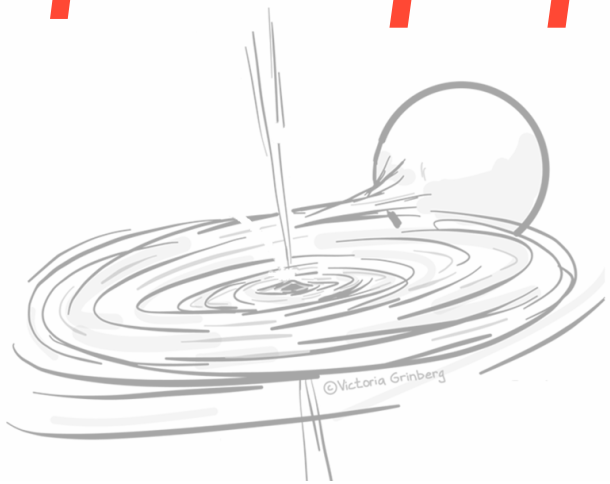
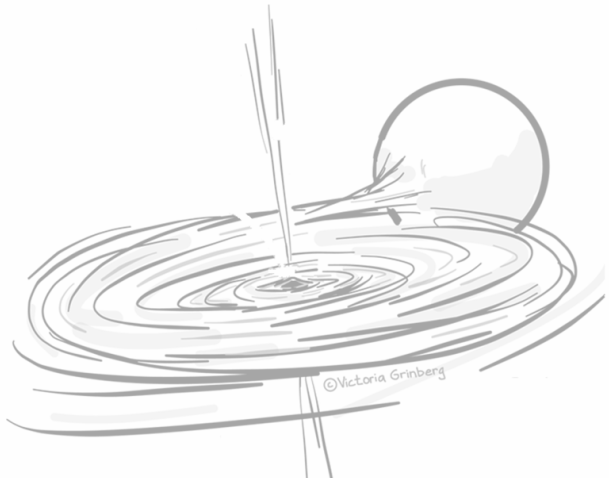
THE END OF THE BEGINNING

for rp-process nuclear masses

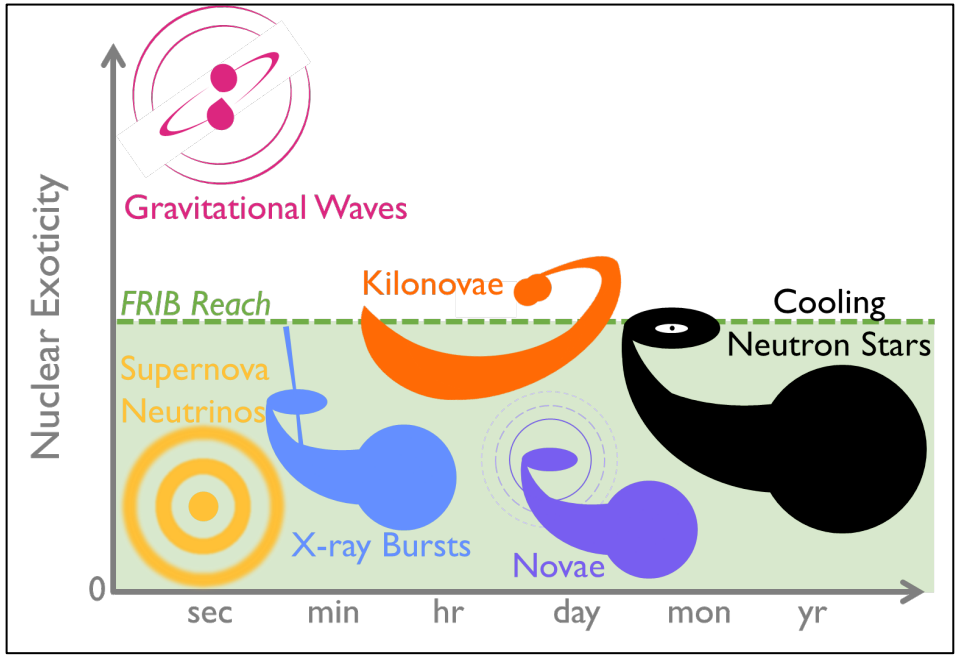


Zach Meisel
Air Force Institute of Technology
May 2026

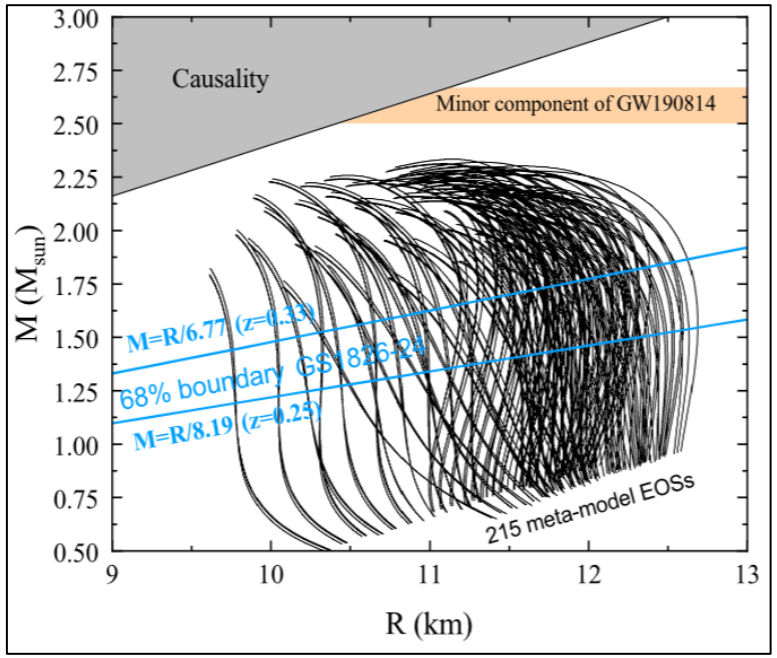


Several interesting problems require understanding the rapid proton-capture (rp-) process.

Signatures in The Transient Sky:

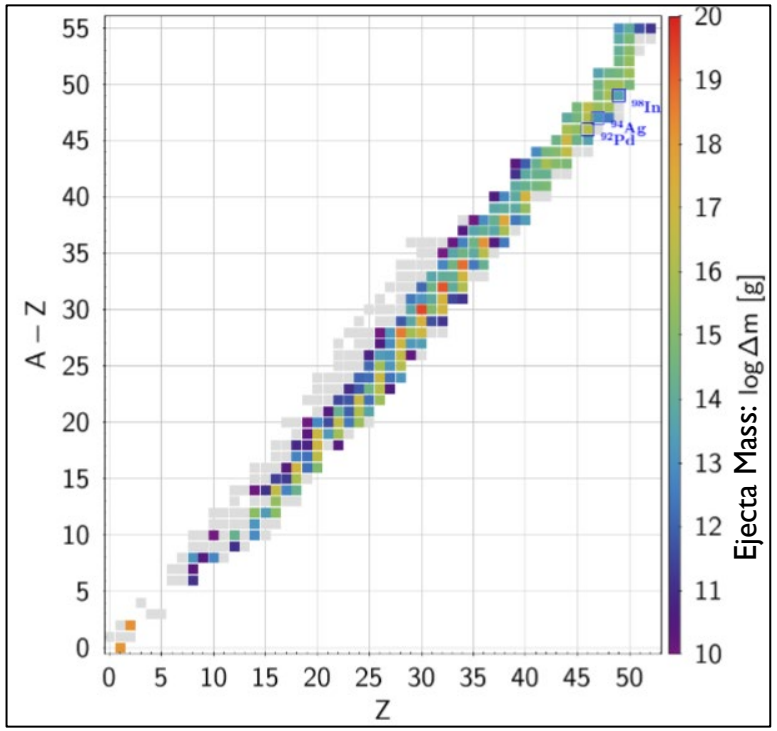


Dense Matter Equation of State:



Xie, Li, & Zhang *PRD* 2024

(minor) Nucleosynthesis:

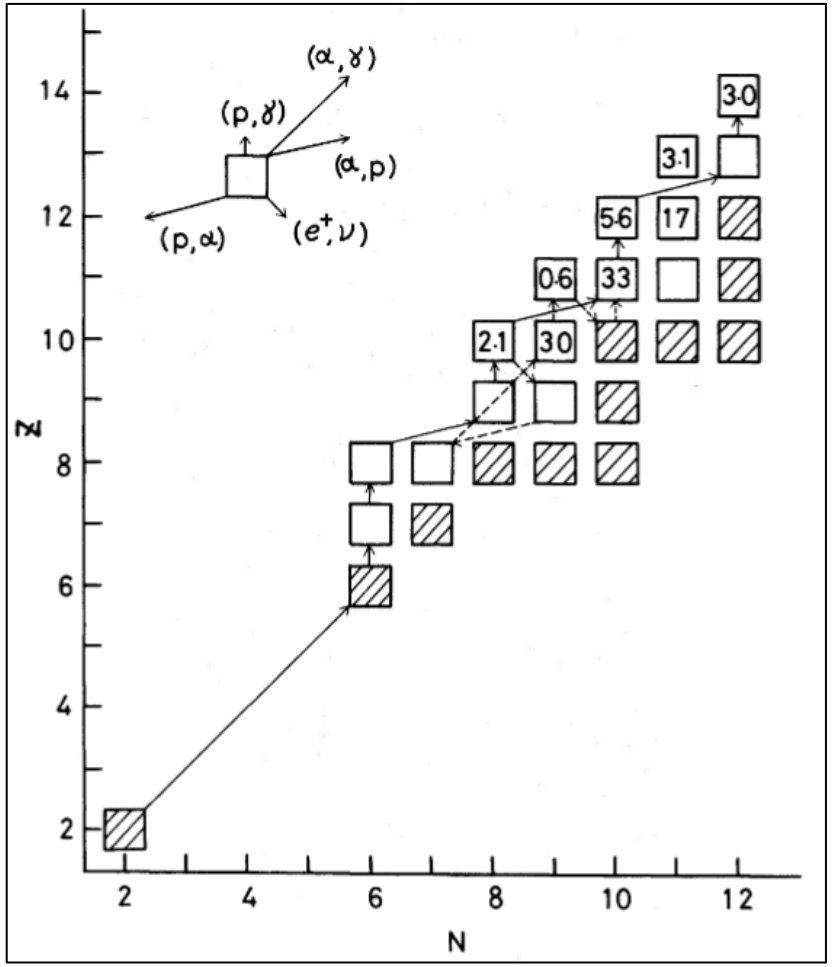


Herrera, Sala, & José *A&A* 2023

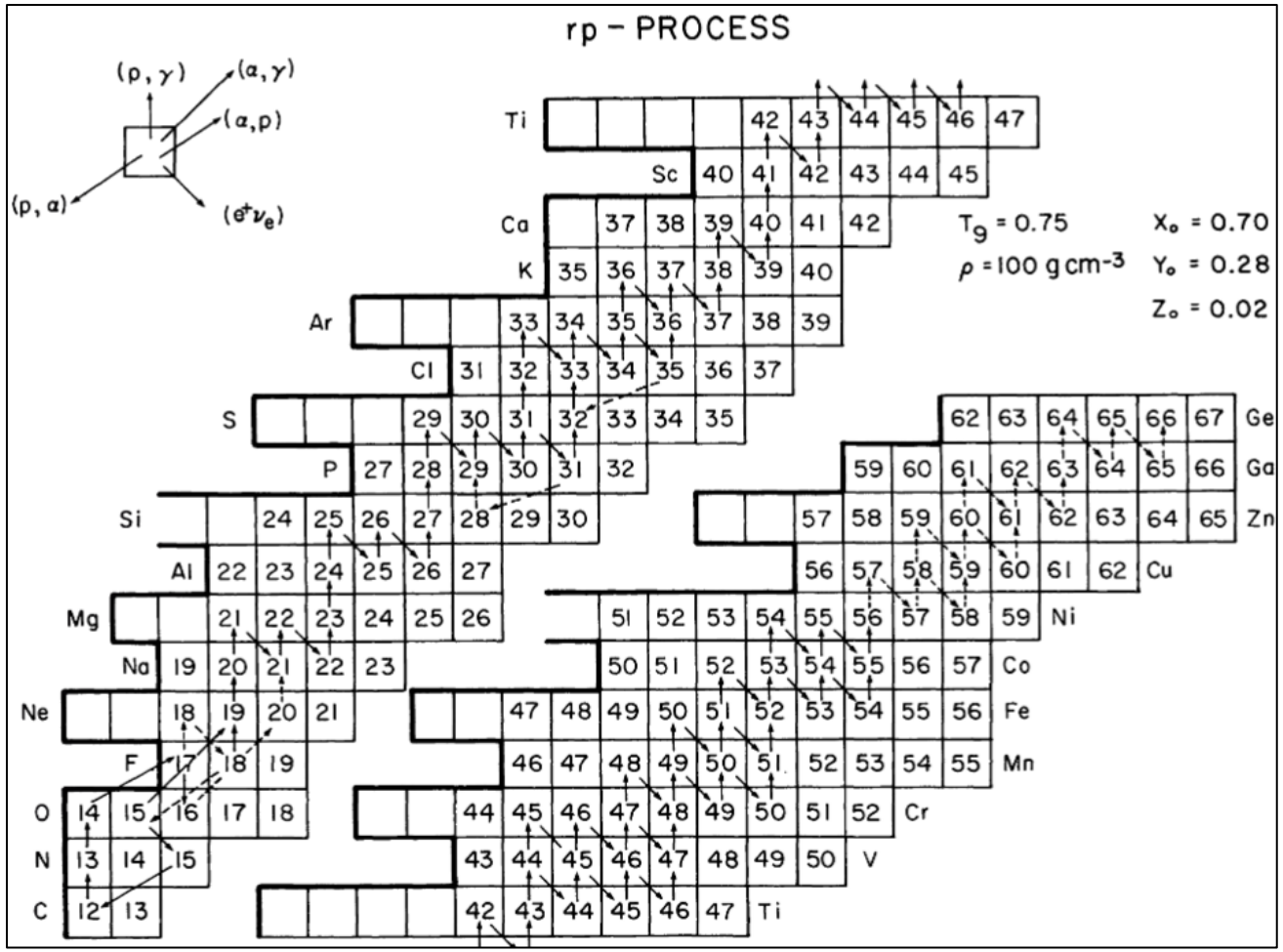
Do we understand it yet? Are we just beginning?
Or are we at the end of the beginning?

IN THE BEGINNING

the rp-process was numerically modeled for the first time ~45 years ago



Fujimoto, Hanawa, & Miyaji *ApJ* (1981)



Wallace & Woosley *ApJS* (1981)

We are now very familiar with the key signposts on the rp-process highway

Waiting Points

often referred to as "waiting points" in the literature

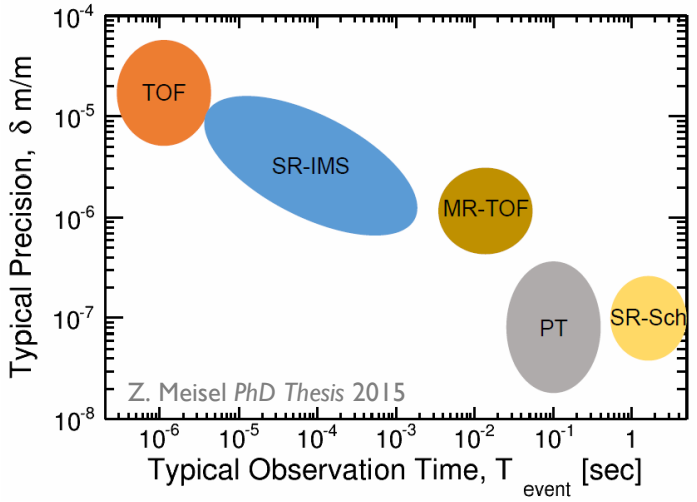
Cycles

Branch Points

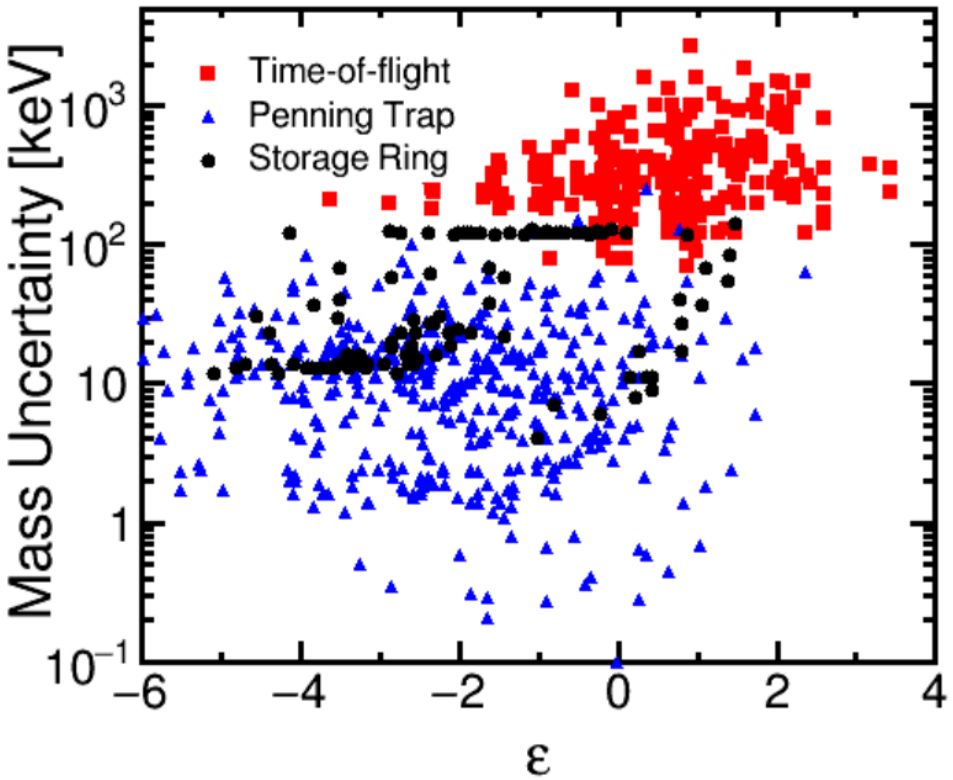
Ignition/Breakout

Nuclear Masses for the rp-process require high precision measurements

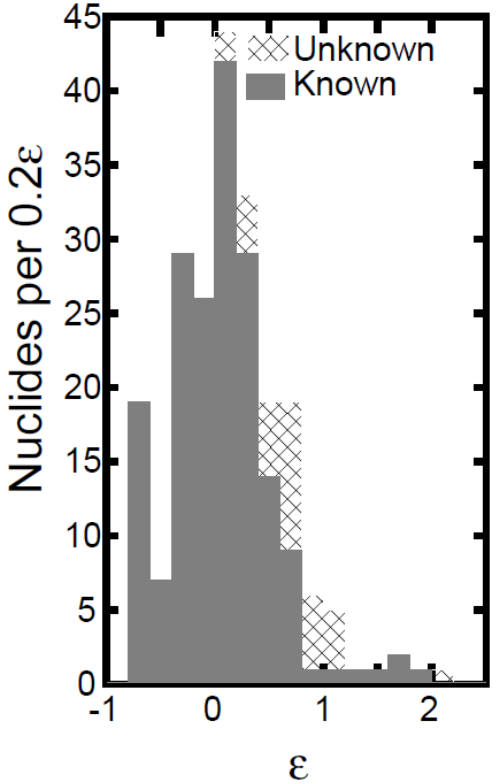
Define "exoticity": $\varepsilon = \log_{10} \left| \frac{\Delta N_{\text{stab.}}}{t_{1/2}(\Delta N_{\text{drip}}+1)} \right|$



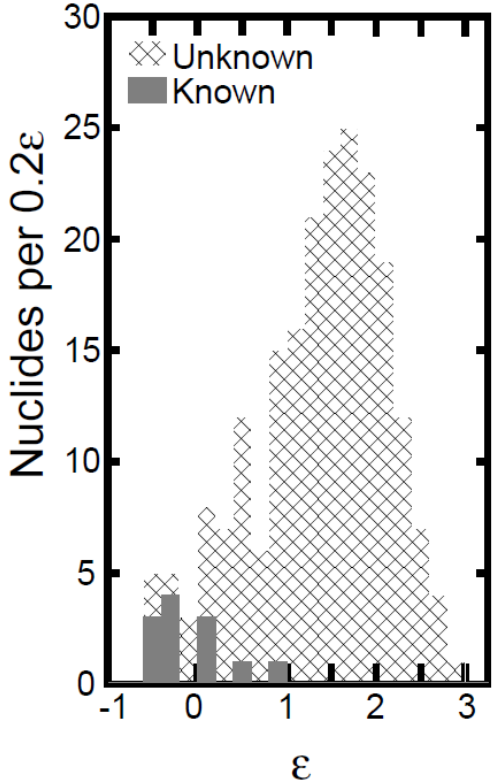
Meisel & George *IJMS* 2013



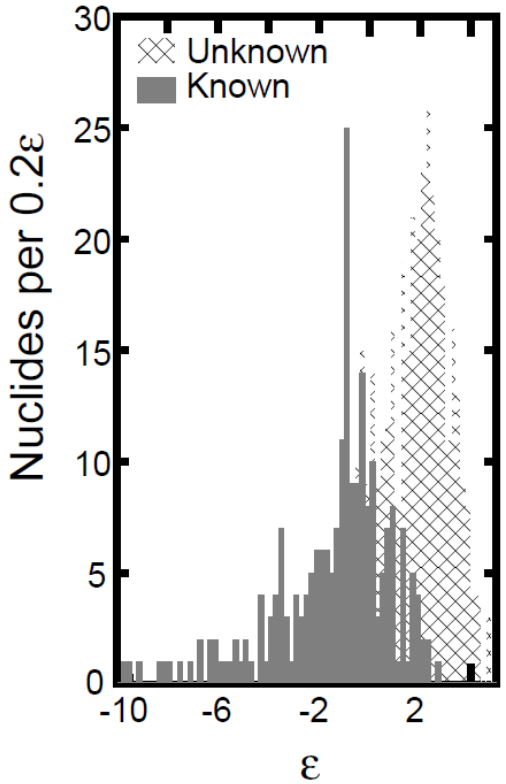
rp-process



r-process

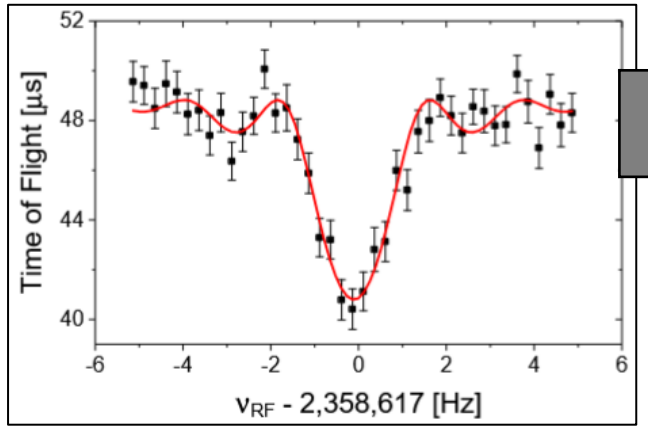


NS crust



There can be a long sequence of connections between fundamental data and NS-observable impacts

^{61}Zn mass

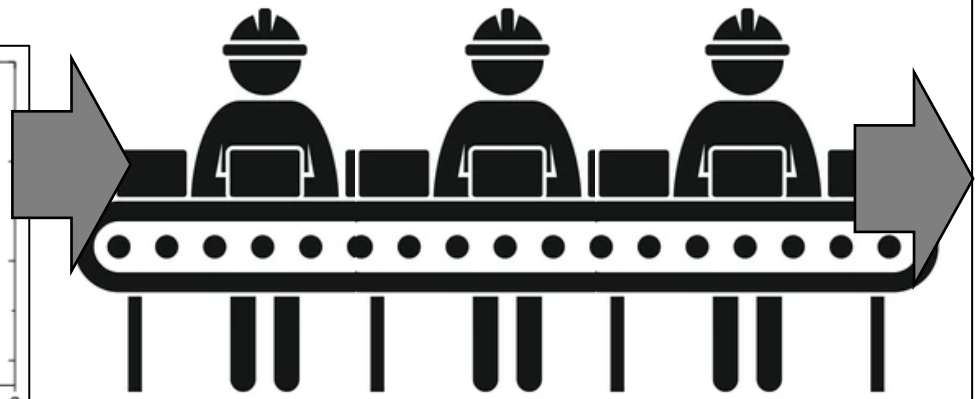


Meisel et al. *PRC* 2022

resonance properties ($E_{R,i}$)

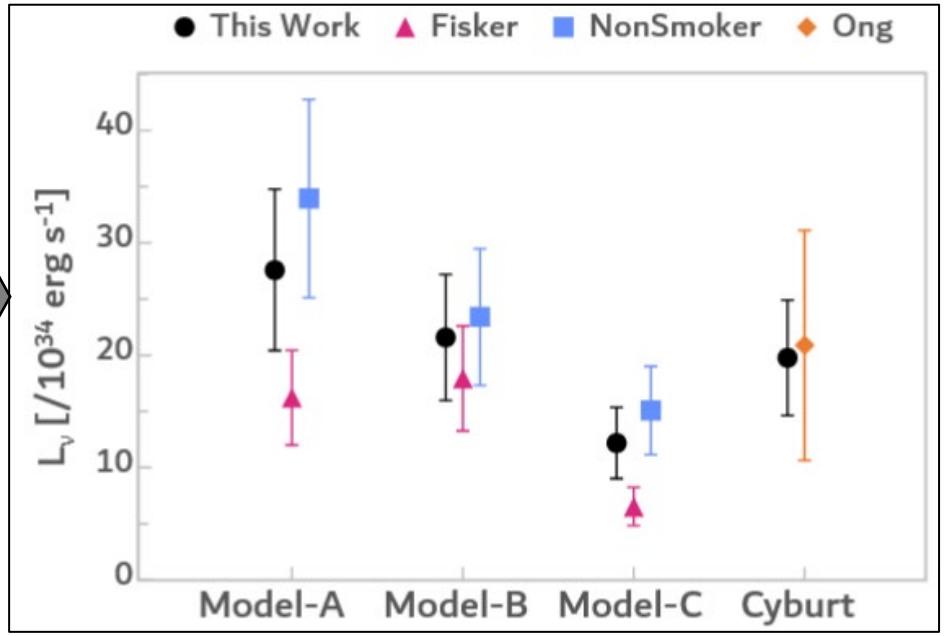
reaction rate

XRB calcs of rp-process ashes



$$N_A\langle\sigma v\rangle \propto \sum_{i=1}^{N} (\omega\gamma)_{R,i} \exp\left(-\frac{11.6045 E_{R,i}}{T_9}\right)$$

NS Crust Urca luminosity



Meisel et al. *PRC* 2022

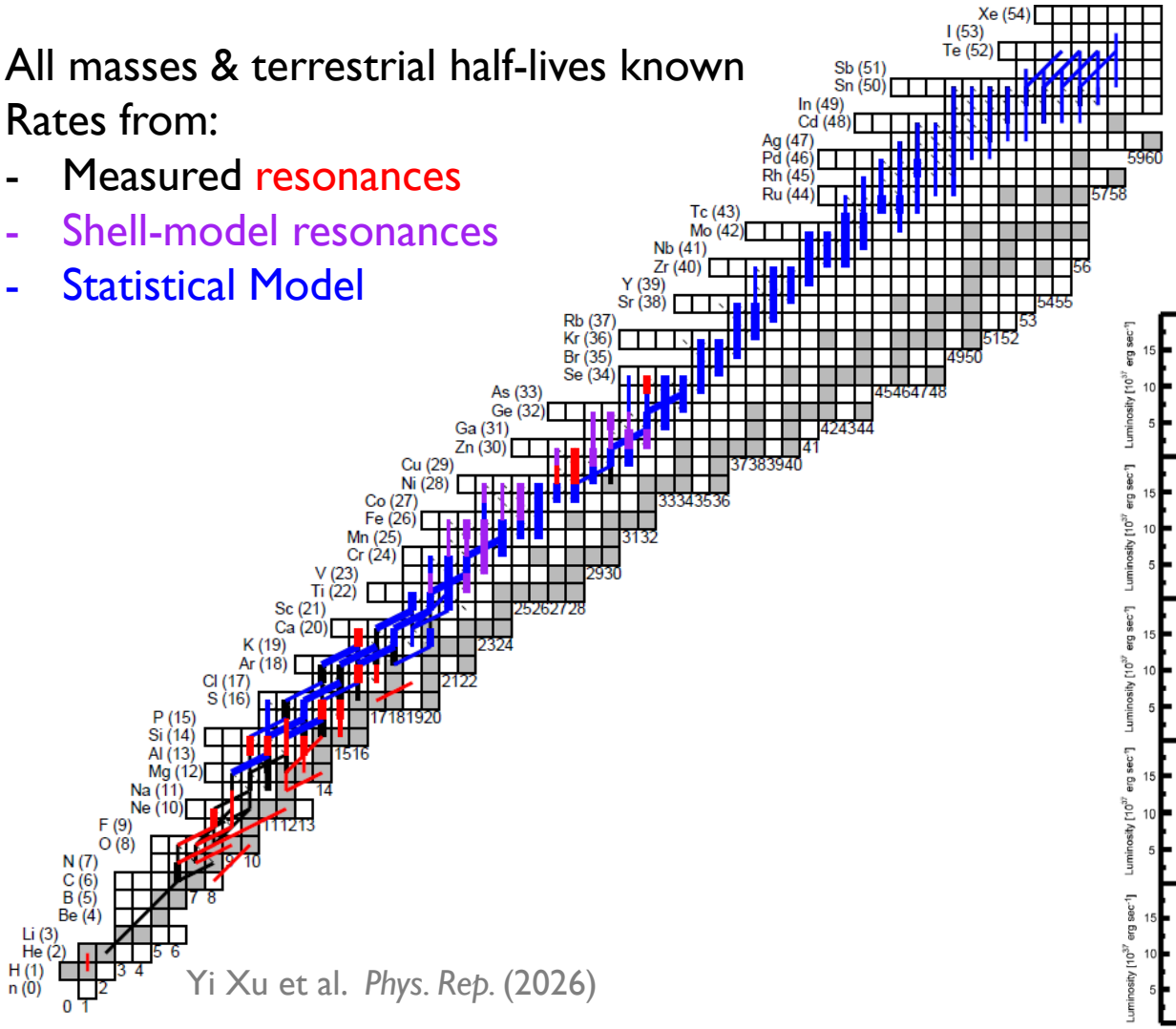
Much of the key reaction physics is constrained

…for clockburster-like conditions

All masses & terrestrial half-lives known

Rates from:

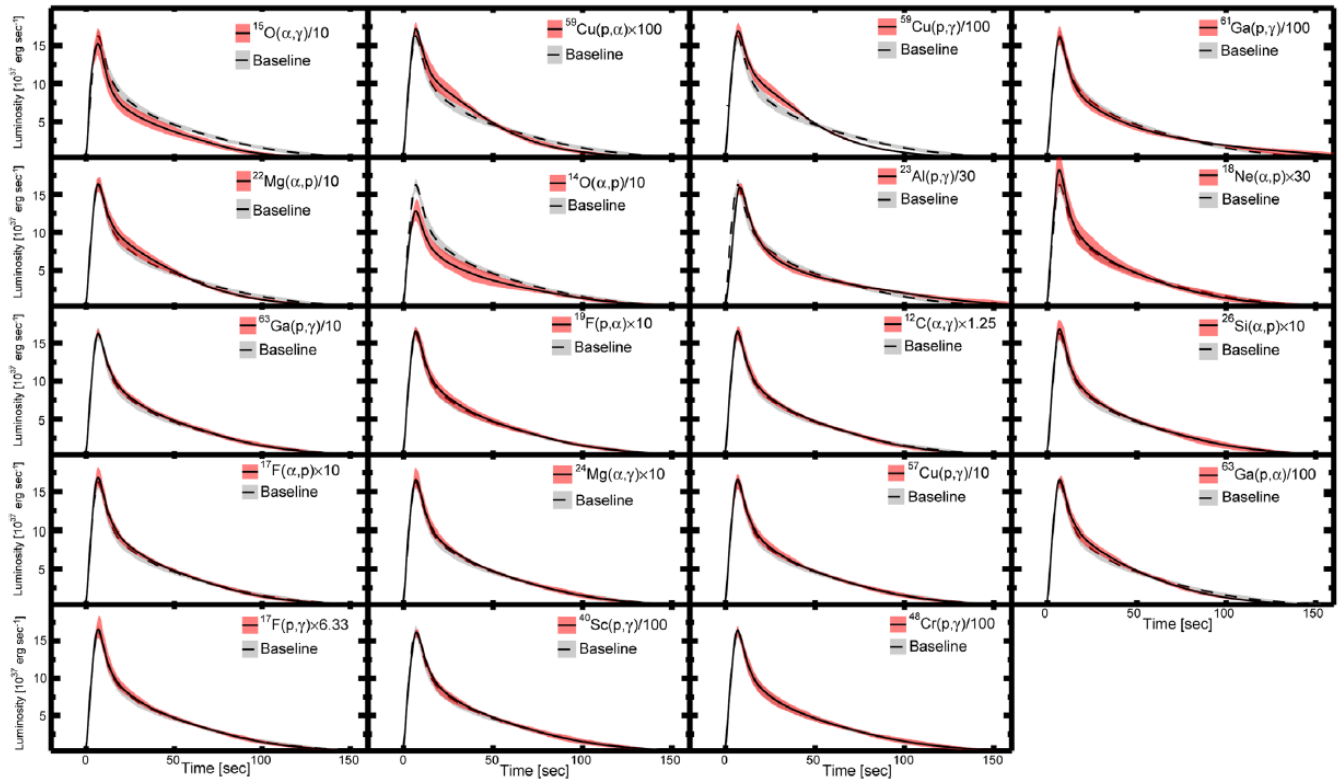
- Measured resonances
- Shell-model resonances
- Statistical Model



Yi Xu et al. *Phys. Rep.* (2026)

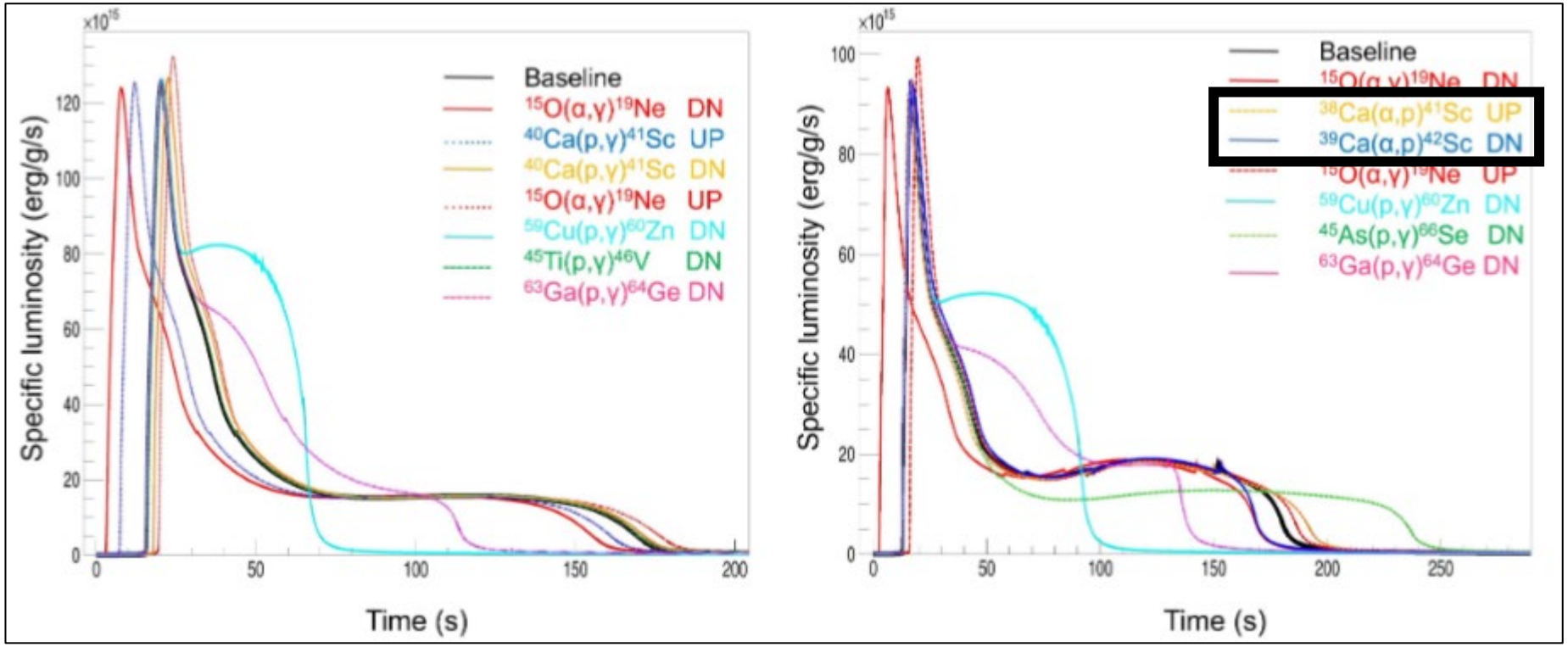
There are some controversies (^{22}Mg(α,*p*)) and evergreen challenges (^{15}O(a,*γ*)), but the most impacts are modest.

Meisel, Merz, & Medvid *ApJ* (2019)



This is the END OF THE BEGINNING for XRB calculations, because we need to explore more conditions

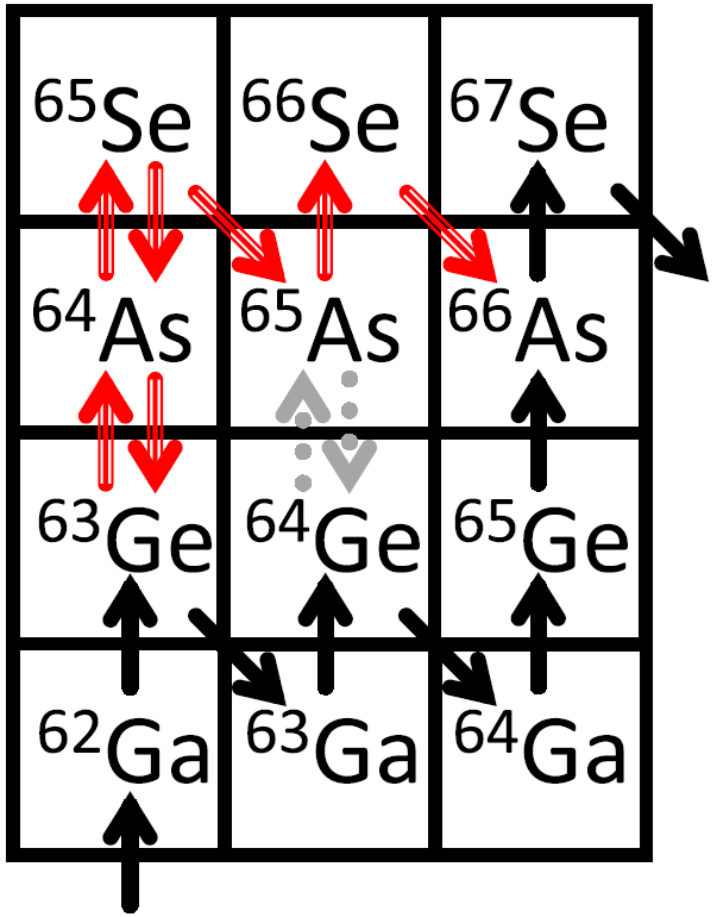
Irin Sultana et al. *EPJWeb* 2022 & arXiv 2025



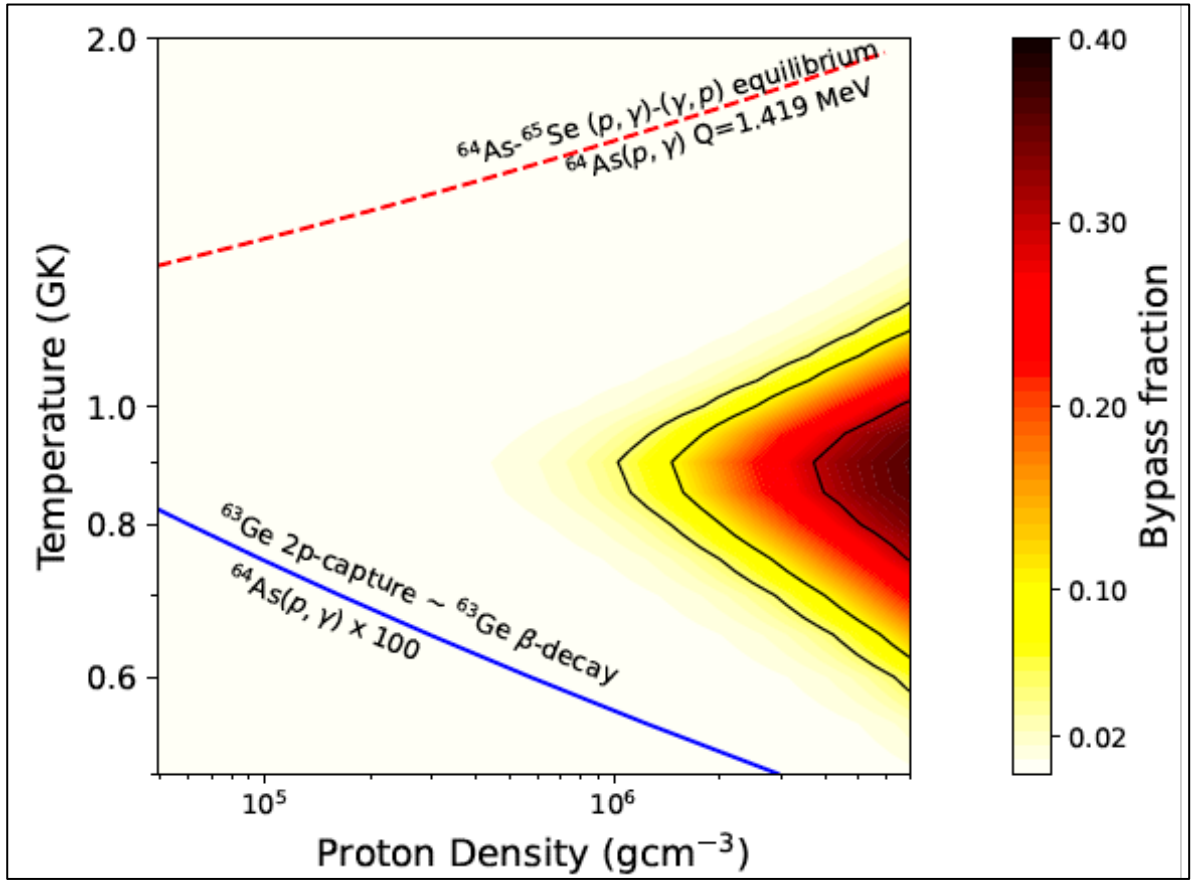
When this is done, see sensitivity to many familiar reactions, but a few new ones too

*See paper on the new Clocked Burster: A. Dohi et al. PASJ **77**, L17 (2025)*

Extreme conditions may even modify the rp-process path



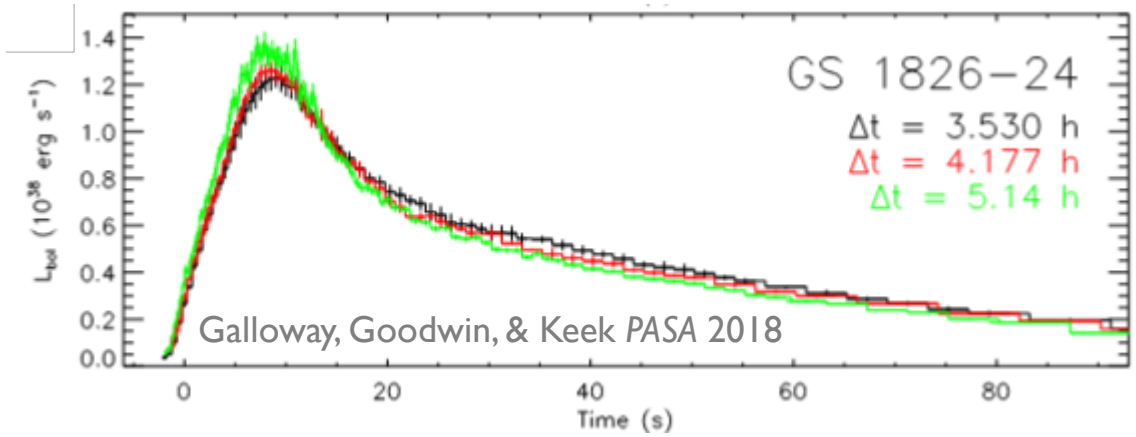
Meisel, Ong, & Randhawa *ApJ* 2025

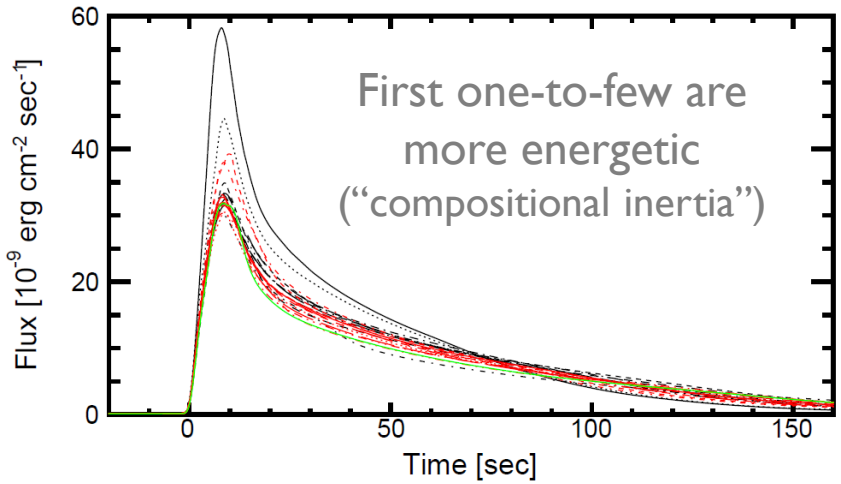


This calls for improved measurements of ^{65}Se mass, structure, and beta-delayed proton emission branching.

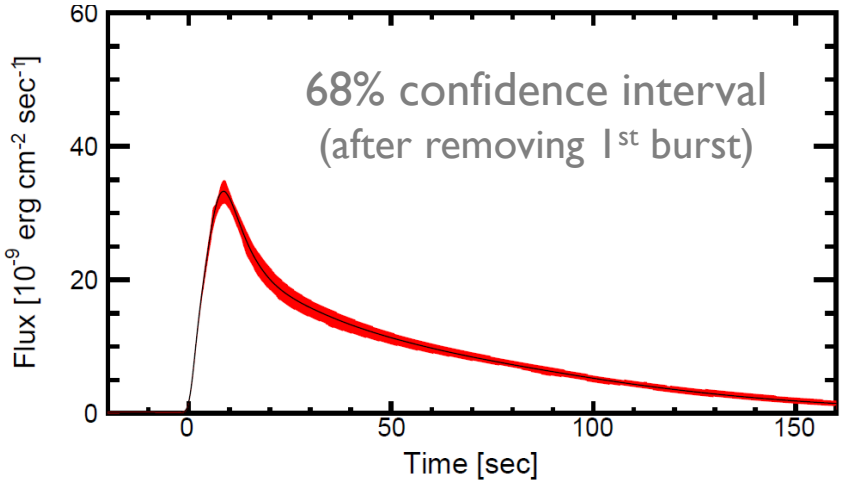
Before going much further with other conditions in 1D, we should confront the puzzle of burst-to-burst variability

The clock burster is well-behaved observationally and in models:



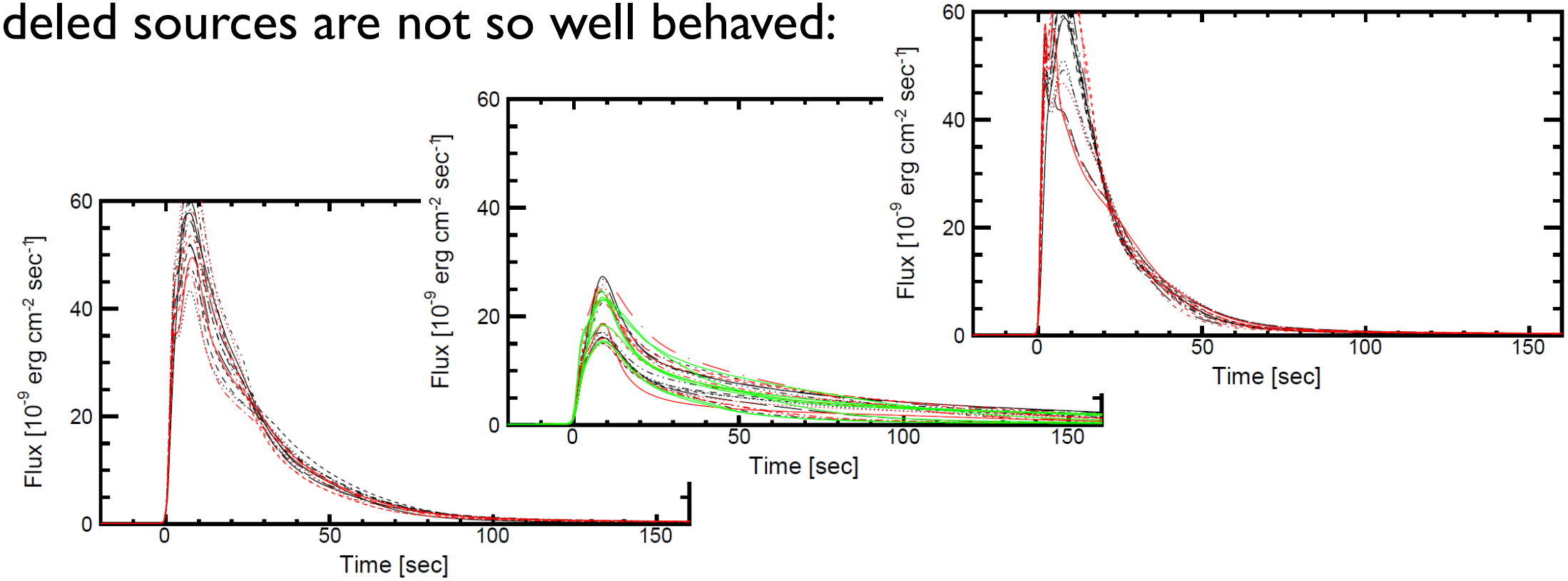


Meisel *ApJ* 2018



Before going much further with other conditions in 1D, we should confront the puzzle of burst-to-burst variability

Many modeled sources are not so well behaved:

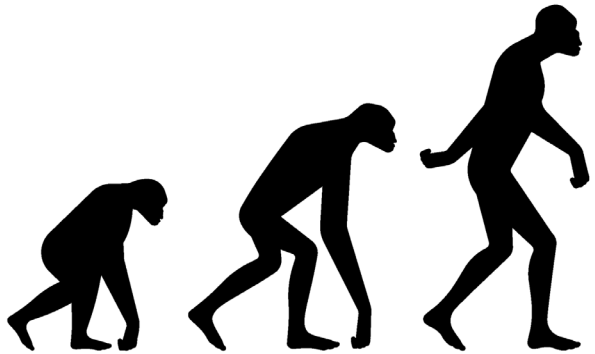


Maybe it's a complicated compositional inertia effect?

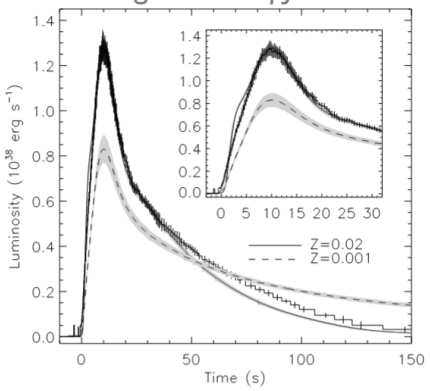
We don't know!

Before going much further with other conditions in 1D, we should make sure we have the right conditions!

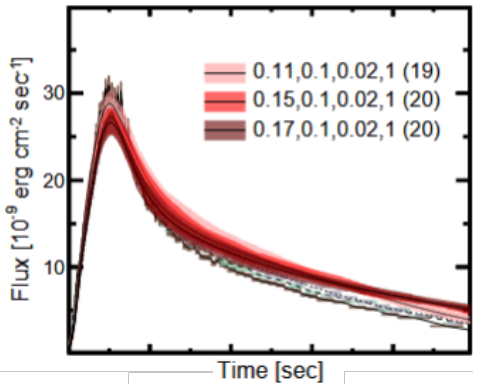
We've been relying on adding "shallow heating" …but maybe just need more realistic accretion!



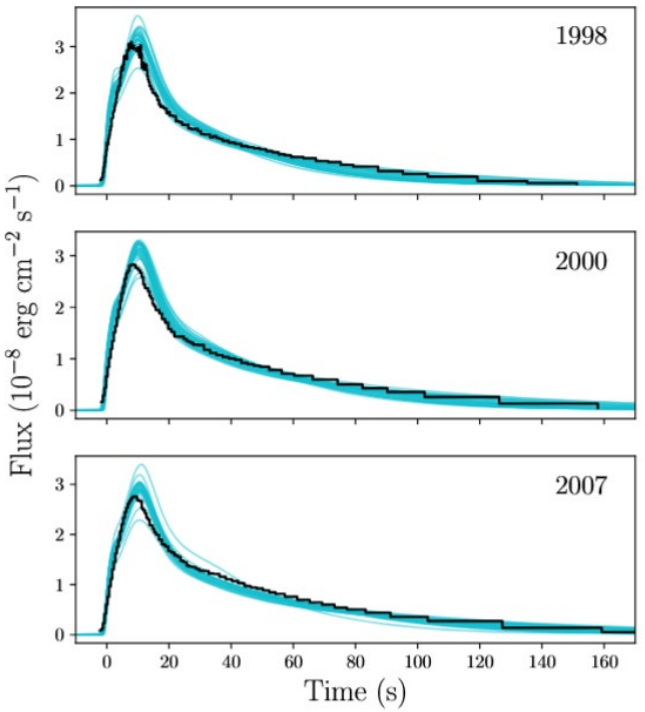
Heger et al. *ApJL* 2007



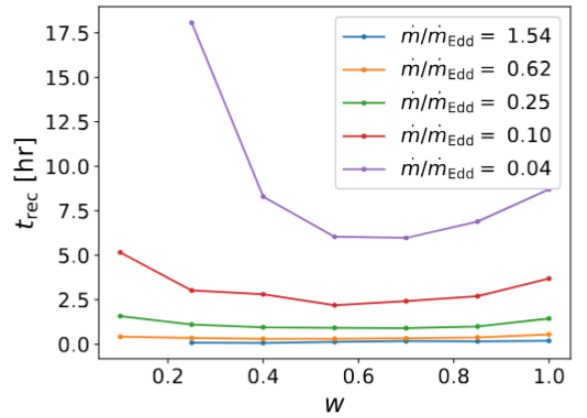
Meisel *ApJ* 2018

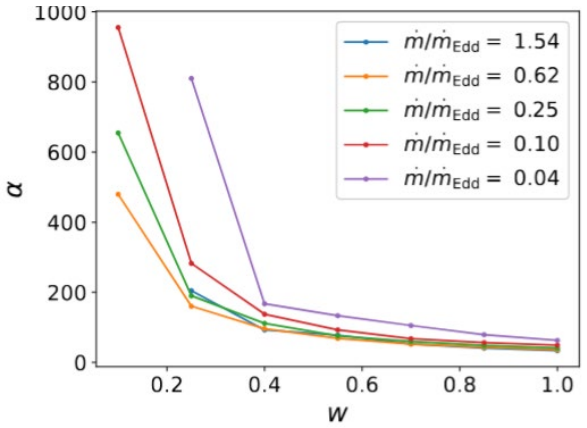


Johnston, Heger, & Galloway *MNRAS* 2020



Cavecchi et al. ApJ 2026

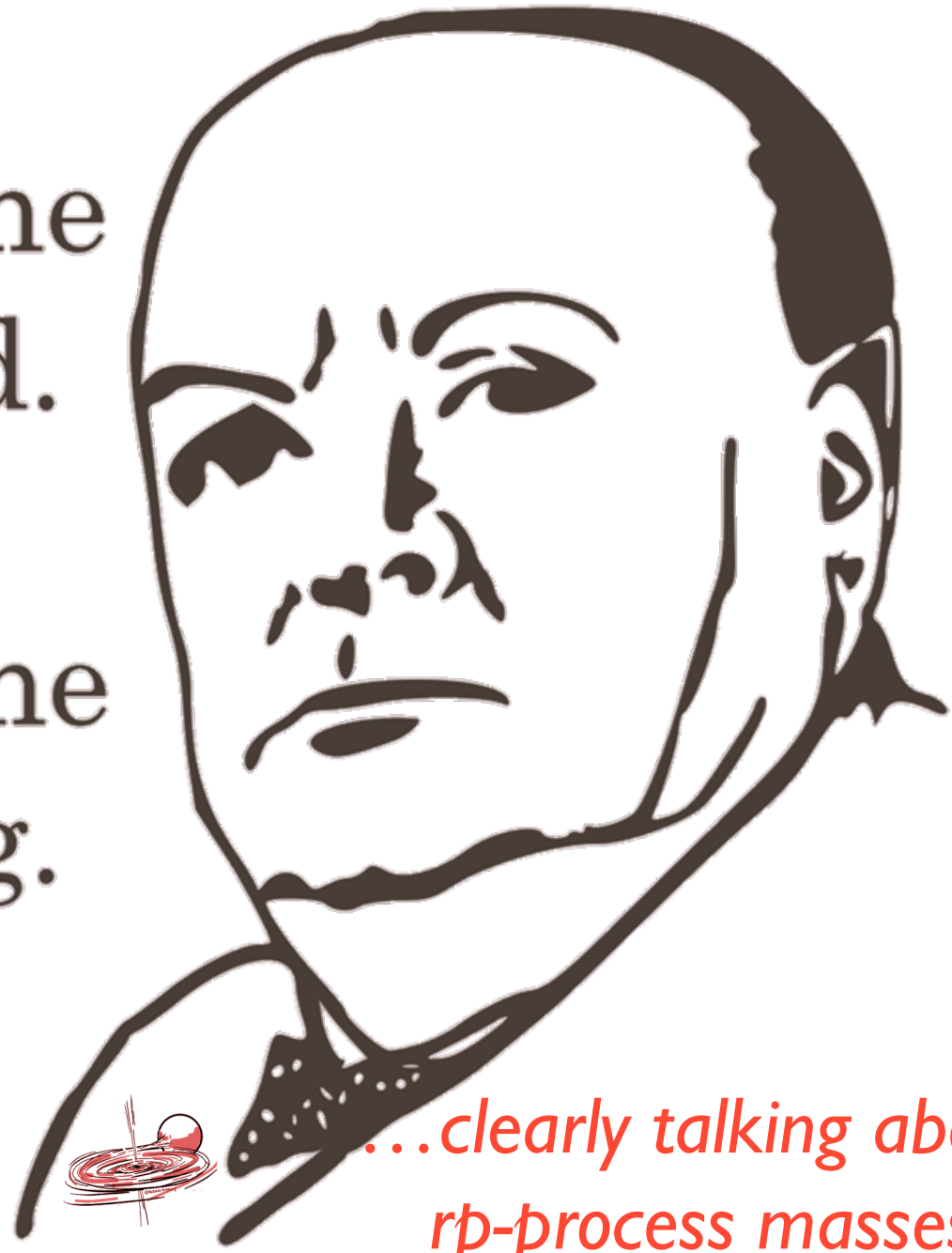




Now this is not the end. It is not even the beginning of the end.

But it is, perhaps, the end of the beginning.

Winston Churchill



…clearly talking about rp-process masses