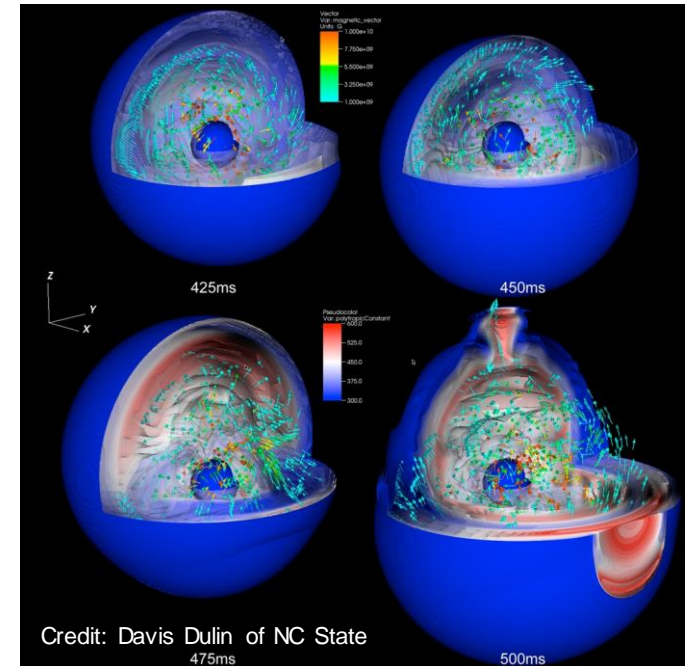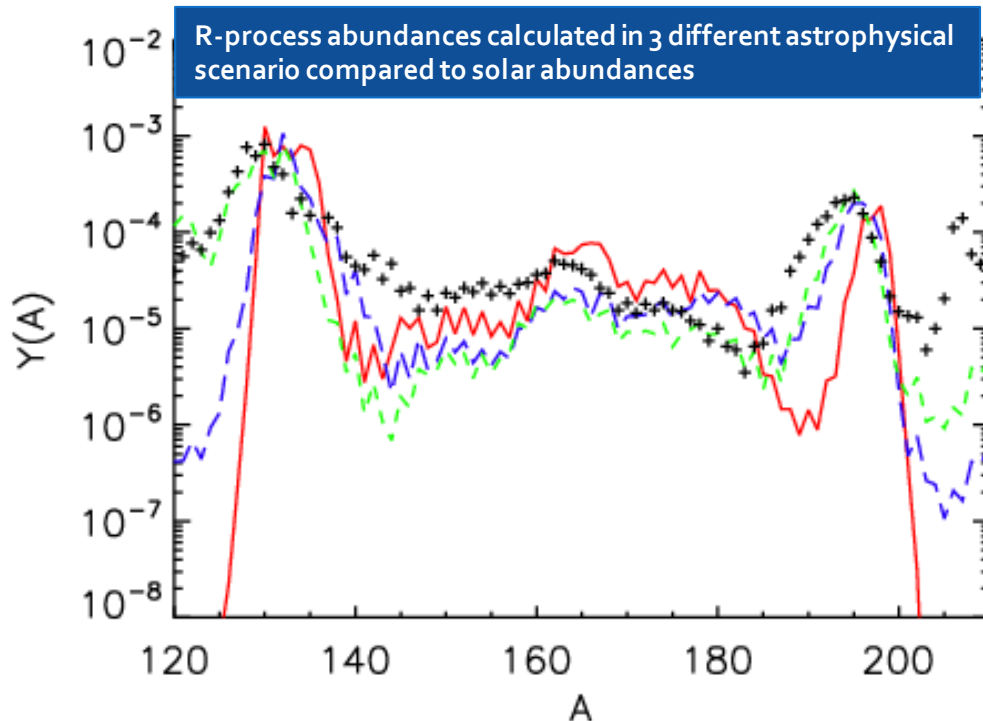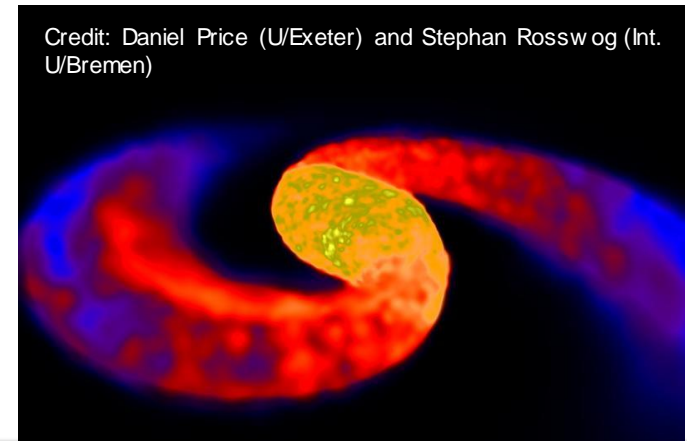# We do not know how and where the heaviest elements are formed

- Heavy elements are formed by nuclear reactions involving rapid neutron capture (r-process) in stellar environments

- Exact astrophysical conditions of the r-process (neutron star merger? core-collapse supernova?) remain unknown
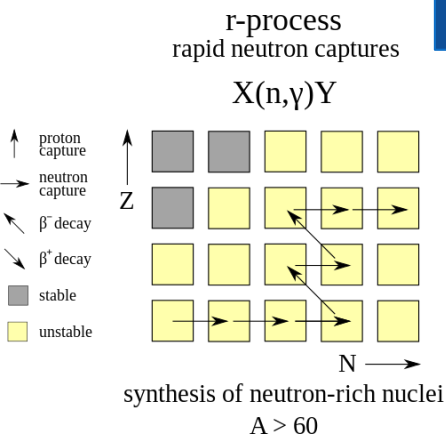

R-process abundances calculated in 3 different astrophysical scenario compared to solar abundances

Credit: Davis Dulin of NC State

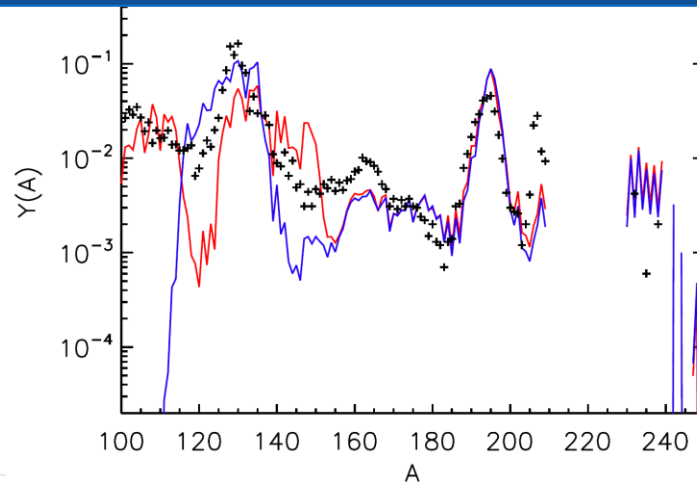Credit: Daniel Price (U/Exeter) and Stephan Rosswog (Int. U/Bremen)

# Accurate and reliable nuclear data is essential to identify the astrophysical conditions of the r-process

- Calculated r-process abundances depend crucially on masses, separation energies, decay rates (β-decay, γ-emission, fission), capture rates, etc.

- Fission has a major impact on the r-process

  - Fission properties are by far the most uncertain data for r-process simulations

  - NNSA laboratories have developed advanced capabilities to describe fission

 - Fission may be the key to pinpointing the location of the r-process

r-process
rapid neutron captures

$X(n,\gamma)Y$

proton capture
neutron capture
β⁻ decay
β⁺ decay
stable
unstable

synthesis of neutron-rich nuclei
A > 60

Predictions of fission fragment mass distributions for ^{239}Pu(n,f) (thermal neutrons)

- Schilleebeeckx (1992)
- Nishio (1995)
- SkM*
- D1S

Influence of the shape (symmetric of asymmetric) of fission fragment distributions on r-process abundance predictions
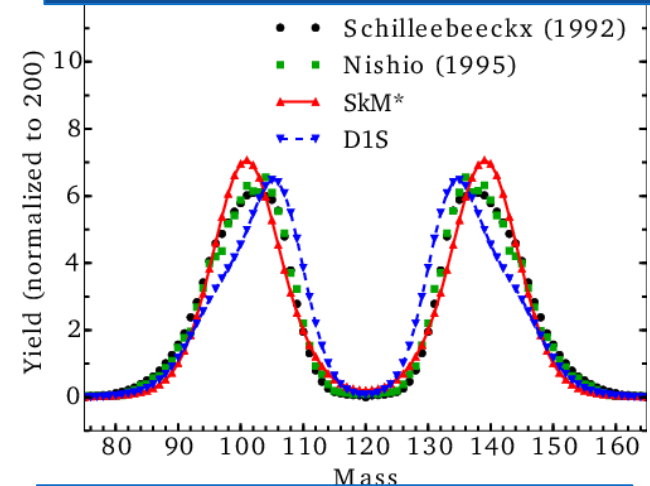
Prompt neutron multiplicities for ^{252}Cf(sf)

^{252}Cf (sf)

Dushin, 2004
Zeynalov, 2011
Becker et al (model calc.), 2011
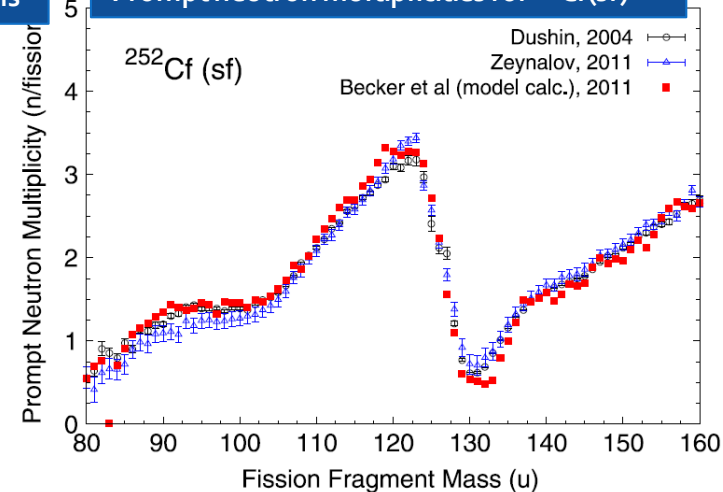
FIRE – Fission In R-process Elements
A joint DOE/NP – NNSA/NA221 project to answer fundamental questions about the formation of elements in the universe

- Incorporate state-of-the-art fission models developed at NNSA laboratories into simulations of the r-process

  - Participants: LLNL (lead), LANL, BNL + Notre Dame, North Carolina State University

  - Jointly support by DOE/NP and NNSA/NA221

- Pipeline for future workforce

- Produce theoretical database

Predictions of spontaneous fission fragment distributions for ^{240}Pu with uncertainties
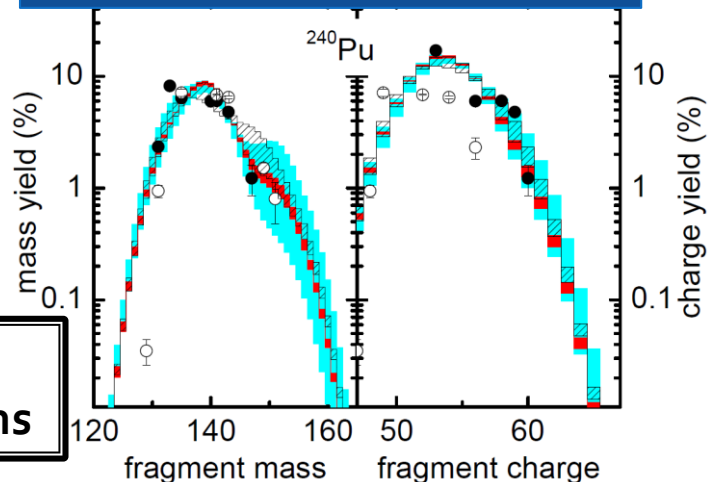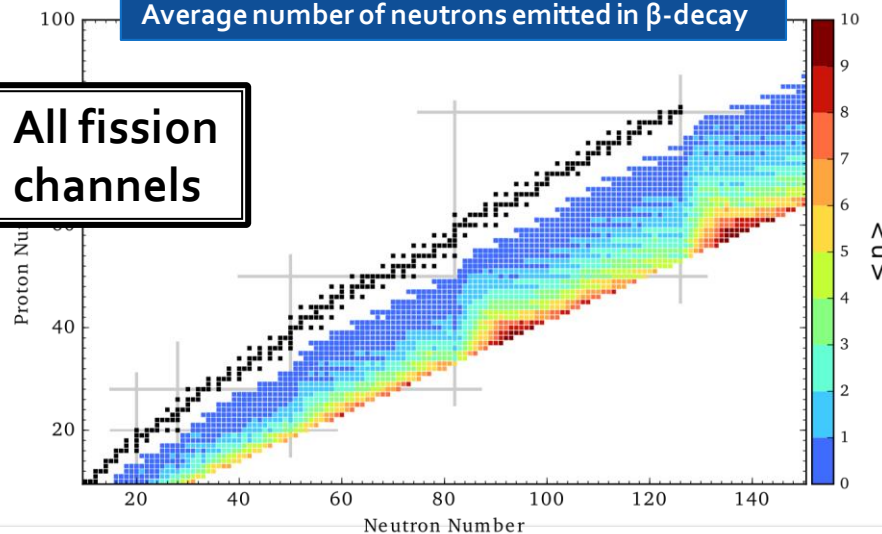

Accurate distributions

UQ

Dependence of calculated abundances on uncertain nuclear mass model
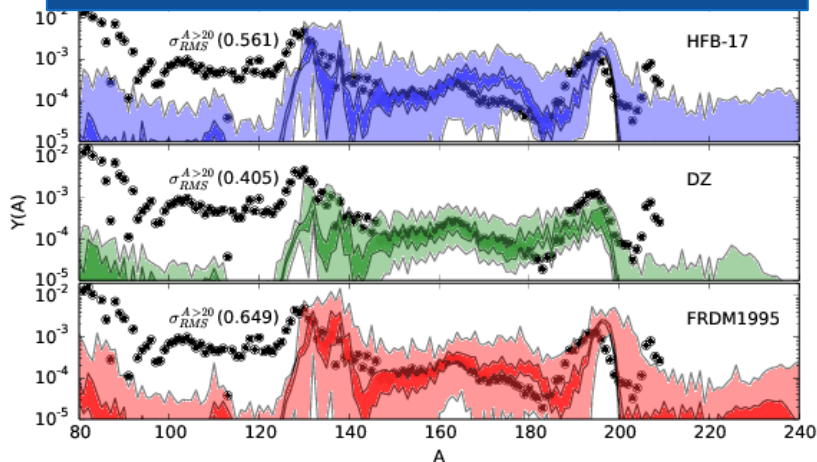
All fission channels

Average number of neutrons emitted in β-decay

FIRE brings experts in fission theory, nuclear data and nuclear astrophysics

- Project team:
  - LLNL: N.Schunck (PI), R. Vogt
  - LANL: T. Kawano, P. Talou, A. Hayes-Sterbenz
  - BNL: A. Sonzogni, L. McCutchan
  - Notre Dame: R. Surman
  - North Carolina State: G. McLaughlin
- Additional participants
  - 1 postdoc at LANL
  - 1 postdoc at Notre Dame
  - 1 graduate student at NCSU
  - 1 summer student at LLNL

National Nuclear Security Administration