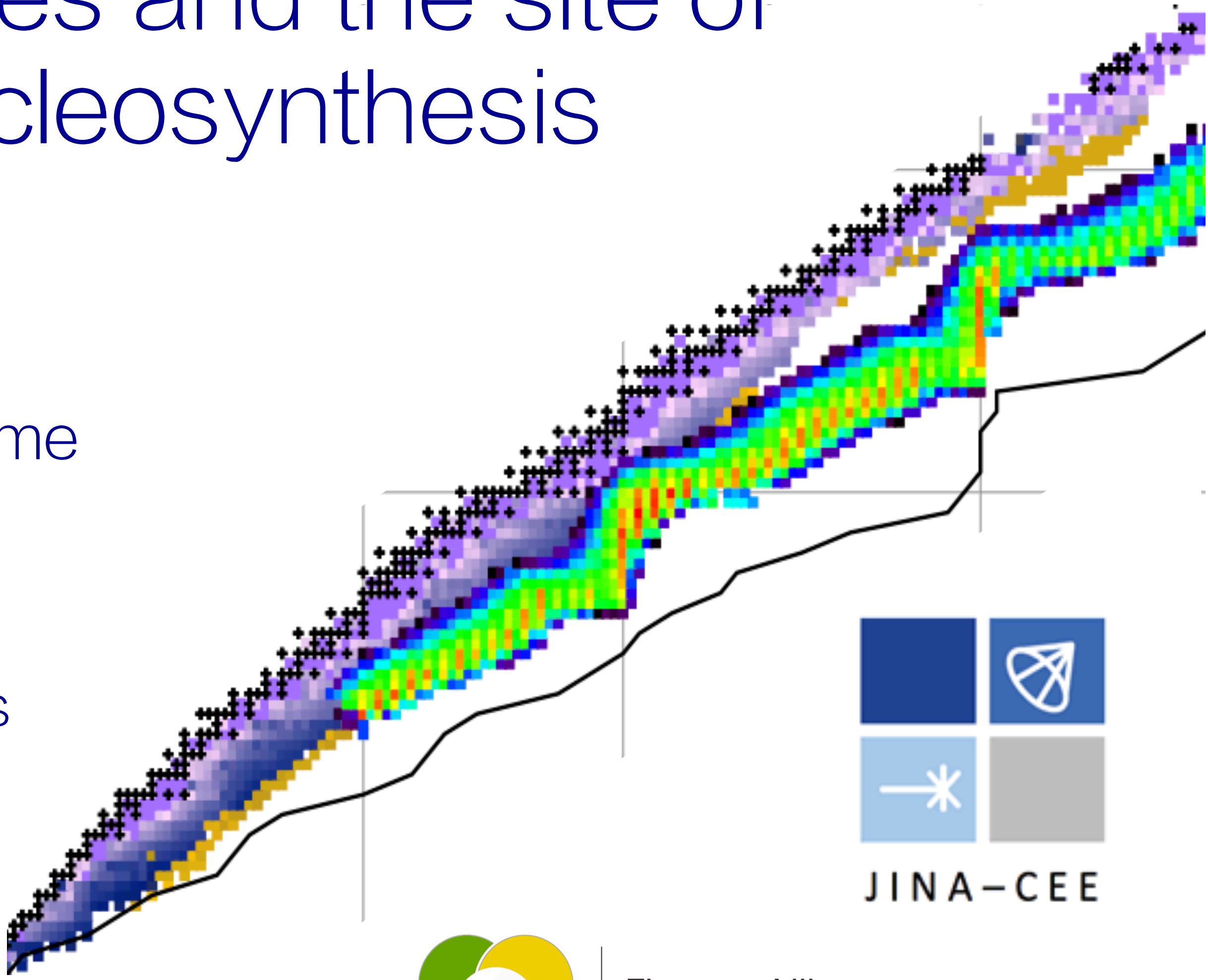
nuclear masses and the site of *r*–process nucleosynthesis



Rebecca Surman
University of Notre Dame

Hirschegg 2017
Neutron star mergers:
From gravitational waves
to nucleosynthesis

Hirschegg, Austria
17 Jan 2017

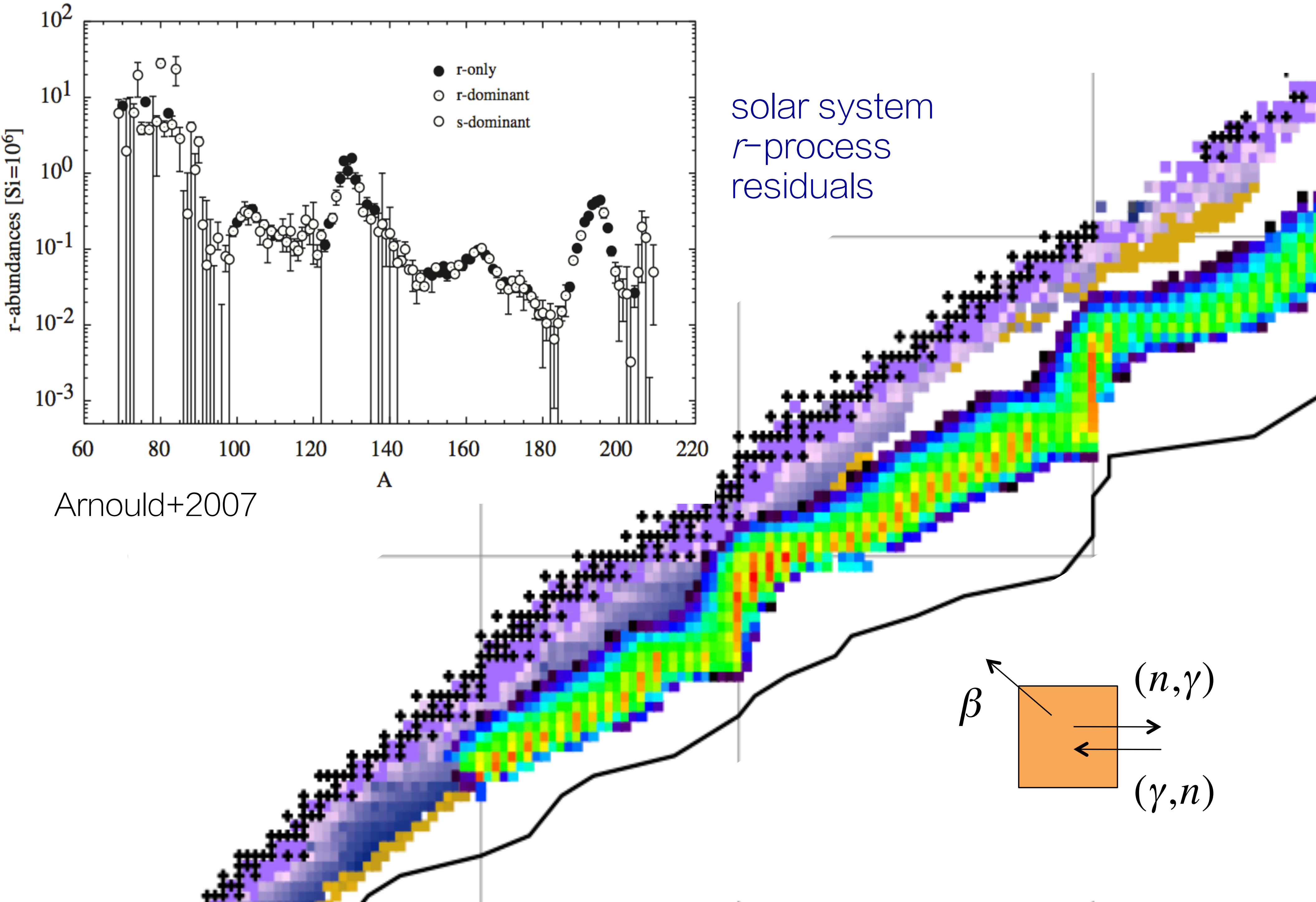
JINA–CEE

Theory Alliance
FACILITY FOR RARE ISOTOPE BEAMS

UNIVERSITY OF NOTRE DAME
College of Science

U.S. DEPARTMENT OF ENERGY
Office of Science

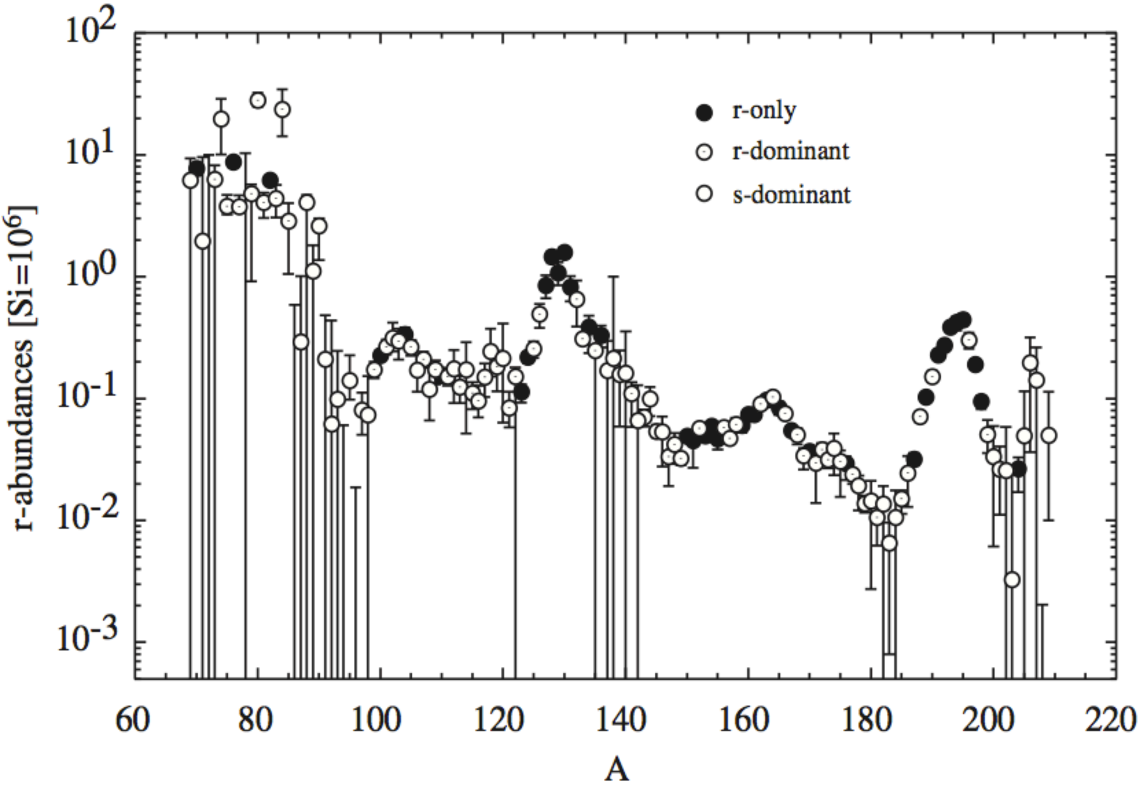
r−process nucleosynthesis



Arnould+2007

solar system
r−process
residuals

r–process nucleosynthesis

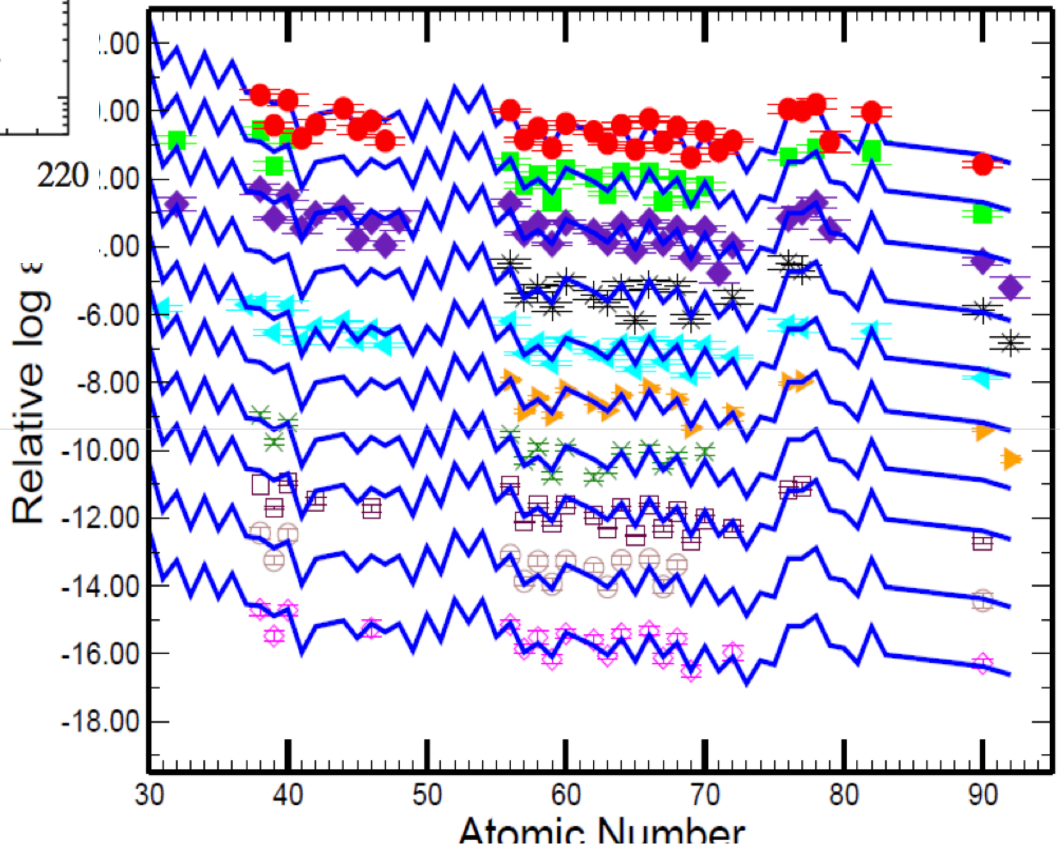


Arnould+2007

solar system
r–process
residuals

elemental abundances
from *r*–process–
enhanced metal–poor
halo stars

Cowan+2011



r−process astrophysical site: BNS/NSBH mergers?

astrophysical modeling of BNS/NSBH mergers

talks by A Bauswein, S Rosswog, M Wu, T Piran

electromagnetic transient: macronova/kilonova

talks by J Barnes, R Wollaeger

gravitational waves from merger events

talks by B Sathyaprakash, S Rosswog

r−process elements in low metallicity stars

talks by A Frebel, T Hansen, C Hansen

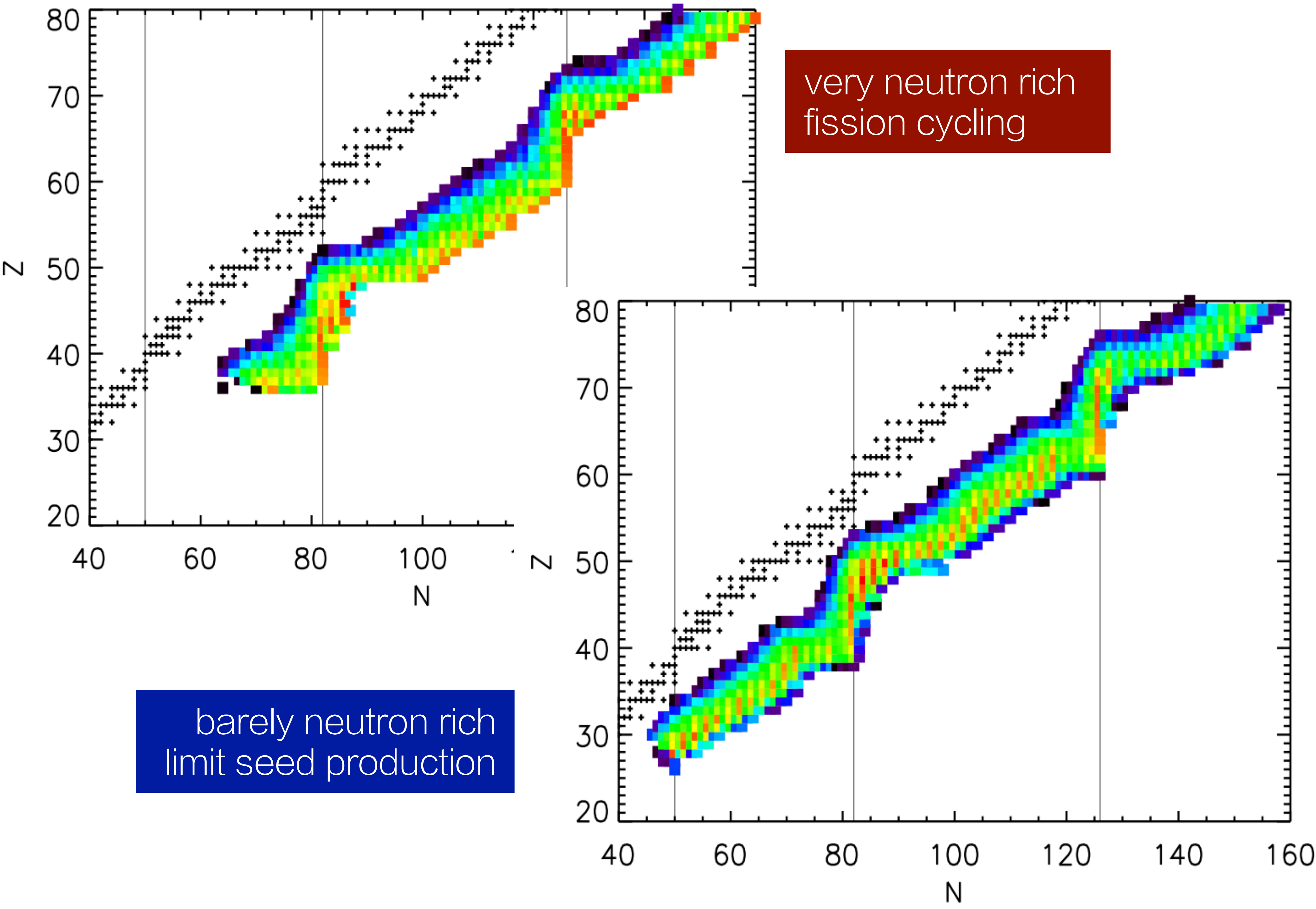
galactic chemical evolution studies

talks by F Matteucci, T Kajino

neutrino physics of merger events

talks by G McLaughlin, H Yasin, M Wu

r−process abundance pattern signatures



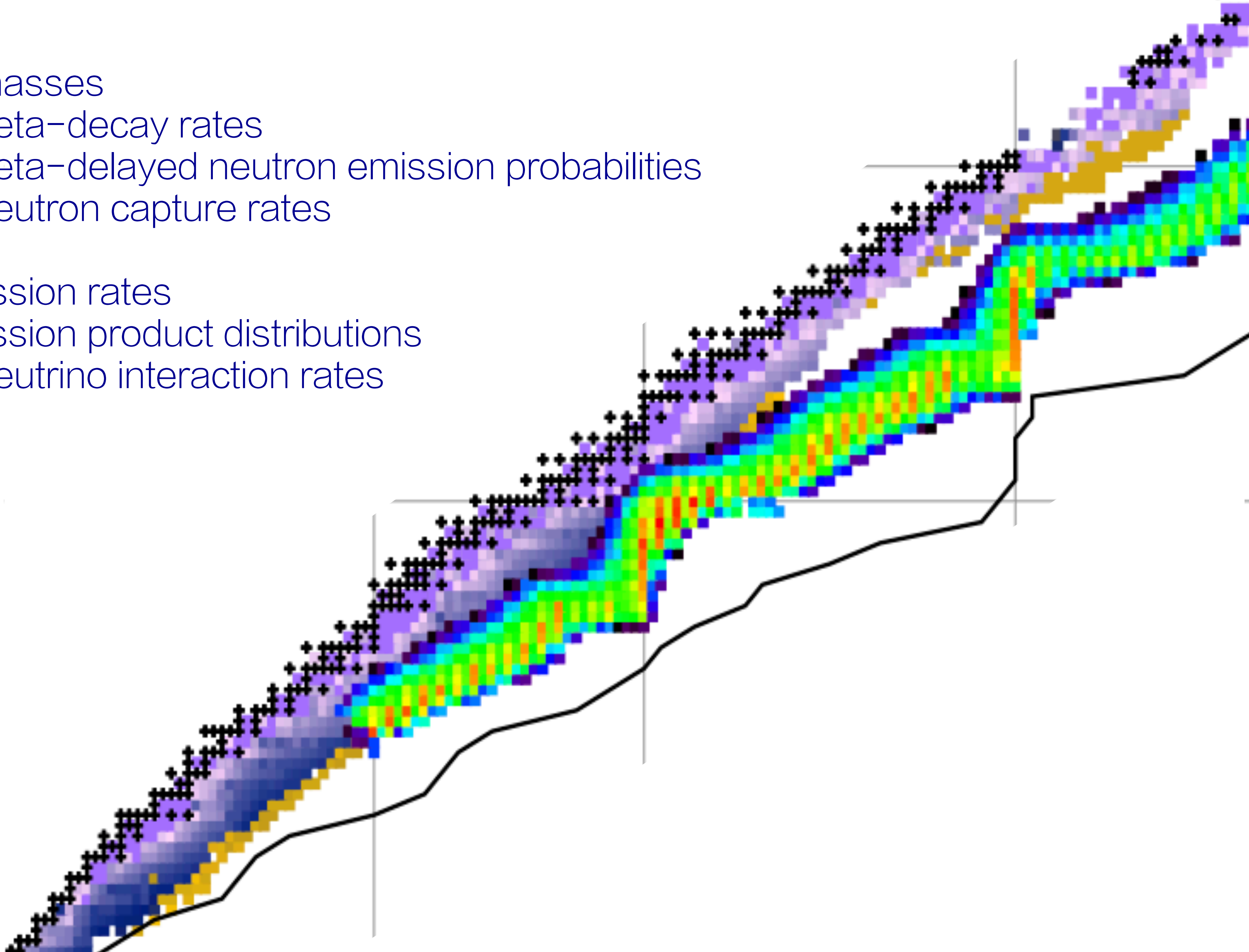
very neutron rich
fission cycling

barely neutron rich
limit seed production

r–process simulations: required nuclear data

masses
beta–decay rates
beta–delayed neutron emission probabilities
neutron capture rates

fission rates
fission product distributions
neutrino interaction rates



r–process simulations: required nuclear data

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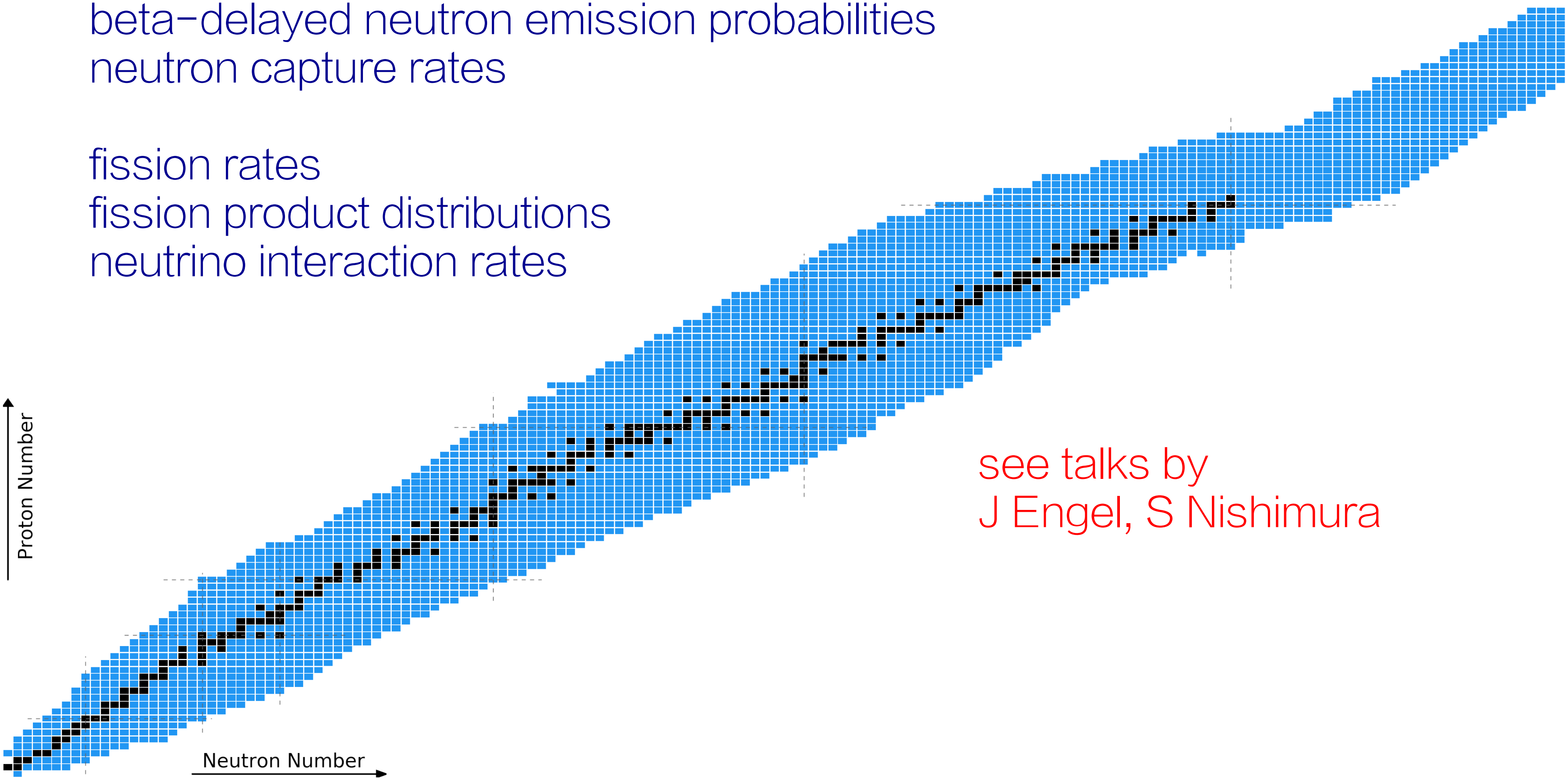

see talks by
J Engel, S Nishimura

figure by M Mumpower

r−process simulations: required nuclear data

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beta−decay rates
beta−delayed neutron emission probabilities
neutron capture rates

fission rates
fission product distributions
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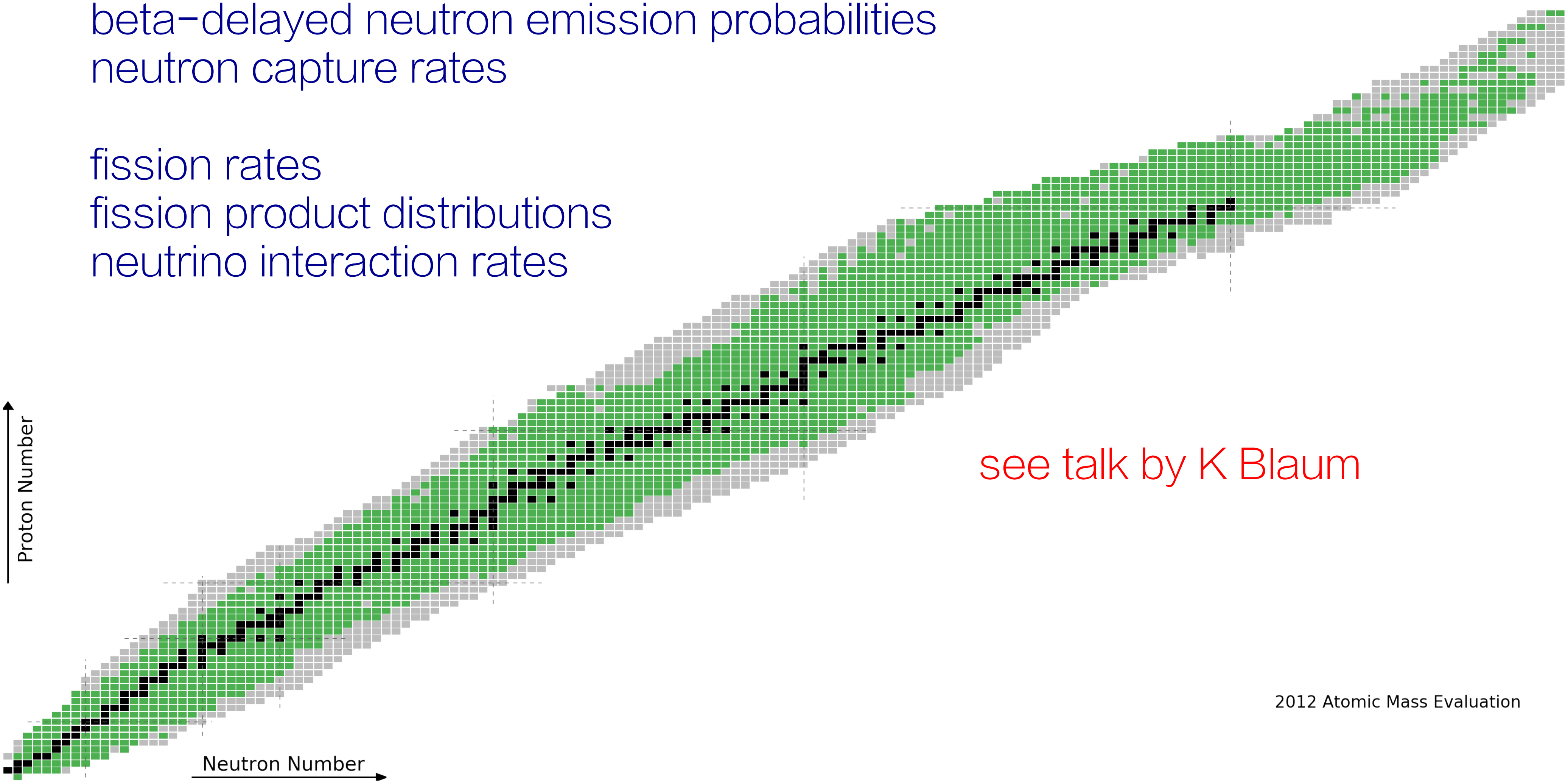

see talk by K Blaum

figure by M Mumpower

r−process simulations: required nuclear data

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beta−decay rates
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neutrino interaction rates

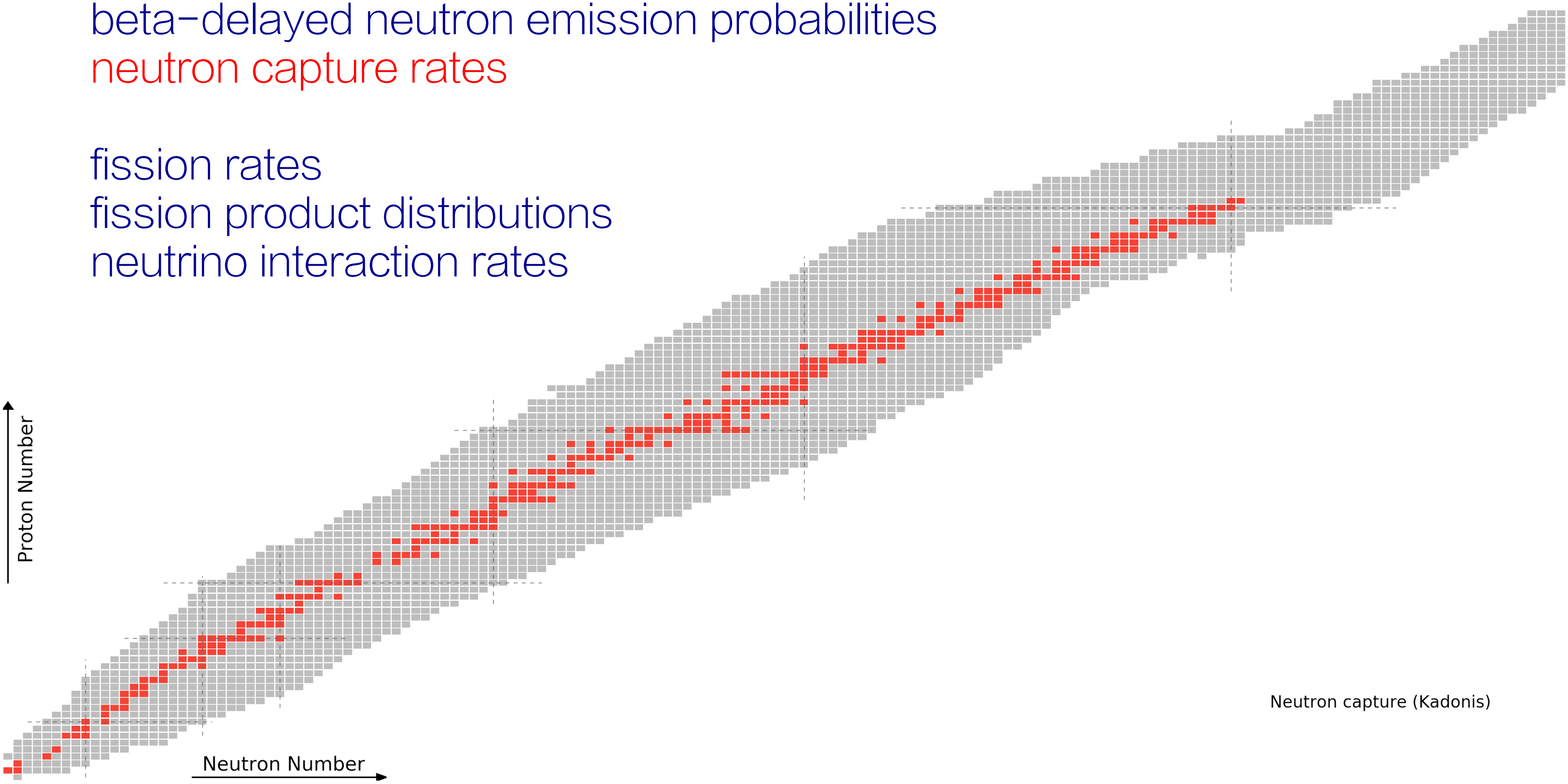

figure by M Mumpower

r−process simulations: required nuclear data

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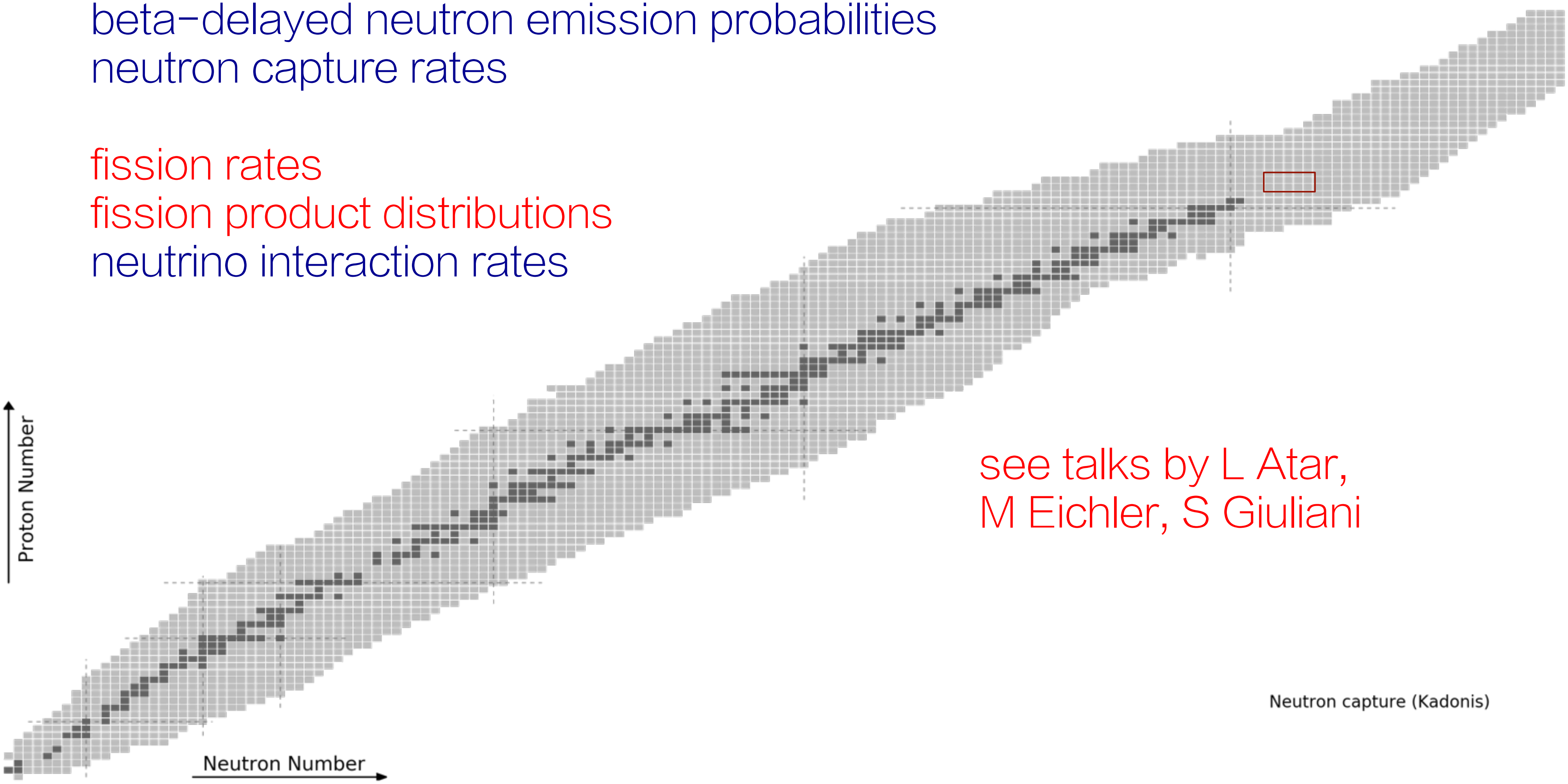

see talks by L Atar,
M Eichler, S Giuliani

figure by M Mumpower

r–process simulations: required nuclear data

masses
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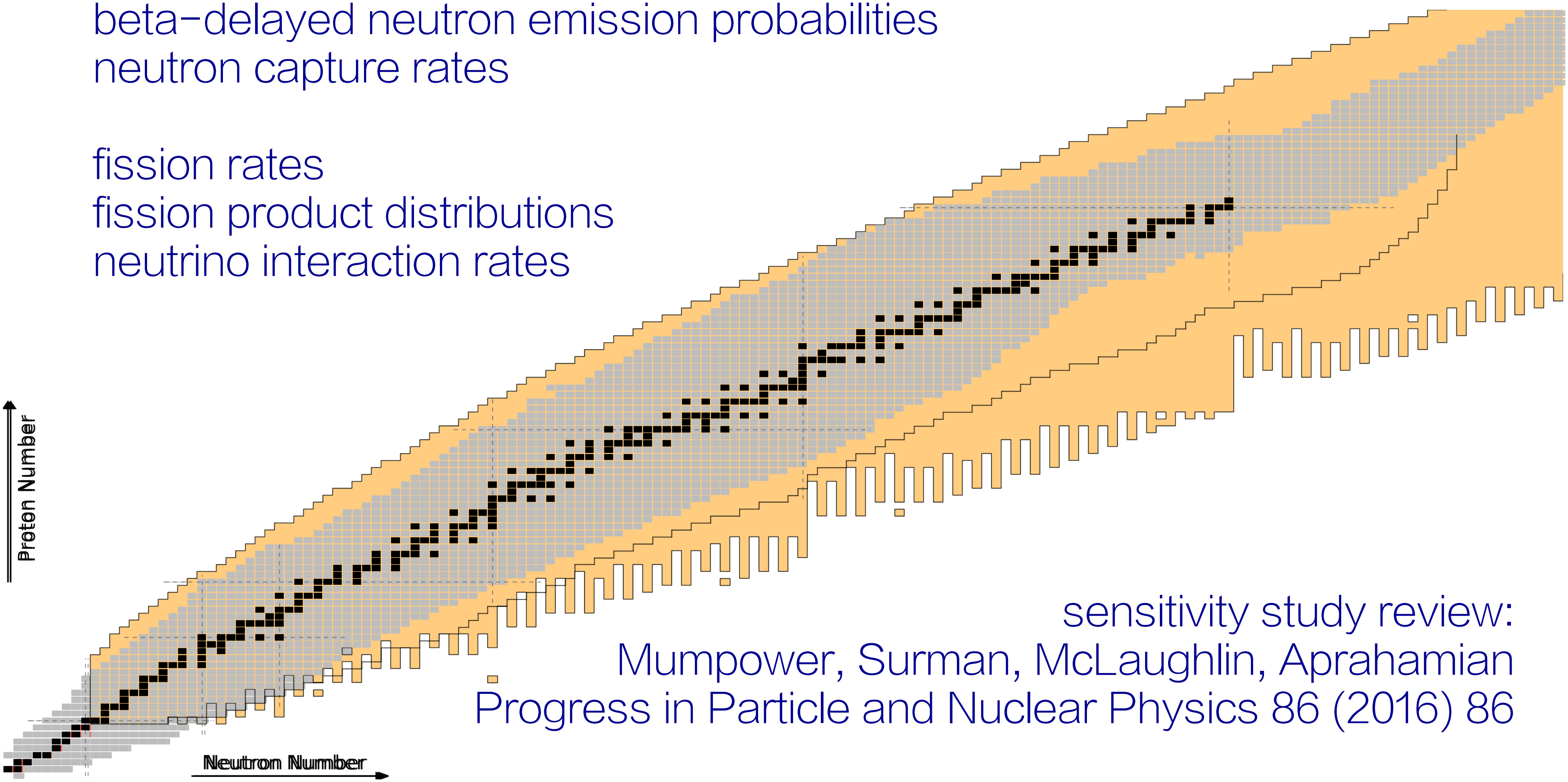
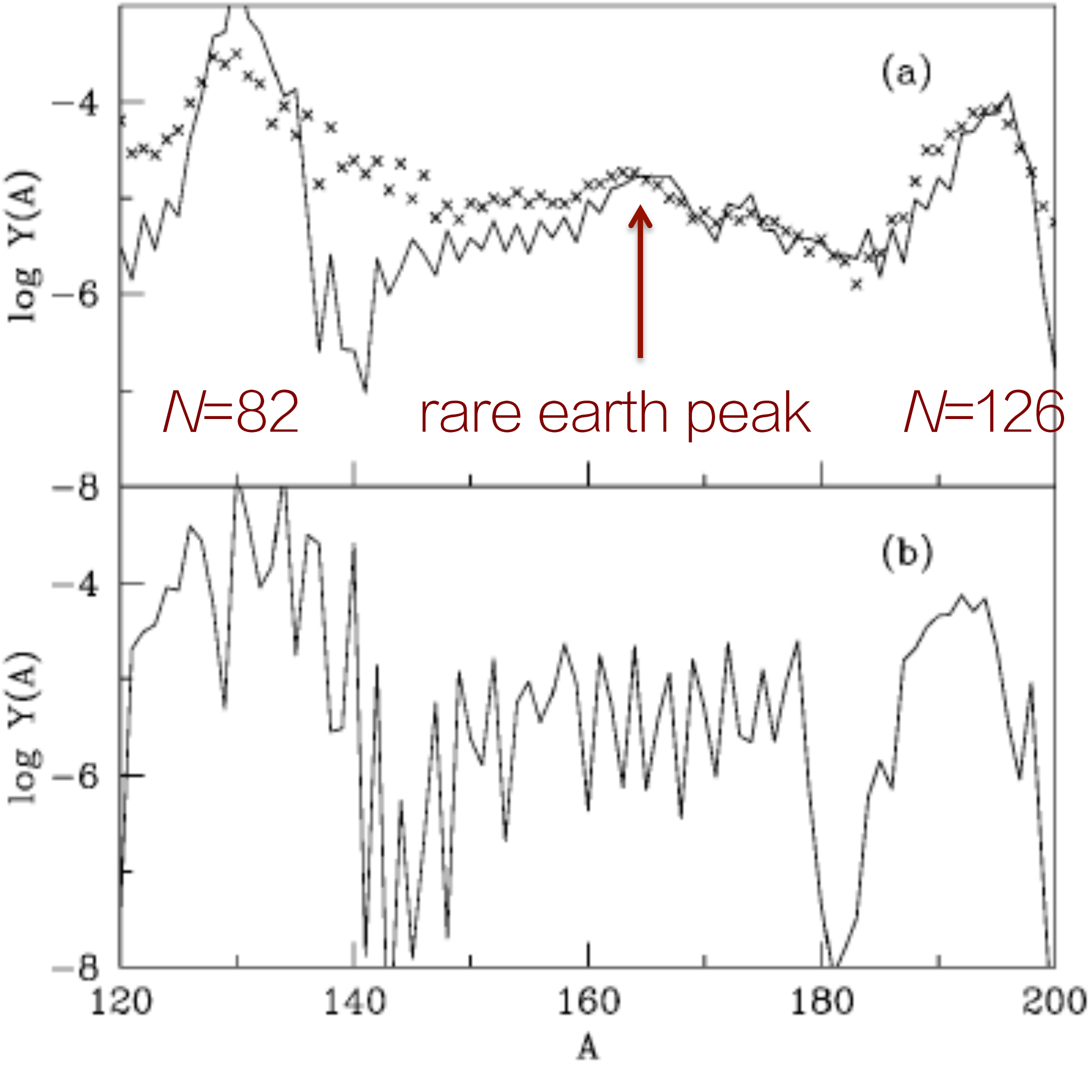


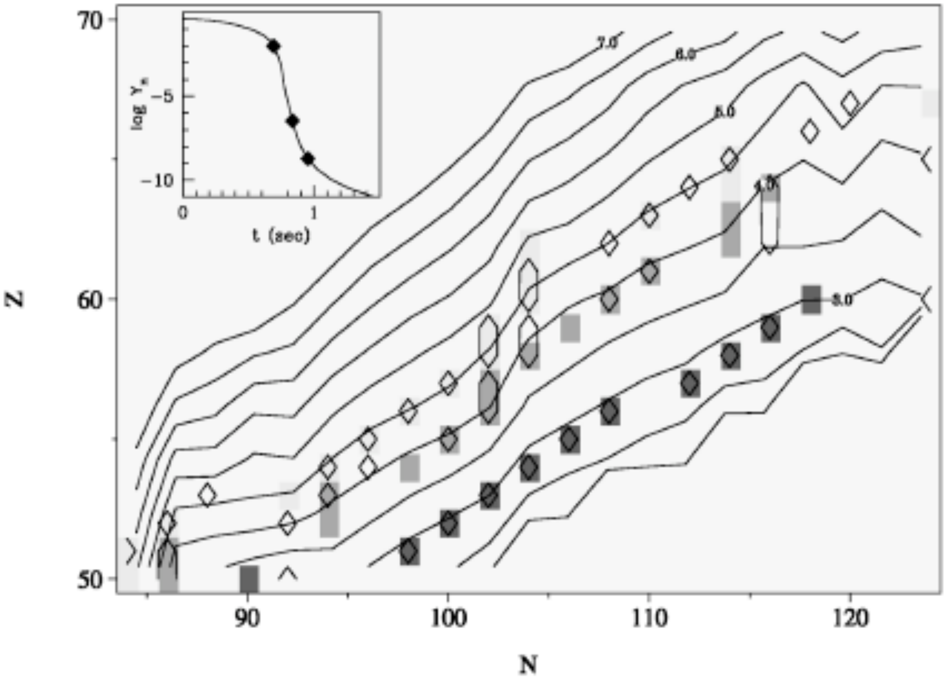
sensitivity study review:
Mumpower, Surman, McLaughlin, Aprahamian
Progress in Particle and Nuclear Physics 86 (2016) 86

figure by M Mumpower

the rare earth peak

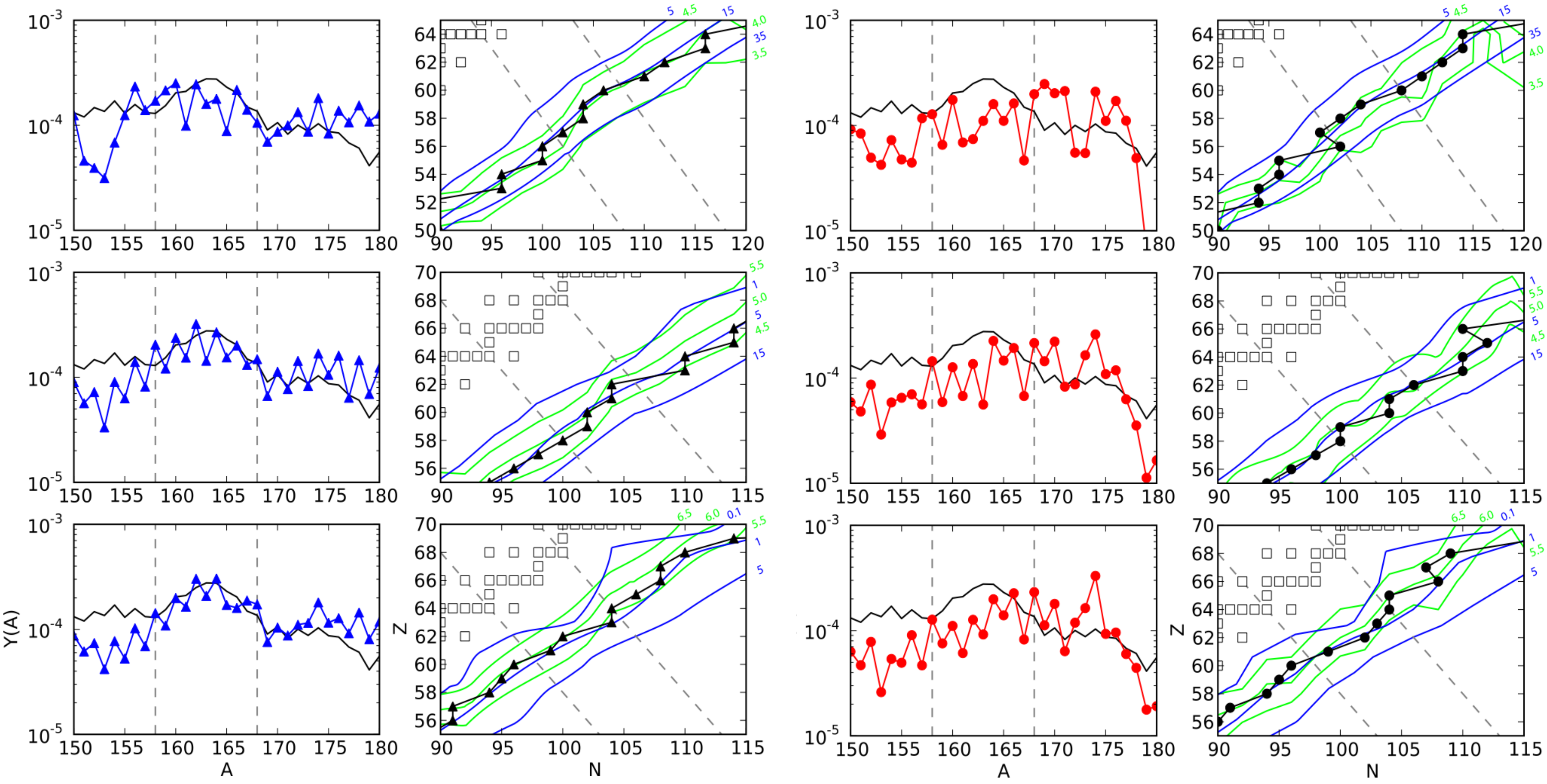
Its formation mechanism is sensitive to both the astrophysical conditions of the late phase of the *r*−process and the nuclear physics of the nuclei populated at this time





Surman, Engel, Bennett, Meyer 1997

rare earth peak formation

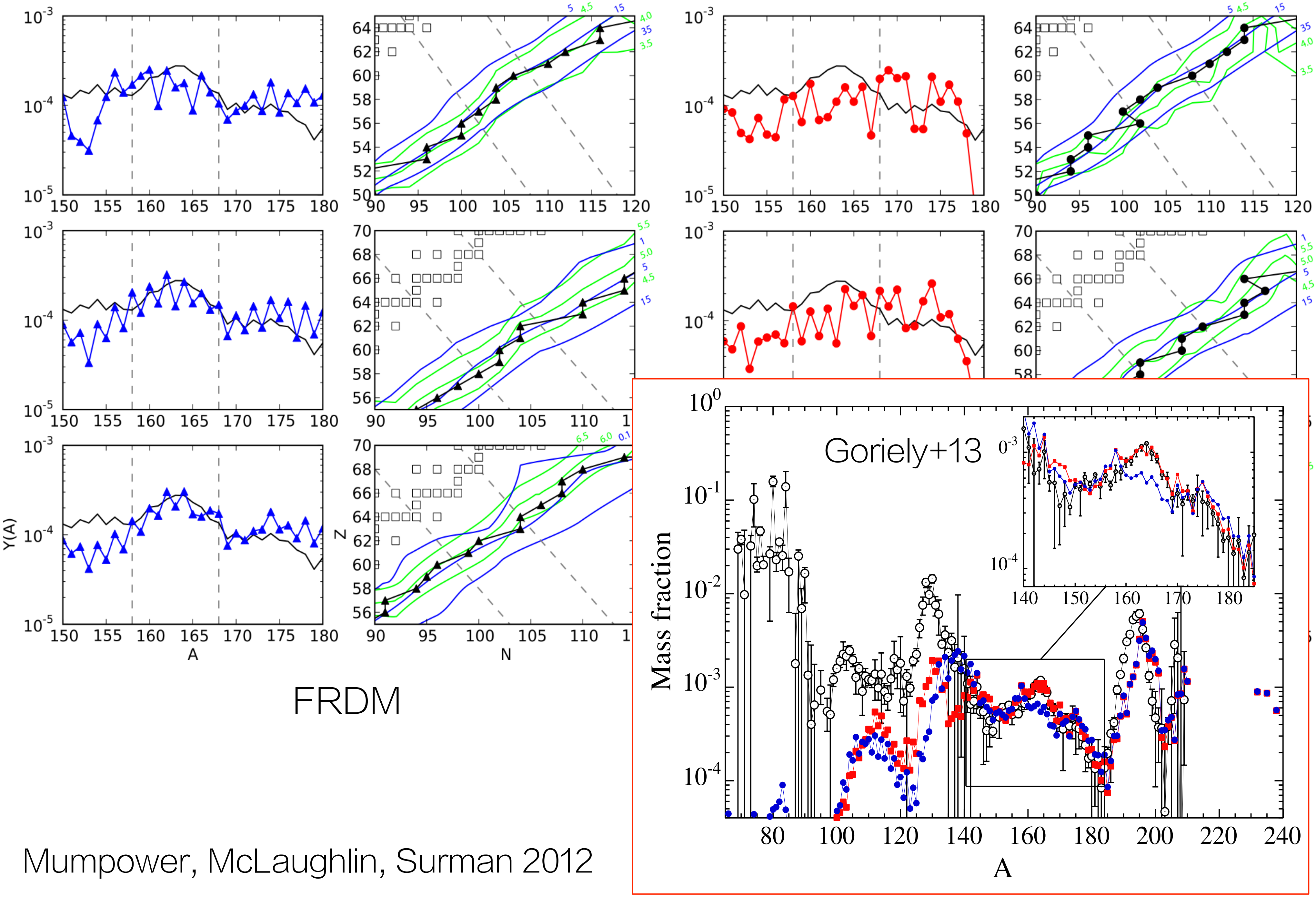


FRDM

HFB−21

Mumpower, McLaughlin, Surman 2012

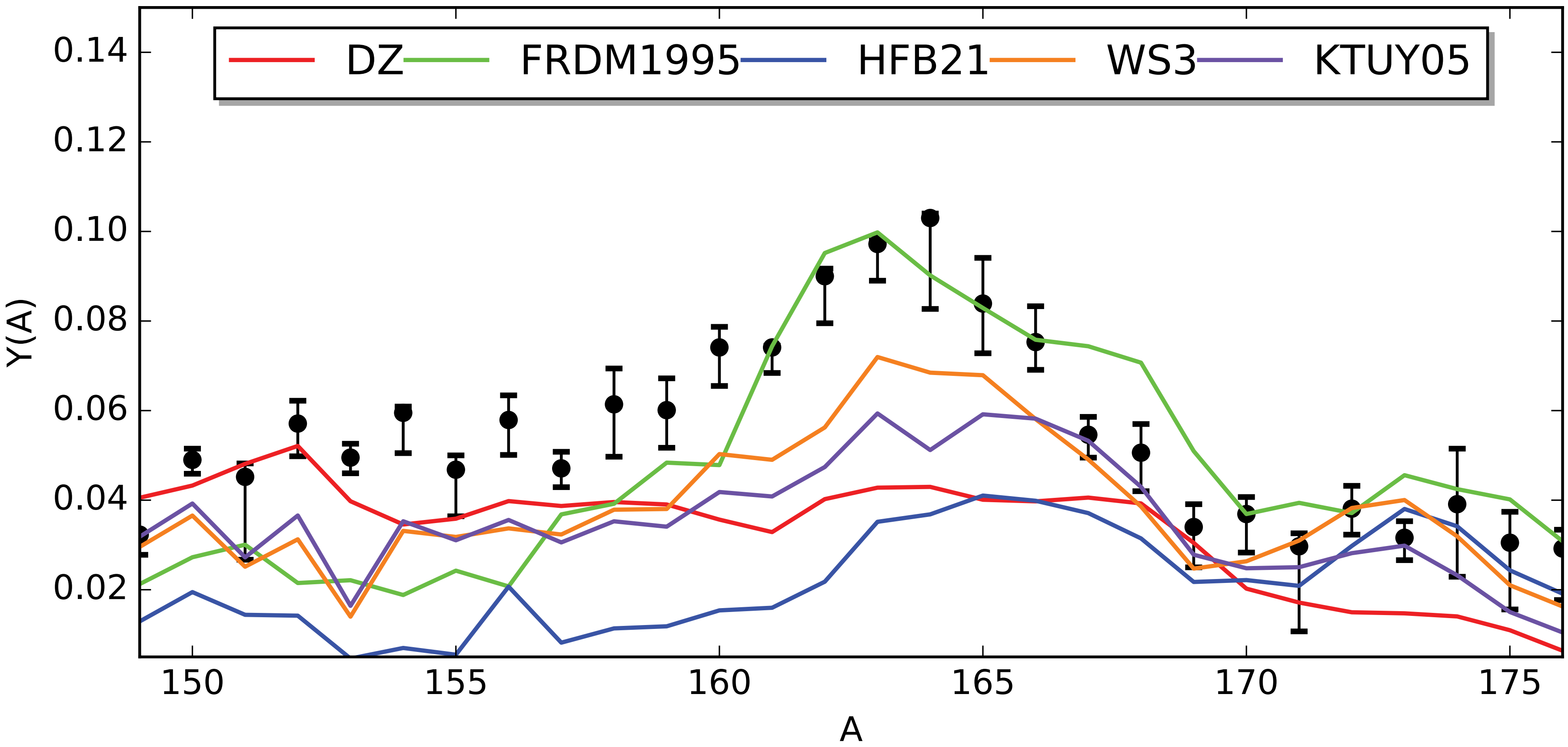
rare earth peak formation



FRDM

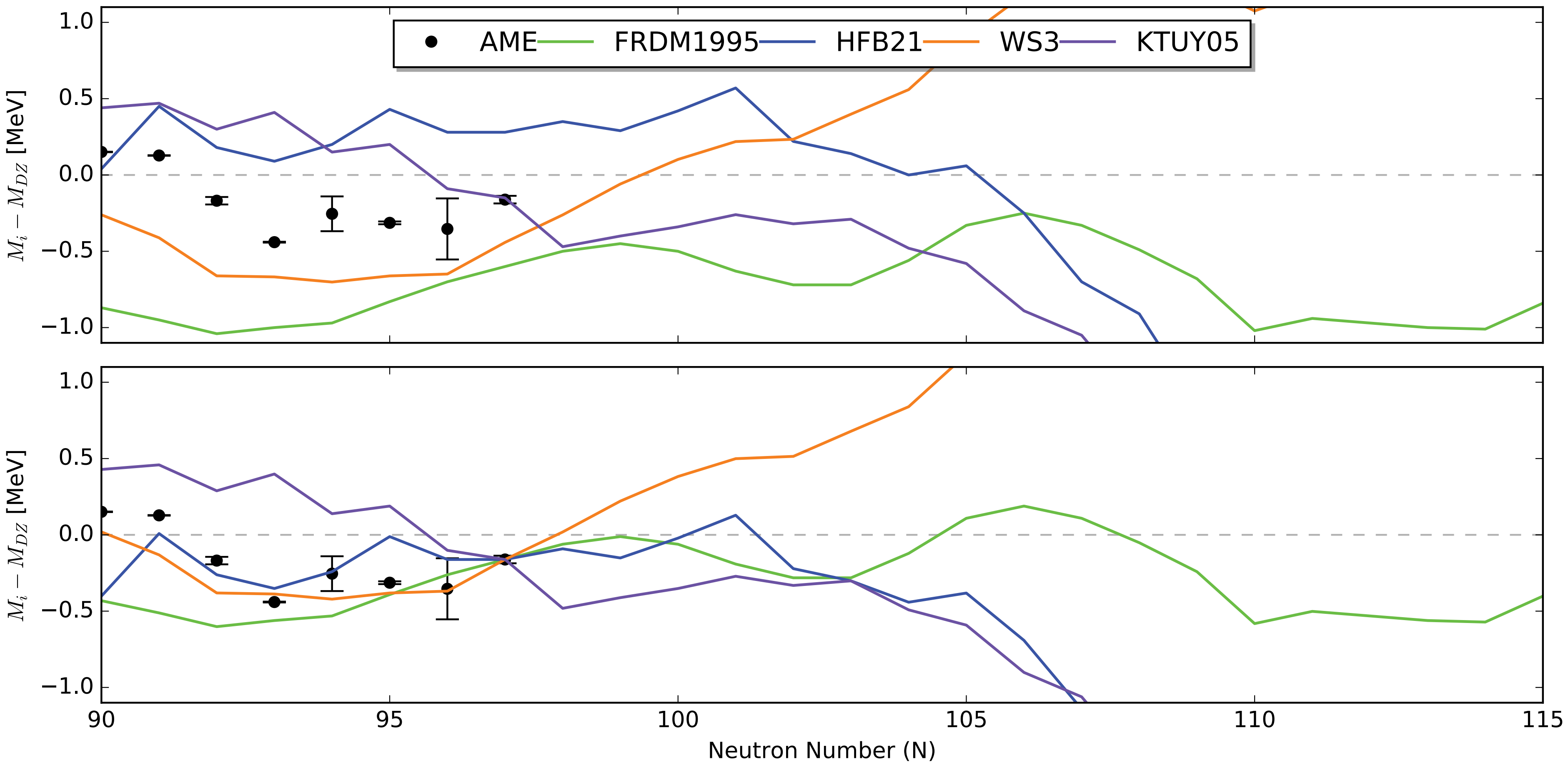
Mumpower, McLaughlin, Surman 2012

rare earth peak formation



Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted

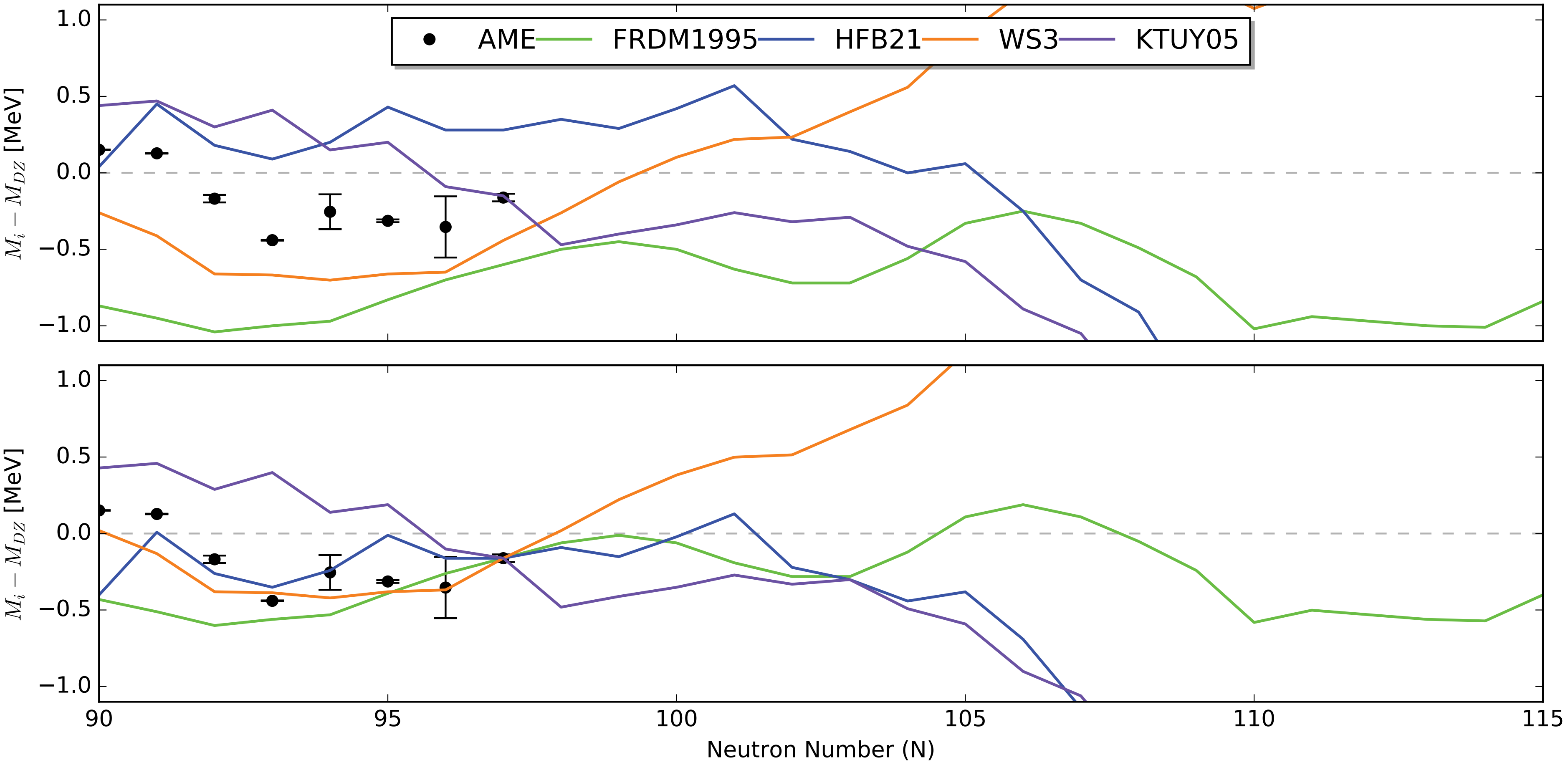
rare earth peak formation



Neodymium ($Z = 60$) isotopic chain

Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted

reverse-engineering the rare earth masses

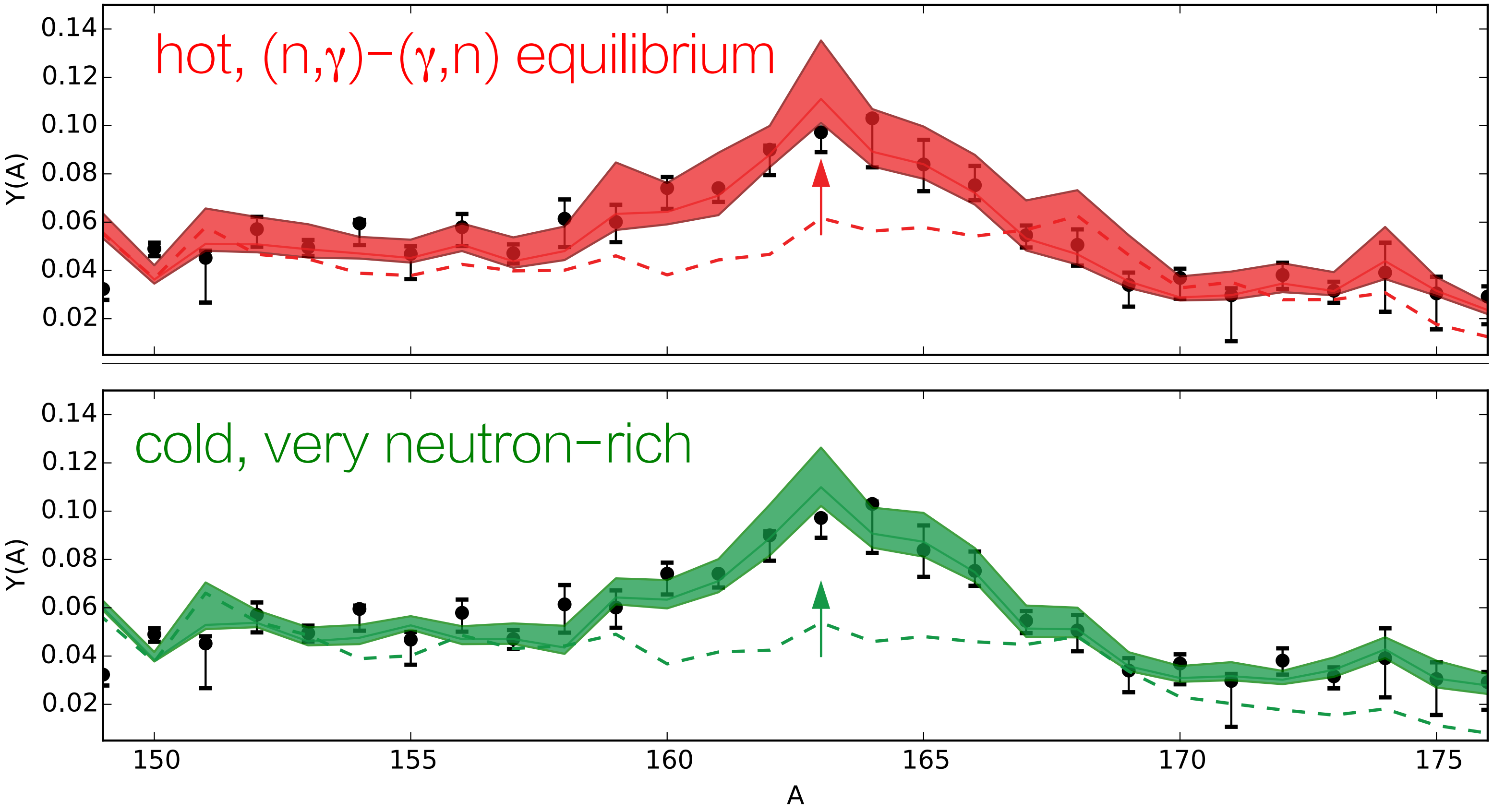


mass modification parameterization:

$$M(Z,N) = M_{DZ}(Z,N) + a_N e^{-(Z-C)^2/2f}$$

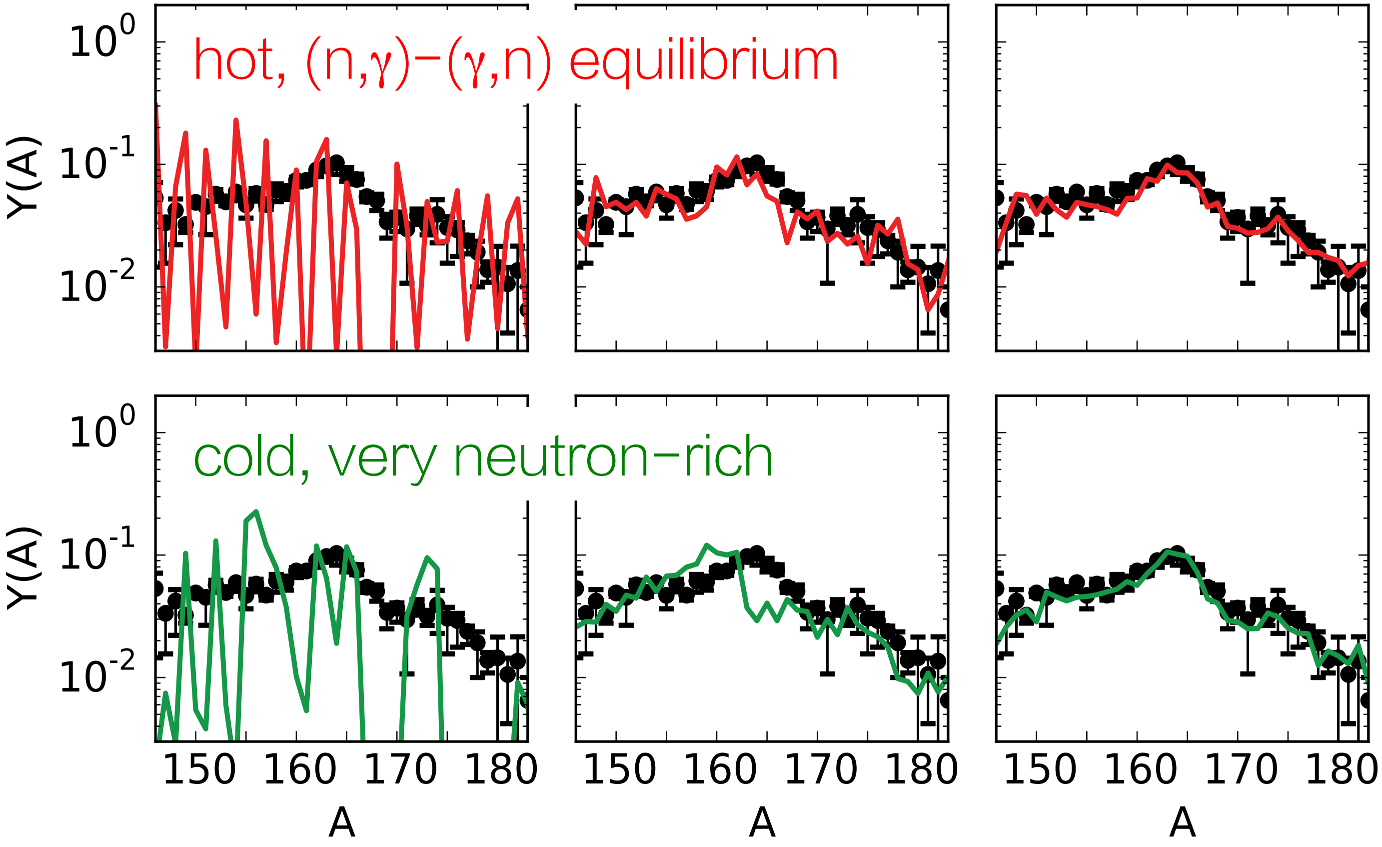
Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted

reverse-engineering the rare earth masses



Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted

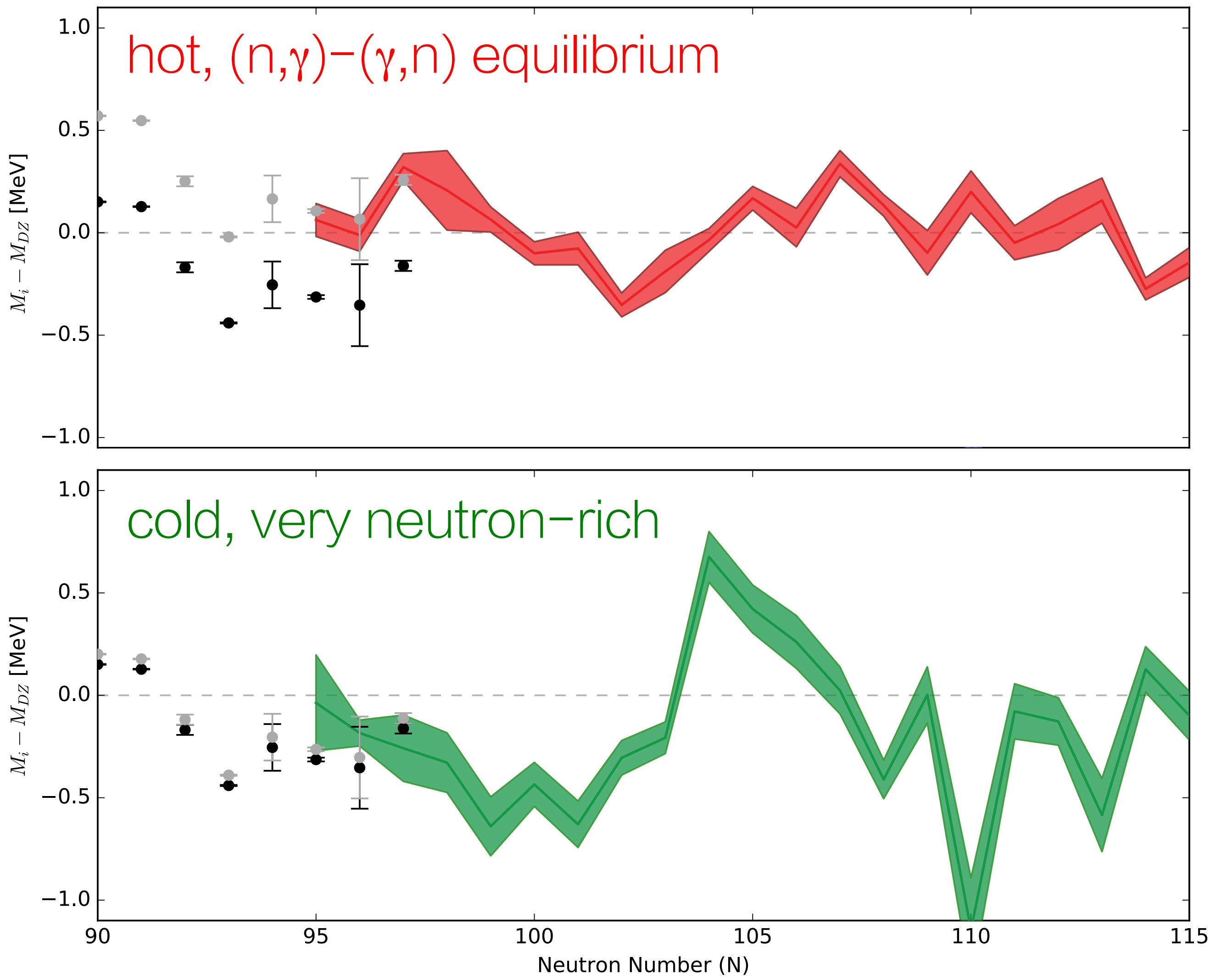
rare earth peak formation comparison



Mumpower, McLaughlin, Surman, Steiner ApJ 2016

predicted mass surfaces

persistent feature,
single
astrophysical
trajectory

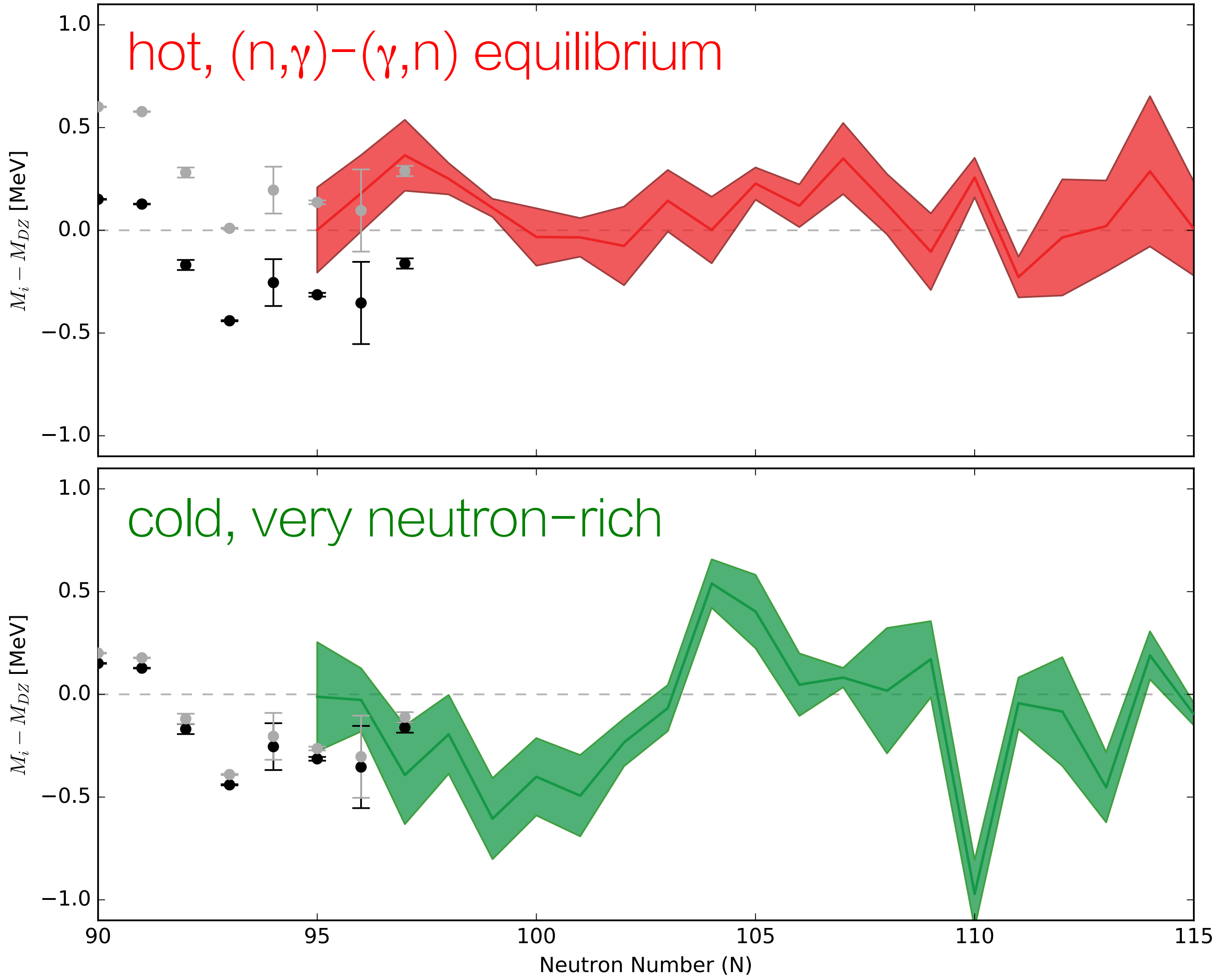


Neodymium ($Z = 60$) isotopic chain

Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted

predicted mass surfaces

persistent feature, multiple astrophysical trajectories

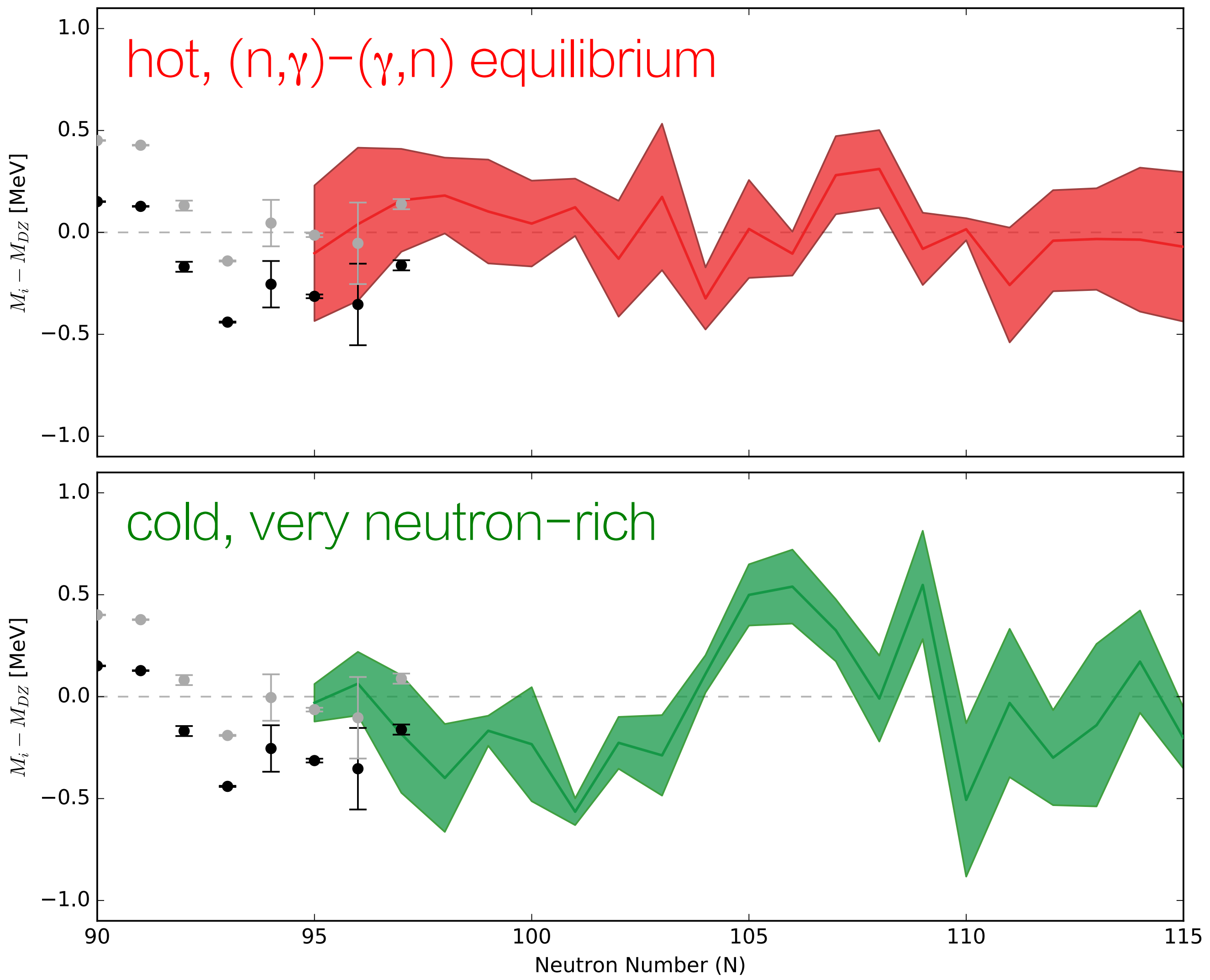


Neodymium (*Z* = 60) isotopic chain

Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted

predicted mass surfaces

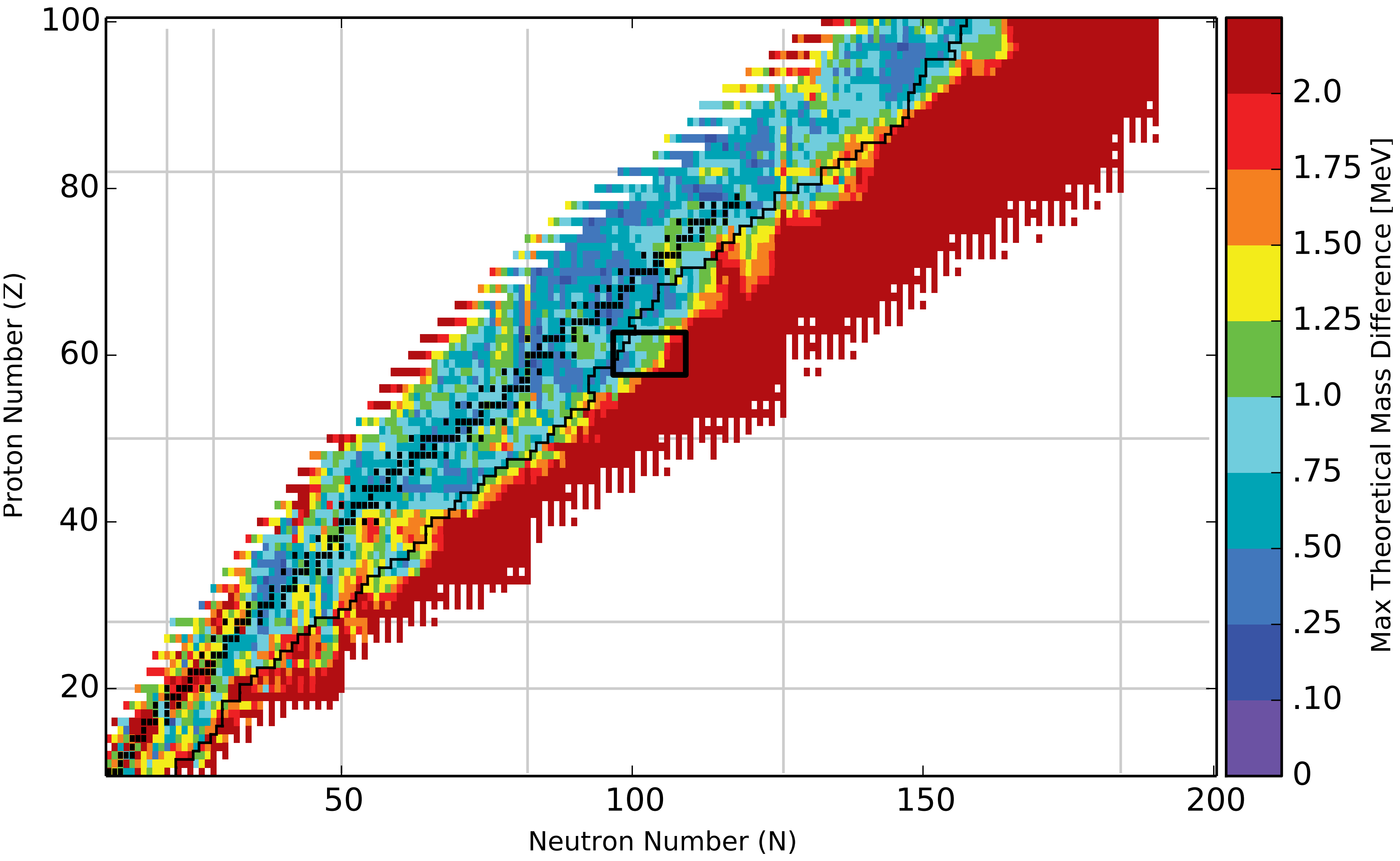
localized feature,
multiple
astrophysical
trajectories



Neodymium ($Z = 60$) isotopic chain

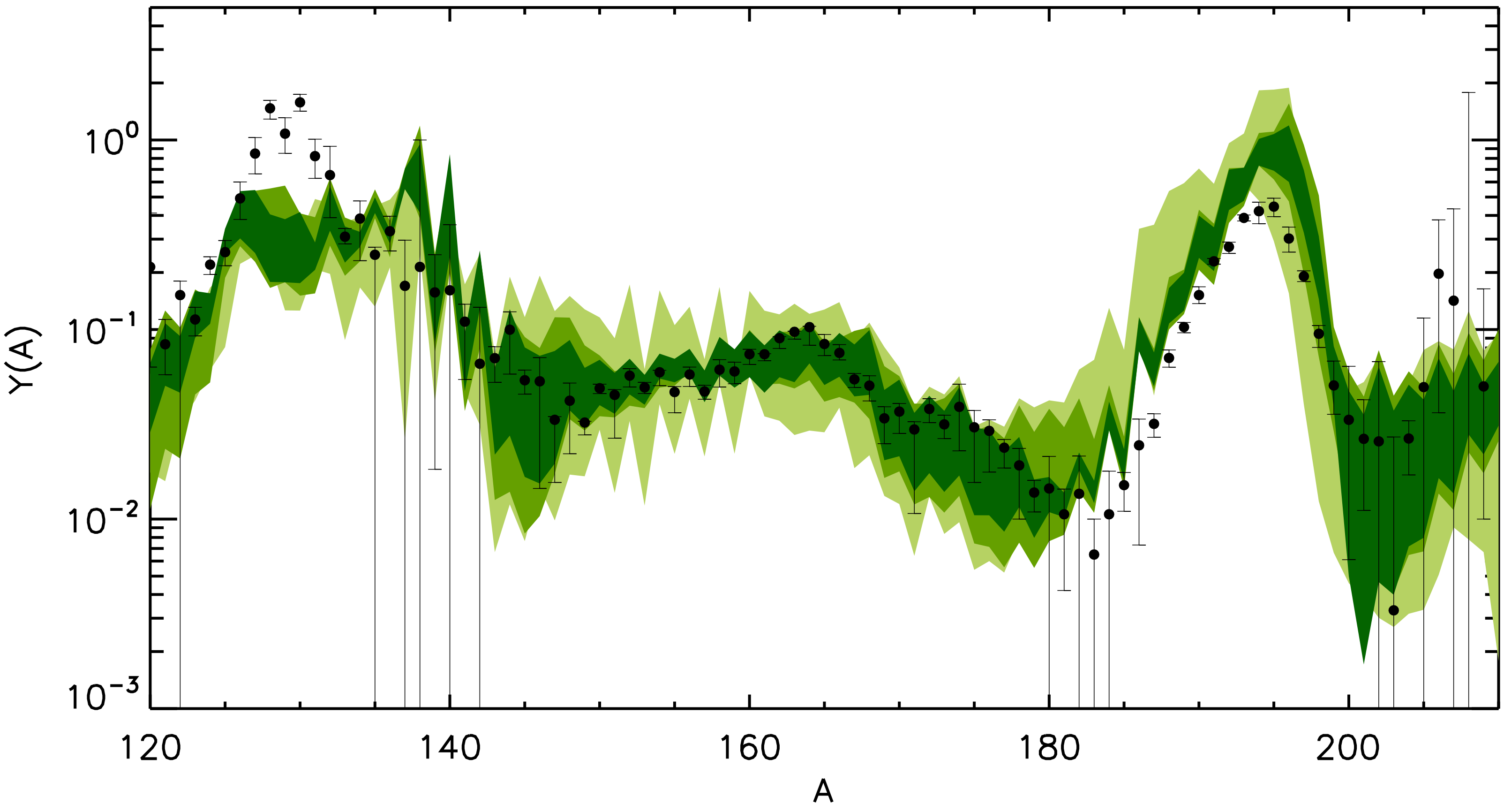
Mumpower, McLaughlin, Surman, Steiner, JPhys G, accepted

uncertainties in nuclear masses



Mumpower, Surman, Fang, Beard, Aprahamian 2016

systematic uncertainties in nuclear masses: impact on *r*−process simulations



Surman, Mumpower, McLaughlin 2016

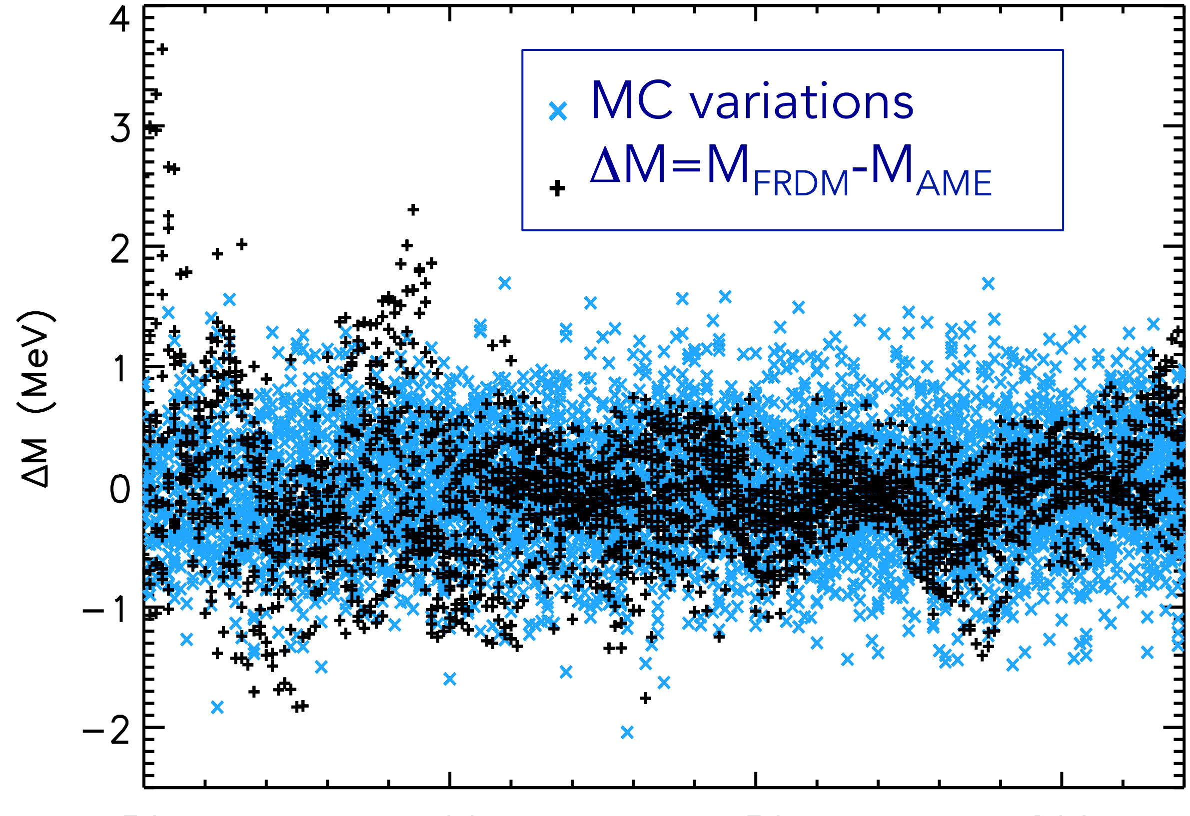
masses from massexplorer.frib.msu.edu: Olsen, Nazarewicz:

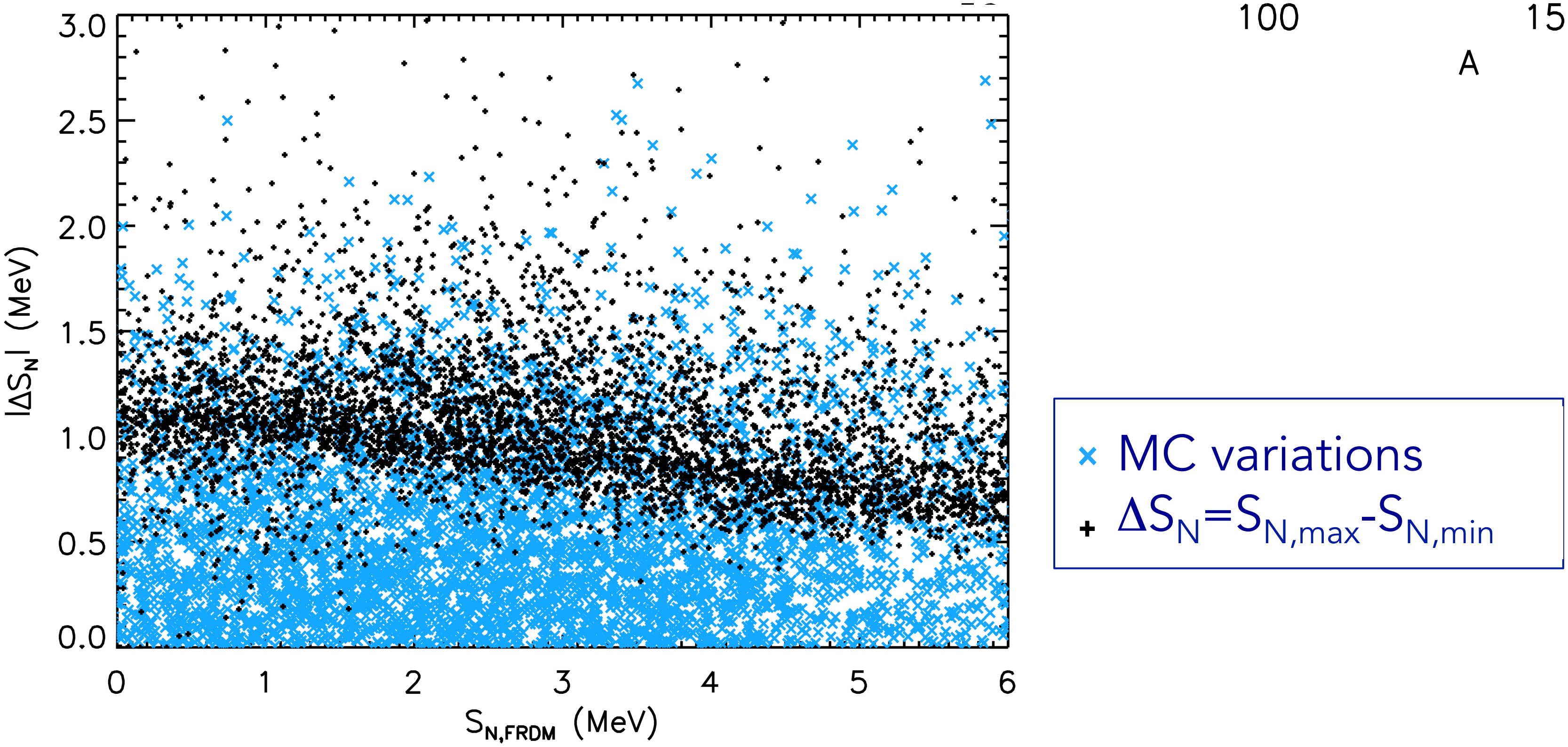
SKM*
SKP−3
SLY4
SV−MIN
UNEDF0
UNEDF1

see also Martin+2016

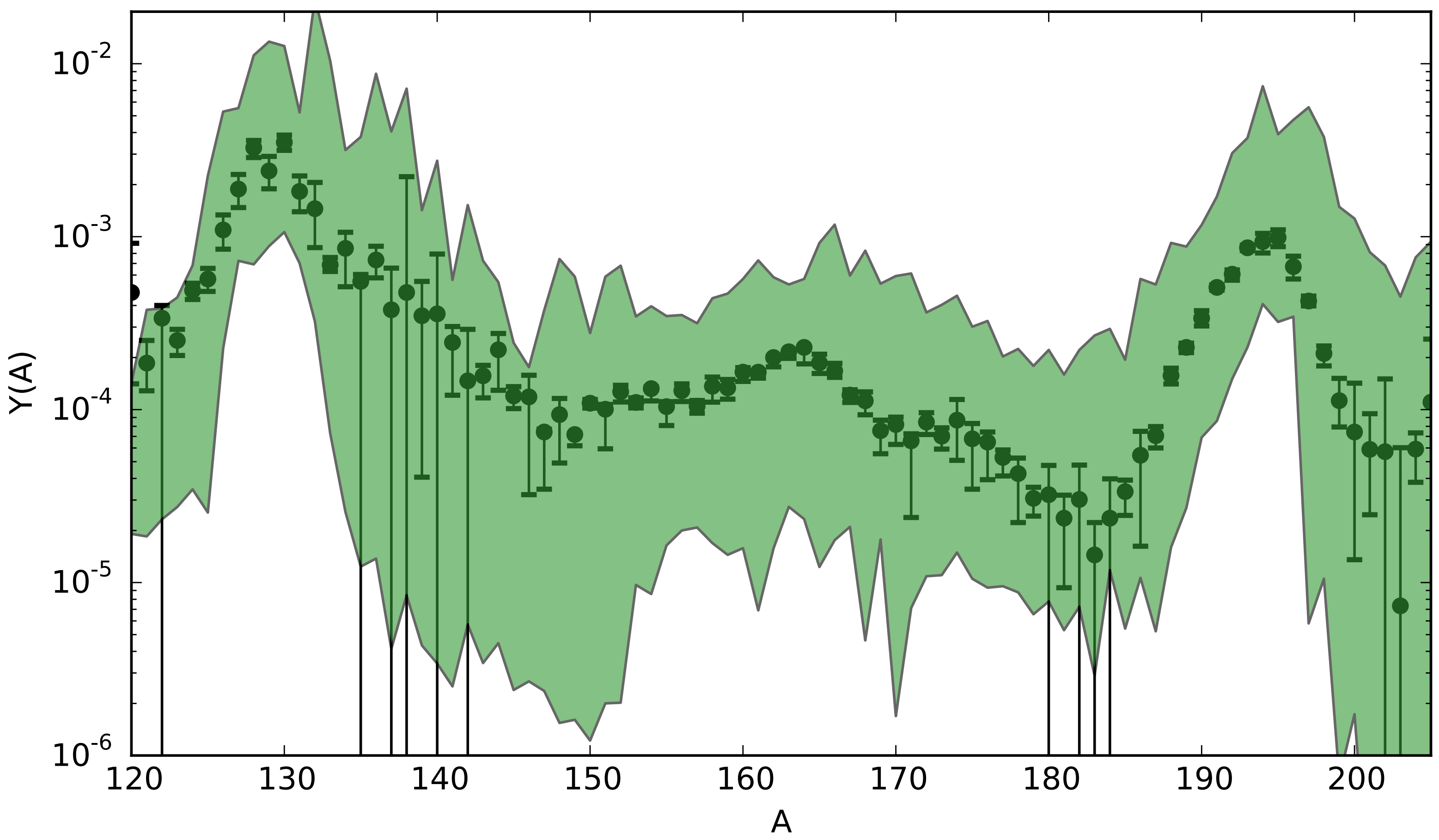
uncertainties in nuclear masses

Surman, Mumpower, Aprahamian 2016





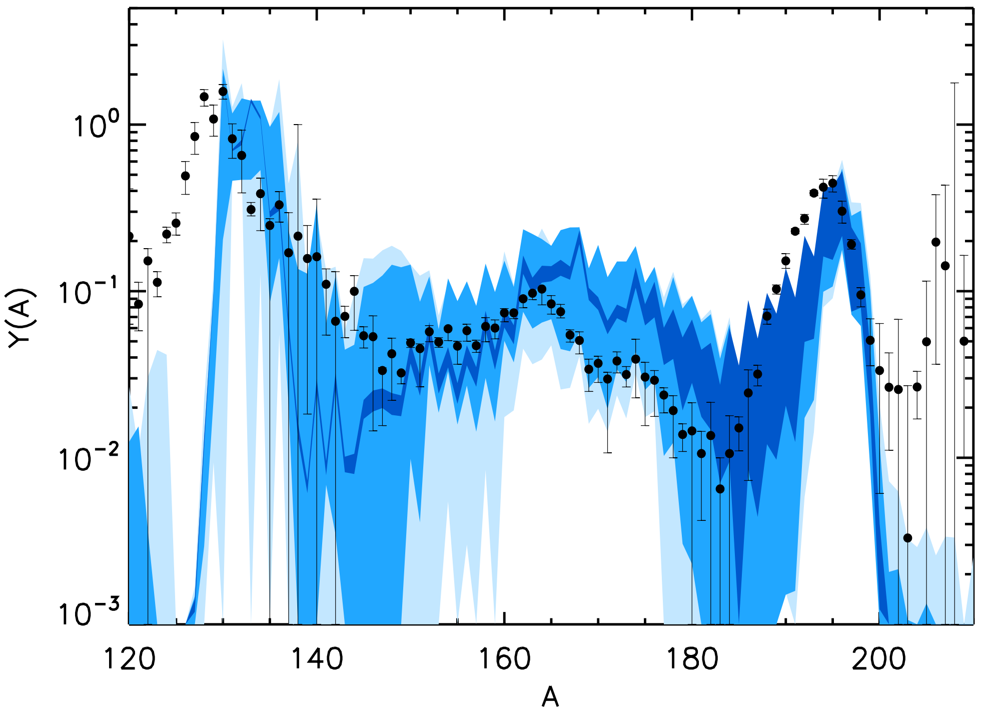
random uncorrelated uncertainties in masses: impact on *r*−process simulations

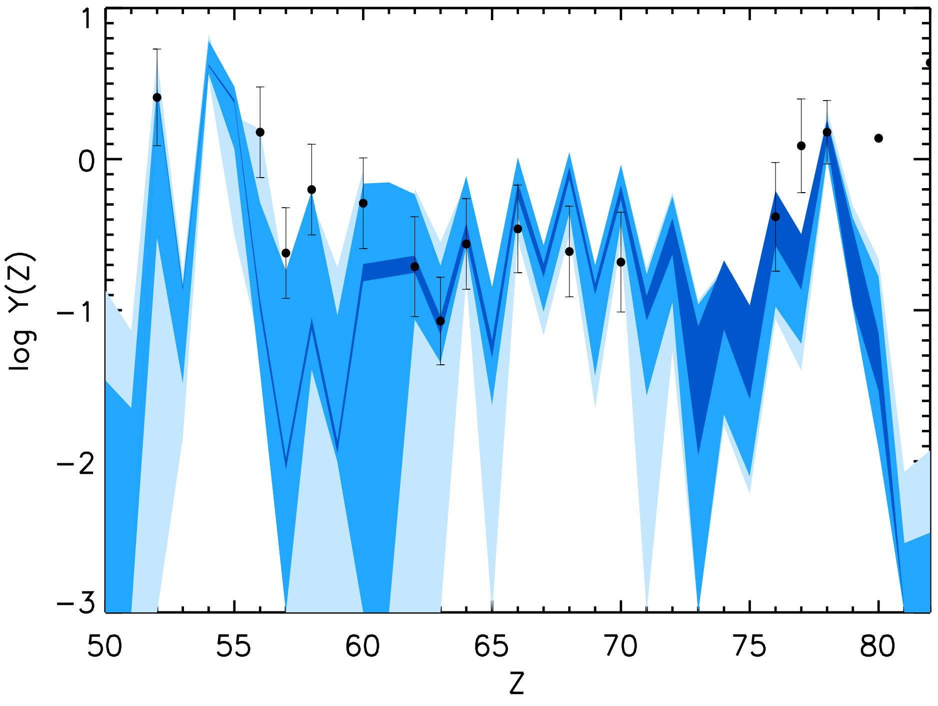


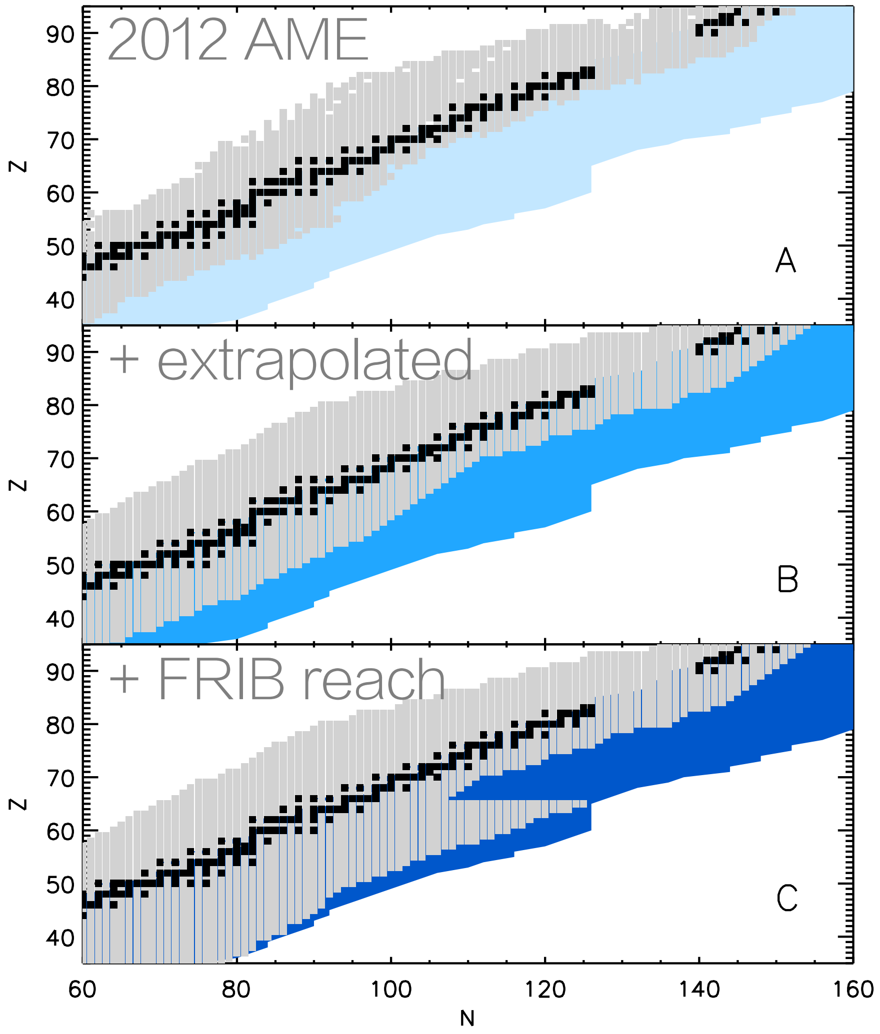
Surman, Mumpower, McLaughlin 2016

FRDM masses + Monte Carlo variations within mass model rms (~0.5 MeV)

impact of upcoming measurements







Surman, Mumpower,
Aprahamian 2016

summary

The role of compact object mergers in the synthesis of the heaviest elements is under investigation from many directions

One such avenue is through nuclear physics, where current and next–generation radioactive beam facilities will continue to push the boundaries of our knowledge of extremely neutron–rich nuclei

As nuclear physics uncertainties are reduced, we can exploit details of the *r*–process abundance pattern, such as the rare earth peak, to explore the nature of the *r*–process site

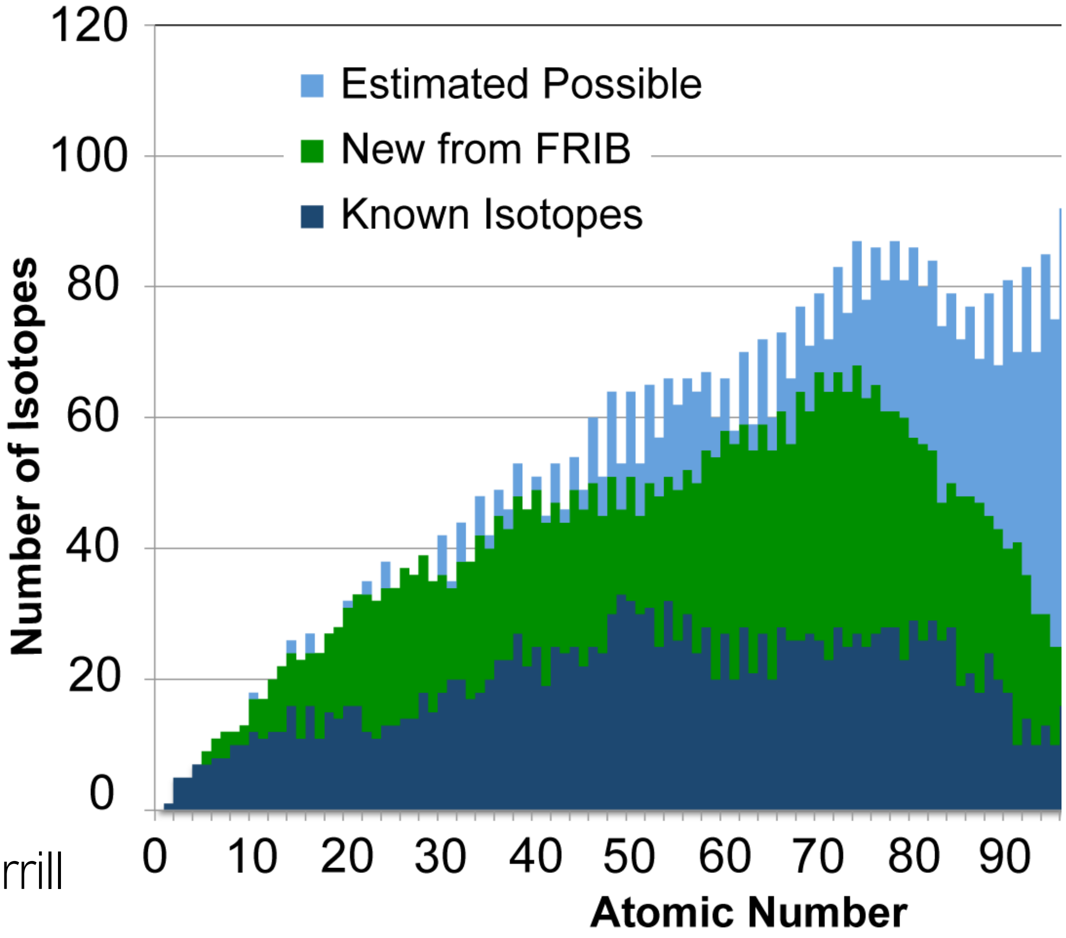


figure from B Sherrill