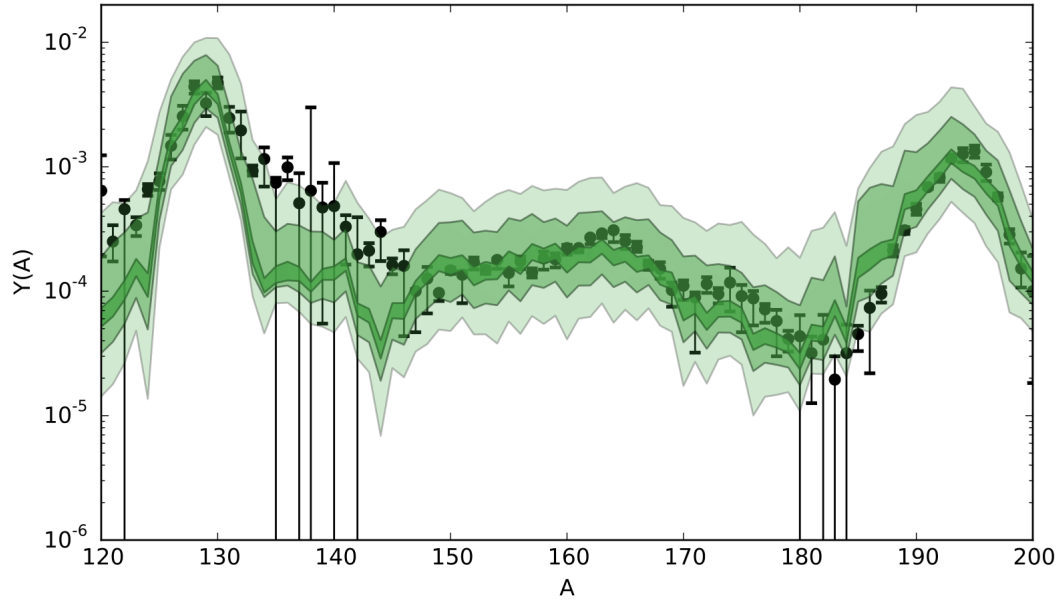
Neutron capture sensitivities in the r process



Los Alamos NATIONAL LABORATORY EST. 1943

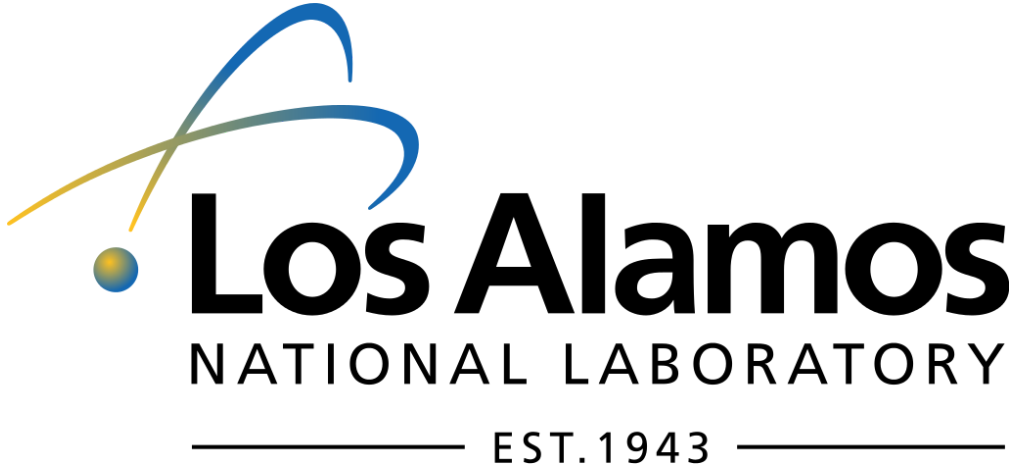
LA-UR-22-30907

MATTHEW MUMPOWER

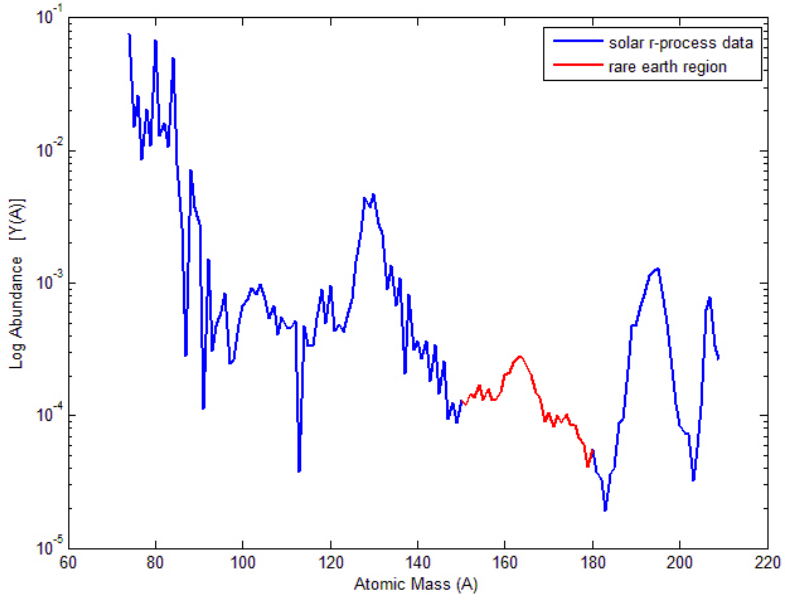
Opportunities with Neutron Induced Reaction Measurements

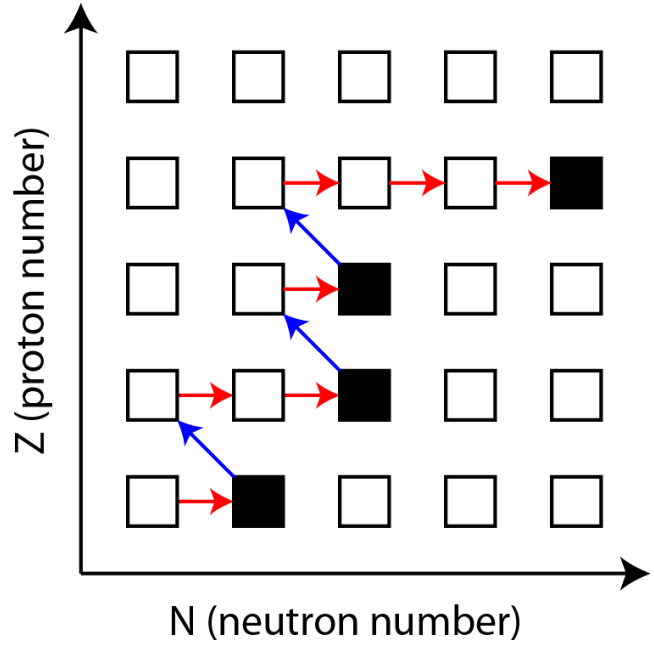
THEORETICAL DIVISION Since 1943

10/17/2022



THE RAPID NEUTRON CAPTURE PROCESS





Rapid neutron capture that occurs in astrophysical environments allowing for the production of heavy elements

Neutron captures are initially much faster than β-decays

Relative slowdown in the nuclear flow (right) produces peak structures in the observed abundances (left)

Astrophysical environment must produce a lot of free neutrons in order for this process to proceed

Horowitz ***et al.*** J Phys G 083001 (2019) • Kajino *et al.* PPNP 107 (2019) • Cowan *et al.* RMP 93 015002 (2021)

THE IMPORTANCE OF NEUTRON CAPTURE

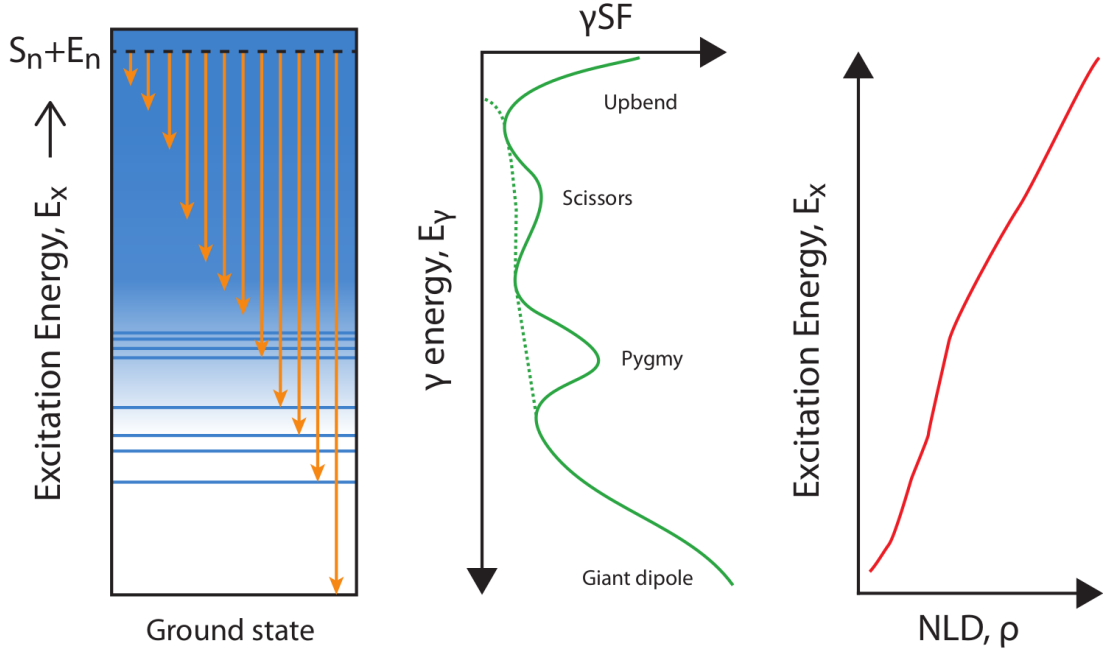
Neutron capture tells us the rate at which we move to nuclei with more N/Z

By detailed balance, they also impact photodissociation rates when $T_9 \gtrsim 1$

Density plays an important role in calculating the rate

When (n,γ) $\Leftrightarrow$ (γ,n) equilibrium breaks, individual capture rates matter!

Interplay between (n,γ), (n,2n) and (n,f) is critical for understanding nuclear flow at the extremes



Surman ***et al.*** AIP Adv 4 041008 (2014) • **Mumpower** *et al.* PRC 86 035803 (2012)

NEUTRON CAPTURE HAS THE LEAST INFORMATION OF ALL NUCLEAR DATA ENTERING INTO SIMULATIONS!

Neutron capture rates

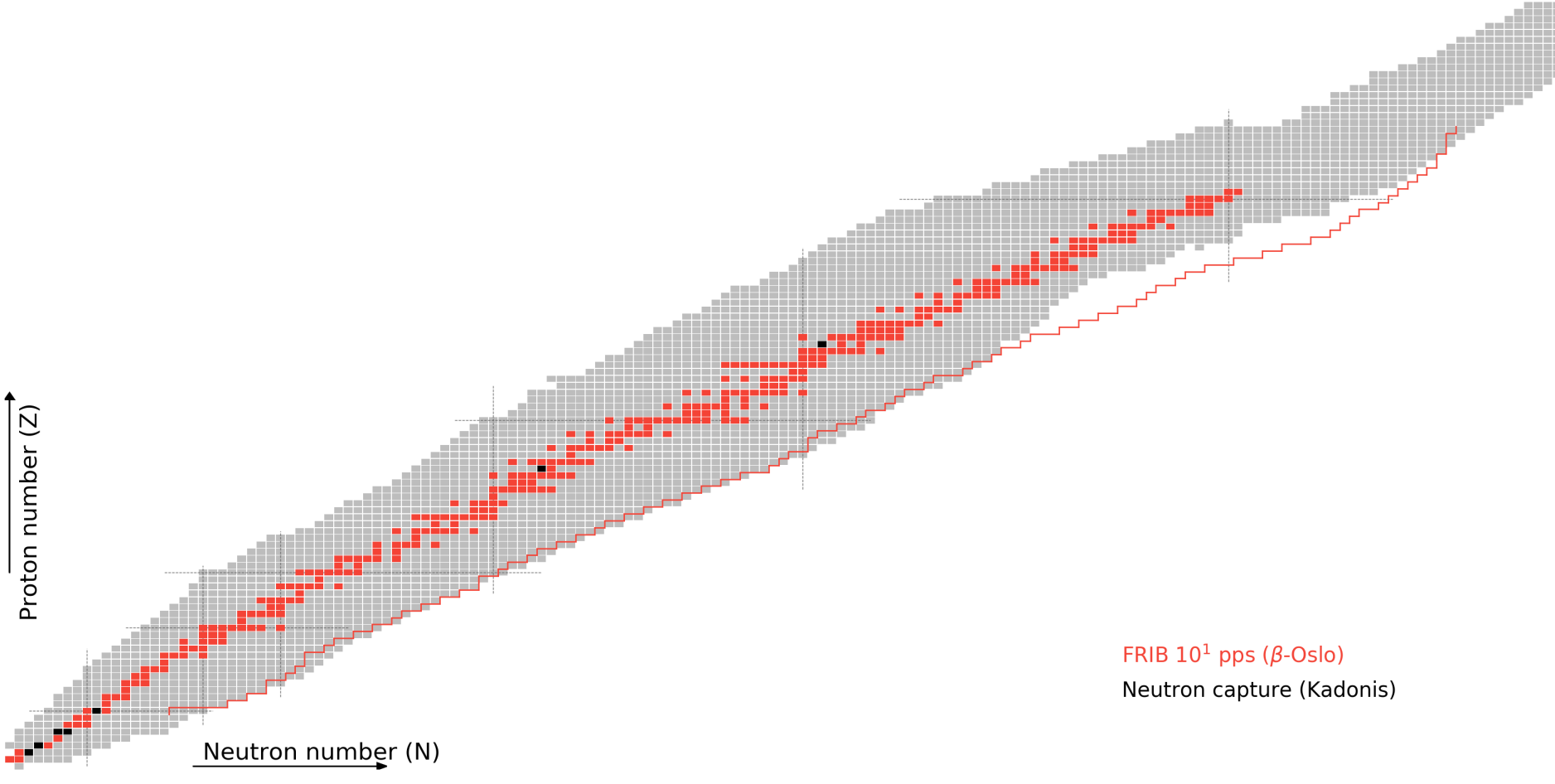
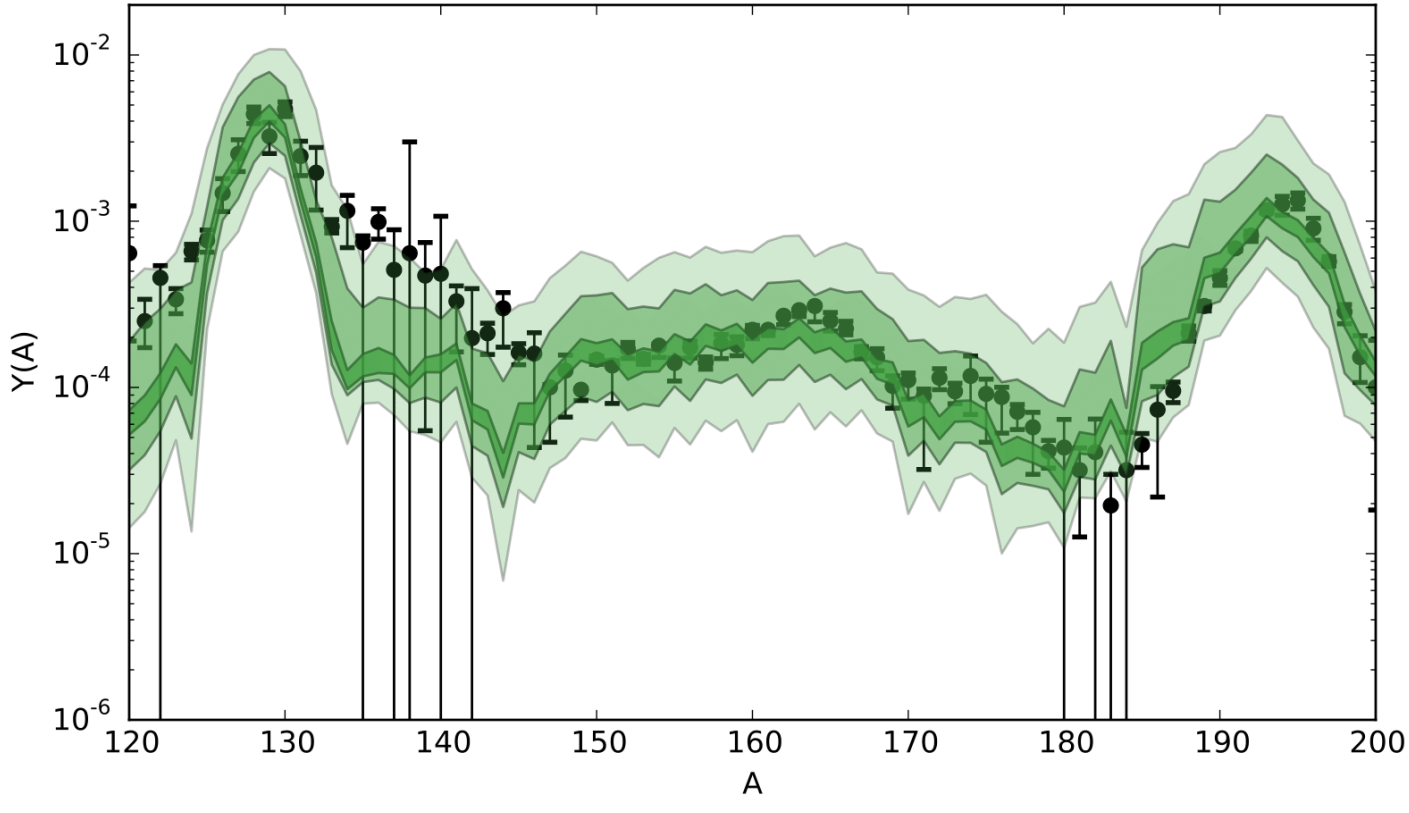


Figure by **Mumpower**

CURRENT UNCERTAINTIES FROM NEUTRON CAPTURE

It is difficult to predict abundances at a factor of 100 or 10 uncertainty (currently)



Factor uncertainty: 100 10 2

Monte Carlo variation of neutron capture rates

We can resolve abundance features once uncertainties are reduced

Liddick ***et al.*** PRL 116 242502 (2016)

WHAT NUCLEI DO WE FOCUS ON?

This isn't an easy question...

It depends on what you want to learn!

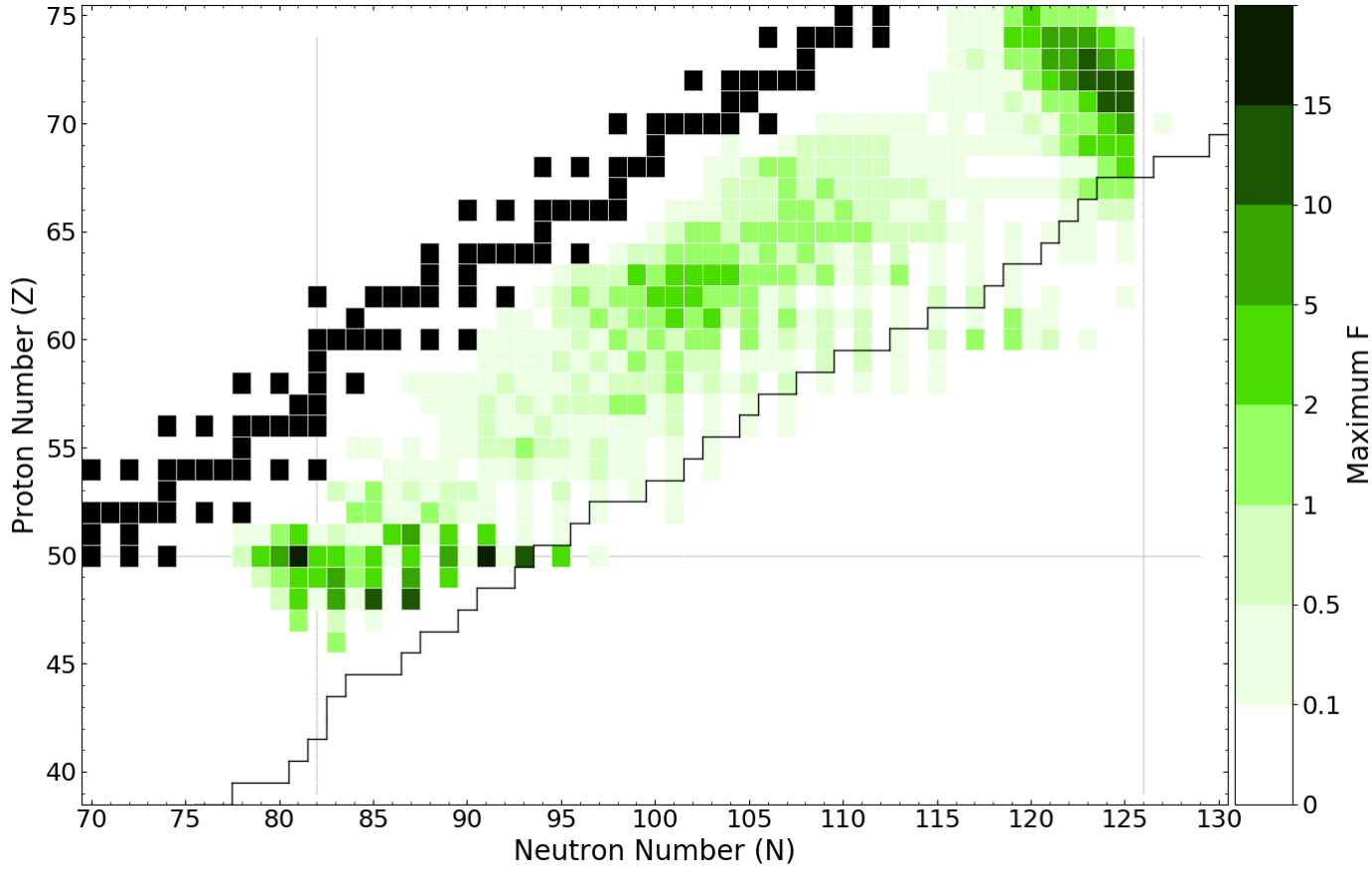
You may want to learn something about nuclear structure or underlying reaction mechanisms

Or about the formation of heavy elements

Ideally we gain information about each of these topics in a single measurement

GLOBAL SENSITVITY STUDIES

Hot wind (low entropy)

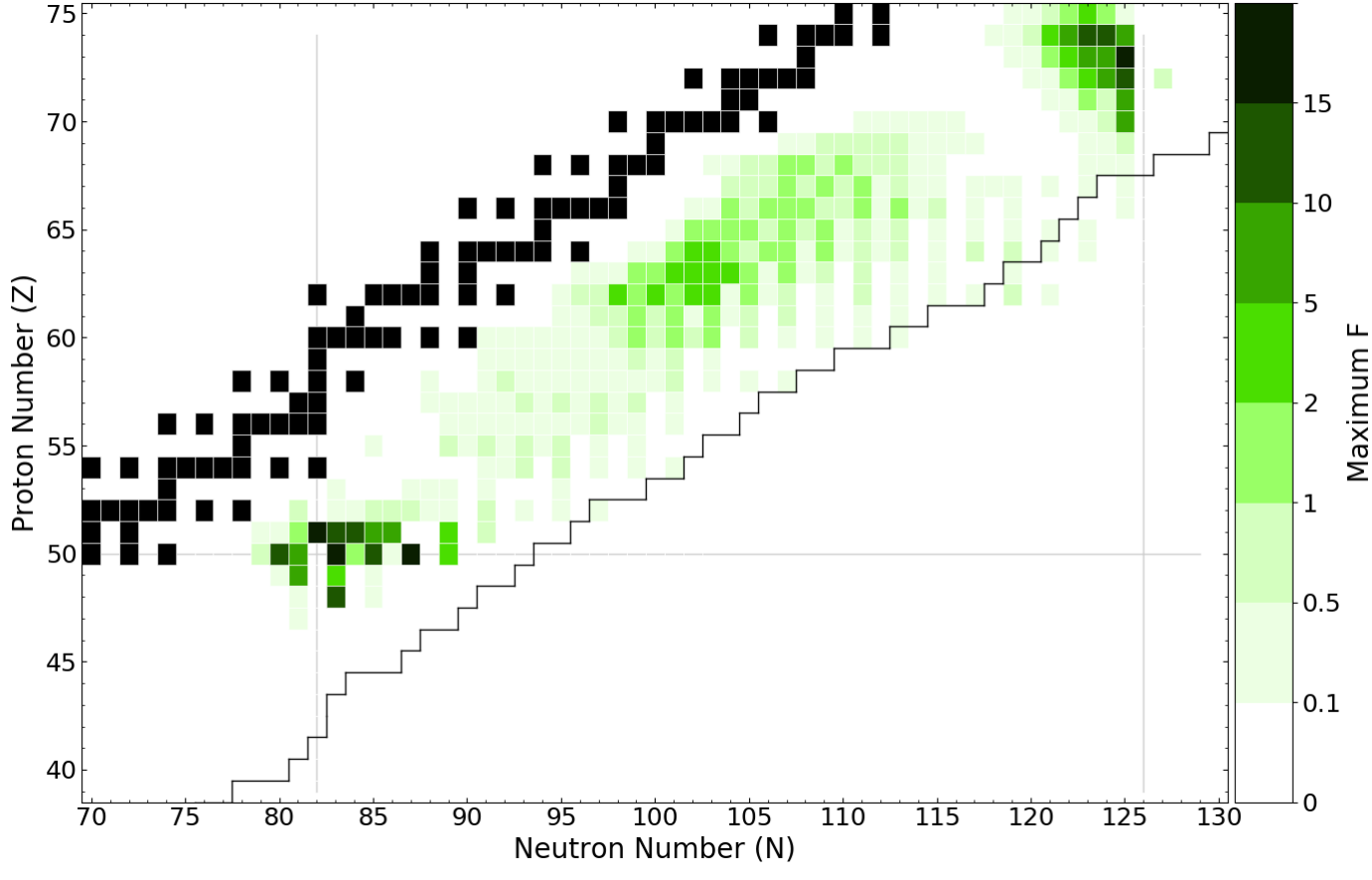


Nuclei with a large nuclear flow typically impart a global change

Mumpower *et al.* PPNP 86 (2016)

GLOBAL SENSITVITY STUDIES

Hot wind (high entropy)

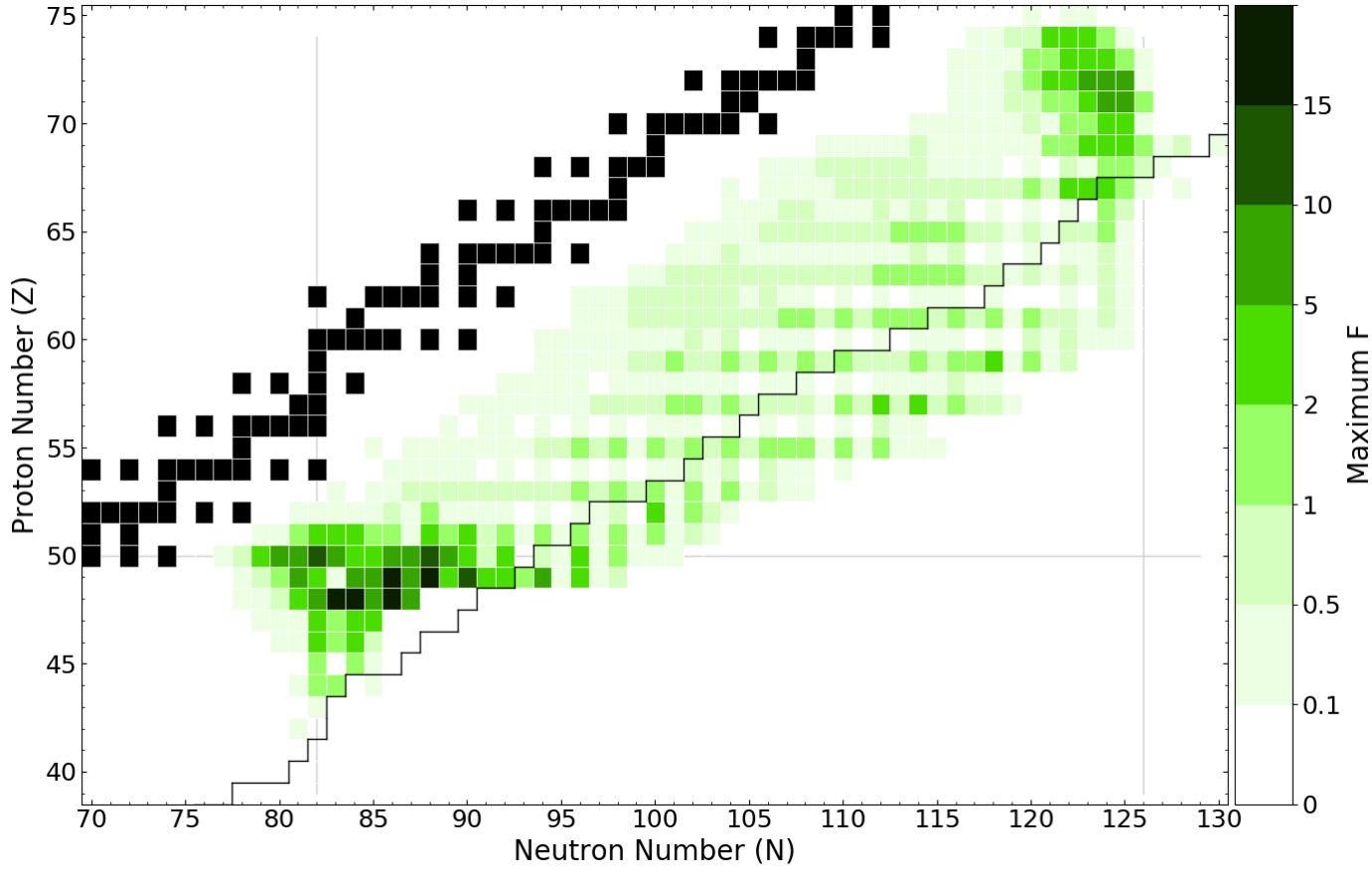


These tend to cluster around the major closed shell

Mumpower *et al.* PPNP 86 (2016)

GLOBAL SENSITVITY STUDIES

Cold wind

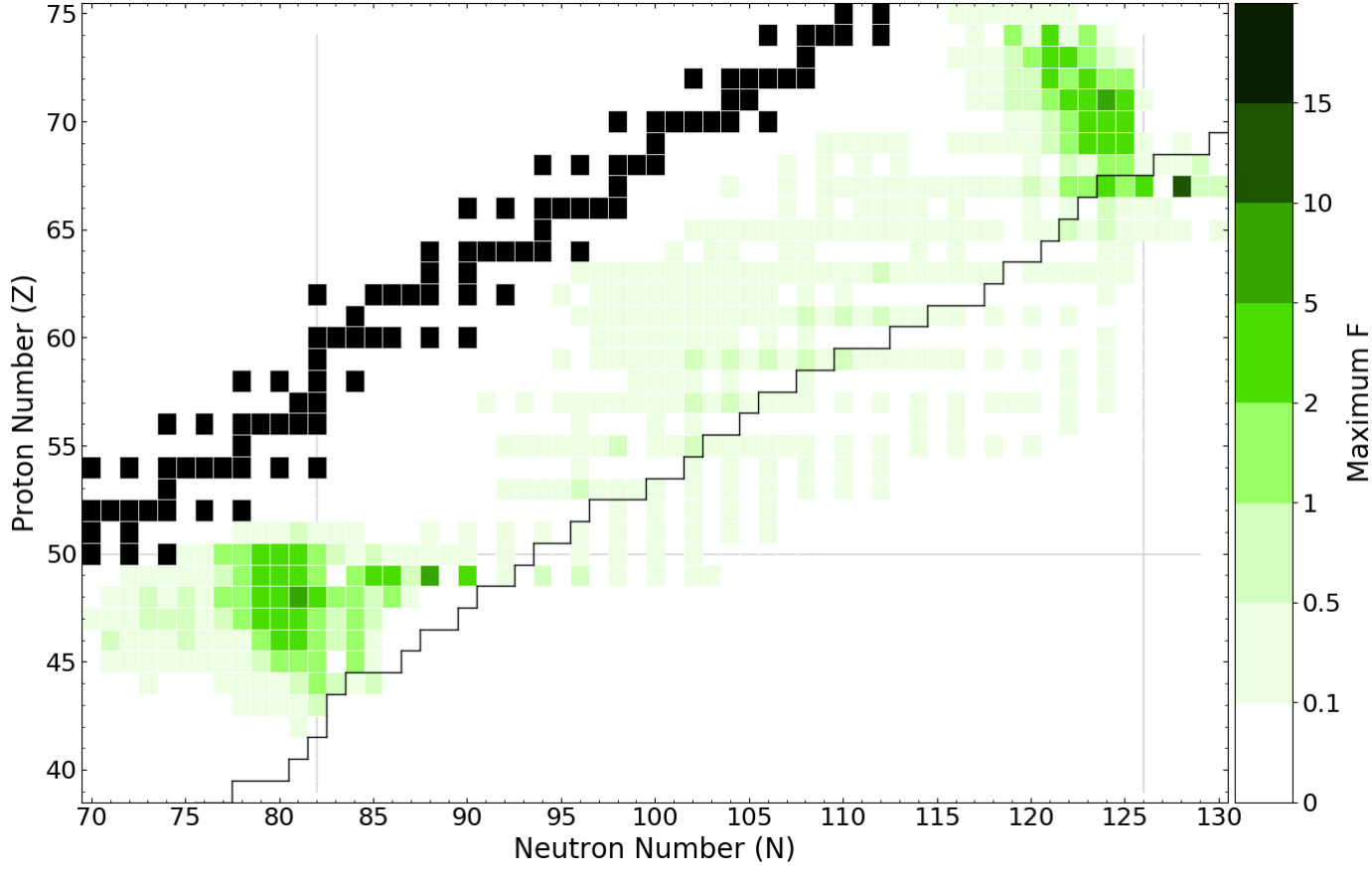


Regional changes are important for understanding isotopic ratios

Mumpower *et al.* PPNP 86 (2016)

GLOBAL SENSITVITY STUDIES

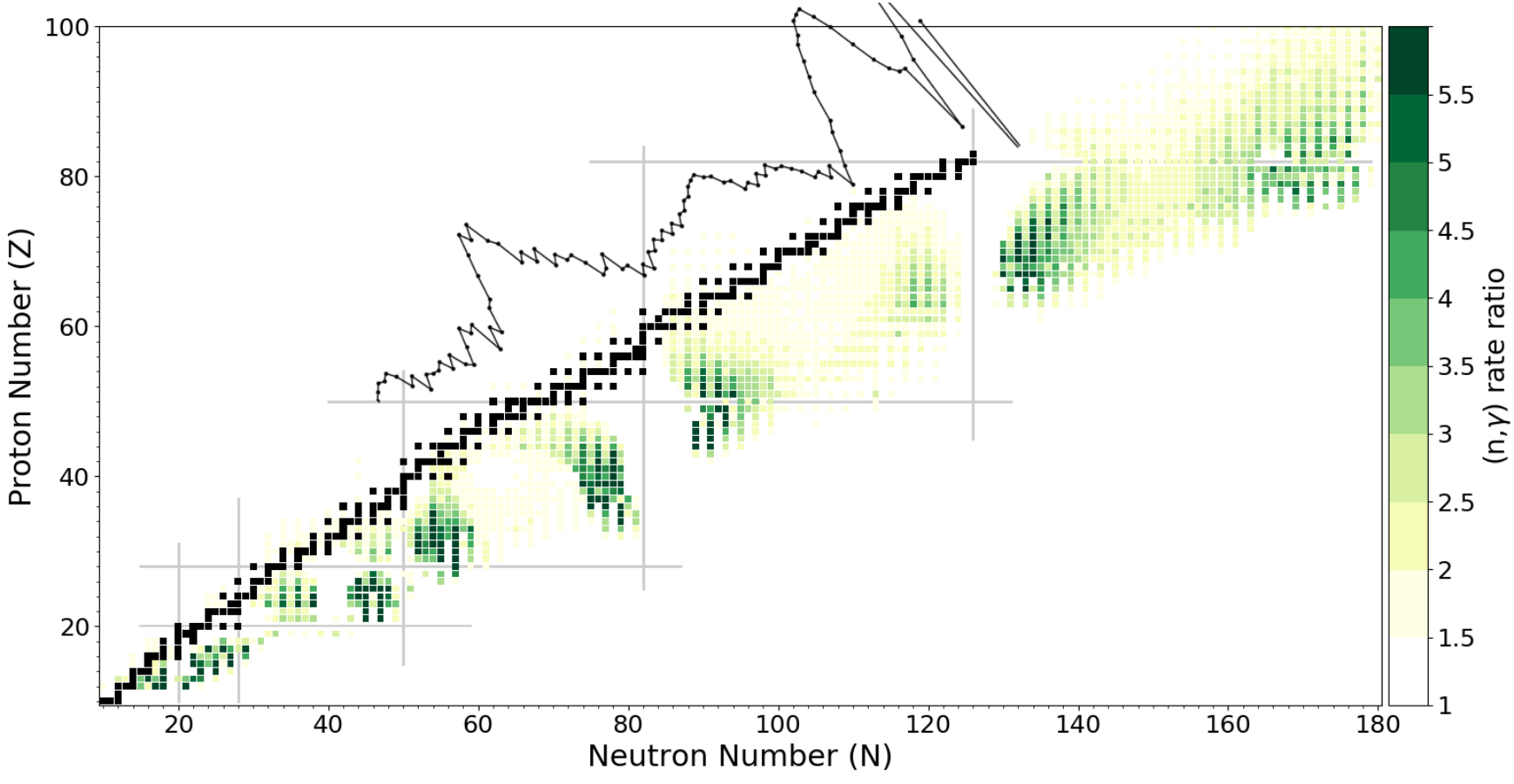
Dynamical ejecta from a neutron star merger



It is important to consider the variation in r-process conditions

Mumpower *et al.* PPNP 86 (2016)

M1 ENHANCEMENT OF CAPTURE RATES



The impact (darker color) to neutron-rich nuclei is even larger than for those near stability

An intriguing result... follows the solar isotopic pattern

Many candidates (Ce, La, Pr) and lighter elements may be within reach of future reaction studies

Ullmann *et al.* PRC 89 034603 (2014) • **Mumpower** *et al.* PRC 96 024612 (2017)

FUTURE NEUTRON FACILITIES

Researchers should seek to balance the opportunity cost between:

Measurements which can teach us about structure / reaction mechanisms

Measurements which provide insight into the operation of nucleosynthesis processes

Measurements that can suss out important trends that may be extrapolated

Such a facility would be invaluable for:

Scientific applications (e.g. s, i, r processes in astrophysics)

Nuclear energy

National security

It is important to remember that nuclear data is correlated; see e.g. Kiss ***et al.*** ApJ 936 107 (2022)

New information on neutron-induced reactions will also impact insights into other nuclear properties (potentially in unpredictable ways)

See Shea Mosby's talk regarding MORDOR