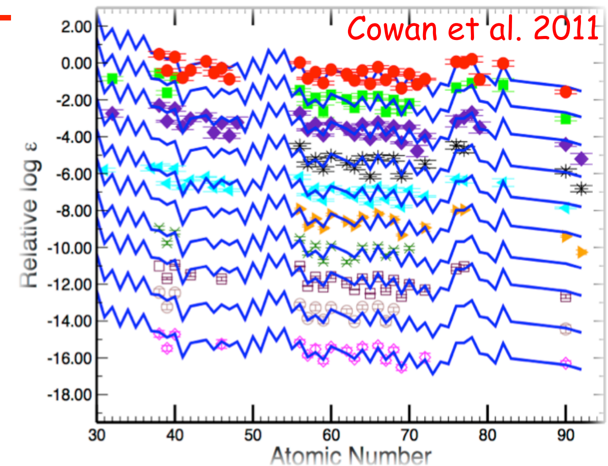
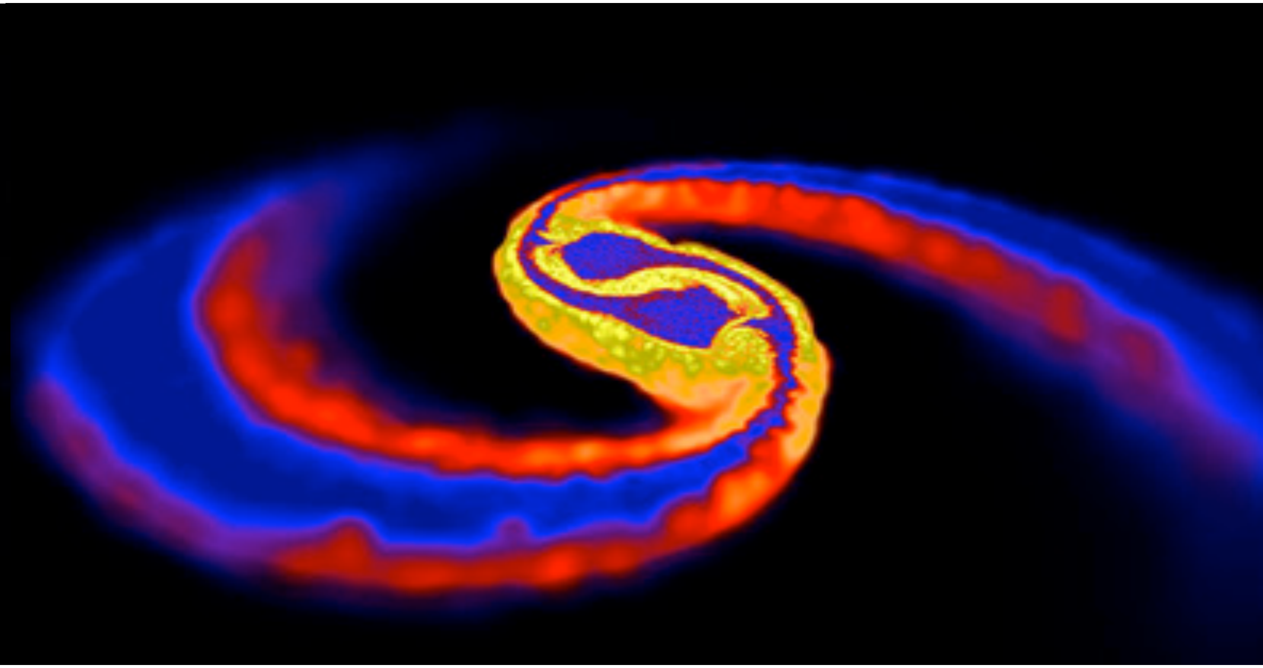
Where is the site of the r-process?

Ani Aprahamian
Institute for Structure & Nuclear Astrophysics
University of Notre Dame, Notre Dame, IN (USA)

Astrophysics: What do we know?

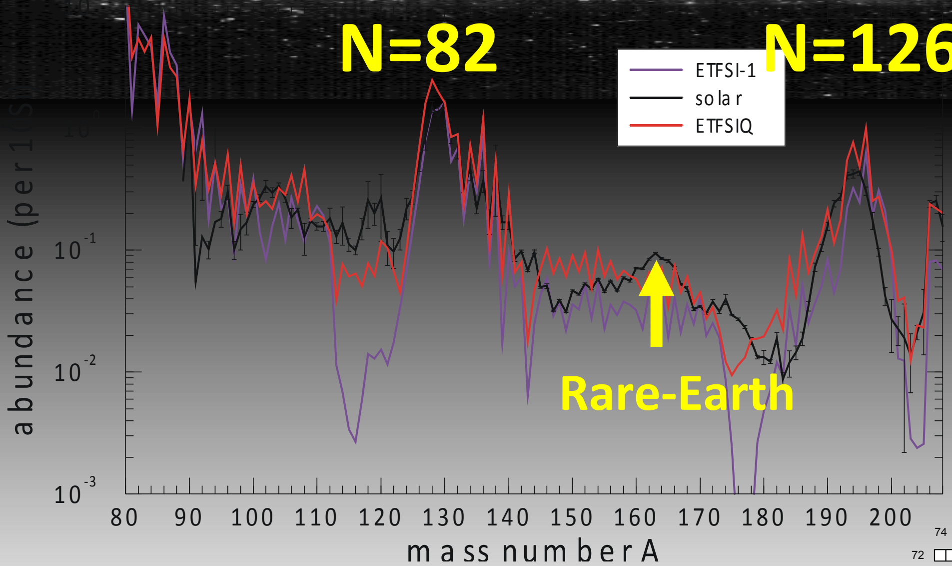


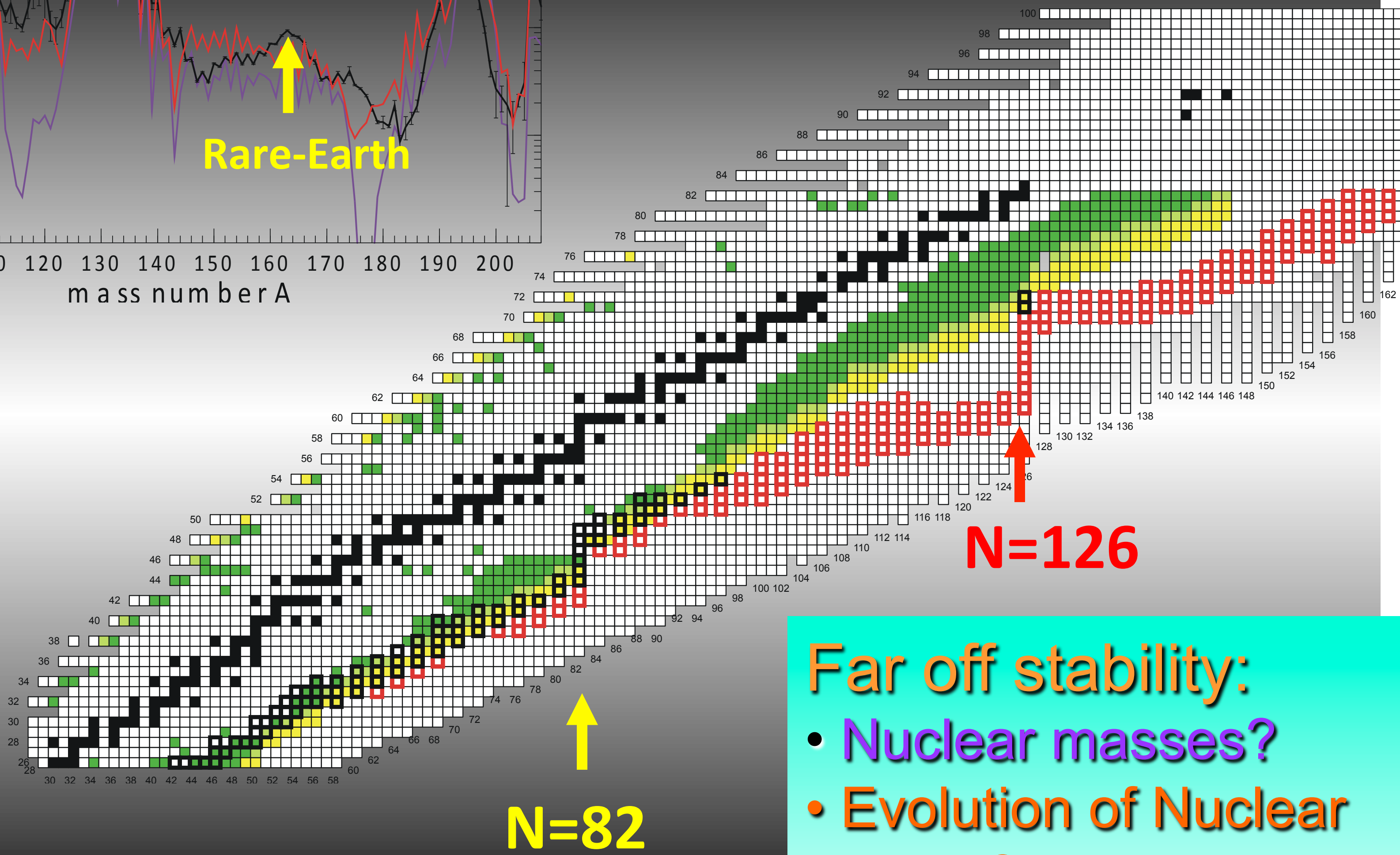
r-process



Temperature, density as a function of time, initial compositions, neutrons

r-process

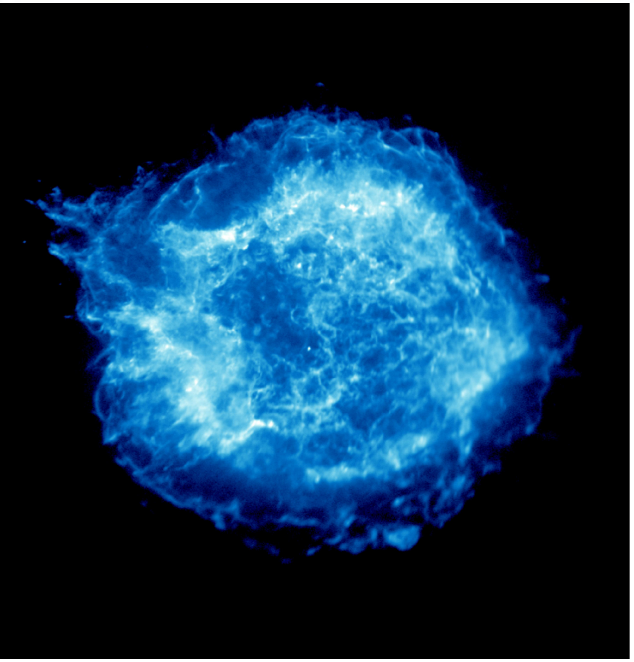




Far off stability:

- Nuclear masses?
- Evolution of Nuclear shapes?

Potential r-process sites: Neutron richness,
High entropy, and fast outflow to reach U/Th, Temperature/ density variations as a function of time.



Trajectories describing four scenarios

1. Hot low entropy 0.20 Ye 70ms
2. Hot high entropy 0.25 Ye 80ms
3. Cold neutrino driven wind 0.31 Ye
4. Neutron star merger (Bauswein & Janka)fission recycling

r-process sensitivity studies

dynamic r-process simulations developed by R. Surman et al.

Approach:

Choose a baseline simulation

Vary one piece of nuclear data by a set amount, rerun the simulation,

compare the final abundance pattern to the baseline

Repeat for each nucleus in the network

How we measure the effect of the changes

$$\boxed{F = 100 \times \sum_A |X_{\mathrm{baseline}}(A) - X(A)|.}$$

r-process sensitivity studies

dynamic r-process simulations developed by R. Surman et al.

- neutron capture rates
- masses/neutron separation energies/binding energies
- beta decay rates
- Beta-delayed neutron emission probabilities
- masses/capture rates/beta decay rates (propagated)

Example: varied **mass models**-
FRDM, Duflo-Zuker, ETFSIQ, HFB-21, F-spin
Adjusted the binding energy of each nucleus ± 1MeV
(**3010 nuclei twice….**)

Sensitivity studies for the main r process: nuclear masses

A. Aprahamian,[1] I. Bentley,[2] M. Mumpower,[1] and R. Surman[3]

ΔBE=+/-1 MeV

Cd isotopes

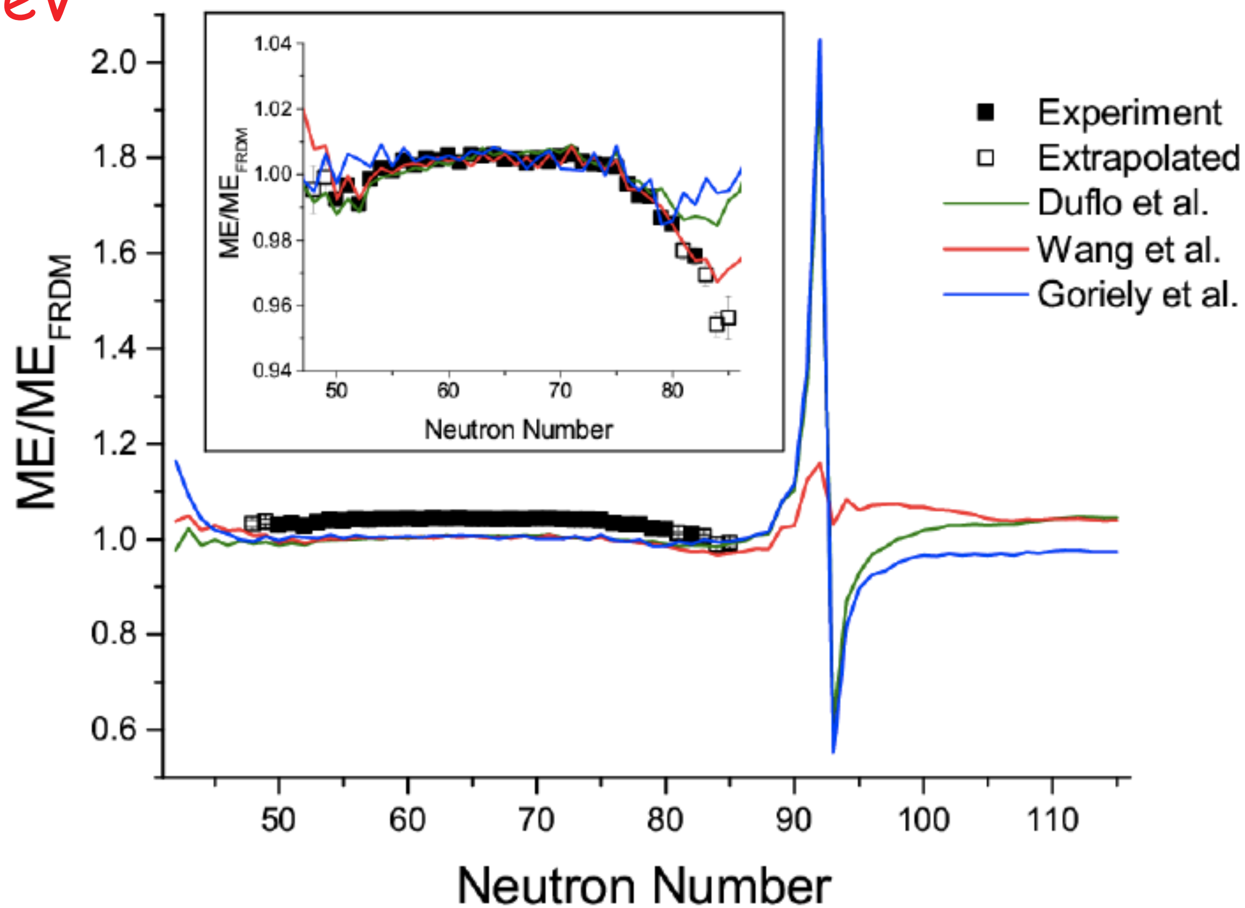
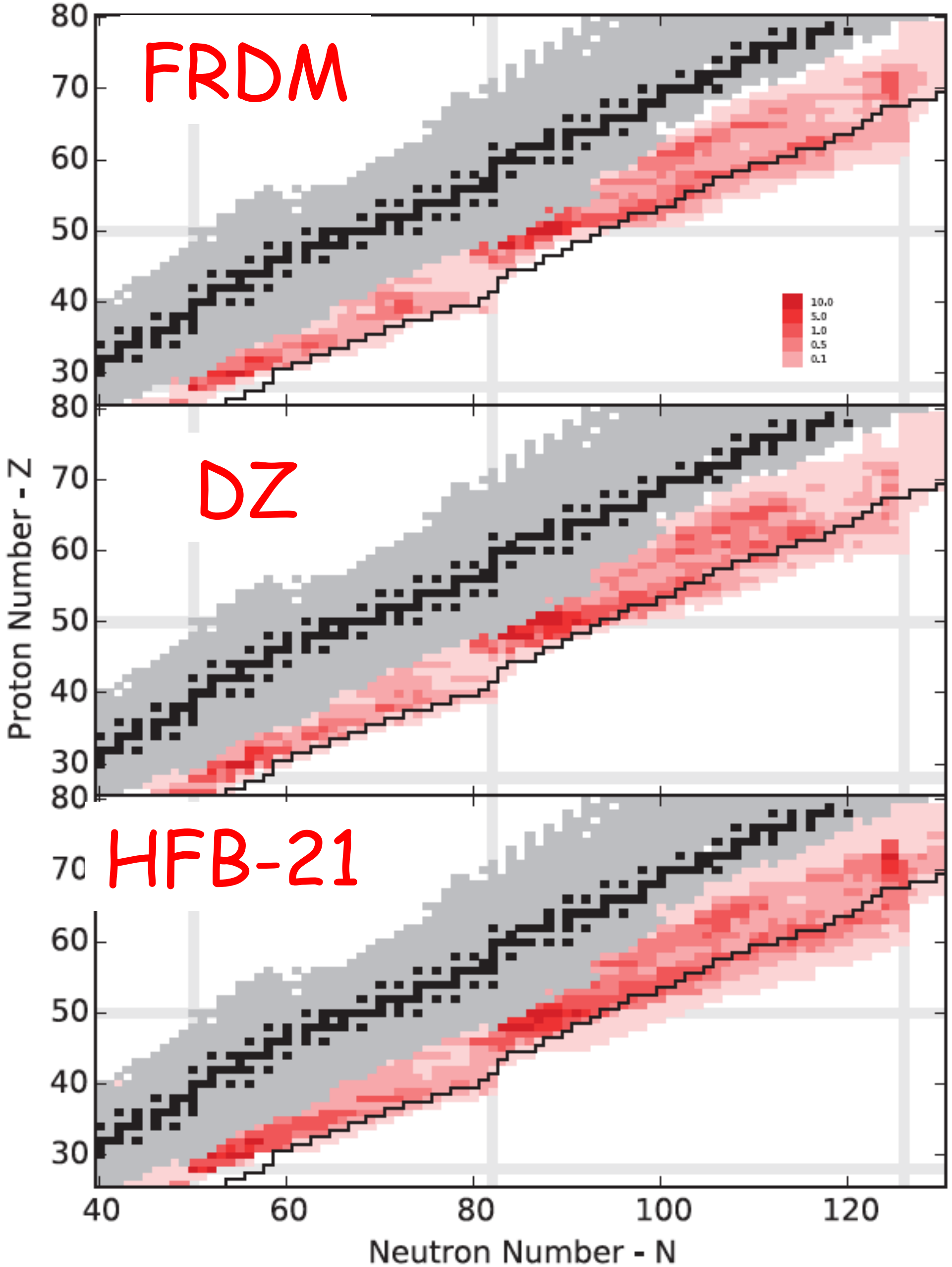


FIG. 1. The mass excess of cadmium isotopes consisting of experimental (filled boxes) and extrapolated (open boxes) values from AME2012[19] compared to theoretical values from Duflo & Zuker[20], Goriely et al.[21], and Wang et al.[22], all scaled to the mass excess from the FRDM[18].

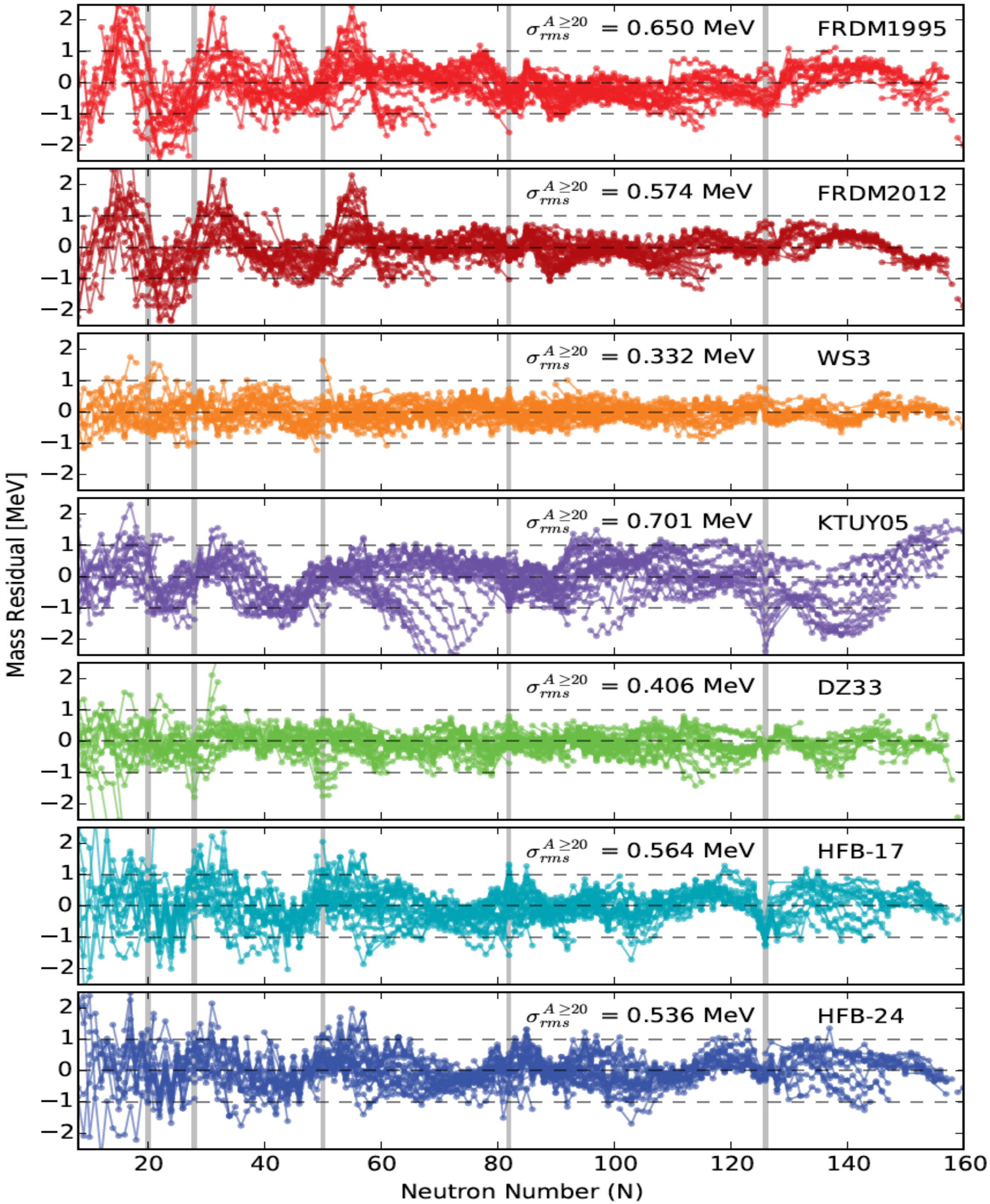
Same astrophysical trajectory (hot r-process): 3 different mass models



FRIB

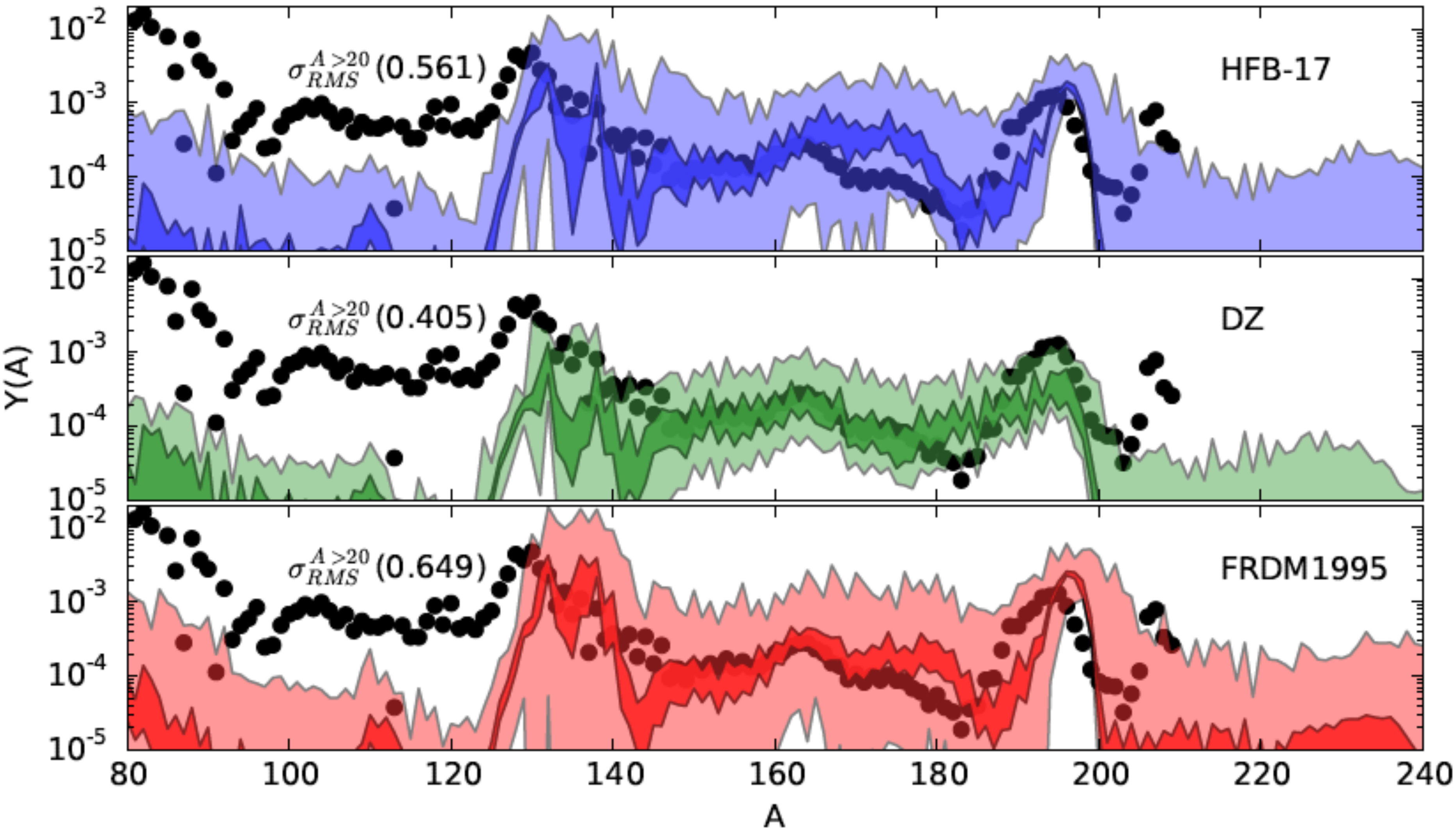
Sensitivity studies for the main r process: nuclear masses

A. Aprahamian,[1] I. Bentley,[2] M. Mumpower,[1] and R. Surman[3]



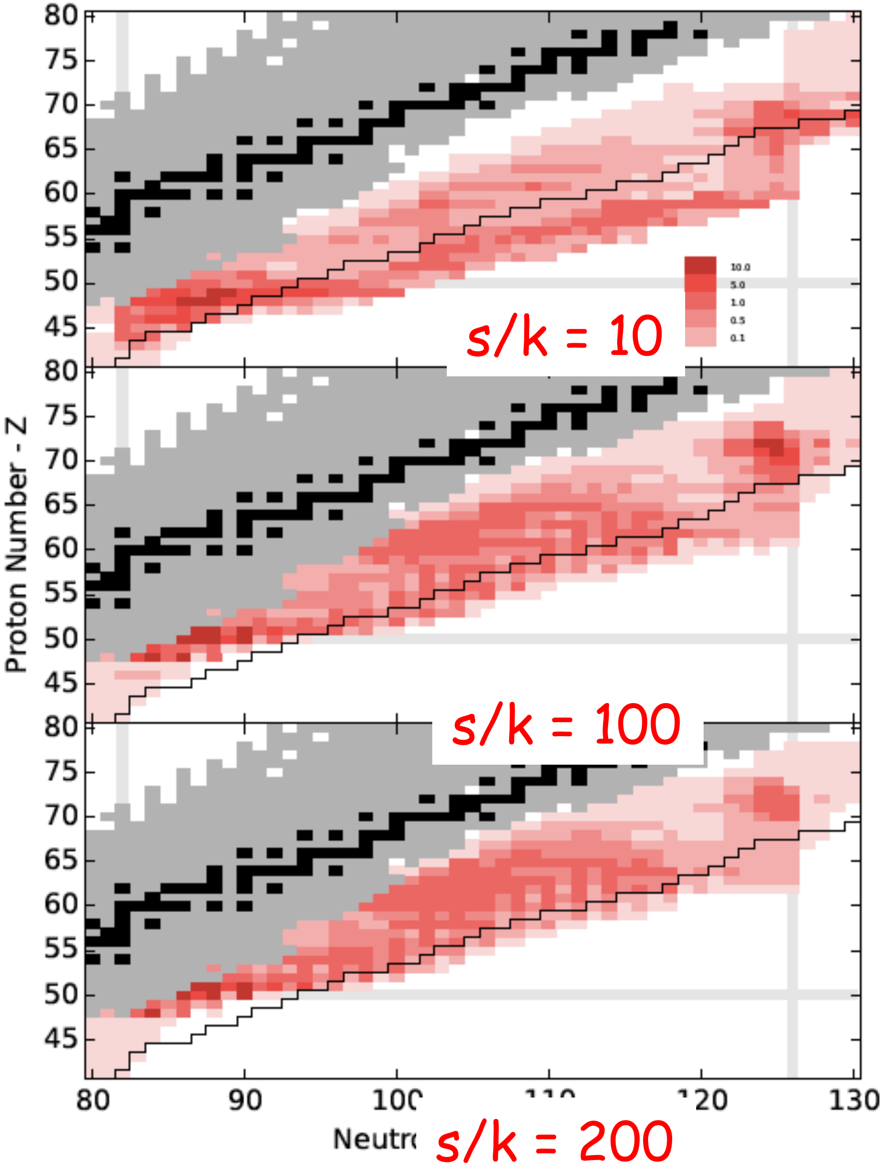
ΔBE=+/- 0.5 MeV

Hot r-process trajectory



Mumpower, Surman, Aprahamian, CGS15 proceedings (2015)

3 different astrophysical scenarios with the same mass model (FRDM)

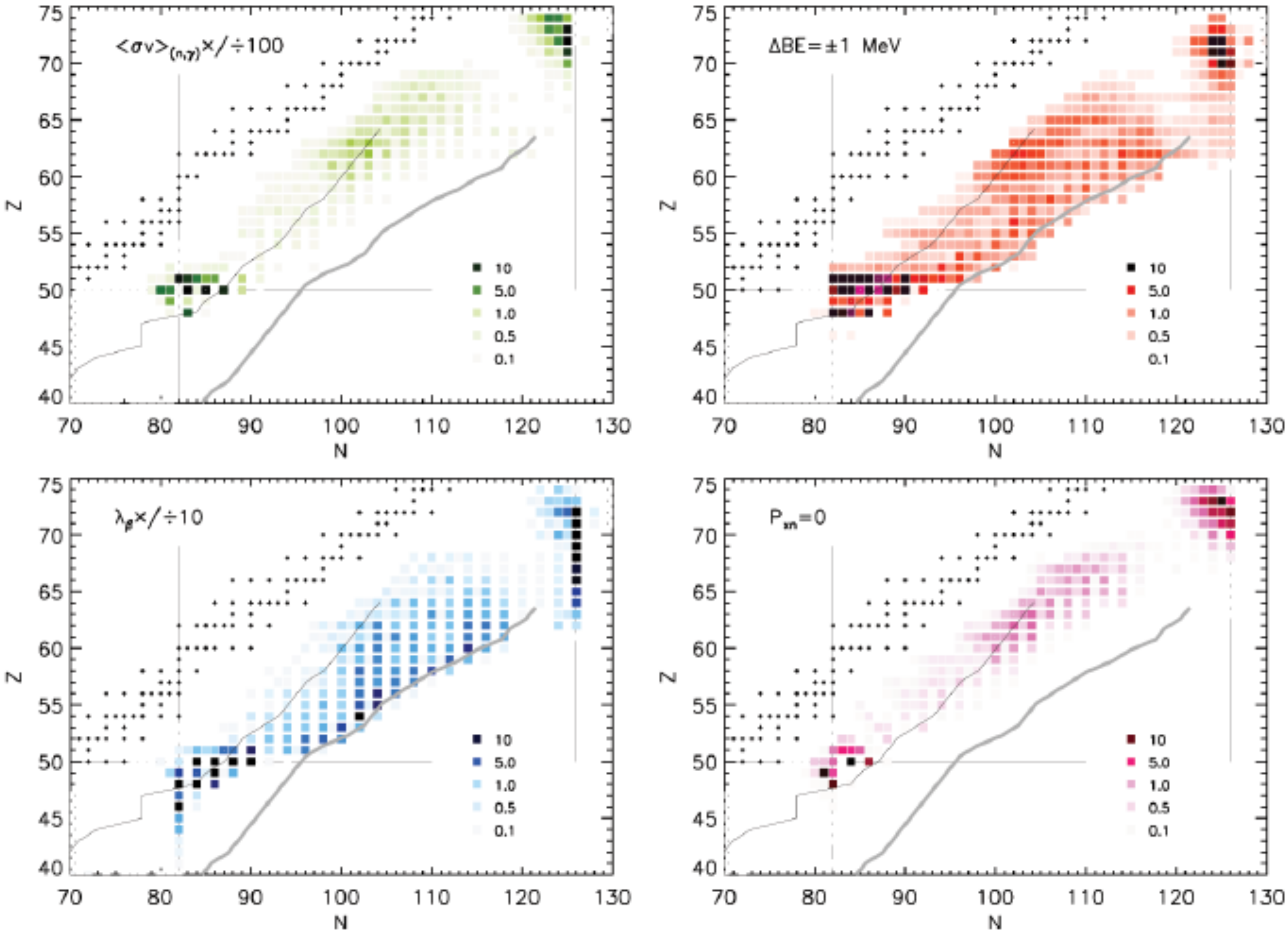


Adiabatic wind parametrizationo of Meyer with a dynamic time scale

Sensitivity studies for the main r process: nuclear masses

A. Aprahamian,[1] I. Bentley,[2] M. Mumpower,[1] and R. Surman[3]

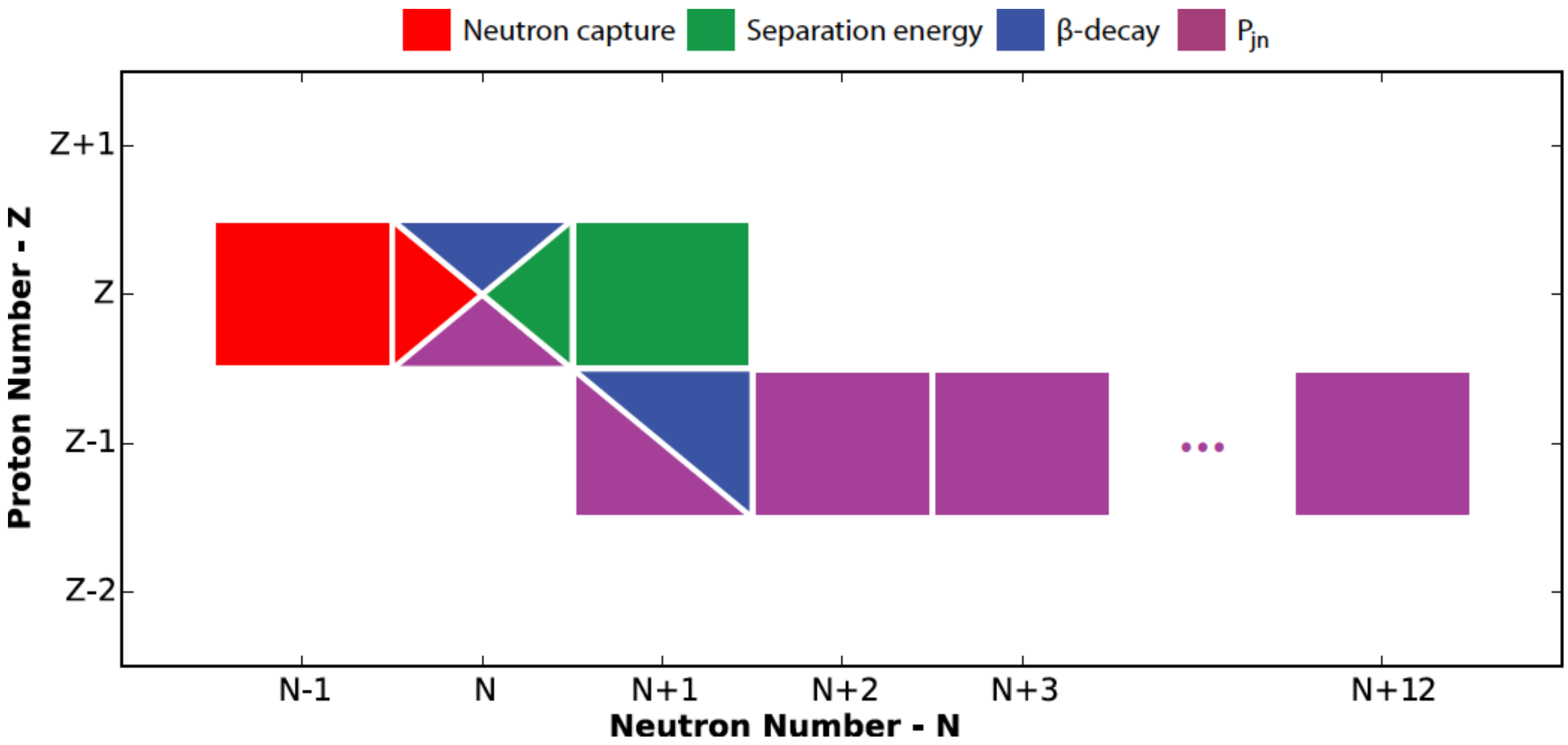
Wind r-Process Sensitivity Study Results



Accessibility Limits CARIBU Predicted FRIB

Putting it all together…

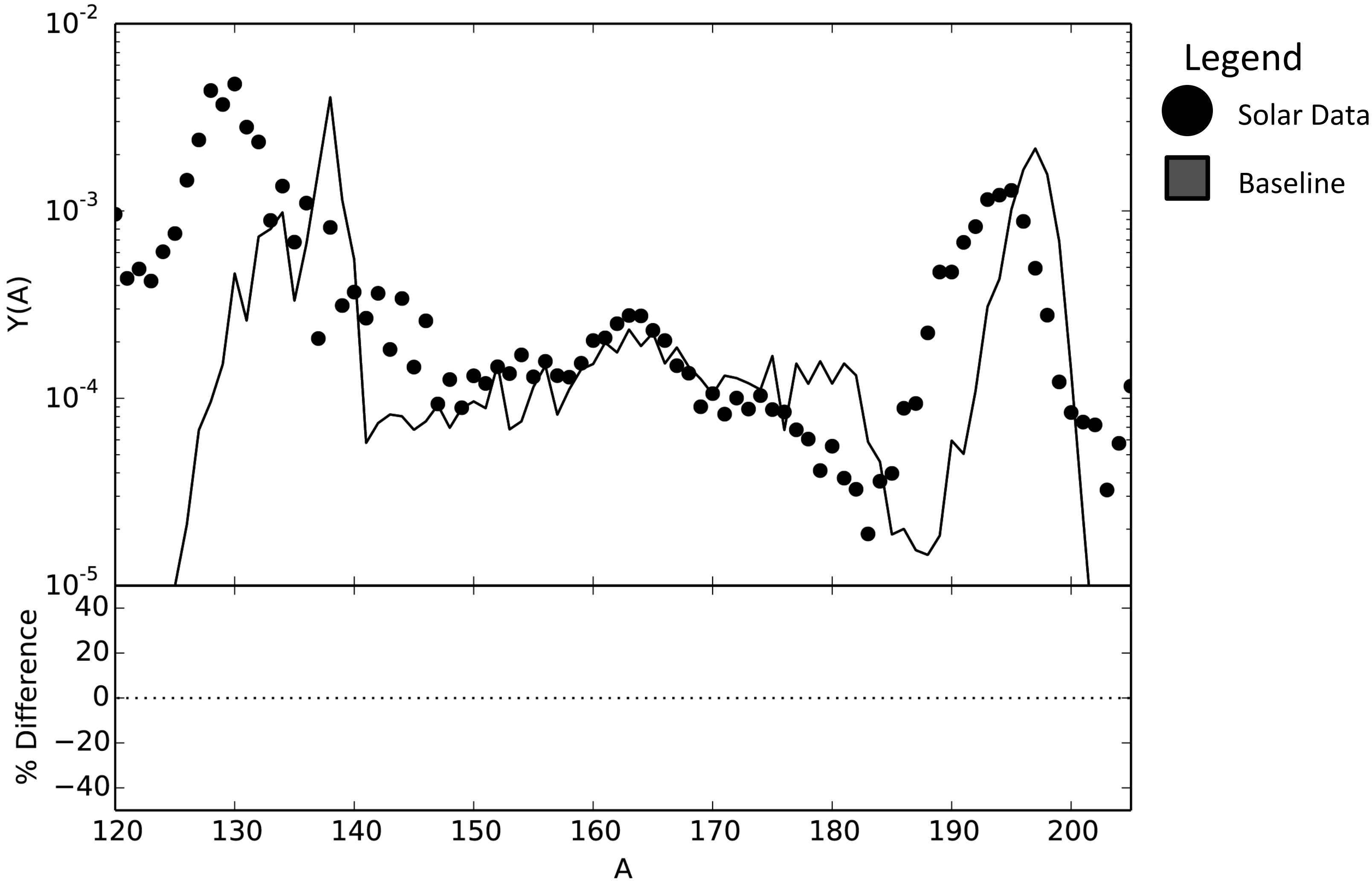
Building a fully self-consistent sensitivity study

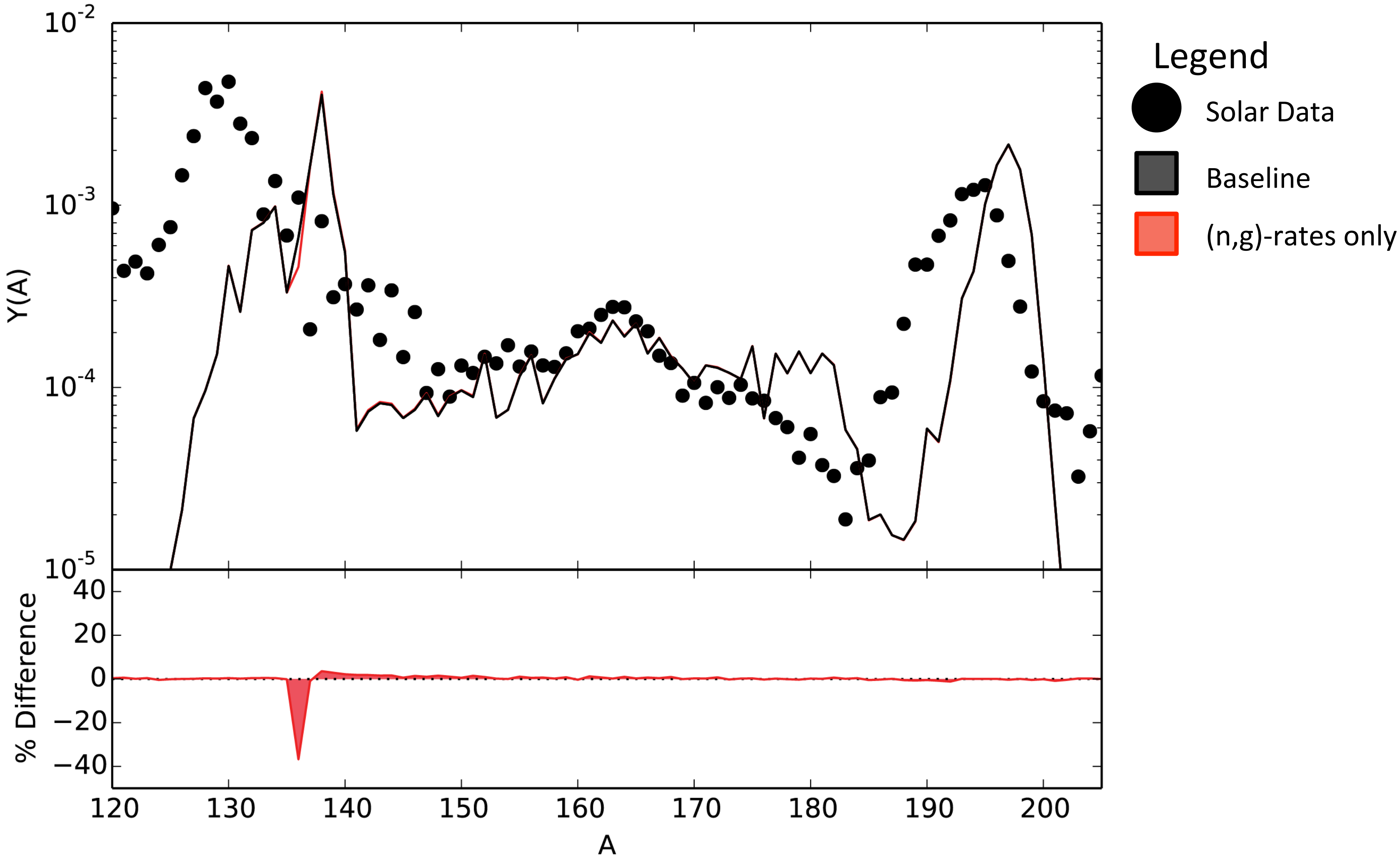


N=82: Mumpower, Surman, Fang, Beard, Aprahamian (2015); J. Phys G 42, 034027

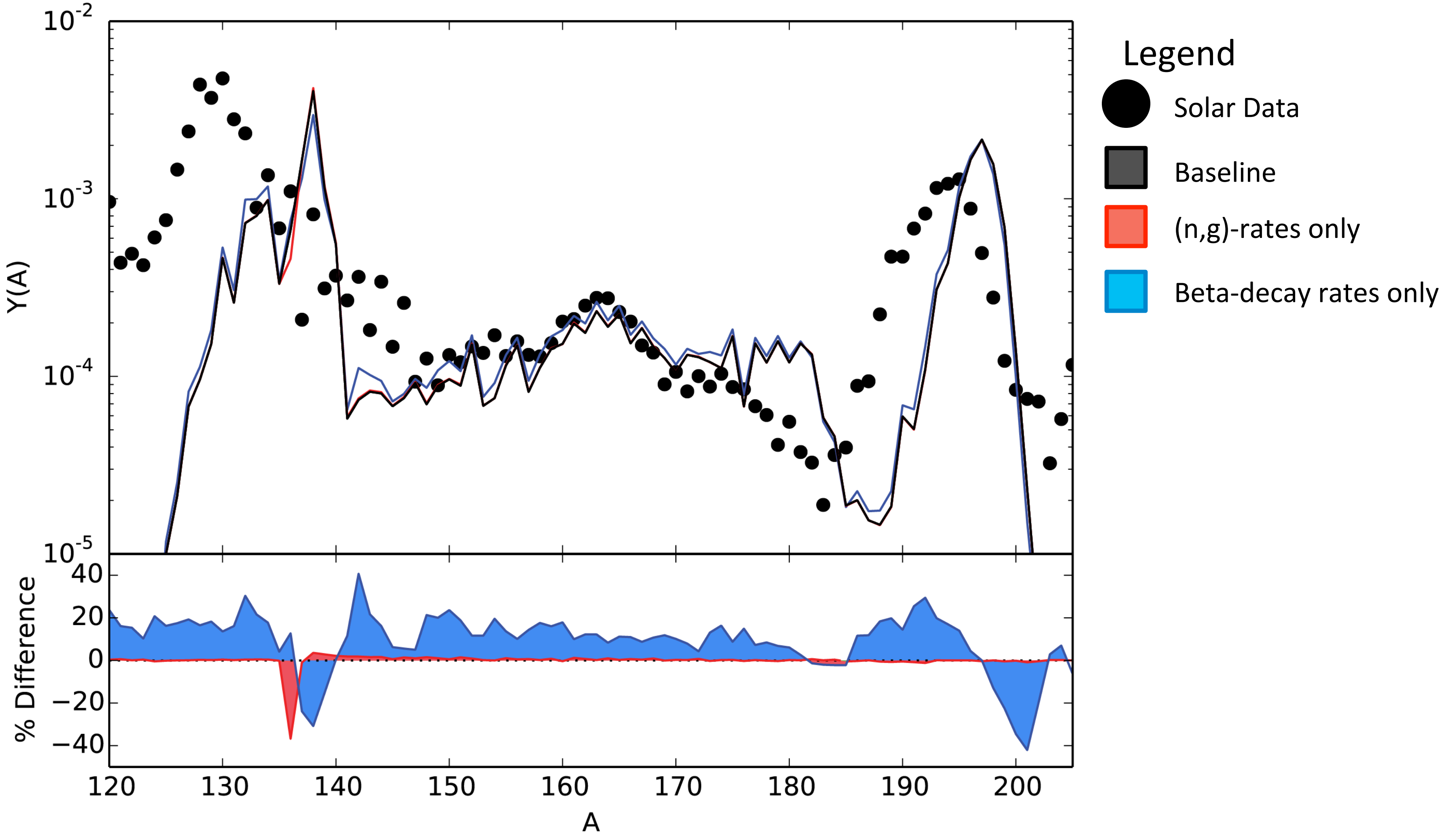
N=126: Mumpower, Surman, Fang, Beard, Moller, Aprahamian (2015); subm.

Baseline calculation for ^{140}Sn

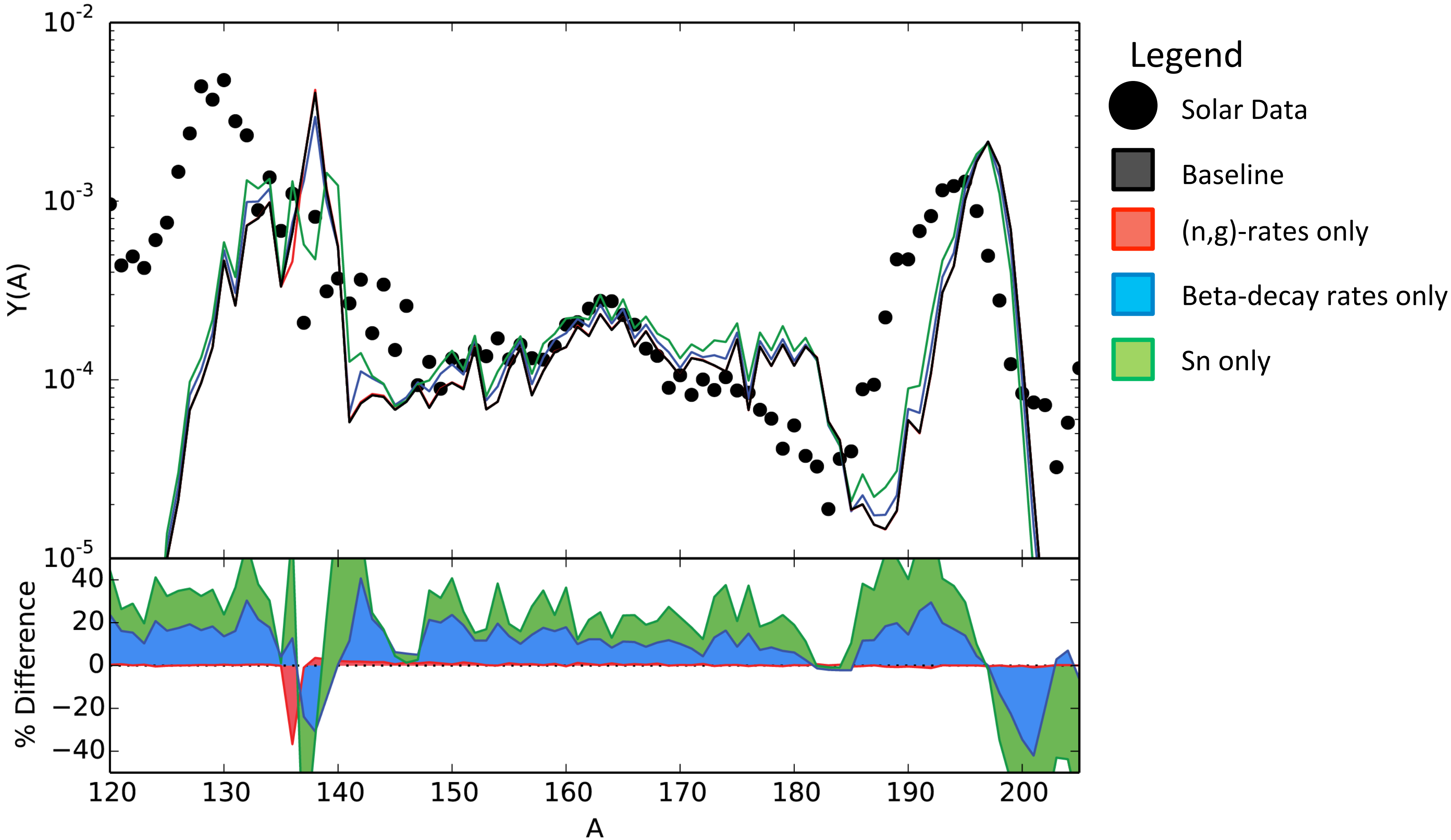




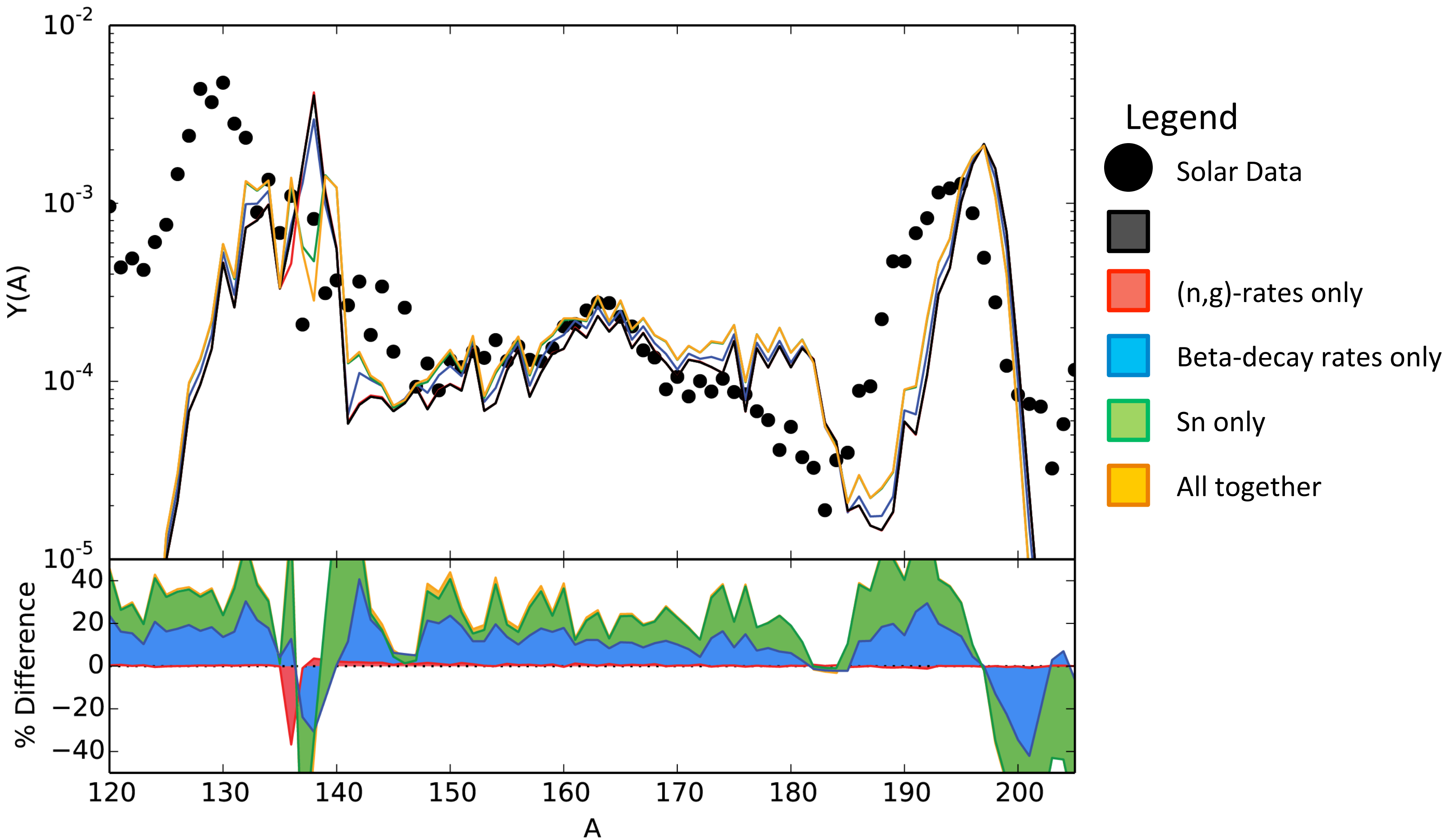
Legend
Solar Data
Baseline
(n,g)-rates only
Y(A)
% Difference
A



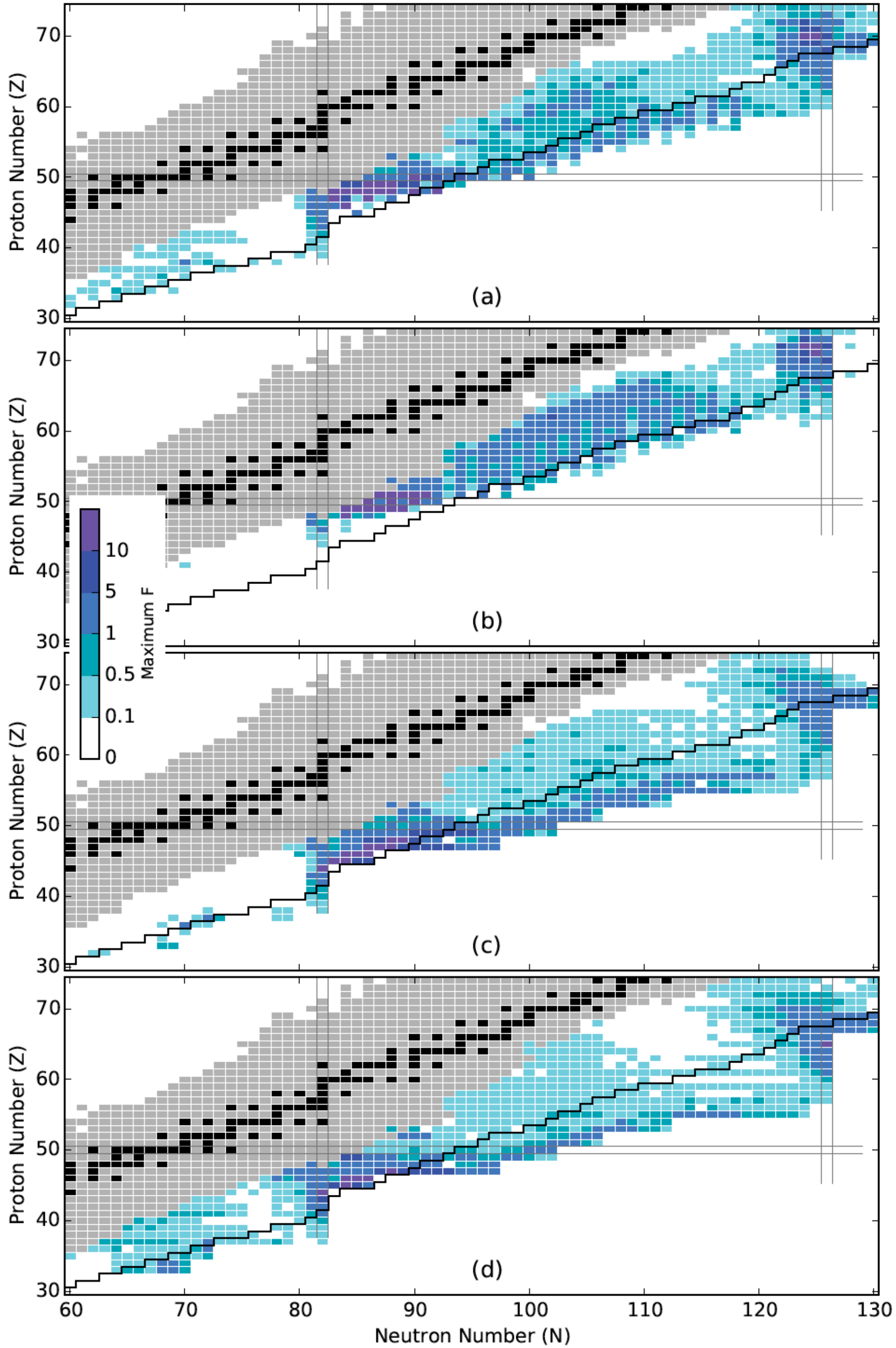
Legend
Solar Data
Baseline
(n,g)-rates only
Beta-decay rates only
Y(A)
% Difference
A
10^{-2}
10^{-3}
10^{-4}
10^{-5}
40
20
0
−20
−40
120
130
140
150
160
170
180
190
200



Legend
Solar Data
Baseline
(n,g)-rates only
Beta-decay rates only
Sn only
Y(A)
% Difference
A



Over an *order of magnitude* difference in the Y(A) for **0.5MeV** addition in mass of 140-Sn!

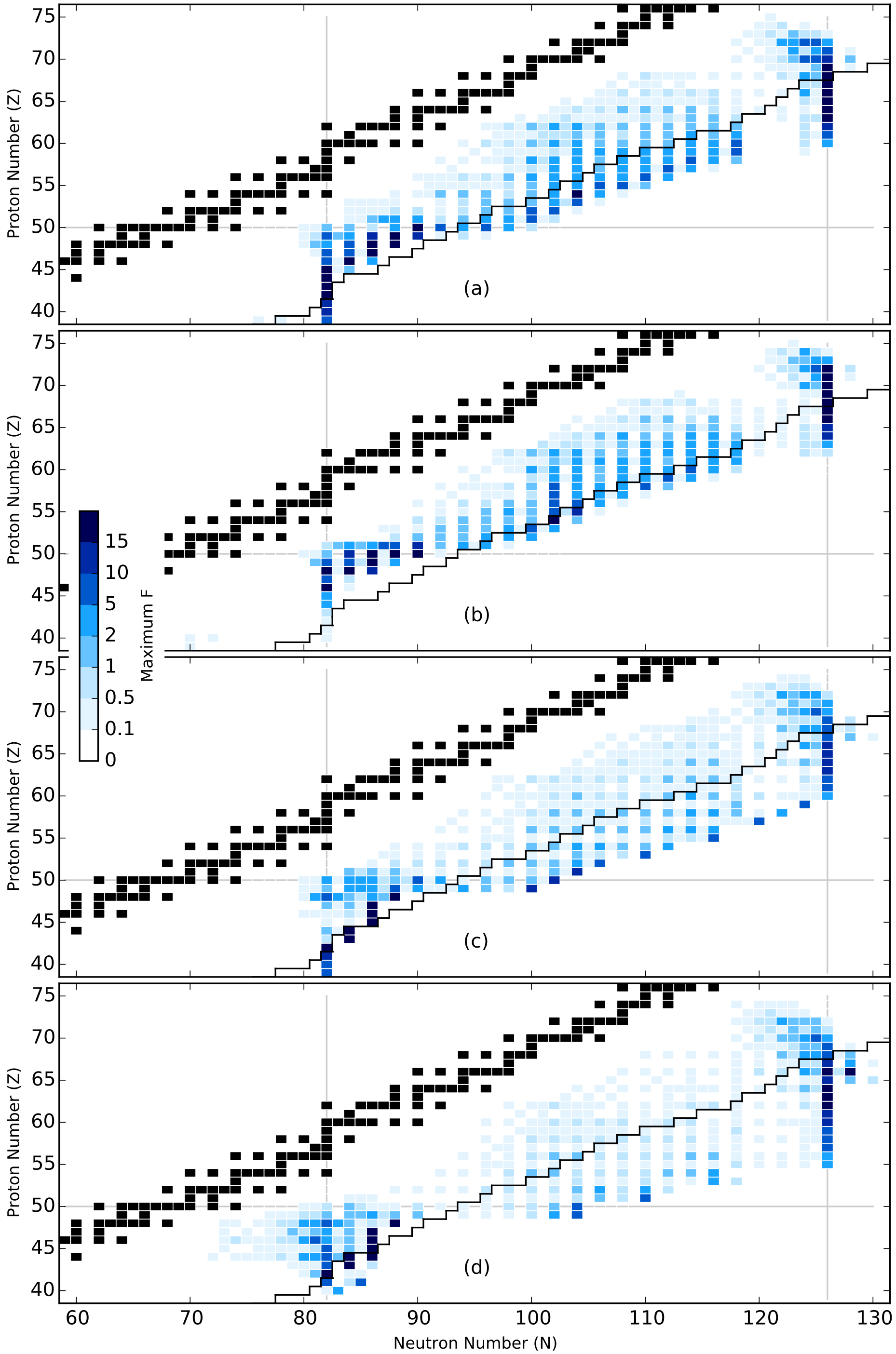


Low entropy hot wind

High entropy hot wind

Cold wind

Neutron Star Merger



Low entropy hot wind

High entropy hot wind

Cold wind

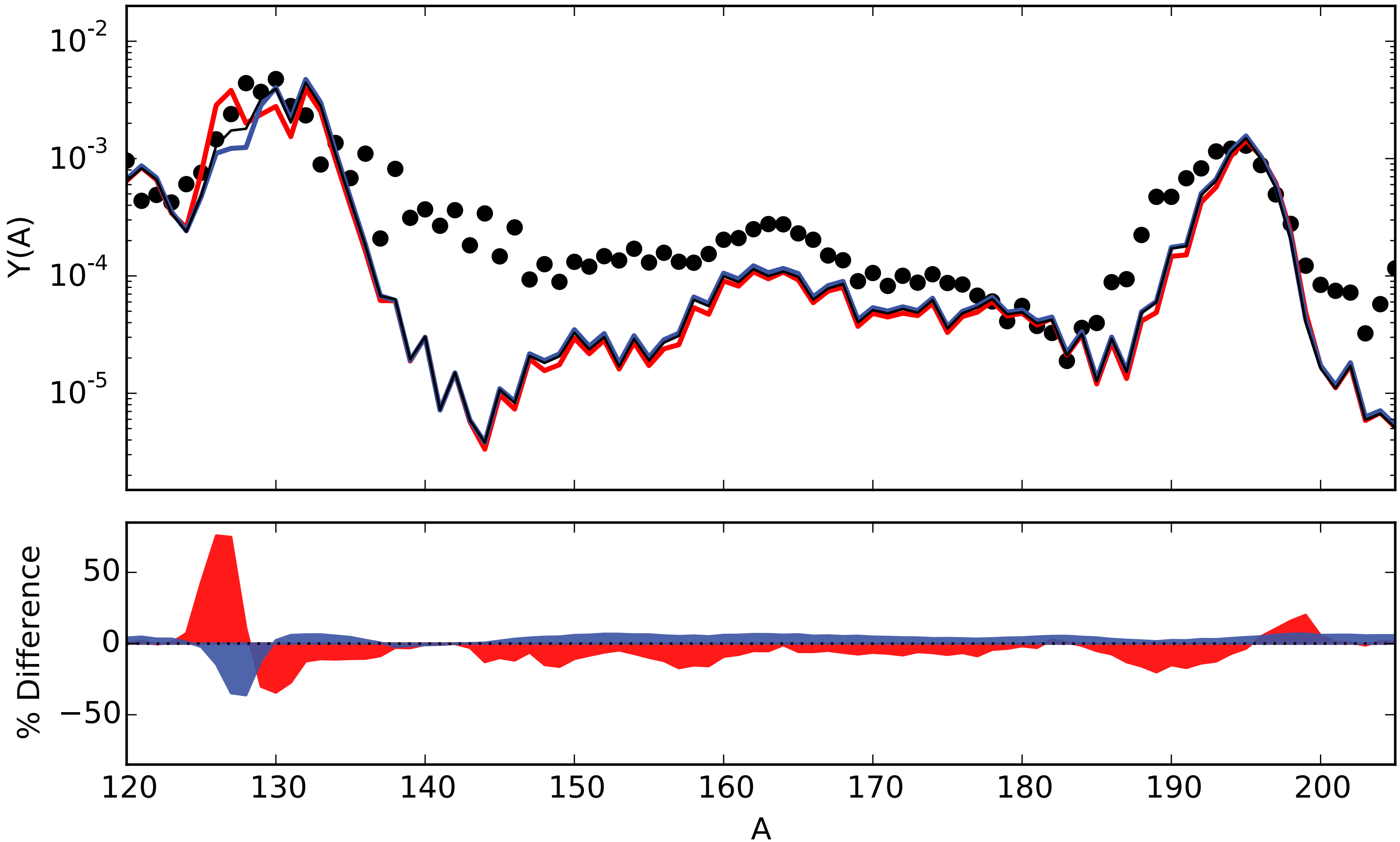
Neutron Star Merger

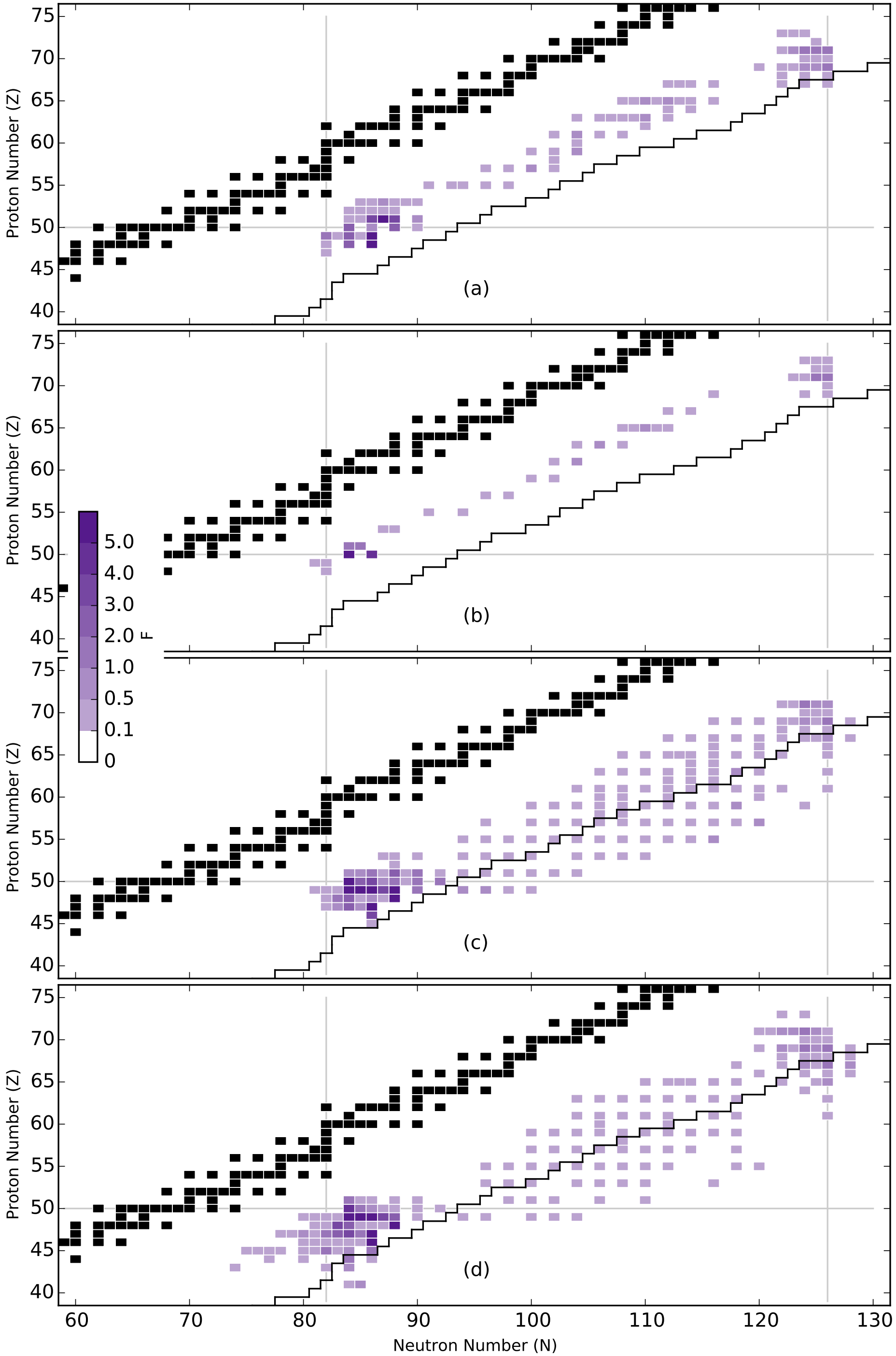
Beta-decay rates: factor of 10

^{128}Ru

F=20.5 for decreasing the β-decay rate (Red) by 10

F=7.56 for increasing the β-decay rate (Blue) by 10





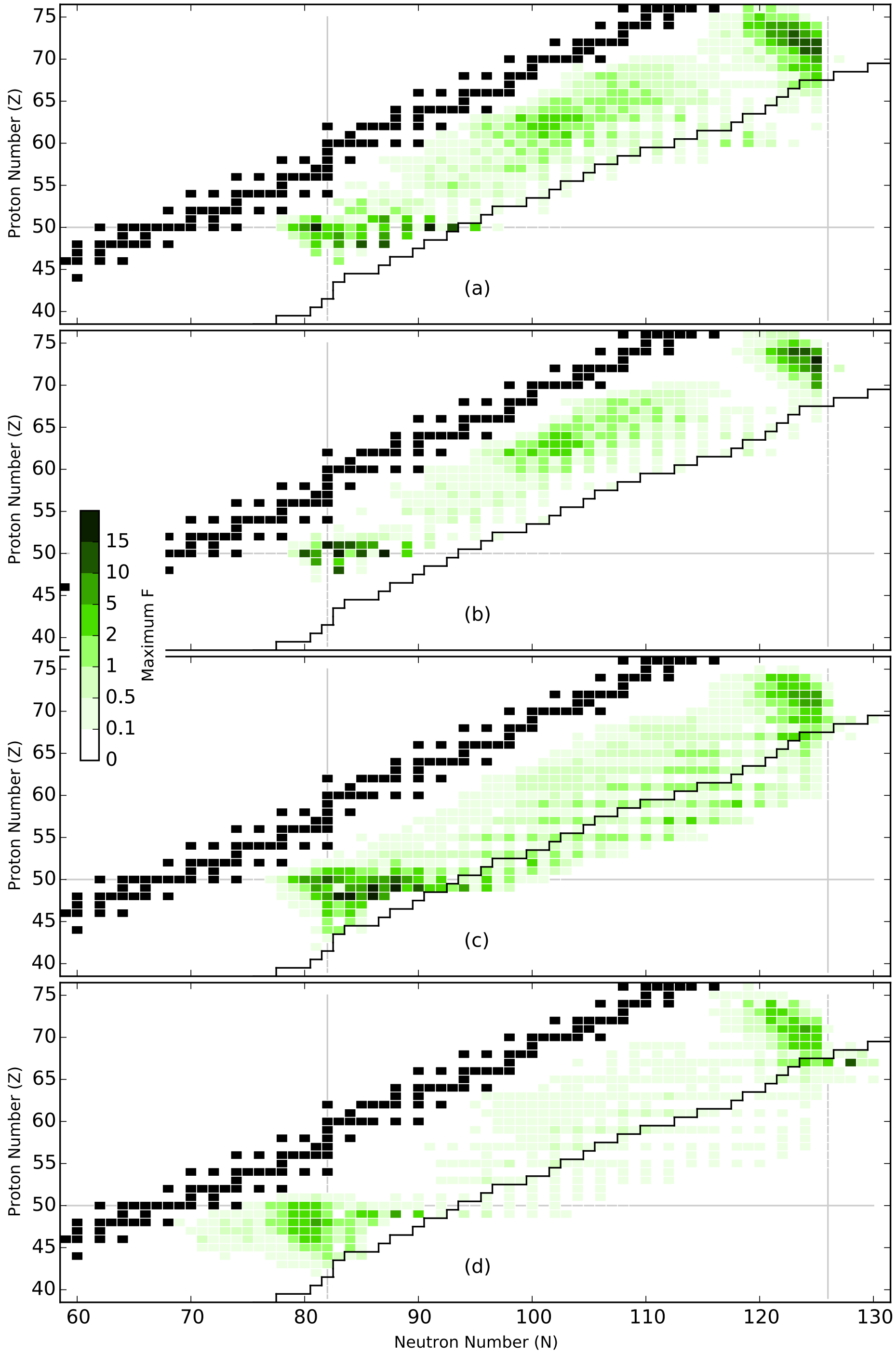
Low entropy hot wind

High entropy hot wind

Cold wind

Neutron Star Merger

Beta-delayed neutron emission Probabilities



Low entropy hot wind

High entropy hot wind

Cold wind

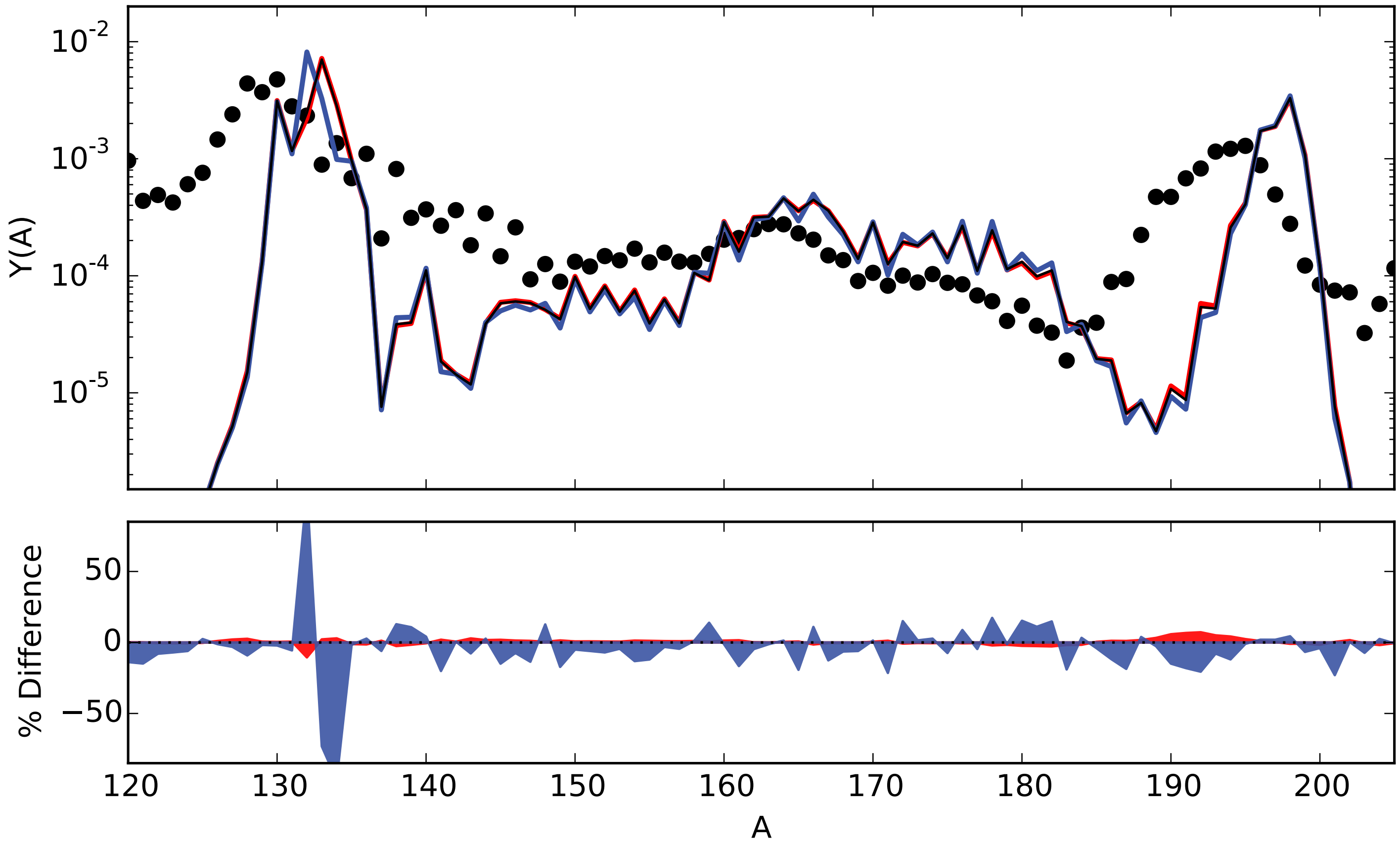
Neutron Star Merger

Neutron capture rates: factor of 100

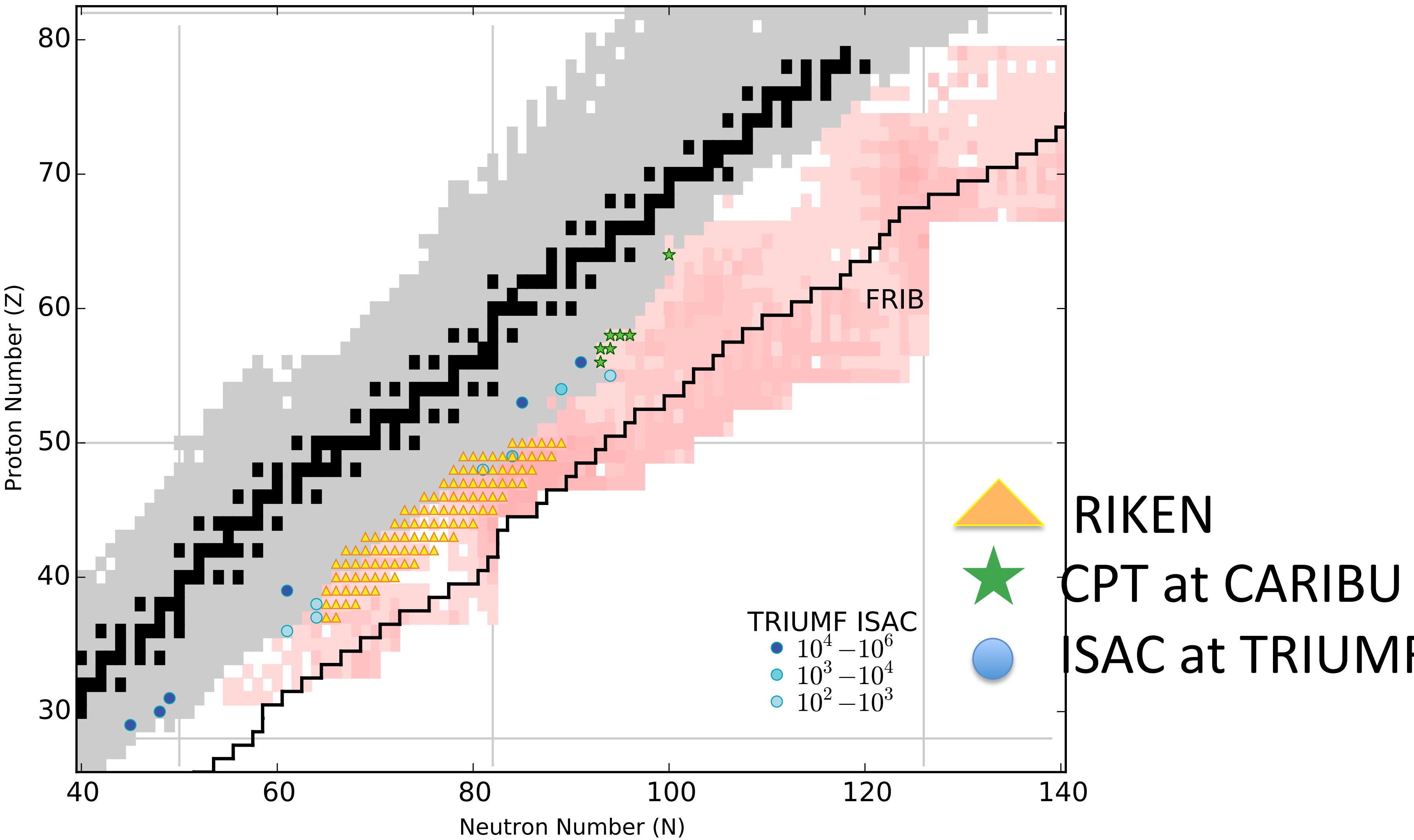
^{133}Sn: Hot wind r-process

F=1.77 for decreasing n-capture rate (Red) by 100

F=20.6 for increasing the n-capture rate (Blue) by 100



Experimental reach for the present and future…



Conclusions

Comprehensive sensitivity studies of the r-process to individual nuclear properties

Propagation of mass changes to all dependent properties
(self-consistence)

Identifying the site of the r-process path....
Disentangling Nuclear Physics uncertainties
from the Astrophysical uncertainties...Progress but not there yet.

We need much better precision on nuclear models

some insight to the r-process with nuclear physics.....

Sensitivity Study β-decay rates

Julie Cass

Giuseppe Passucci

Mathew Mumpower

Rebecca Surman

A^2

Sensitivity Study β-delayed neutron emission rates

Mathew Mumpower

Rebecca Surman

A^2

Sensitivity Study Masses

Samuel Brett

Ian Bentley

Nancy Paul

Matthew Mumpower

Rebecca Surman

A^2

Fully Consistent Sensitivity Studies

Matthew Mumpower

Mary Beard

D. Liang

G. McLaughlin

P. Moller

Rebecca Surman

A^2