Underproduced nuclides in unexplored explosions

Sophie Abrahams (she/her)
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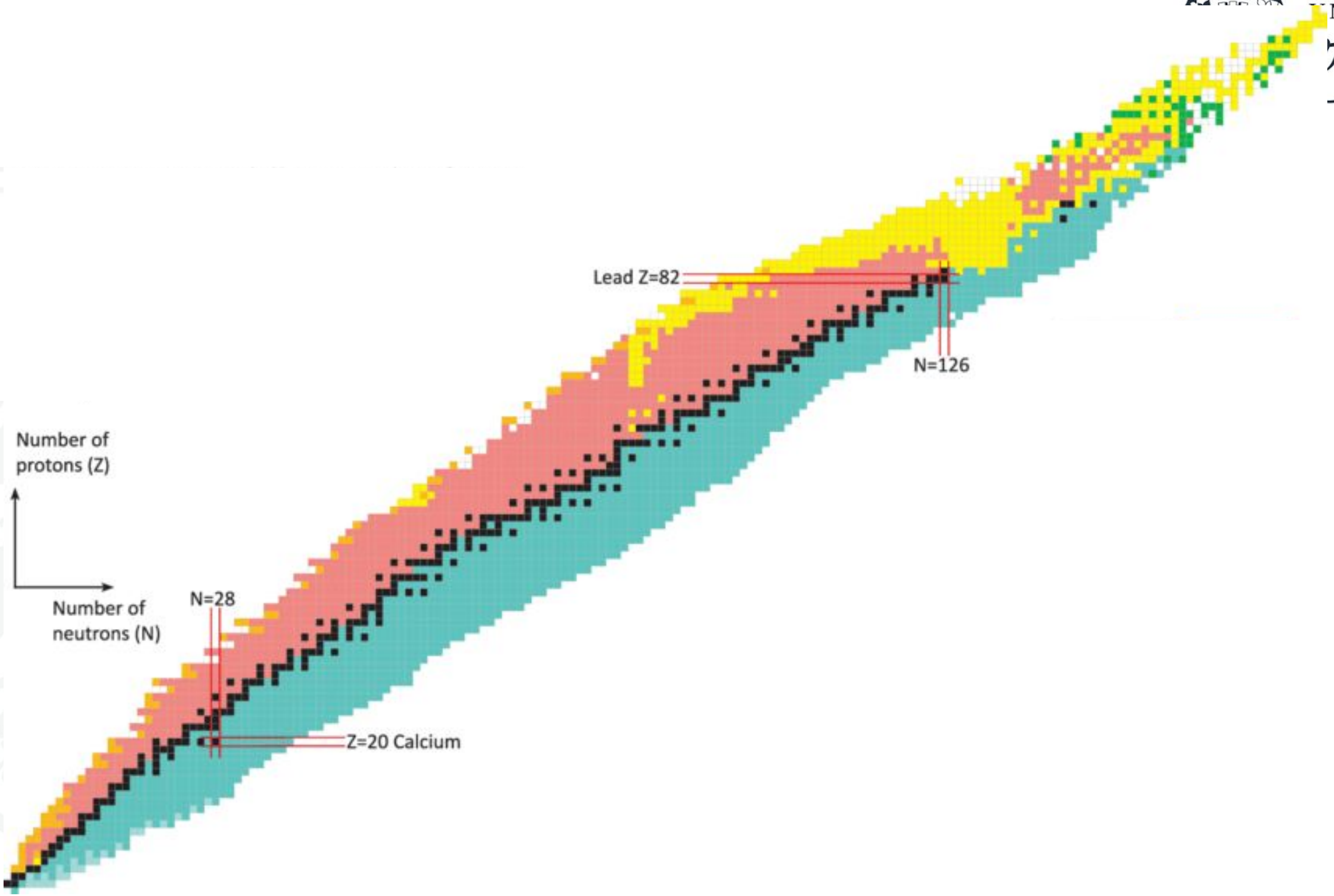
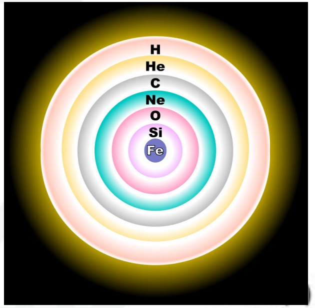
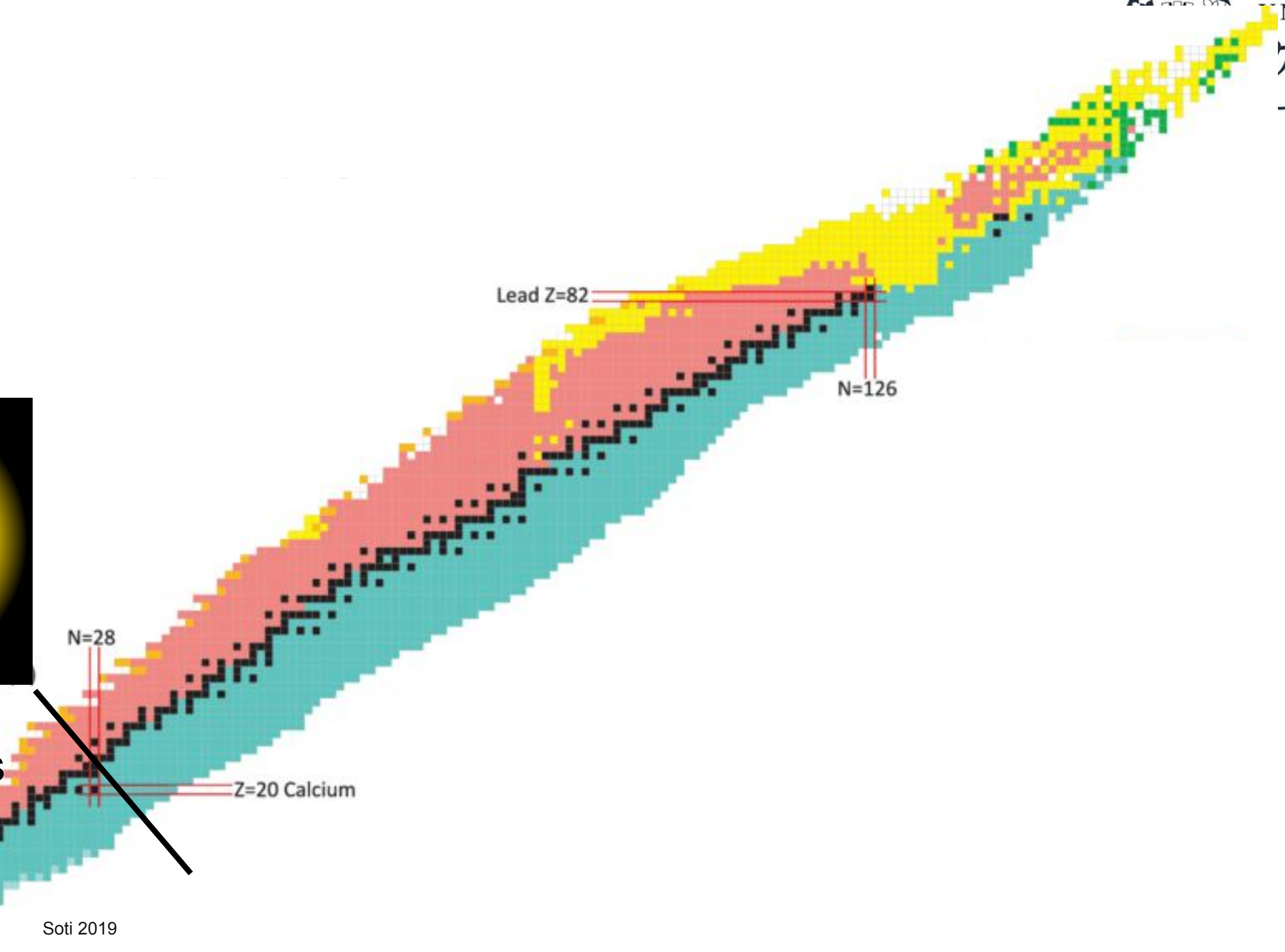

Lead Z=82
N=126
Number of protons (Z)
Number of neutrons (N)
N=28
Z=20 Calcium

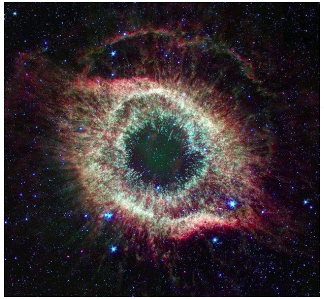


Stellar nucleosynthesis

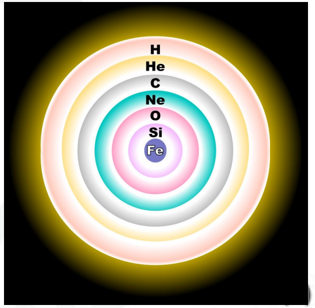


Soti 2019

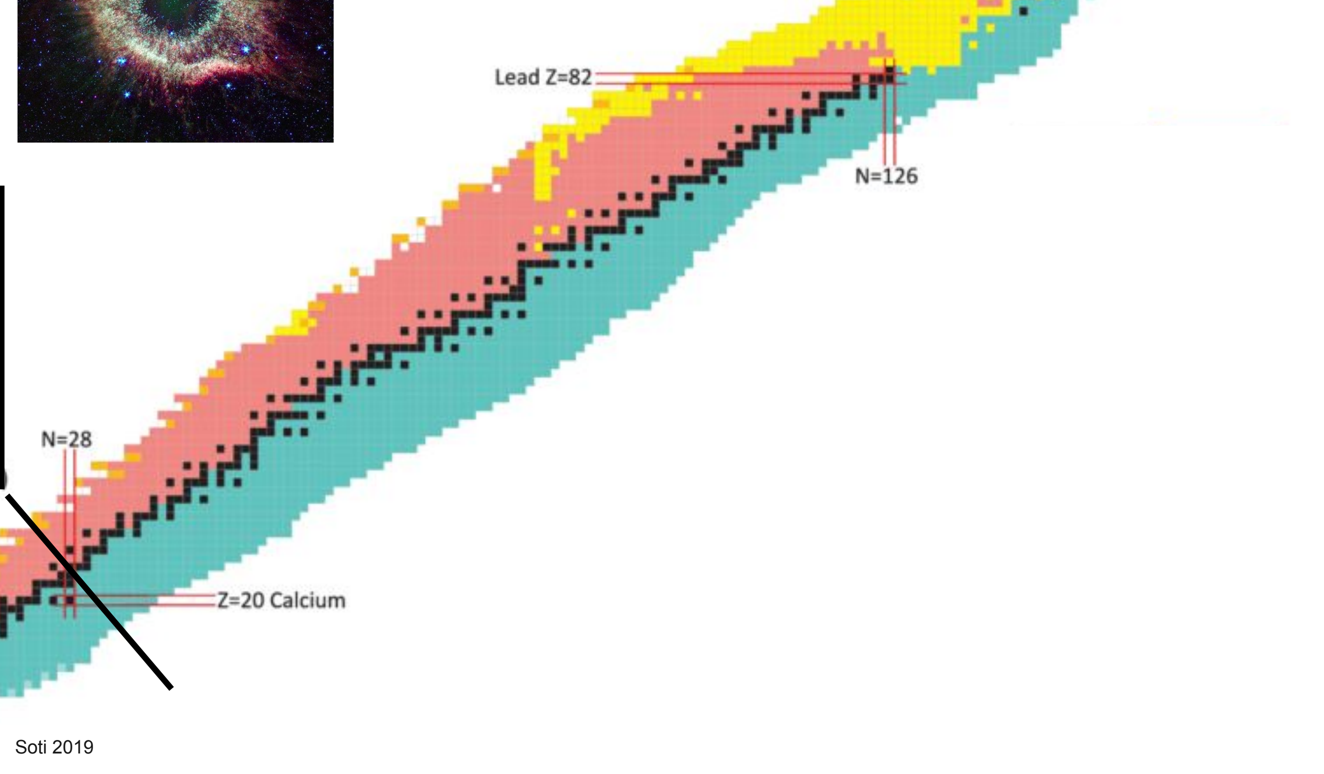
Valley of stability: slow neutron capture process



Hora, Latter, Smith & Marengo, 2006

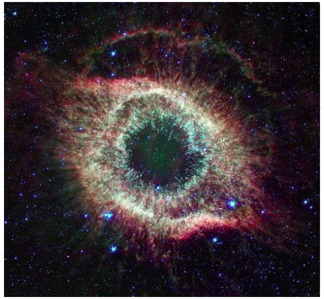


Stellar nucleosynthesis



Soti 2019

Valley of stability: slow neutron capture process



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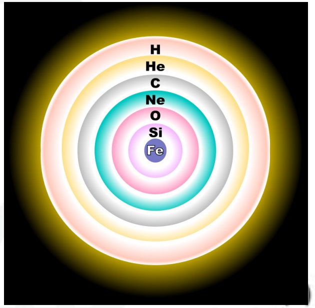
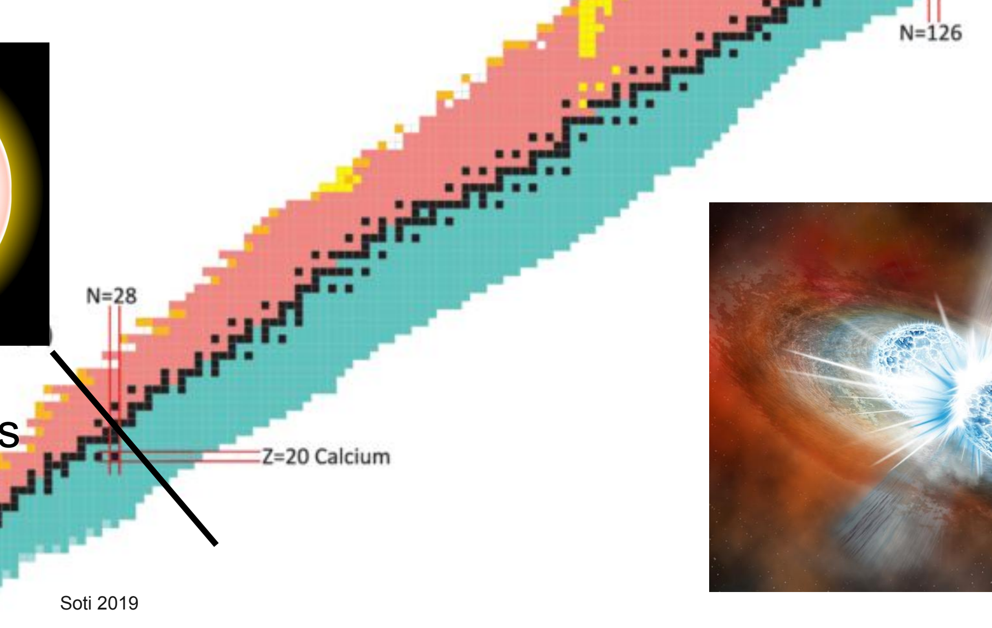


Stellar nucleosynthesis



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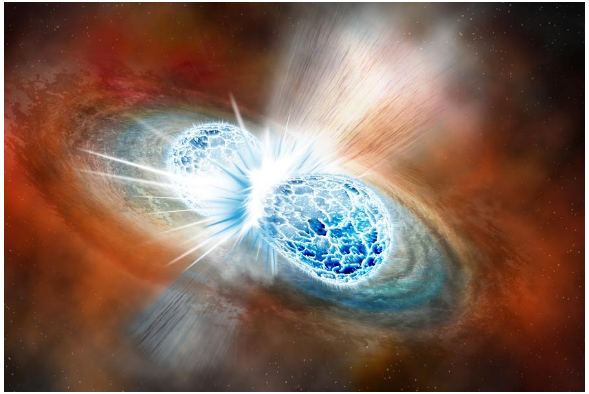
Right of the valley of stability: rapid neutron capture process



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?

Isotopes to the left of stability: “p-process”
Name: p-nuclides

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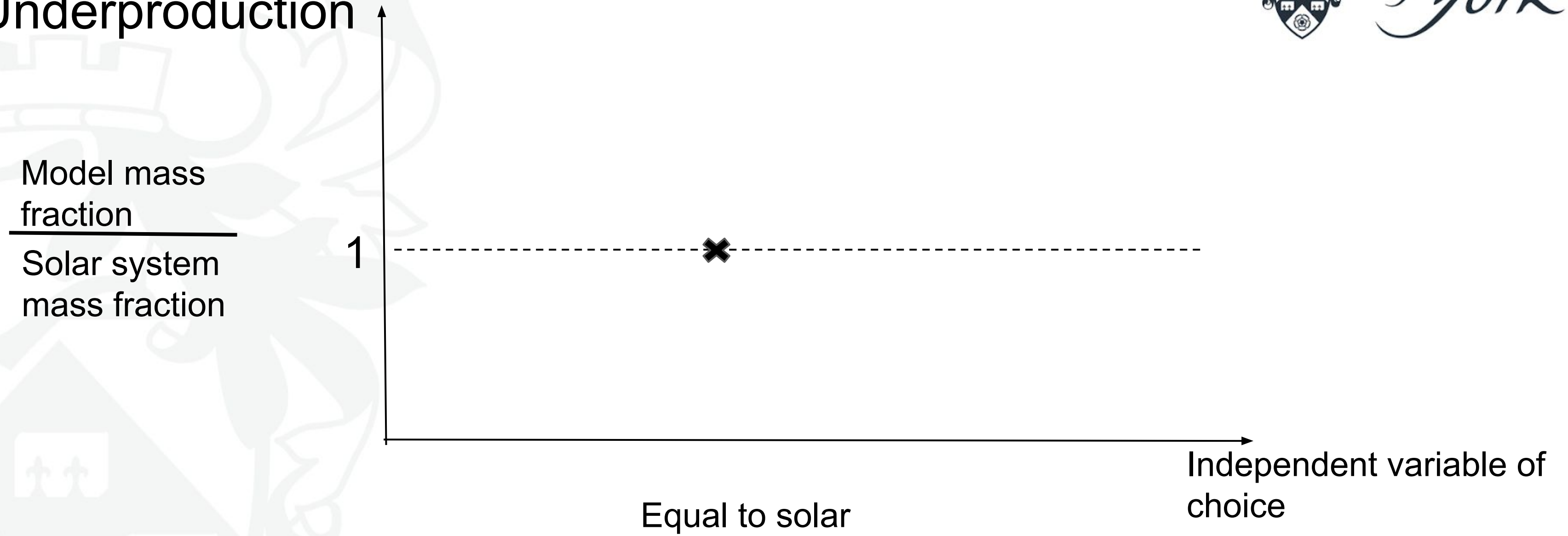
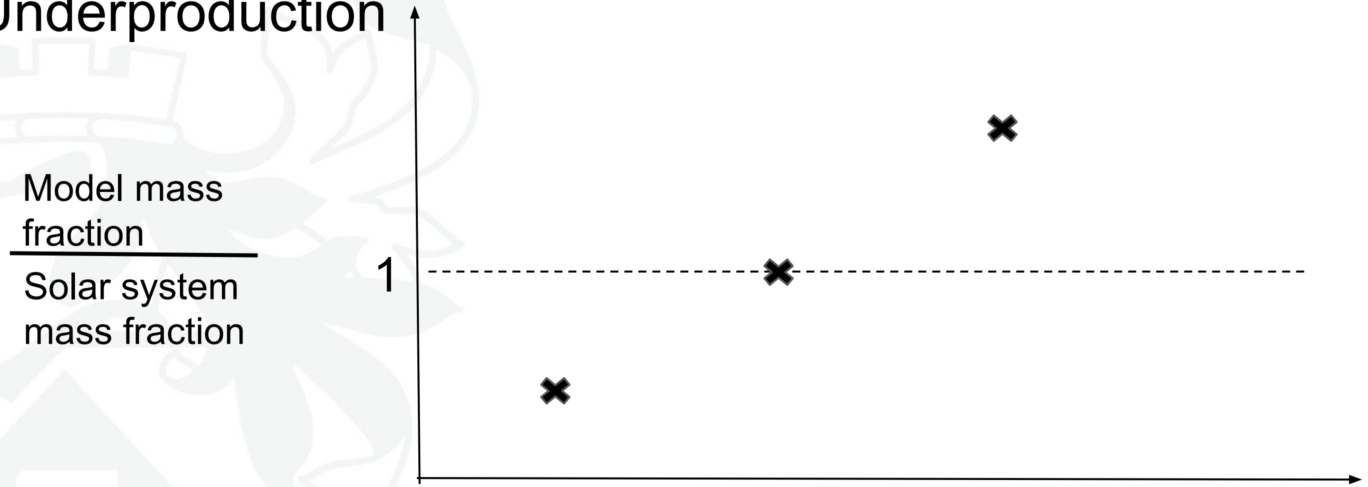
Important term in nuclear astrophysics: Overproduction and Underproduction



Equal to solar production

A model produces exactly the amount of an isotope we see in the solar system

Important term in nuclear astrophysics: Overproduction and Underproduction



Underproduction

Equal to solar production

Overproduction

A model produces less of an isotope than we see in our solar system

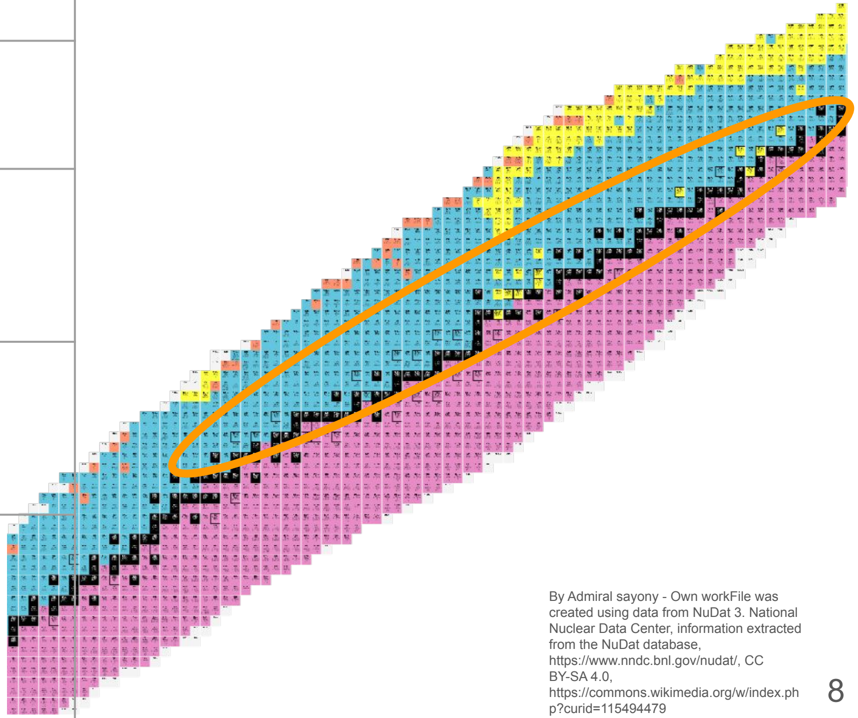
A model produces exactly the amount of an isotope we see in the solar system

A model produces more of an isotope than we see in our solar system

A problem in nuclear astrophysics: The p-nuclides

- Set of ~35 proton rich isotopes, ranging from ^{74}Se to ^{196}Hg that cannot be made by the s- or r-process
- Models underproduce p-nuclides by a factor of four compared to their solar system abundances (Pignatari et al. 2016)

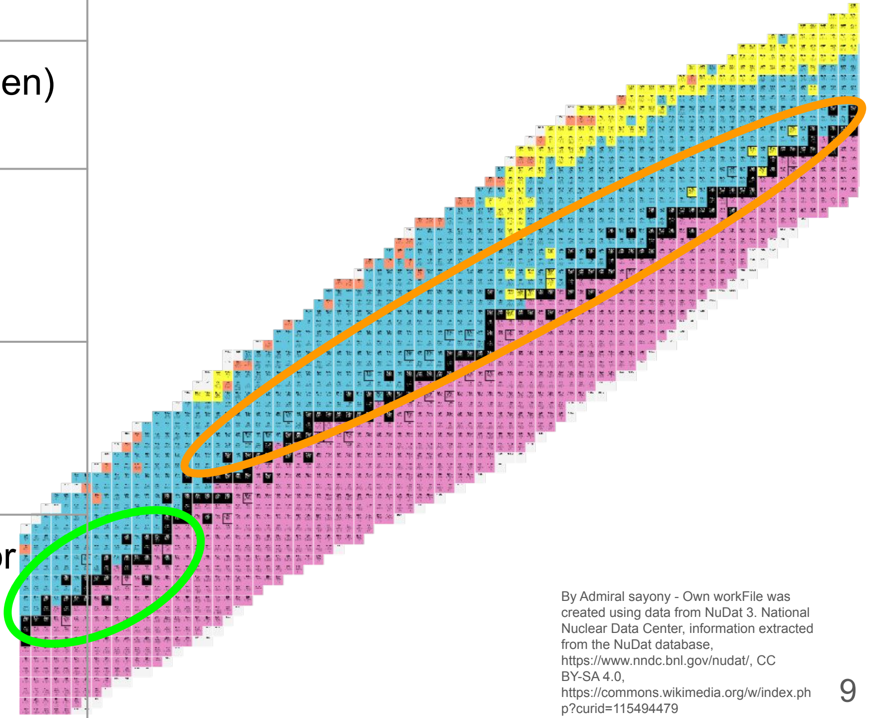
—	**Heavy p-nuclides**	
What	~^{106}Cd - ^{196}Hg (orange)	
Where	Mainly core collapse supernovae (CCNSe)	
How	Mainly gamma-process (photodisintegrations)	
Problems	Different CCNSe models produce varying amounts of p-nuclides, particular heavy p-nuclides present problems	



A problem in nuclear astrophysics: The p-nuclides

- Set of ~35 proton rich isotopes, ranging from ^{74}Se to ^{196}Hg that cannot be made by the s- or r-process
- Models underproduce p-nuclides by a factor of four compared to their solar system abundances (Pignatari et al. 2016)

—	Heavy p-nuclides	Light p-nuclides
What	~^{106}Cd - ^{196}Hg (orange)	^{74}Se - ~^{102}Pd (green)
Where	Mainly core collapse supernovae (CCNSe)	?
How	Mainly gamma-process (photodisintegrations)	?
Problems	Different CCNSe models produce varying amounts of p-nuclides, particular heavy p-nuclides present problems	Don’t know how or where the light p-nuclides are produced



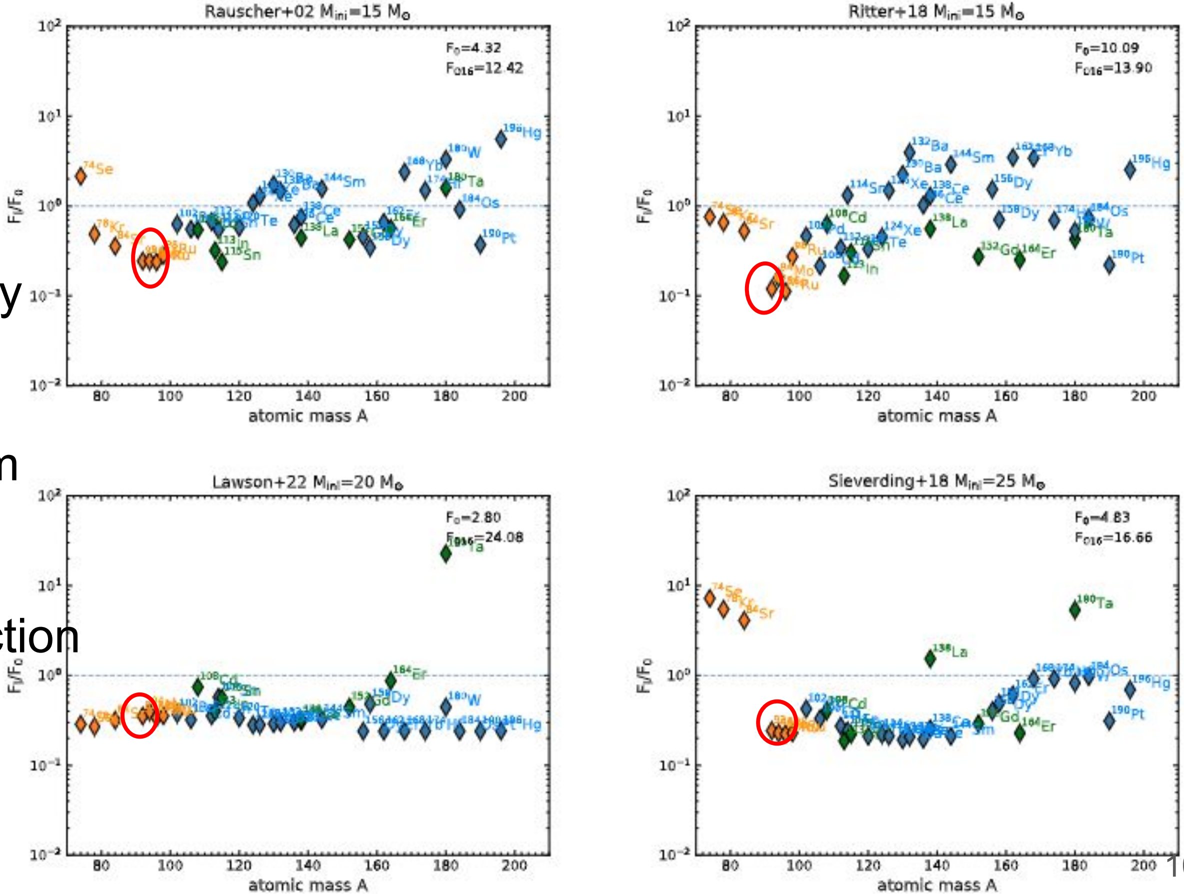
By Admiral sayony - Own workFile was created using data from NuDat 3. National Nuclear Data Center, information extracted from the NuDat database, https://www.nndc.bnl.gov/nudat/, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=115494479

A particular problem: ^{92}Mo

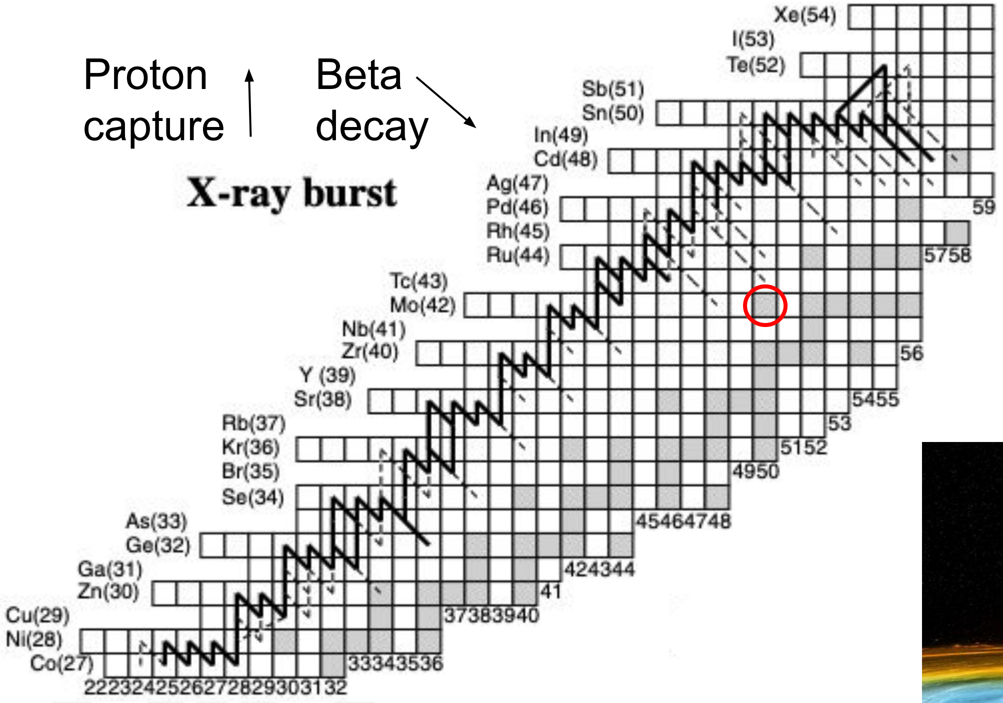
Roberti el al. 2023 - ^{92}Mo consistently not produced across four different core collapse supernovae models

UNIVERSITY of York

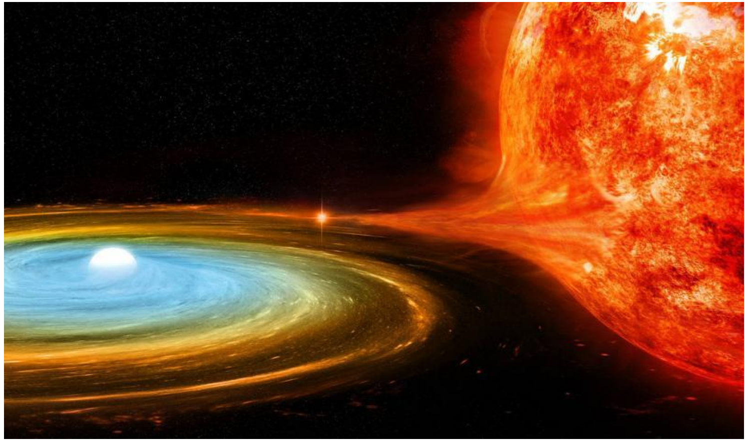
- We don't know:
  - Where?
  - How?
- Underproduced in models by an order of magnitude compared to its solar system abundance
- Our goal: to find overproduction of ^{92}Mo



The rapid proton capture process in X-ray Bursters (XRB)



- Proton rich material accretes from companion star's hydrogen envelope
- rp-process occurs
- ^{92}Mo overproduced (José 2010)



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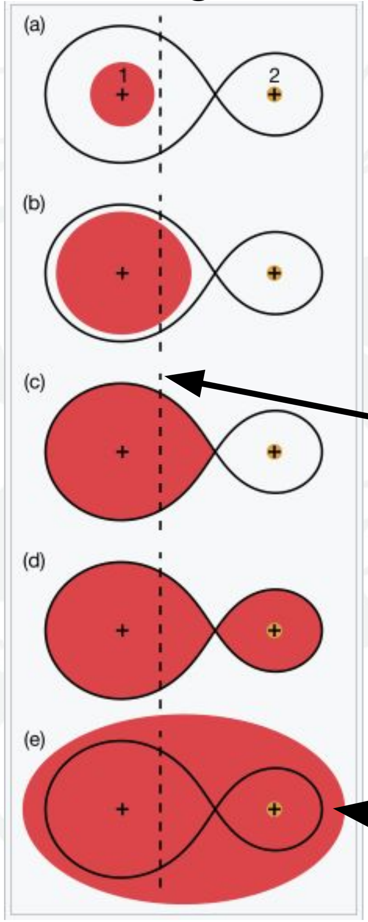
Introducing an alternative accretion scenario

Star 1: star with a hydrogen rich envelope
Star 2: neutron star

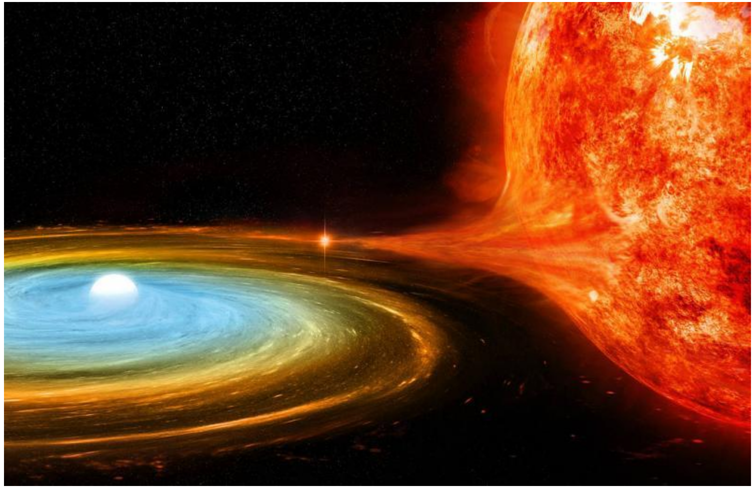


Time

Izzard et al. 2011

X-ray Burster

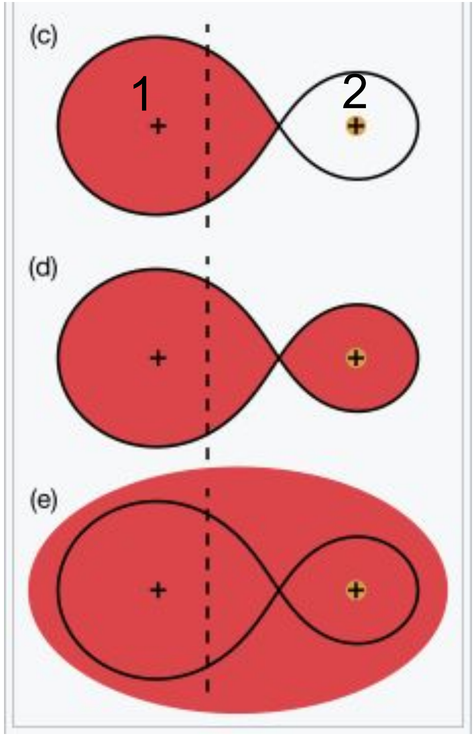
Common envelope



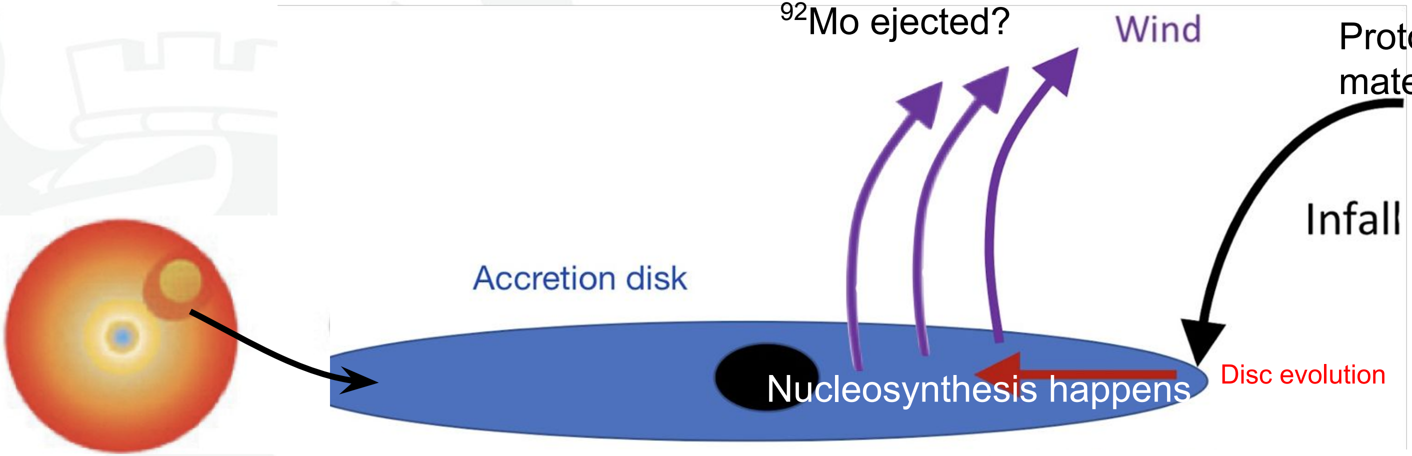
NASA/CXC/M. WEISS

How material escapes from a common envelope (CE)

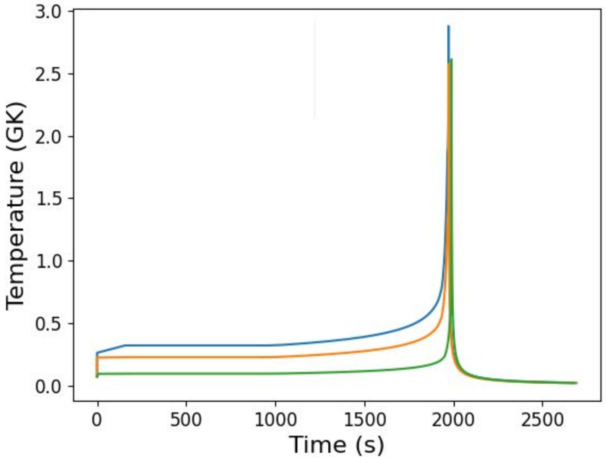
- Neutron star accretes proton rich material
- ~25% of accreted material can escape neutron star! (Fryer et al. 2006)
- At end of CE, accreted material enters interstellar medium
- Significant since this does not happen in XRB



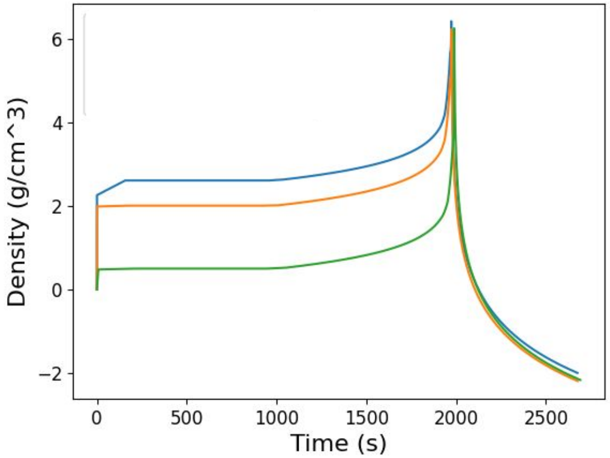
Our model



^{92}Mo ejected?
Wind
Proton rich material
Infall
Accretion disk
Nucleosynthesis happens
Disc evolution



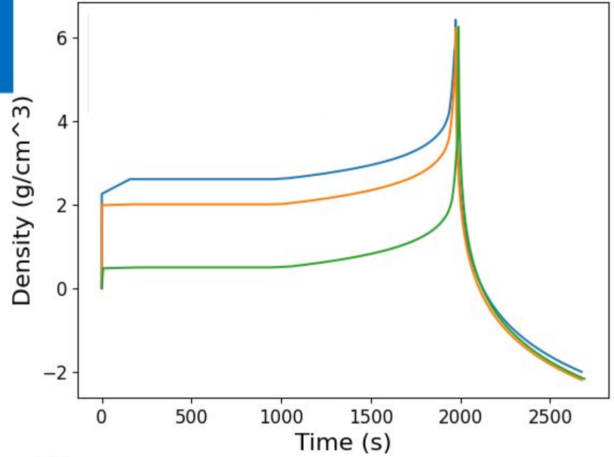
Temperature (GK)
Time (s)

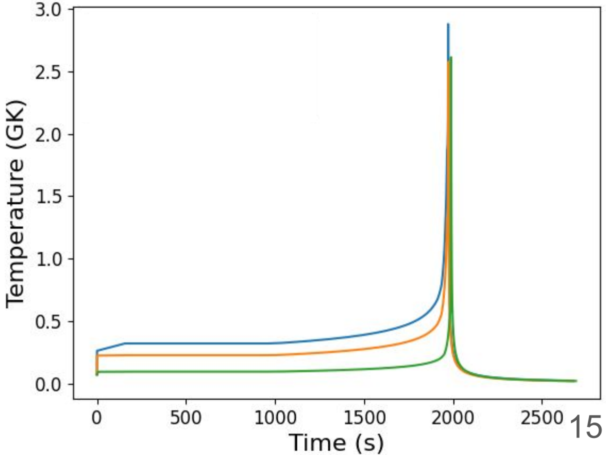


Density (g/cm^3)
Time (s)

NuGrid - PPN

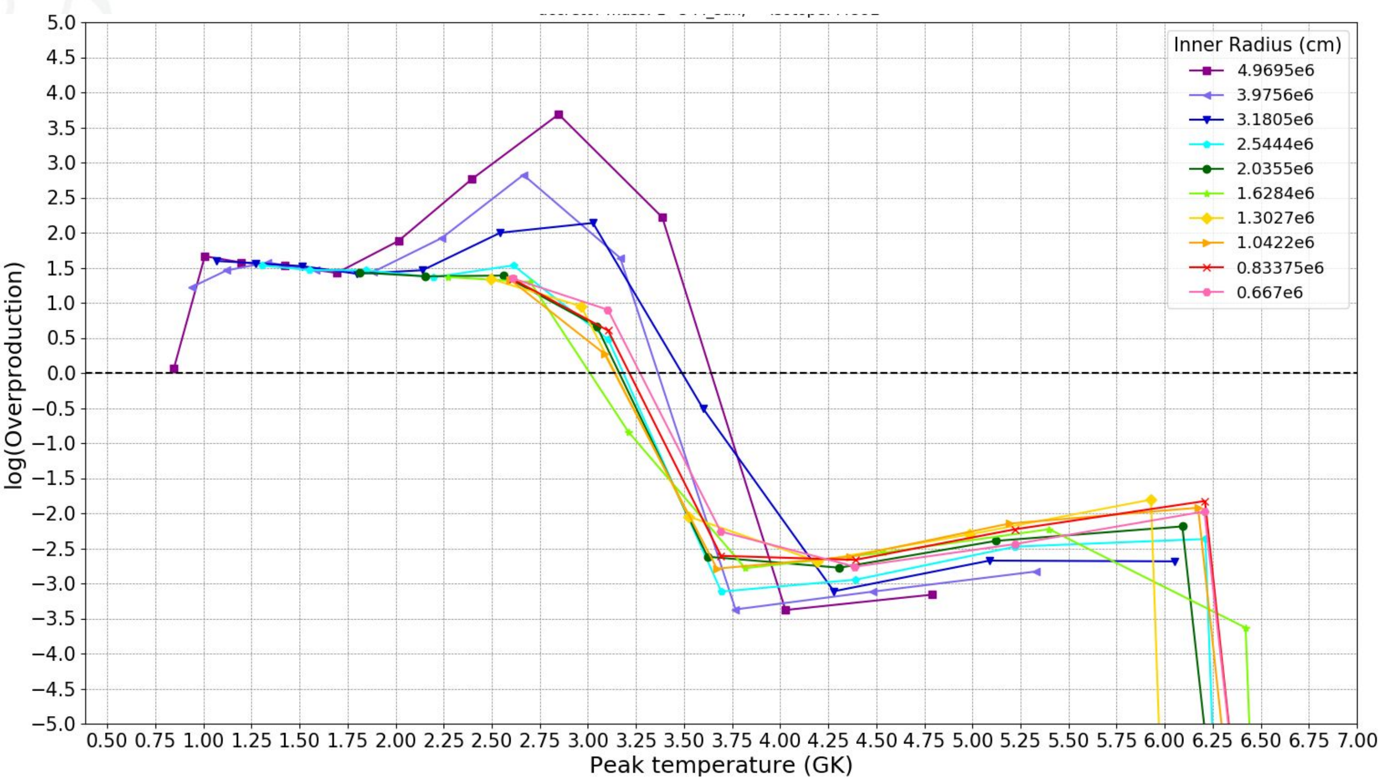
- Calculates nuclear yields based on:
  - Initial abundances provided
  - Temperature
  - Density
  - Time
- Nuclear inputs from mainly REACLIB
- Outputs mass fraction information





Overproduction of ^{92}Mo

- 40% of models overproduce ^{92}Mo
- Most overproduced by just under four orders of magnitude
  - (Dex 3.7)
- For p-nuclide overproduction: GOOD



Summary

- **Motivation:** p-nuclide ^{92}Mo is underproduced in current p-process models
- **Goal:** to find a scenario which overproduces ^{92}Mo in order to inject *more* ^{92}Mo into our Galaxy than was initially there
- **Our work:** gave a model of an accretion disk around a neutron star to a nuclear post processing network
- **Result:** Our model overproduces light p-nuclide ^{92}Mo

Thank you to: Alex Hall-Smith, Josh Wilson, Alison Laird, Christian Diget

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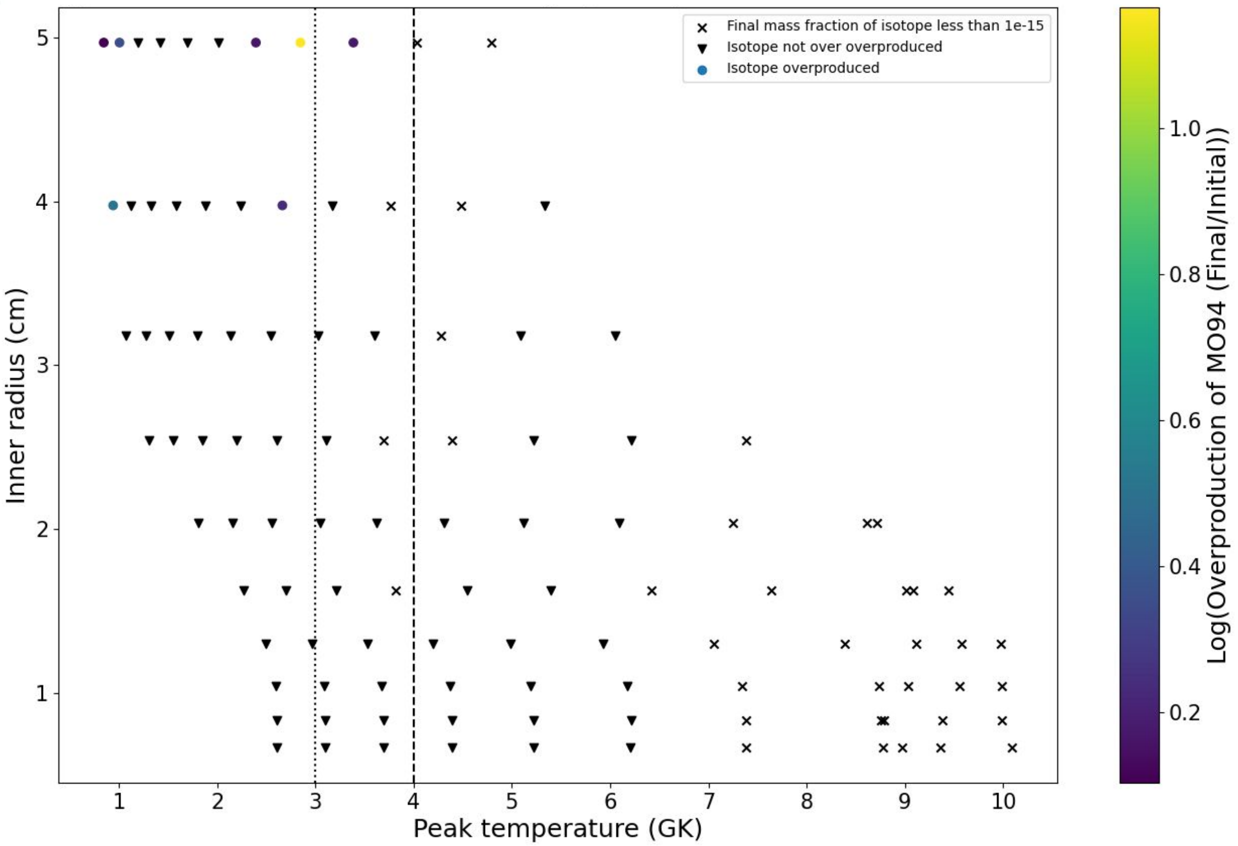
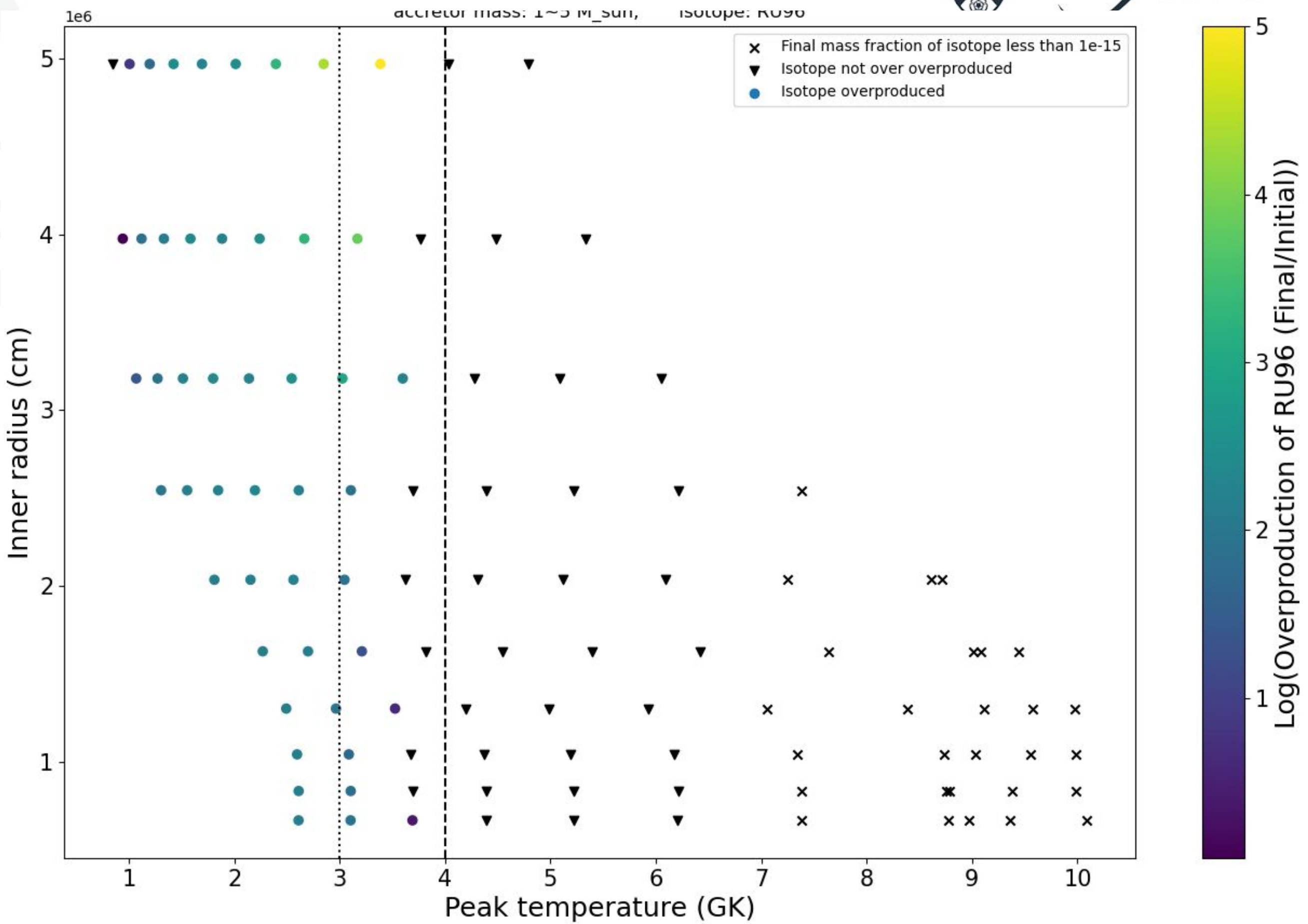
Overproduction Trends in 94Mo

- 7 out of 110 trajectories overproduce 94Mo
- Most overproduced by just over one orders of magnitude
  - (Dex 1.1)



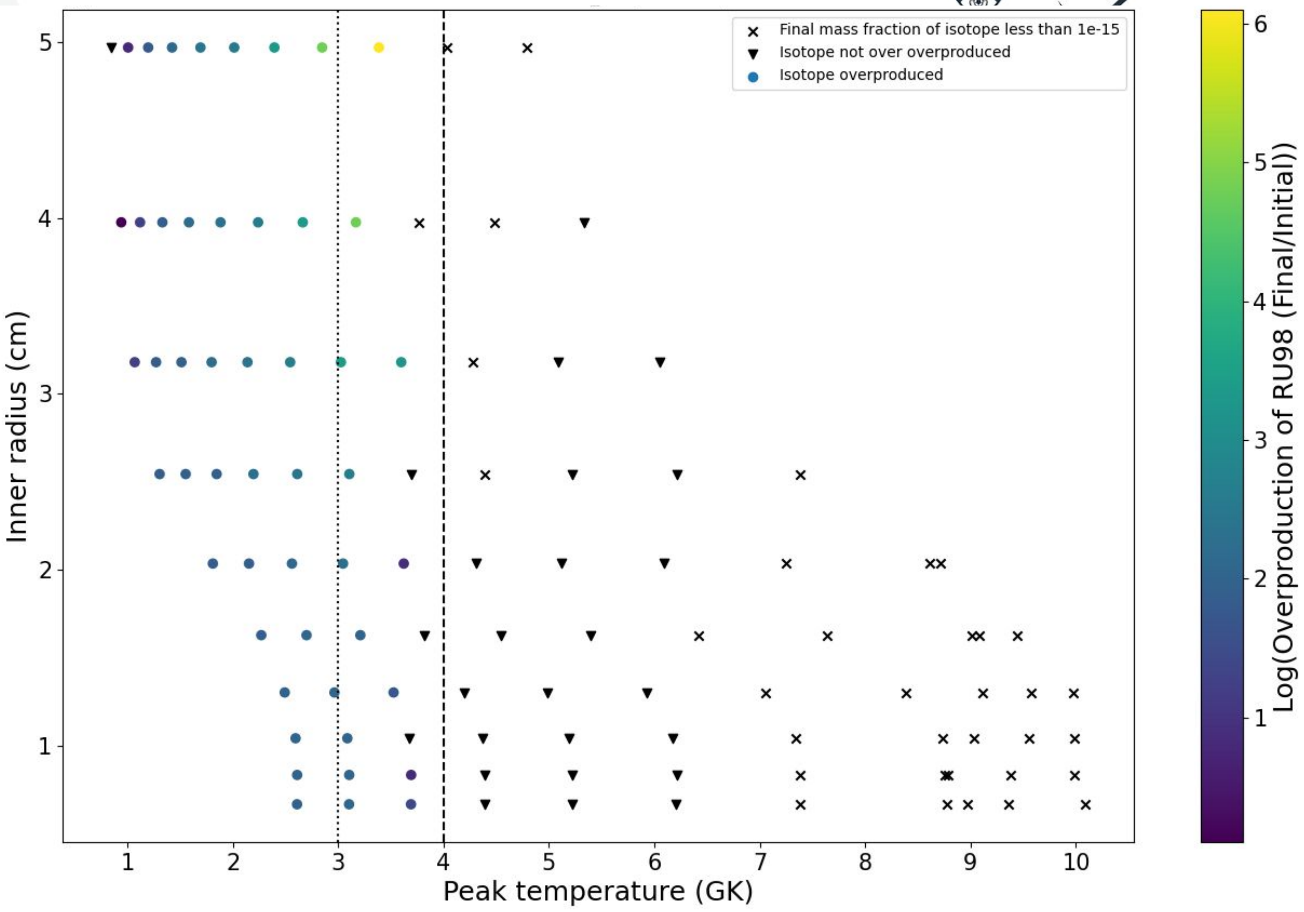
Overproduction Trends in 96Ru

- 47 out of 110 trajectories overproduce 96Ru
- Most overproduced by just over four orders of magnitude
  - (Dex 5.0)



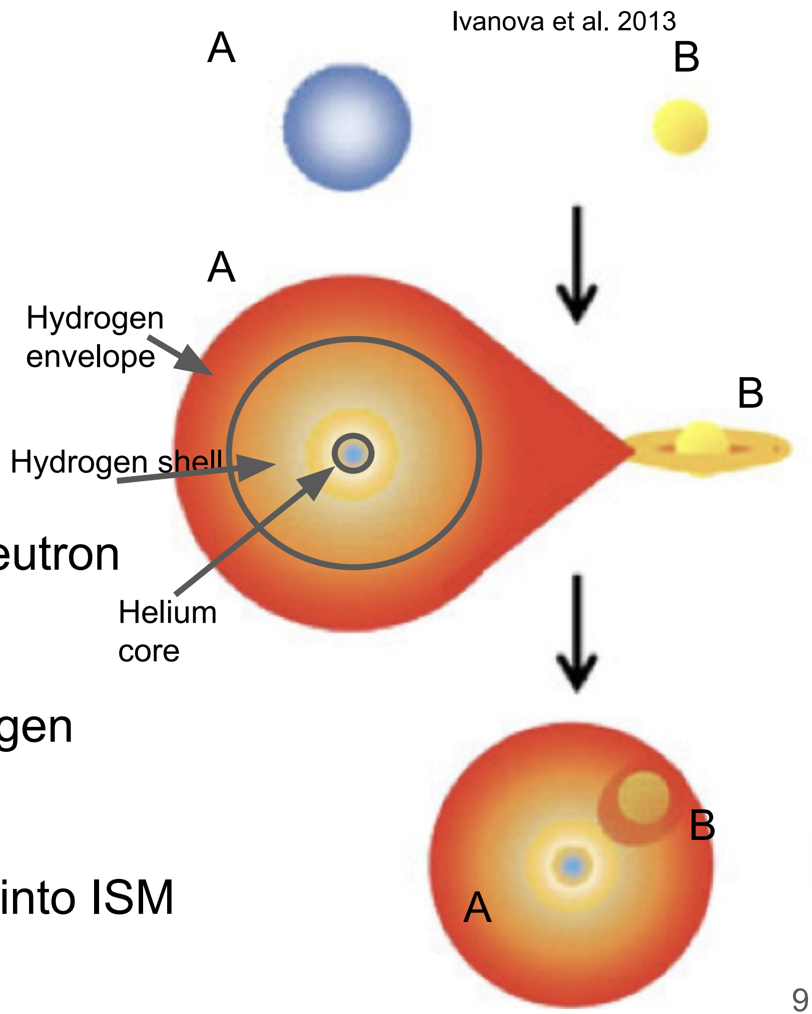
Overproduction Trends in 98Ru

- 49 out of 110 trajectories overproduce 98Ru
- Most overproduced by just over six orders of magnitude
    - (Dex 6.1)



Neutron star CE

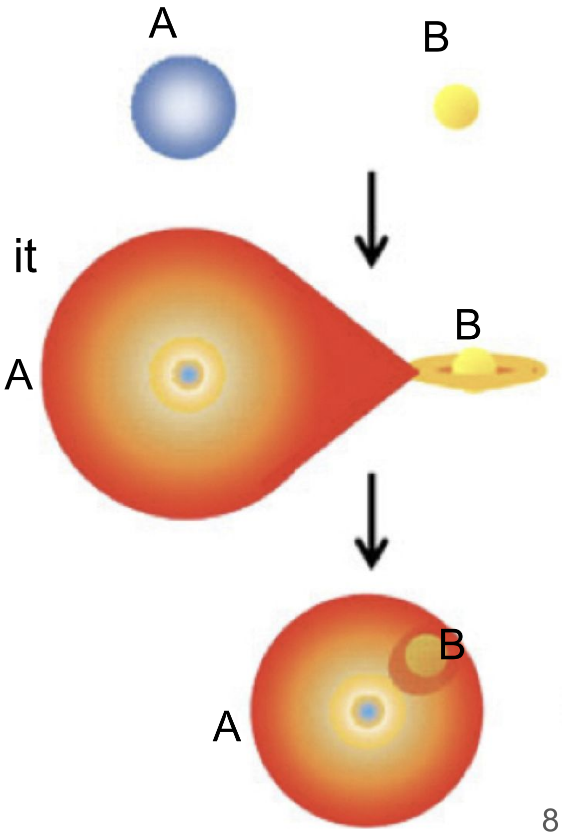
- In my system of interest:
  - A = star entering red giant phase
    - Hydrogen envelope
  - B = neutron star
- Neutron star accretes proton rich material
  - ~25% of accreted material can escape neutron star! (Fryer et al. 2006)
  - Accreted material moves back into hydrogen envelope of A
  - At end of CE, accreted material escapes into ISM
- Significant since this does not happen in XRB



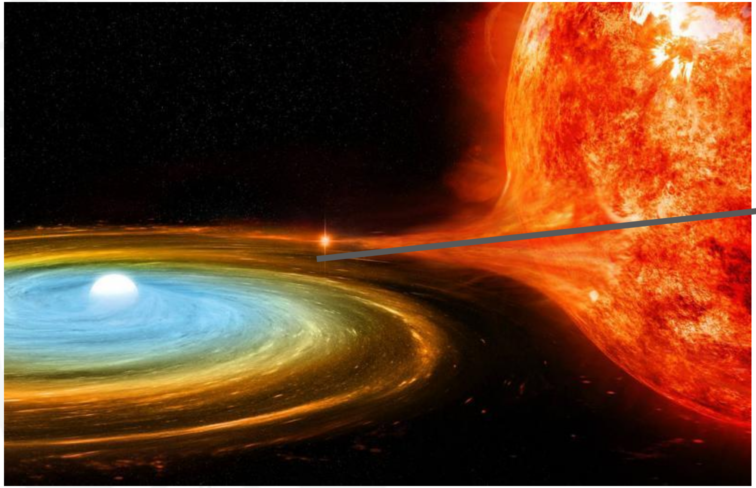
Common envelopes (CE)

- Stars existing in a shared stellar envelope
- Process:
    - A goes through an expansion phrase
        - Overflows its Roche Lobe
    - Material accretes onto B faster than it can incorporate it
    - B is overwhelmed by material from A, and is engulfed by A's stellar envelope
    - At some point, A's stellar envelope is ejected into interstellar medium (ISM) and CE ends
- B accretes material from A the entire time

Ivanova et al. 2013



Star 1: red giant with a hydrogen rich envelope
Star 2: neutron star



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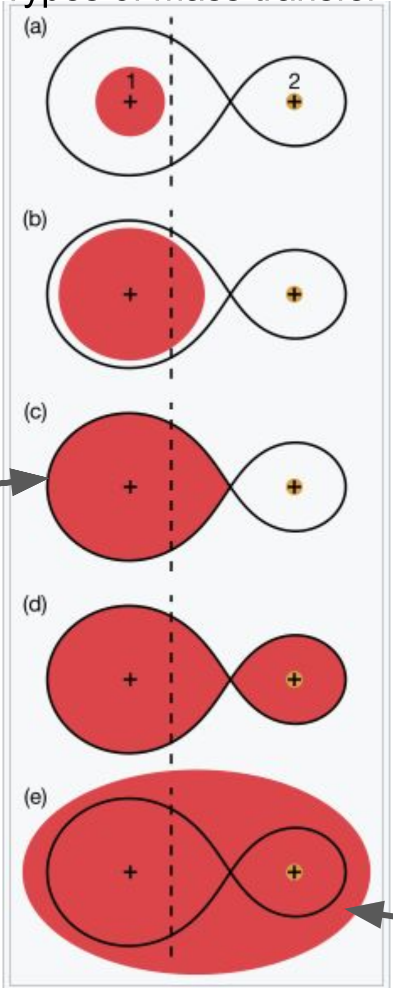
XRB

Types of mass transfer



Izzard et al. 2011

No mass transfer

Roche Lobe overflow occurs, mass transfer can occur from here

Potential for a lot of mass transfer

XRB happen here - stable mass transfer

What about accretion around a neutron star which happens here?

A **common envelope**