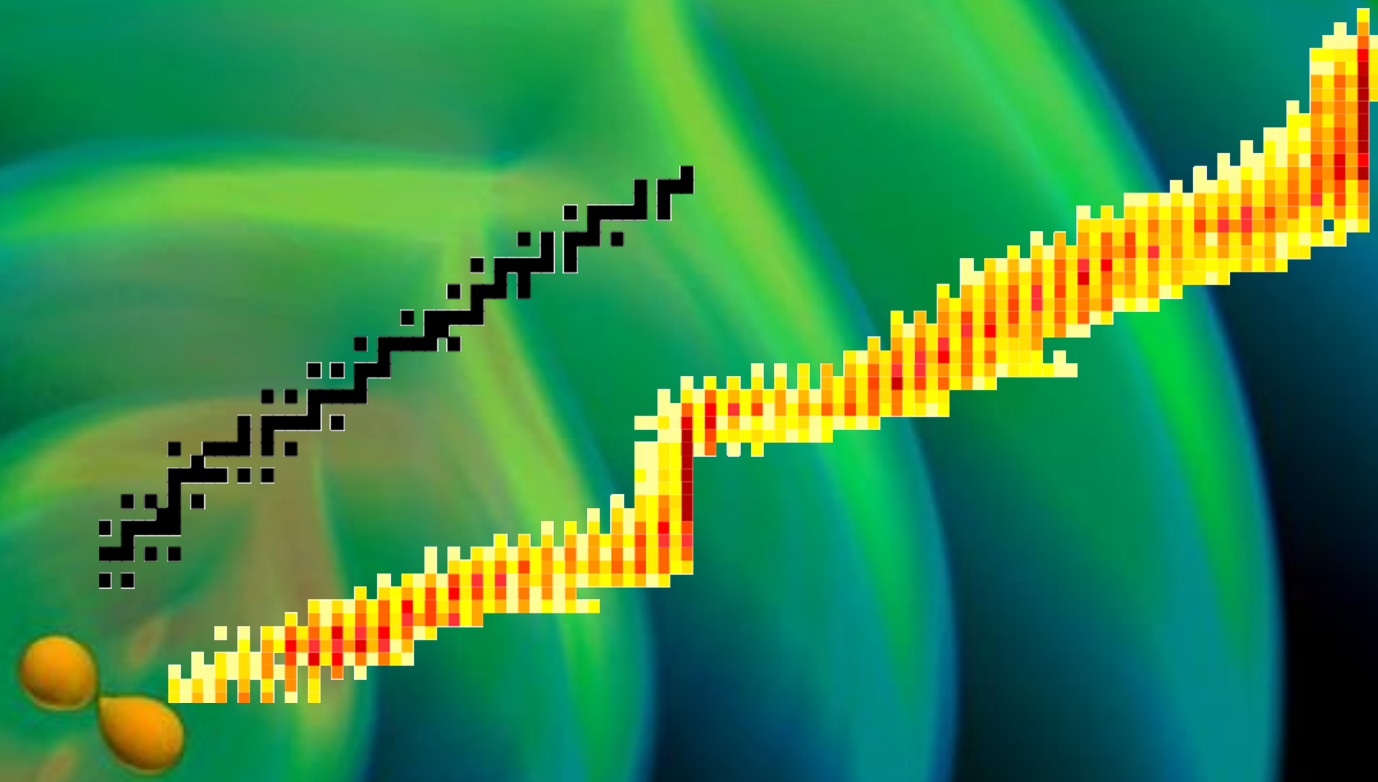
Heavy Element Nucleosynthesis



TRIUMF

JINA-CEE

FIRE

Fission In R-process Elements

Nicole Vassh

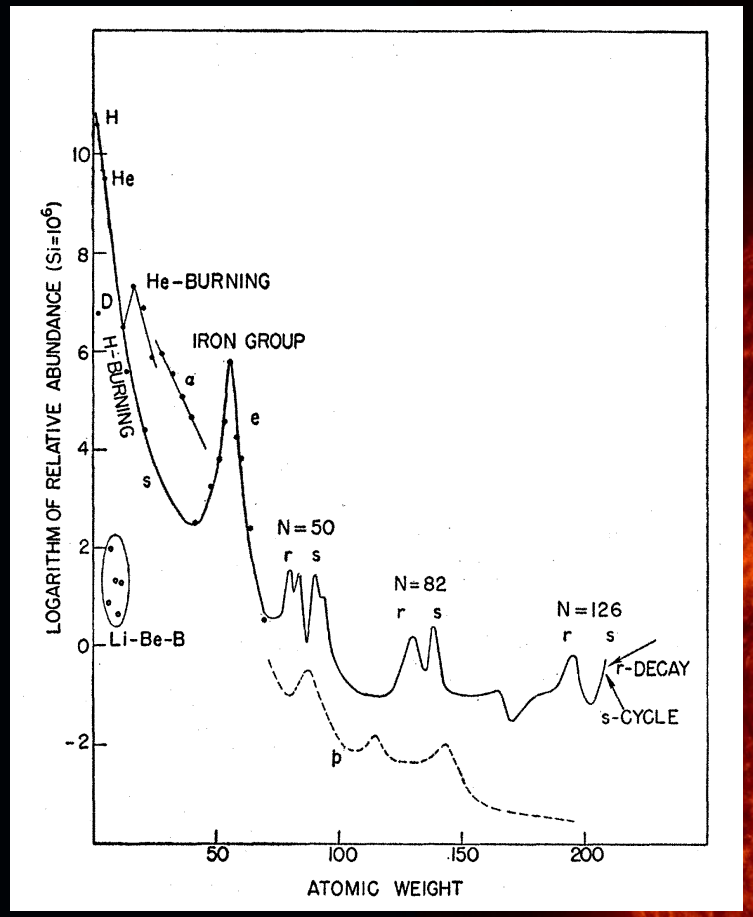
TRIUMF Theory Group

TRIUMF Science Week,

Live from home :/

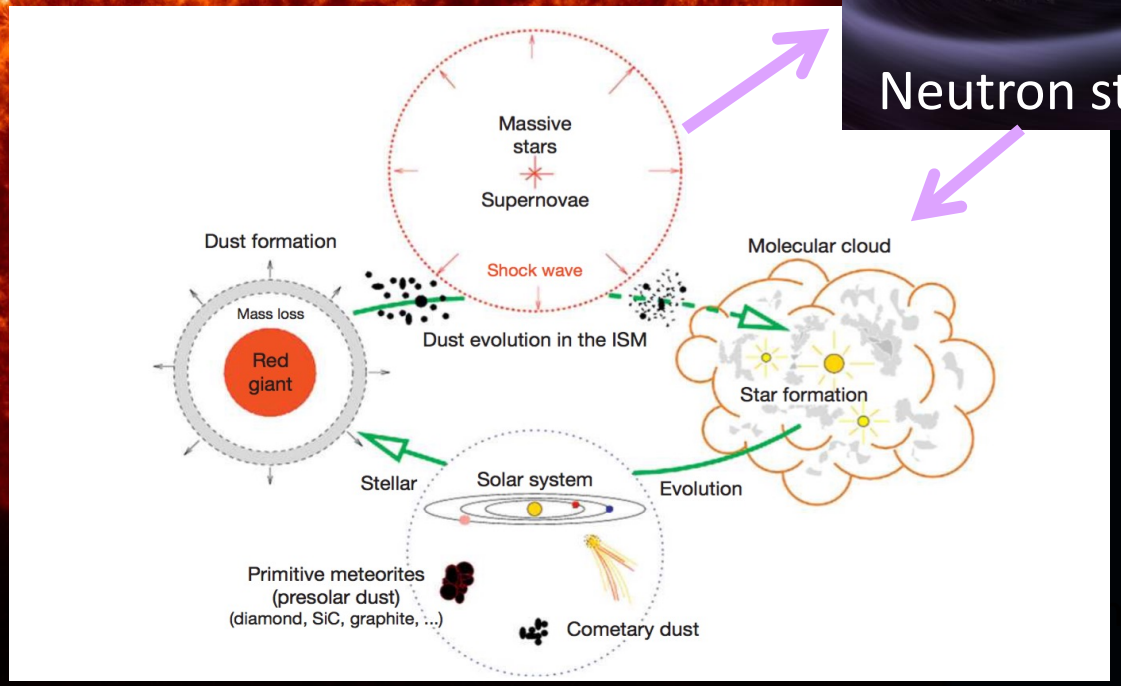
August 16, 2021

The solar composition can be decomposed into many processes → multiple nucleosynthesis sites enriched the solar system



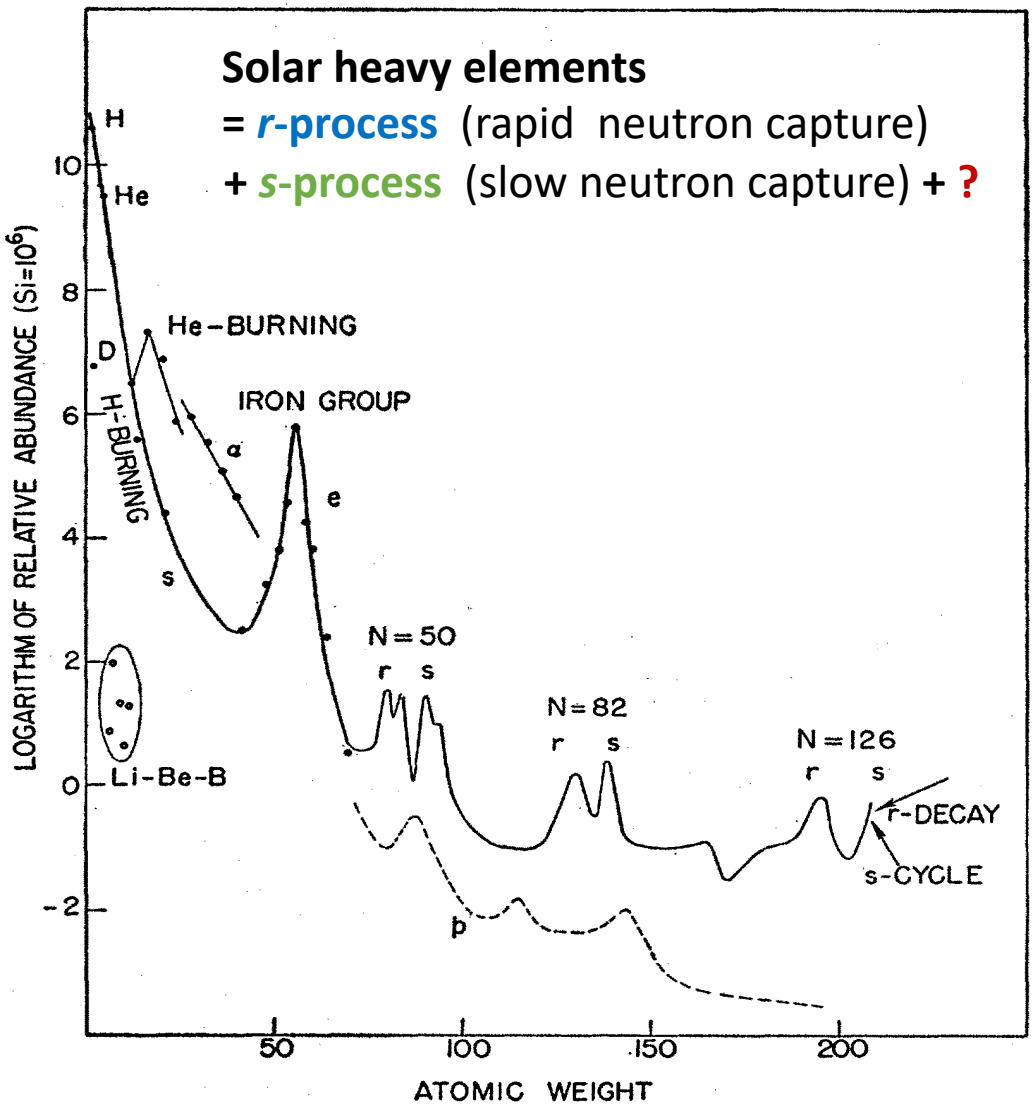
Burbidge, Burbidge, Fowler and Hoyle (B^2FH) (1957)

Neutron star mergers

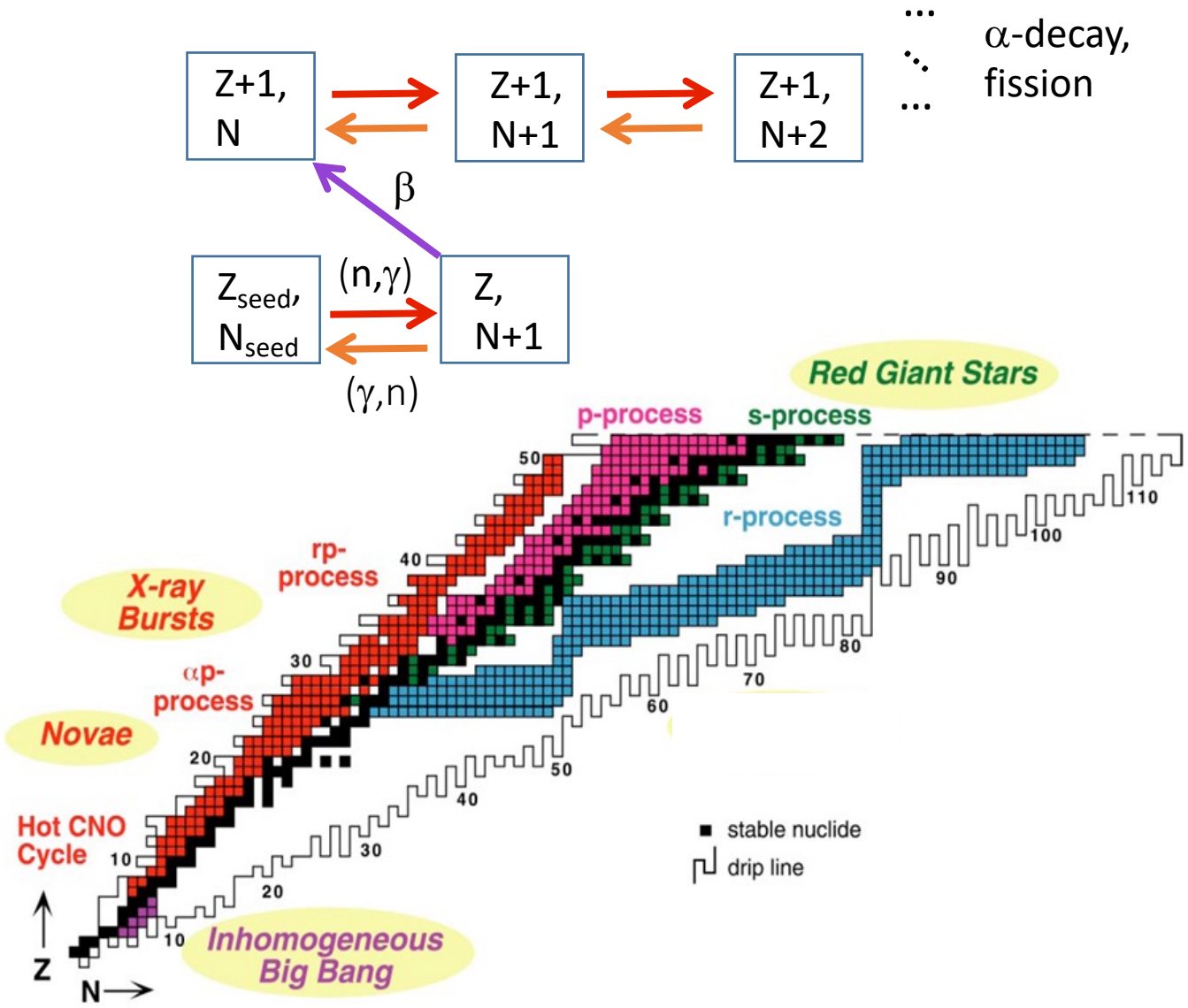


Palm+14

Nuclear properties shape the solar abundances

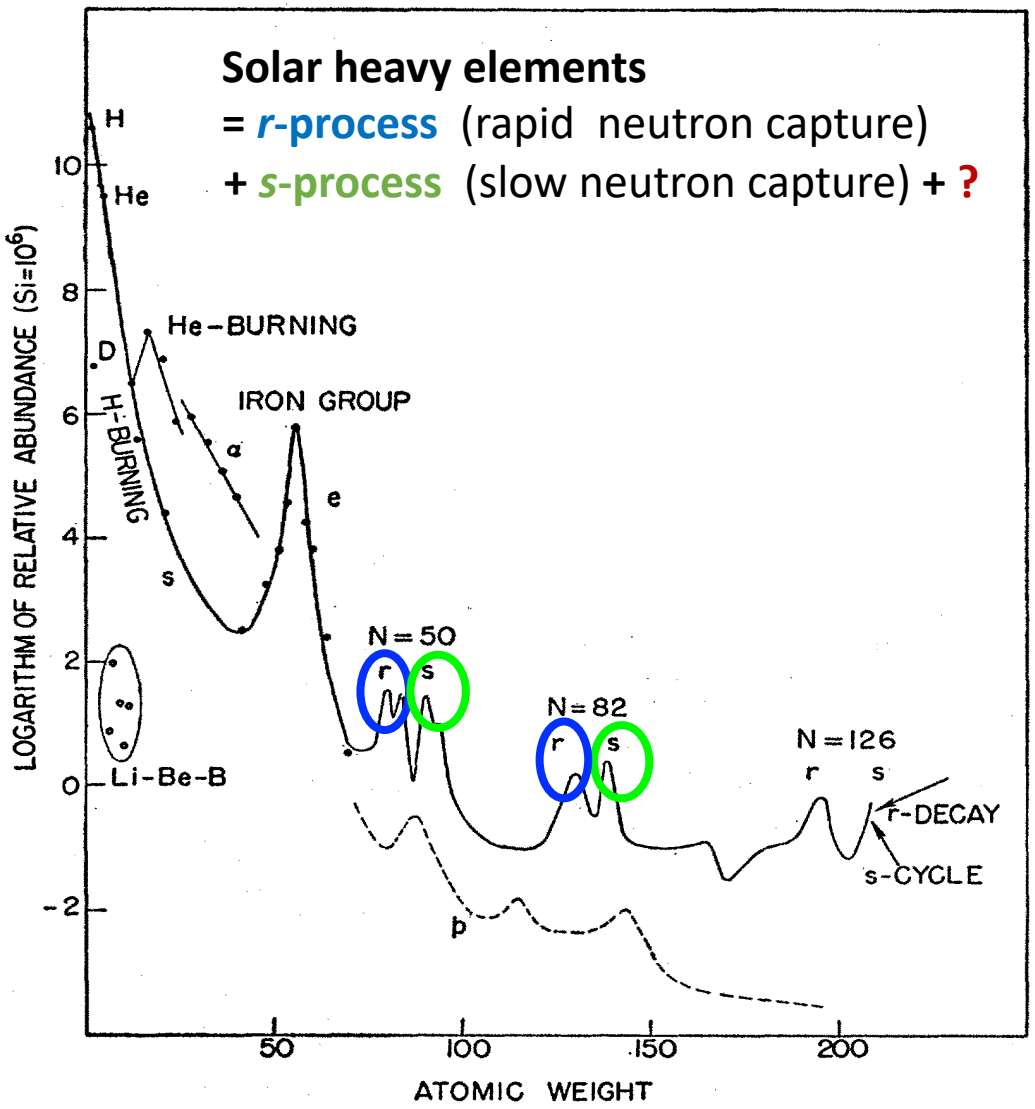


Burbidge, Burbidge, Fowler, and Hoyle (B^2FH) (1957)

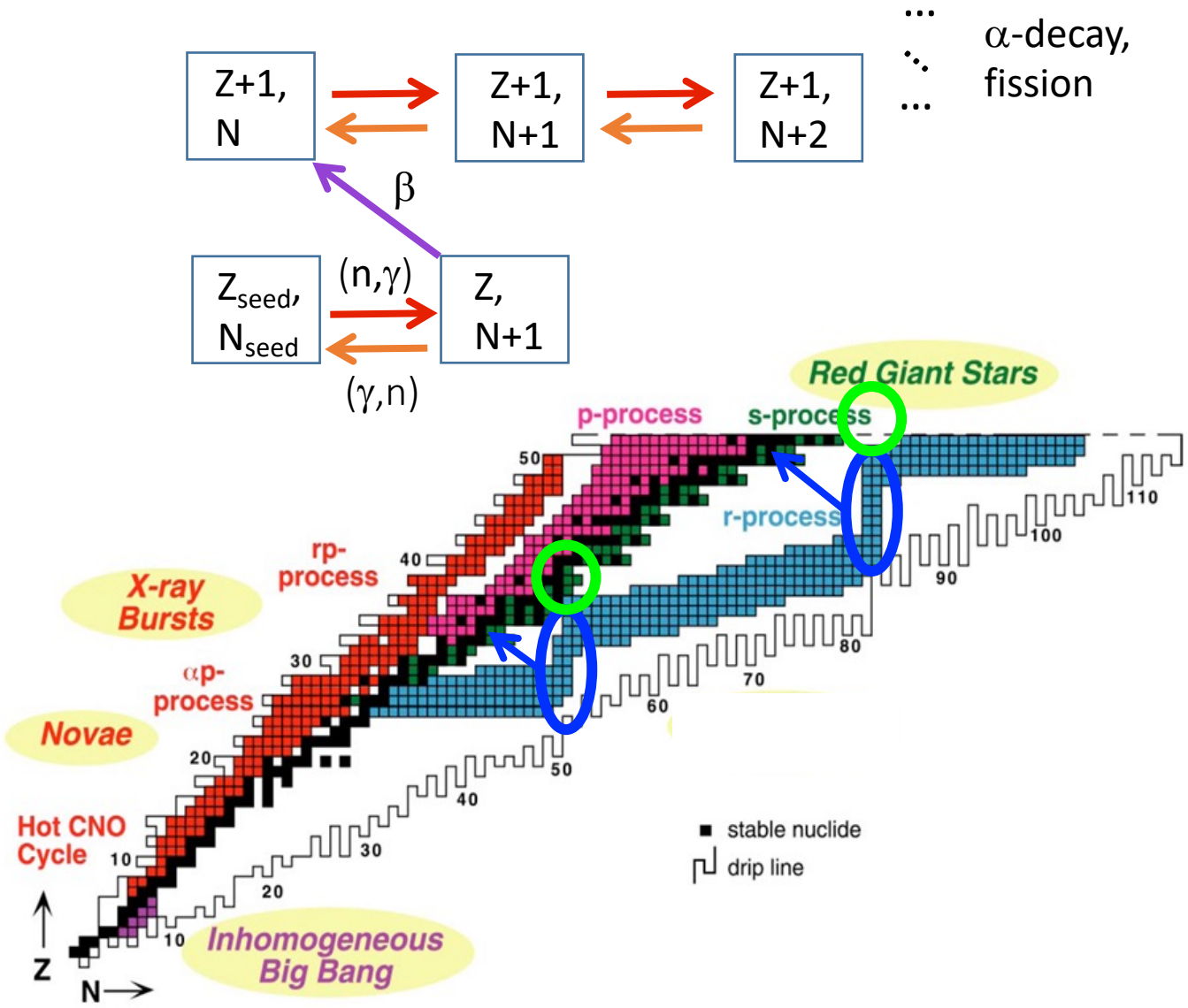


Smith&Rehm 01

Nuclear properties shape the solar abundances



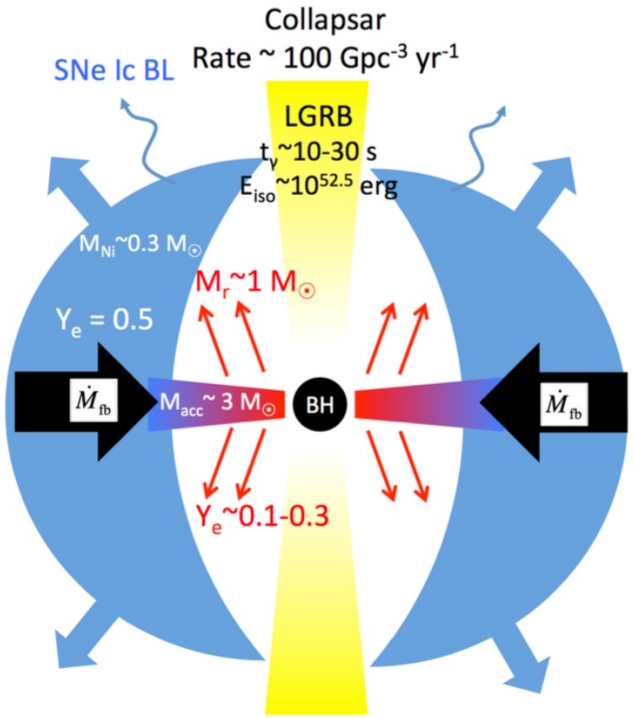
Burbidge, Burbidge, Fowler, and Hoyle (B^2FH) (1957)



Smith&Rehm 01

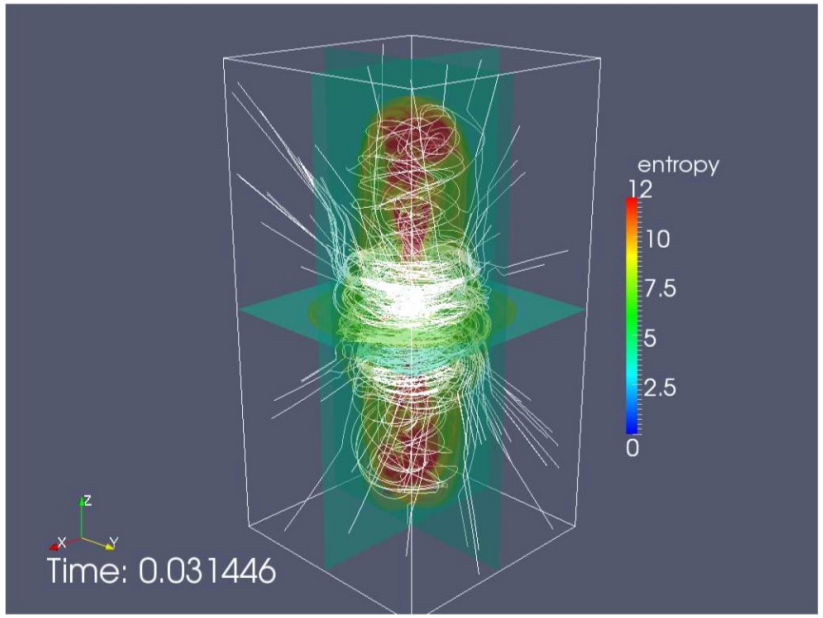
Some candidate sites for *r*-process element production

Collapsar disk winds



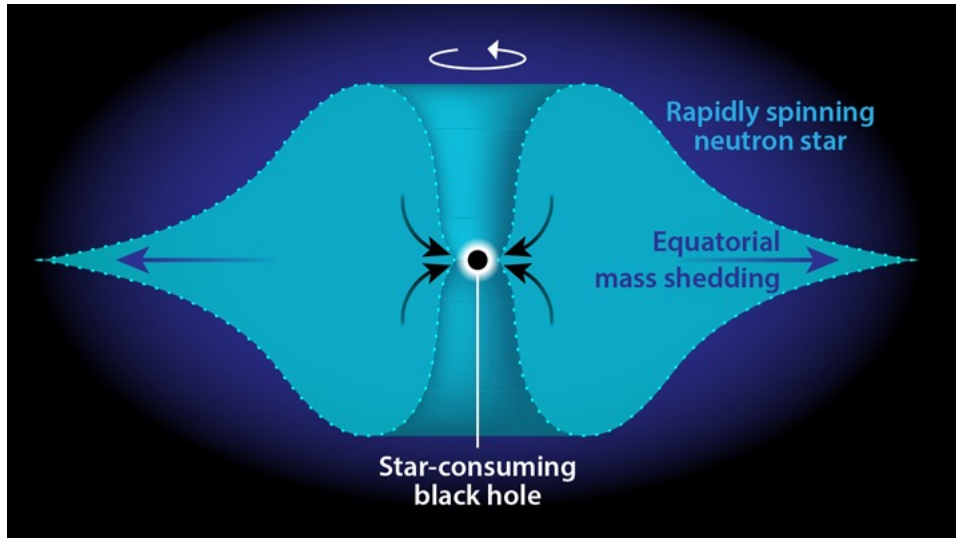
Siegel+18; also McLaughlin&Surman 05, Miller+19

Magneto-rotationally driven (MHD) supernovae



Winteler+12; also Mosta+17

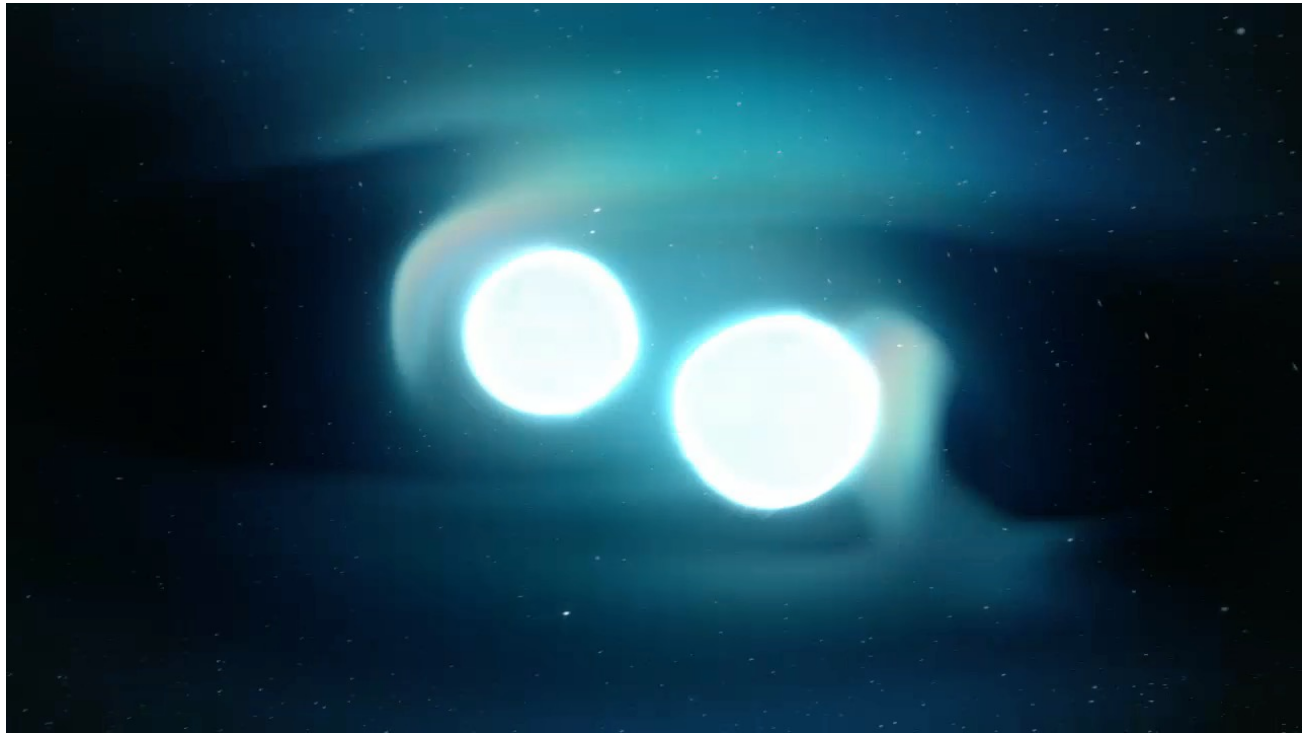
Primordial black hole + neutron star



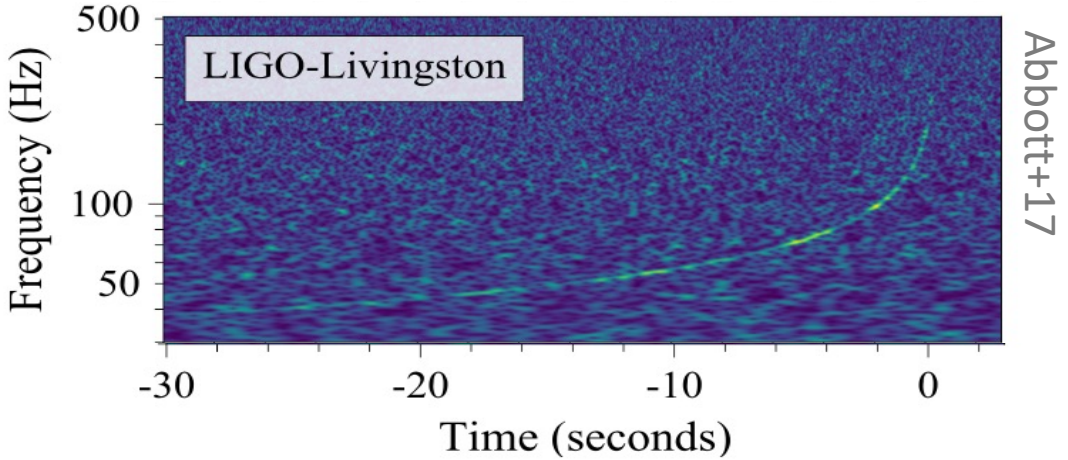
Credit: APS/Alan Stonebraker, via *Physics*

Fuller+17

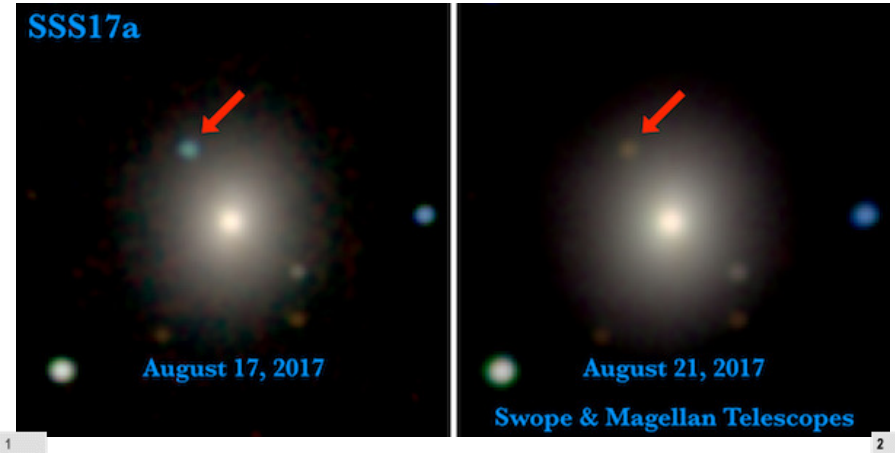
The GW170817 binary neutron star merger



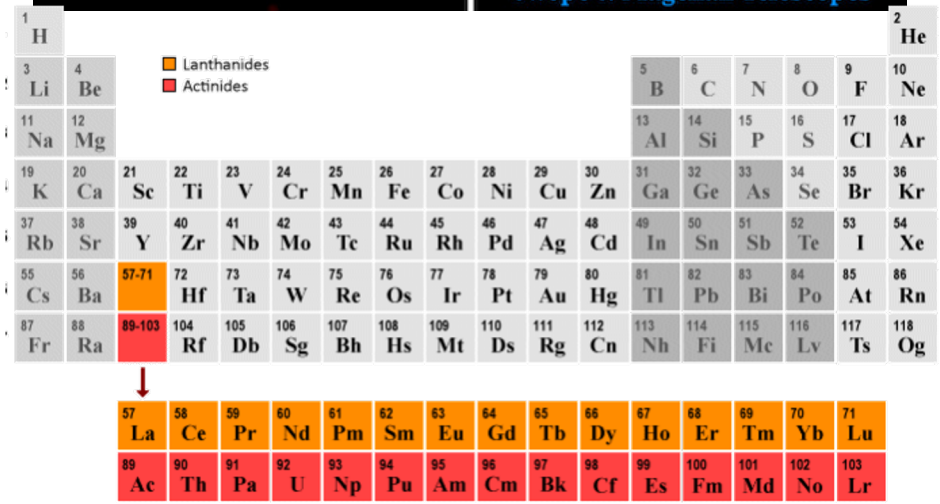
NASA Goddard



Abbott+17



Hurt/Kasliwal/Hallinan, Evans and the GROWTH collab.

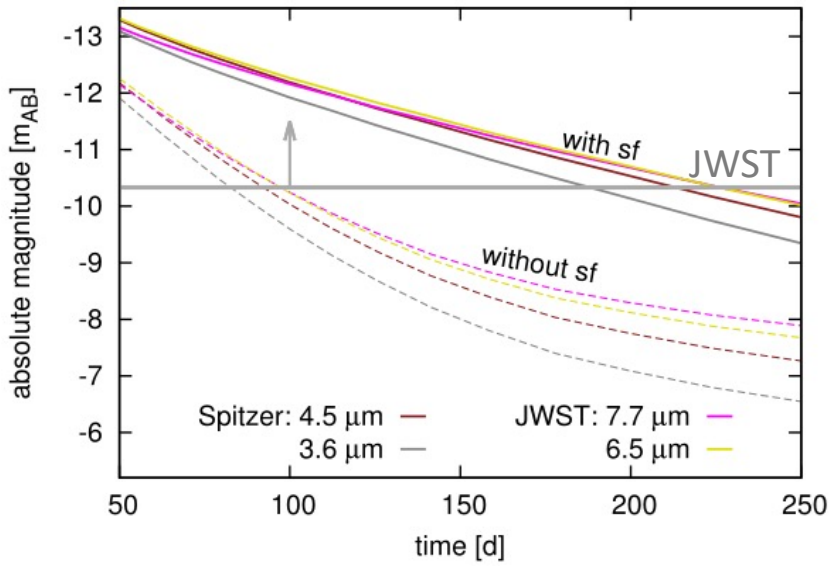


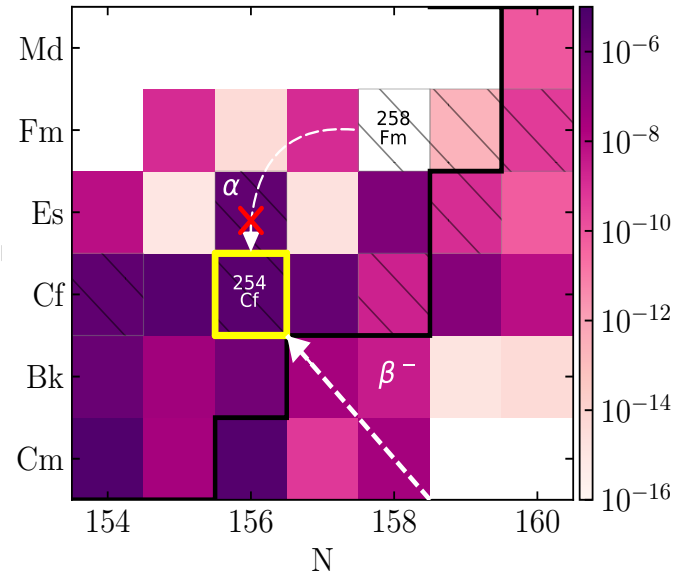
Over ~70 observing teams (~1/3 of the worldwide astronomical community) followed up on the merger event!

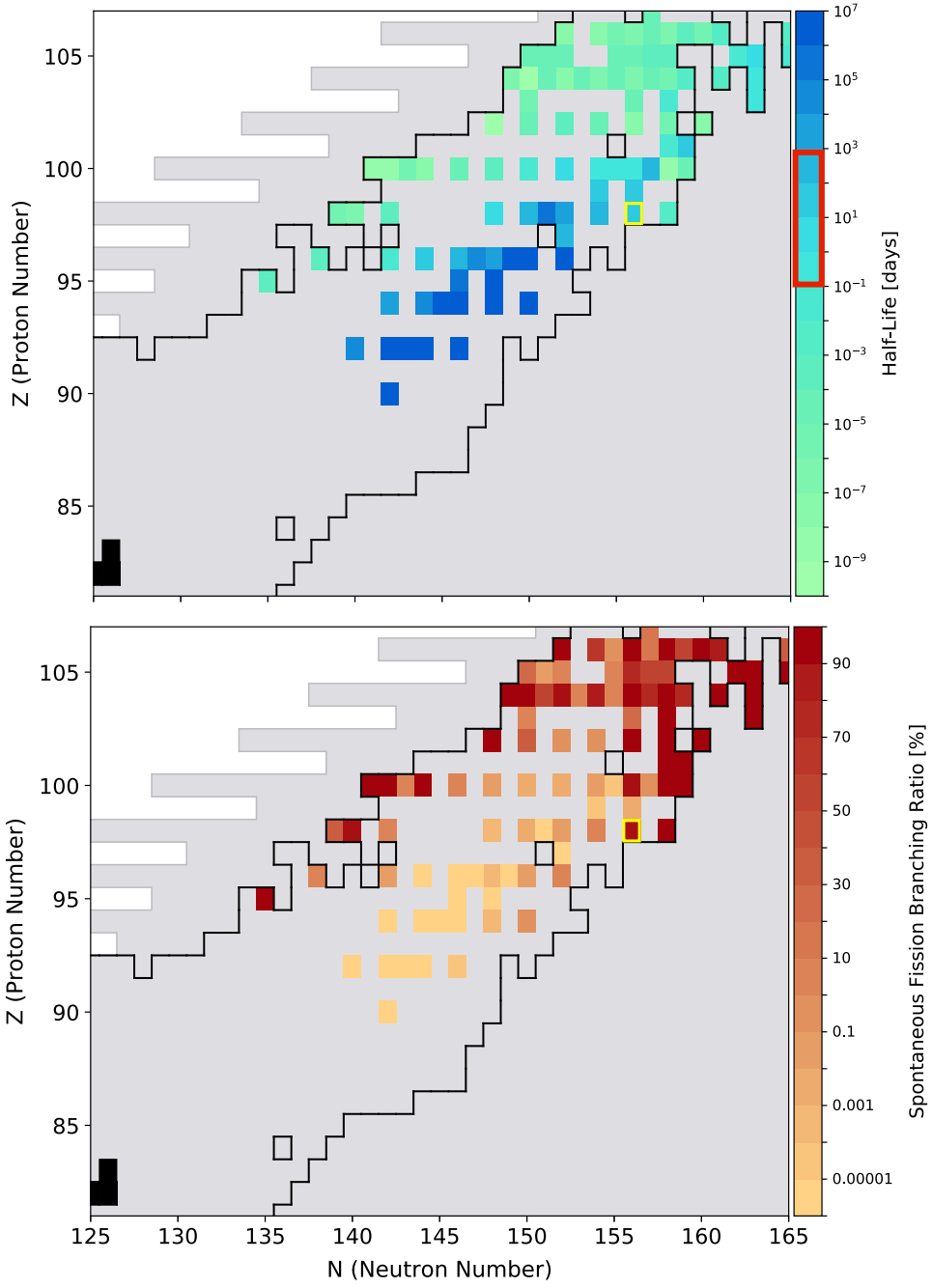
Observed in UV, infrared, radio, γ-ray, X-ray, and optical

Lanthanide and/or actinide mass fraction ↑, opacity ↑, longer duration kilonova light curve shifted toward infrared

Actinide production and kilonovae: what is the reach of the *r* process in mergers?



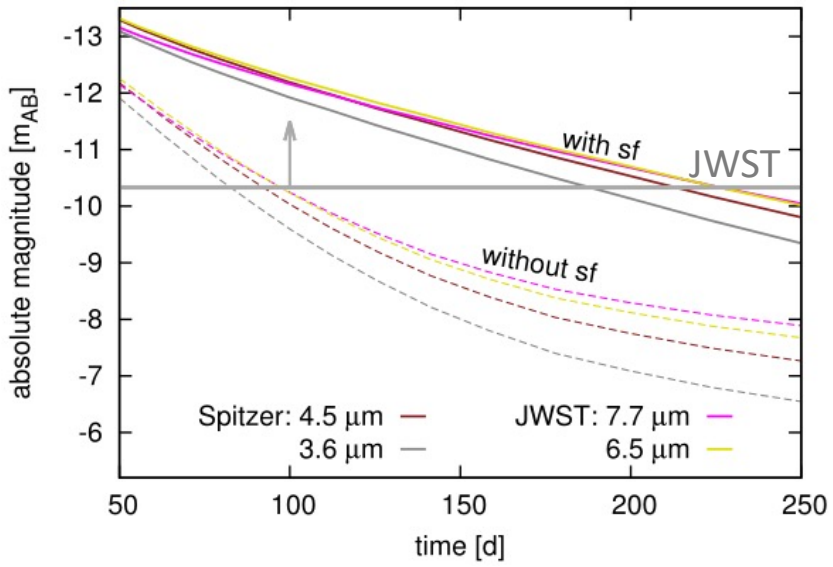


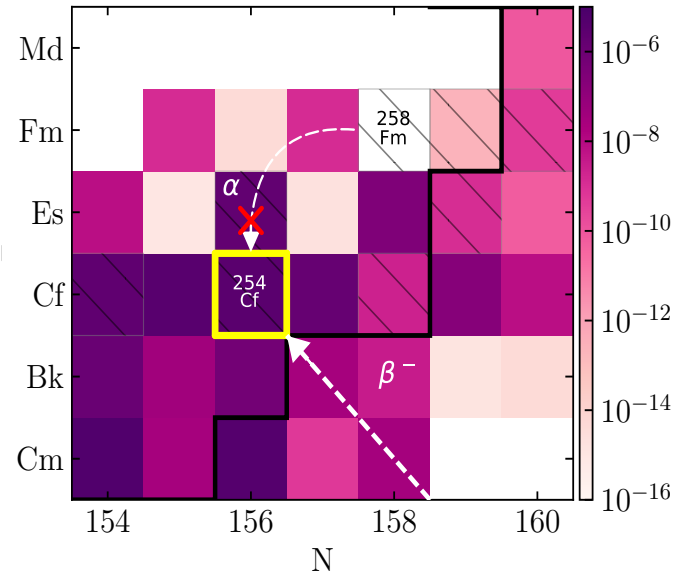


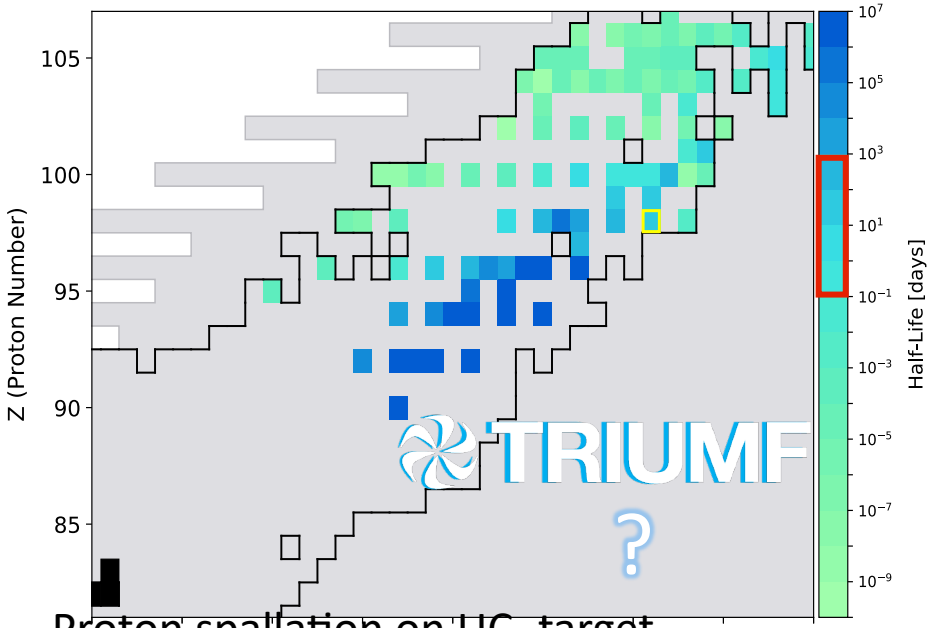
Zhu, Wollaeger, Vassh+18 (ApJ Letters 863, L23);
See also Vassh+19 (J. Phys. G 46, 065202),
Zhu, Lund+21 (including NV) (ApJ 906, 94)

Plots by Vassh (NUBASE2016 data)

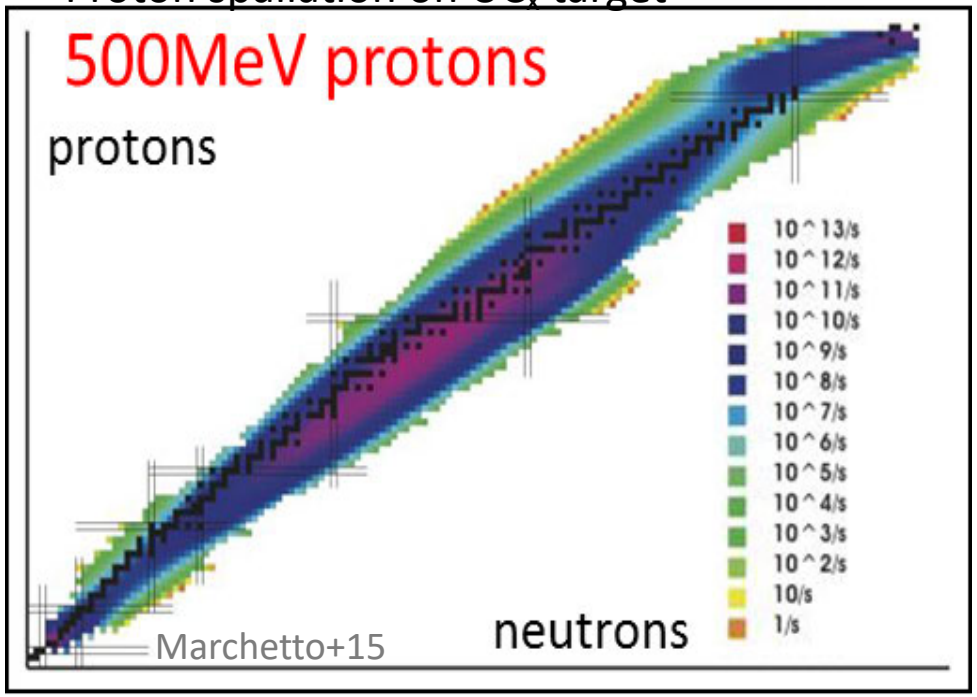
Actinide production and kilonovae: what is the reach of the *r* process in mergers?







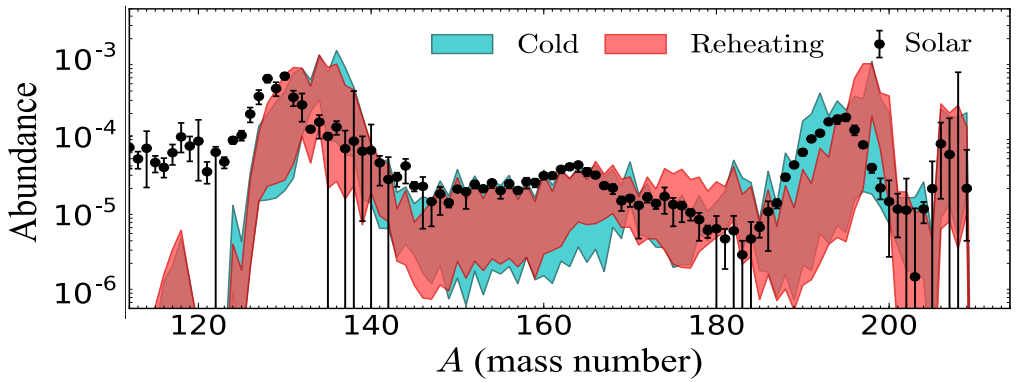
Proton spallation on UC_x target



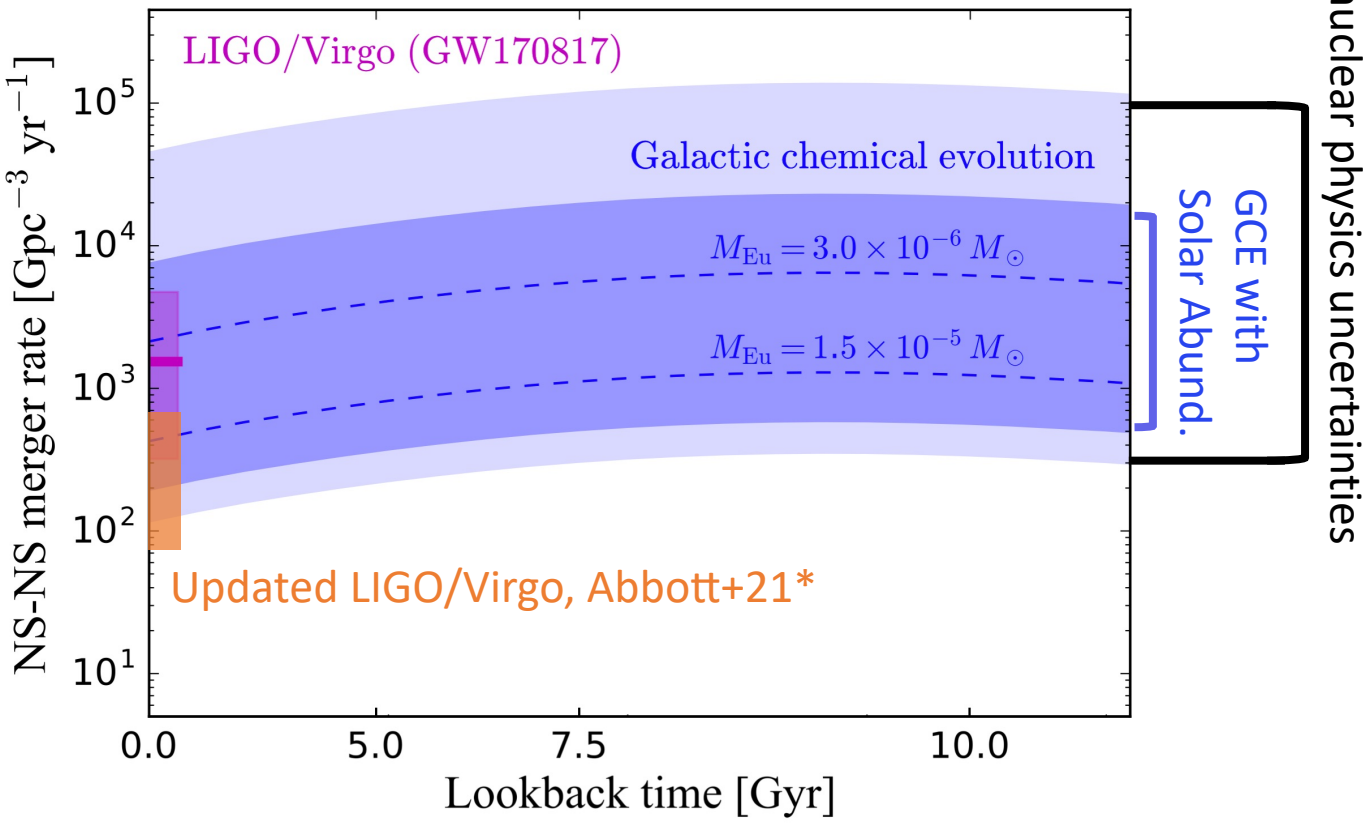
Zhu, Wollaeger, Vassh+18 (ApJ Letters 863, L23);
See also Vassh+19 (J. Phys. G 46, 065202),
Zhu, Lund+21 (including NV) (ApJ 906, 94)

Do binary NS mergers make enough heavy elements?

Galactic Chemical Evolution



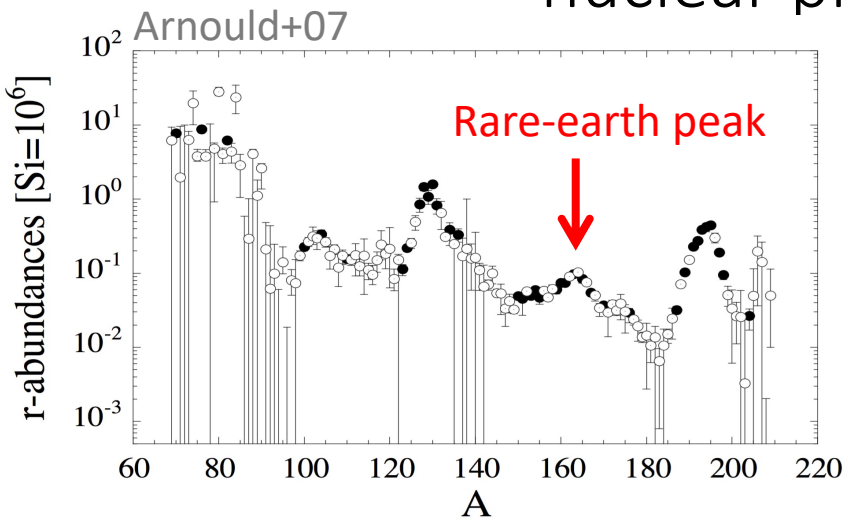
Nucleosynthesis Predictions:
Abundance range from 10 mass models



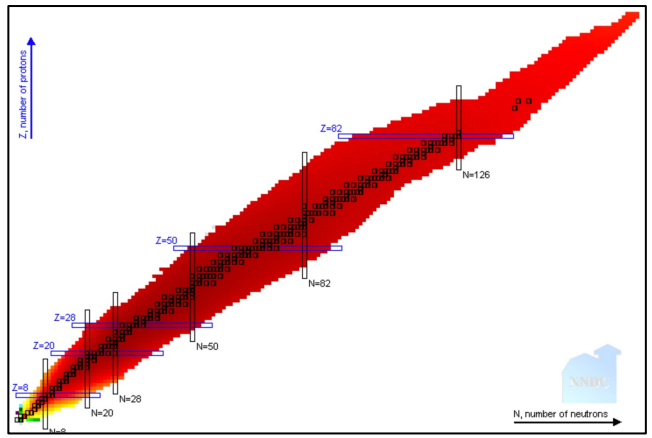
Côté, Fryer, Belczynski, Korobkin, Chruślińska, Vassh+18 (ApJ 855, 2)

*Now another confirmed NSNS merger GW190425 observed by LIGO
as well as a June 2021 confirmation of two observed NSBH mergers GW200105 and 200115!

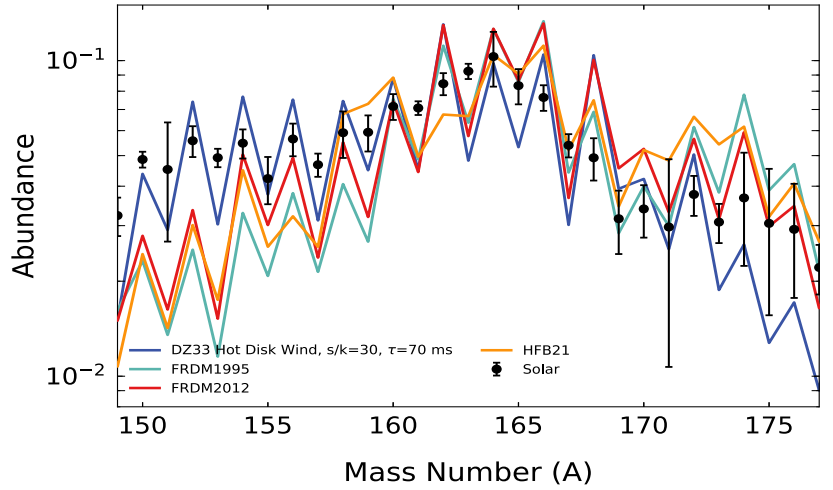
A modern approach to exploit the interplay between nuclear properties and astrophysical outcomes



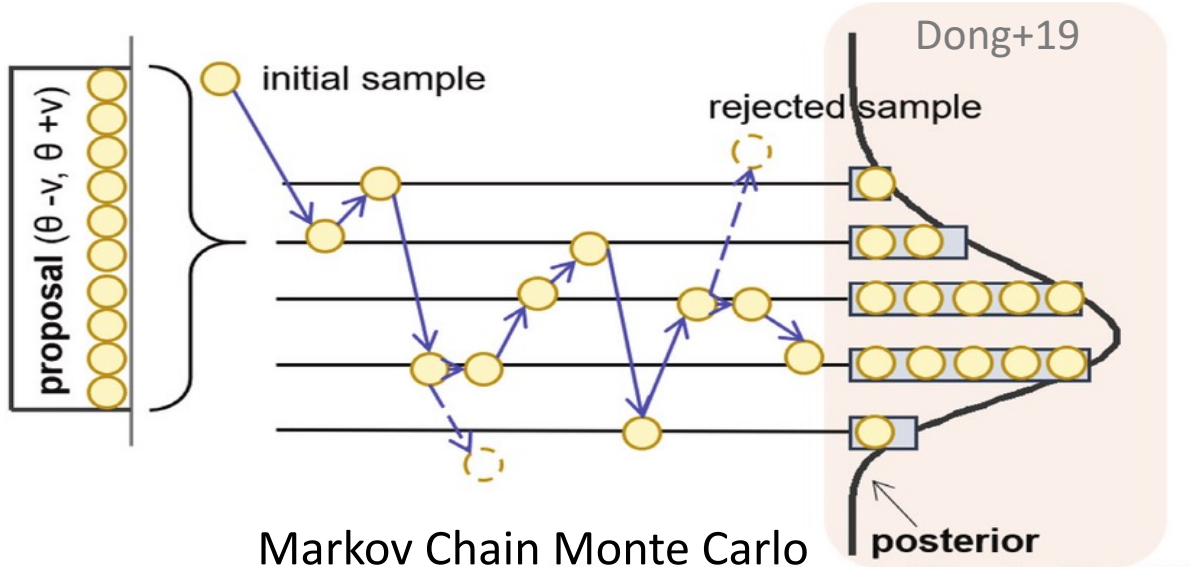
Nuclear structure (shell closures, deformation…) affects abundances



We have mass data to inform us but don't yet know masses of some important neutron-rich nuclei

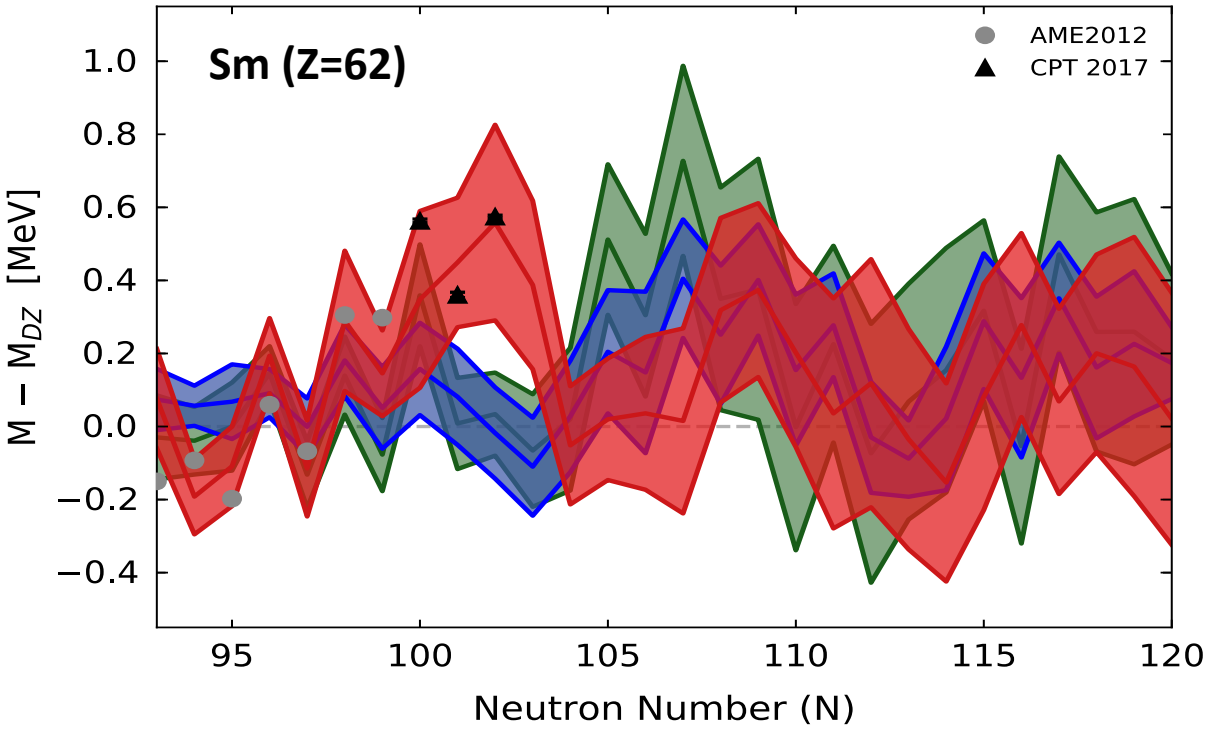


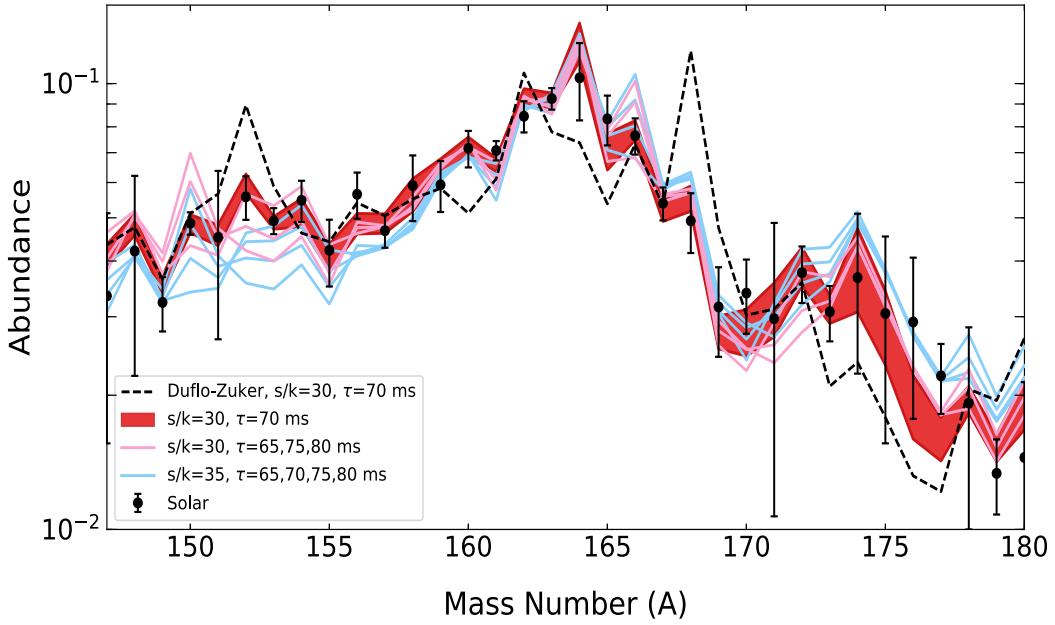
Nuclear masses are key inputs for reaction and decay rates

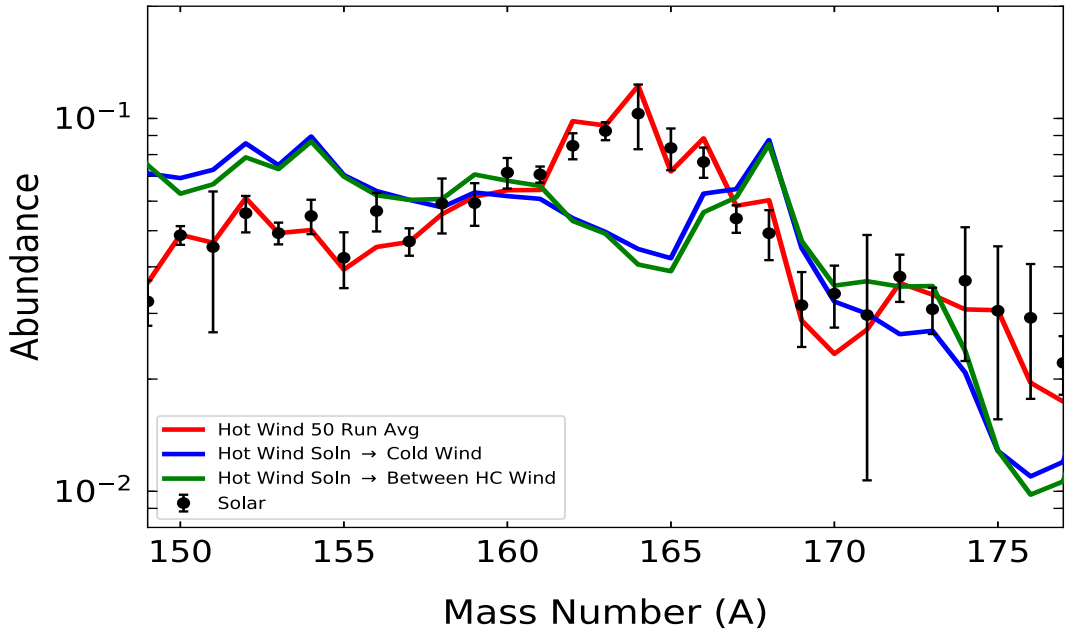


Markov Chain Monte Carlo

MCMC results in *similar* vs *distinct* astrophysical outflows







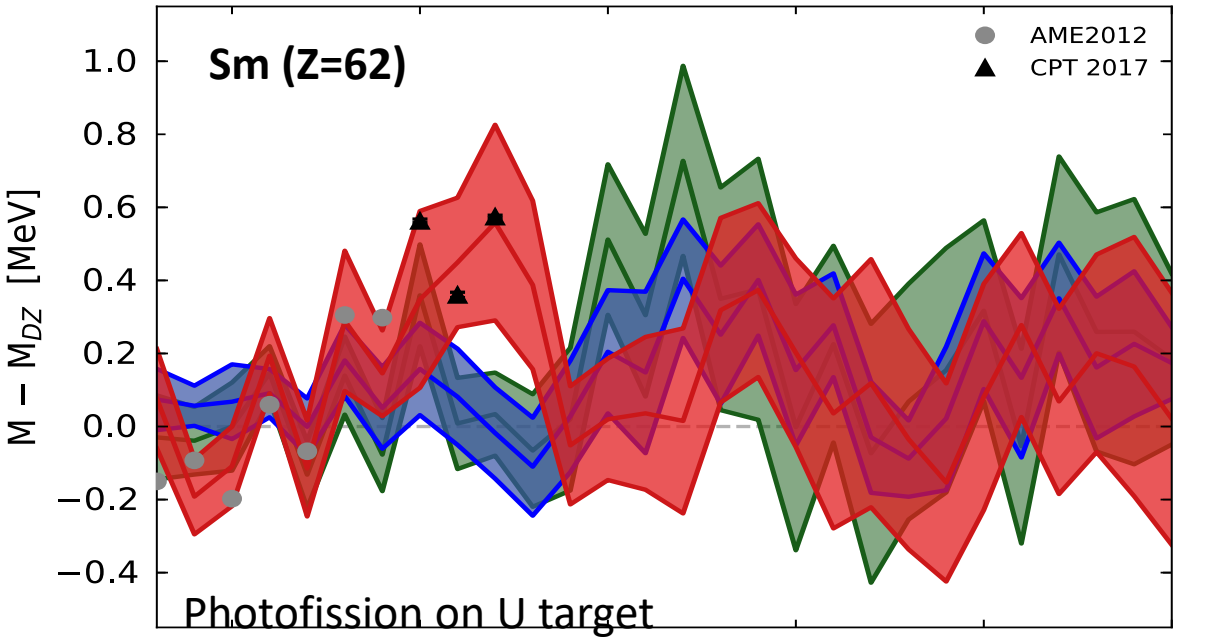
Neutron star merger accretion disk winds with:

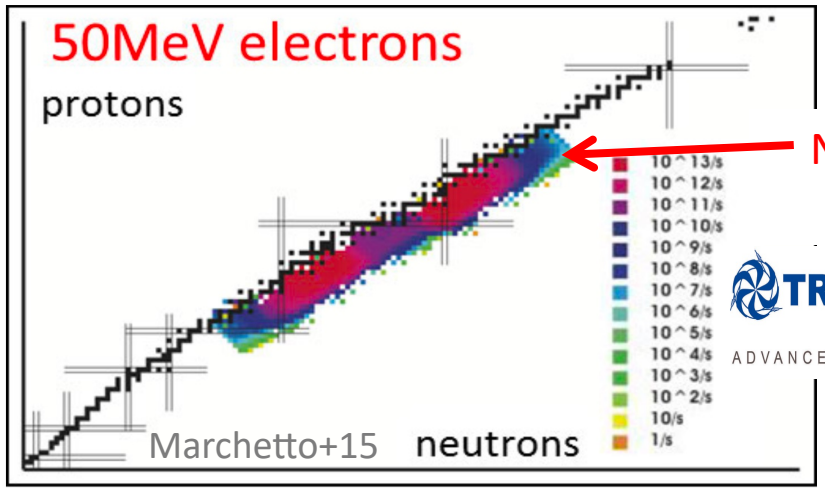
Hot = extended (n,γ)⇆(γ,n) equilibrium

Cold = photodissociation falls out early

Vassh+21 (ApJ 907, 98);
Orford,Vassh+18 (Phys. Rev. Lett. 120, 262702)

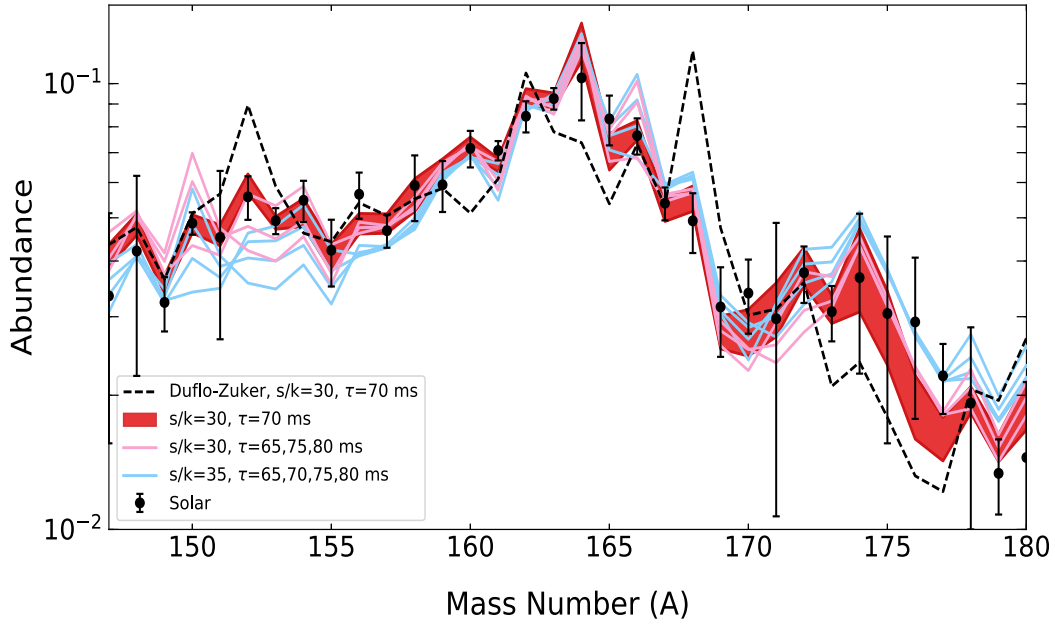
MCMC results in *similar* vs *distinct* astrophysical outflows

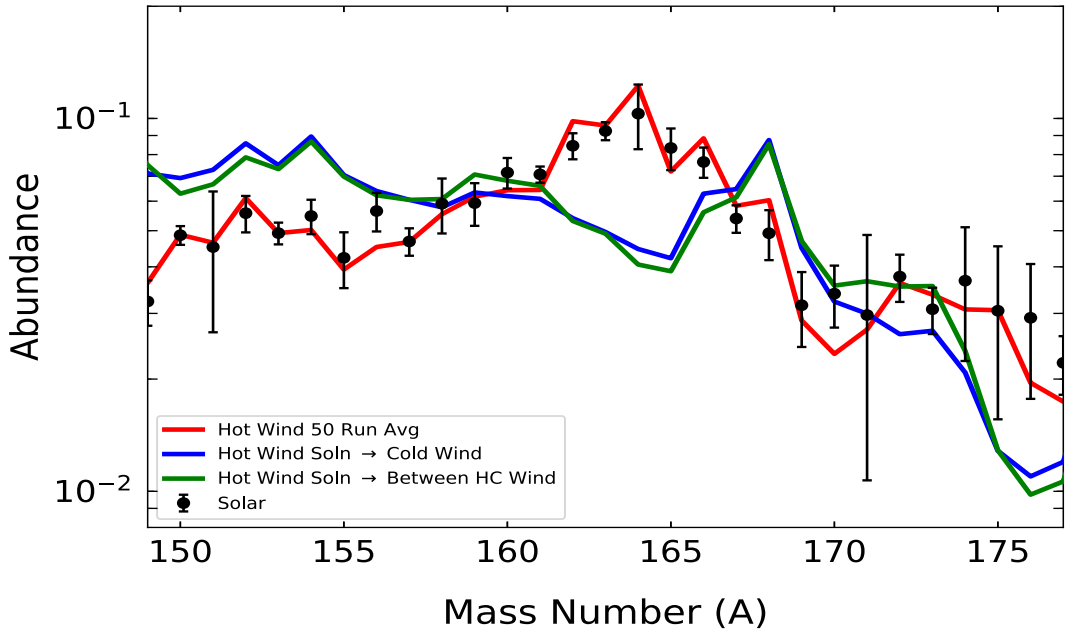




Neutron-rich rare-earths

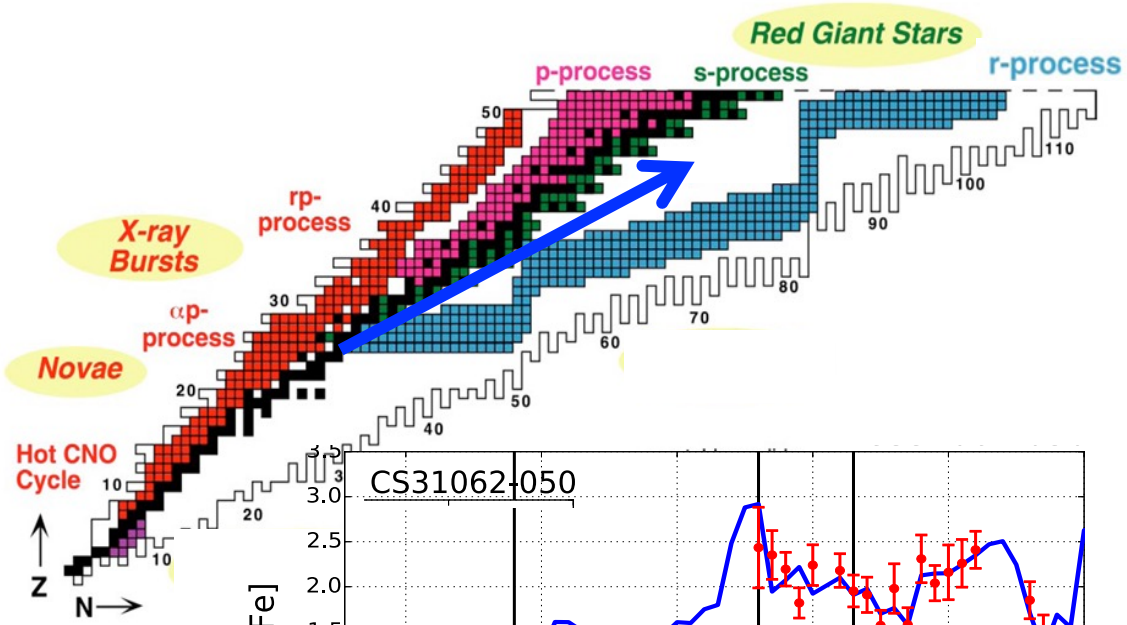
TRIUMF ARIEL
ADVANCED RARE ISOTOPE LABORATORY

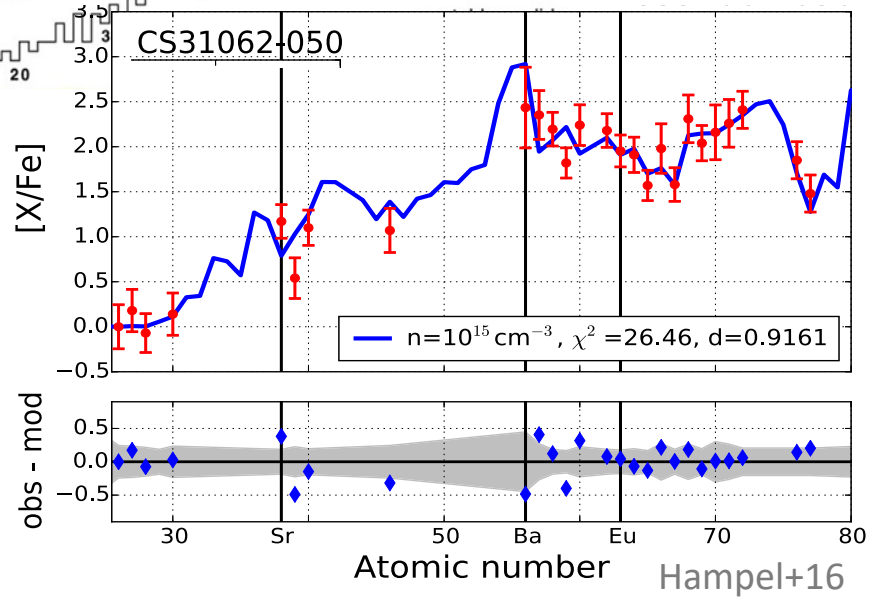




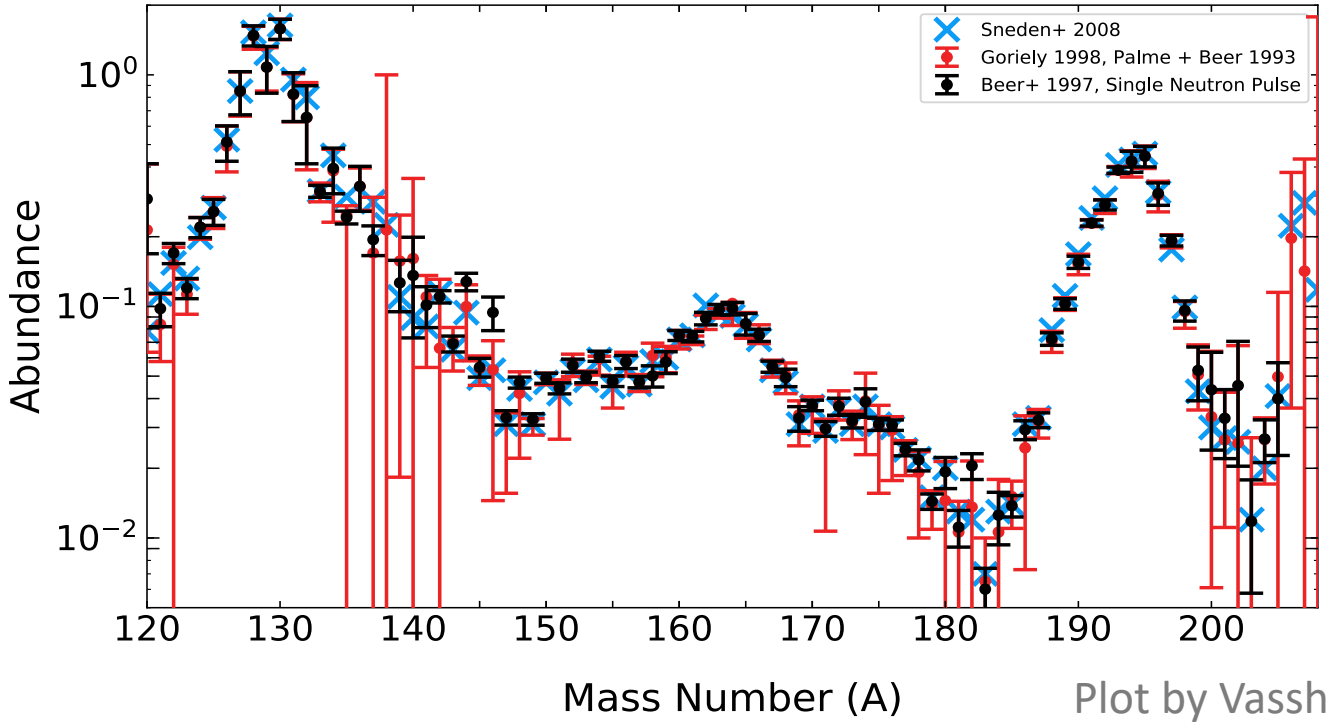
Additional neutron capture processes hidden in the solar abundances?

***r*-process** (rapid neutron capture) = **Solar** – ***s*-process** (slow neutron capture) – ***i*-process** (intermediate neutron capture) – …?





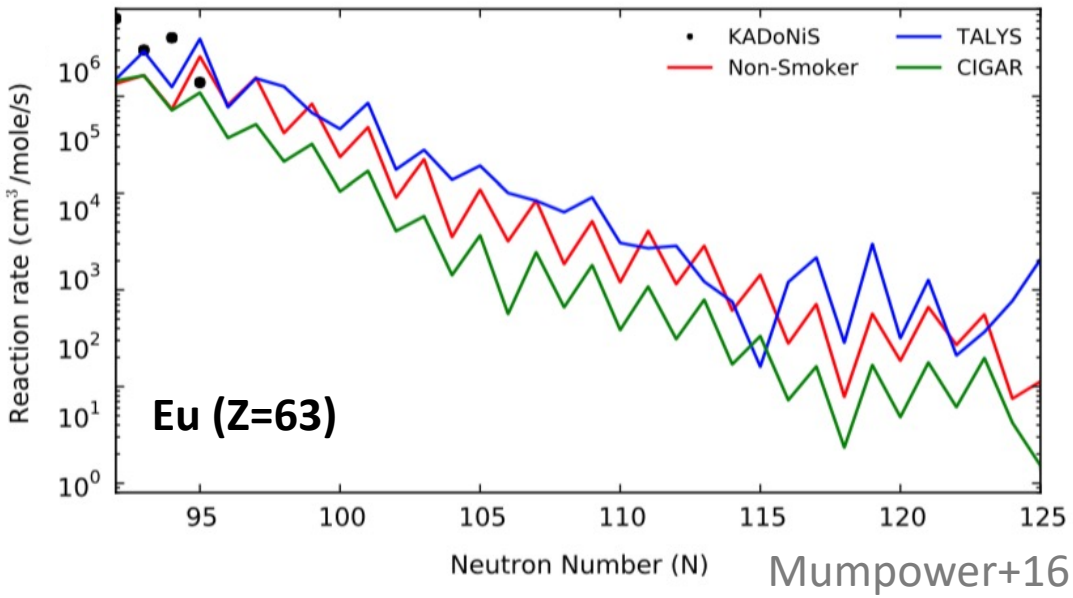
Hampel+16



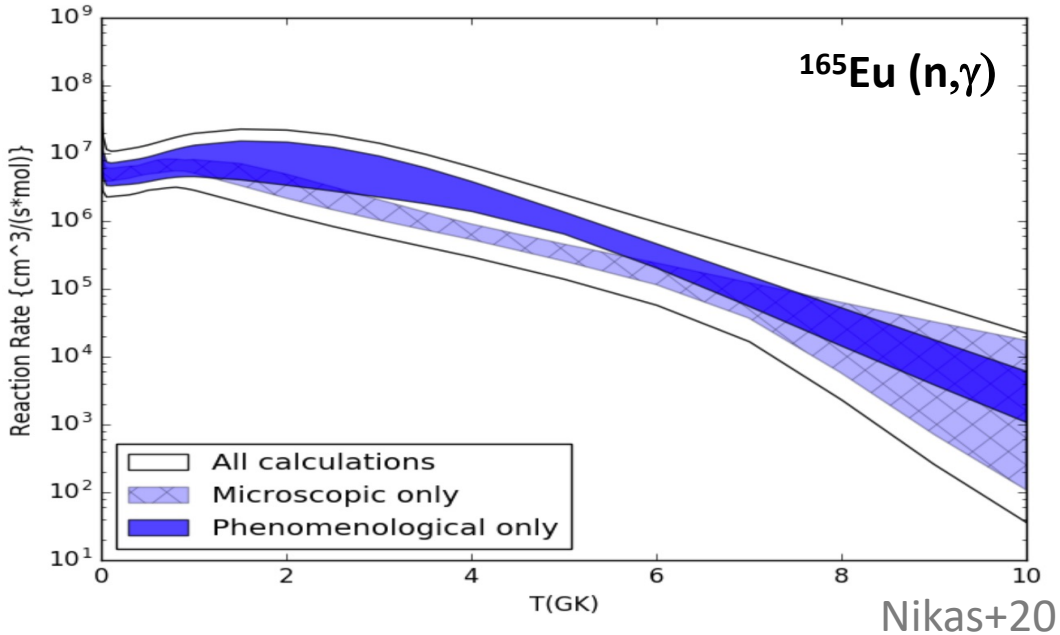
Plot by Vassh

*Studies suggest *r*+*s* cannot explain some stellar patterns

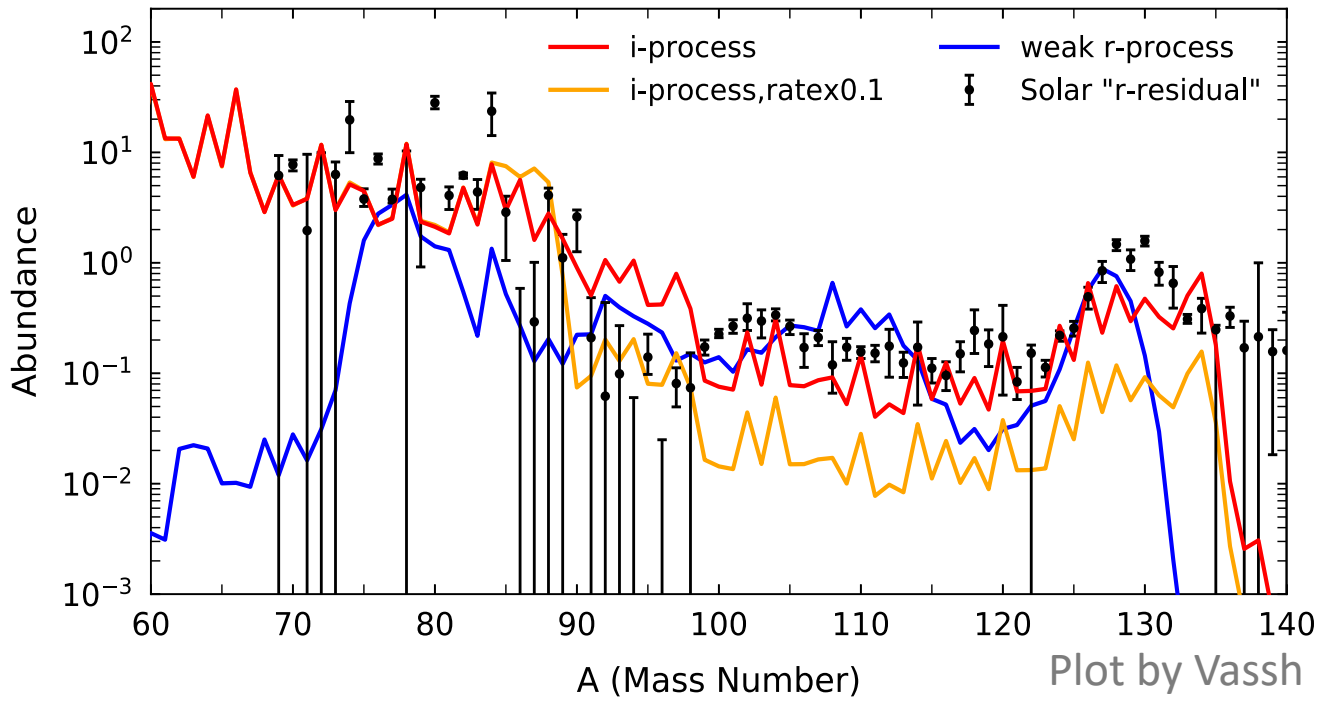
Impact of neutron capture rates



Mumpower+16



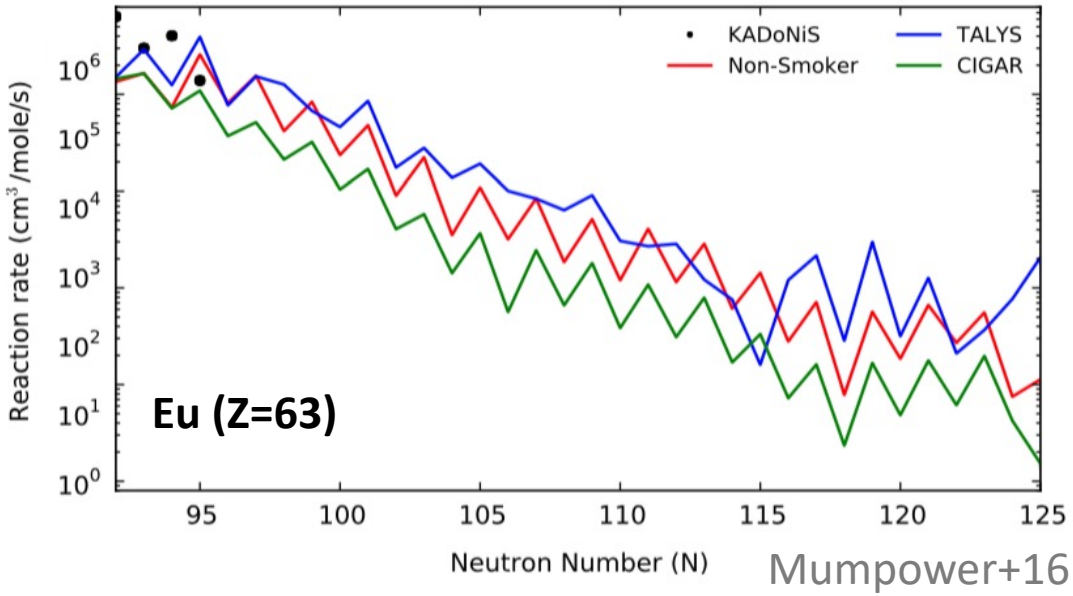
Nikas+20



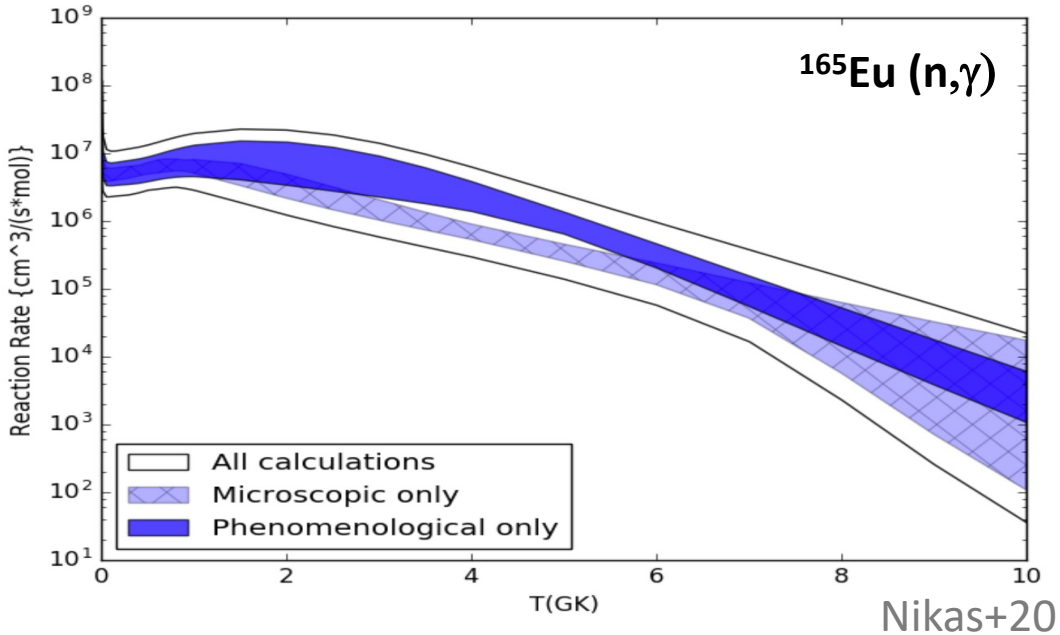
Plot by Vassh

i-process abundances when vary capture rate for ^{85,87}Br and ^{87,88,89}Kr

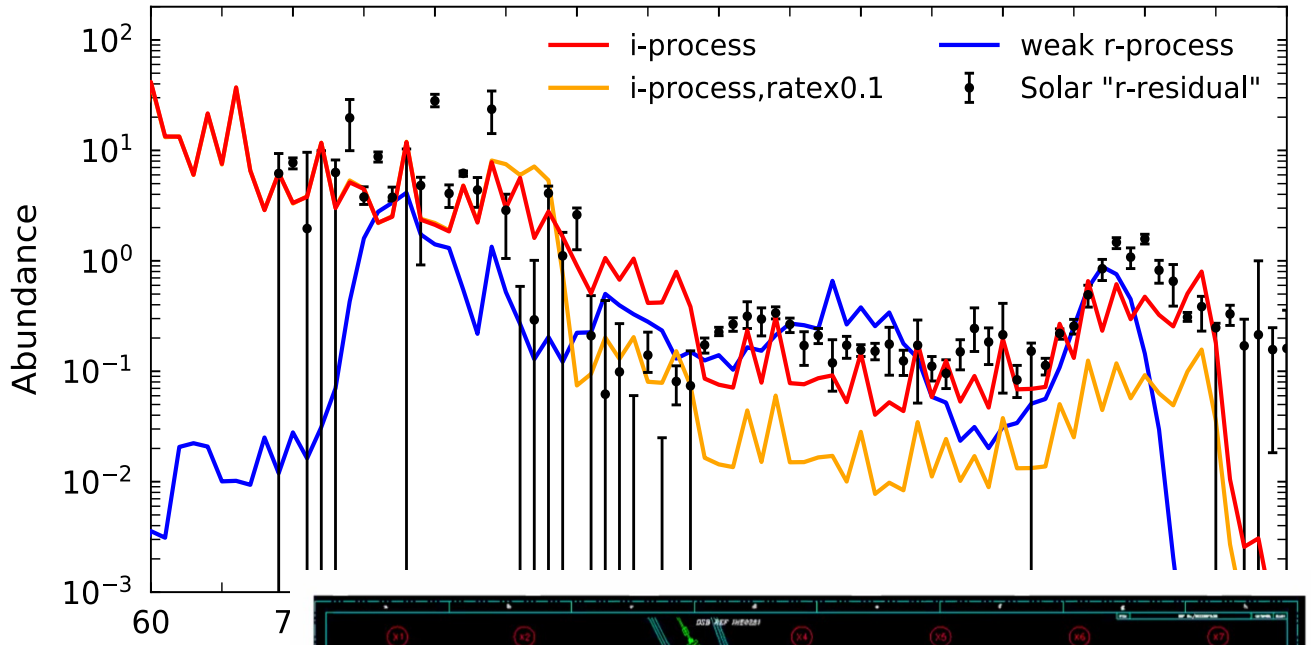
Impact of neutron capture rates

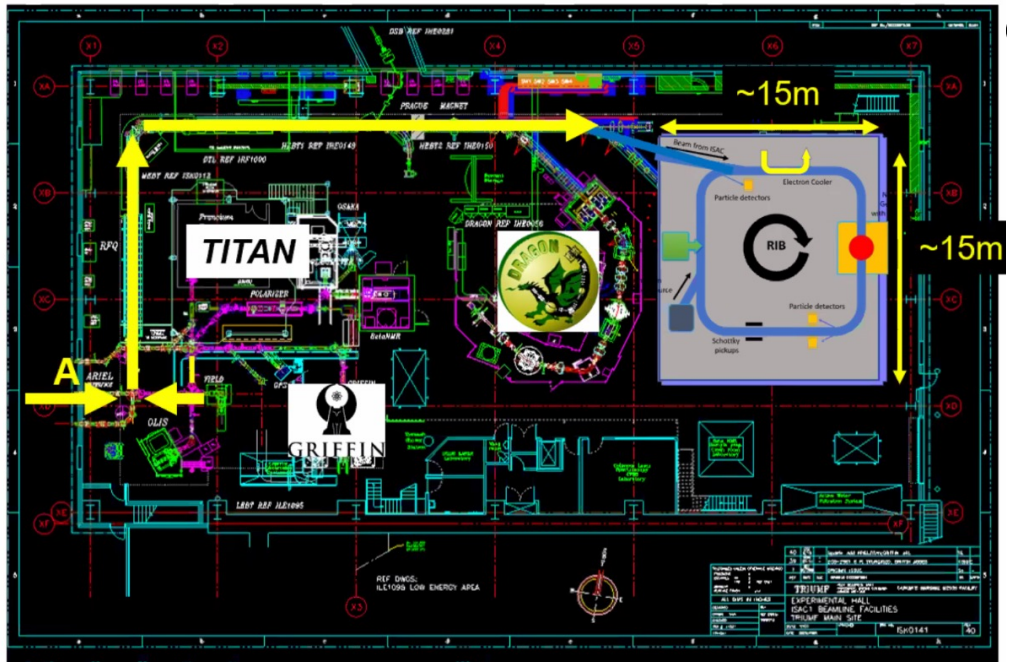


Mumpower+16



Nikas+20



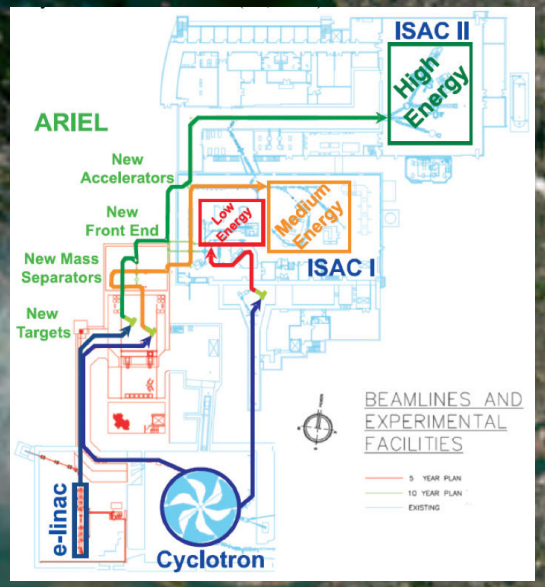


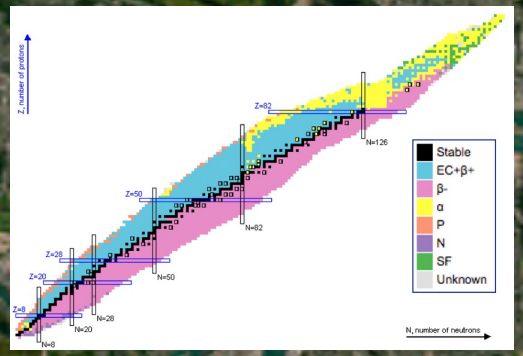
TRISR

TRIUMF neutron storage ring

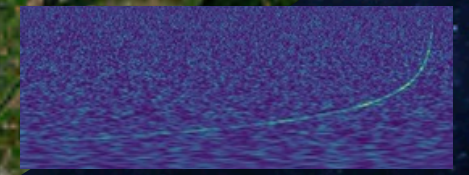
A>50 (*r*- and *i*-process)

Multi-messenger (and multi-disciplinary) nuclear astrophysics

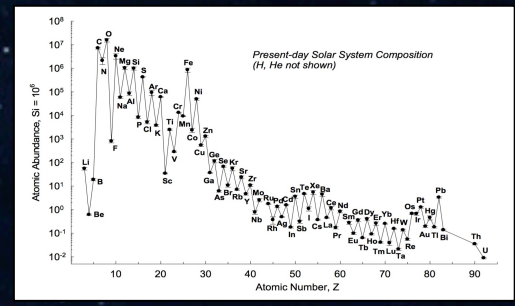




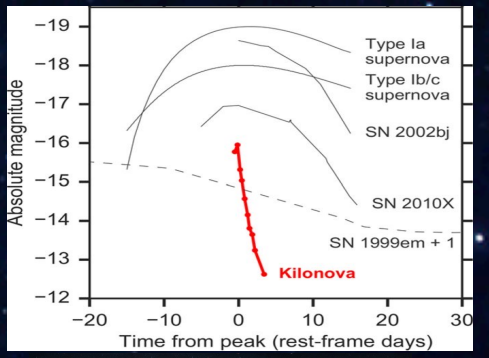
Gravitational Waves



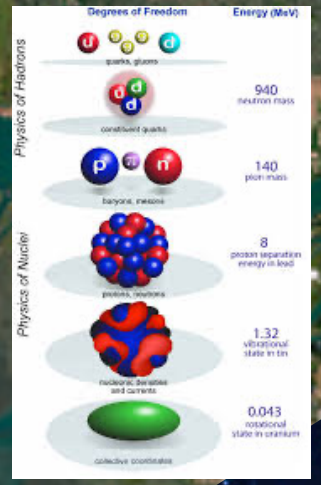
Solar and Stellar Abundances



Electromagnetic Emission



Experiment + Fundamental Theory



Nuclear Properties + Astrophysical Sites

Astrophysical Observables

Galactic Origins