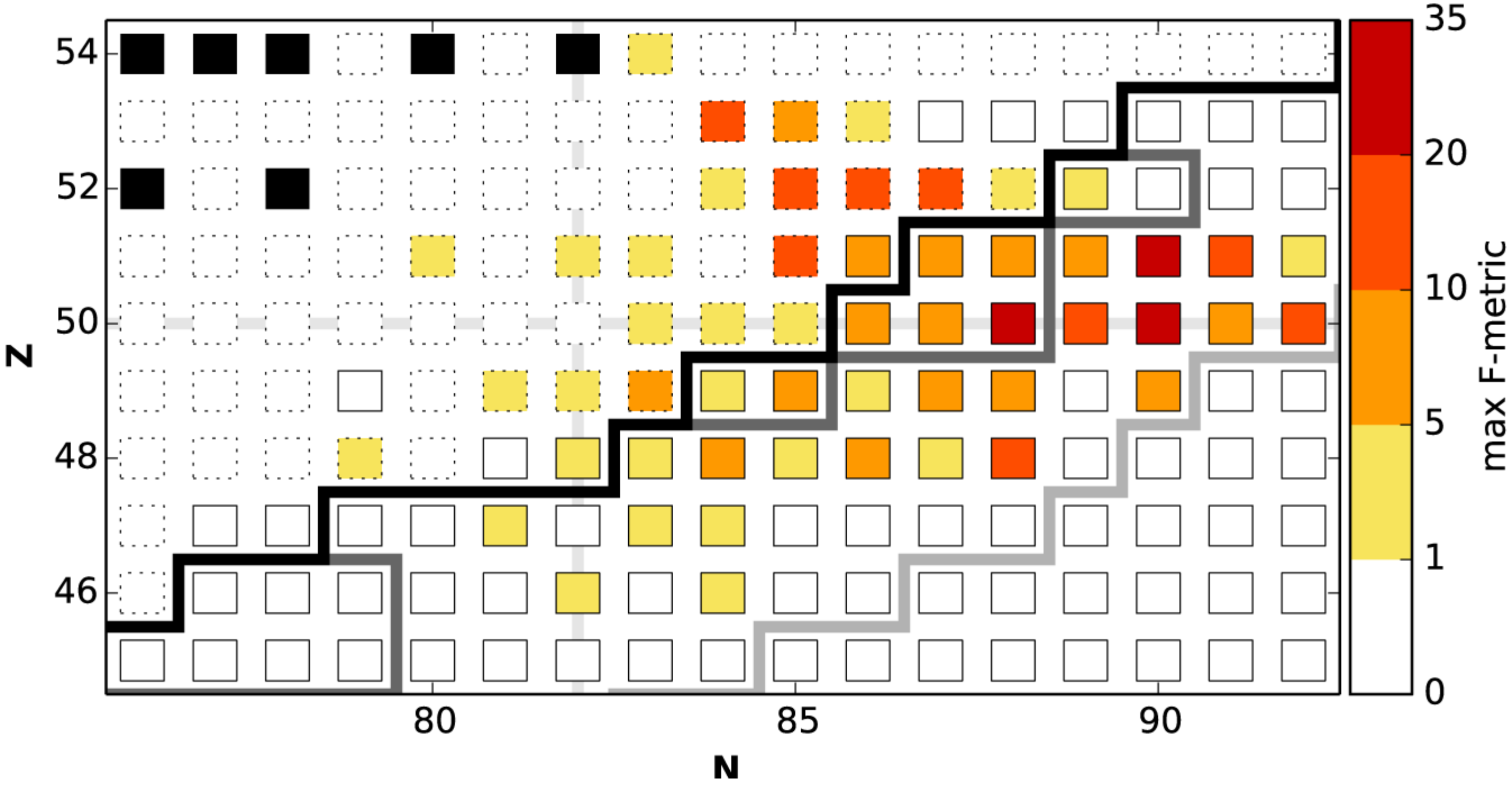
The *r*-process and nuclear masses near closed shells



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Thursday May 15th 2014

ATLAS User Meeting

The *r*-Process

"rapid" neutron capture (as compared to beta decay)

Far from stable isotopes → nuclides participating are short lived

→ little to no experimental data

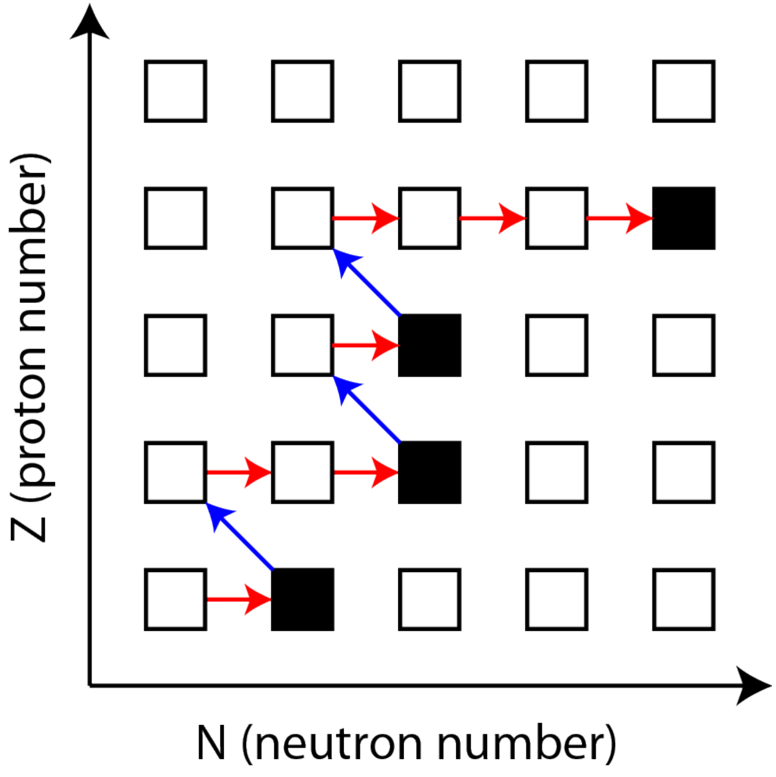
e.g. Uranium Z=92, N=146 → need lots of neutrons

Neutron Capture / Photo-dissociation

$$(Z, N) + n \leftrightarrow (Z, N+1) + \gamma$$

Beta Decay

$$(Z, N) \rightarrow (Z+1, N-1) + e^- + \overline{\nu}_e$$



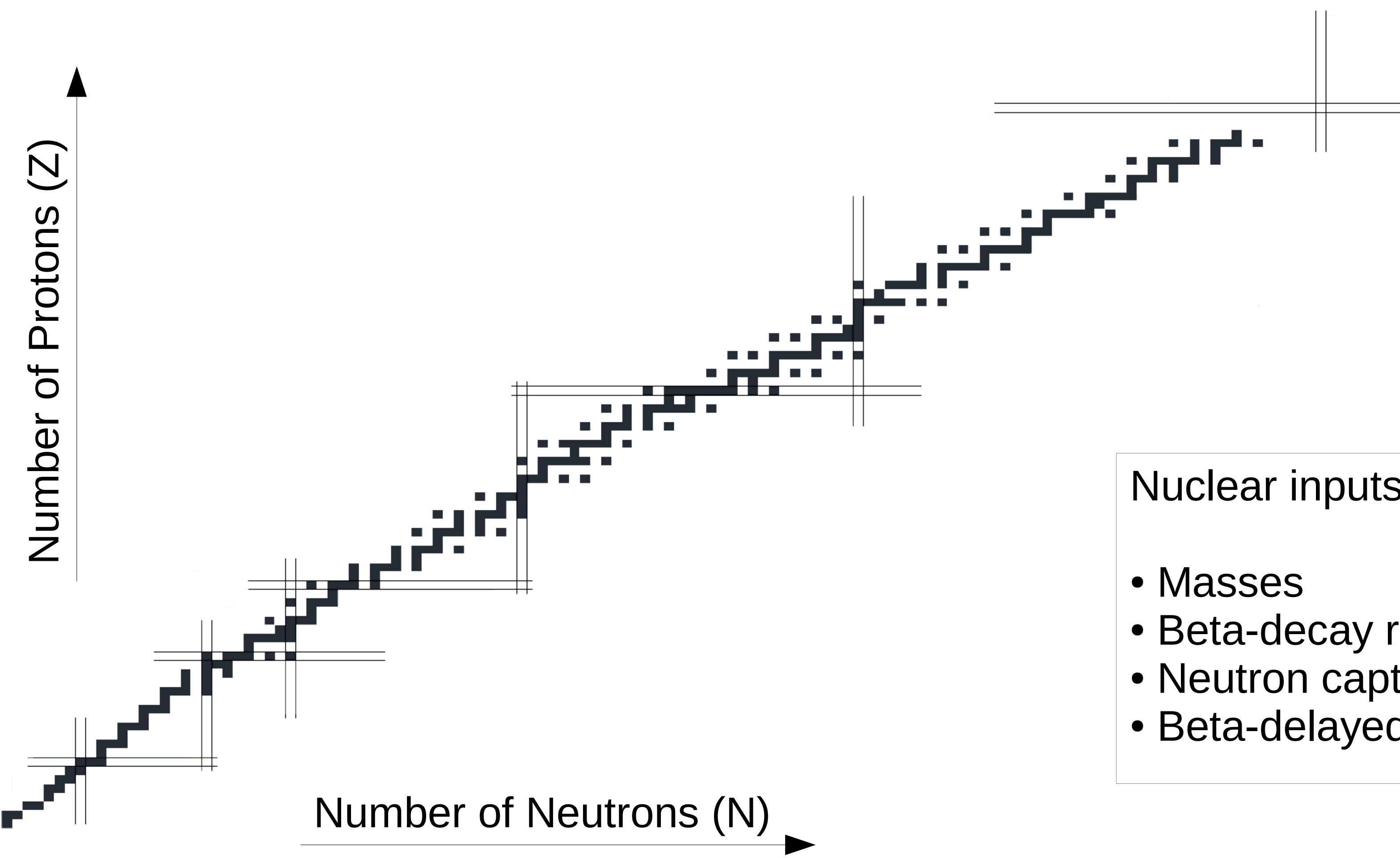
Nuclear Data

The Nuclear Chart

Legend

Stable

Closed shells

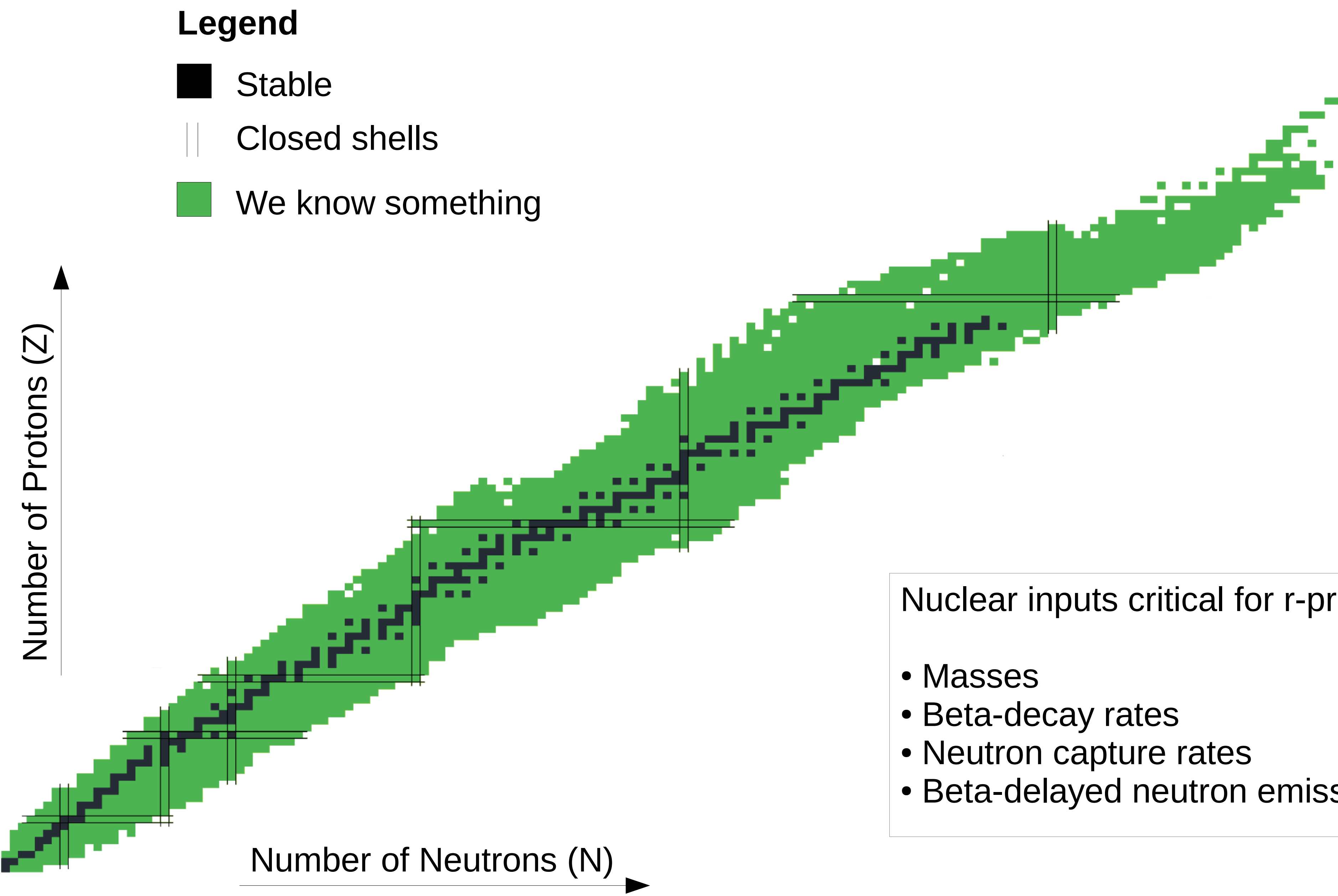


Nuclear inputs critical for r-process

- Masses
- Beta-decay rates
- Neutron capture rates
- Beta-delayed neutron emission

Nuclear Data

What Do We Know?



Nuclear inputs critical for r-process

- Masses
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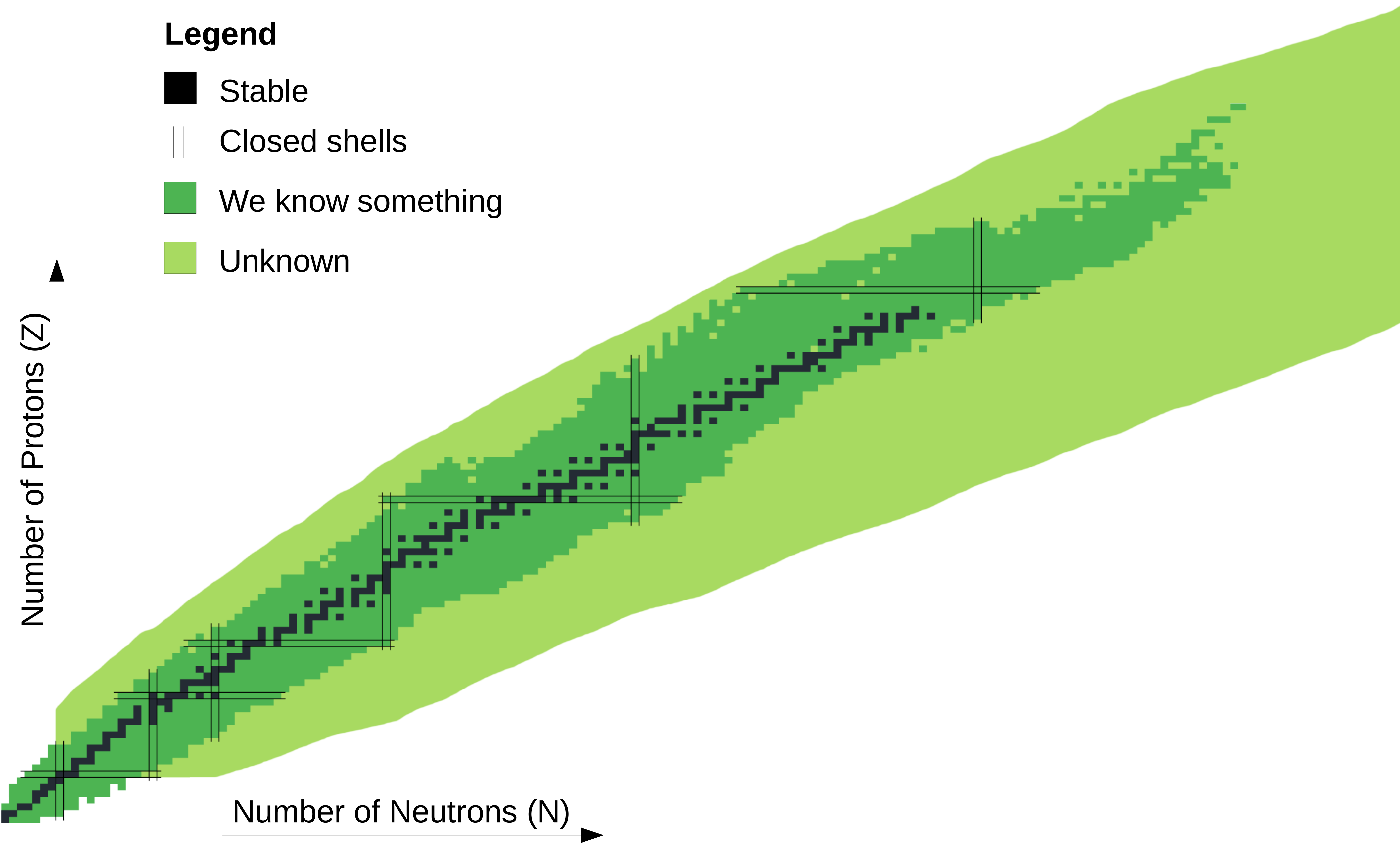
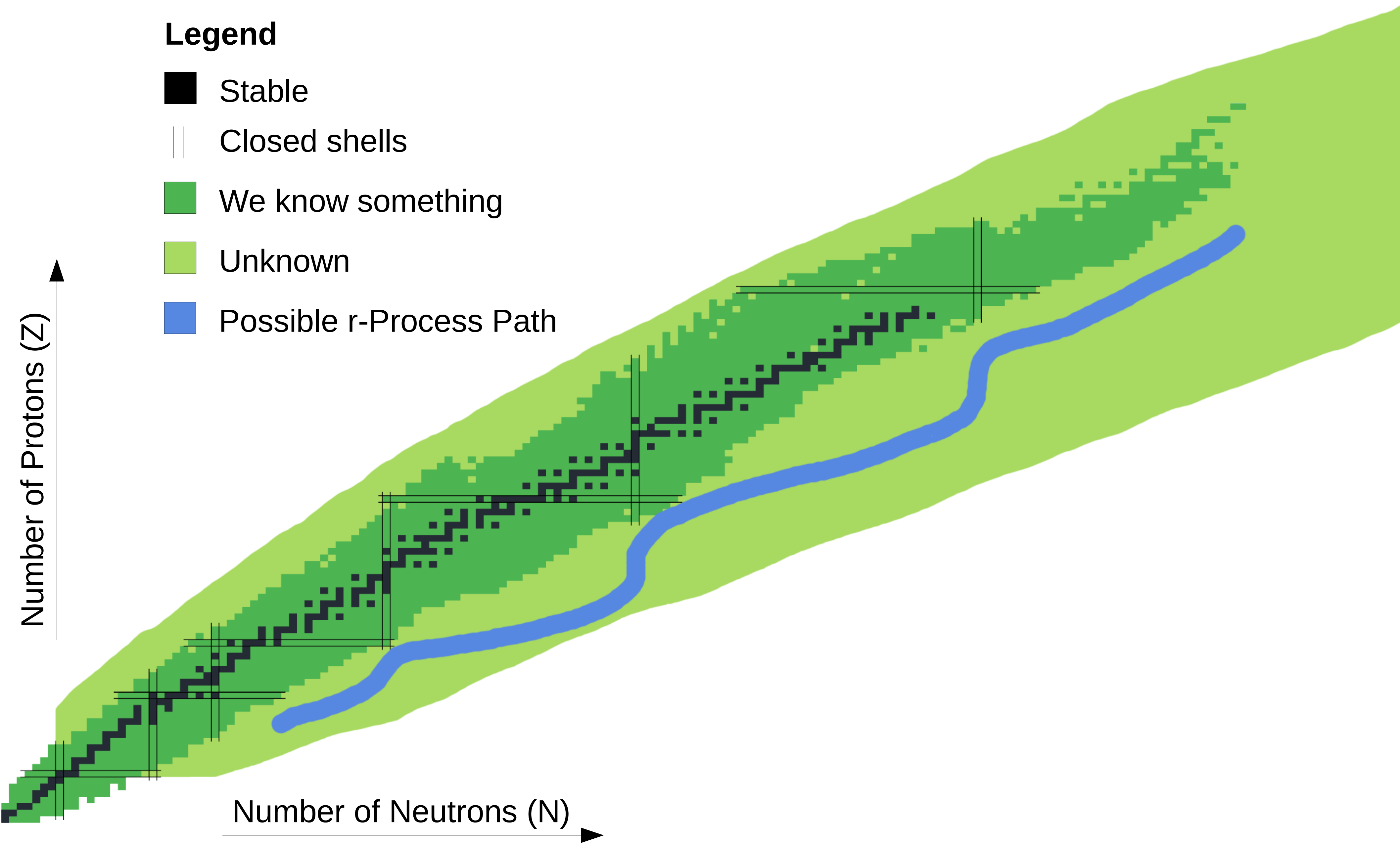
Nuclear Data

What We Don't Know



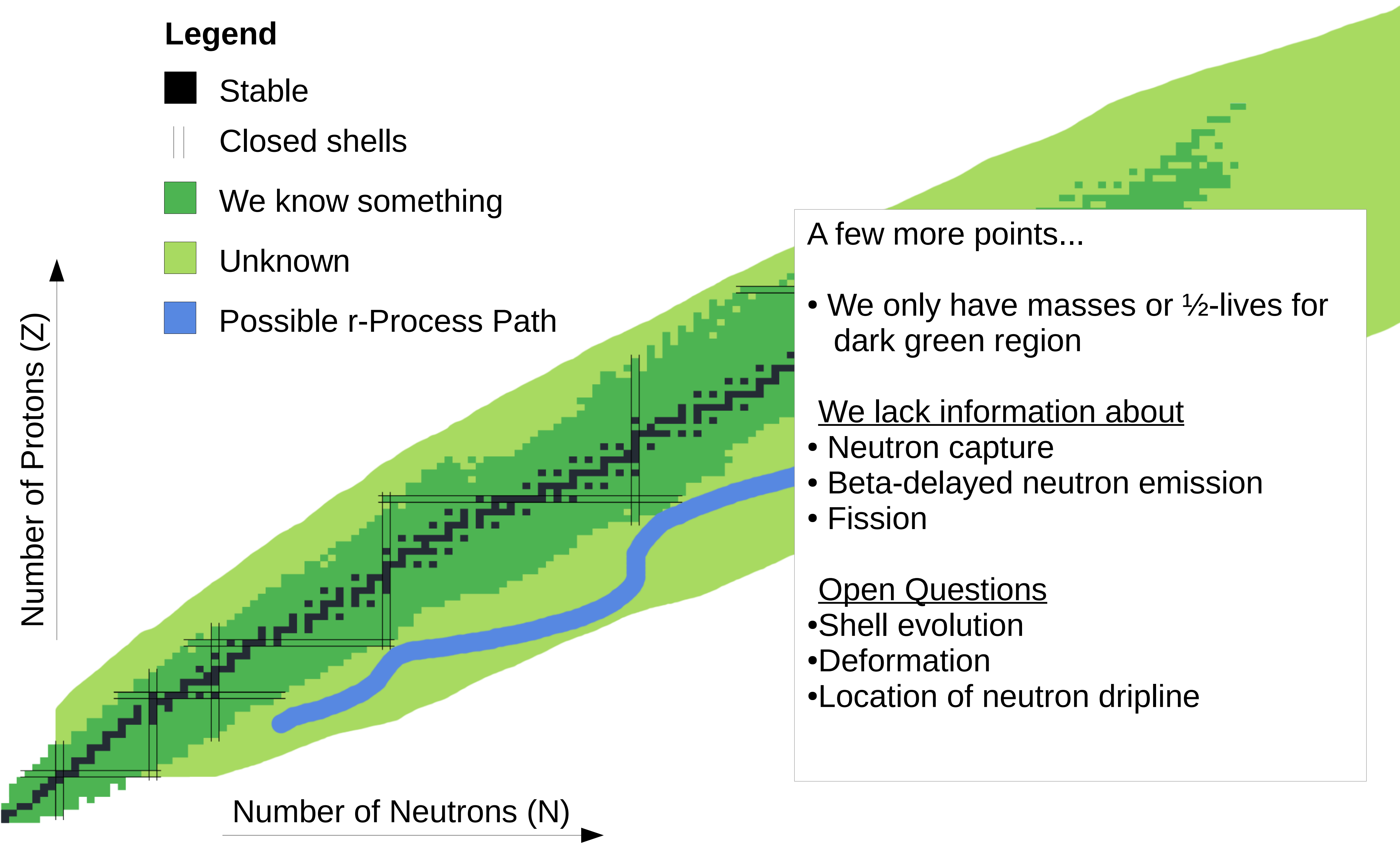
Nuclear Data

Possible r-Process Path



Nuclear Data

Possible r-Process Path



A few more points...

- We only have masses or ½-lives for dark green region

<u>We lack information about</u>

- Neutron capture
- Beta-delayed neutron emission
- Fission

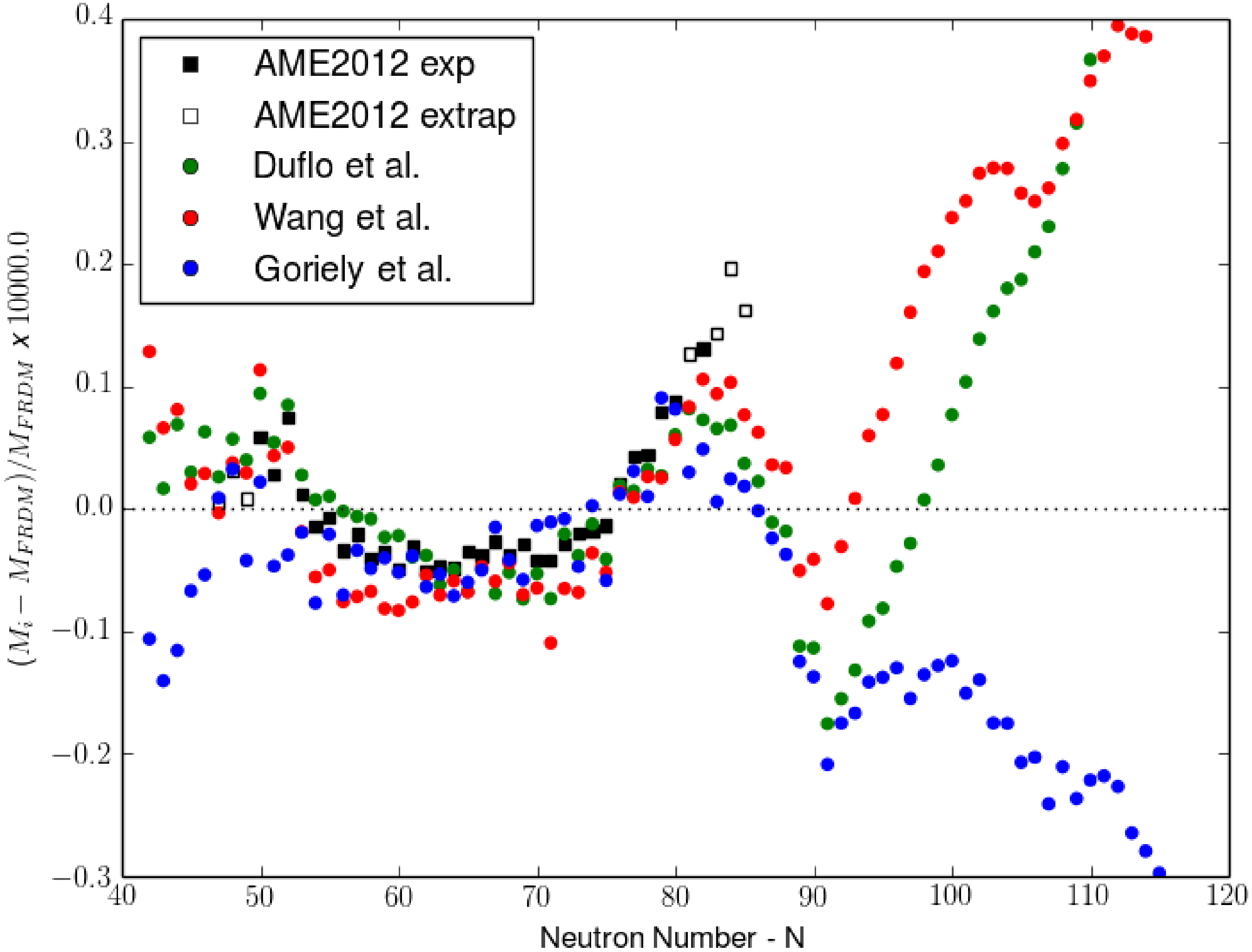
<u>Open Questions</u>

- Shell evolution
- Deformation
- Location of neutron dripline

Nuclear Masses

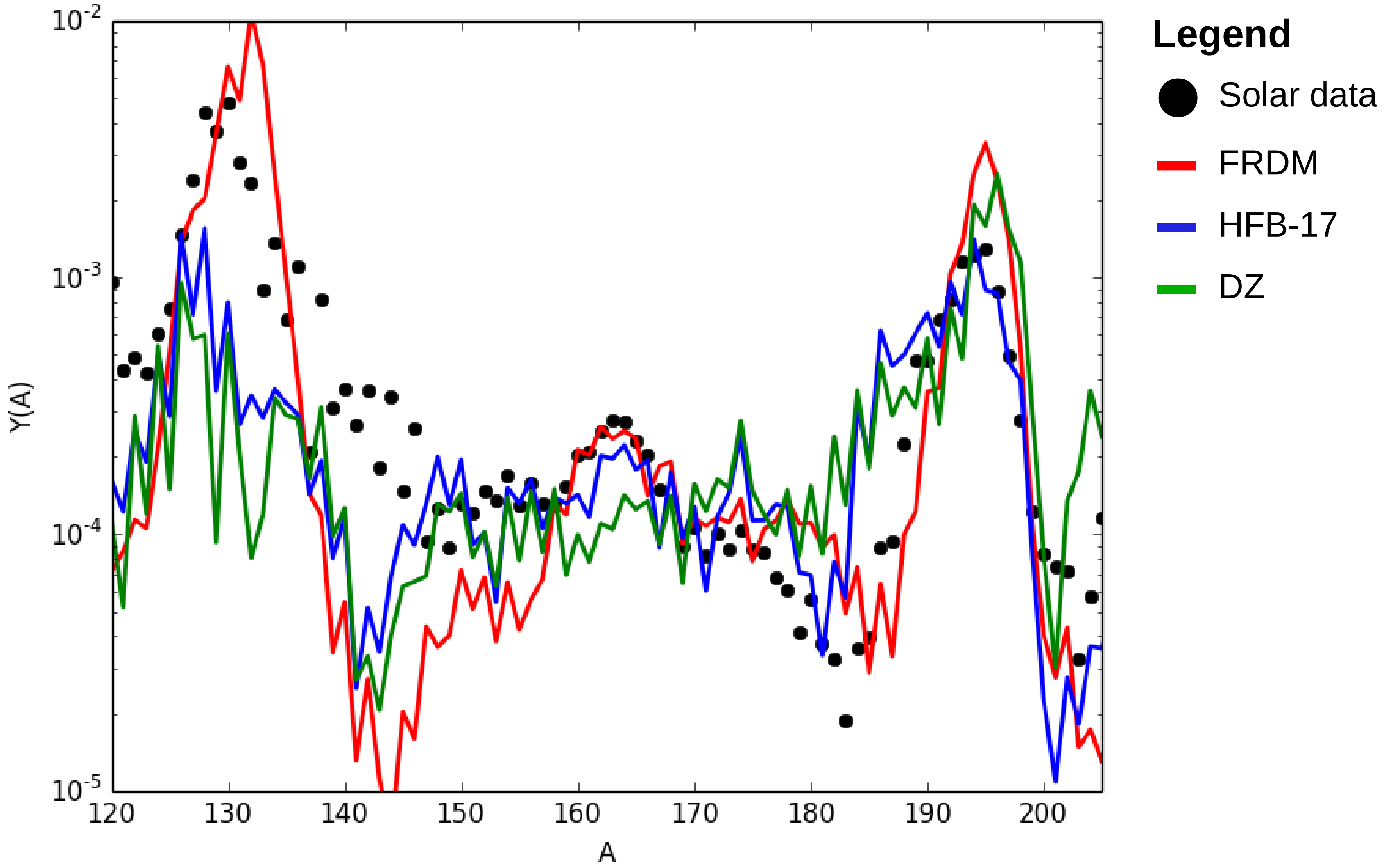
Large Deviations Outside Experimentally Measured

Cd (Z=48) isotopic chain



Nuclear Masses

Impact On *r*-Process Abundances



Sensitivity Studies Tell Us What Is Important

- How do abundances change with change in nuclear inputs?
- Baseline simulation – fix conditions & nuclear physics models
- Modified simulation – single nuclear physics input is changed
- Measure change by comparing differences in final composition:

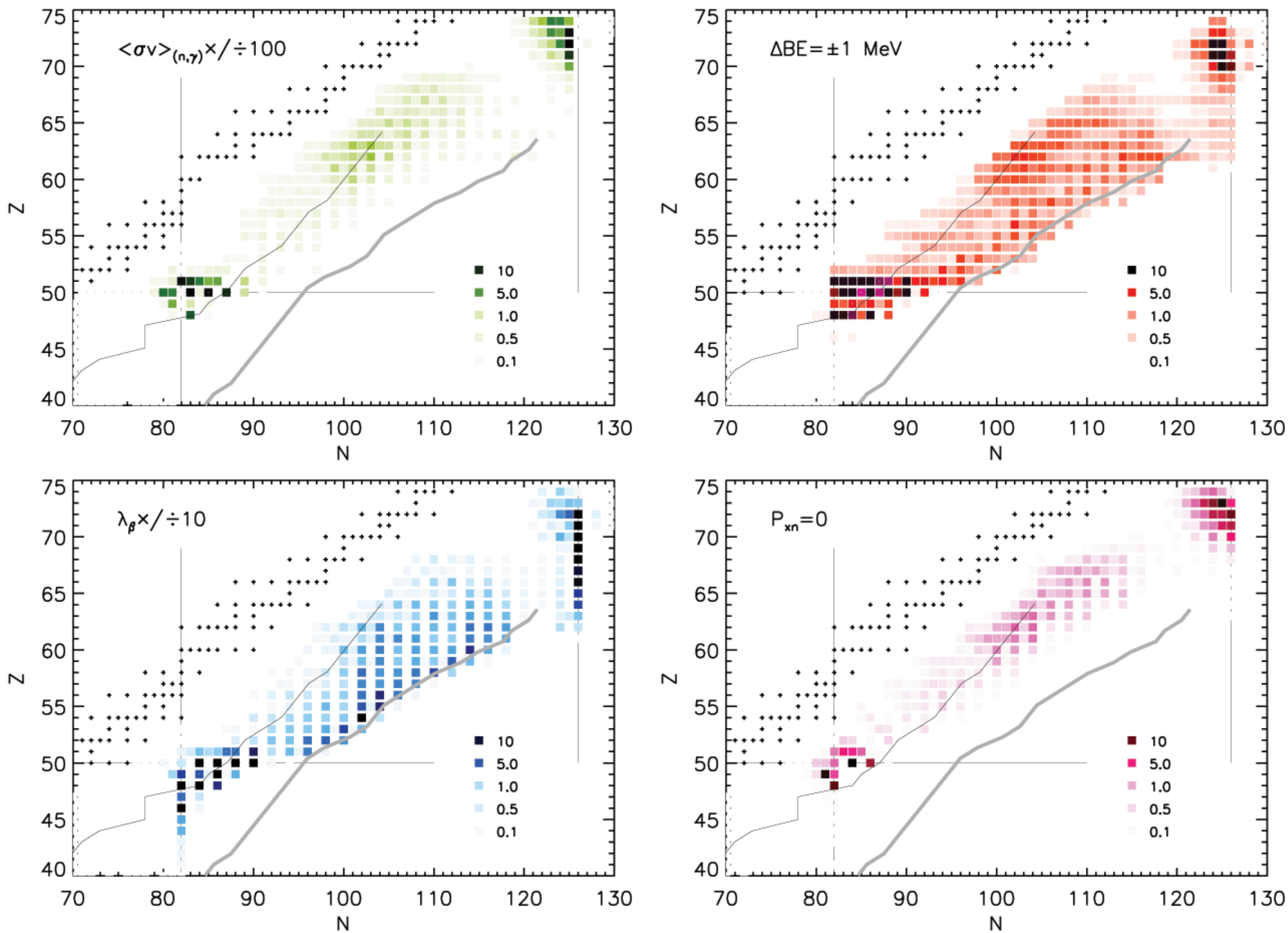
$$F = 100 \sum_A \left| X_{baseline}(A) - X(A) \right|$$

where $X(A) = AY(A)$ Mass fraction (X) ↔ abundance (Y)

$$\sum_A X(A) = 1$$

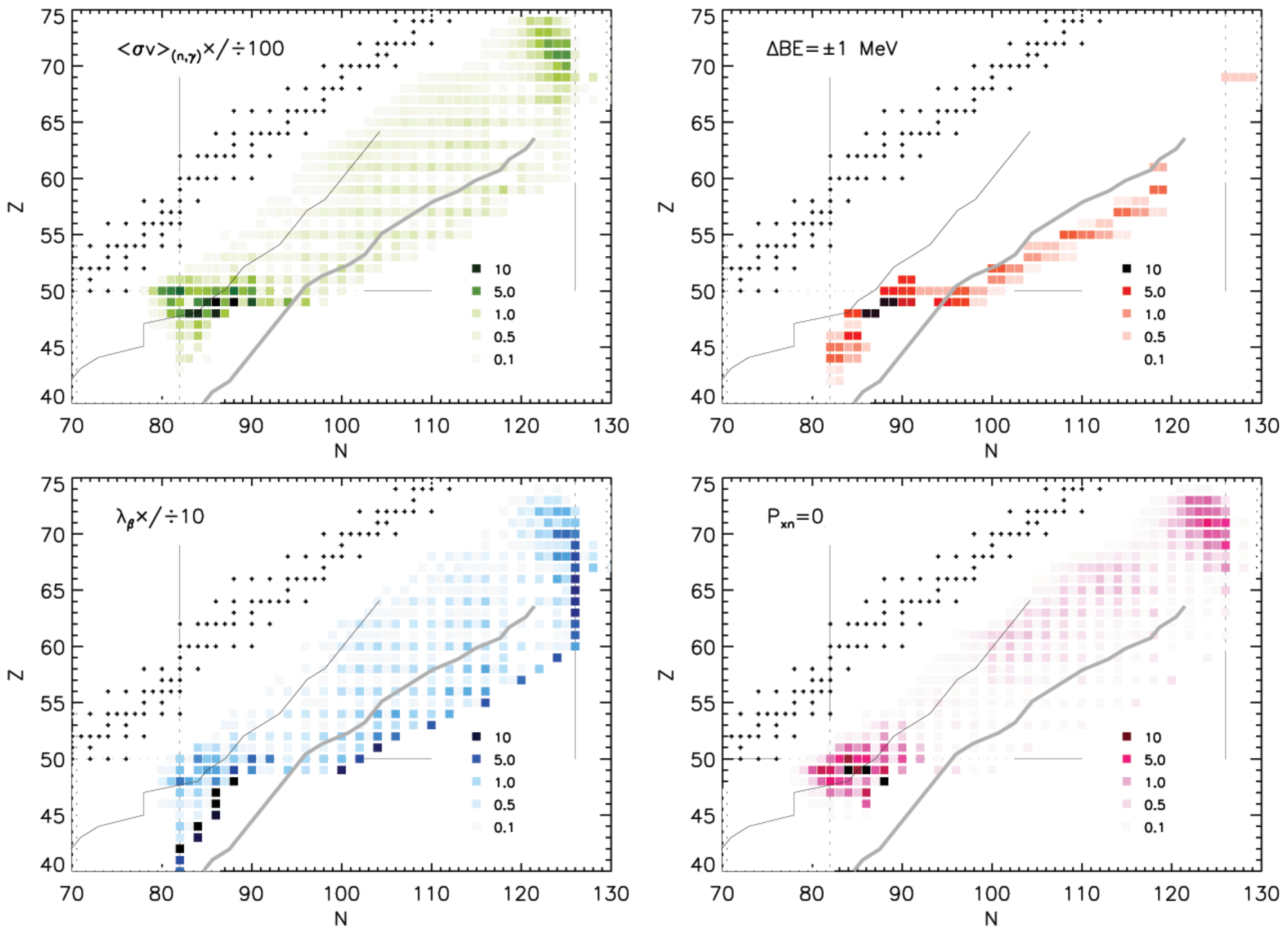
Mass conservation

Hot r-Process Sensitivity Study Results



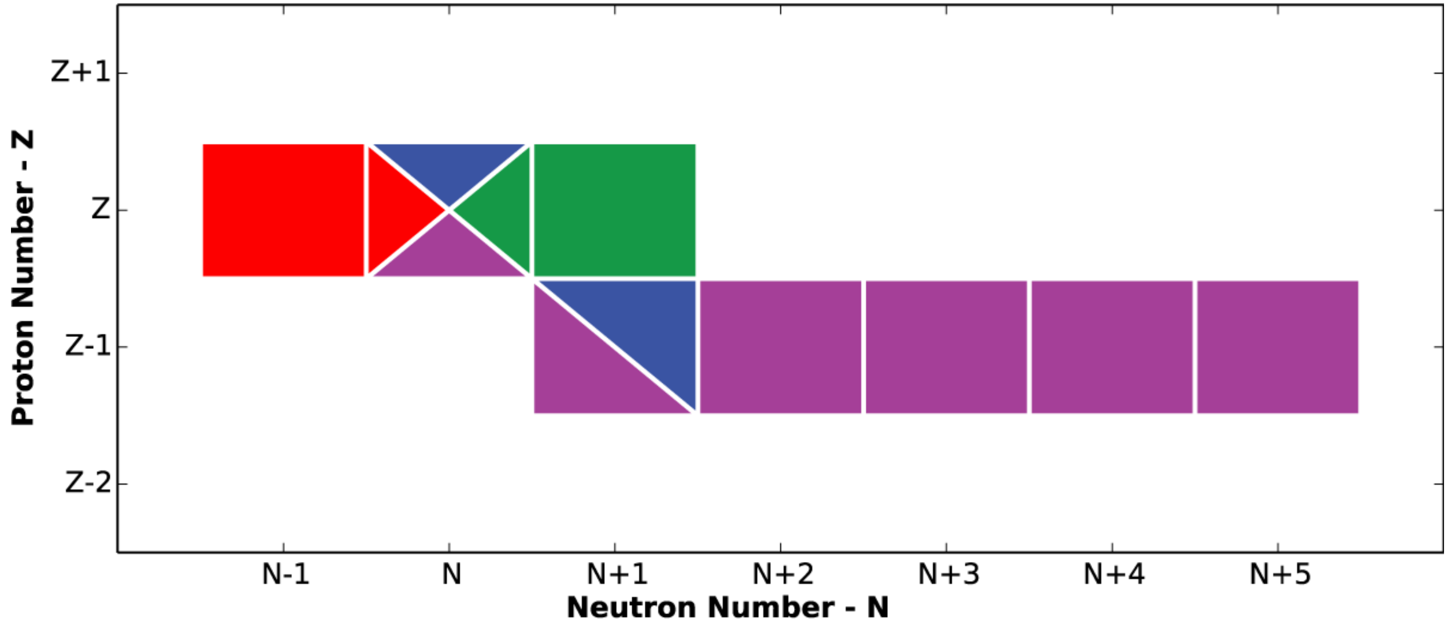
Accessibility Limits CARIBU Predicted FRIB

Cold r-Process Sensitivity Study Results



Accessibility Limits CARIBU Predicted FRIB

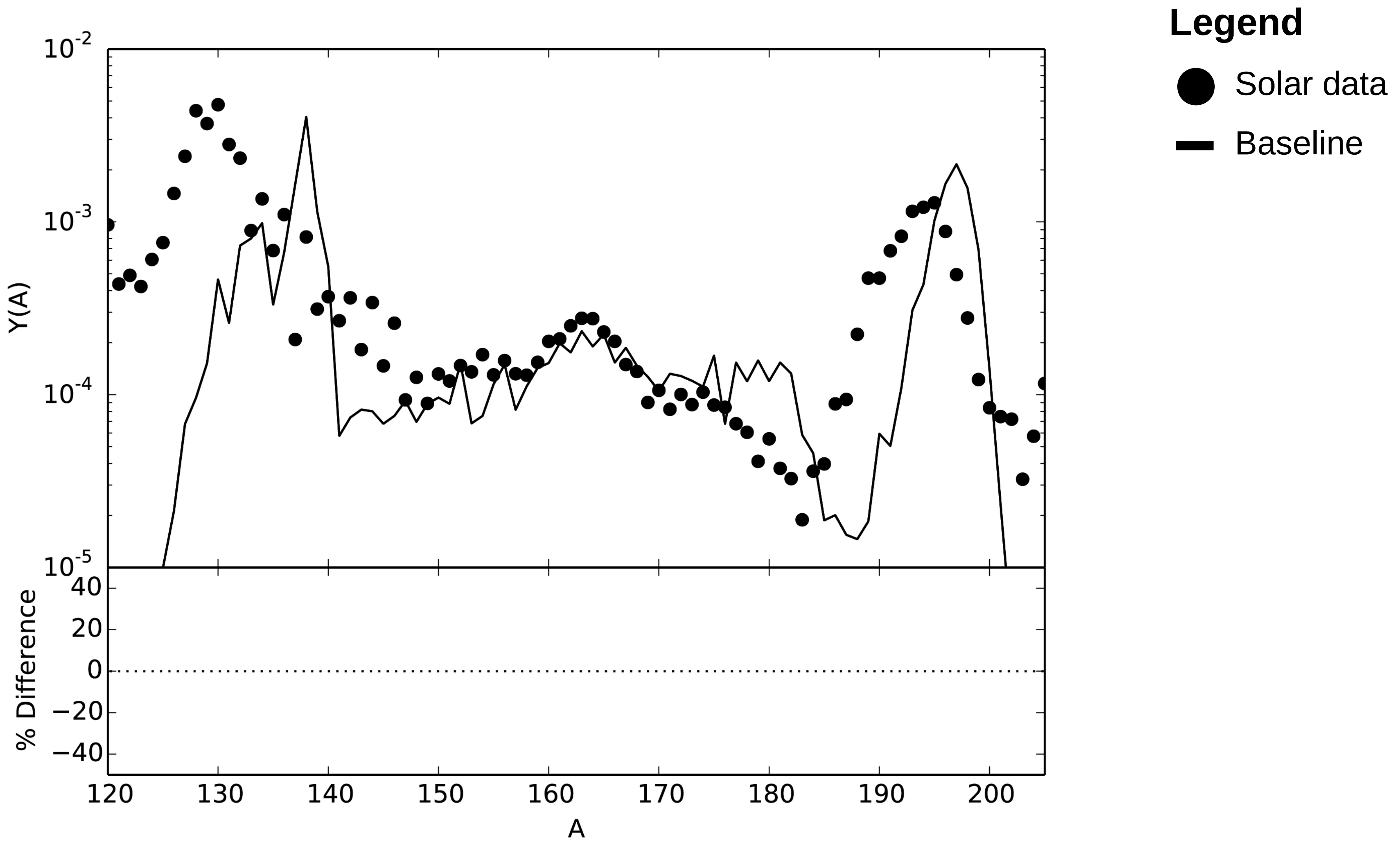
Towards A Self-Consistent Sensitivity Study



How do mass uncertainties change final abundances?

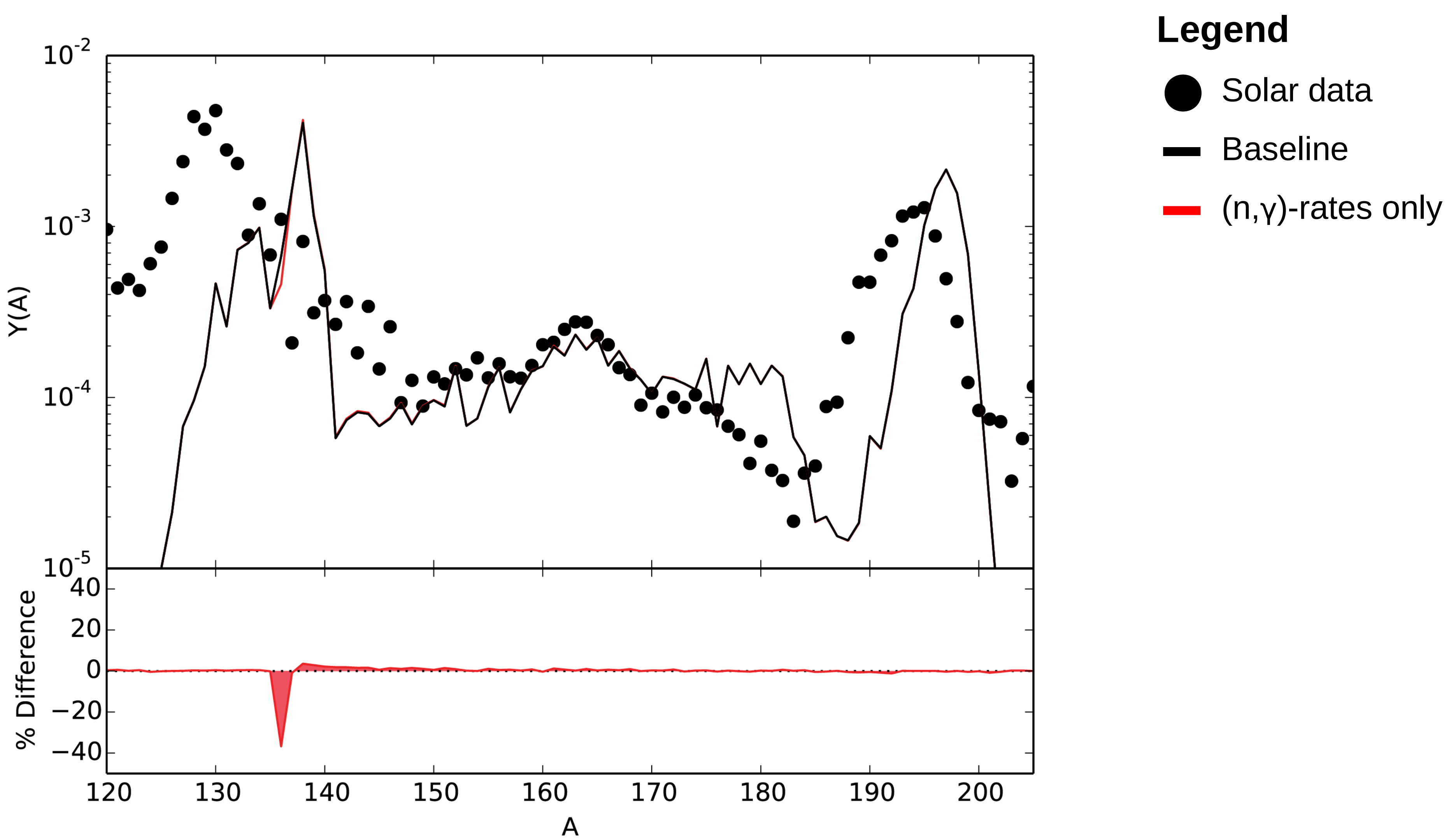
- Neutron separation energies (Z,A) (Z,A+1)
- Neutron capture rates (Z,A) (Z,A-1)
- Beta-decay rates (Z,A) (Z-1,A)
- Beta-delayed n-emission probabilities (Z,A) (Z-1,A) → (Z-1,A+3)

Result: ^{140}Sn (Z=50) +0.5MeV



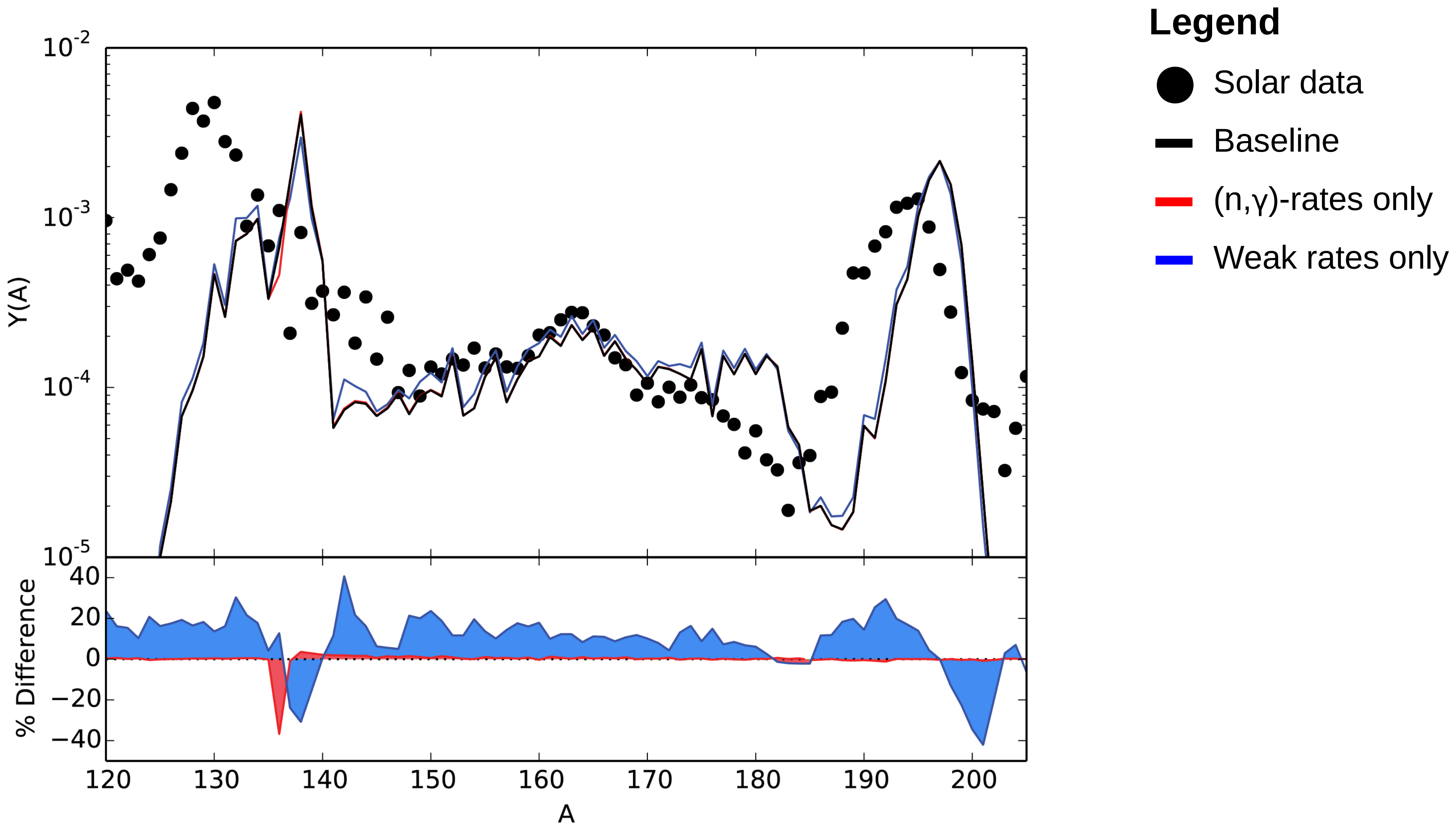
Mumpower et al. (in prep)

^{140}Sn (Z=50) neutron capture rates only



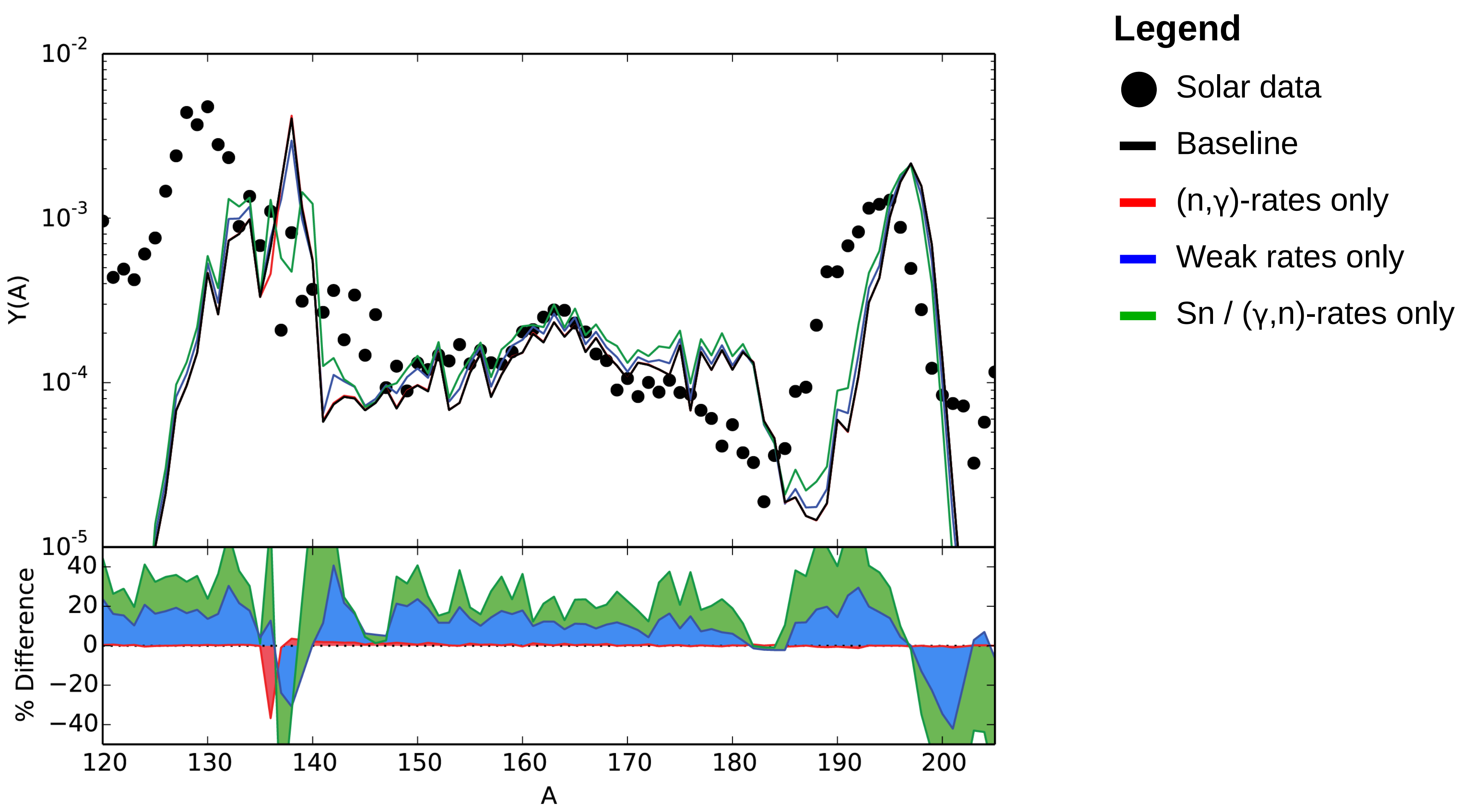
Mumpower et al. (in prep)

^{140}Sn (Z=50) beta-decay only



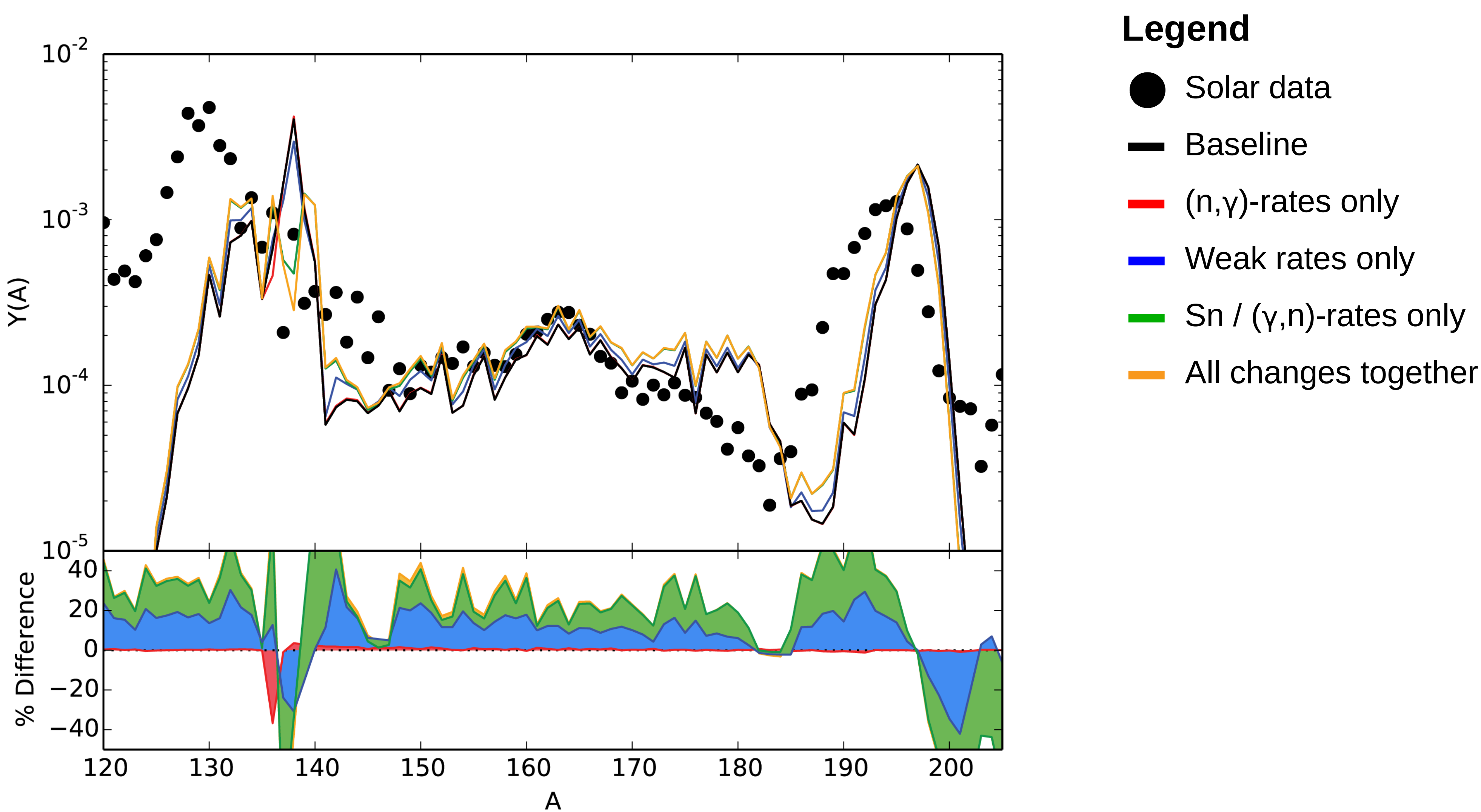
Mumpower et al. (in prep)

^{140}Sn (Z=50) photodissociation rates



Mumpower et al. (in prep)

^{140}Sn (Z=50) All changes together

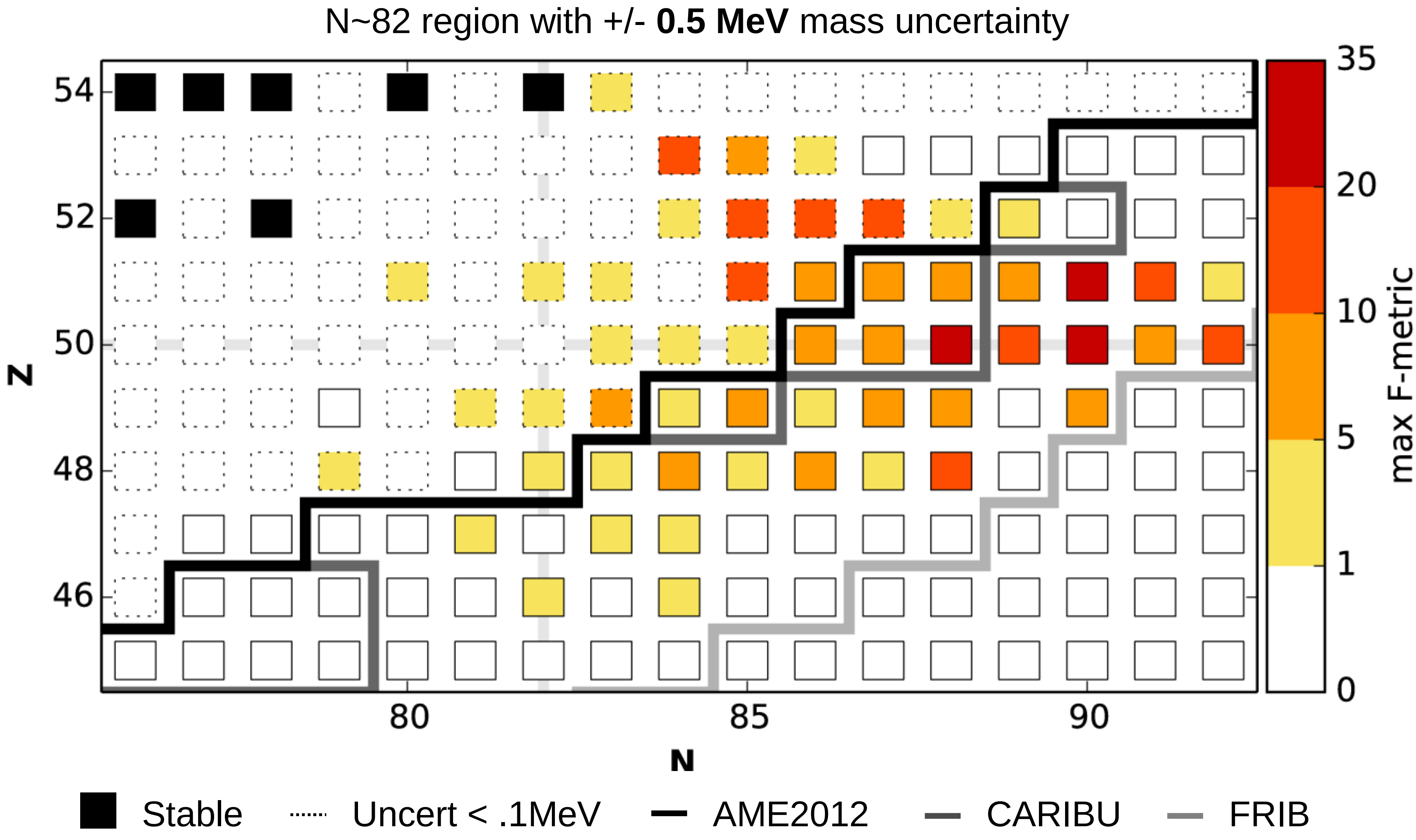


Over an order of magnitude change in the abundance for +**0.5MeV** change in mass of 140-Sn!

Mumpower et al. (in prep)

Self-Consistent Mass Sensitivity Study

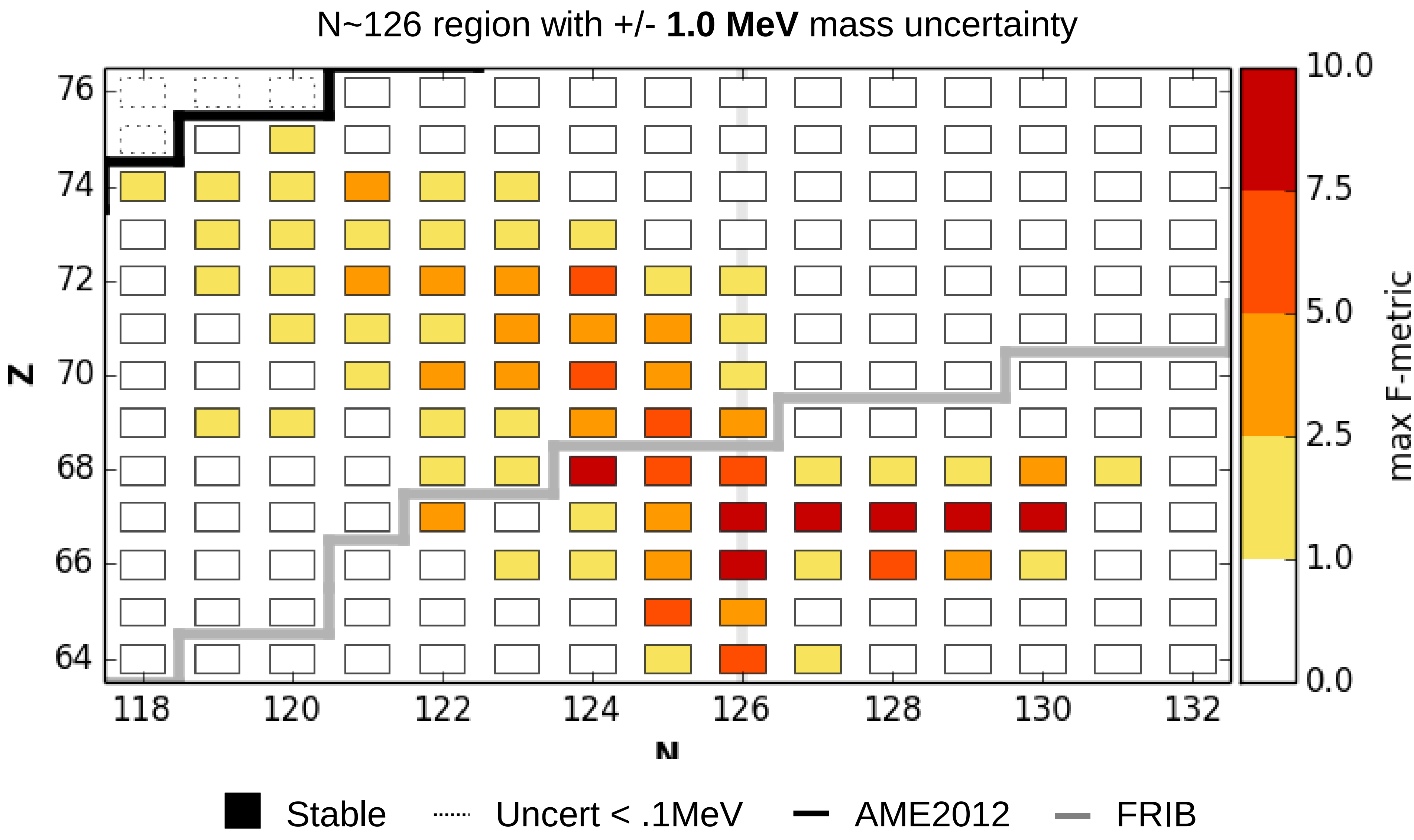
“Hot” *r*-Process



Mumpower et al. (submitted)

Self-Consistent Mass Sensitivity Study

Neutron Star Merger *r*-Process



Mumpower et al. (submitted)

Summary & Outlook

Sensitivity studies help us to understand what is important for the *r*-process
We don't need to measure everything

- Also tell us when nuclear physics inputs play their part (modeling)
- Recent results have driven new experimental campaigns (e.g. mass and beta-delayed neutron emission measurements @ CARIBU)
- We are now able to perform self-consistent studies near closed shells. A~130 (N~82) and A~195 (N~126) regions
- More measurements → better constraints on site of r-process