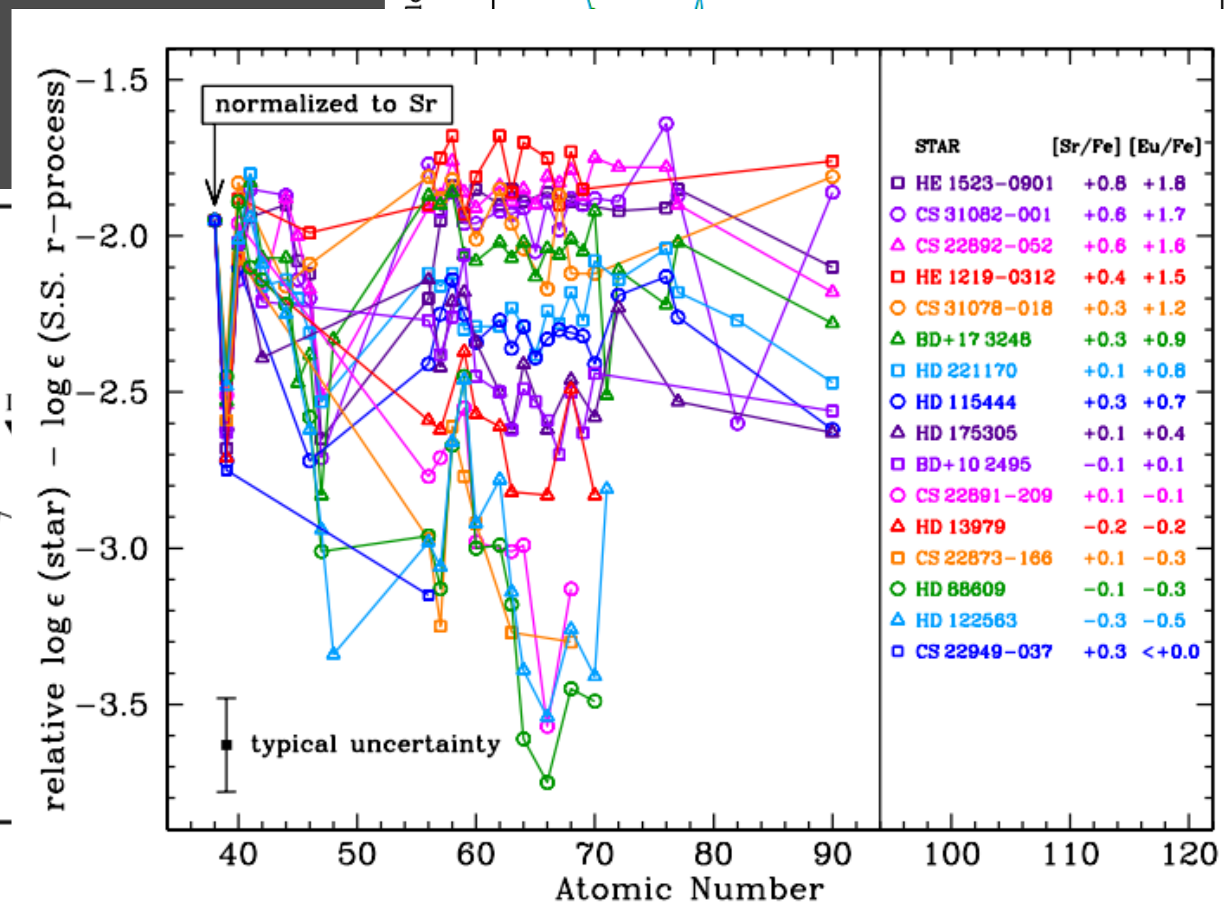
Roederer et al. (2010): Several groups of R-process enrichment in metal-poor stars.

BUT, there are not just two groups of stars!

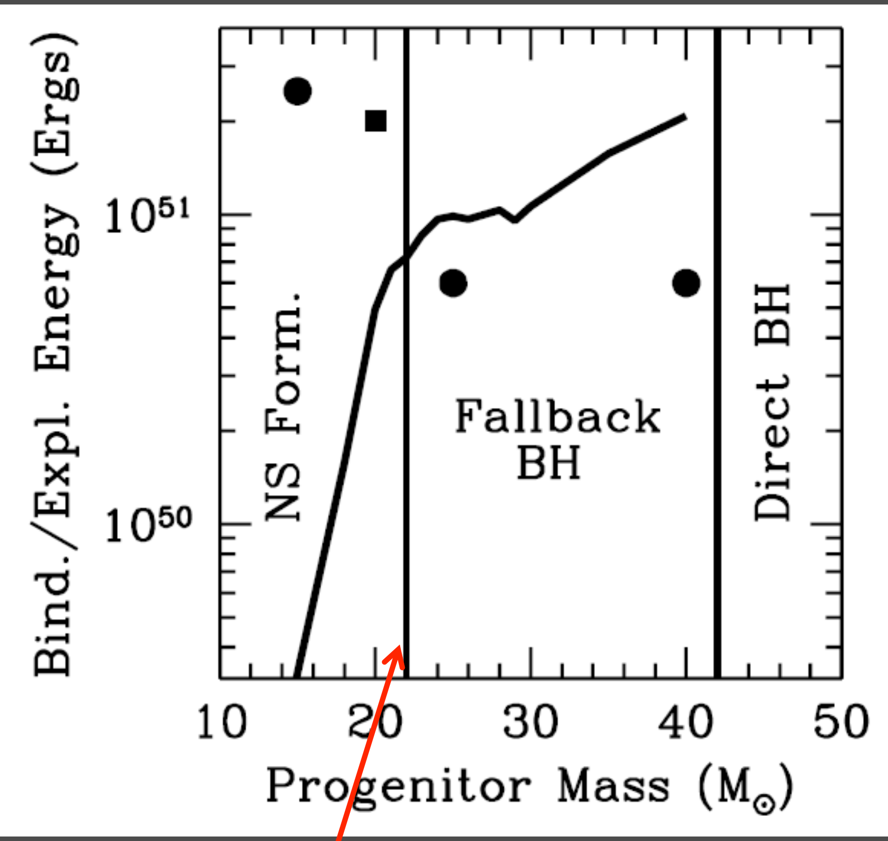


A “truncation” in the r-process distribution



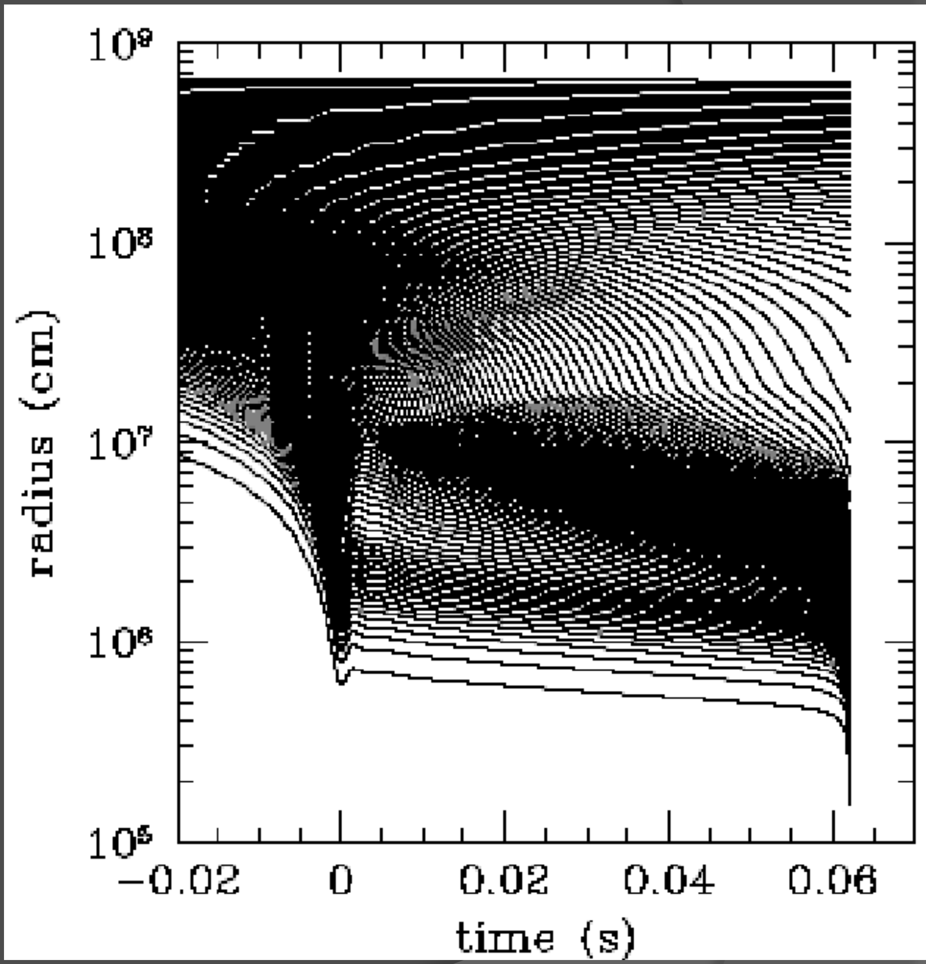


Truncated r-Process: Schematic



"Fine line"

Fryer et al. (1999)



Delayed Collapse: ~30-100 of ms after core bounce.

Nakazato et al. (2007)

A spectrum of intermediate collapse scenarios.
We're primarily interested in the ~20 – 40 solar mass range.

Truncated r-Process: Possible Effects

- Reduction or alteration in neutrino and antineutrino spectrum.
- Cutoff of material outflow.
- Alterations in system shock.
- Neutrino heating cutoff.
- Stalled ejecta of outer layers
  - Escape velocity: Fallback
  - “Capture”
- Others?

Our Simple First Approximation

Collapse Model of Woosley et al. (1994).

Event horizon radius forms
Promptly at time t_{ev} and radius R_{ev}

Where and when is the
Event Horizon?
- Previous results of
  Nakazato et al.

Even more general: Mass points
Intersecting the event horizon
At any time do not escape.
(Our modus operandi).

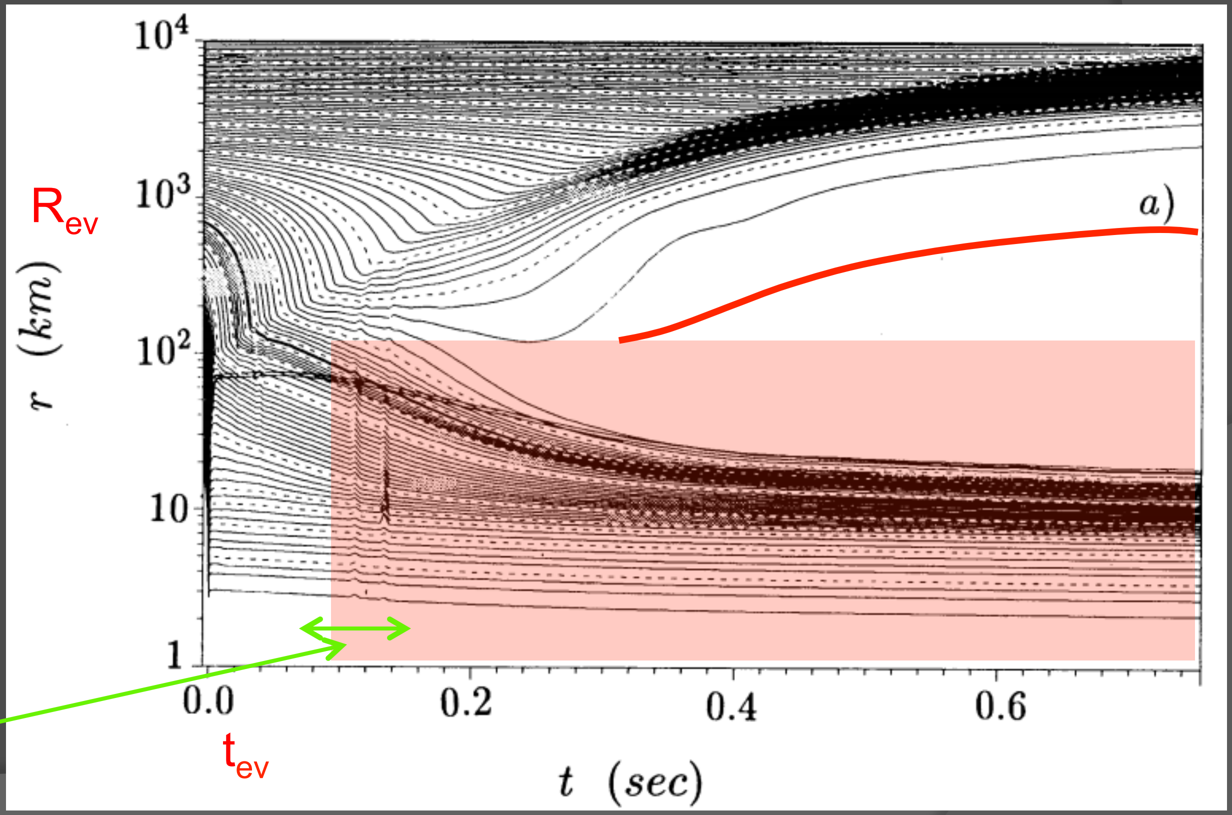
Coupled to a full network calculation,
Including decays, charged-particle
reactions.

Very high entropy wind.

Fallback time.

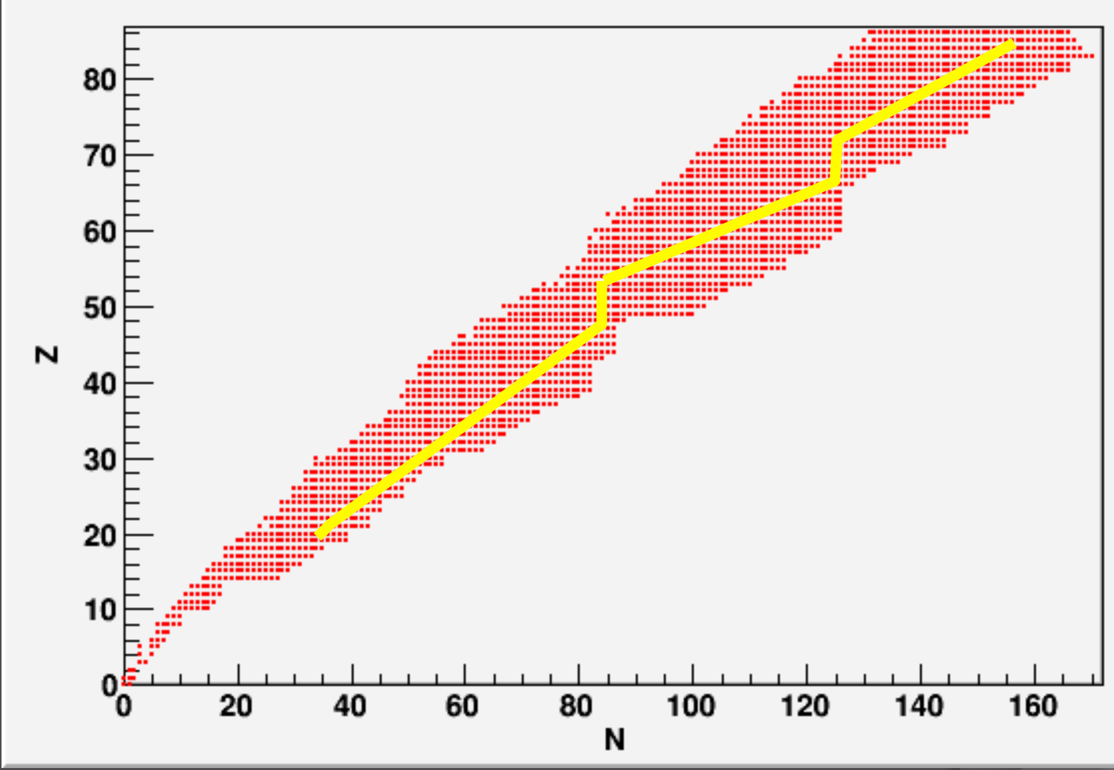
Fryer et al. (1999) – Core collapse, expansion, and recollapse all happening on the same scale.

First Simple Model!



The Model:

- Woosley Hydrodynamics
  - Shell ejecta
- Nuclear Reaction Network
  - Heavy Network ~5000 nuclei
  - Reaction list
- Model Assumptions
  - Adiabatic expansion at $T_9<2.5$
  - Entropy varies between shells.



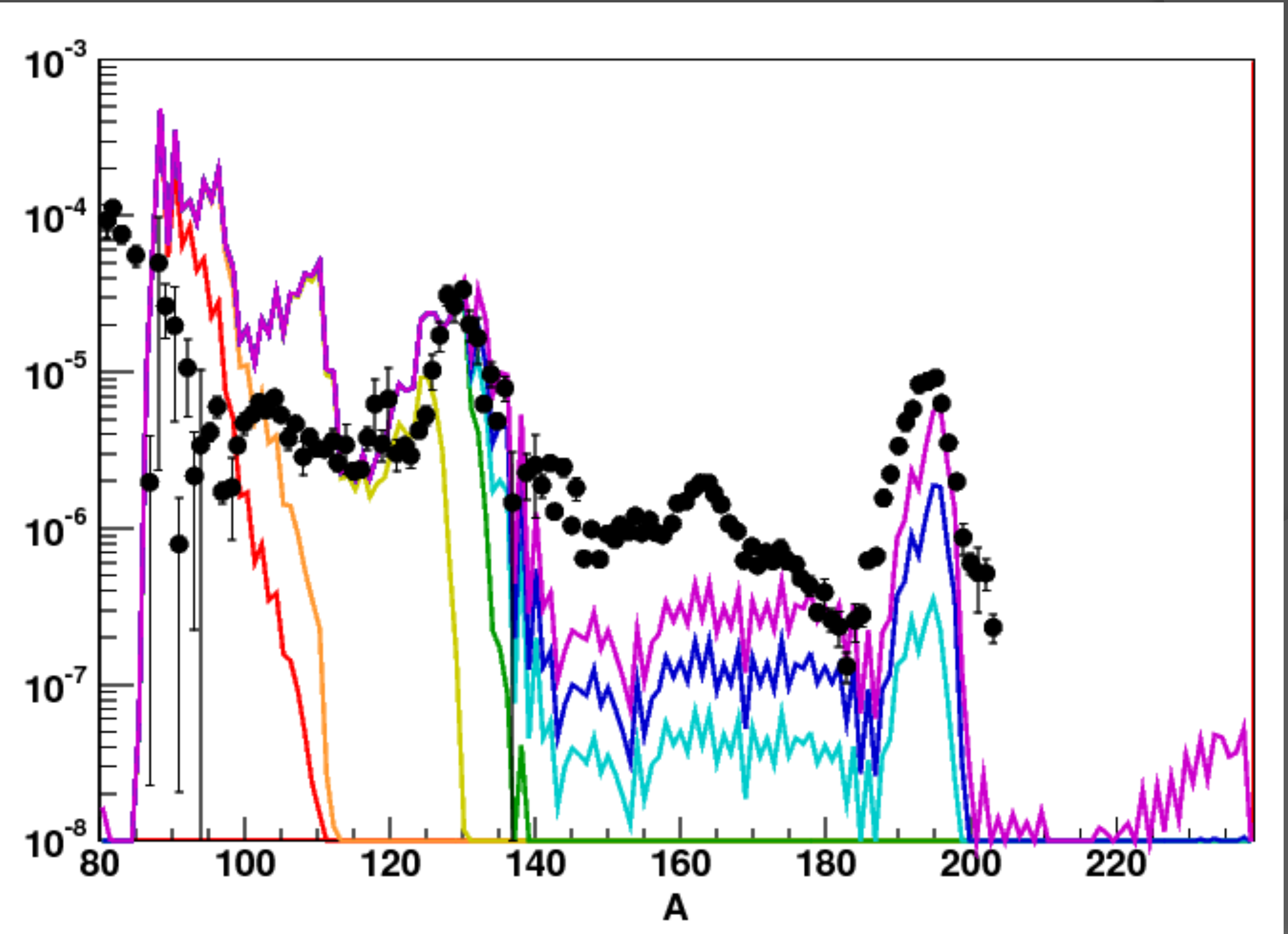
Model Results

Normalized abundance distributions as a function of emission Radius (Event Horizon Radius).

Approximations:
- Post processing
- Fission Cycling?

$$Y = \frac{1}{M}\sum_i m_i Y_i$$

Enhanced abundance
At lower mass.



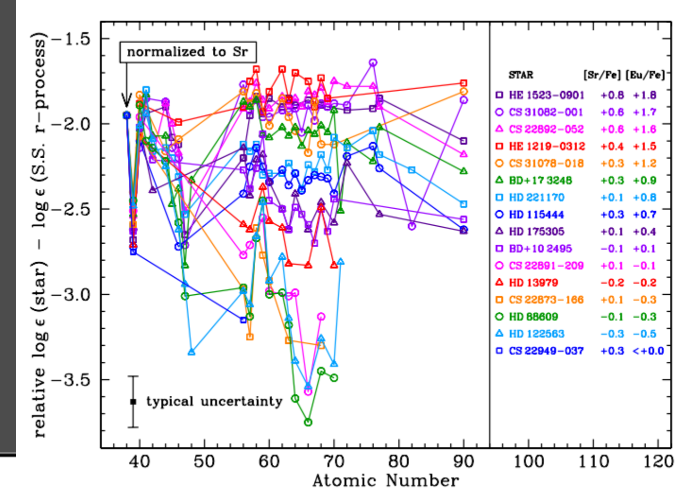
Elemental Abundance Comparison

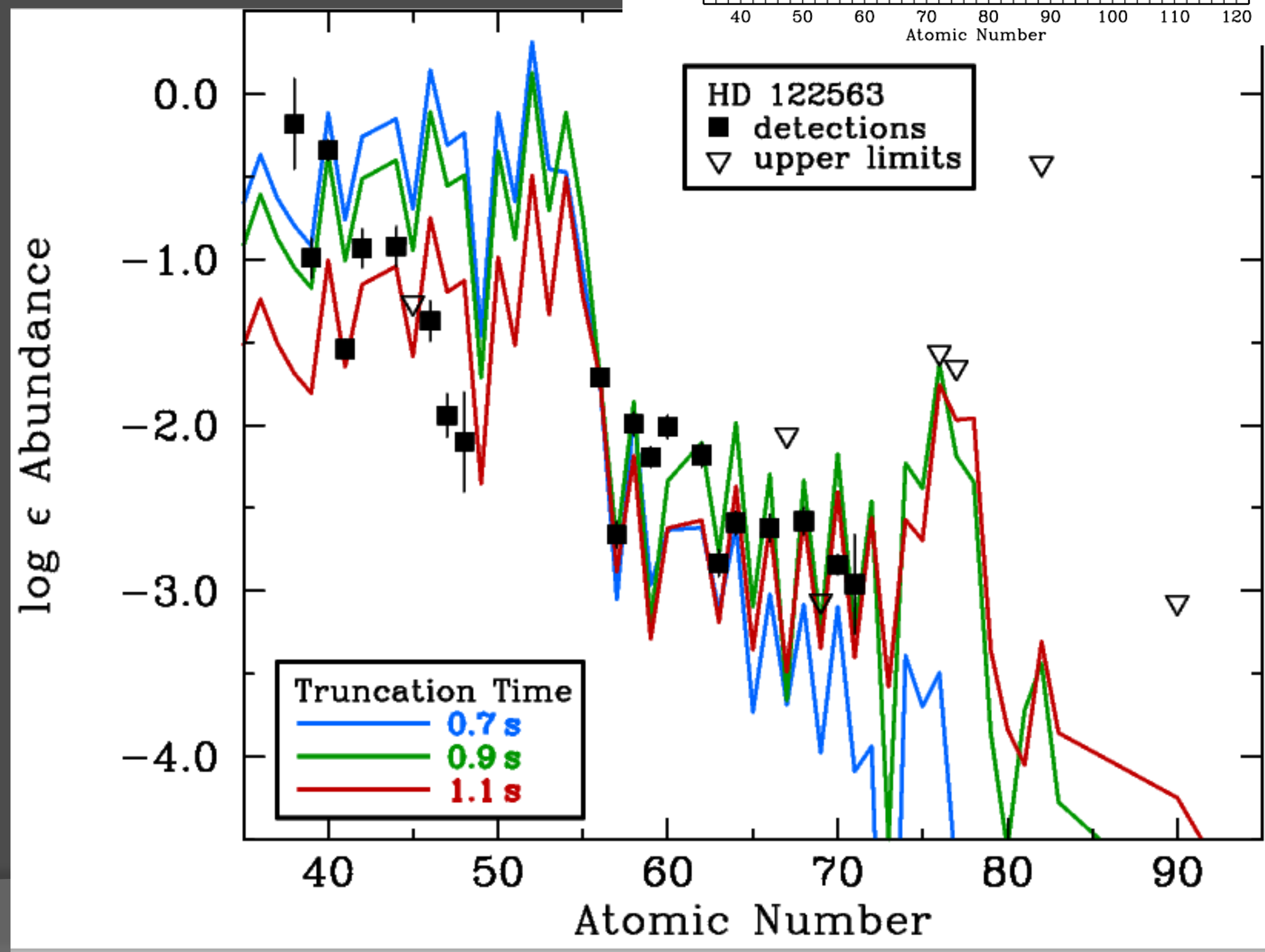
Reasonable comparison
To HD 122568 elemental
Abundance distributions.

We should be a little
Careful, as the r-process
Progresses very rapidly
Through the rare earths.

Where we cut it off at can
Be quite fine.

Production sensitive to
Collapse time and radius!





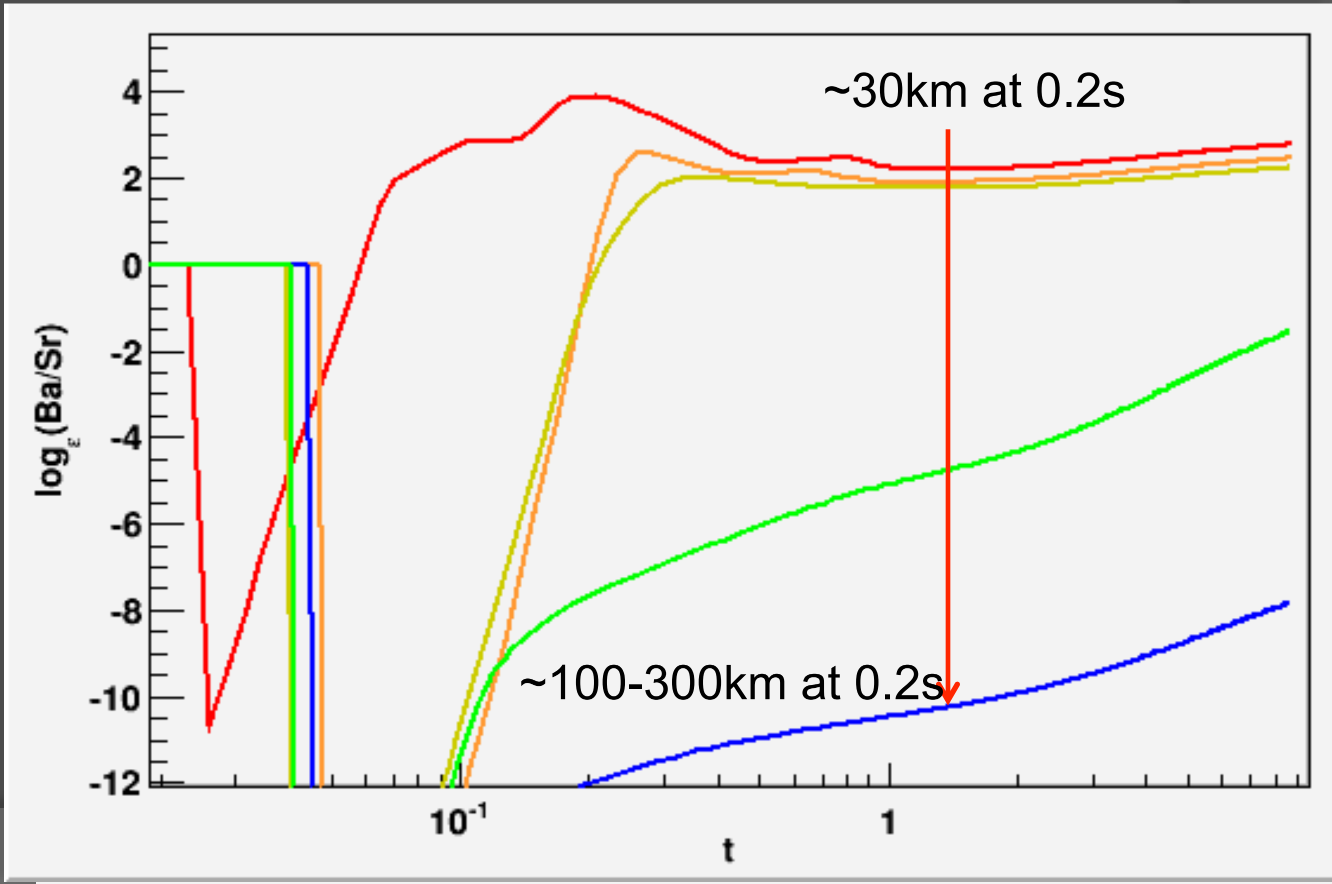
Ba/Dy Ratio for Various Shells

Uncertainties in observations at larger Z may require a different set of predictions.

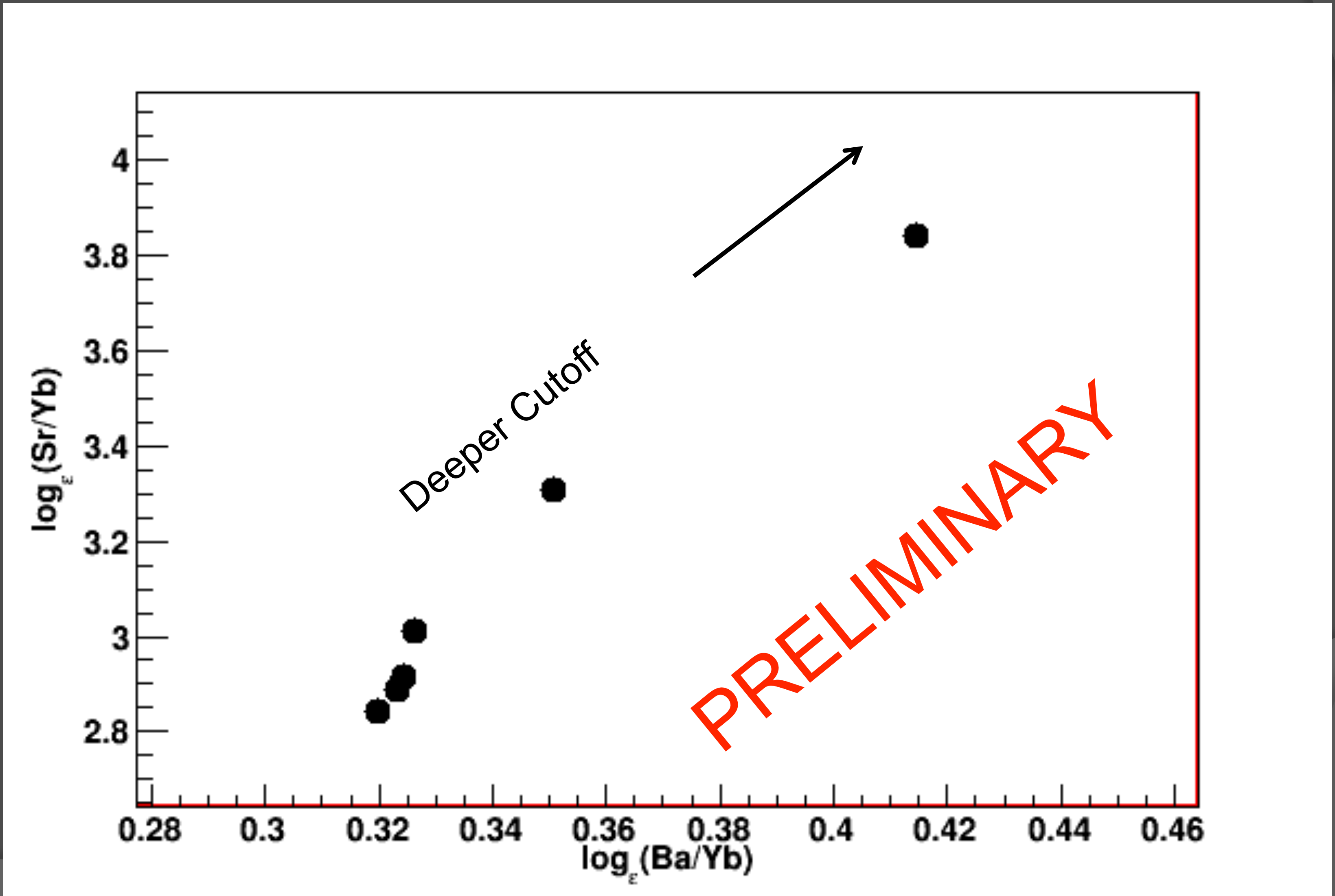
Abundances of INDIVIDUAL mass elements.

In this case, possible observational signatures may be:
- $\log_{\varepsilon}$(Ba/Dy)
- $\log_{\varepsilon}$(Sr/Ba)
- Others

Lines indicate cutoff of mass flow from cutoff at larger radii.



Relative Sr vs. Ba Abundance



Distribution Comparisons: Issues

- Preliminary results
- Probability of occurrence of r-process stars with low mass enrichment
- For a Salpeter IMF → $\frac{N_{DBH}}{N_{NS}} \approx 0.13$
  - McWilliam [Eu/Fe]>1 ~10% of all metal poor stars.
  - Roederer: [Eu/Fe]<0: Low mass r-process candidates: Difficult to establish, so…
  - Use Ba data: Est. ~55% as candidates for enrichment in a truncated r-process

Future Work

- Hydrodynamics
  - WHERE and WHEN does the event horizon form?
  - E.g., Nakazato Model
- Neutrinos
  - Three Possible Scenarios for prompt collapse
    - Event horizon below anti-electron neutrinosphere (no change in r-process?)
    - Event horizon above electron neutrinosphere (no r-process?)
    - Event horizon between neutrinospheres (most interesting)
  - Heating effects from neutrinos
- Difficulties in Observation: Additional astronomical observations
- First principles calculation
- Tighter constraints on mass distribution
  - Constraints from IMF
  - Which BH collapse masses and models are most interesting?

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