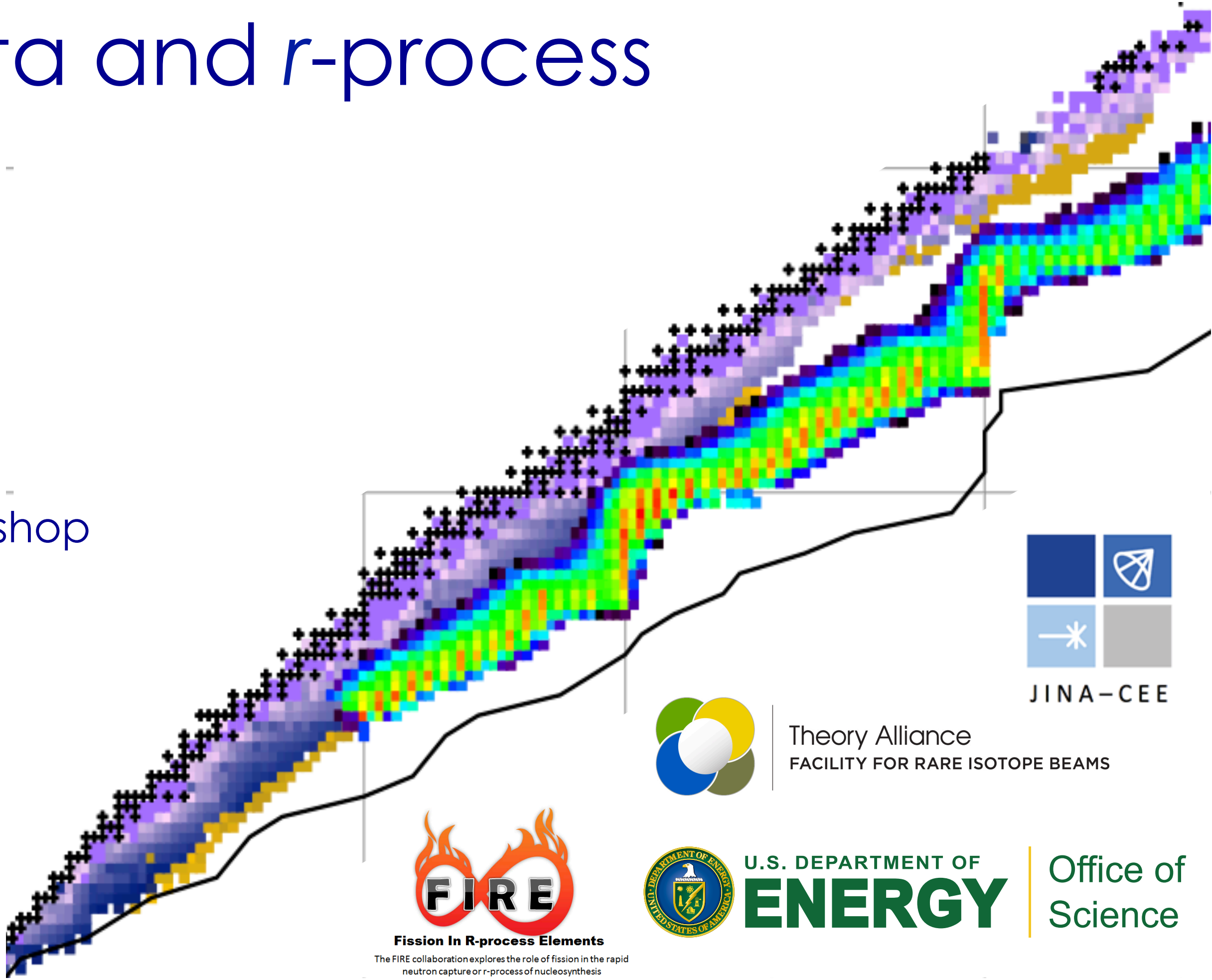
β-decay data and *r*-process analysis

Rebecca Surman
University of Notre Dame

FRIB Decay Station Workshop

25 January 2018



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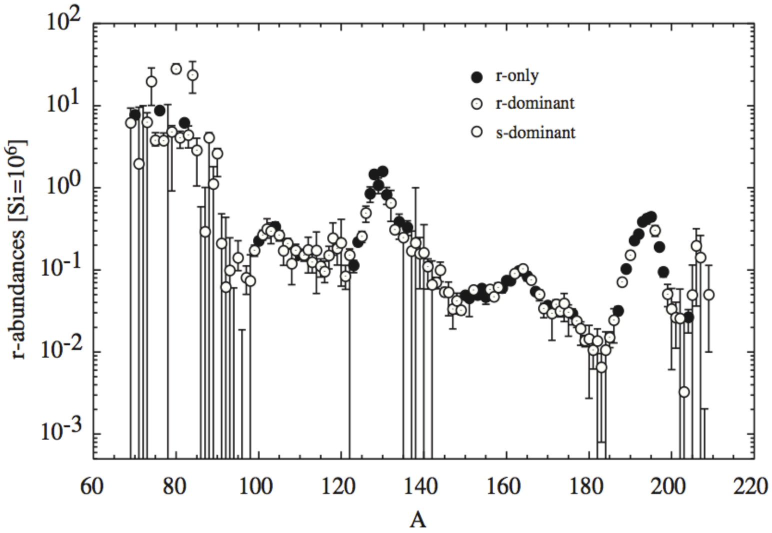
Theory Alliance
FACILITY FOR RARE ISOTOPE BEAMS

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

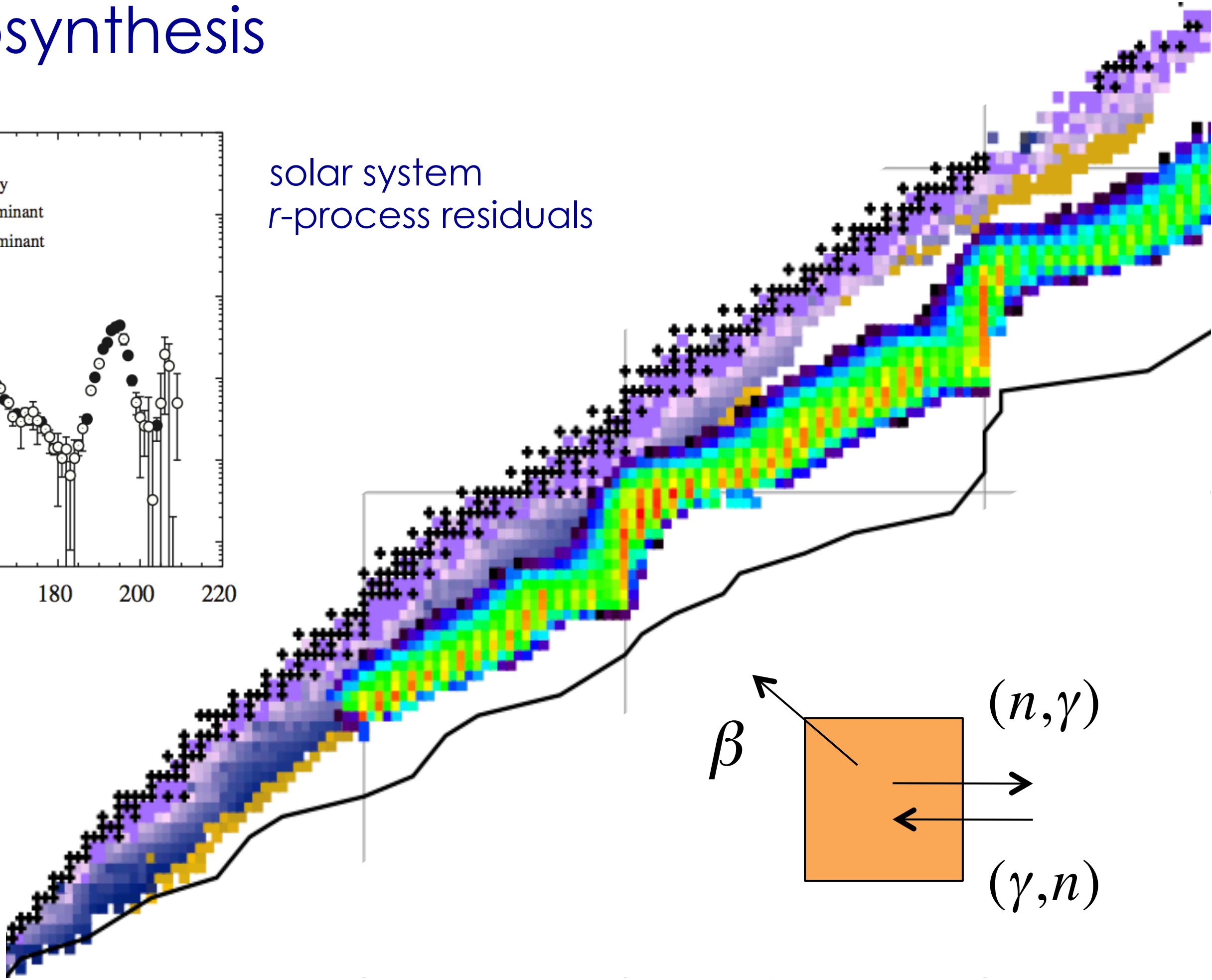
U.S. DEPARTMENT OF ENERGY
Office of Science

r-process nucleosynthesis

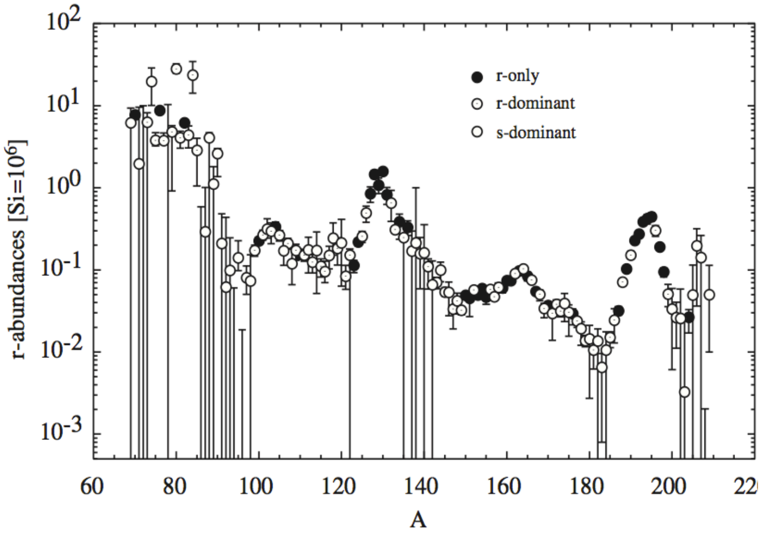


Arnould+2007

solar system
r-process residuals



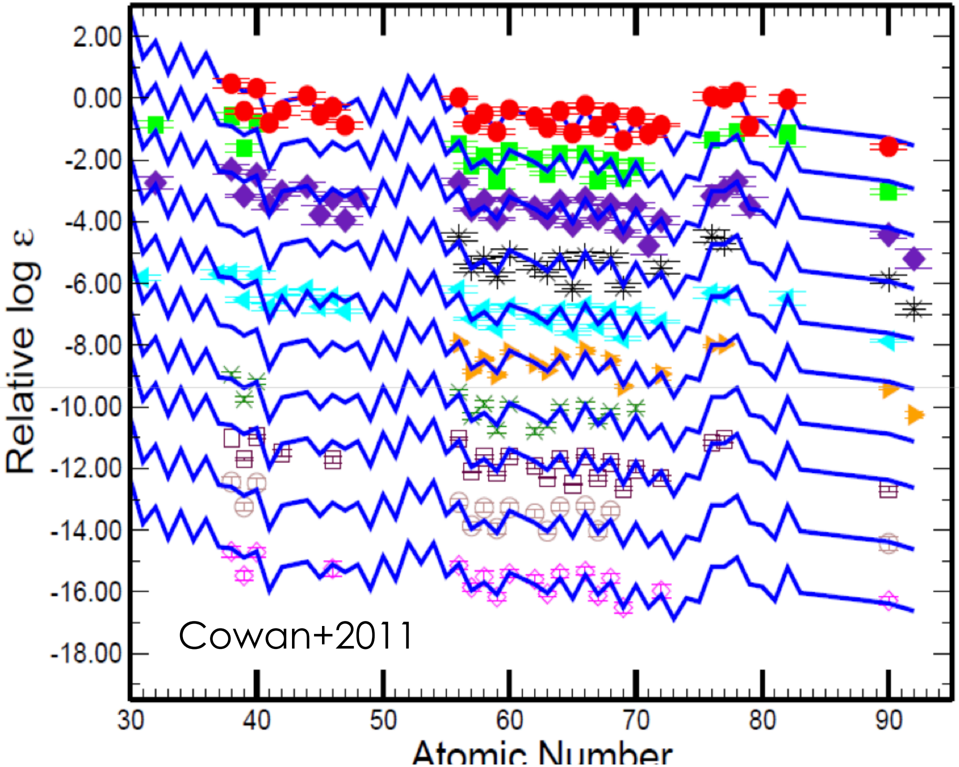
r-process elements in metal-poor stars



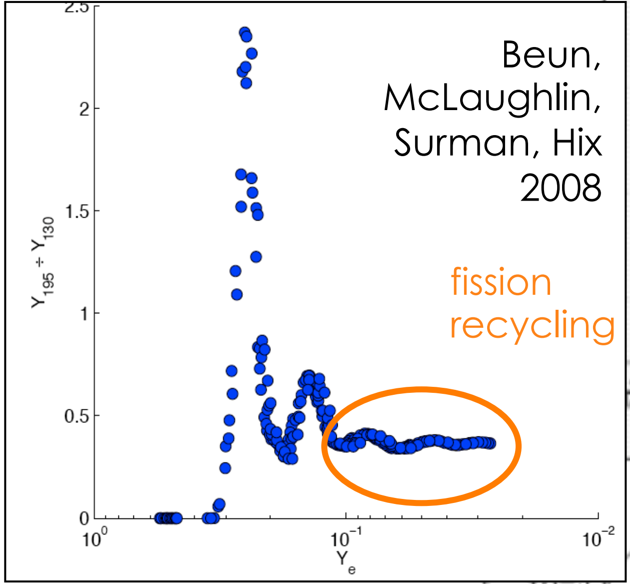
Arnould+2007

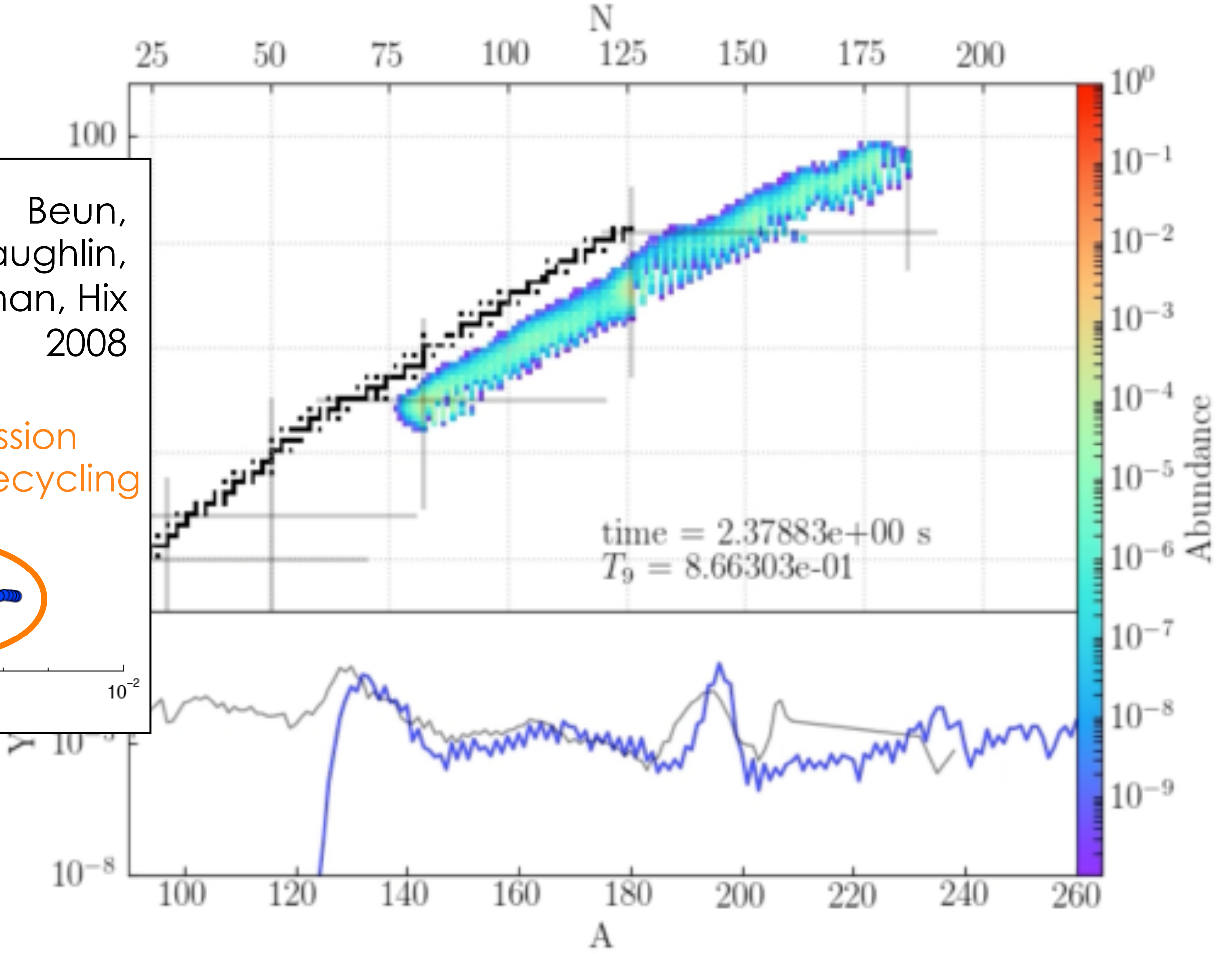
solar system
r-process residuals

elemental abundances
from *r*-process-enhanced
metal-poor stars



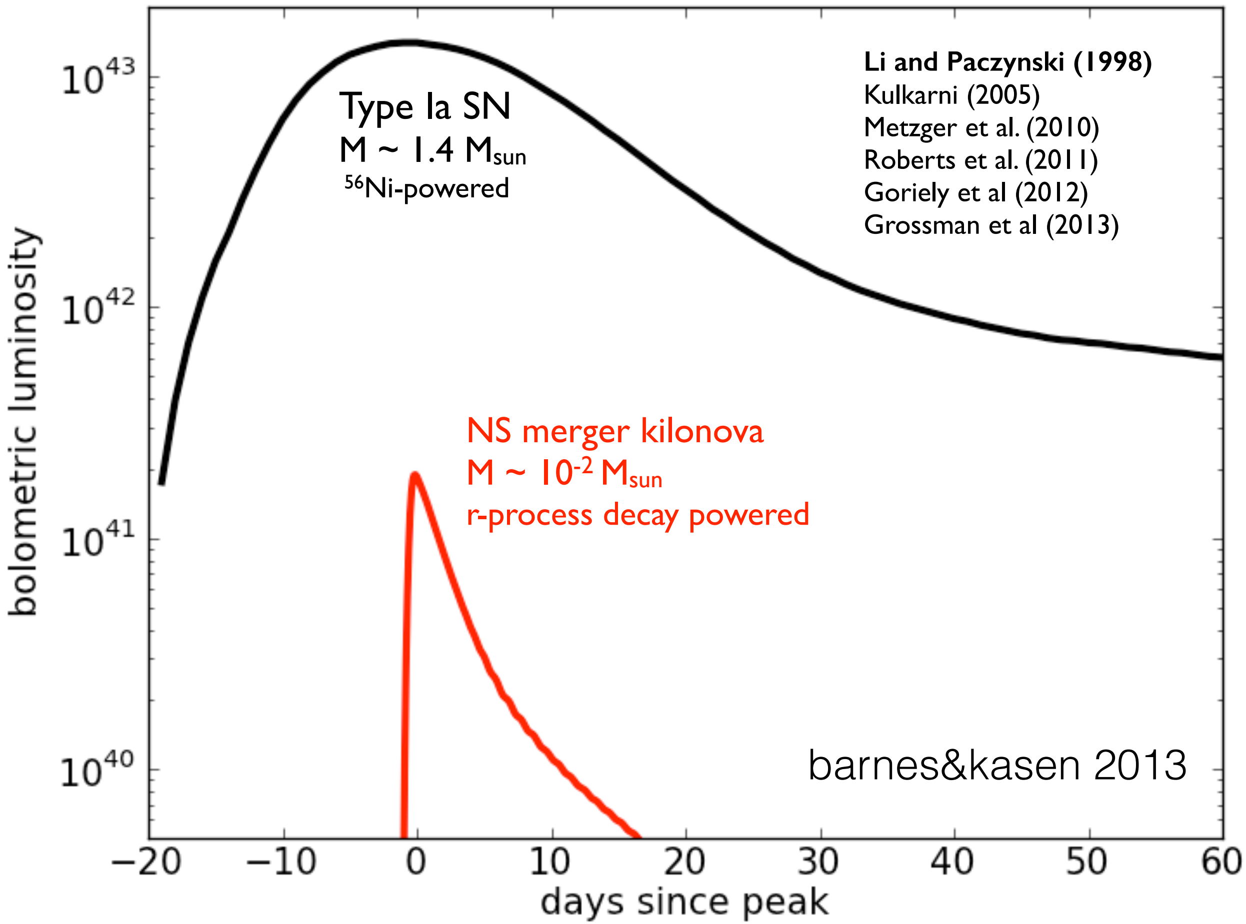
r-process simulations





network calculation by
E. Holmbeck, T. Sprouse
NSM trajectory from
Just+15

electromagnetic signatures of merger events



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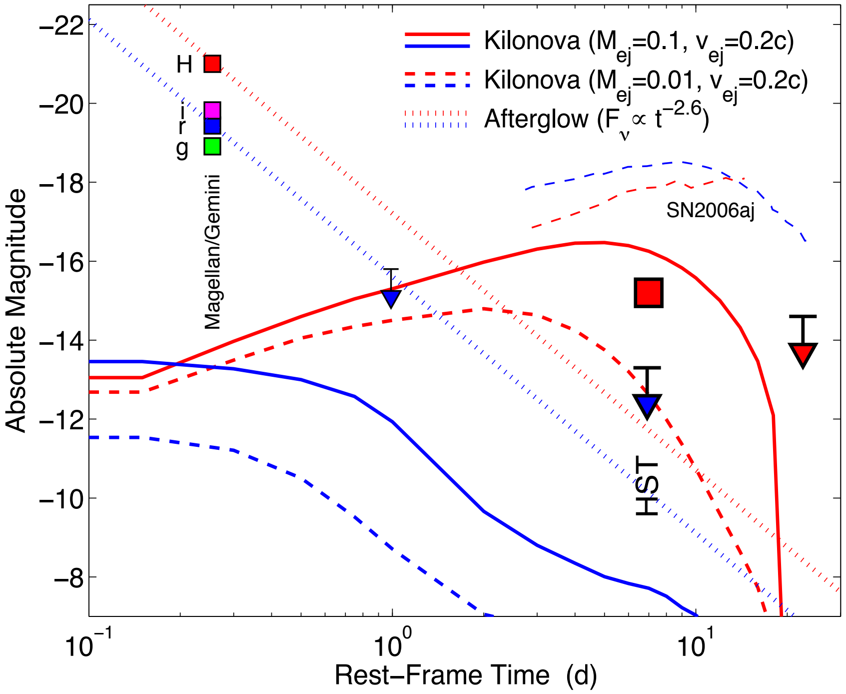
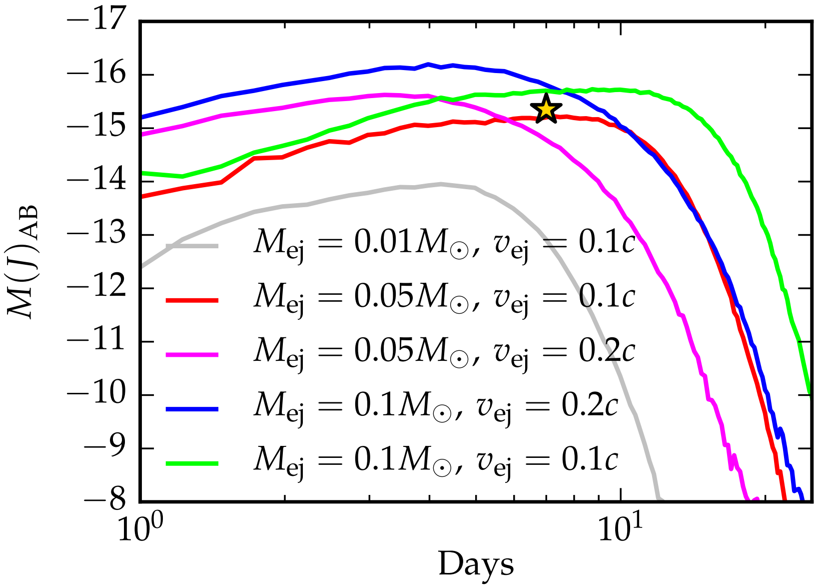
electromagnetic signatures of merger events



Berger+2013

Tanvir+2013, Berger+13:
kilonova/macronova candidate
sGRB 130603B



Barnes+2016

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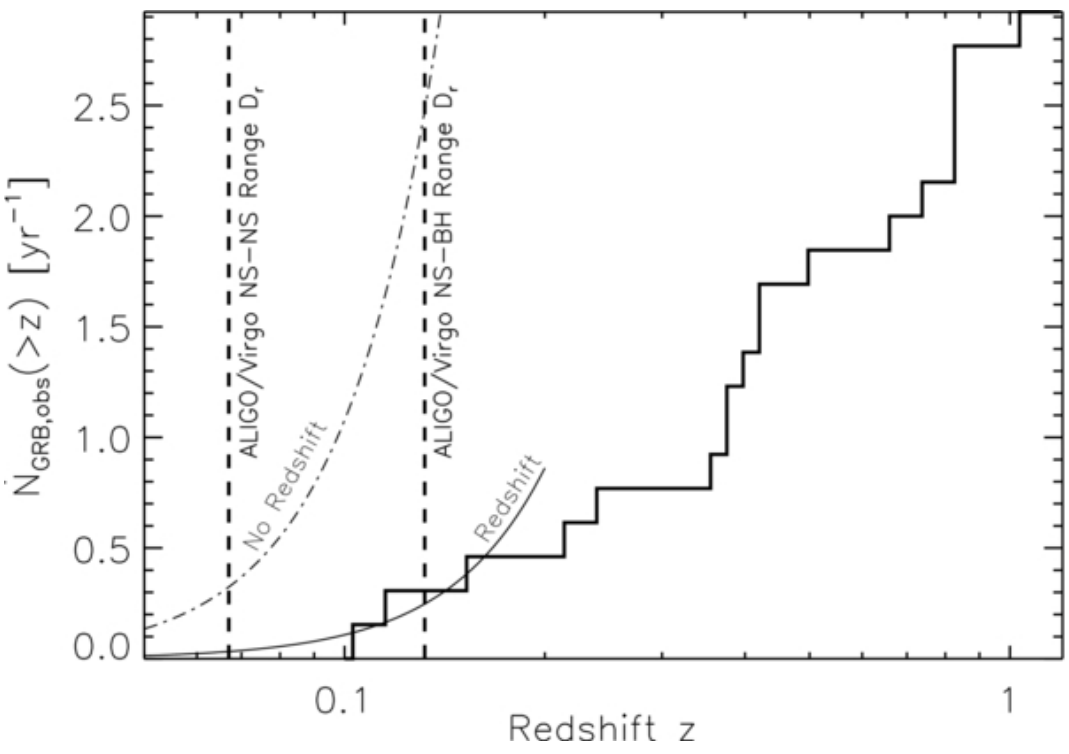
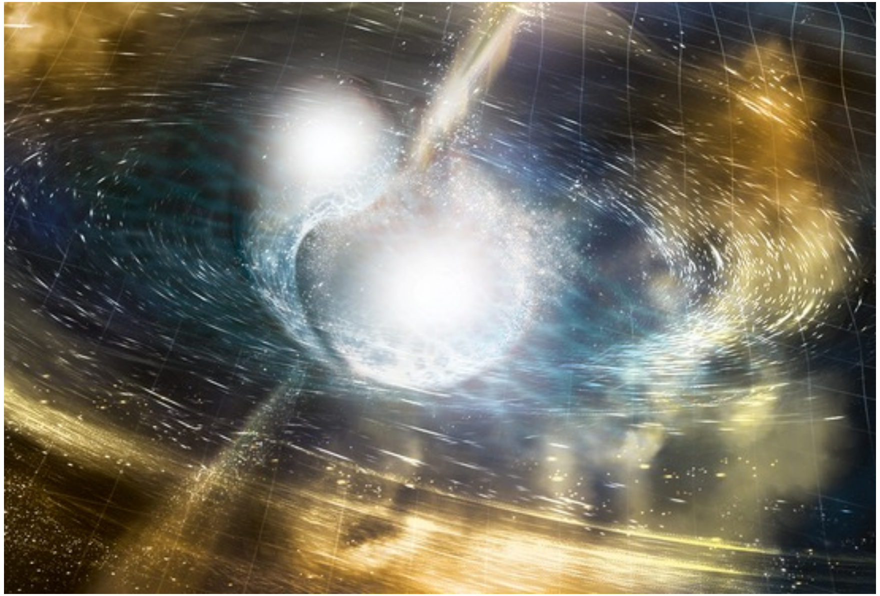
prospects for detecting gravitational waves from NS-NS/NS-BH mergers

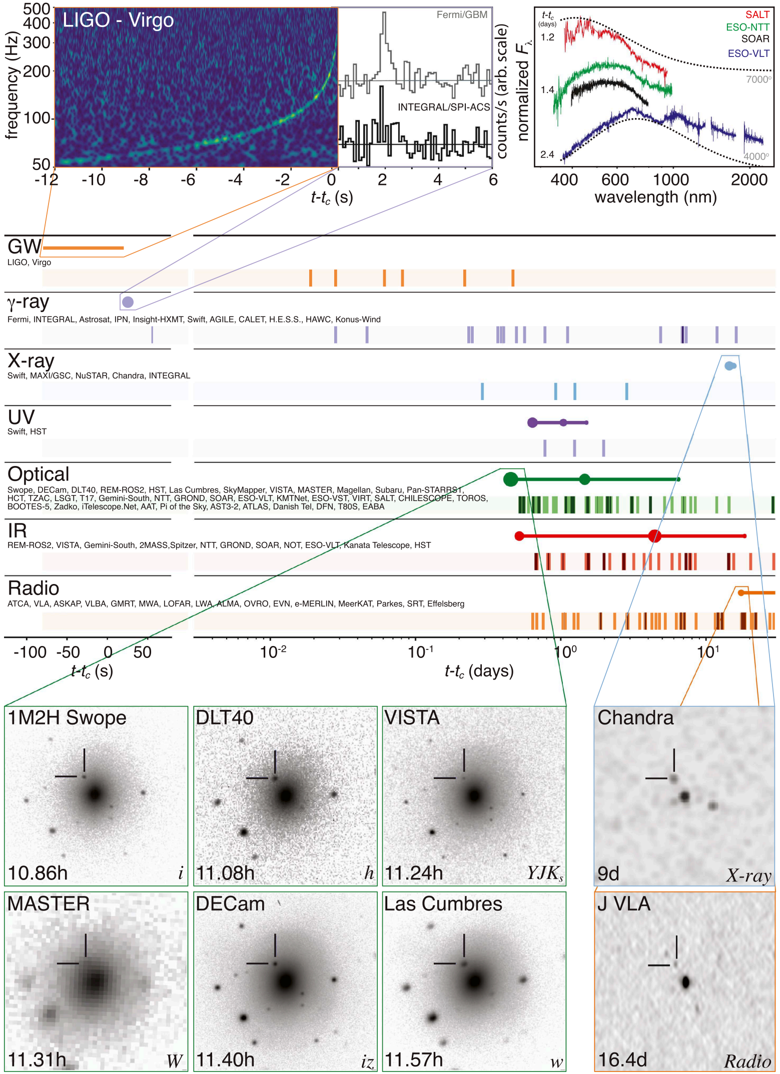


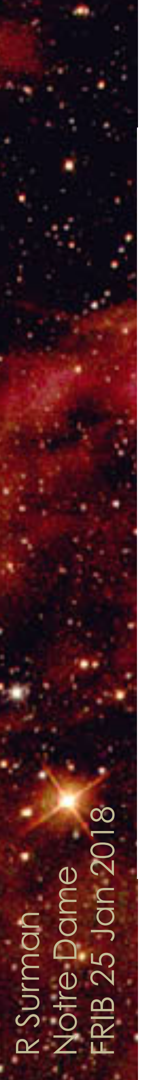
Metzger + Berger 2012

GW170817/ GRB170817A/SSS17a



LIGO/Virgo +
70 observatories

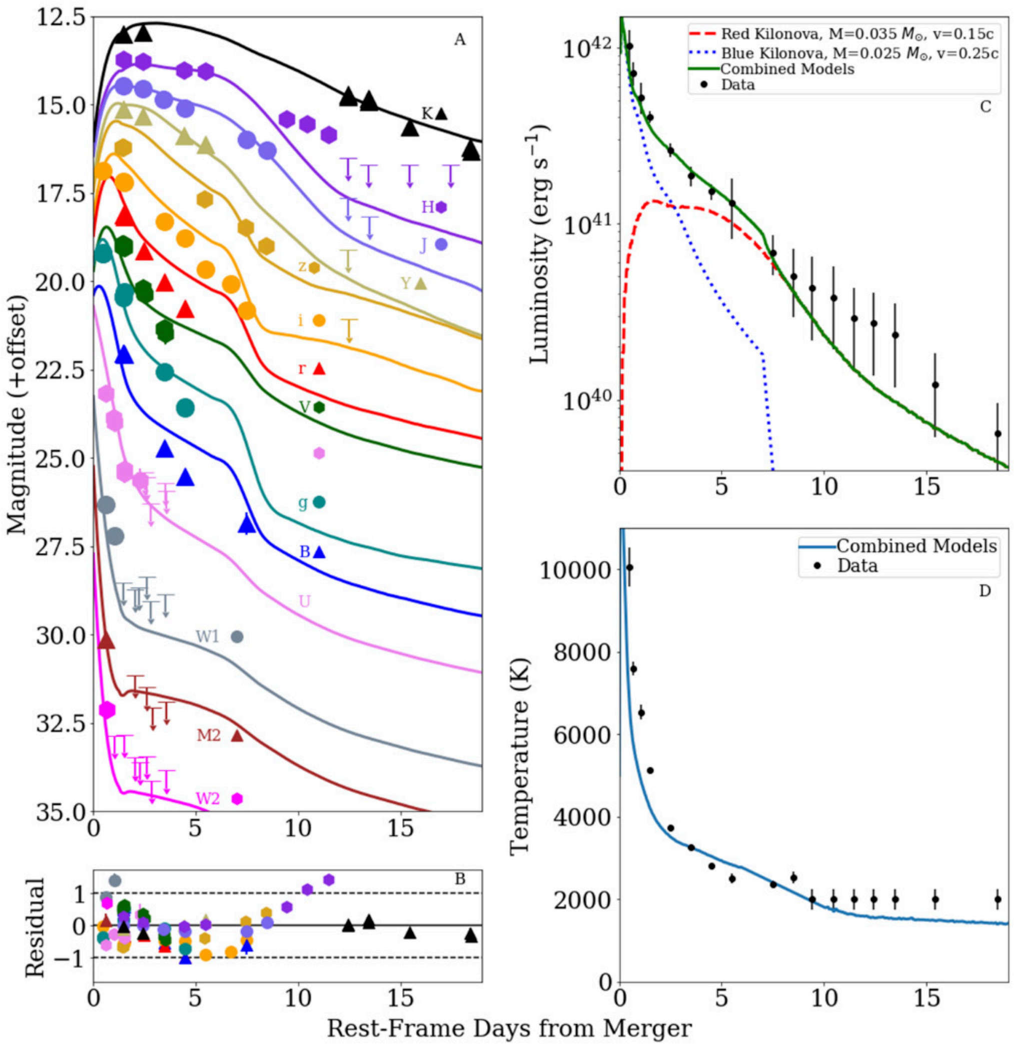




GW170817 kilonova

Reference	$m_{\rm dyn}$ [$M_\odot$]	$m_{\rm w}$ [$M_\odot$]
Abbott et al. (2017a)	0.001 – 0.01	–
Arcavi et al. (2017)	–	0.02 – 0.025
Cowperthwaite et al. (2017)	0.04	0.01
Chornock et al. (2017)	0.035	0.02
Evans et al. (2017)	0.002 – 0.03	0.03 – 0.1
Kasen et al. (2017)	0.04	0.025
Kasliwal et al. (2017b)	> 0.02	> 0.03
Nicholl et al. (2017)	0.03	–
Perego et al. (2017)	0.005 – 0.01	10^{-5} – 0.024
Rosswog et al. (2017)	0.01	0.03
Smartt et al. (2017)	0.03 – 0.05	0.018
Tanaka et al. (2017a)	0.01	0.03
Tanvir et al. (2017)	0.002 – 0.01	0.015
Troja et al. (2017)	0.001 – 0.01	0.015 – 0.03

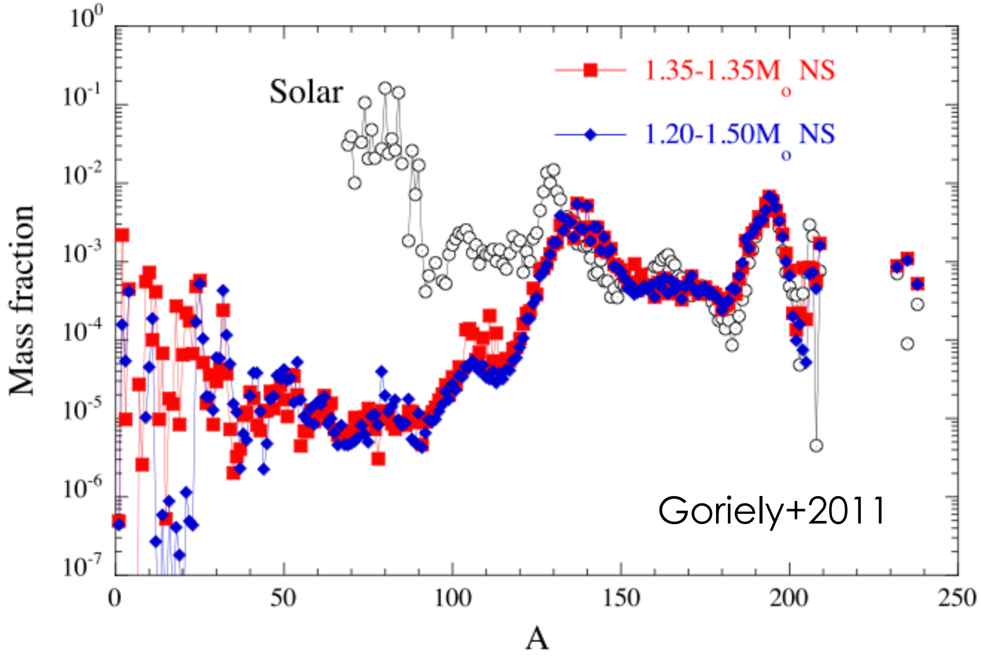
Cote+18

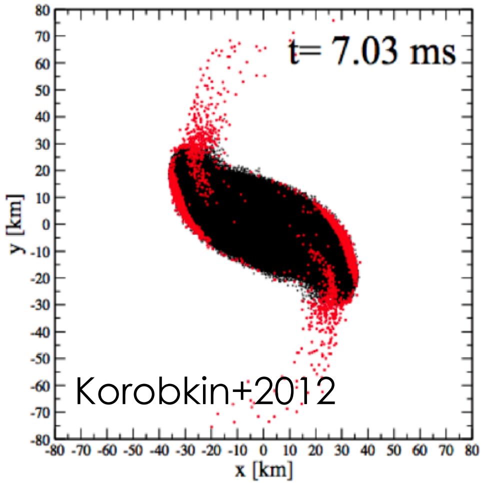


Kilpatrick+17
Kasen+17

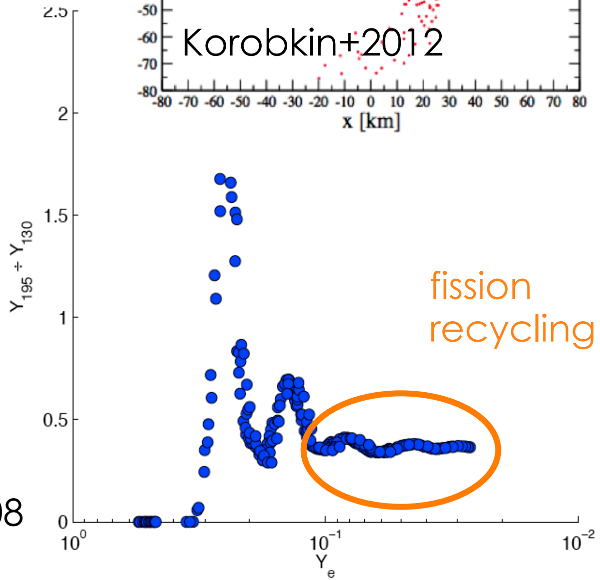
NSM environments for element synthesis

cold/mildly heated prompt ejecta

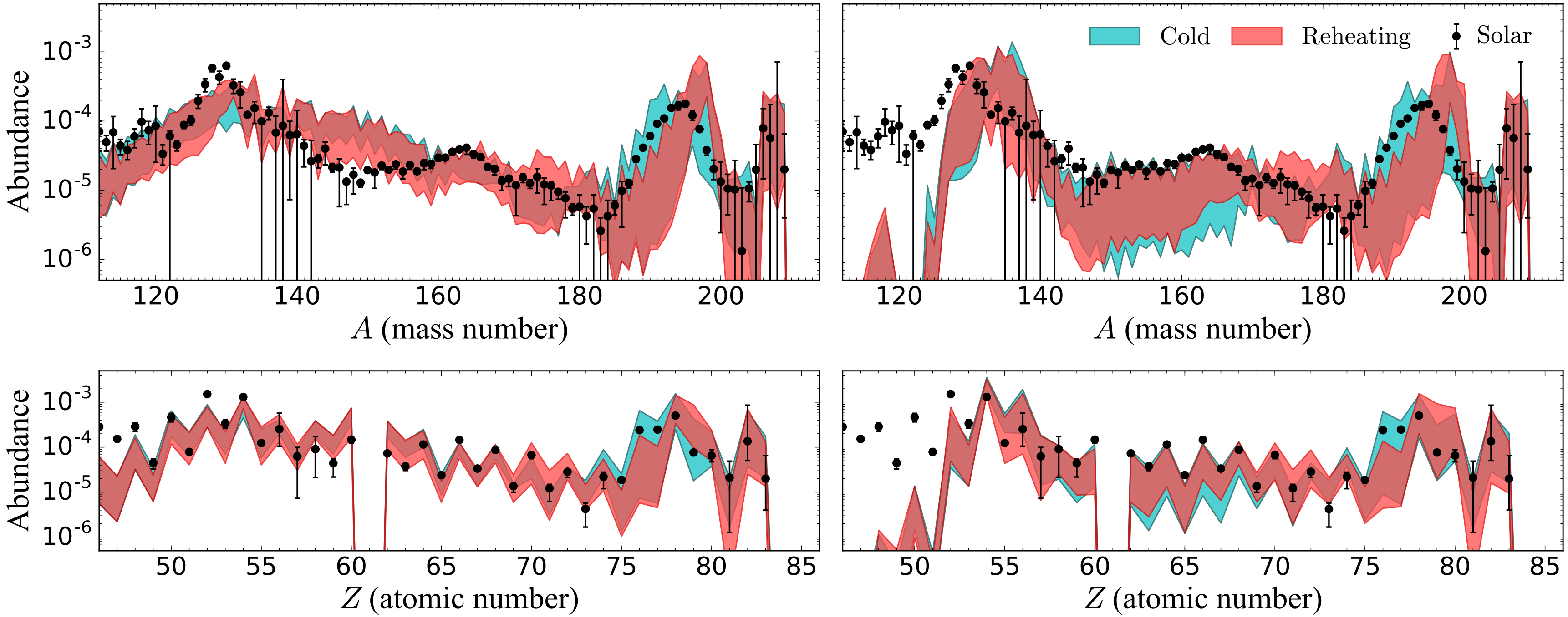




Beun, McLaughlin, Surman, Hix 2008

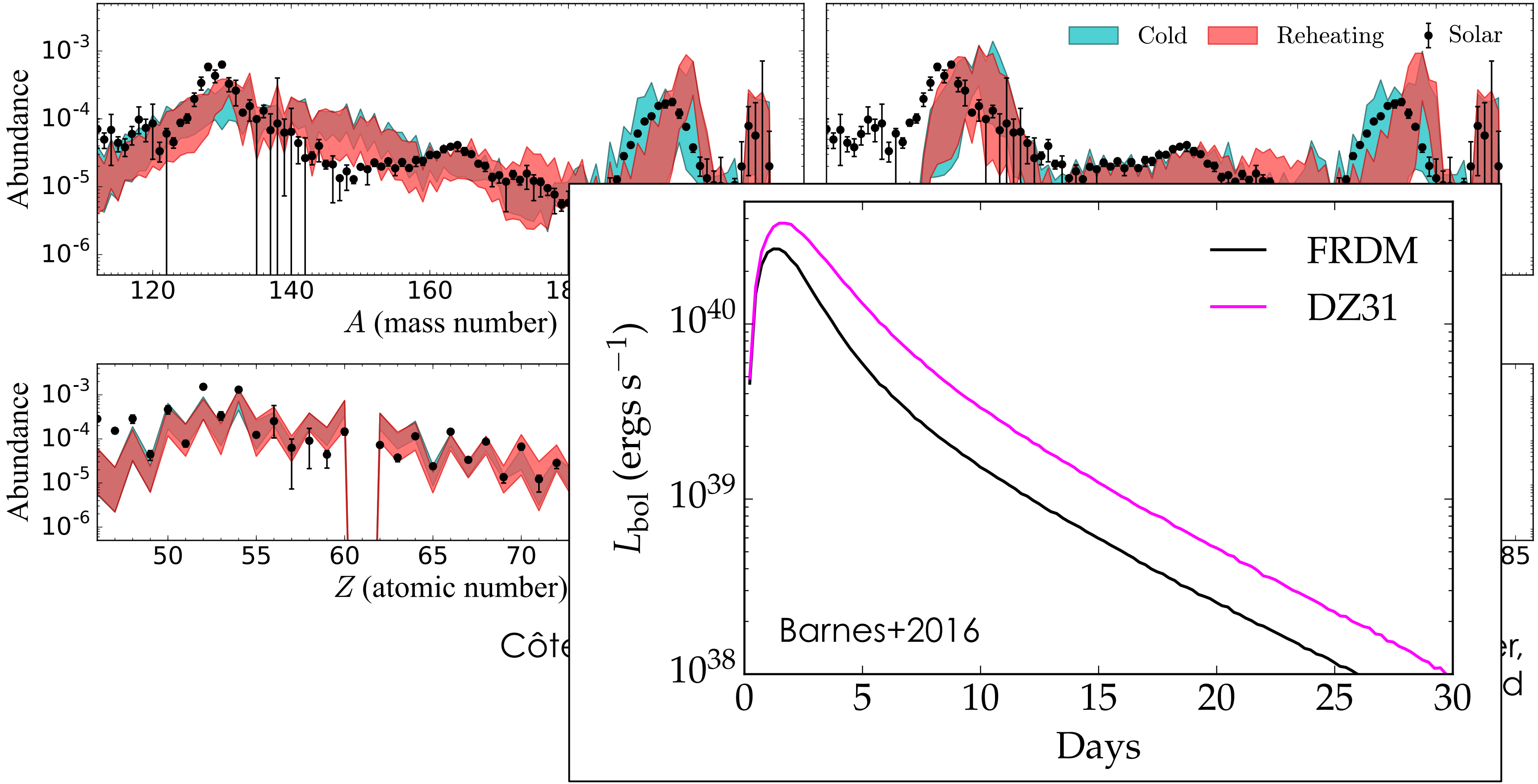


impact of systematic mass uncertainties



Côté, Fryer, Belczynski, Korobkin, Chruślińska, Vassh, Mumpower, Lippuner, Sprouse, Surman, Wollaeger, submitted

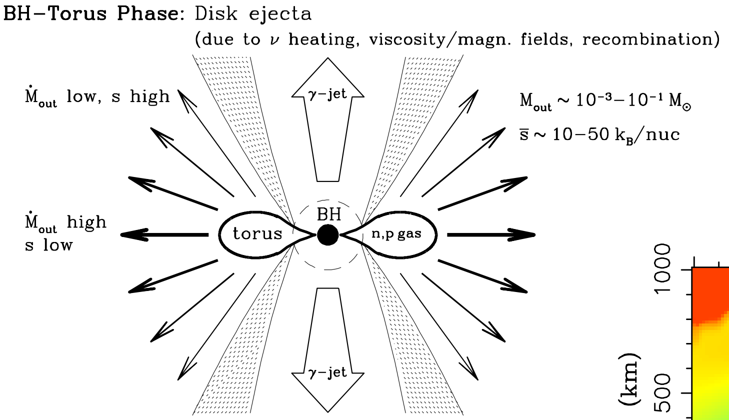
impact of systematic mass uncertainties



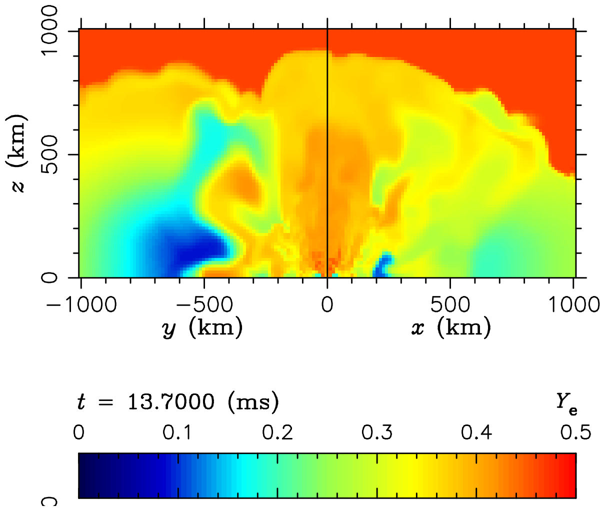
Côte ... er, ... d

NSM environments for element synthesis

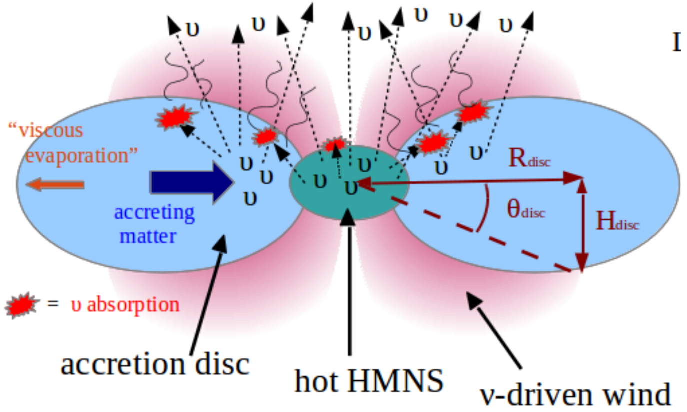
ejecta from the accretion disk



viscous outflows
e.g., Just+2015

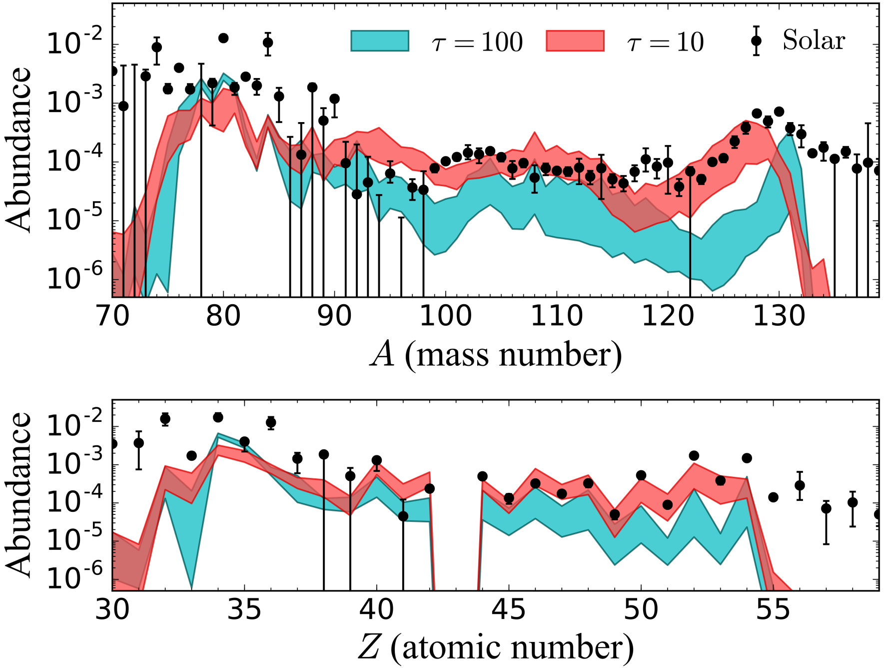


Shock-heated, neutrino-processed ejecta
e.g., Wanajo+2014



neutrino-driven wind
e.g., Perego+2014

impact of systematic mass uncertainties



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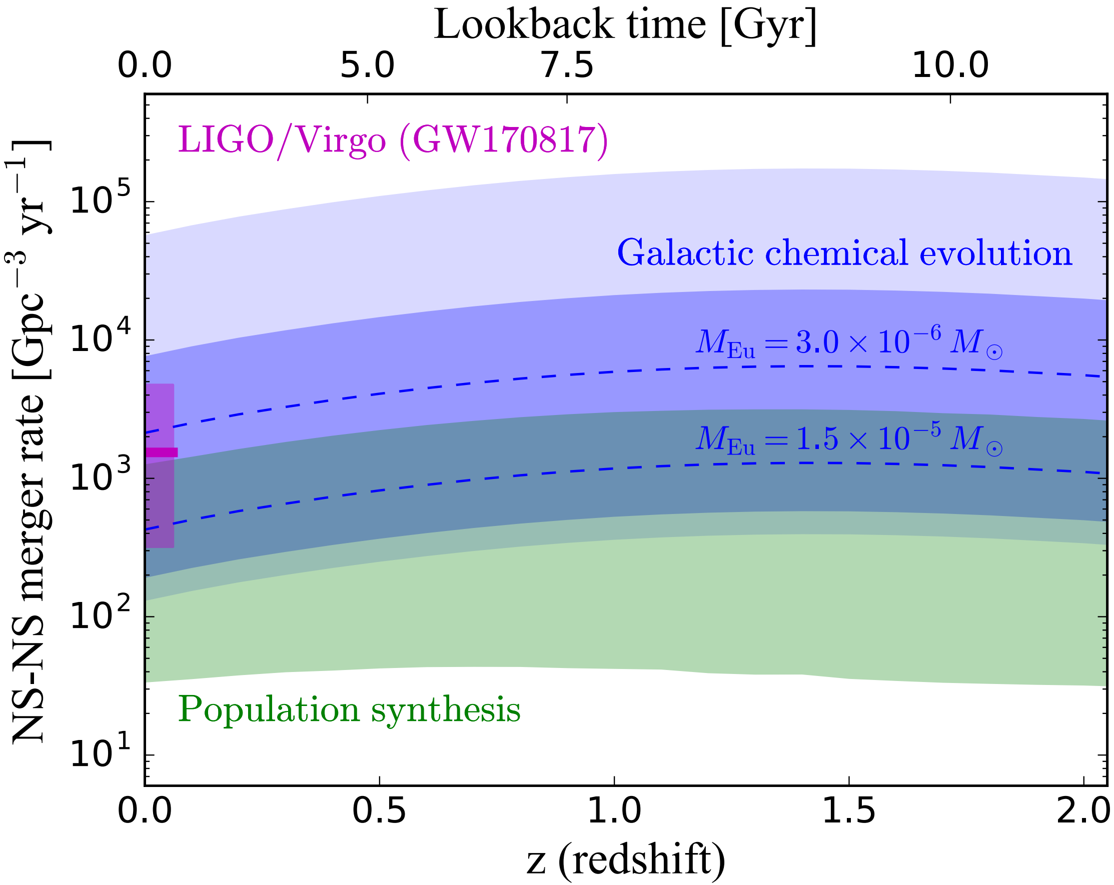
GRB170817A/SSS17a + galactic chemical evolution



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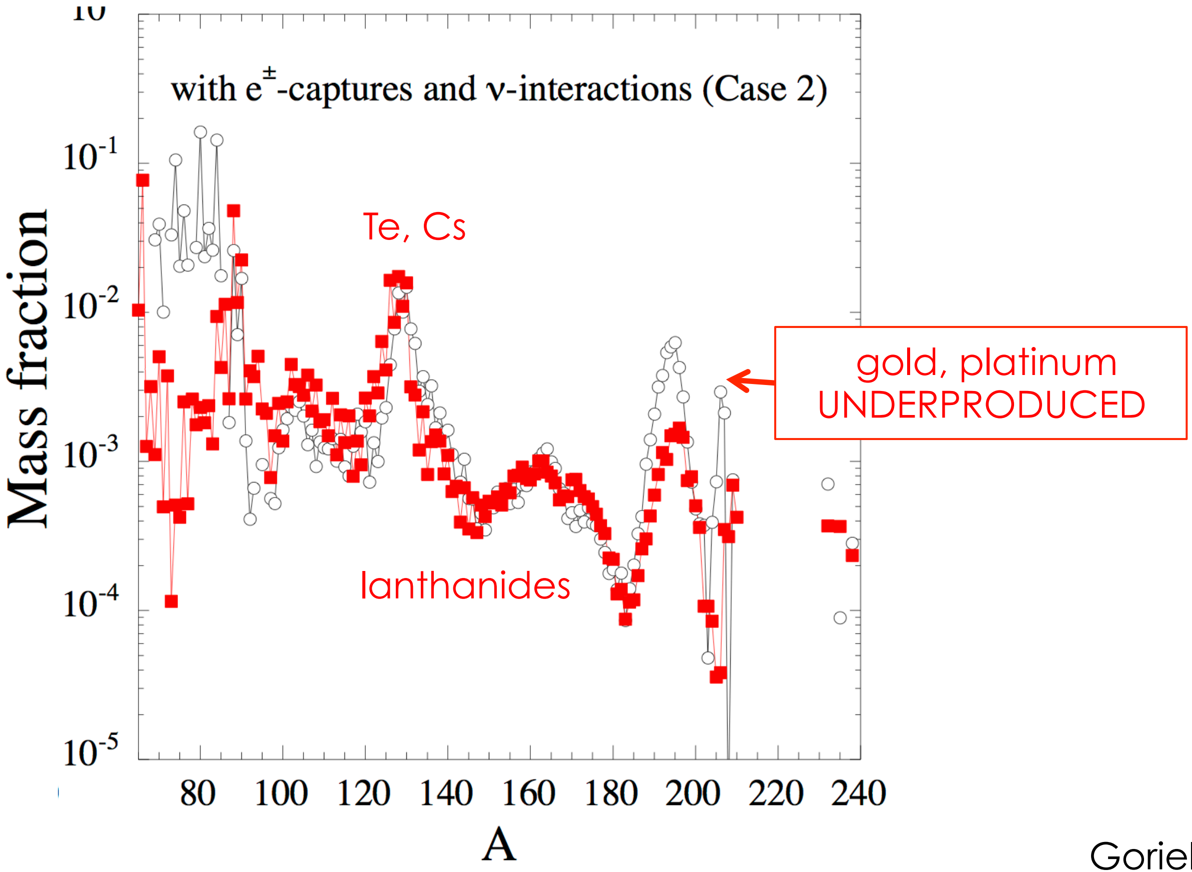
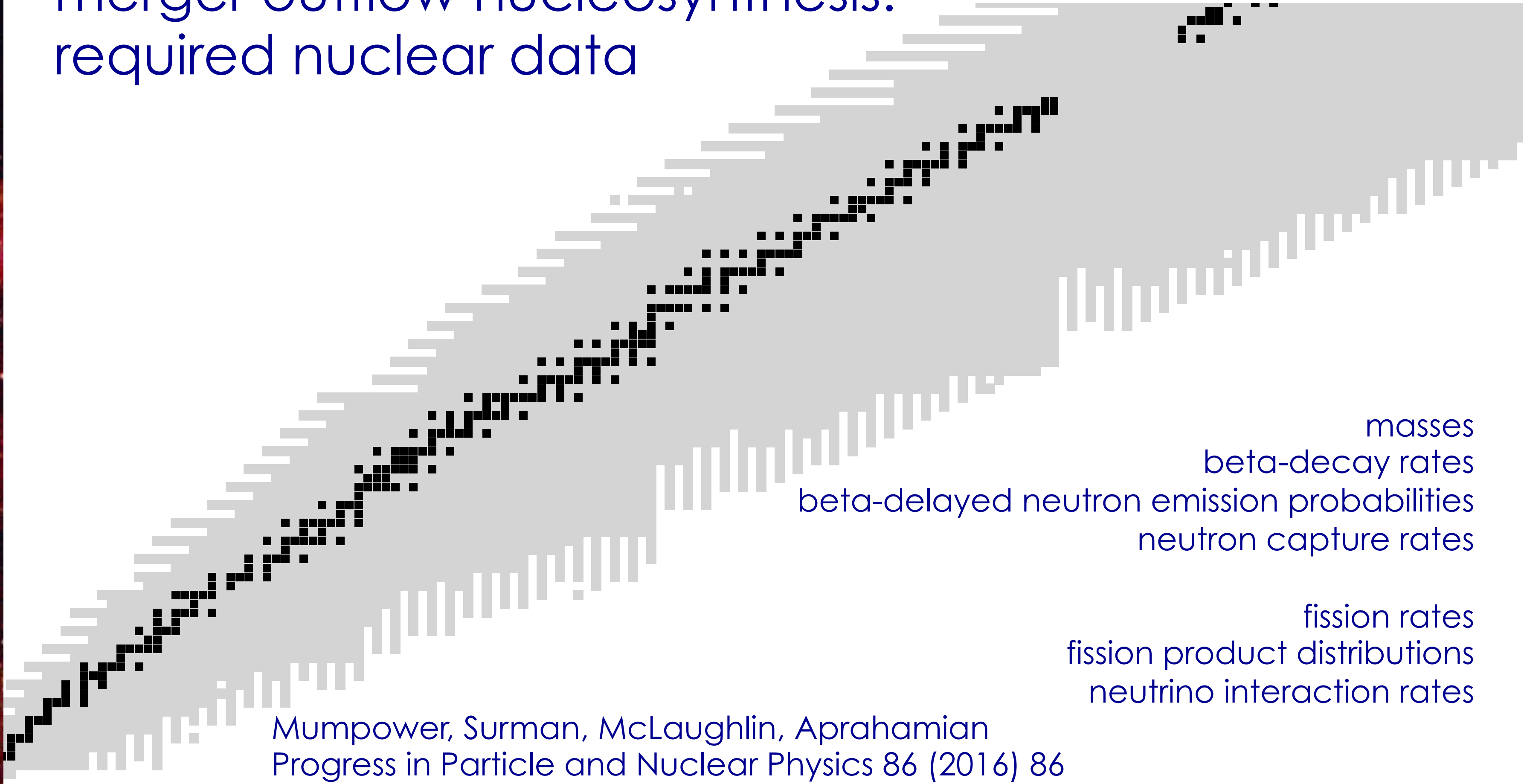
integrated nucleosynthesis with neutrinos



Goriely+2015

merger outflow nucleosynthesis: required nuclear data

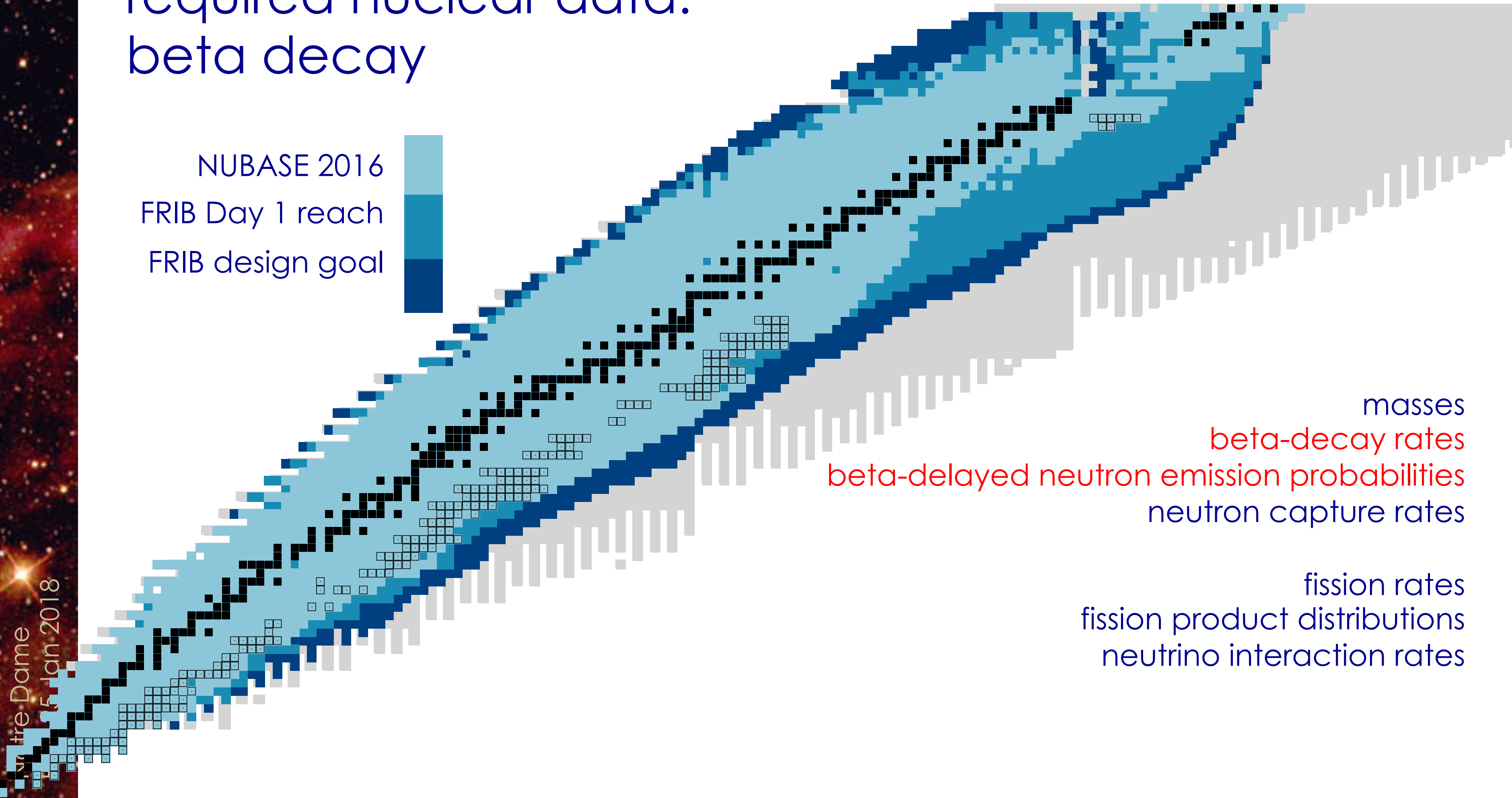


masses
beta-decay rates
beta-delayed neutron emission probabilities
neutron capture rates

fission rates
fission product distributions
neutrino interaction rates

Mumpower, Surman, McLaughlin, Aprahamian
Progress in Particle and Nuclear Physics 86 (2016) 86

required nuclear data: beta decay



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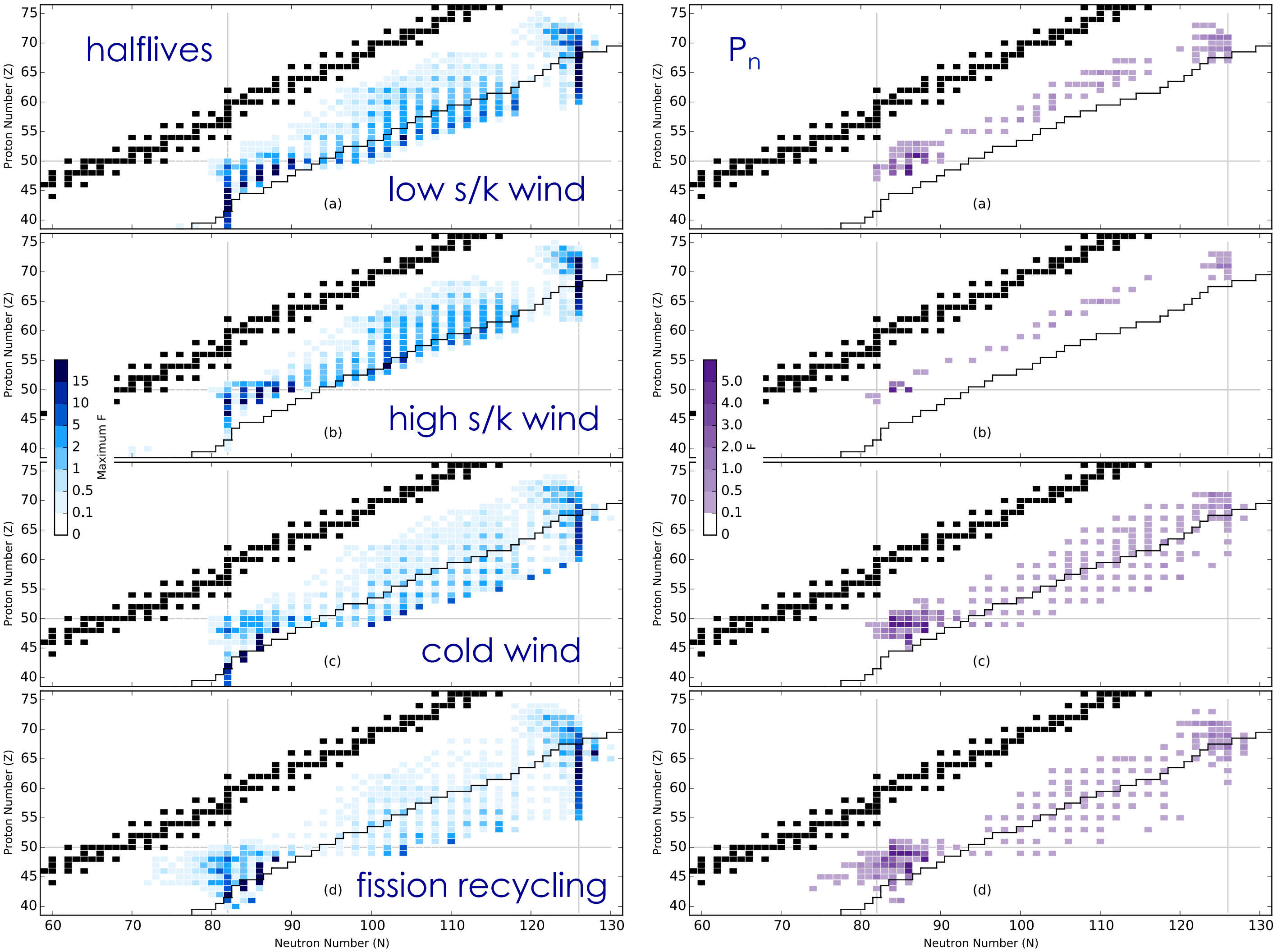

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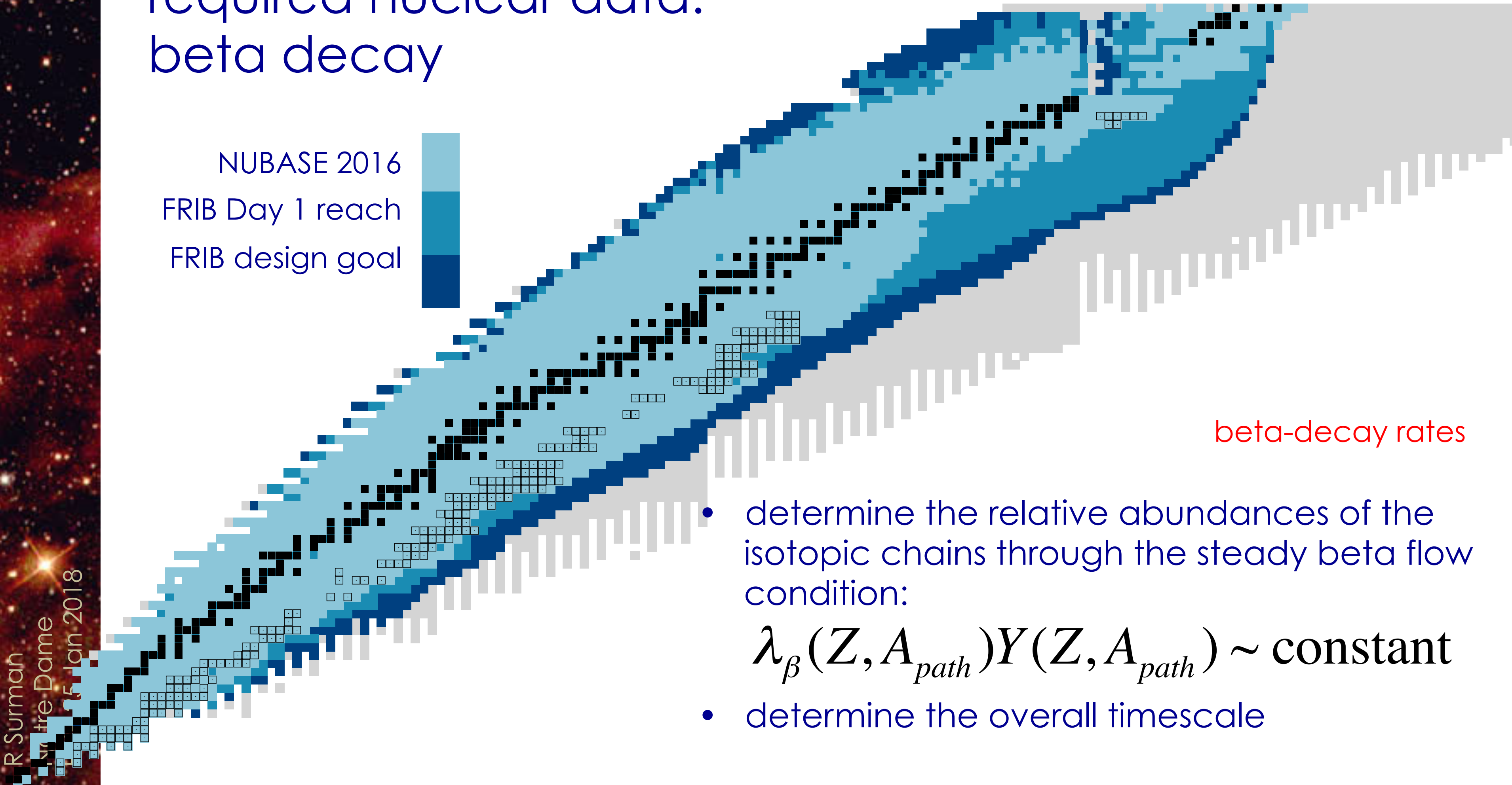
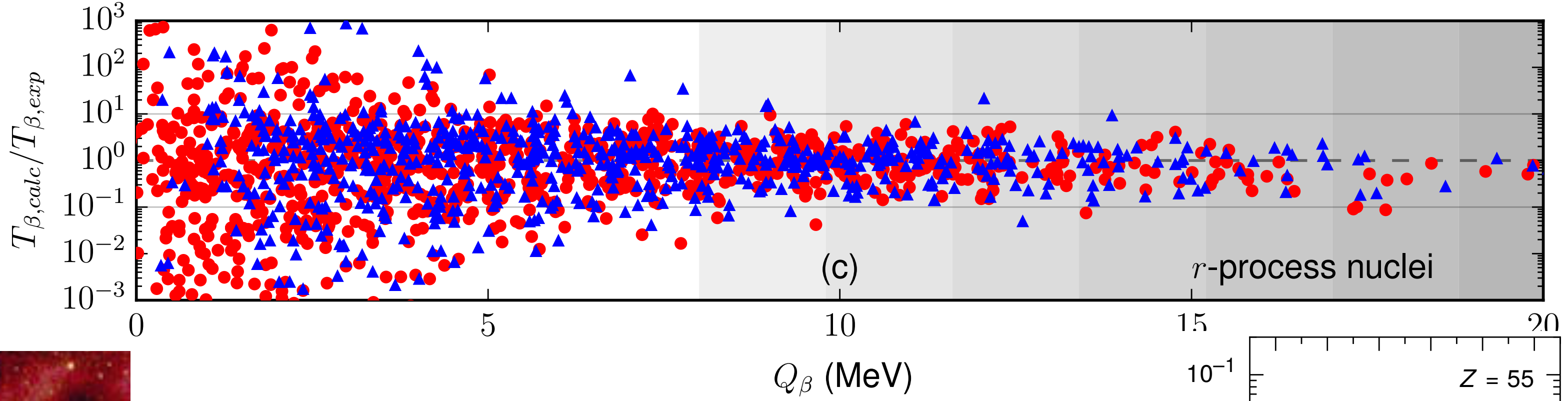
required nuclear data: beta decay



- determine the relative abundances of the isotopic chains through the steady beta flow condition:

$$\lambda_\beta(Z, A_{path})Y(Z, A_{path}) \sim \text{constant}$$

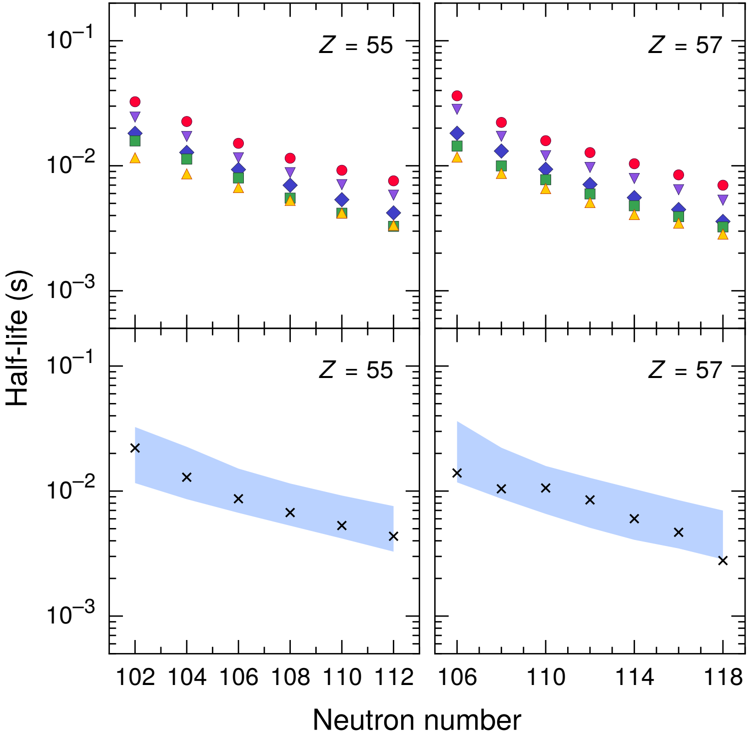
- determine the overall timescale



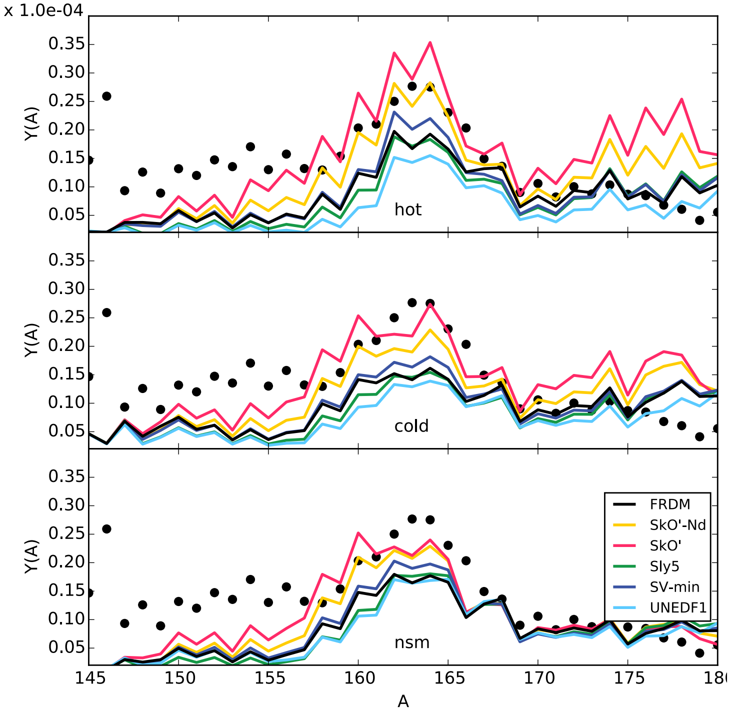
Mumpower, Surman, McLaughlin, Aprahamian 2016

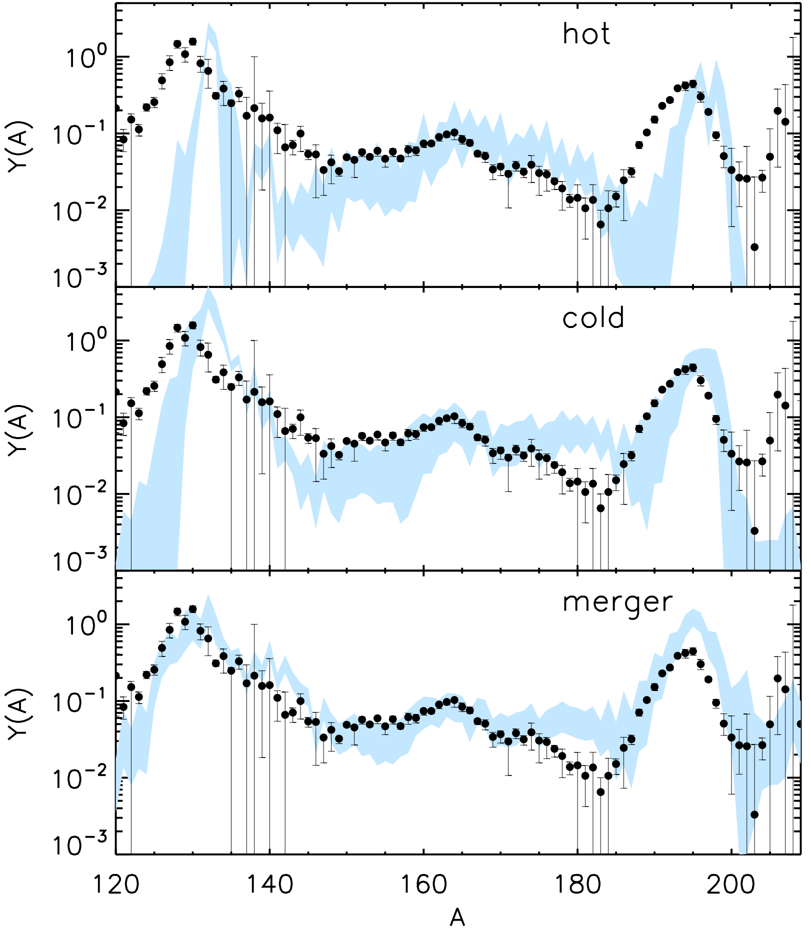
beta decay rate uncertainties

Shafer, Engel, Fröhlich, McLaughlin, Mumpower, Surman 2016



abundance pattern uncertainties due to uncertain beta decay rates





Shafer, Engel, Fröhlich, McLaughlin, Mumpower, Surman 2016

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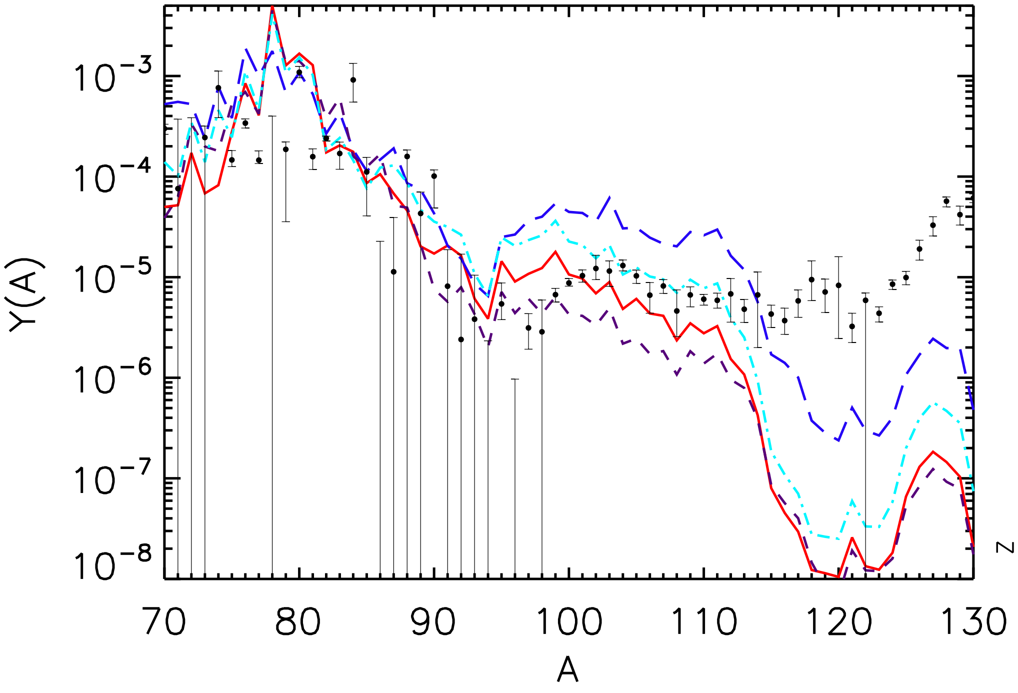
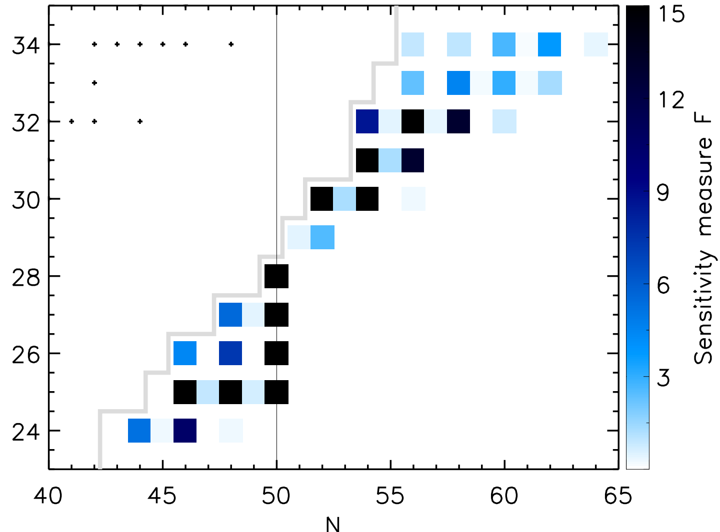
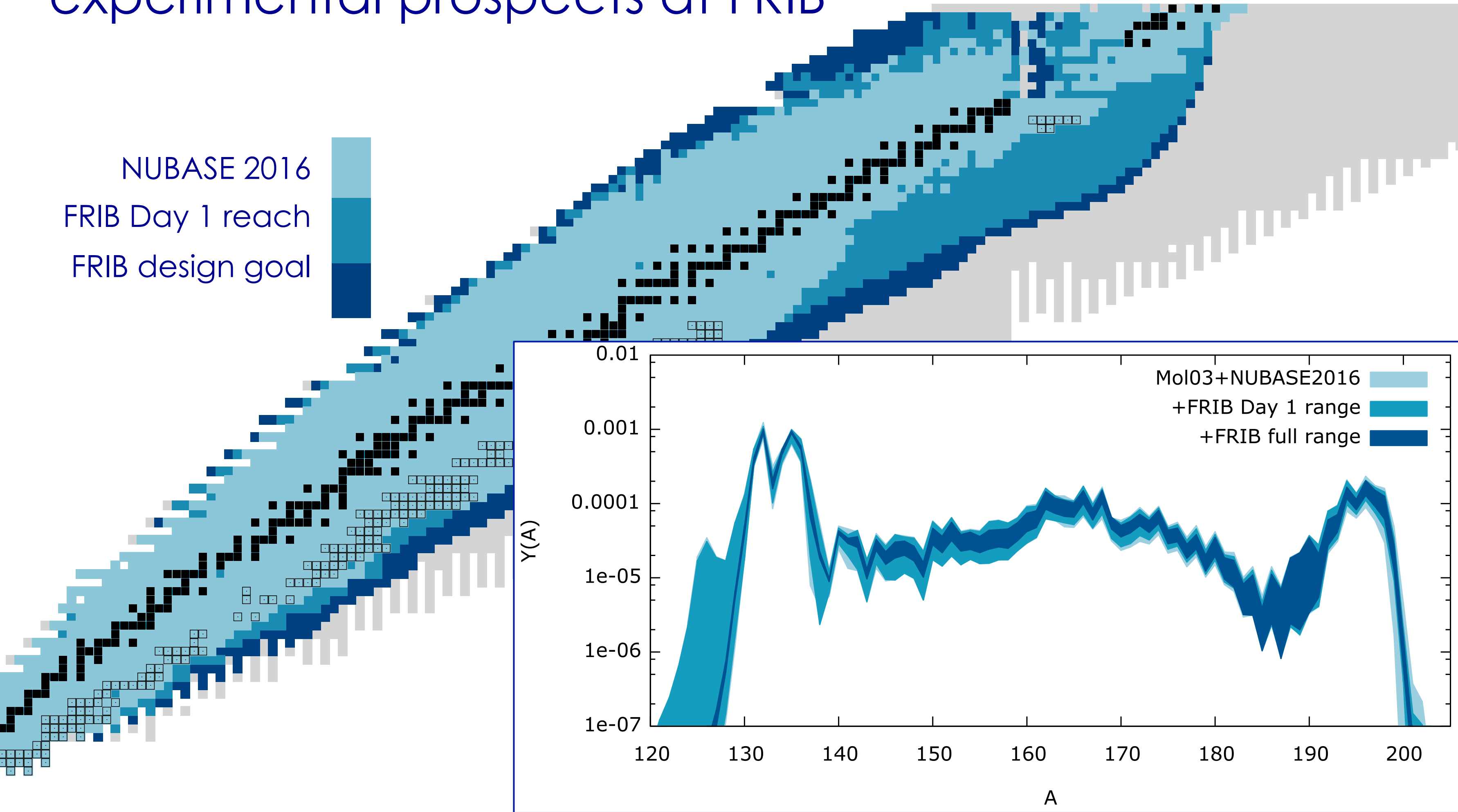




Shafer, Engel, Fröhlich, McLaughlin, Mumpower, Surman 2016

experimental prospects at FRIB



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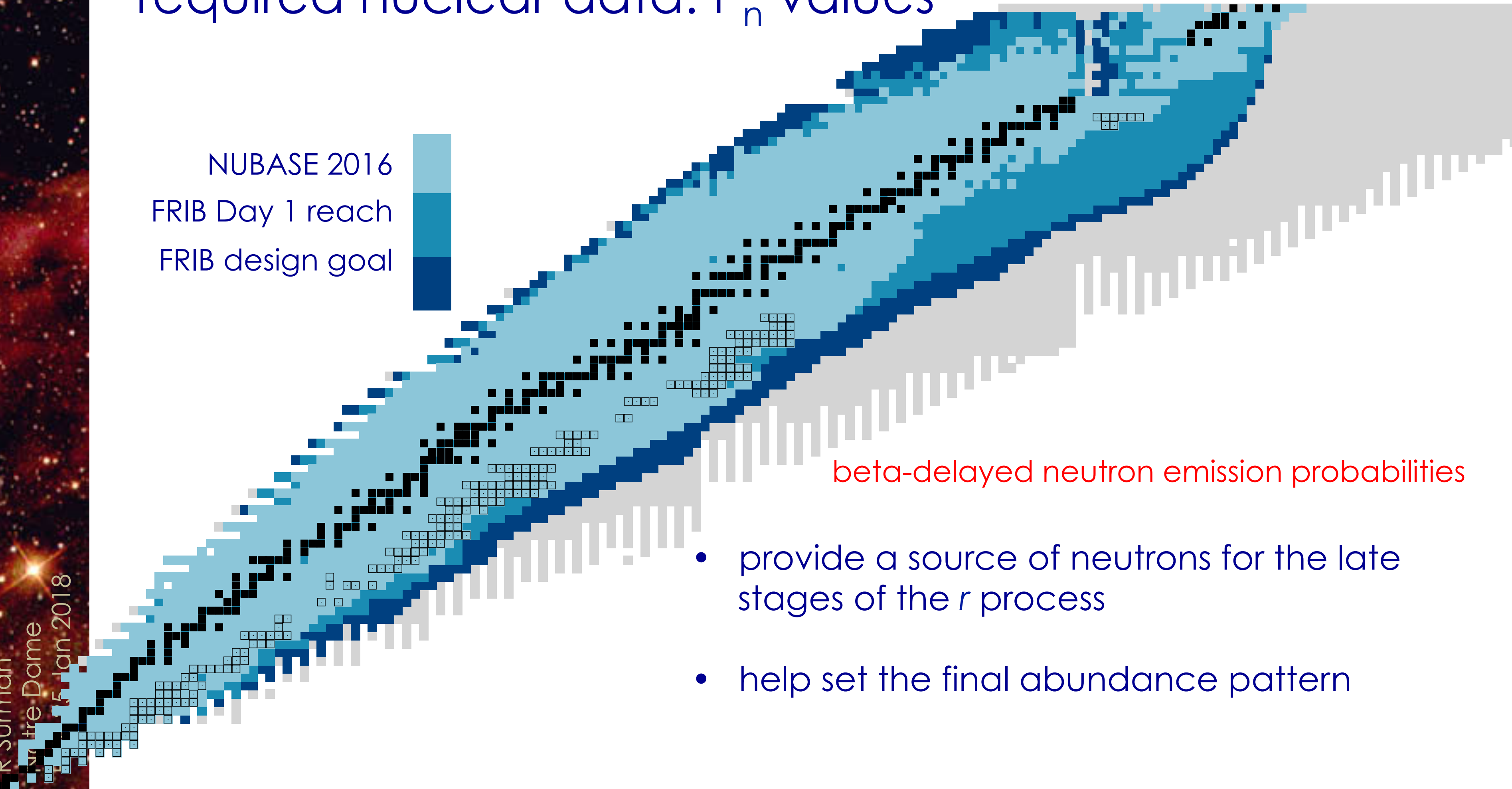
15 Jan 2018

required nuclear data: P_n values



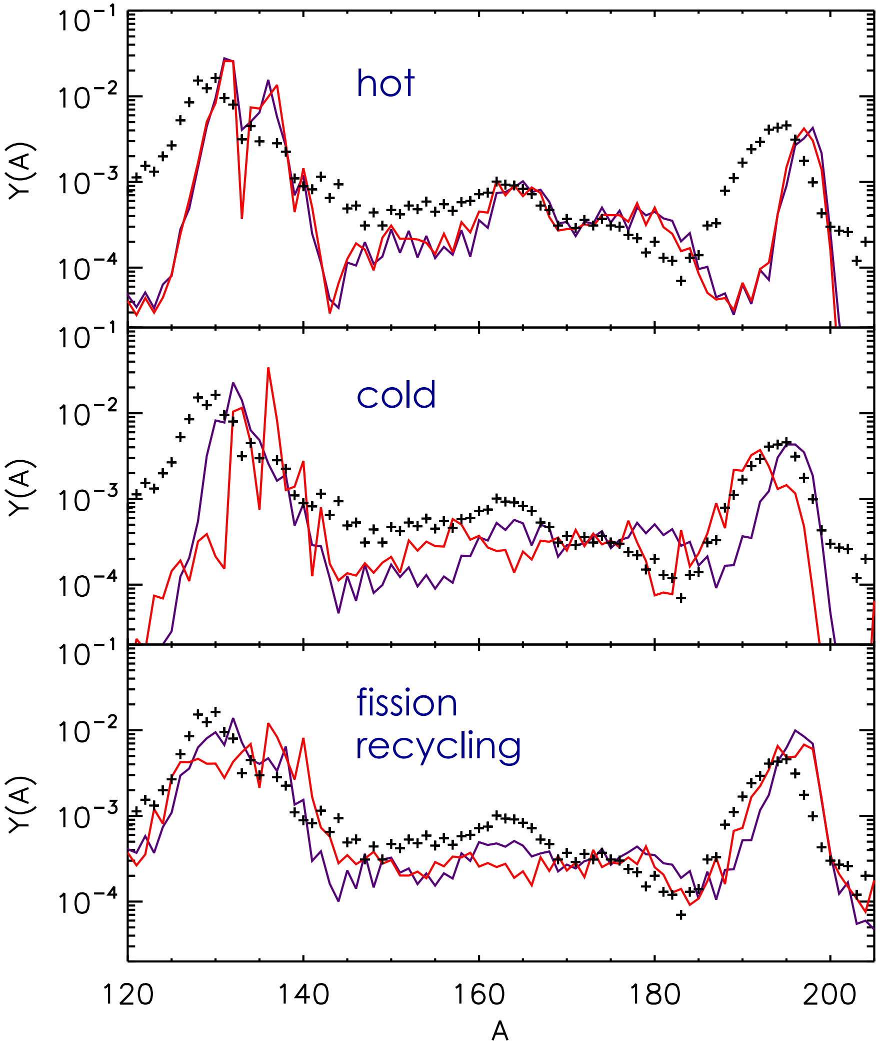
beta-delayed neutron emission probabilities

- provide a source of neutrons for the late stages of the *r* process
- help set the final abundance pattern

beta-delayed neutron emission and the r-process pattern

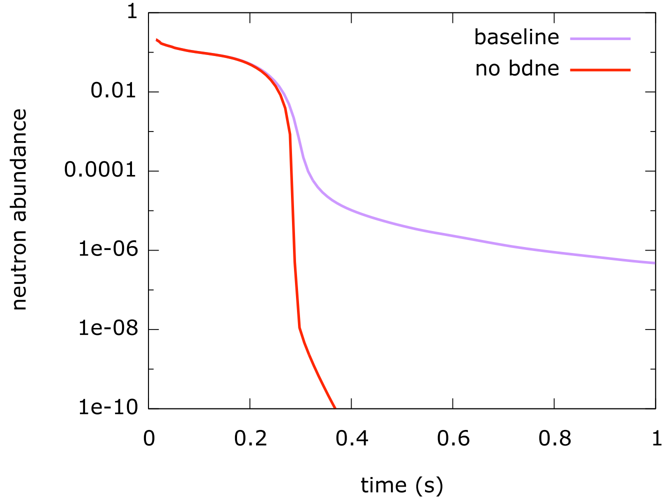
baseline

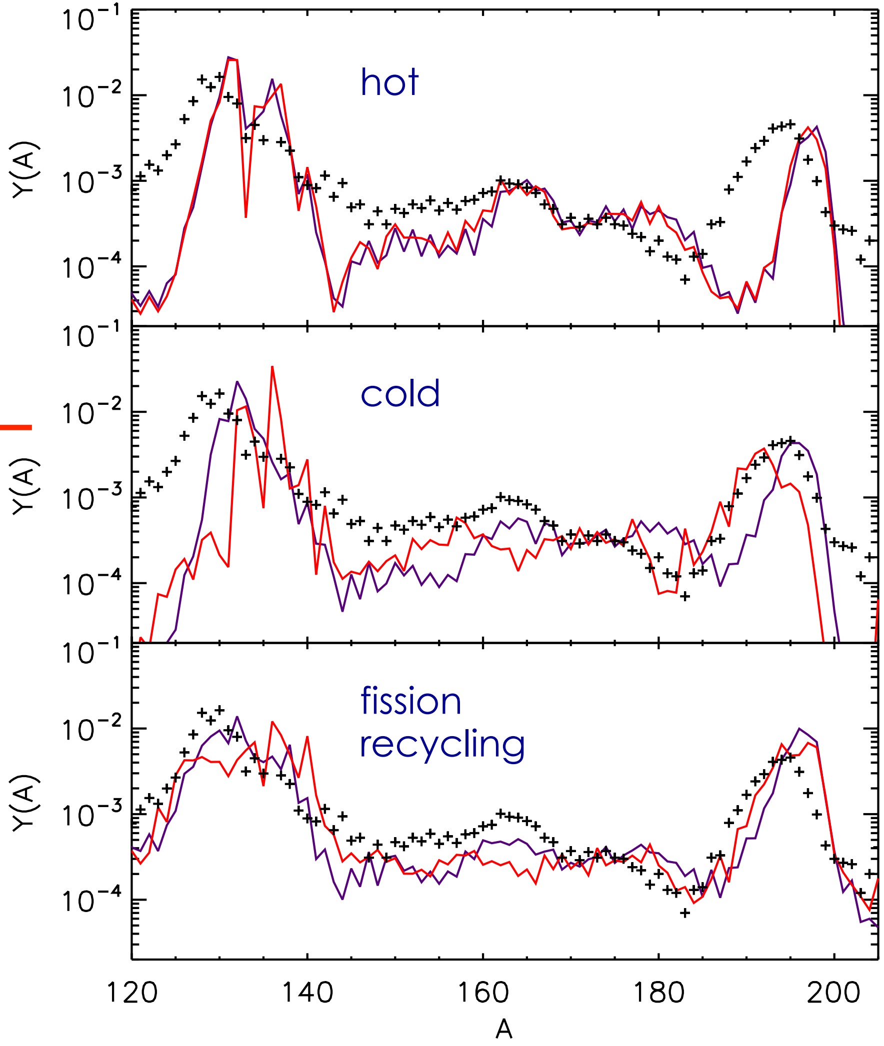
no beta-delayed neutron emission



Surman, Mumpower, Aprahamian 2014

beta-delayed neutron emission and the *r*-process pattern





Surman, Mumpower, Aprahamian 2014

r-process lanthanide production and rare earth nuclei

Experimental Mass Measurements:

AME 2016

Jyväskylä

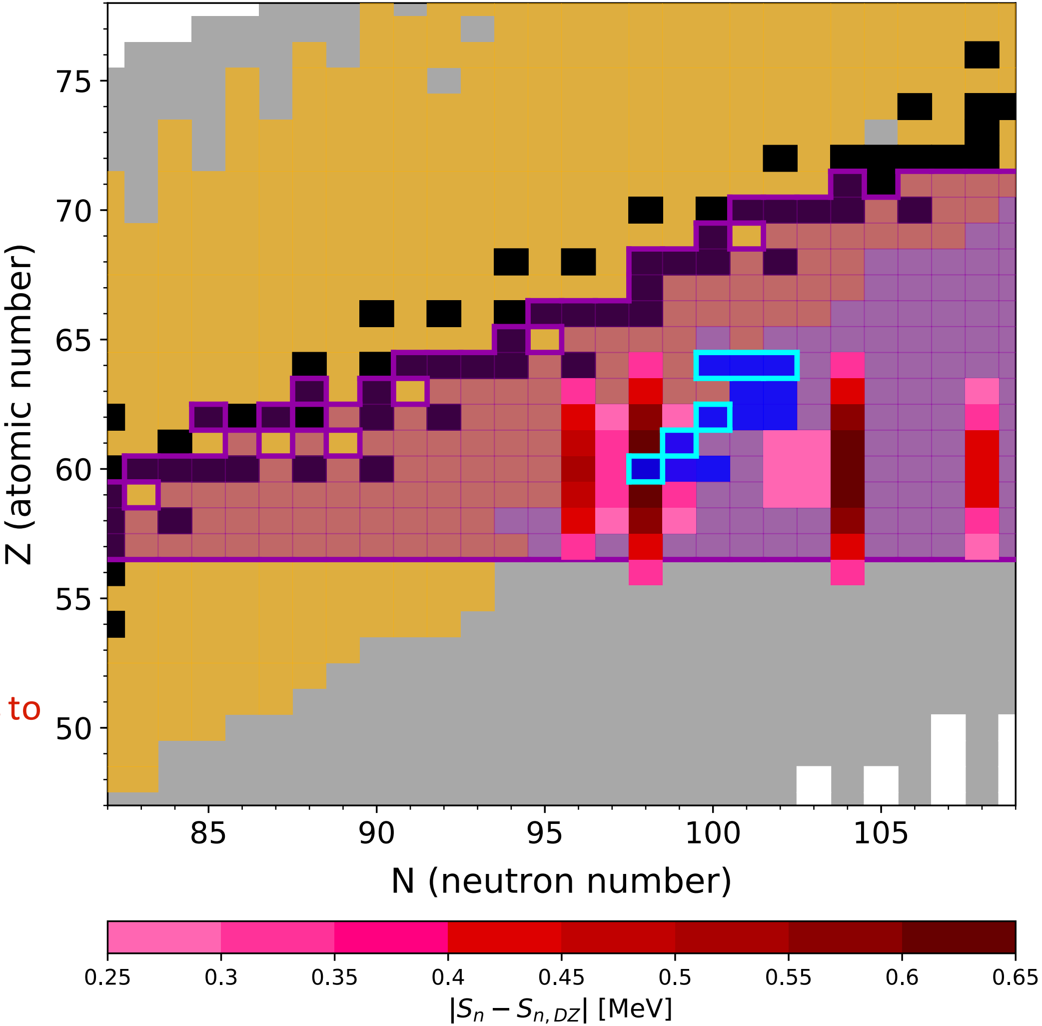
CPT at CARIBU

Theory (ND, NCSU, LANL):

Markov Chain Monte Carlo Mass Corrections to the Duflo-Zuker Model which **reproduce the observed Rare-Earth abundance peak**

(**right**: result with s/k=30, tau=70 ms, Y_e=0.2)

N. Vassh+in preparation

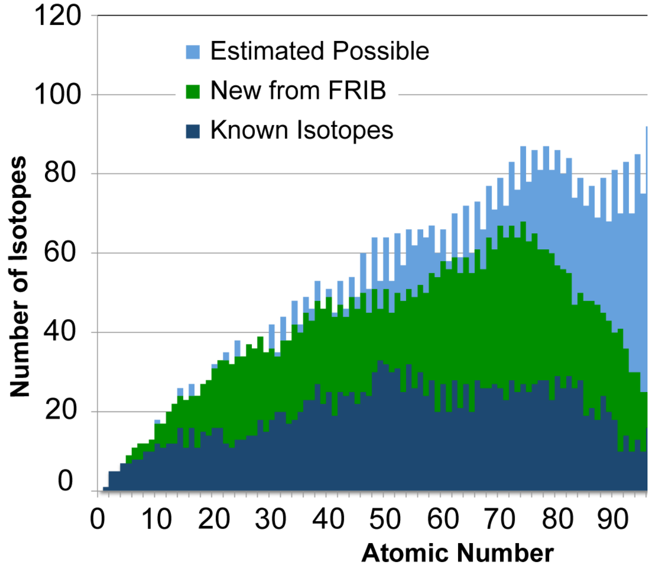


summary

The origin of the heaviest elements in the *r*-process of nucleosynthesis has been one of the greatest mysteries in nuclear astrophysics for decades.

Evidence from a variety of directions – including the recent discovery of GW170817 – increasingly points to neutron star mergers as a primary source of *r*-process elements, but many open questions remain.

Studies of a merger *r* process require detailed knowledge of halflives and P_n values, from the neutron drip line to the valley of stability, as they shape *r*-process abundance pattern formation and in the interpretation of kilonova signals.



Thus direct measurements should be complemented by efforts, e.g., to extract beta-strength functions, in order to drive concurrent improvements to theory