NUCLEAR LEVEL DENSITIES AND γ-STRENGTH FUNCTIONS IN ASTROPHYSICS

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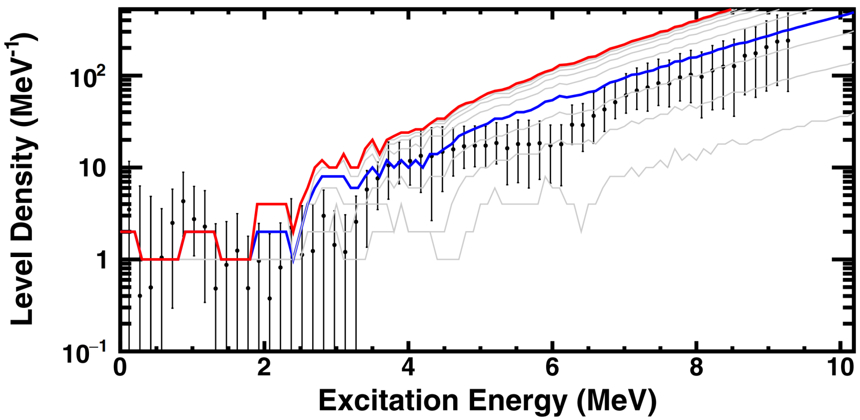
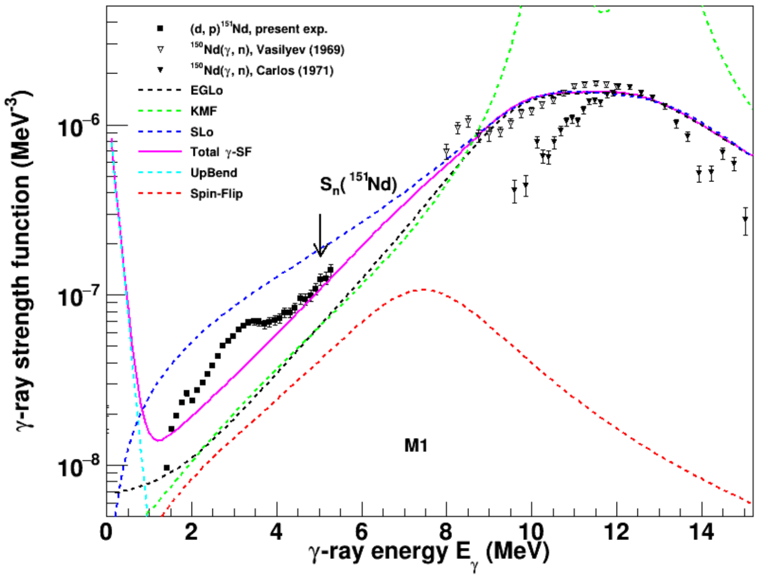
CTA Center for Theoretical ASTROPHYSICS

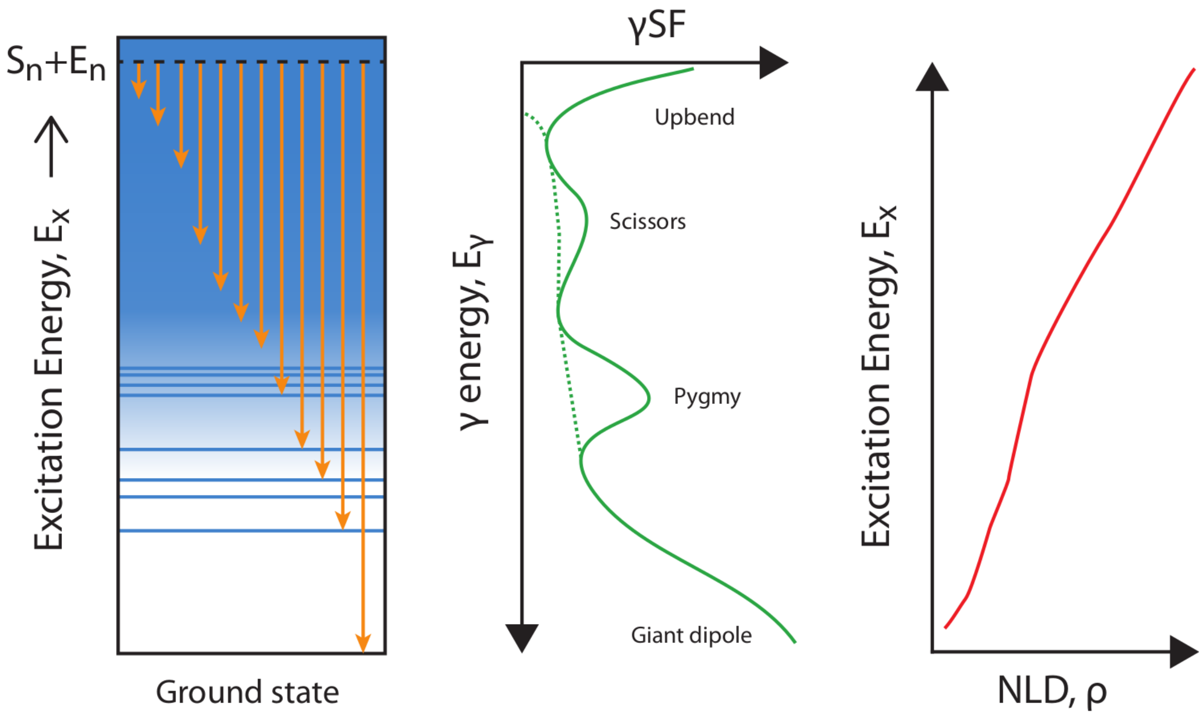
LEVEL DENSITY & γSF





Top figure from D. Soltesz *et al.* PRC 103 015802 (2021) • Bottom figure from K. O. Ay *et al.* J. Phys. Conf. Ser. 766 012027 (2016)

RADIATIVE NEUTRON CAPTURE



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

Key components: Optical potential • γ-ray strength function (γSF) • Nuclear Level Density (NLD)

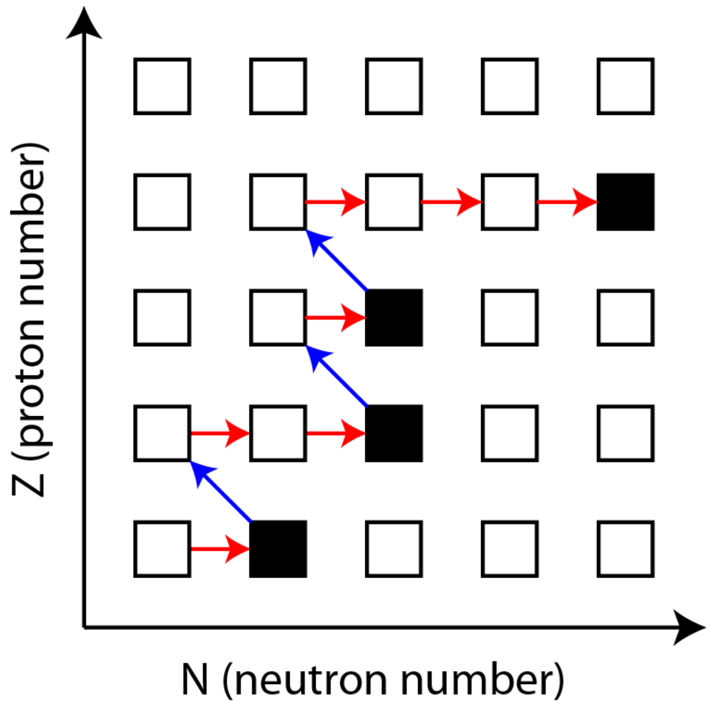
See e.g. Kawano *et al.* PRC 94 014612 (2016) • T. Kawano arXiv:1901.05641 (2019)

IN WHAT ASTROPHYSICAL PROCESSES IS THIS INFO USED?

s-process: neutron capture rates are slow relative to β-decay; $\tau_n \gg \tau_\beta$

r-process: neutron capture rates are fast relative to β-decay; $\tau_n \ll \tau_\beta$

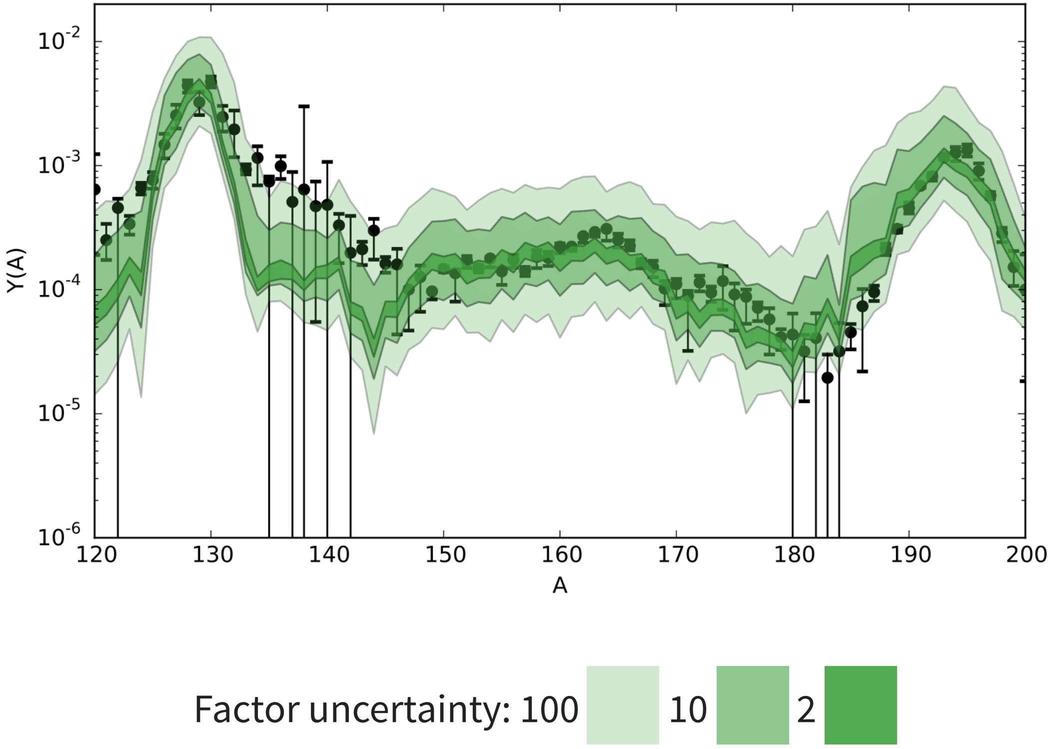
Possibly other environments as well...



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

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

WHERE ARE WE AT WITH CURRENT UNCERTAINTIES?

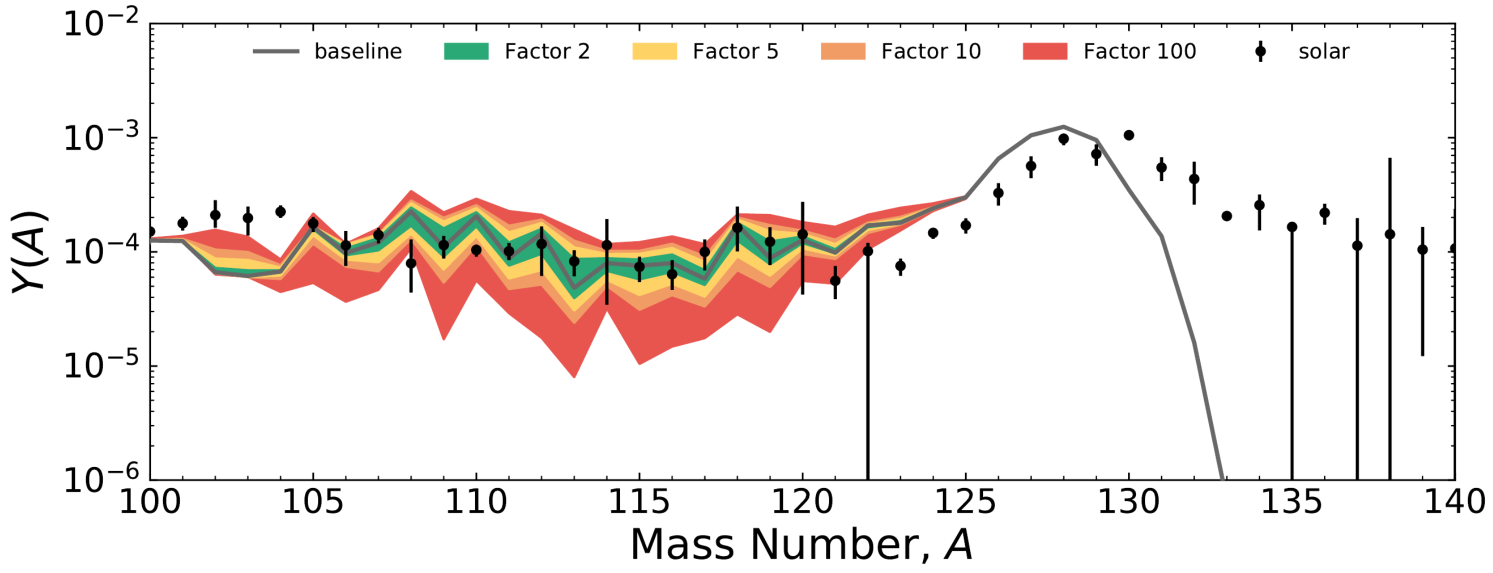


Monte Carlo variation of reaction rates for all nuclei out to the dripline

Current uncertainties likely around an order of magnitude (or more) far from stability

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

WHERE ARE WE AT WITH CURRENT UNCERTAINTIES?



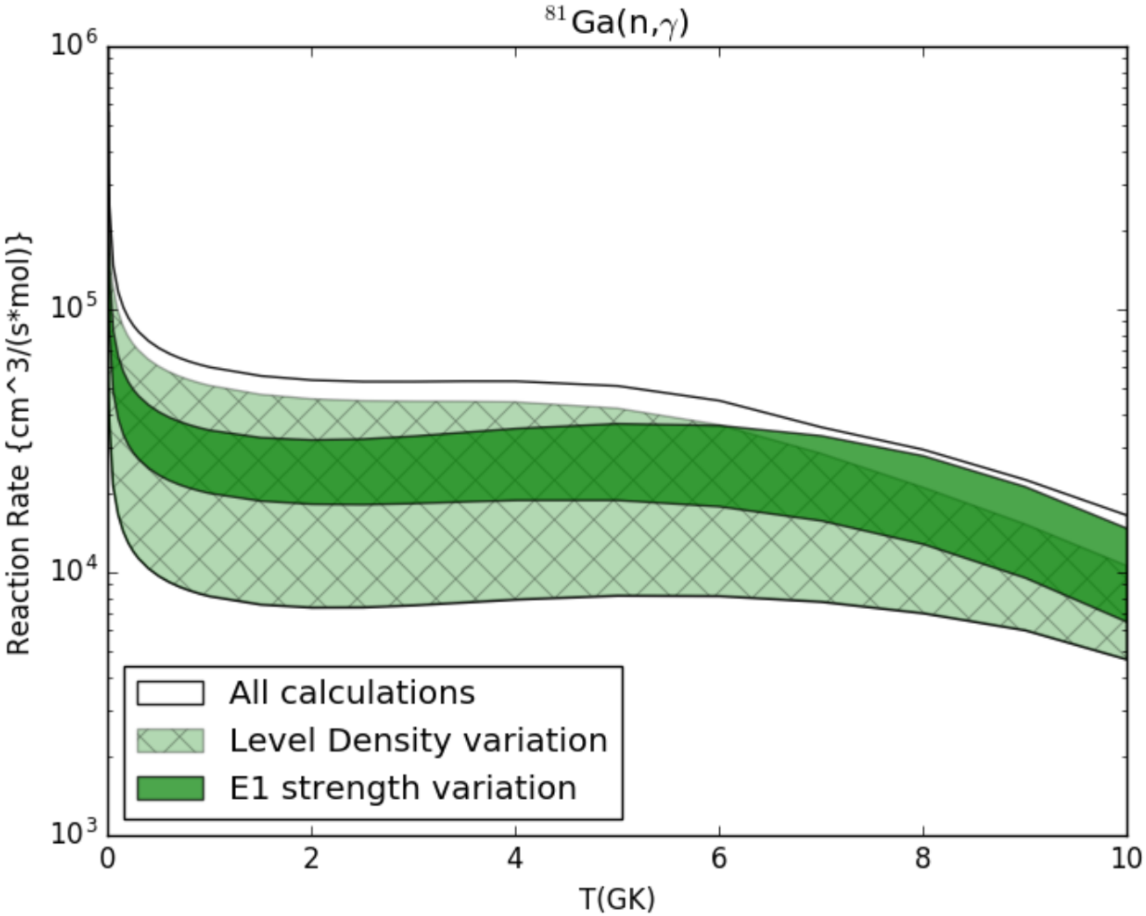
Selection of Monte Carlo'd capture rates between N=65 and N=75

Current uncertainty conclusions hold even in other (less neutron-rich) conditions - weak r-process

We can only resolve abundance features once uncertainties are reduced

Unpublished calculation by **Mumpower** (2019)

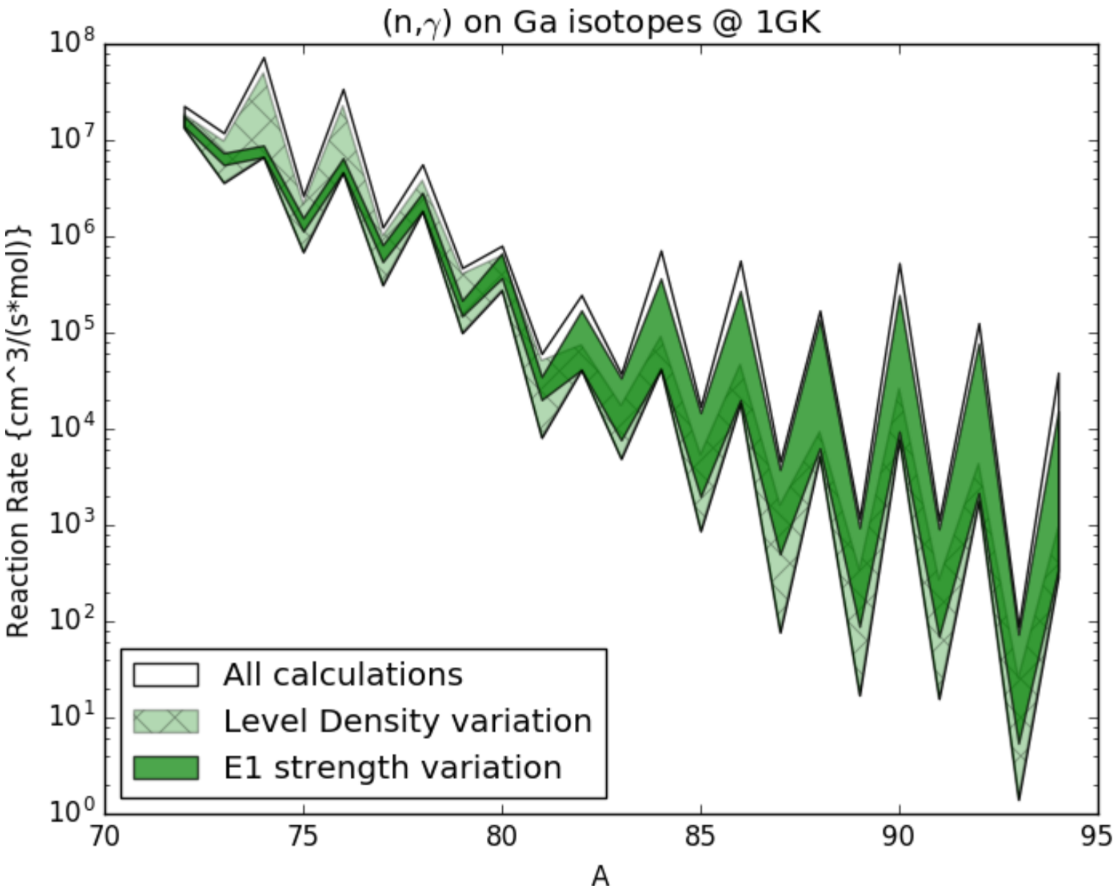
VARIATION OF NLD & γSF



What if we Monte Carlo the NLD or γSFs themselves instead of the resultant rates?

Nikas ***et al.*** arXiv:2010.01698 (2019)

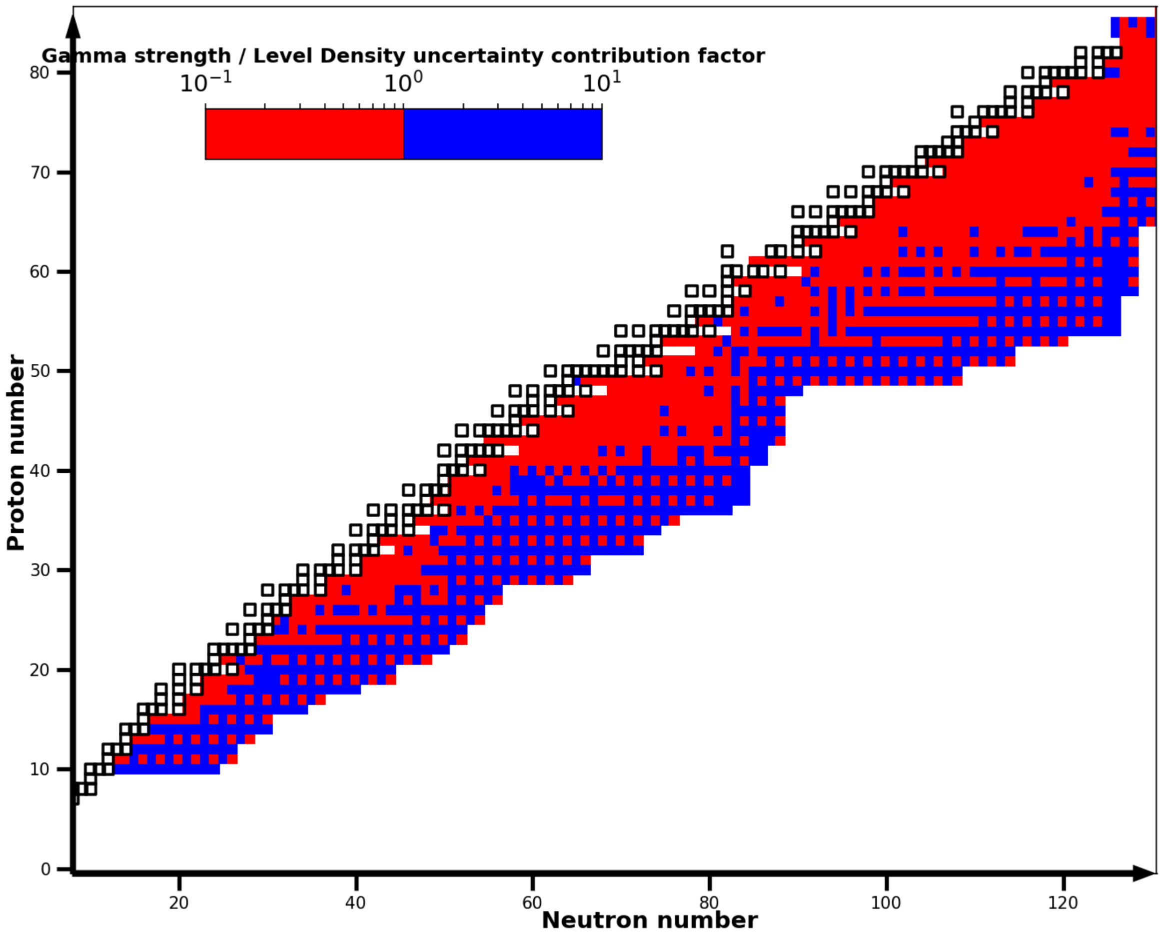
VARIATION OF NLD & γSF



Monte Carlo variation along an isotopic chain

Nikas ***et al.*** arXiv:2010.01698 (2019)

WHICH MODEL HAS THE MOST IMPACT?

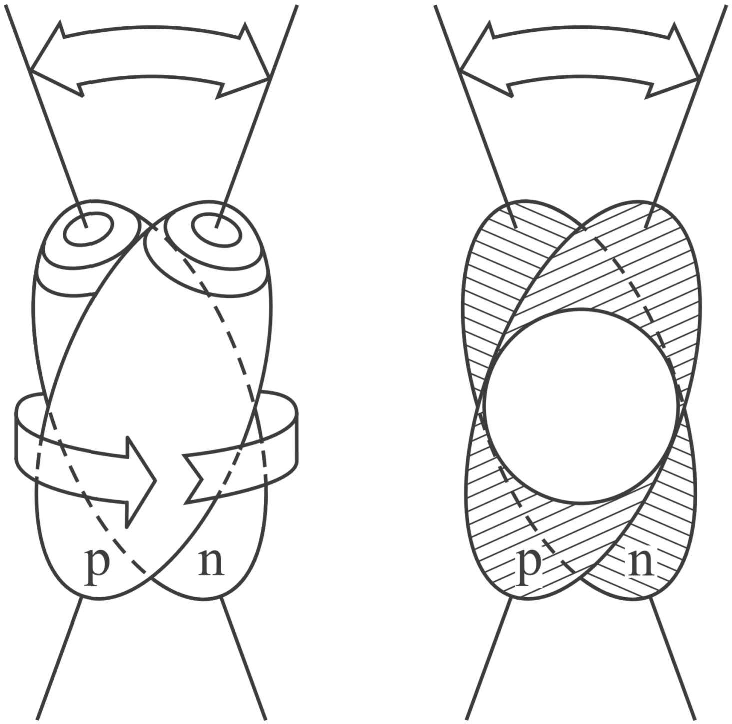


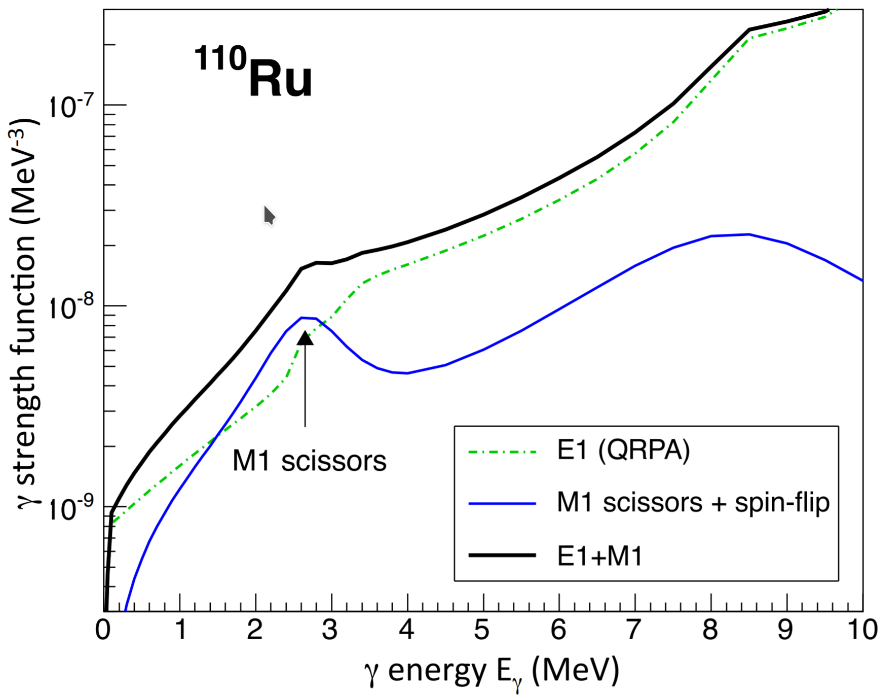
Note the trend: NLD matters closer to stability while γSF has more influence further from stable isotopes

Nikas ***et al.*** arXiv:2010.01698 (2019)

M1 SCISSORS MODE

Magnetic dipole excitation in nuclei



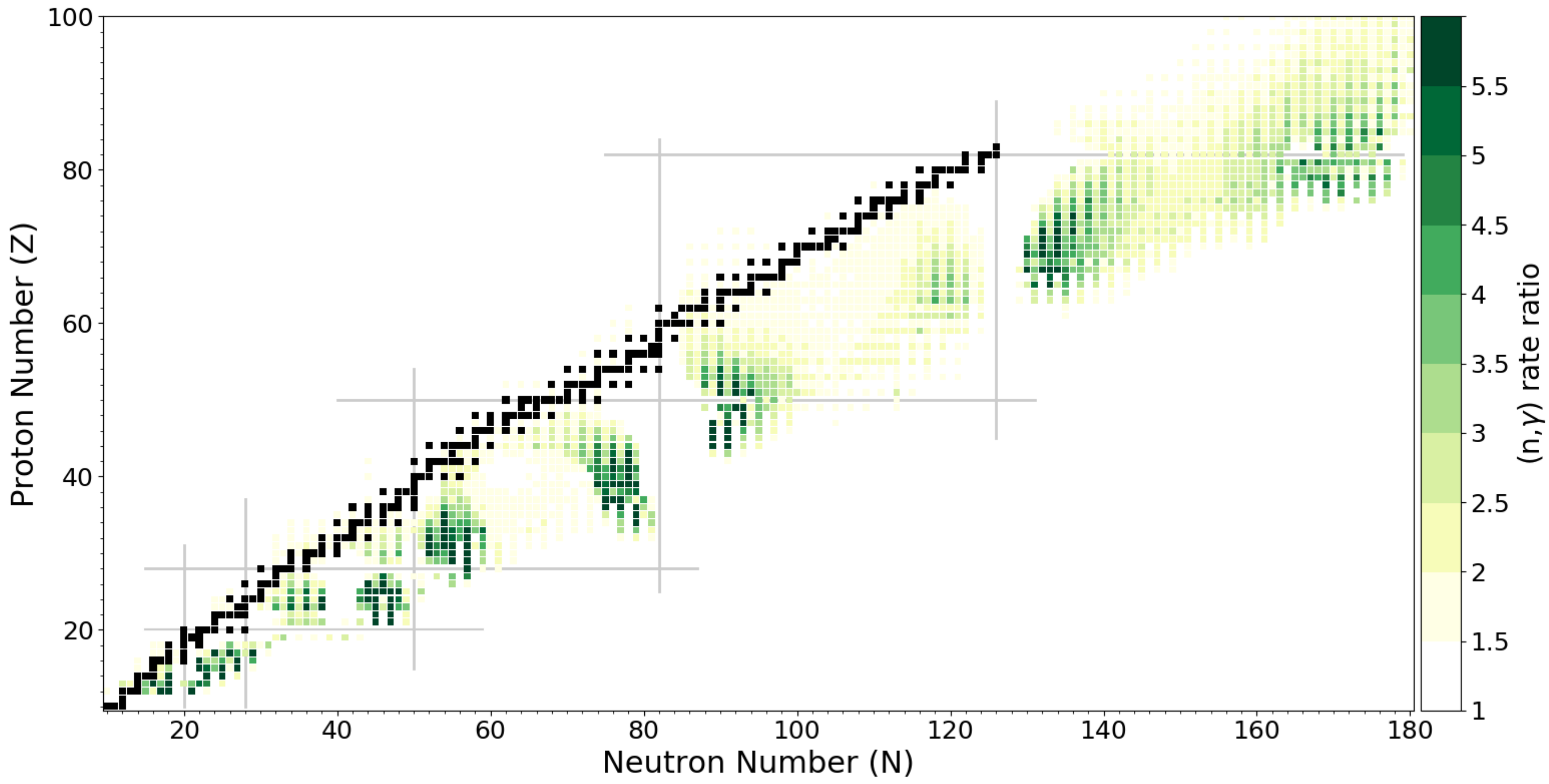


Proposed from the study of theoretical geometric models in the late 1970's

First observed experimentally in the mid 1980's using photon scattering

(left) figure from Heyde *et al.* Rev. Mod. Phys. 82 2365 (2010) • (right) figure from Larsen *et al.* Acta Phys.Polon. B46 (2015)

M1 ENHANCEMENT IN NEUTRON-RICH NUCLEI

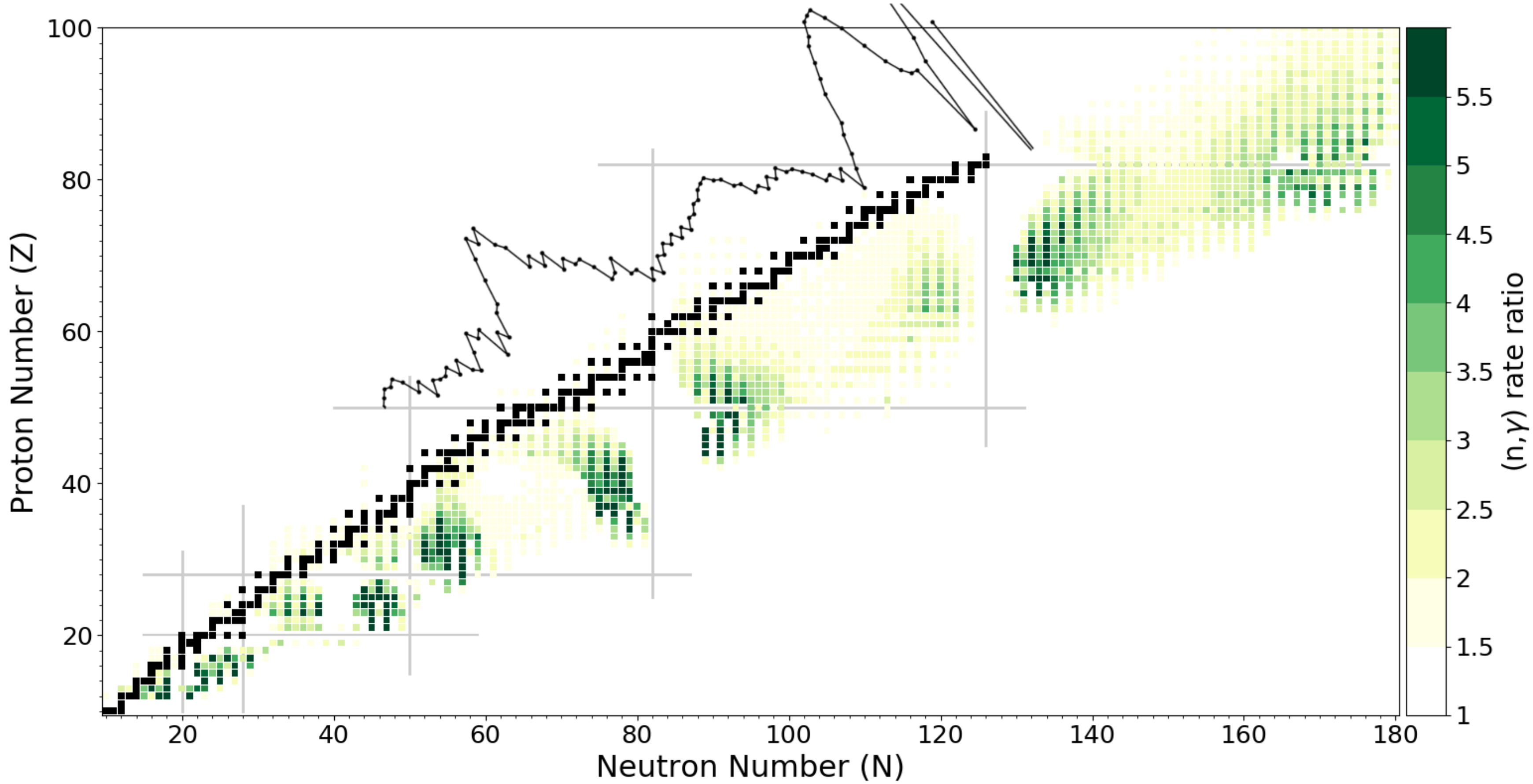


The maximum enhancement is found in transition regions

An intriguing result...

Mumpower *et al.* PRC 96 024612 (2017)

M1 ENHANCEMENT IN NEUTRON-RICH NUCLEI



The impact to neutron-rich nuclei is even larger than at stability

An intriguing result... Follows the solar isotopic pattern

Mumpower *et al.* PRC 96 024612 (2017) • See the new work of H. Sasaki

SUMMARY

Nuclear level densities and γ-strength functions play a crucial role in radiative capture

Nucleosynthetic outcomes (abundances) depend sensitively on the model assumptions of NLDs and γSFs

Modeling suggests a ~1 order of magnitude uncertainty in abundance patterns from rate variations with factor >10

Monte Carlo studies (Nikas *et al.*) suggest that NLDs are most influential close to stability while γSFs are most influential further from stability

Details of behavior of these models (e.g. M1) also impact astrophysical outcomes

Opportunity to apply more microscopic-based modeling (with suitable normalizations to known data) can help the situation, but funding is needed to support such endeavors

Learn more @ https://matthewmumpower.com