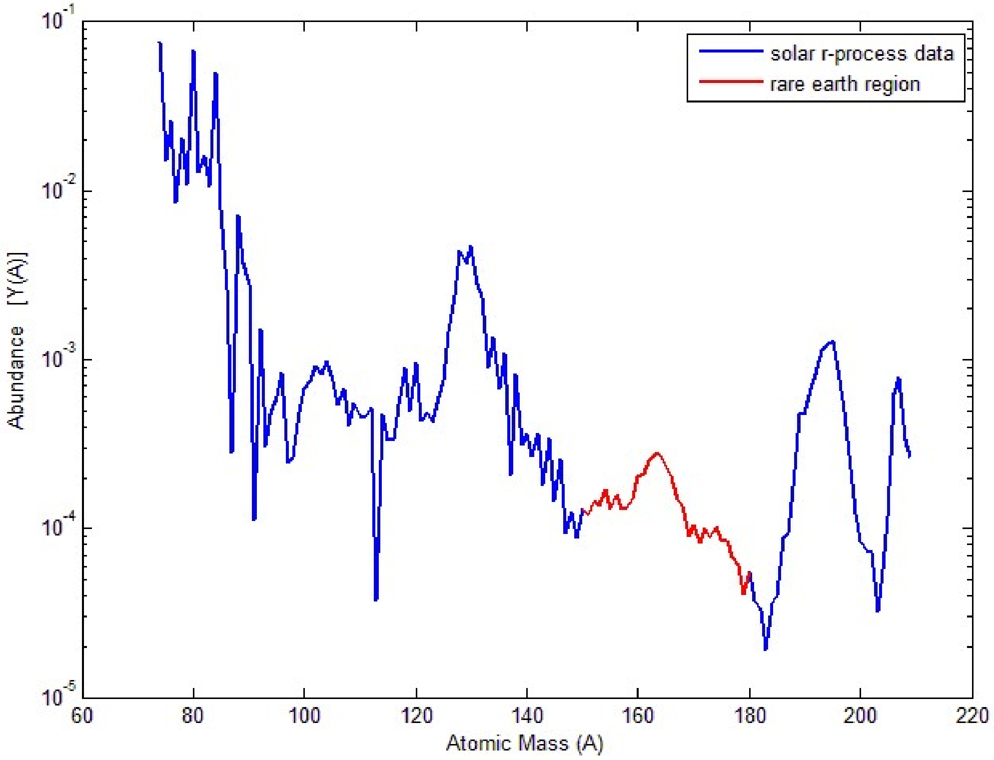
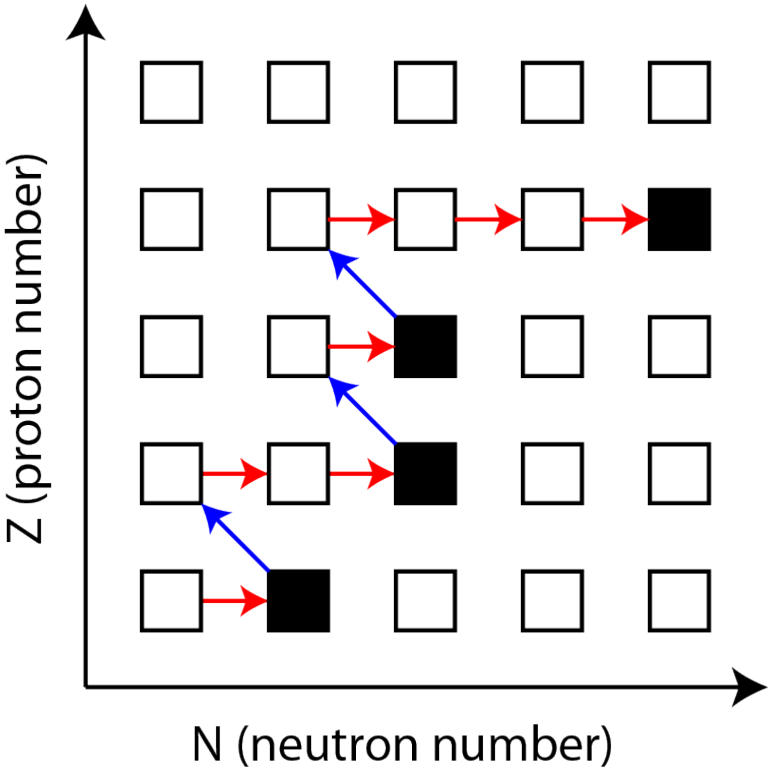
Late Time Dynamics and Implications For *r*-Process Nucleosynthesis





Matthew Mumpower

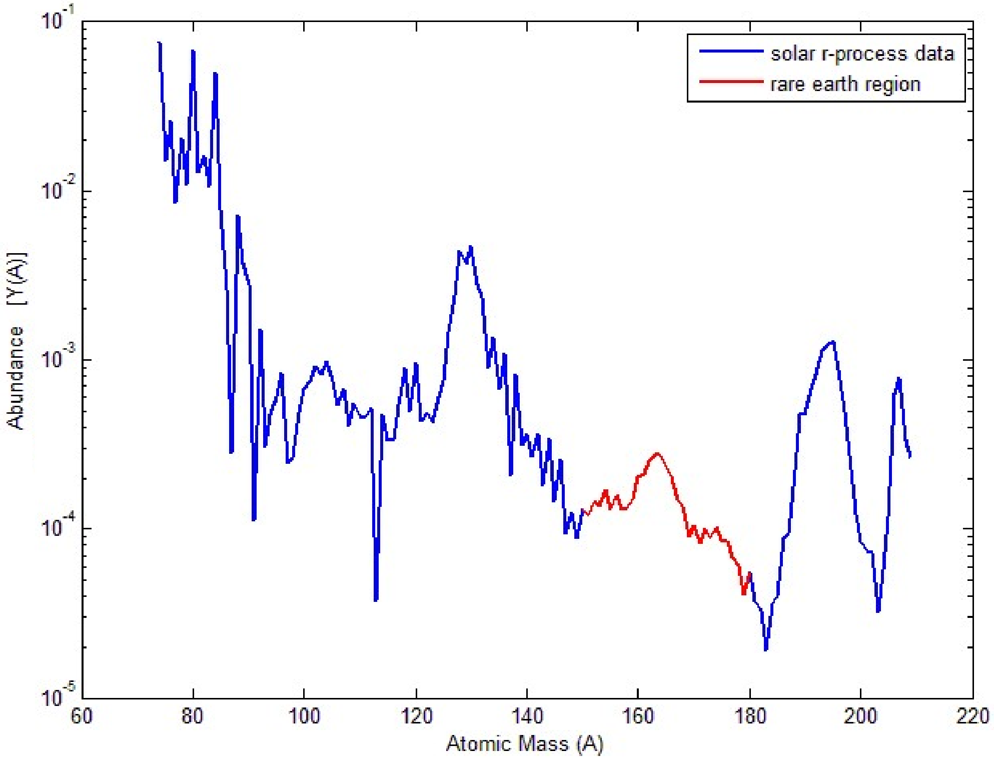
University of Notre Dame

Thursday Nov. 15th 2012

JINA Workshop

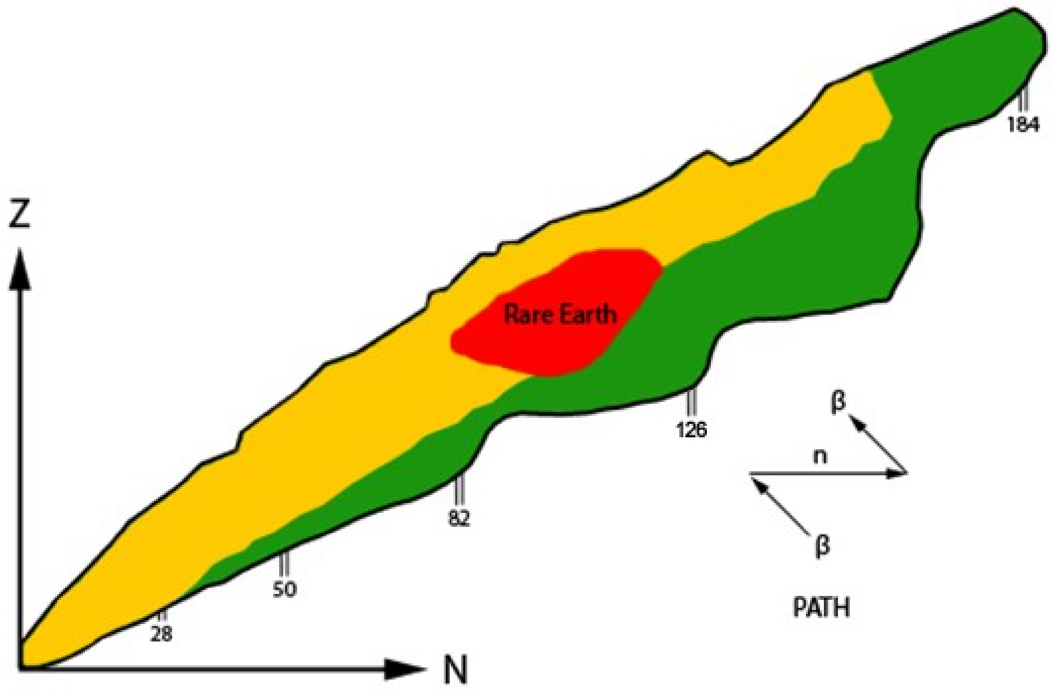
How Do We Probe The Late Time Dynamics Of The *r*-Process?

We need something sensitive to this epoch...



Importance Of The Rare Earth Region

- Peak forms away from closed shells
- Thus, by a different mechanism than A=130, A=195 peaks
- Region forms during last stage of the *r*-process
- Thus, sensitive to **nuclear physics inputs**
- And, **thermodynamic conditions**



🟨 Relatively β-stable

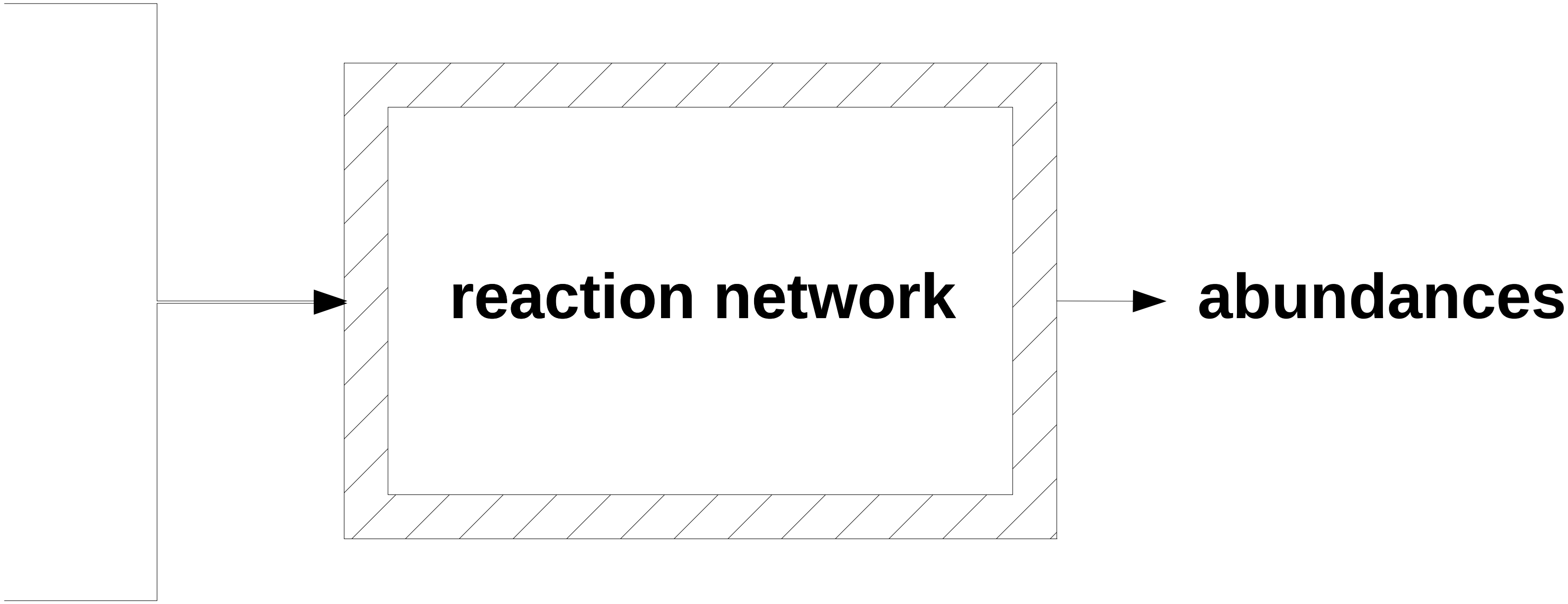
🟩 Relatively β-unstable

🟥 Region of interest

A Simple *r*-Process Calculation

nuclear physics inputs

(Sn, β-rates, n-cap rates, …)



reaction network

abundances

Environment conditions

(temperature, density, ...)

NDW Model

$$\rho(t) = \rho_1 e^{-t/\tau} + \rho_2 \left(\frac{\Delta}{\Delta + t} \right)^n$$

early-time late-time

- Similar to ν-driven wind parameterization by Meyer (2002) with...
- $3\tau = \tau_{dyn}$ and $\rho(0)=\rho_1+\rho_2$ and $\Delta(\tau)$
- n = late time power law
- n = 1-5 (hot)
- n > 5 (cold)
- Separate the early time behavior (neutron-to-seed ratio) from late time behavior (rare earth peak formation)

Comparing Simulations To Data

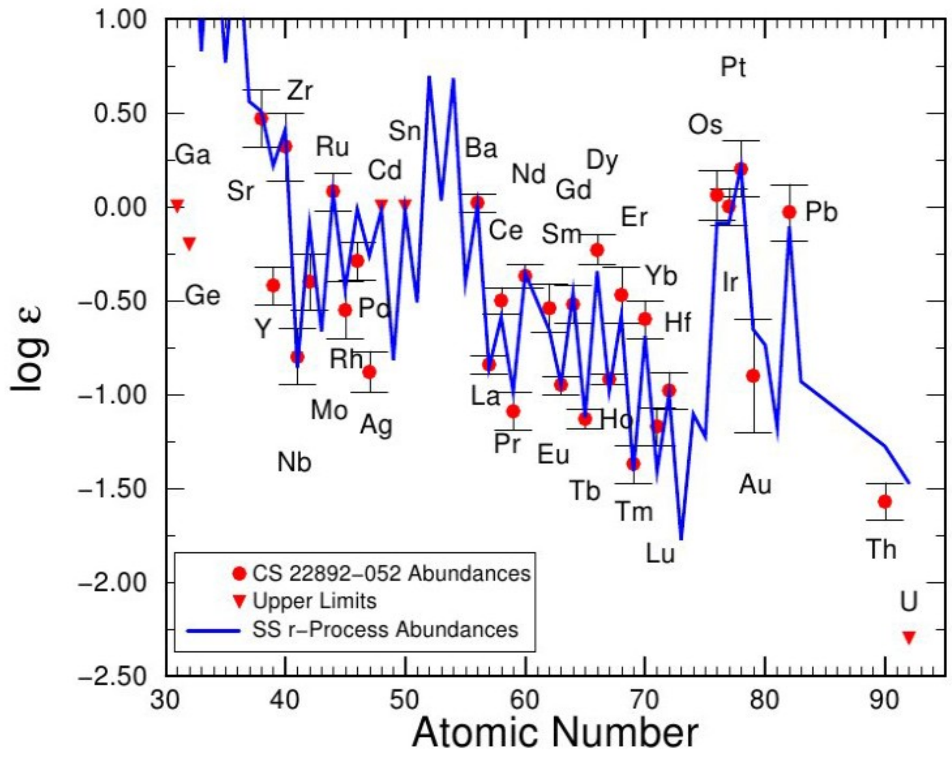
$$\rho(t)=\rho_1 e^{-t/\tau}+\rho_2\left(\frac{\Delta}{\Delta+t}\right)^n$$

early-time

late-time

Fix:

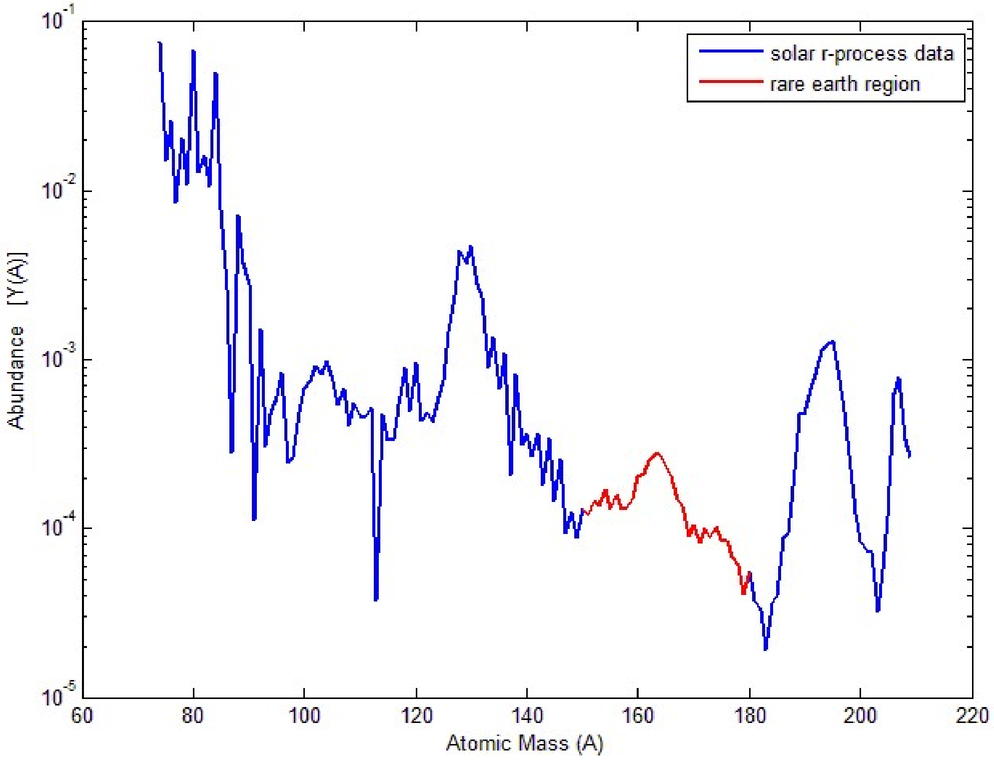
- $\tau \sim 80ms$
- $Ye = 0.30$
- nuclear model (FRDM)
- **Allow other parameters to vary:**
- S ~ 50 to 400
- n ~ 0 to 10



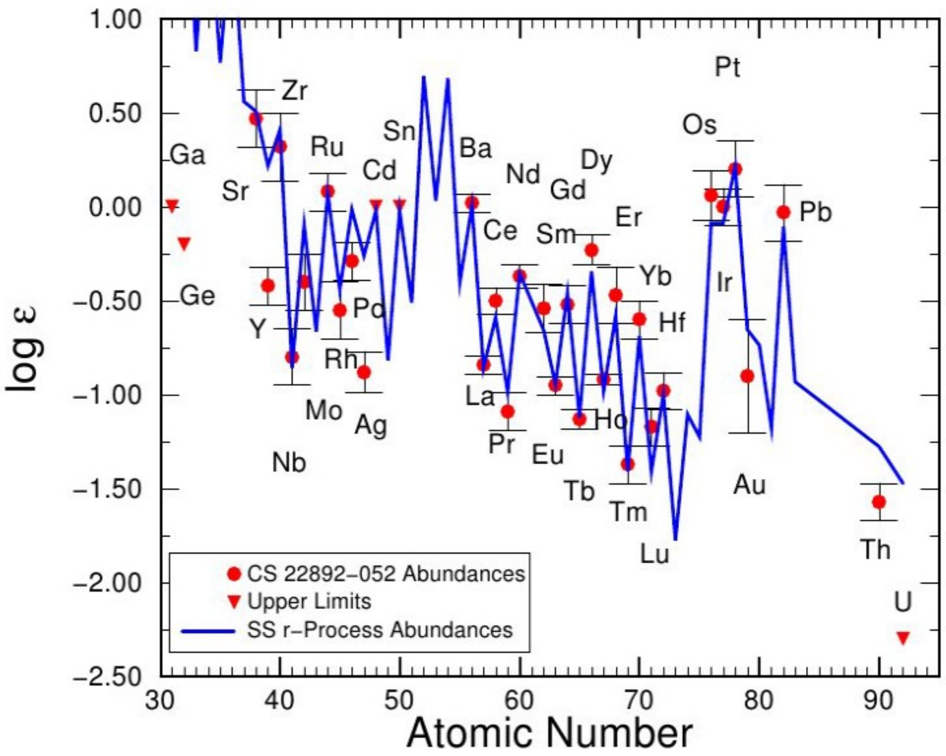
Elemental abundances

A New Way To Constrain r-Process Conditions

- Use successful rare earth peak formation to constrain conditions favorable for the r-process
- Perform many simulations each with differing conditions
- Compare final pattern to both solar and halo star data

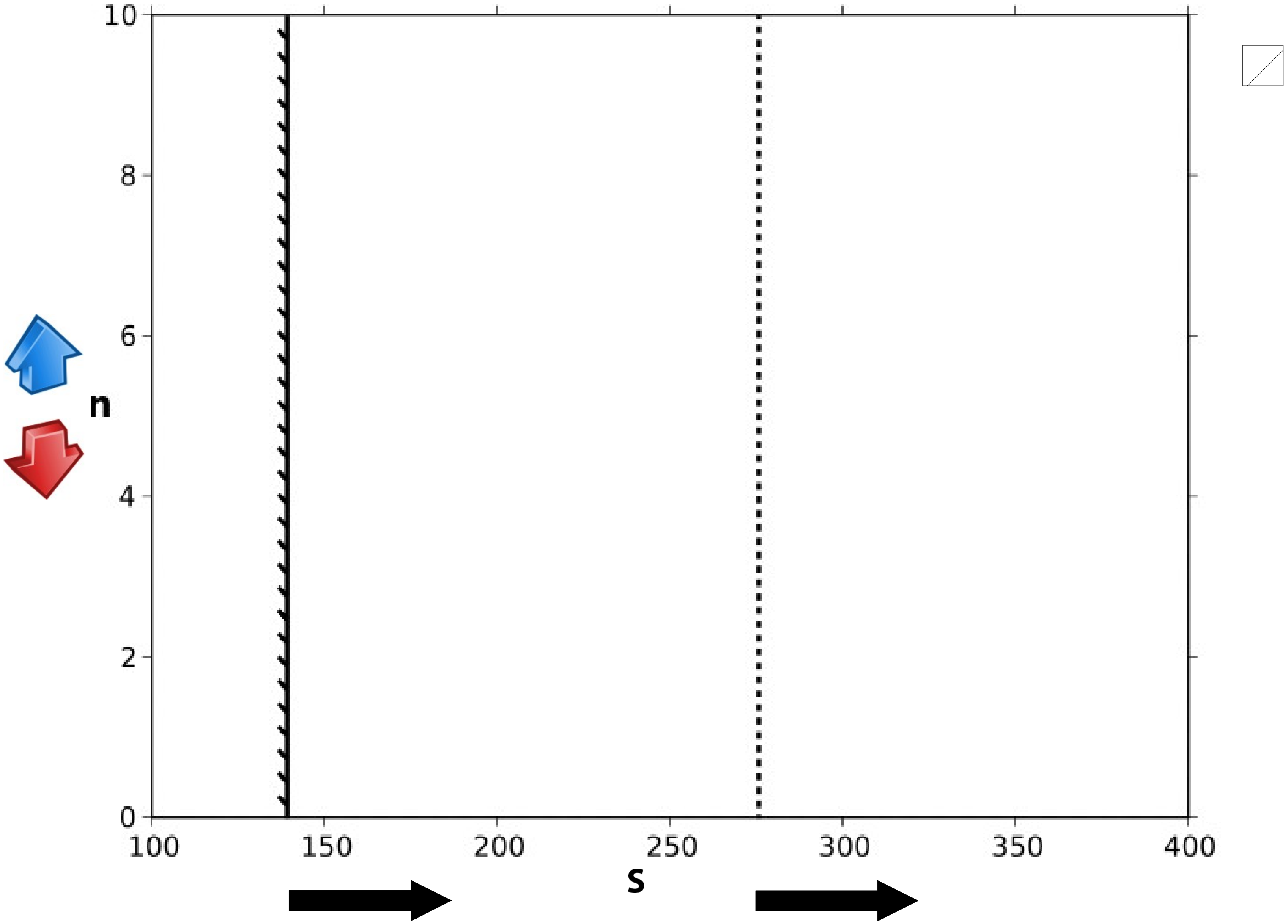


Isotopic abundances



Elemental abundances

Old Constraint: Neutron To Seed Ratio



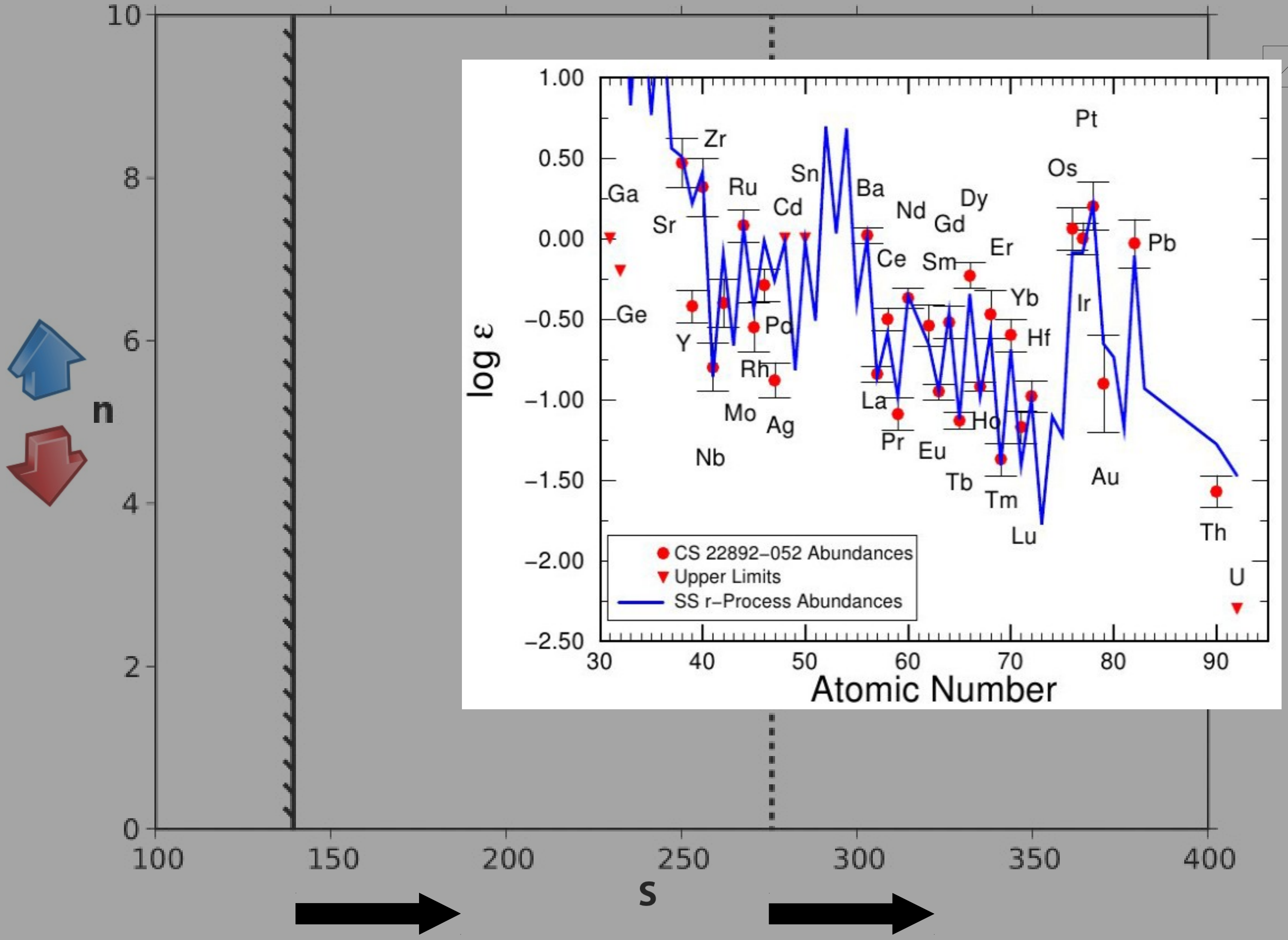
▨ Neutron to seed ratio
R~80

R>80

Fission

Mumpower et al. (2012)

Comparing Simulations To Halo Star Data



Neutron to seed ratio
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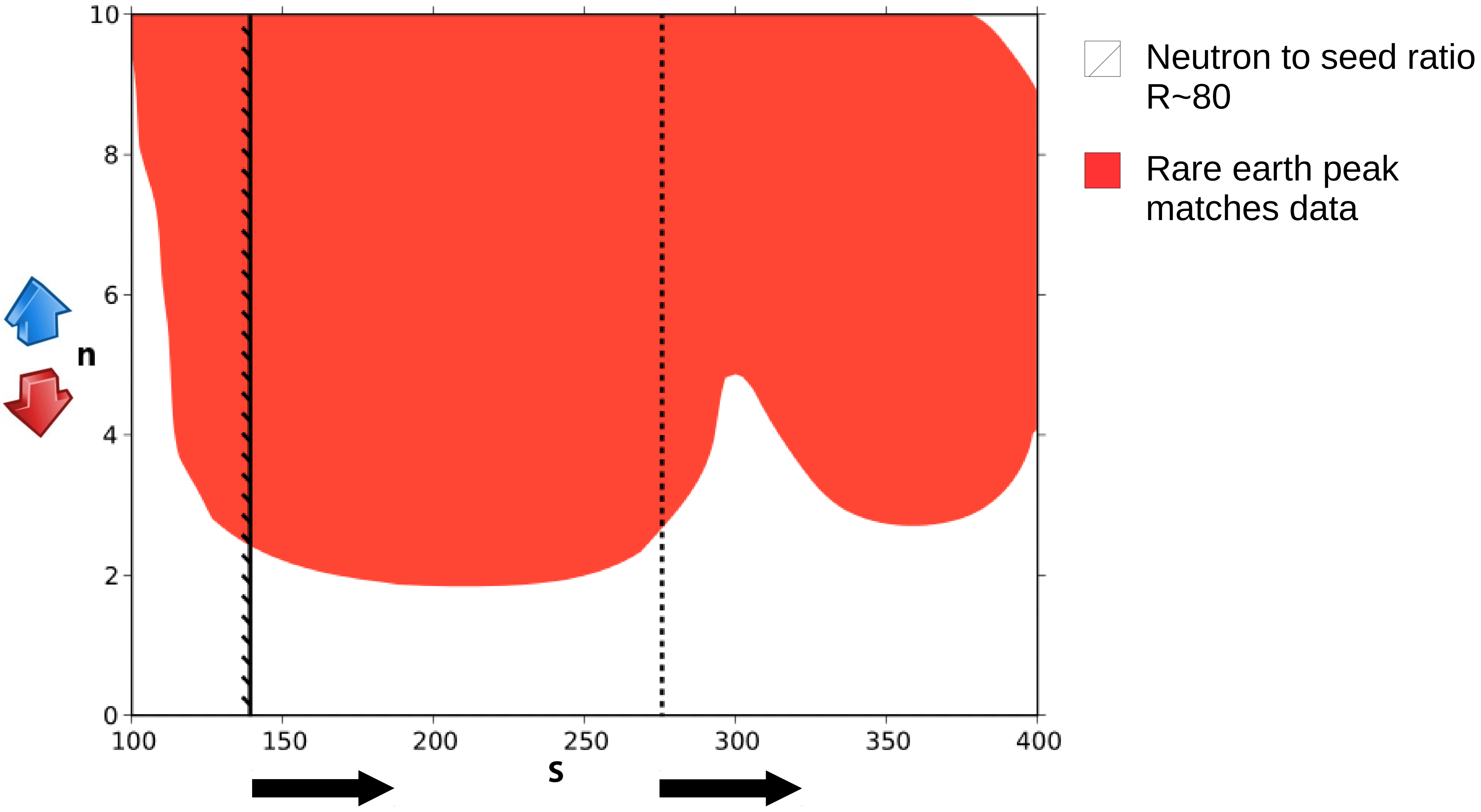
R>80

Fission

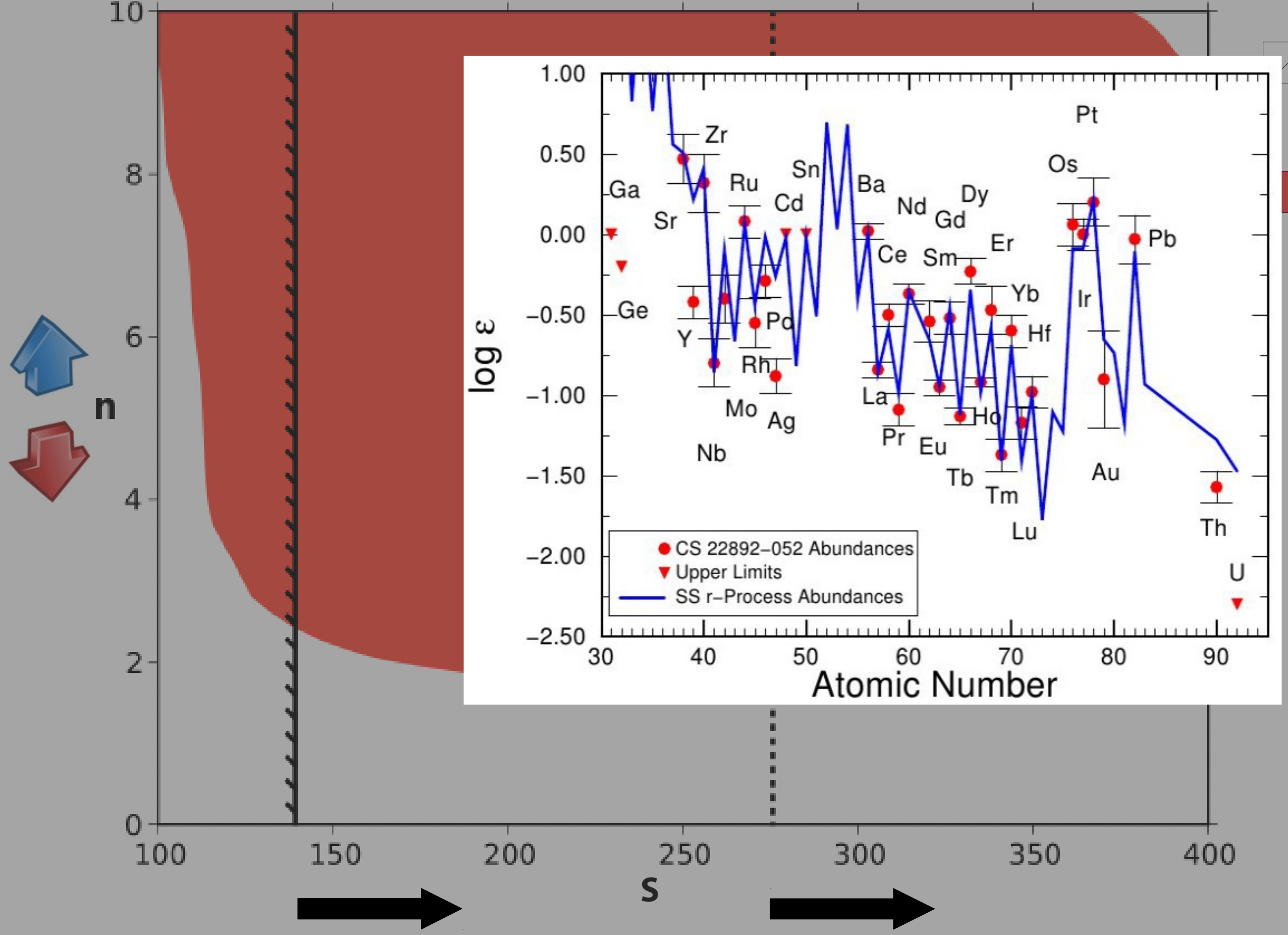
Mumpower et al. (2012)

New Constraint: Rare Earth Peak Forms



Mumpower et al. (2012)

Constraint: Ratio A=195 Peak to REP



▨ Neutron to seed ratio R~80

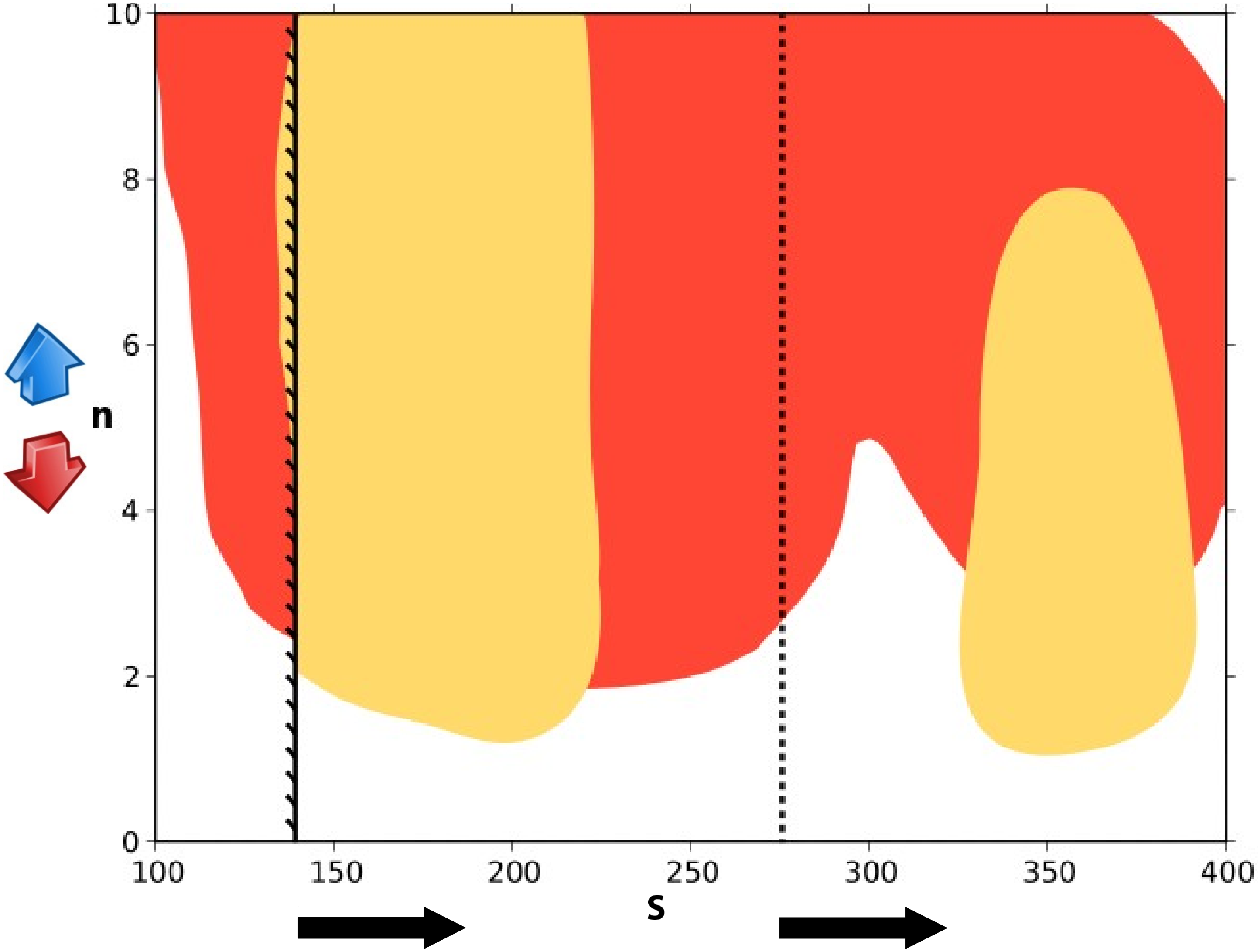
🟥 Rare earth peak matches data

R>80

Fission

Mumpower et al. (2012)

2^{nd} Constraint: Ratio A=195 Peak to REP



▨ Neutron to seed ratio R~80

🟥 Rare earth peak matches data

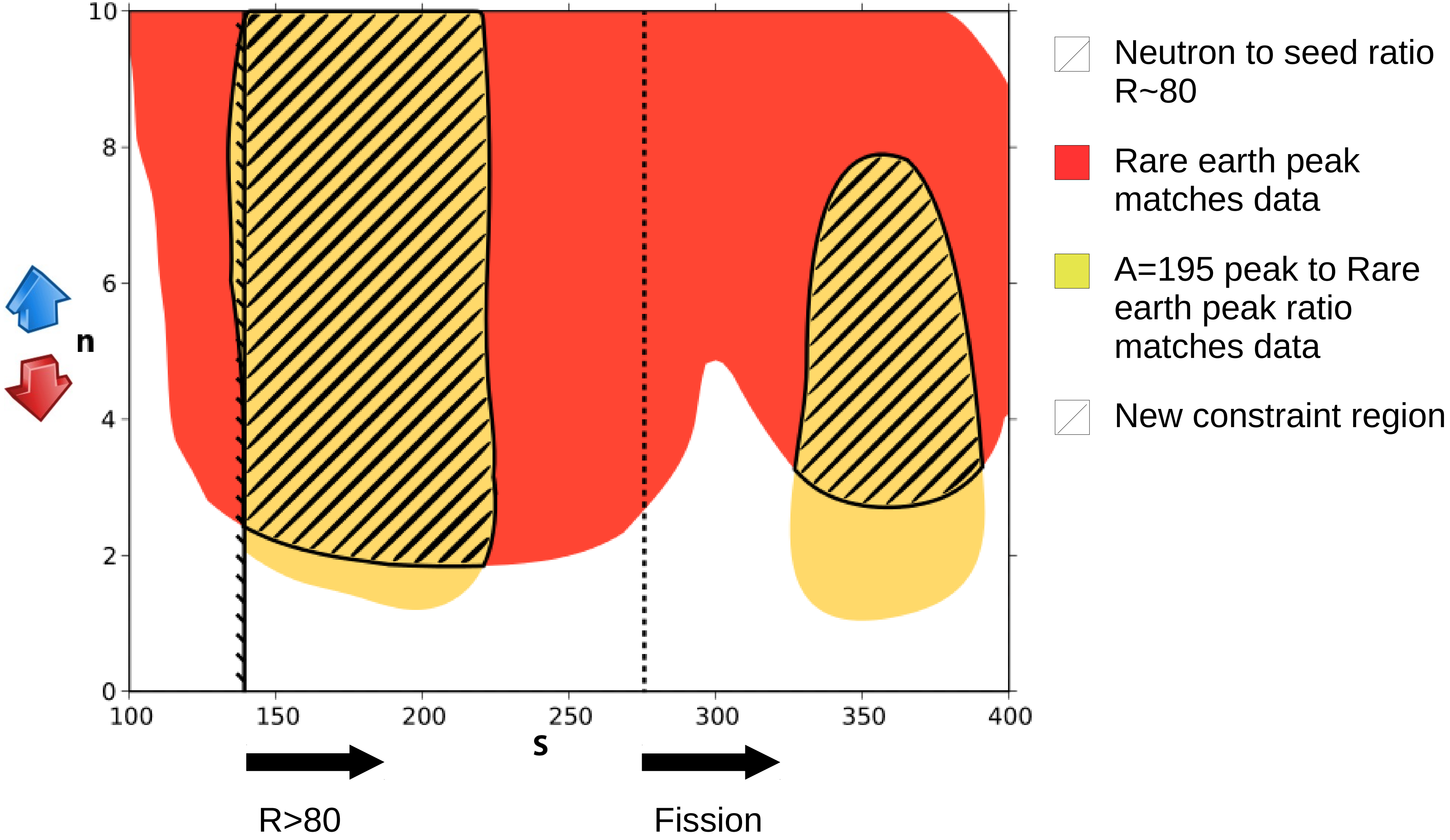
🟨 A=195 peak to Rare earth peak ratio matches data

R>80

Fission

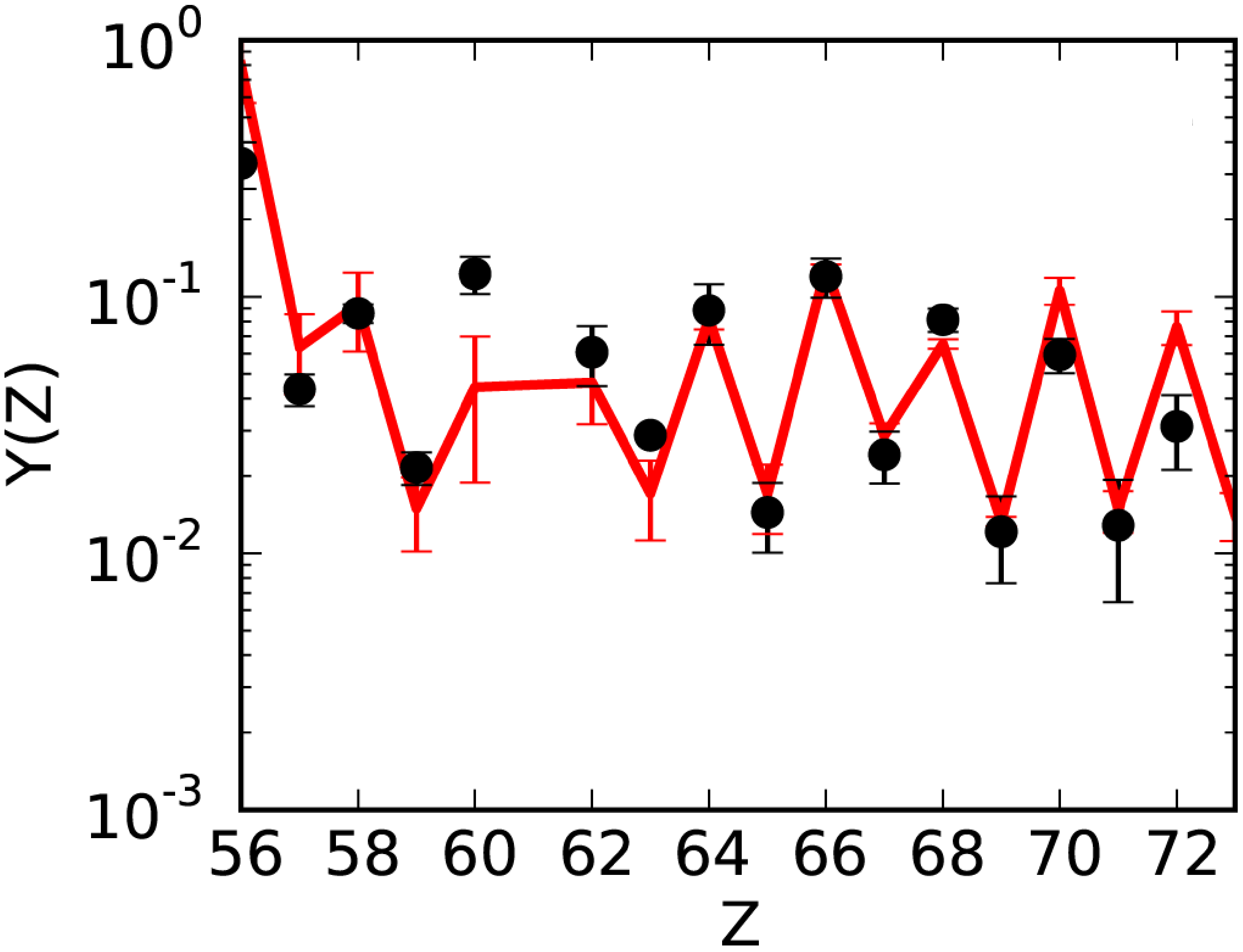
Mumpower et al. (2012)

Result: New (Smaller) Constraint Region



Mumpower et al. (2012)

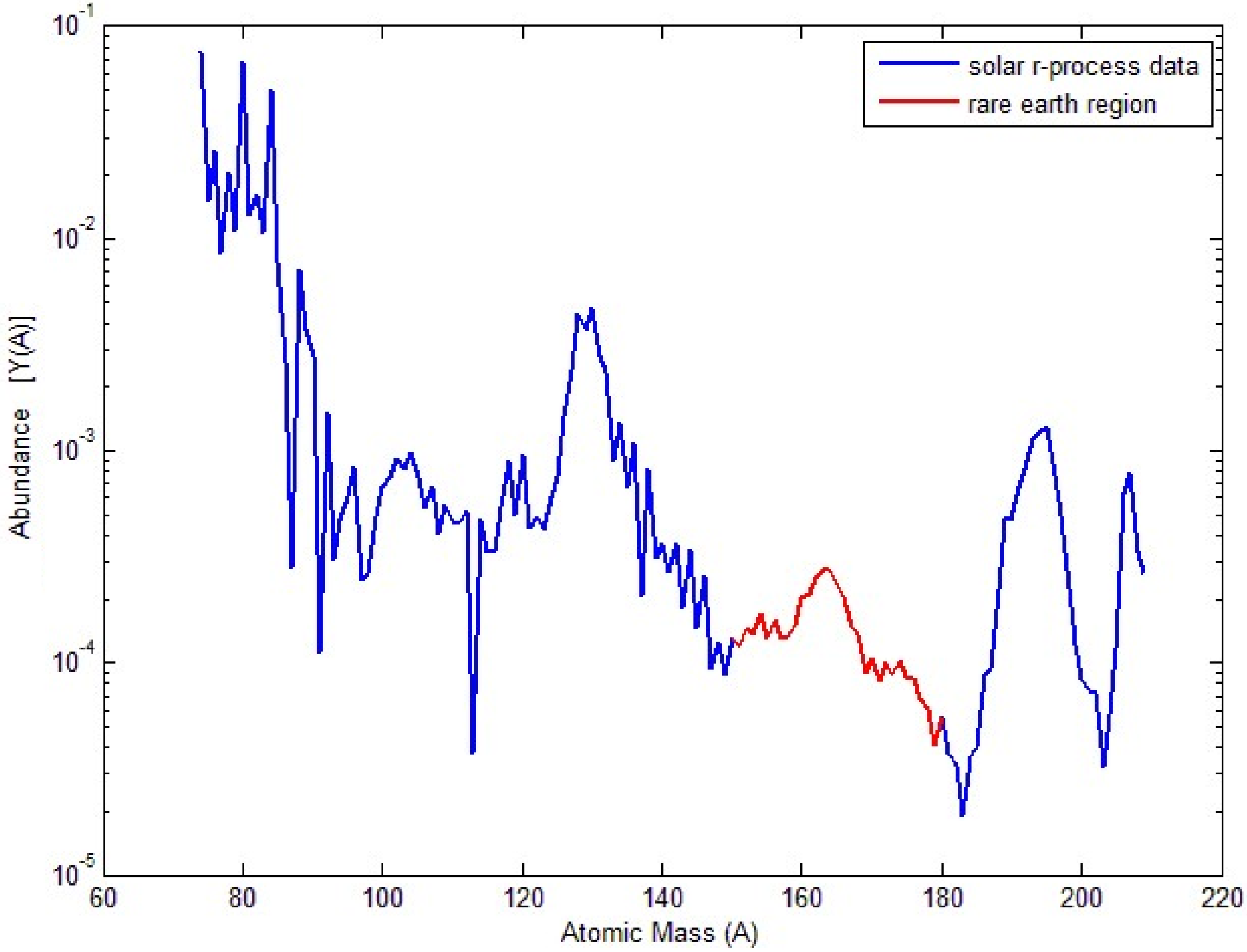
New Constraints Do Remarkably Well



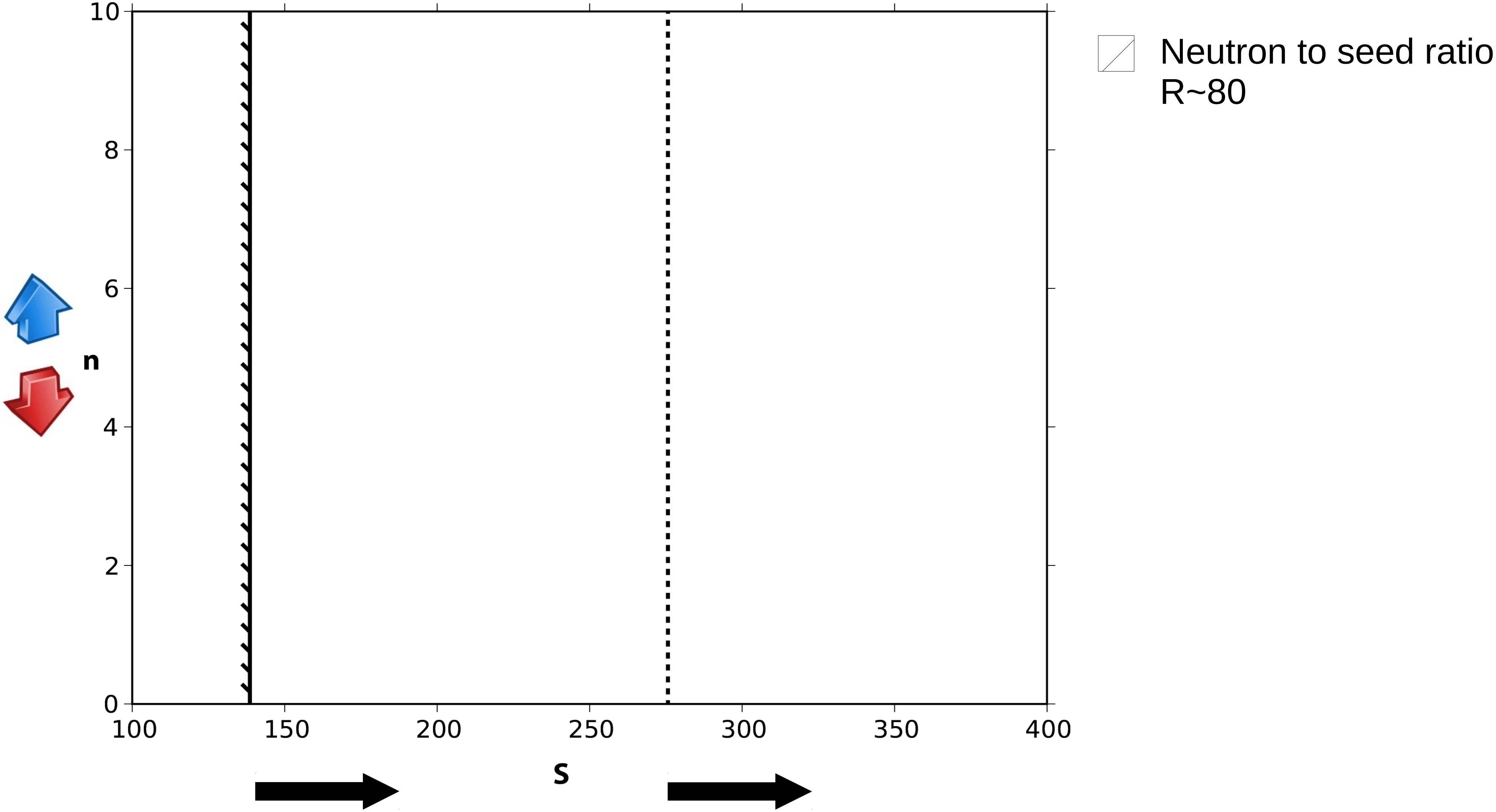
🟥 Avg simulation ⬛ Halo star data

Mumpower et al. (2012)

Comparing Simulations To Solar Data



Old Constraint: Neutron To Seed Ratio



R>80

Fission

Mumpower et al. (2012)

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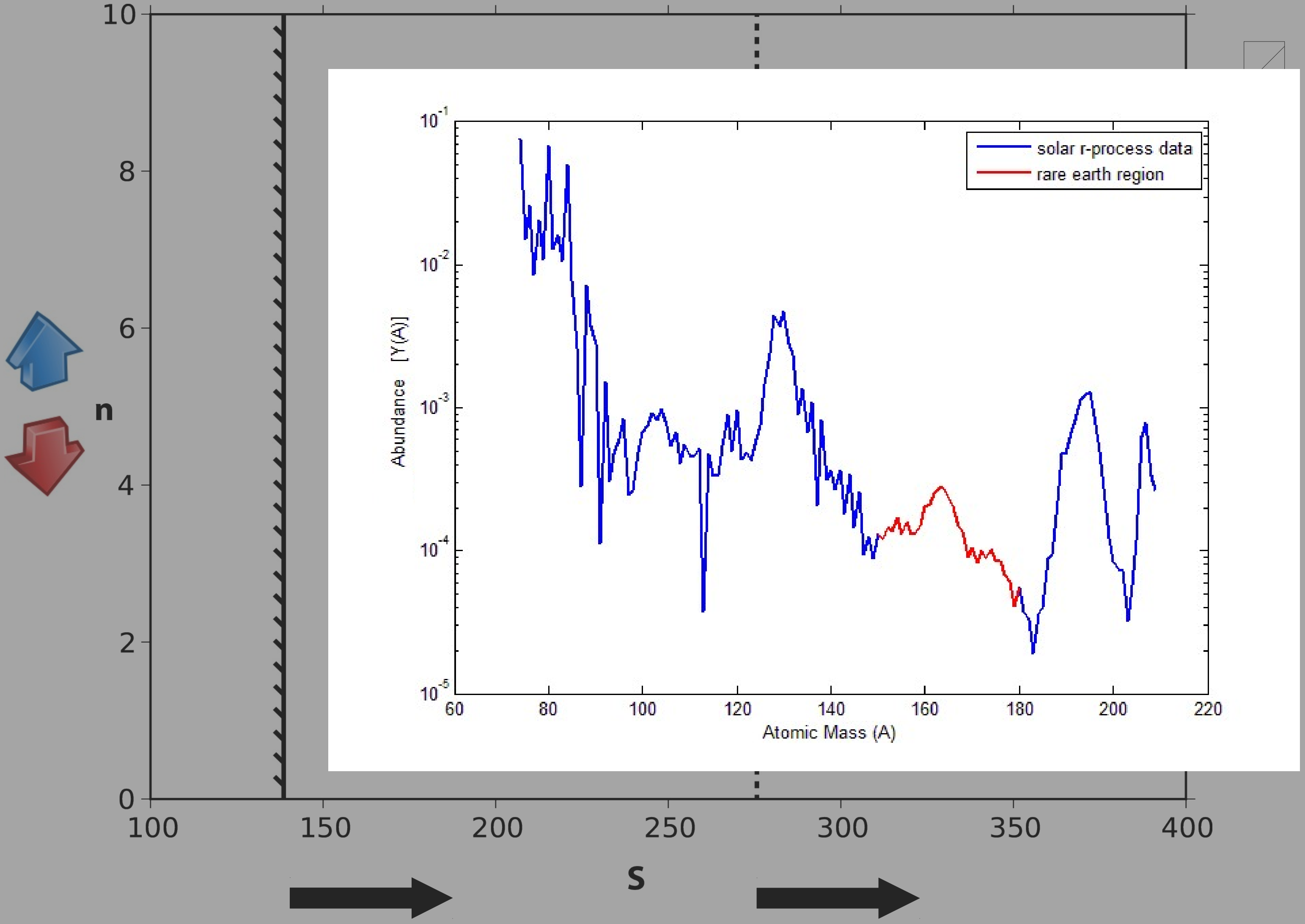


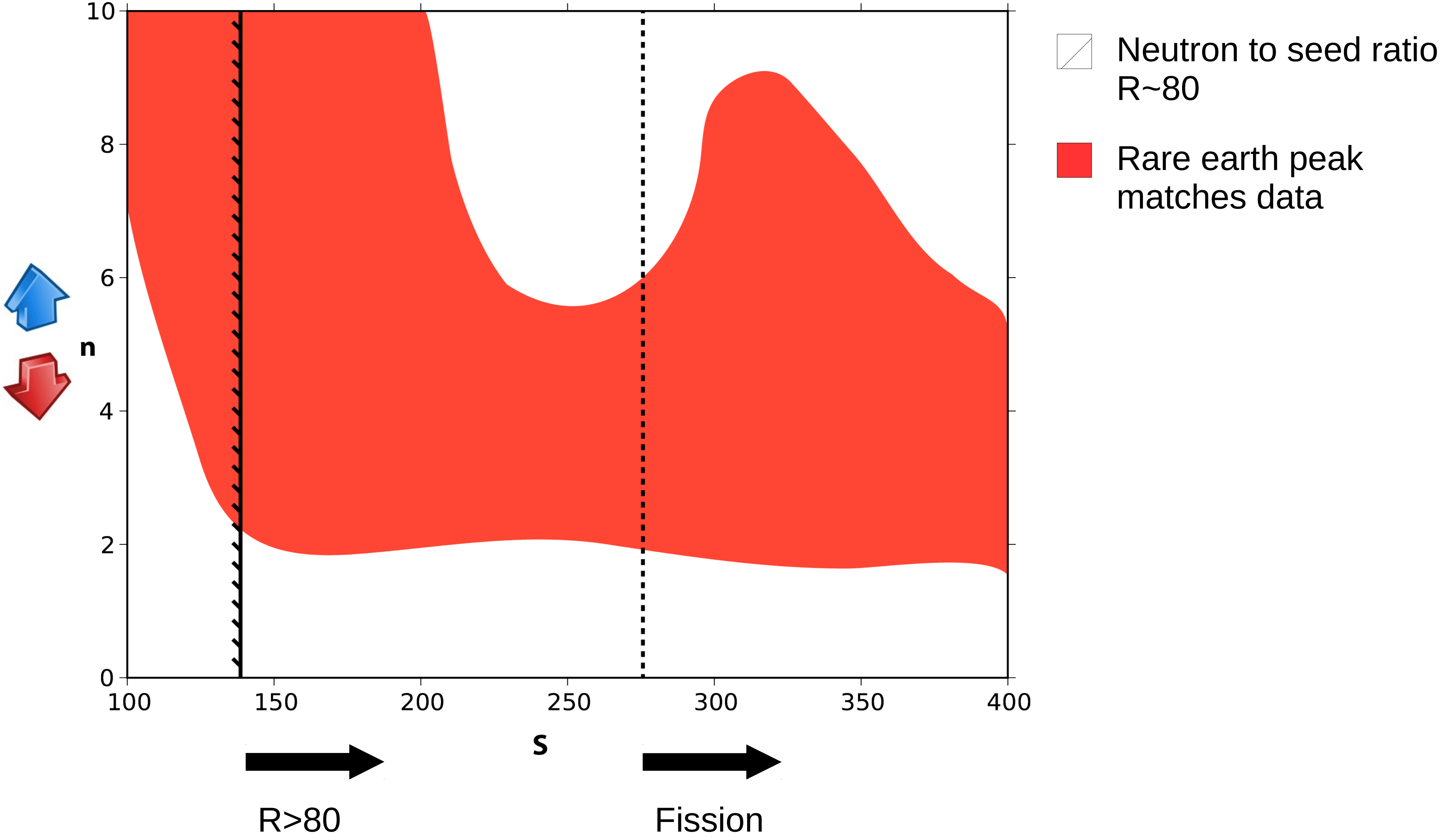
Neutron to seed ratio R~80

R>80

Fission

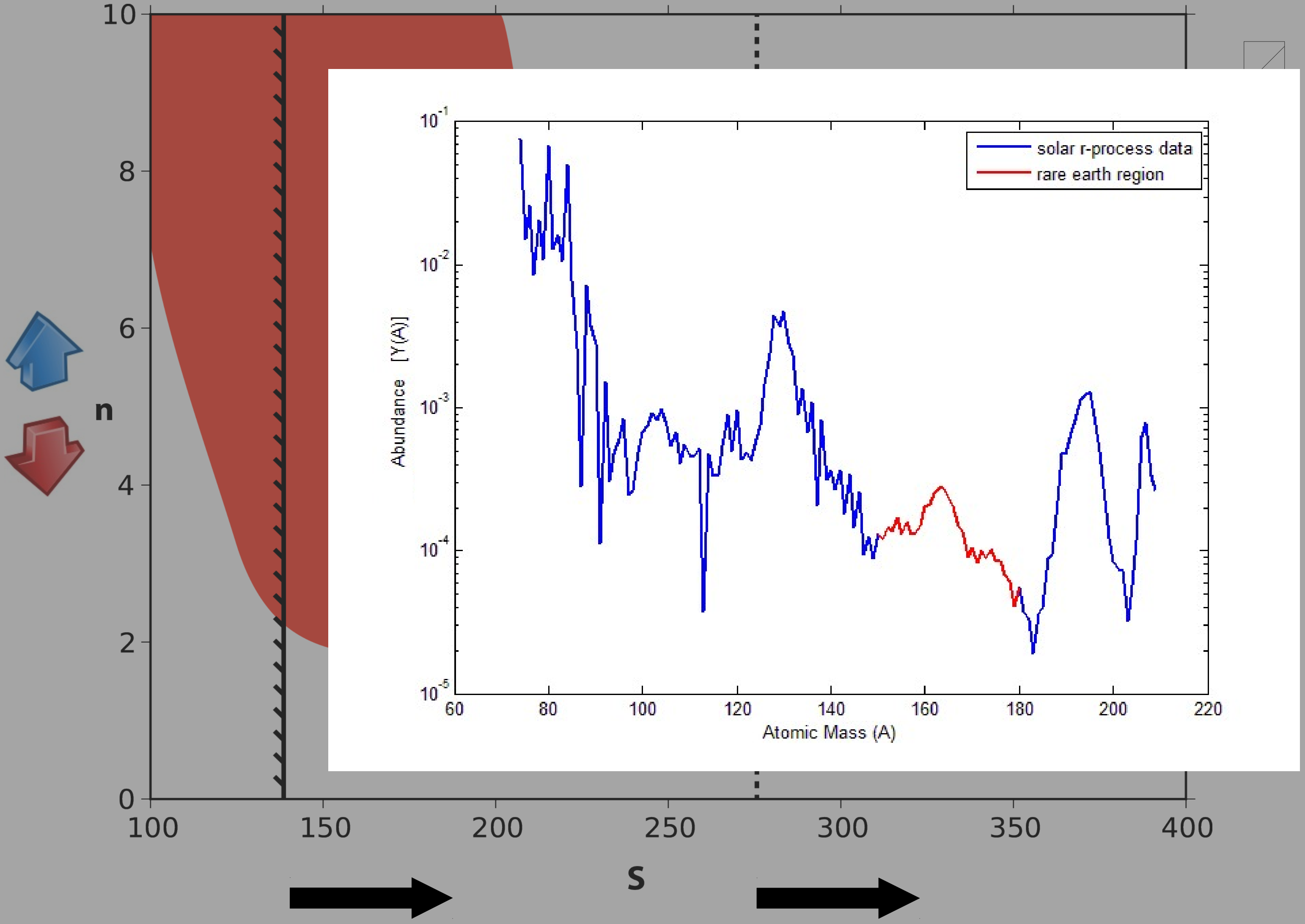
Mumpower et al. (2012)

New Constraint: Rare Earth Peak Forms



Mumpower et al. (2012)

Comparing Simulations To Solar Data



R>80

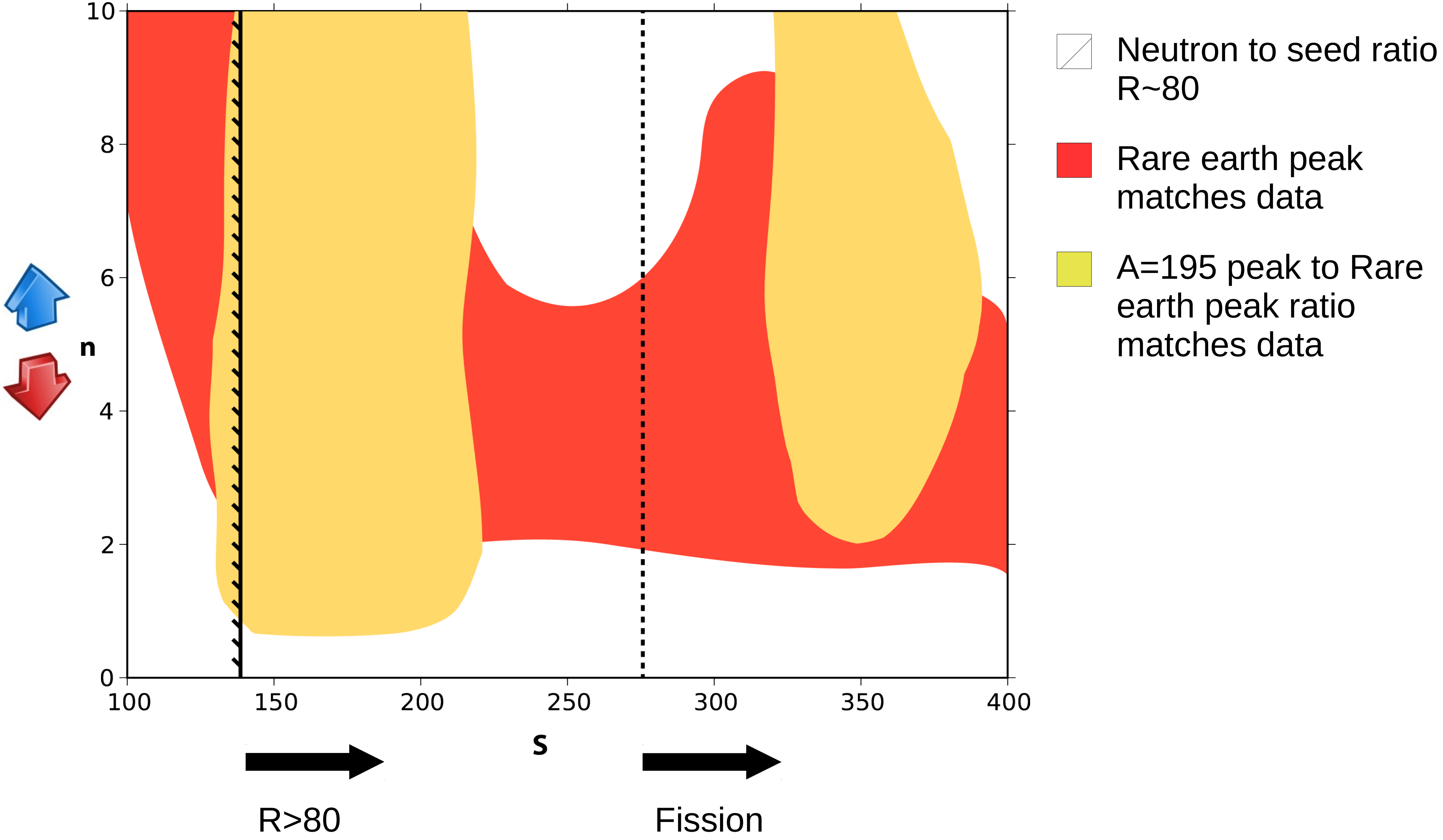
Fission

Neutron to seed ratio R~80

Rare earth peak matches data

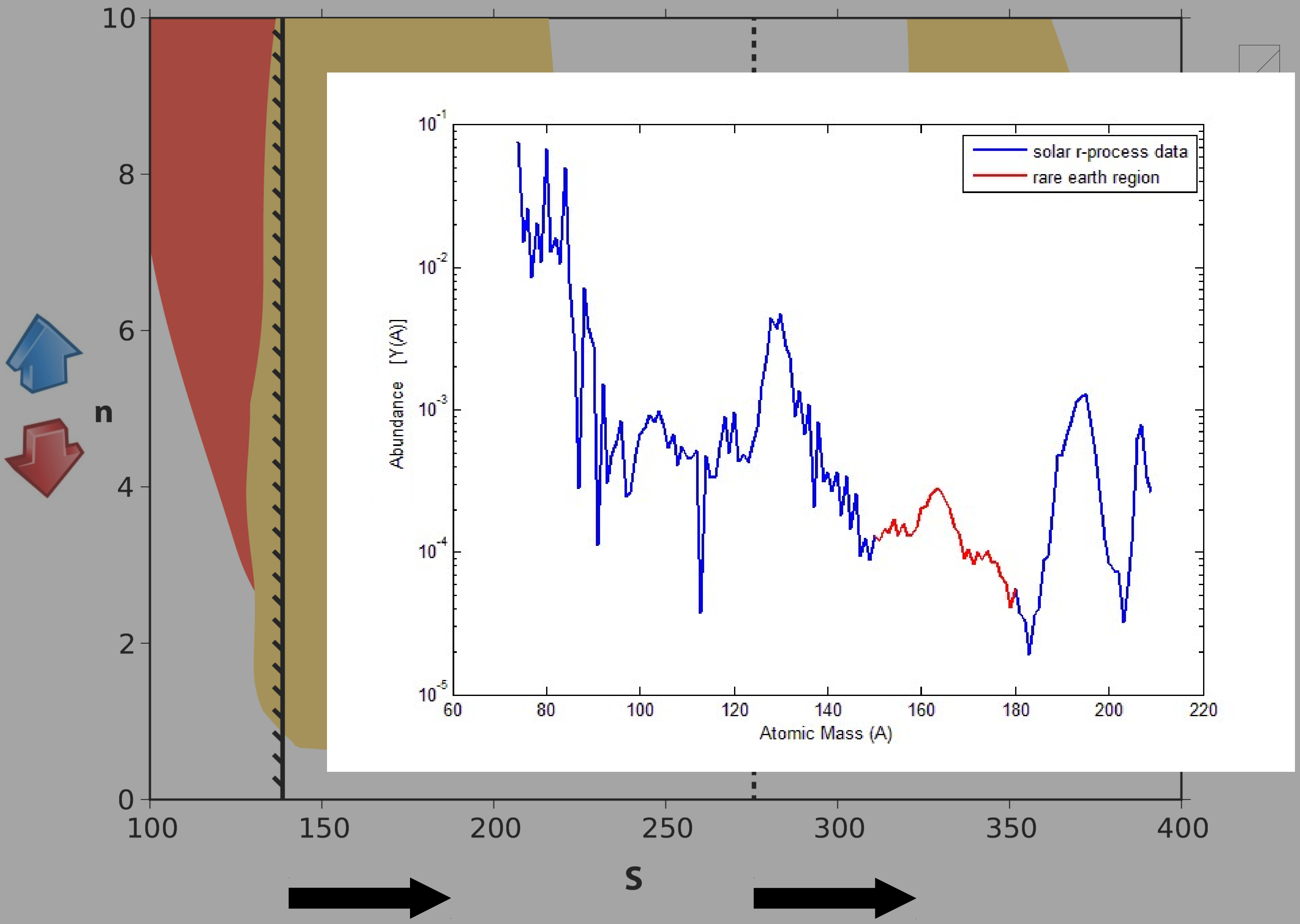
Mumpower et al. (2012)

2nd Constraint: Ratio A=195 Peak to REP



Mumpower et al. (2012)

Comparing Simulations To Solar Data



R>80

Fission

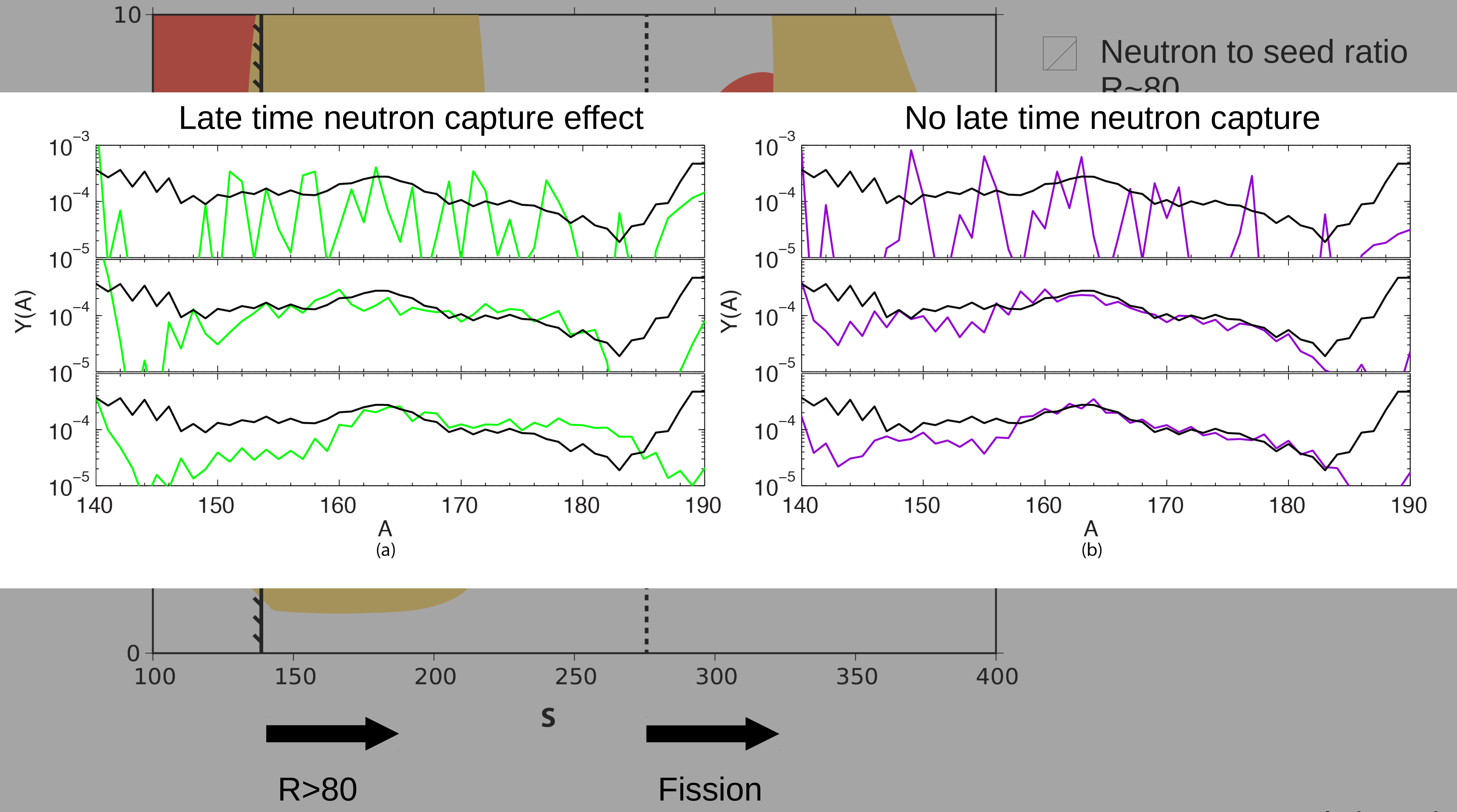
Neutron to seed ratio R~80

Rare earth peak matches data

A=195 peak to Rare earth peak ratio matches data

Mumpower et al. (2012)

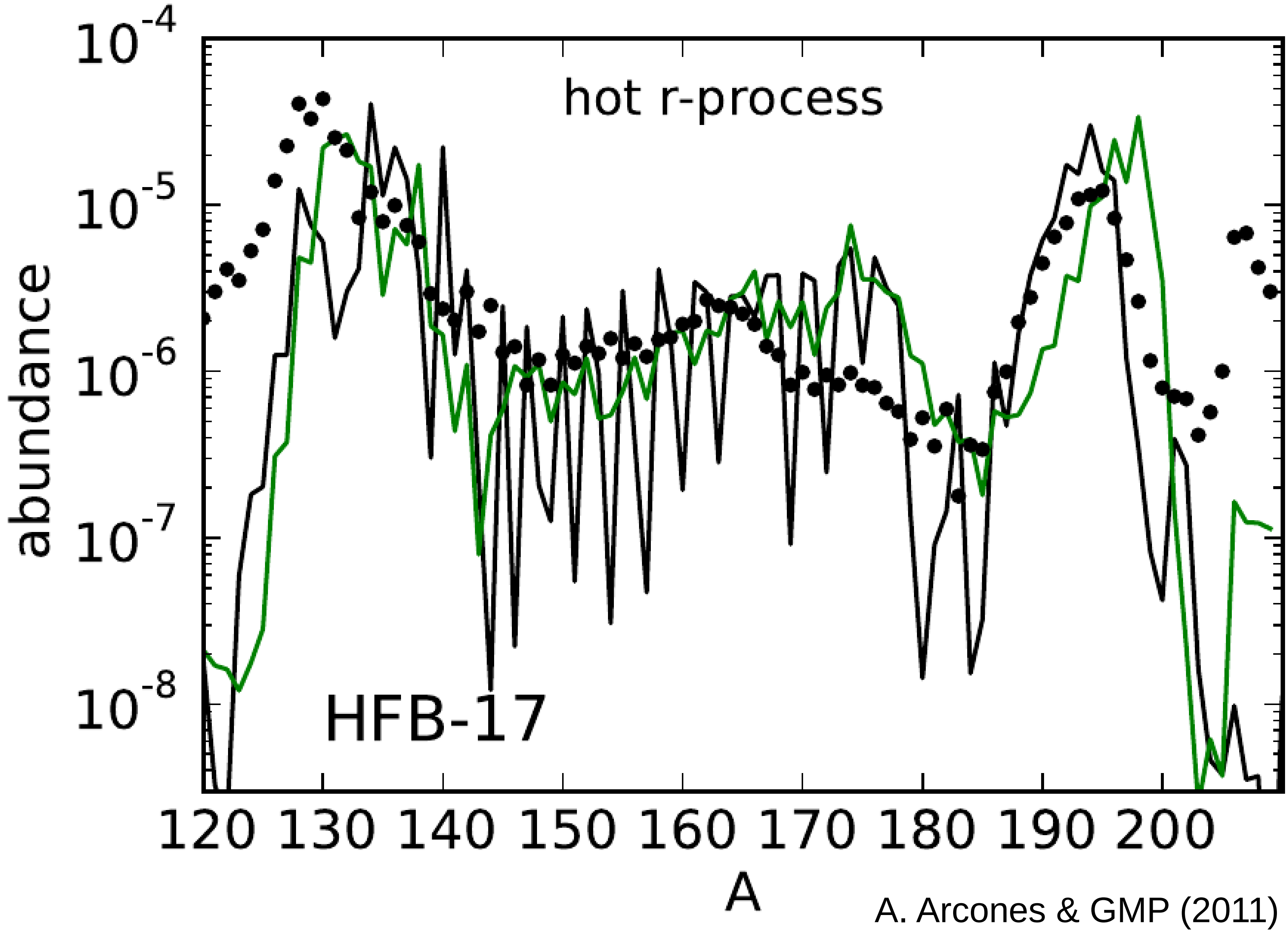
Late Time Neutron Capture Effect


Late time neutron capture effect

No late time neutron capture

Mumpower et al. (2012)

Late Time Neutron Capture Effect



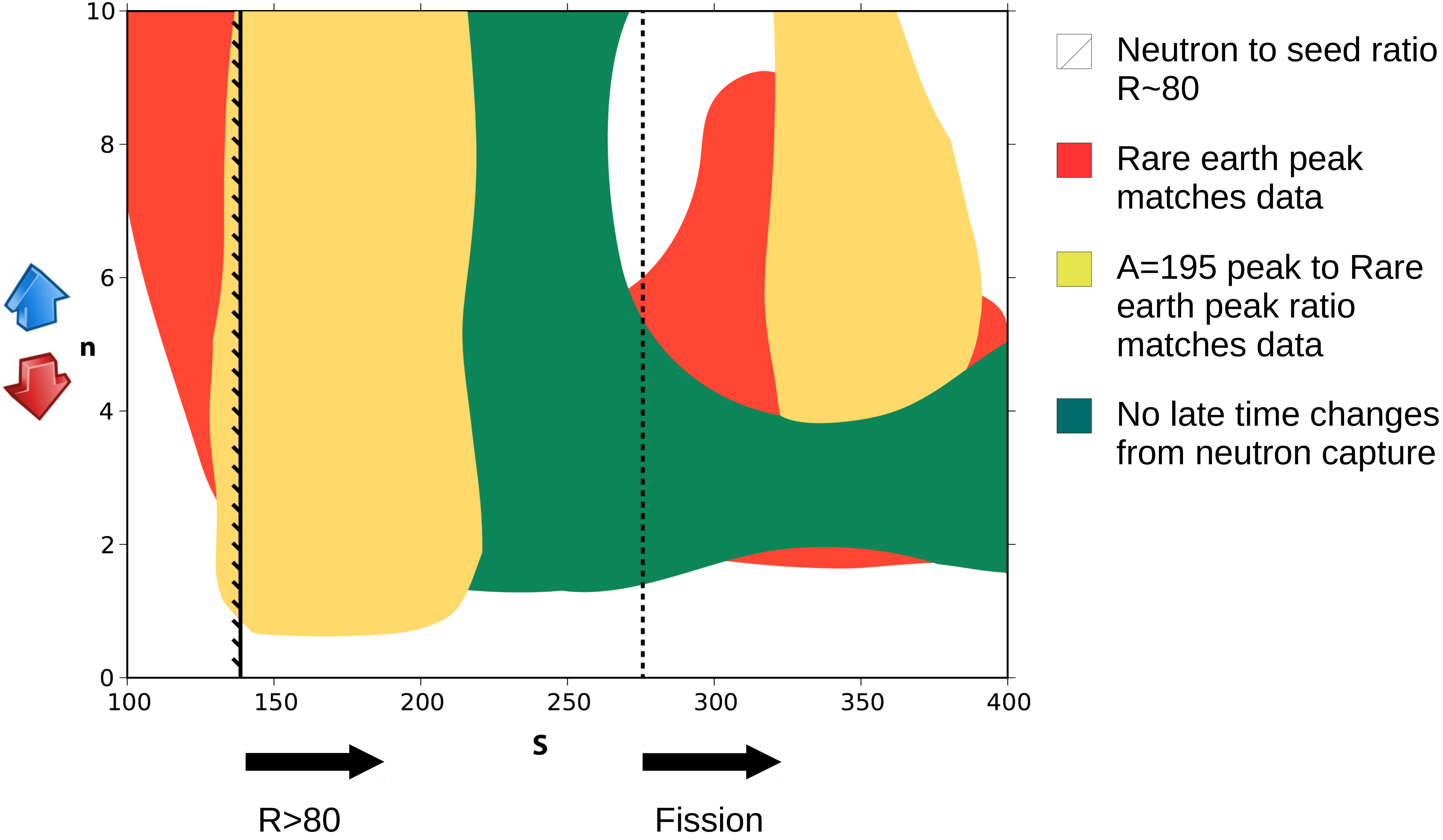
A. Arcones & GMP (2011)

ratio

are

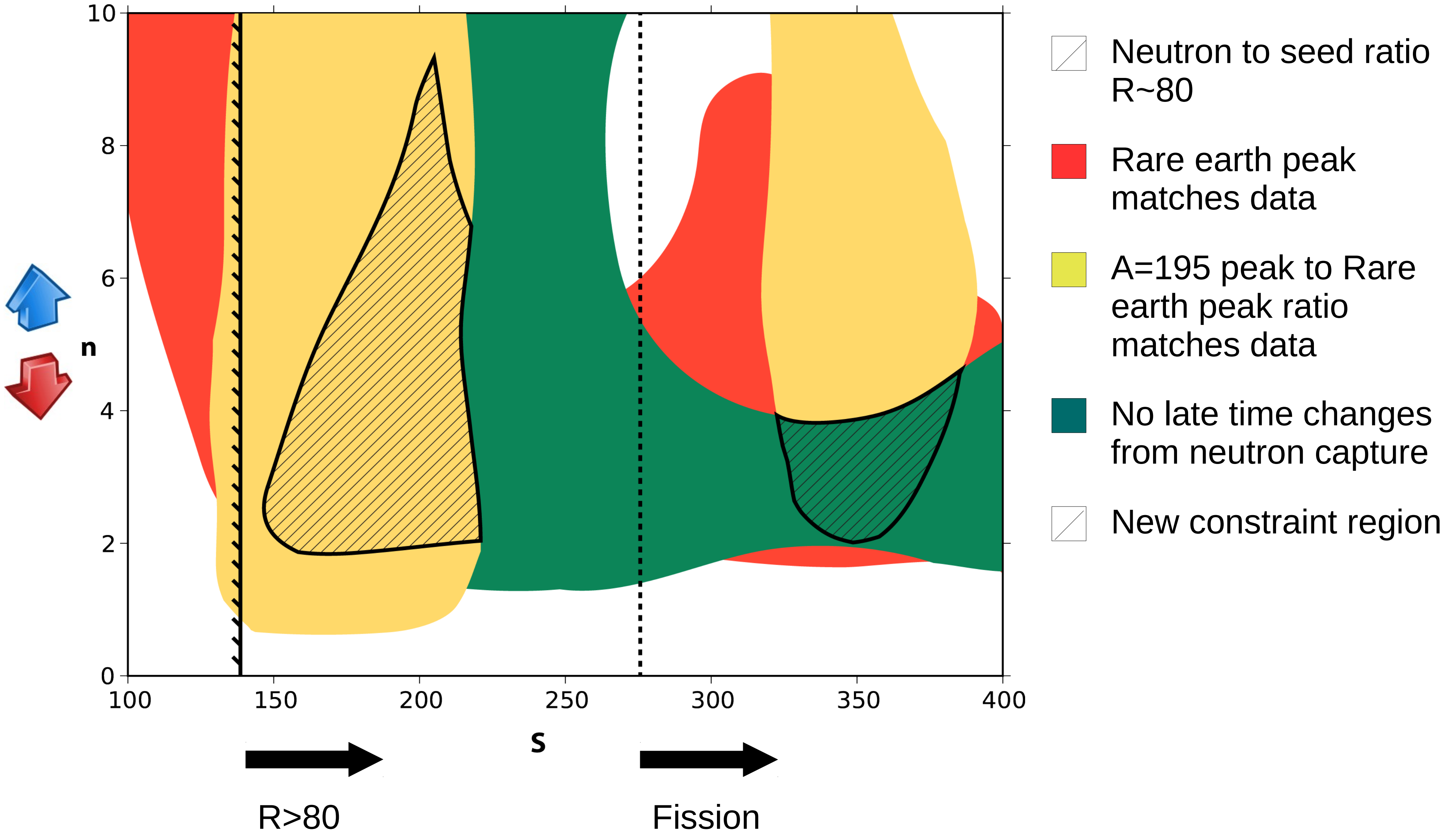
Mumpower et al. (2012)

3rd Constraint: Limit Late Time Neutron Capture



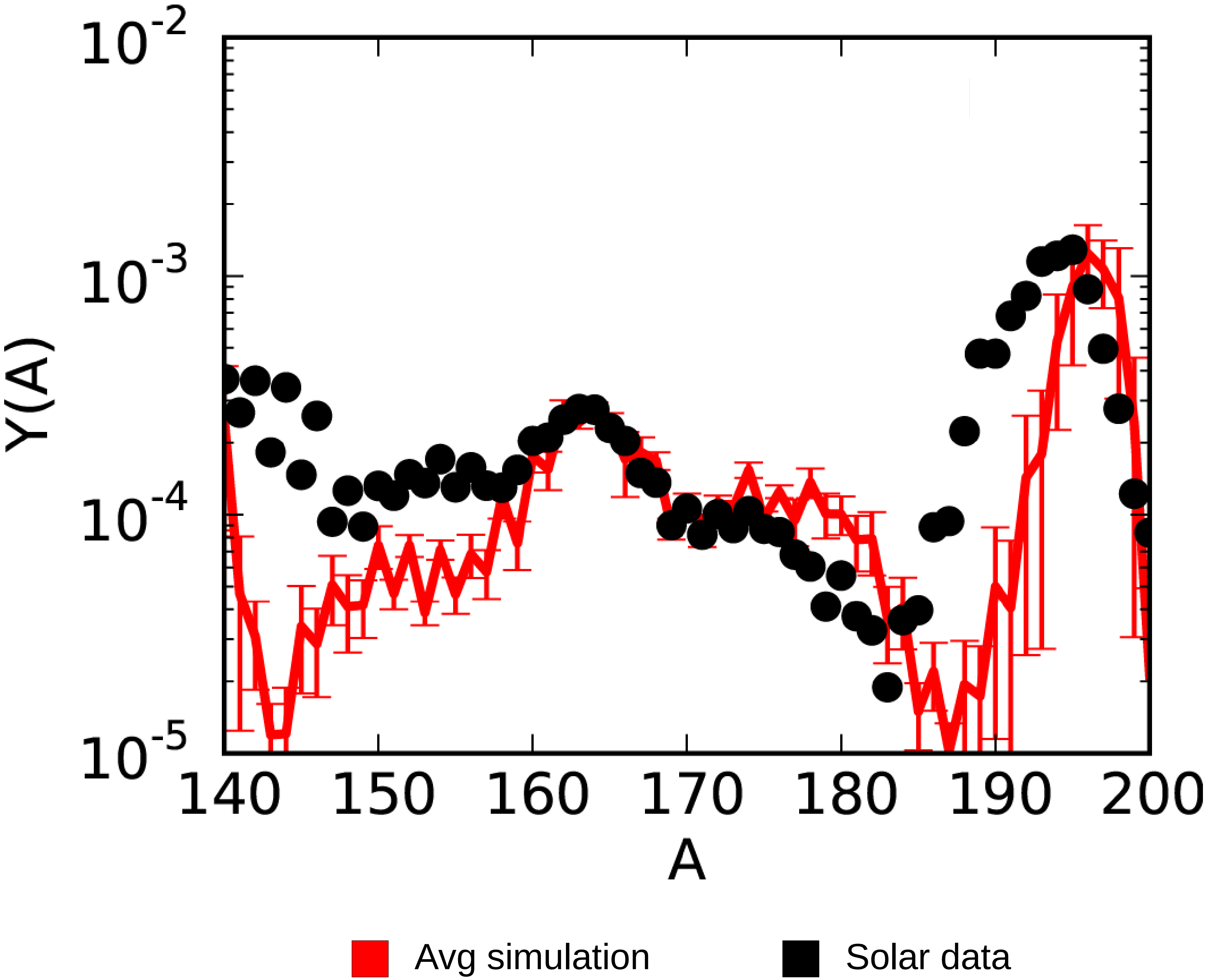
Mumpower et al. (2012)

Result: New (Smaller) Constraint Regions



Mumpower et al. (2012)

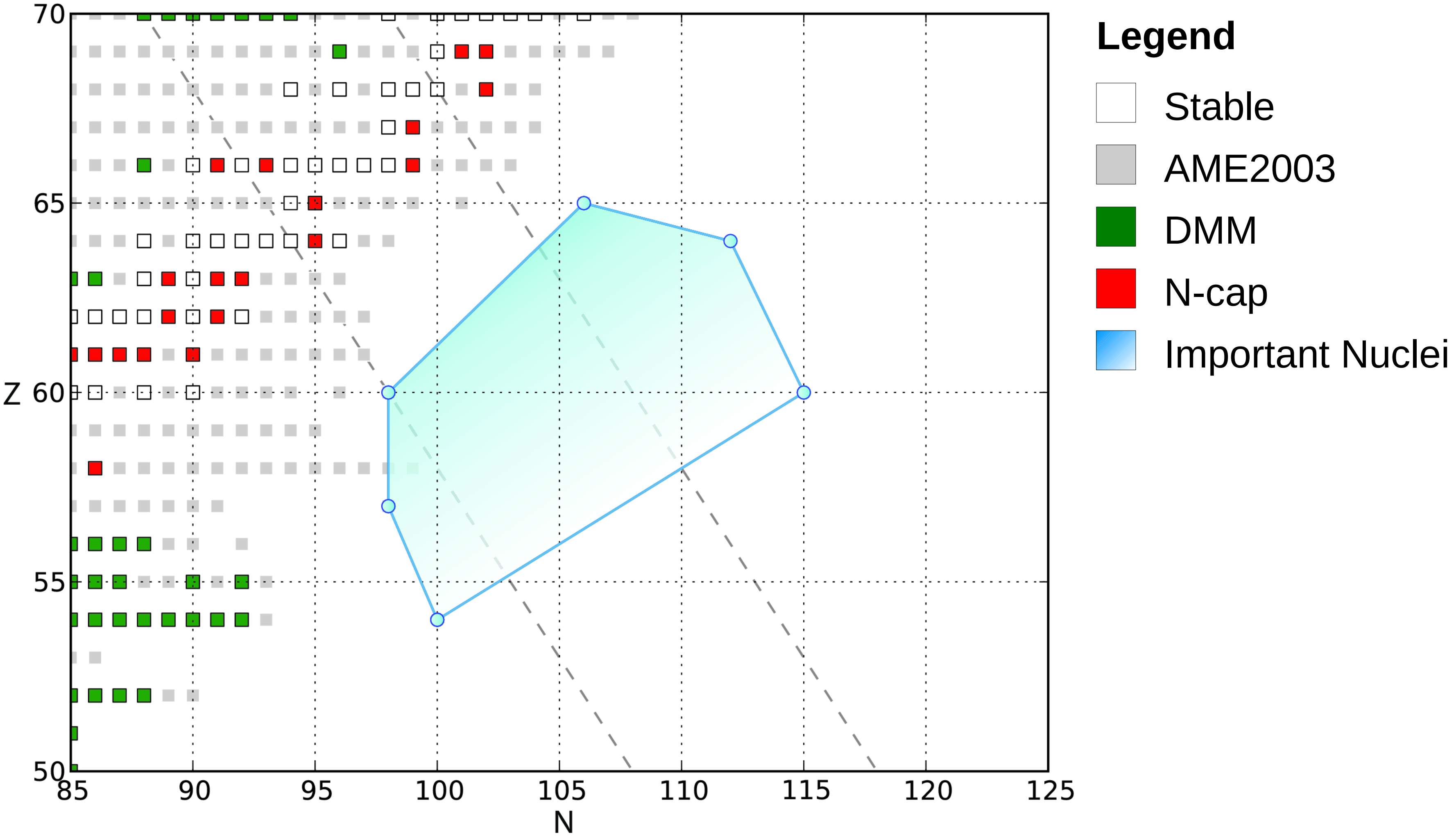
Comparing Simulations To Solar Data



Mumpower et al. (2012)

Which Nuclei In The Rare Earth Region Are Important?

Those nuclei 10-15 neutrons from stability



Mumpower et al. (2012)

SUMMARY

- Rare earth peak offers unique insight into the last stage of the *r*-process

- Formation sensitive to:
  - deformation in the region
  - rate of change of conditions
  - “correct amount” of neutron capture

- Understanding neutron capture at late times is critical.

- Important nuclei 10-15 neutrons from stability.