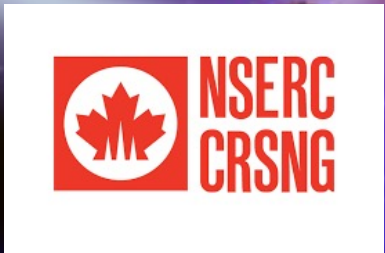


*Nuclear data for astrophysics
(in neutron-rich environments)*



Nicole Vassh

TRIUMF Theory Group

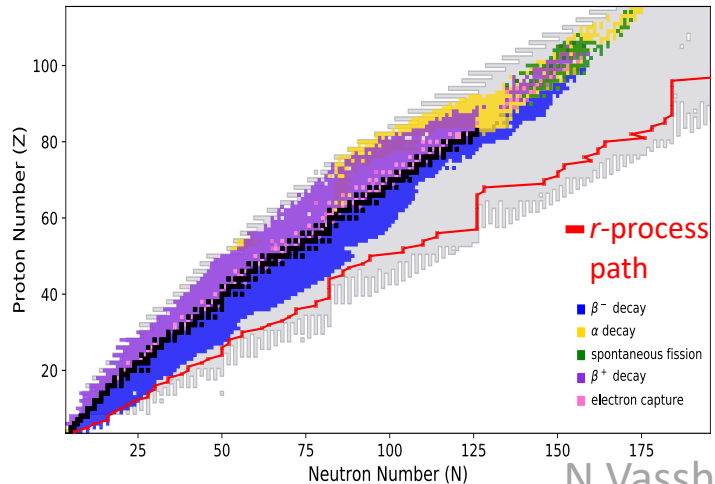
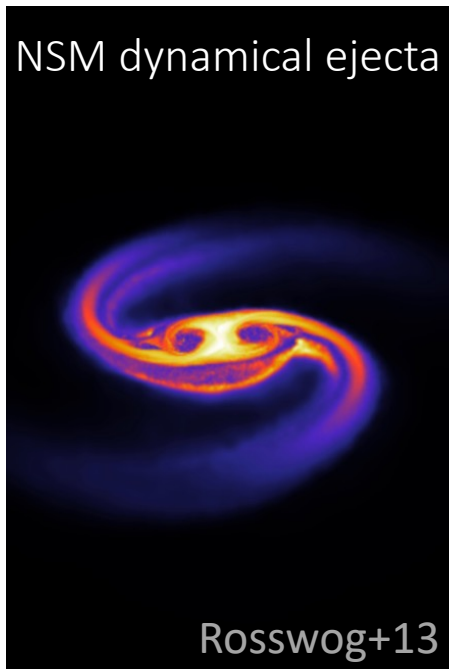
NSAC Long Range Plan Town Hall

Argonne National Laboratory

November 15, 2022

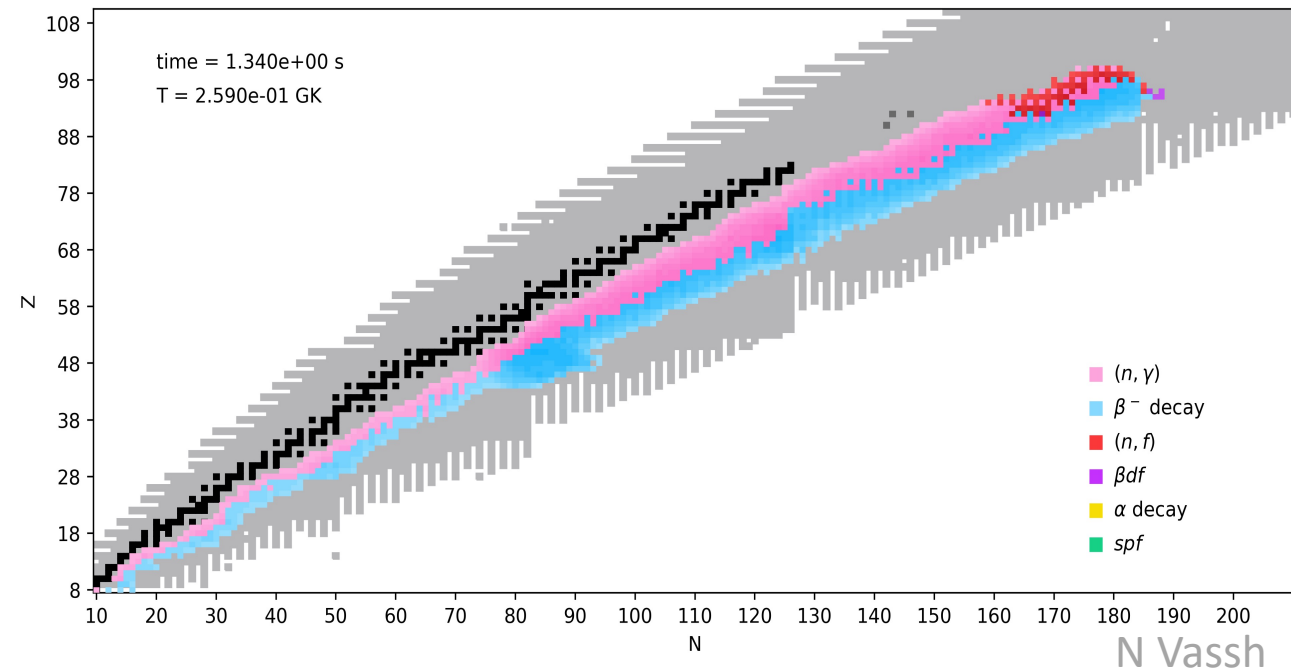
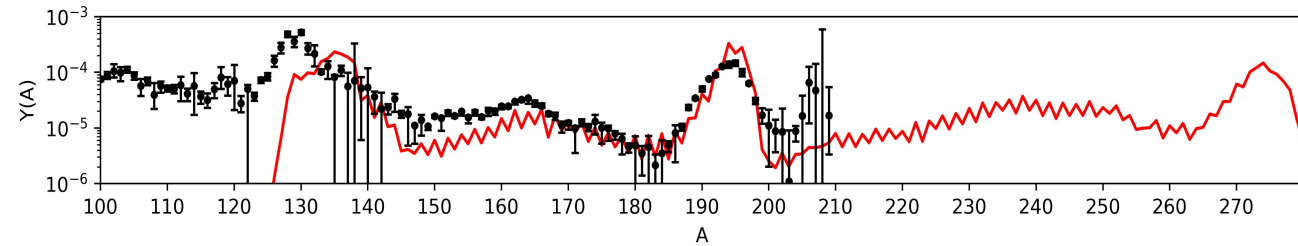
How nucleosynthesis codes work / post-processing

Hydrodynamic simulations provide us with a “trajectory”:
density / temperature / radius
as a function of time



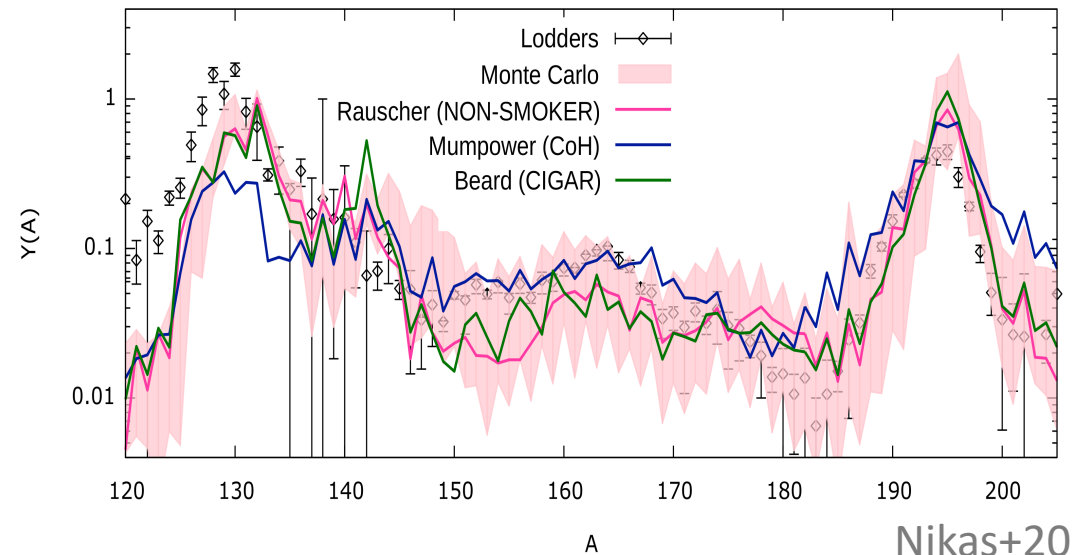
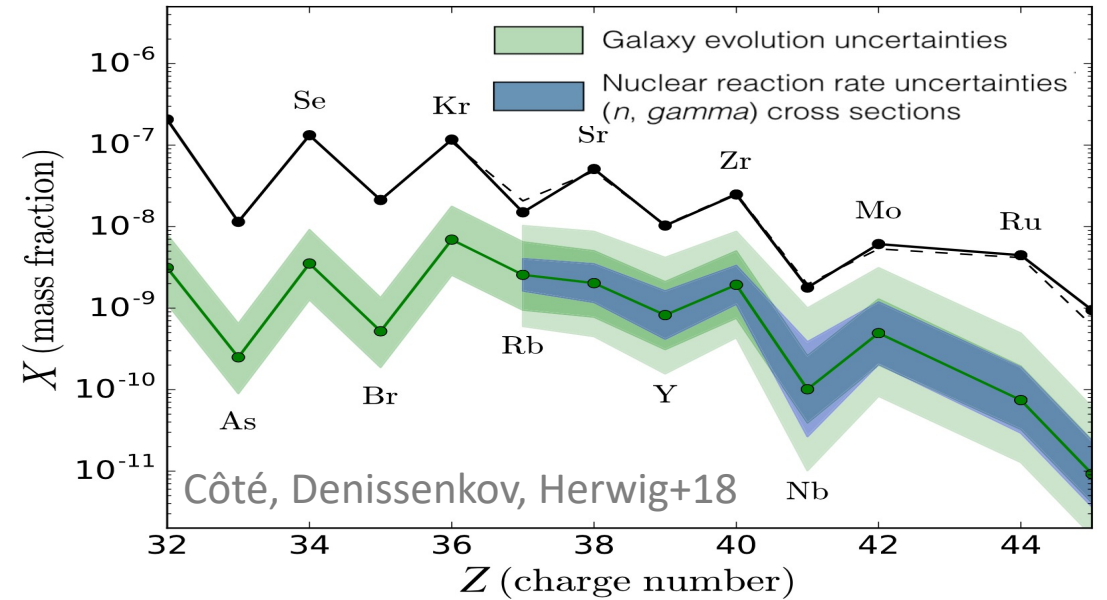
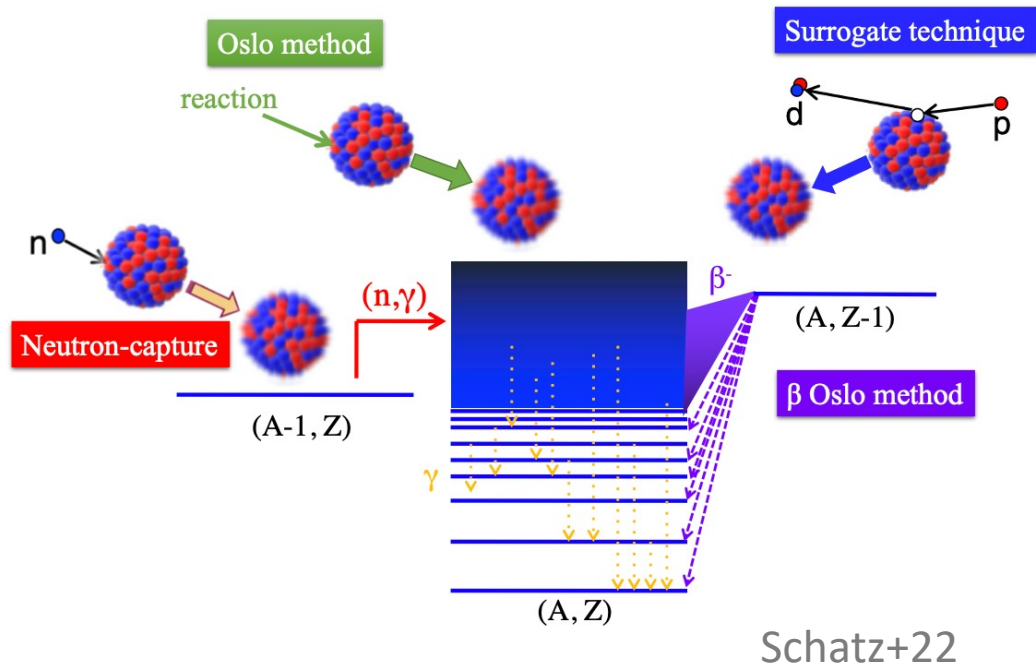
Both experimental + theoretical nuclear data input: reaction rates (temp grid), all decay rates with branching ratios taken into account, nuclear masses, fission rates (temp grid), fission yields and prompt neutrons

- Standard outputs include final abundances (Y), $Y(t)$, and “flows” (rate \times abundance) as a function of time
- The need for nuclear data is not isolated to the data run by the nucleosynthesis network:** outputs are post-processed further to evaluate nuclear heating, light curves, gamma spectra...



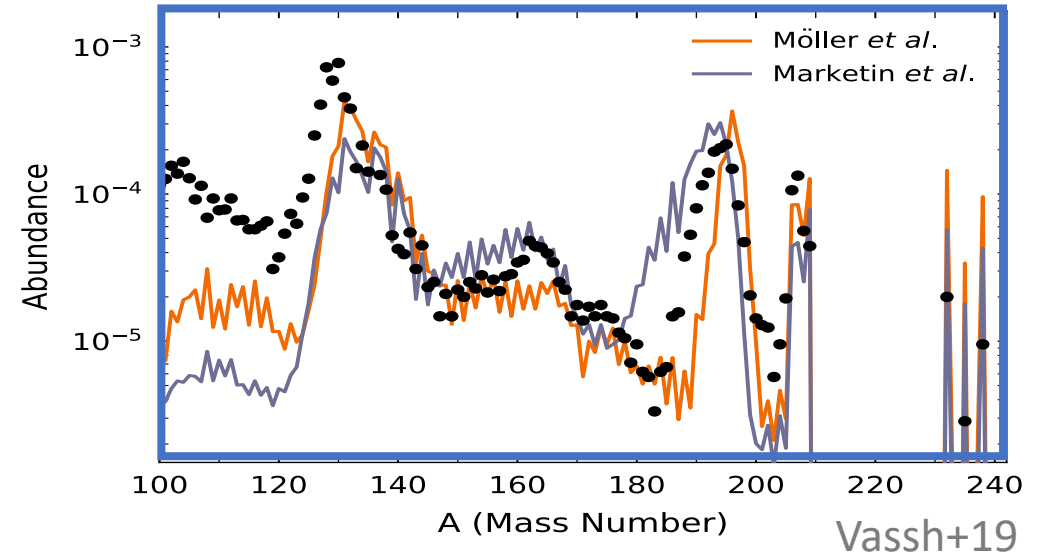
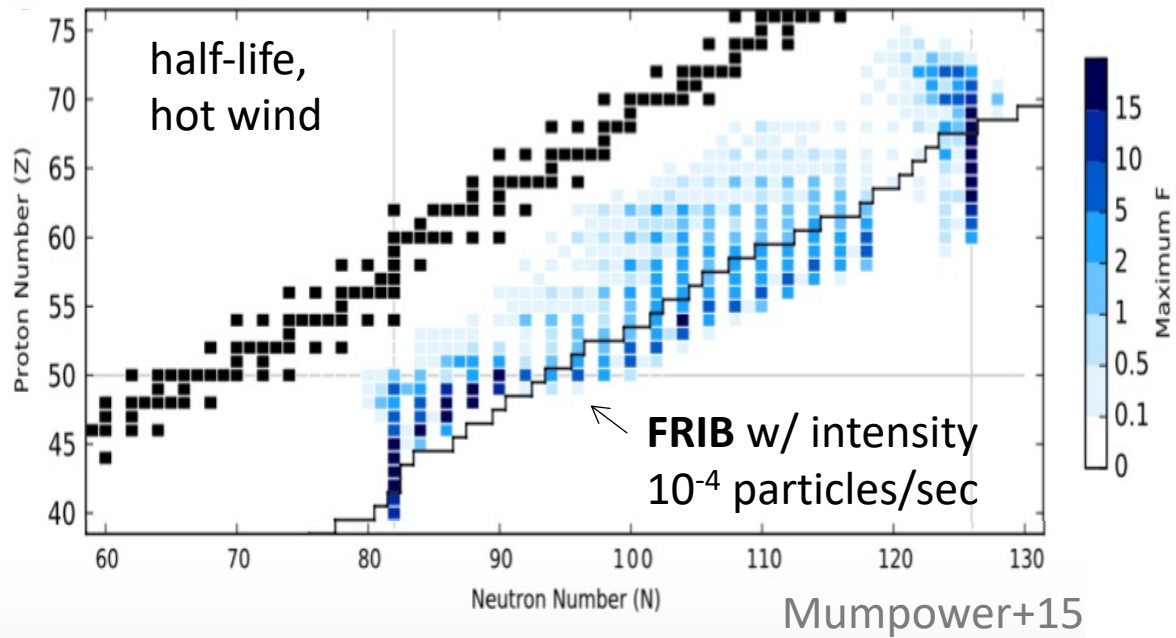
Spotlight on neutron capture

Studies examining variations in theoretical γ -strength functions and nuclear level densities show the large impact of (n,γ) rate uncertainties on astrophysical neutron capture processes (*i*-process and *r*-process)

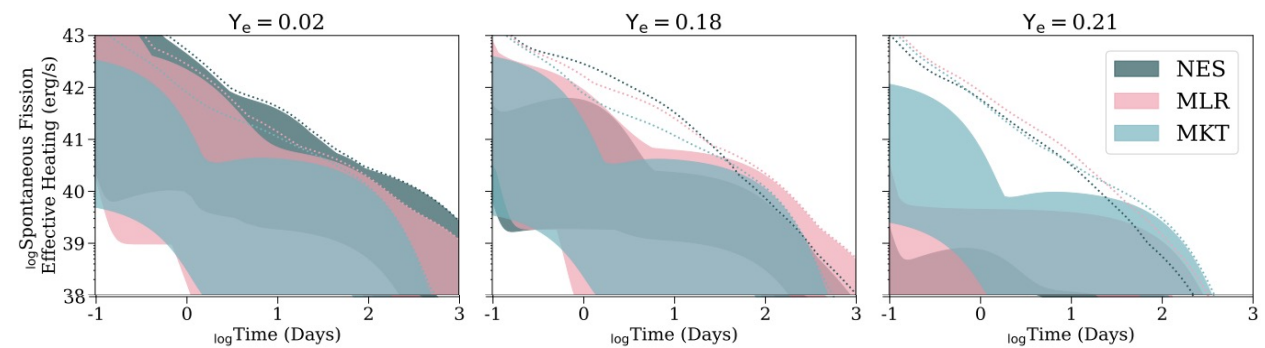


Spotlight on β -decay

r-process calculations sensitive to:
 β -strength functions, Q_β -values, half-lives, P_n
 values, and β -gamma spectra

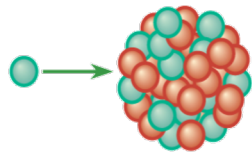


Heating rates for NSM light curves given three β -decay models

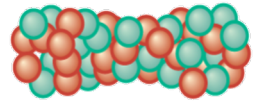


Fission in the *r*-process exemplifies the diversity of data needs for nuclear astrophysics

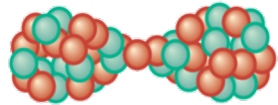
Incident neutron strikes



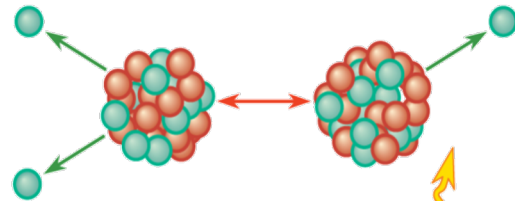
Deformation



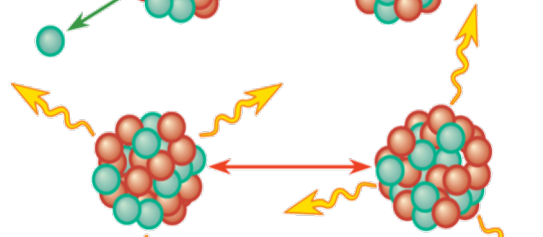
Scission



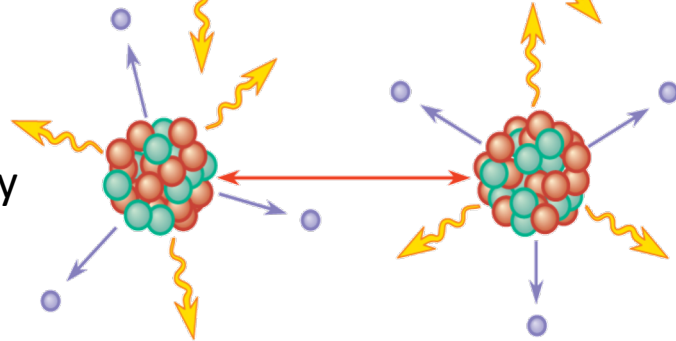
Prompt Neutron Emission from excited fission fragments (~2-3)



Energy release ~200 MeV with kinetic energy of fragments ~170 MeV



Delayed emission from β -decay of n-rich fission products



Incident neutron strikes

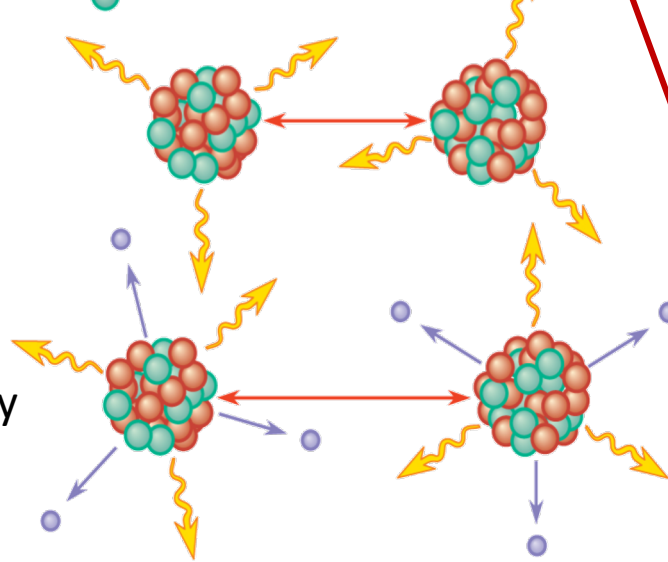
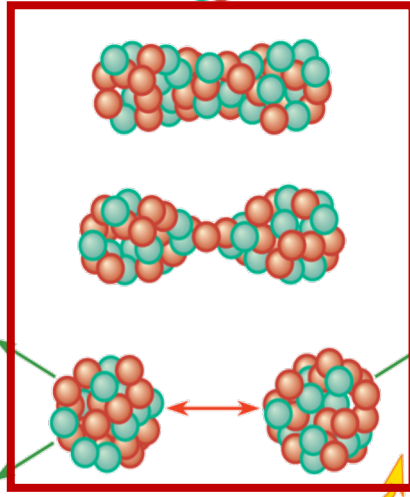
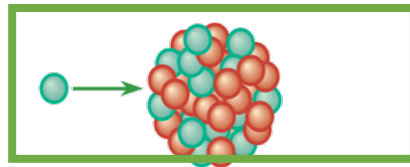
Deformation

Scission

Prompt Neutron Emission from excited fission fragments (~2-3)

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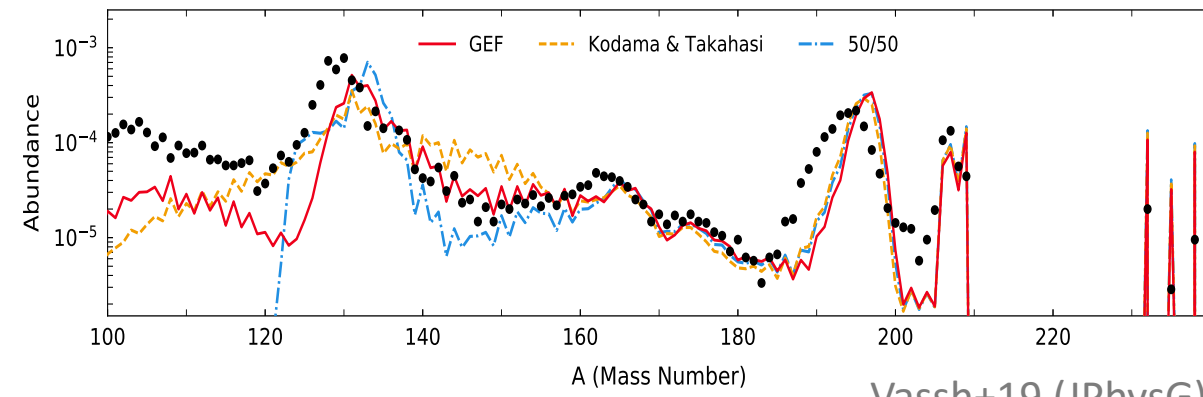
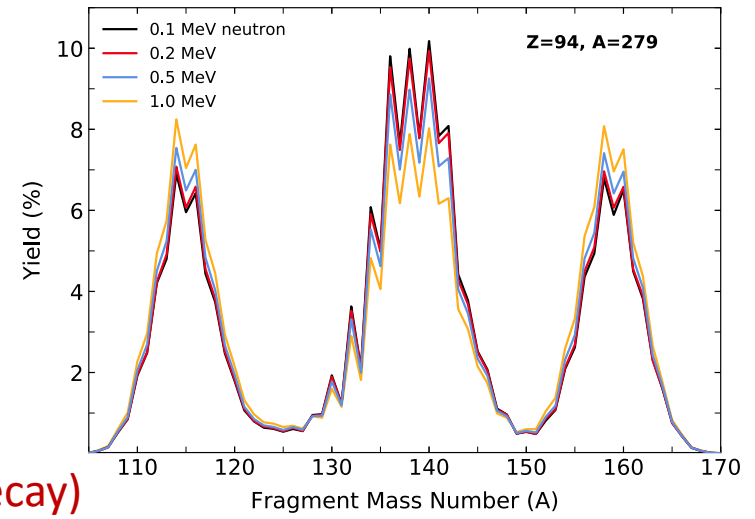
Delayed emission from β -decay of n-rich fission products



Fission in the *r*-process exemplifies the diversity of data needs for nuclear astrophysics

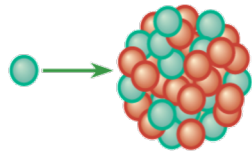
Incident energy dependence ((n,f), β df, sf distinct)

Fission product yield (before β -decay)

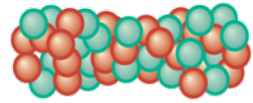


Legend: Neutrons (green circle), Protons (red circle), Beta particles (blue circle), Gamma rays (yellow wavy arrow)

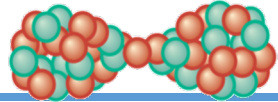
Incident neutron strikes



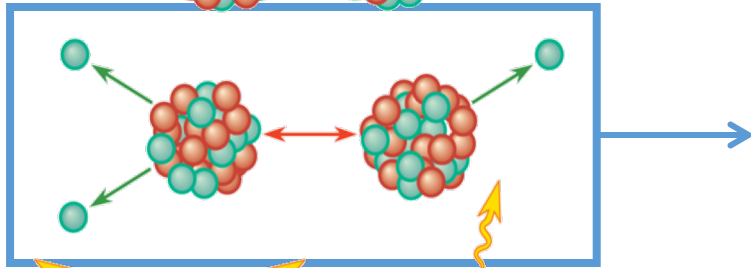
Deformation



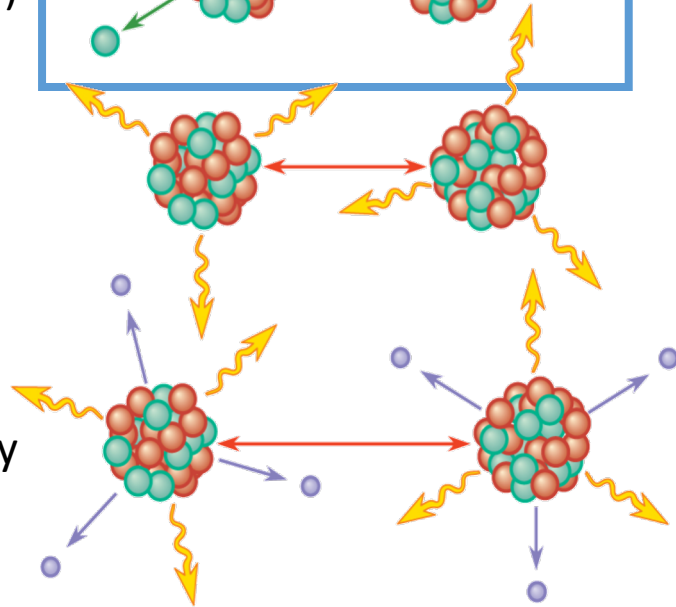
Scission



Prompt Neutron Emission from excited fission fragments (~2-3)



Energy release ~200 MeV with kinetic energy of fragments ~170 MeV

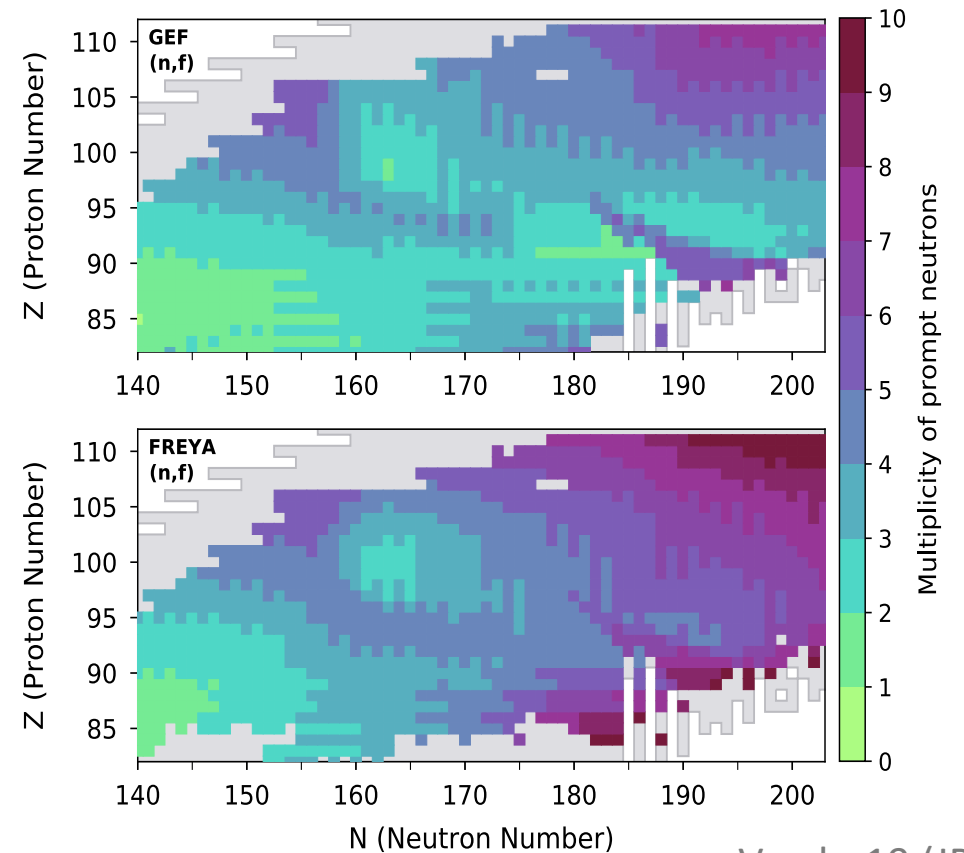


Delayed emission from β -decay of n-rich fission products



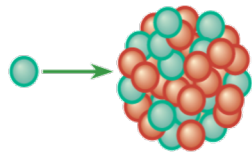
Fission in the *r*-process exemplifies the diversity of data needs for nuclear astrophysics

Prompt neutron emission predictions in neutron-rich regions using the same **fission yields, barrier heights, and TKE**

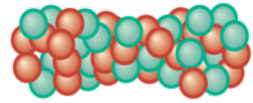


Vassh+19 (JPhysG)

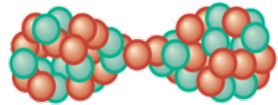
Incident neutron strikes



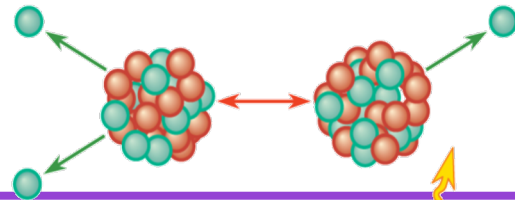
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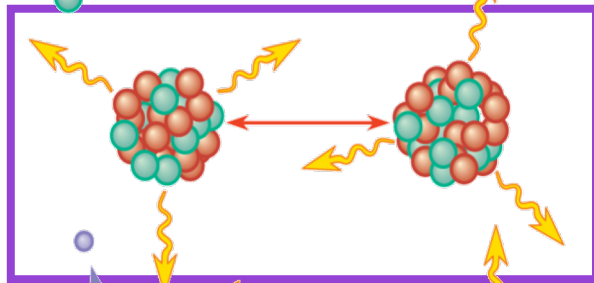
Scission



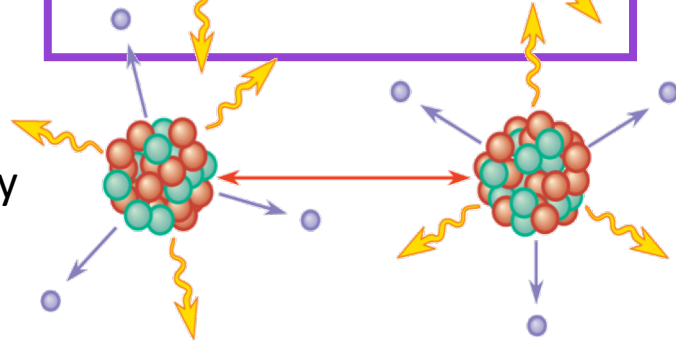
Prompt Neutron Emission from excited fission fragments (~2-3)



Energy release ~200 MeV with kinetic energy of fragments ~170 MeV



Delayed emission from beta-decay of n-rich fission products



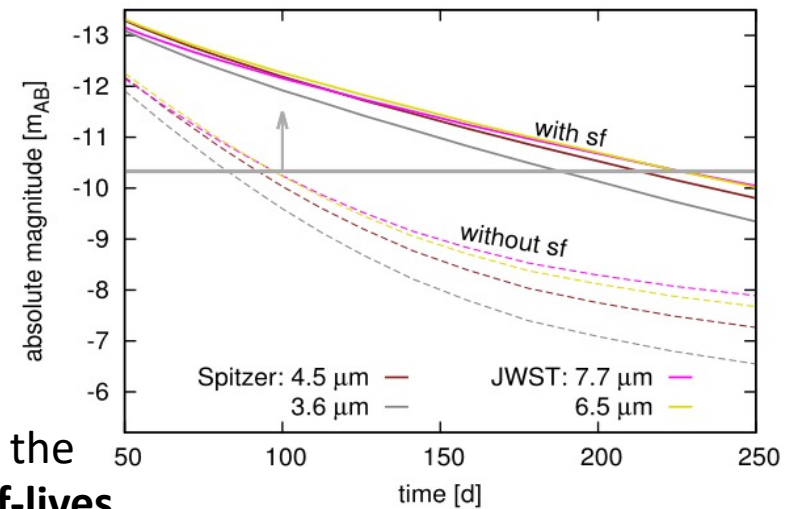
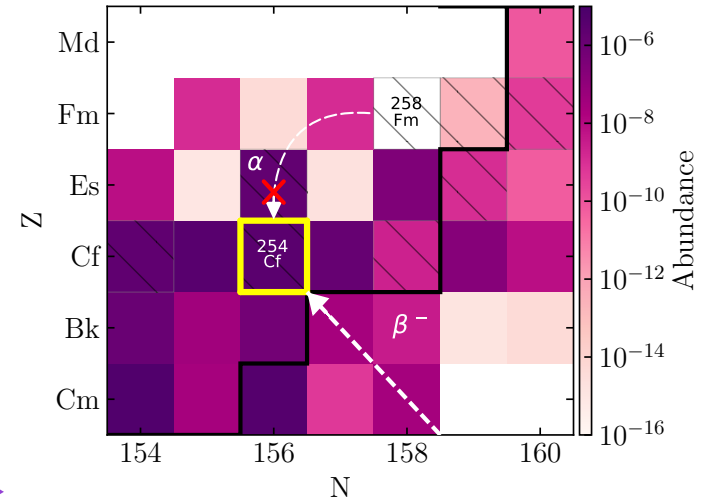
● Neutrons ● Protons ● Beta particles ⚡ Gamma rays

Fission in the *r*-process exemplifies the diversity of data needs for nuclear astrophysics

Cf-254 has measured half-life ~60 days with SF branching 100%

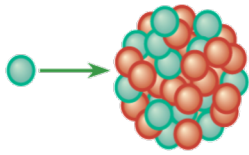
Predicted kilonova light curve* with and without late time Cf heating

*note very sensitive to the branching ratios and half-lives of the surrounding actinides

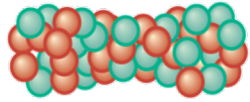


Zhu+18 (including Vassh)(ApJ Letters)

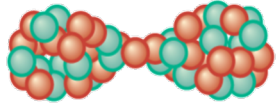
Incident neutron strikes



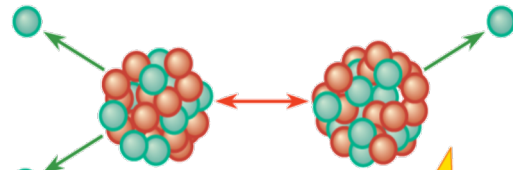
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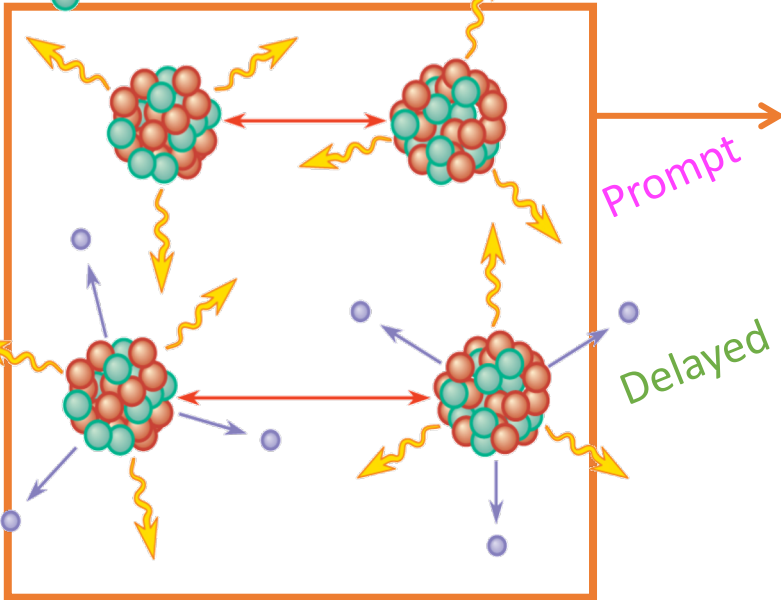
Scission



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Energy release ~200 MeV with kinetic energy of fragments ~170 MeV



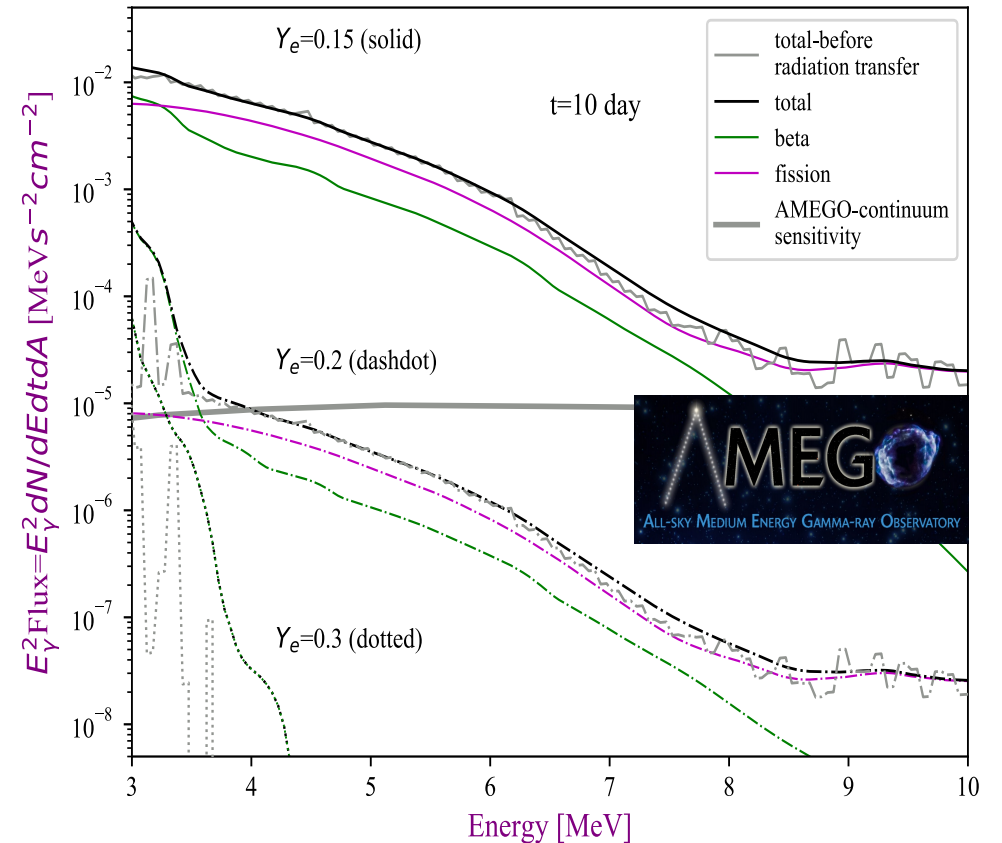
Delayed emission from β -decay of n-rich fission products

Legend:

- Neutrons
- Protons
- Beta particles
- ⚡ Gamma rays

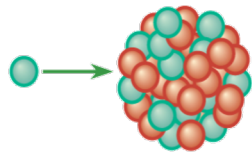
Fission in the *r*-process exemplifies the diversity of data needs for nuclear astrophysics

Gammas > 3.5 MeV: signature of prompt and delayed fission gammas in an astrophysical event!

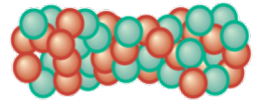


Wang, Vassh+20 (ApJ Letters)

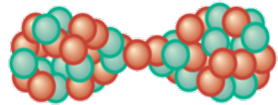
Incident neutron strikes



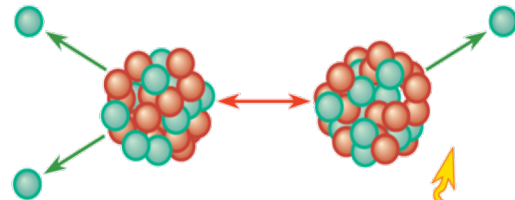
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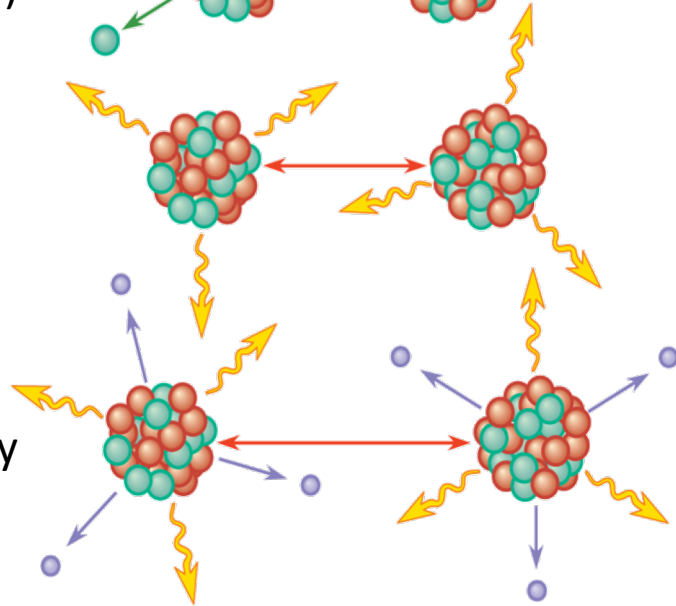
Scission



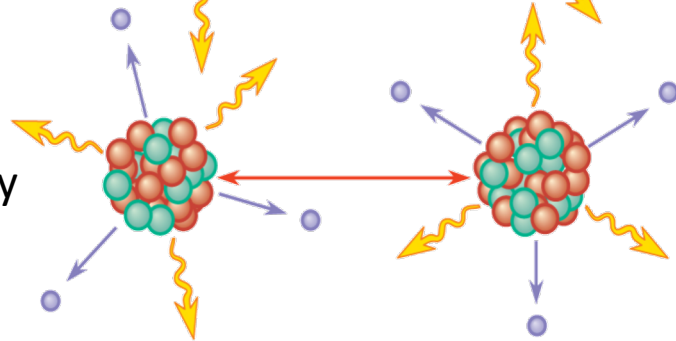
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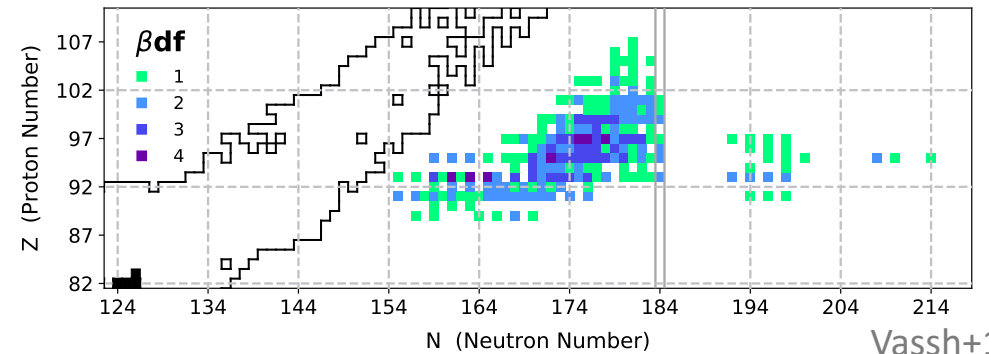
Delayed emission from β -decay of n-rich fission products



Spotlight on fission

r-process calculations need:

Fission **yields** and **rates** for **n-induced** fission, **β -delayed** fission, and **spontaneous** fission for n-rich nuclei (sensitive to **barrier height**)



See also fission sensitivity studies Ward,Vassh+22 (in prep)

Neutron emission probabilities, fission γ spectra, and masses of n-rich products

β -spectra of n-rich products

Some ways to support nuclear astrophysics data needs:

- *open source experimental and theoretical data (want to apply the most up-to-date and vetted datasets!)
- *training for nuclear astrophysics data users
- *more user friendly (= student friendly) data formats and evaluation documentation (noting choices made during evaluation, easy access to citations, guides on best place to find specific data types)
- *peoplepower (nuclear astrophysics students / postdocs)
- *funding topical collaborations like FIRE



Fission In R-process Elements

The FIRE collaboration explores the role of fission in the rapid neutron capture or r-process of nucleosynthesis



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