Nucleosynthesis in Compact Object Common Envelopes

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PACE meeting 2022

Outline

- Why are compact object CEs of interest to nuclear astrophysics
- P-nuclides as an example of important nucleosynthesis in CEs
- What we need from theory/observations

Accreting neutron star in CE - of interest to nuclear physics

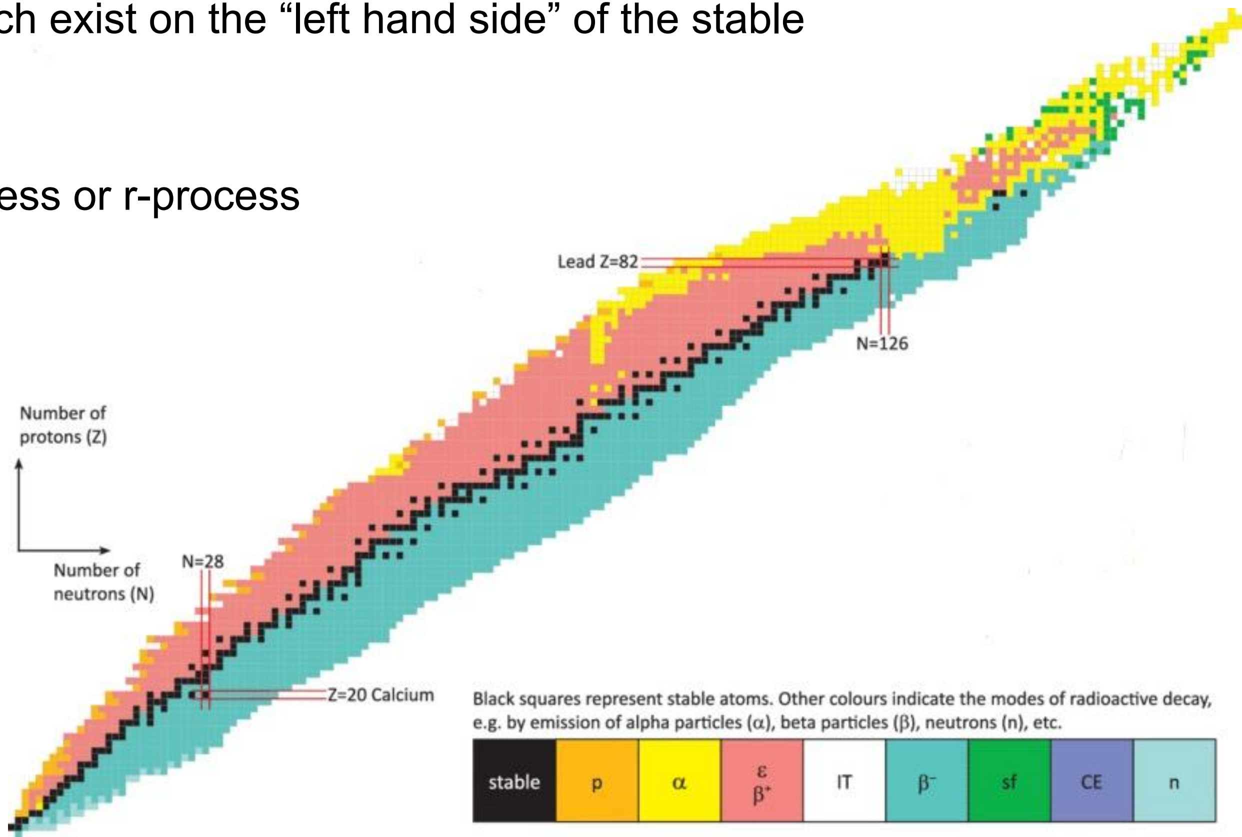
- Binary system with massive stars
  - NS with companion that enters RGB phase
- Of interest for nucleosynthesis because:
  - High densities and temperatures -> interesting nucleosynthesis
  - Material accreted may be ejected into ISM -> contribute to GCE
- Keegans et. al (2019) showed that isotopes produced in common envelopes are potentially important to galactic chemical evolution

P-nuclides

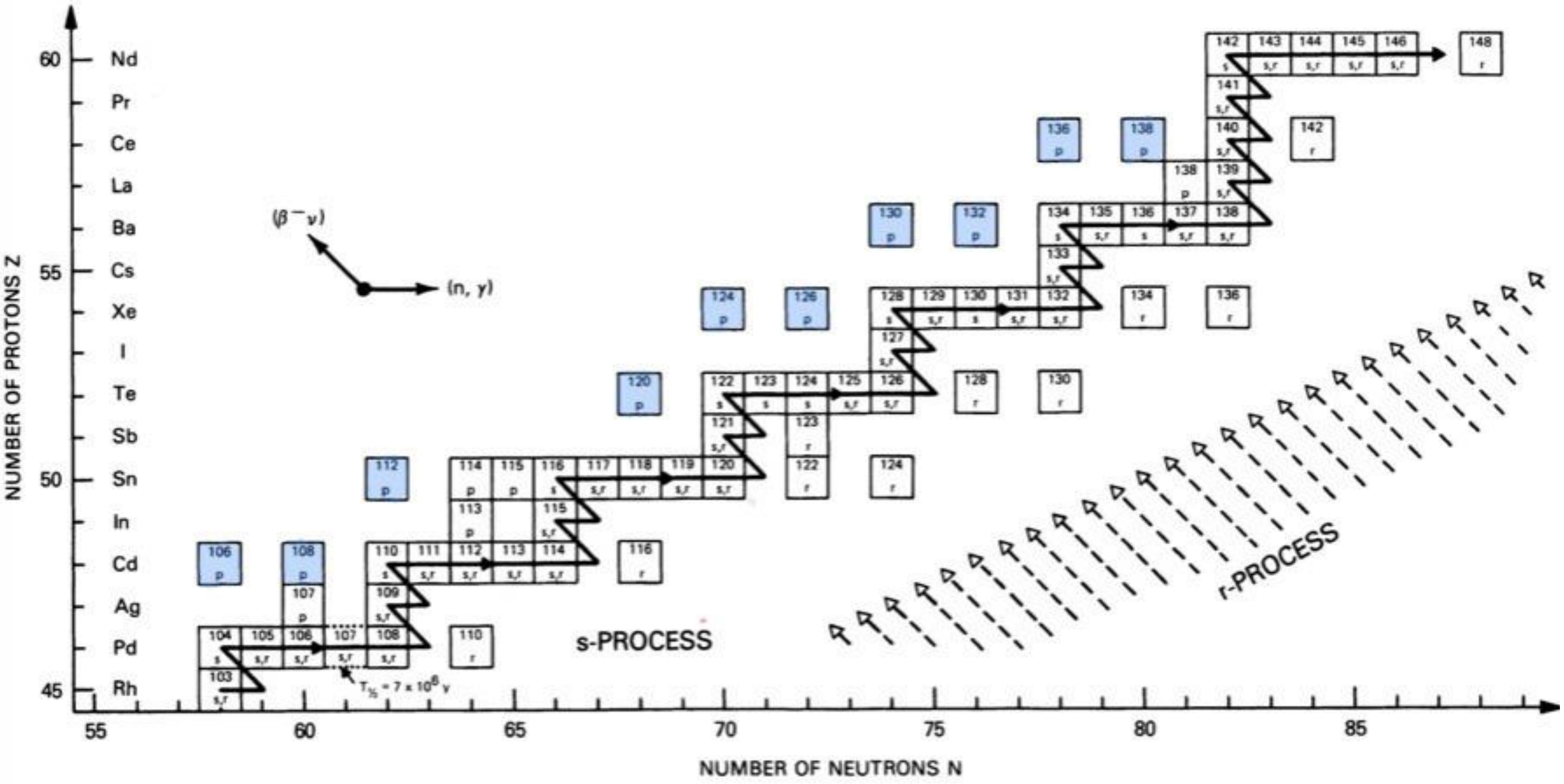
- Set of proton rich isotopes which exist on the “left hand side” of the stable isotopes on the nuclide charts

- Cannot be produced by s-process or r-process

- Not yet confirmed WHERE p-nuclides made or WHAT process makes them

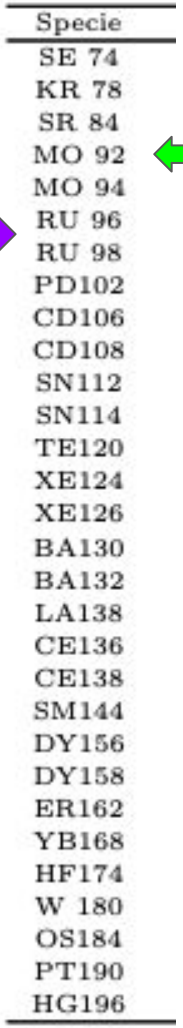


Black squares represent stable atoms. Other colours indicate the modes of radioactive decay, e.g. by emission of alpha particles (α), beta particles (β), neutrons (n), etc.


NUMBER OF PROTONS Z
60 Nd
Pr
Ce
La
Ba
55 Cs
Xe
I
Te
Sb
50 Sn
In
Cd
Ag
Pd
45 Rh
(β⁻ν)
(n, γ)
142 s
143 s,r
144 s,r
145 s,r
146 s,r
148 r
141 s,r
136 p
138 p
140 s,r
142 r
138 p
139 s,r
130 p
132 p
134 s
135 s,r
136 s
137 s,r
138 s,r
133 s,r
124 p
126 p
128 s
129 s,r
130 s
131 s,r
132 s,r
134 r
136 r
127 s,r
120 p
122 s
123 s
124 s
125 s,r
126 s,r
128 r
130 r
121 s,r
123 r
112 p
114 p
115 p
116 s
117 s,r
118 s,r
119 s,r
120 s,r
122 r
124 r
113 p
115 s,r
106 p
108 p
110 s
111 s,r
112 s,r
113 s,r
114 s,r
116 r
107 p
109 s,r
104 s
105 s,r
106 s,r
107 s,r
108 s,r
110 r
103 s,r
T½ = 7 x 10⁶ y
s-PROCESS
r-PROCESS
55
60
65
70
75
80
85
NUMBER OF NEUTRONS N

P-nuclides cont.

- Range from 74Se to 196Hg
- Underproduced by factor of four compared to solar system abundances in current models (Pignatari et al. 2016) [3].
- In particular, 92Mo, 96Ru and 98Ru are underproduced by an additional order of magnitude compared to other p-nuclides.



Specie
SE 74
KR 78
SR 84
MO 92
MO 94
RU 96
RU 98
PD102
CD106
CD108
SN112
SN114
TE120
XE124
XE126
BA130
BA132
LA138
CE136
CE138
SM144
DY156
DY158
ER162
YB168
HF174
W 180
OS184
PT190
HG196

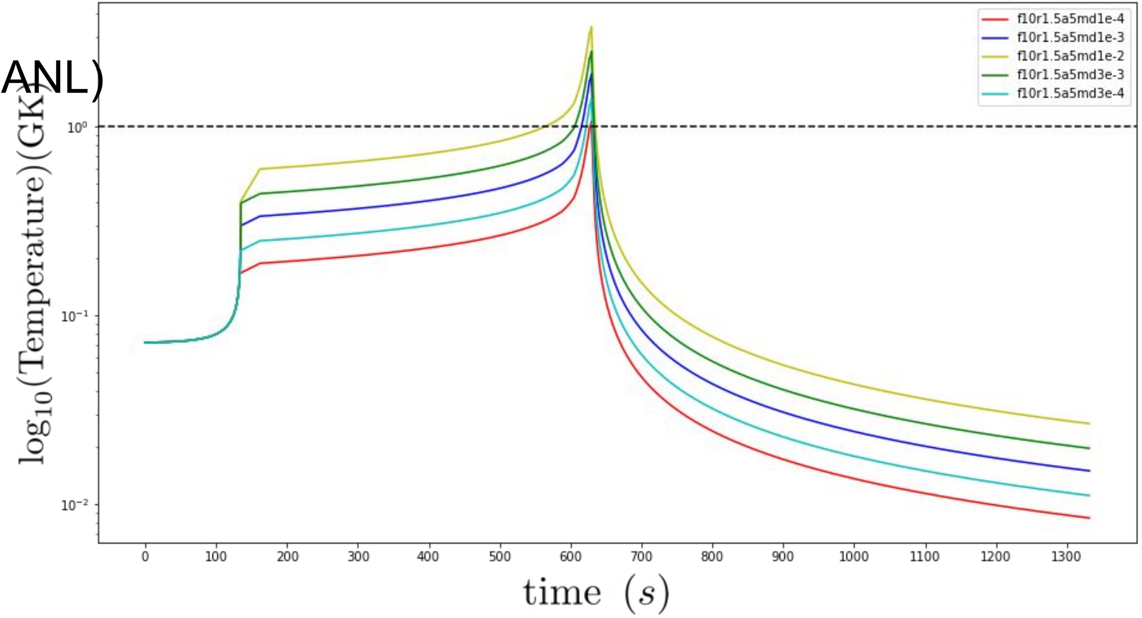
Taken from Battino et al. 2020

Modelling CE accretion disk

PRISM

Portable Routines for Integrated nucleoSynthesis Modeling

- Trajectories from LANL for temperature and density
    - Vary accretion rate
- Run through PRISM (Mumpower & Sprouse at LANL)
- Input:
    - Trajectory
    - Nuclear data (NuBase, NDI, Reaclib)
    - Initial mass fraction
- Output:
    - Final mass fractions

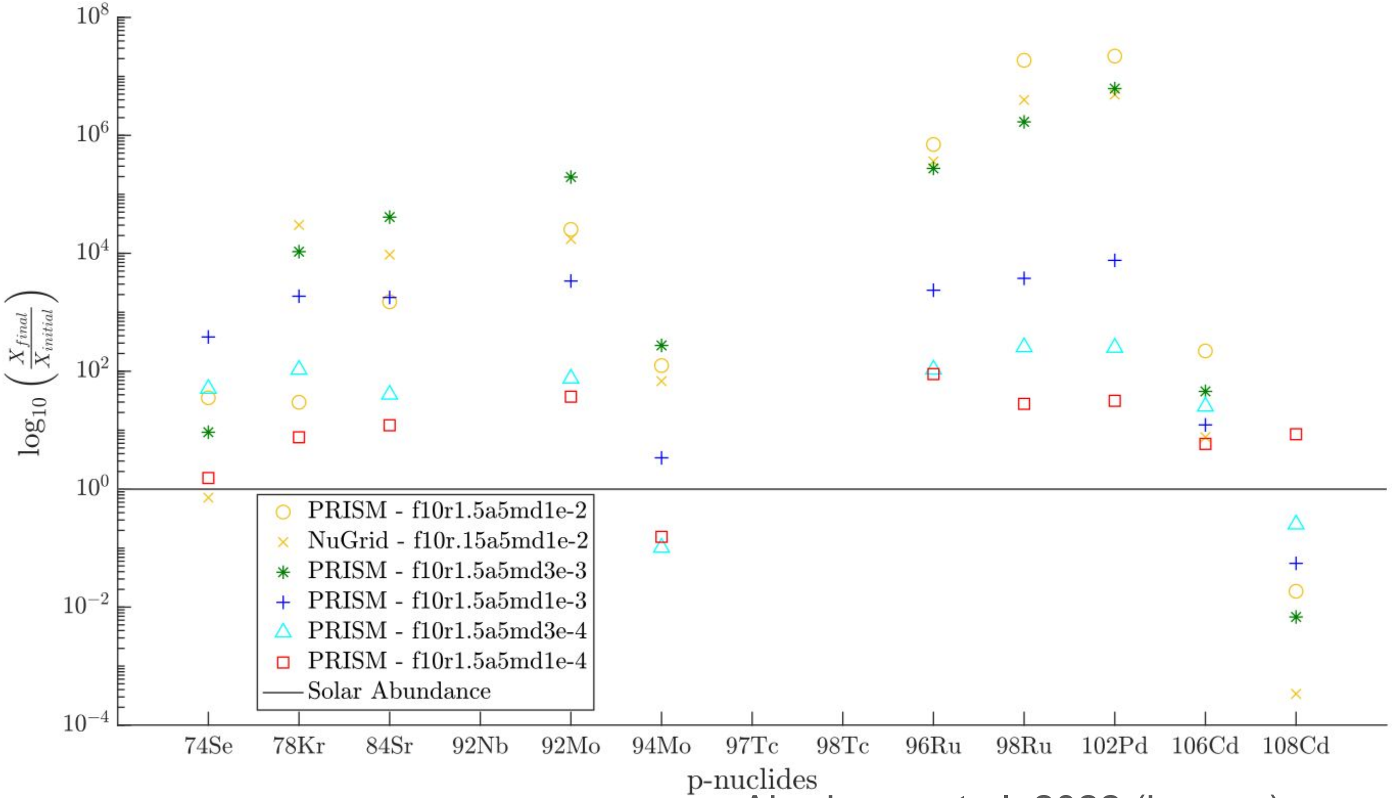


Abrahams et al. 2022 (in prep)

High production of p-nuclides

- High final mass fractions of several p-nuclides found
  - Higher the accretion rate around the neutron star the more p-nuclides produced

- Results from PRISM compared to NuGrid
  - Similar results



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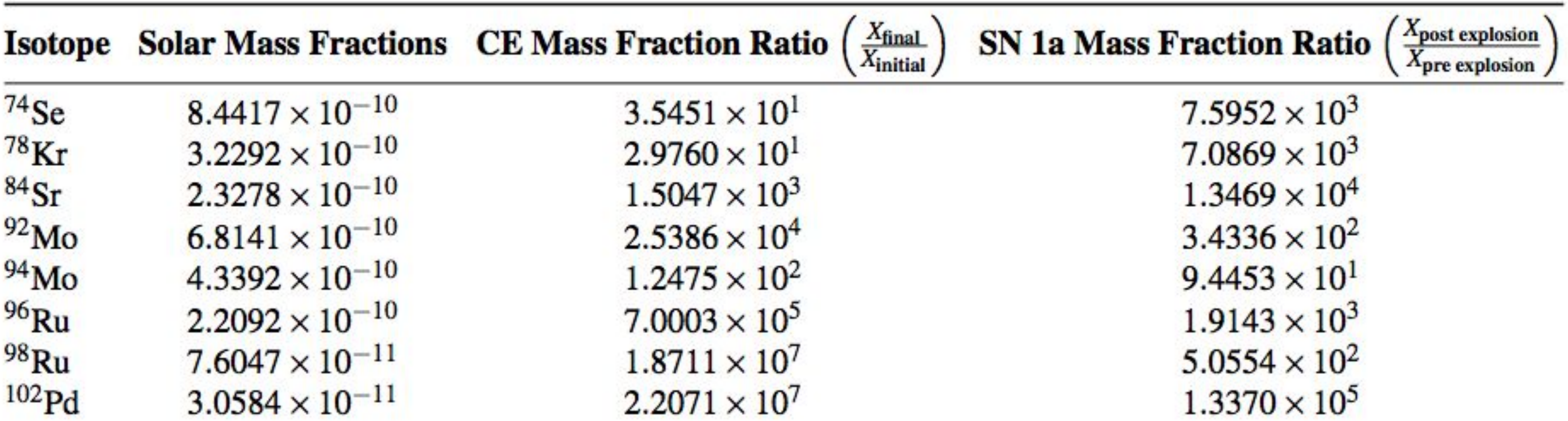
Comparison to SNIa (Battino et al. 2020)



Isotope	Solar Mass Fractions	CE Mass Fraction Ratio $\left(\frac{X_{\text{final}}}{X_{\text{initial}}}\right)$	SN 1a Mass Fraction Ratio $\left(\frac{X_{\text{post explosion}}}{X_{\text{pre explosion}}}\right)$
^{74}Se	8.4417×10^{-10}	3.5451×10^{1}	7.5952×10^{3}
^{78}Kr	3.2292×10^{-10}	2.9760×10^{1}	7.0869×10^{3}
^{84}Sr	2.3278×10^{-10}	1.5047×10^{3}	1.3469×10^{4}
^{92}Mo	6.8141×10^{-10}	2.5386×10^{4}	3.4336×10^{2}
^{94}Mo	4.3392×10^{-10}	1.2475×10^{2}	9.4453×10^{1}
^{96}Ru	2.2092×10^{-10}	7.0003×10^{5}	1.9143×10^{3}
^{98}Ru	7.6047×10^{-11}	1.8711×10^{7}	5.0554×10^{2}
^{102}Pd	3.0584×10^{-11}	2.2071×10^{7}	1.3370×10^{5}

Comparison table for mass fractions ratios from our common envelope model and mass fraction ratios from Battino *et al*.'s model of a type Ia supernova [5].

Abrahams et al. 2022 (in prep)

Ongoing questions

- How much material outflows?
  - How does accretion disk blow off?
  - How much accretion can take place before this happens?
  - Can blown off material enter companion and then enter ISM?
- How deep can neutron star go into companion?
  - Deeper into the star, more He rich, changes nucleosynthesis
- How often do NS-RBG type CE events occur?
  - Impacts how much CEs could impact ISM and GCE

Thank you to Alison Laird, Christian Diget, Chris Fryer and Alexander Hall-Smith

References

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[2] Laird, A. M. From Subatomic Physics to Astrophysics: Nuclear Astrophysics. University of York, Department of Physics
[3] Pignatari M, Gobel K, Reifarth R, Travaglio C. The production of proton-rich isotopes beyond iron: The γ-process in stars. International Journal of Modern Physics E. 2016 Apr 6;25(04):1630003
[4] Mumpower M. R., Sprouse T. M. PRISM - Portable Routines for Integrated nucleoSynthesis Modeling - Manual (version 1.5.0) Los Alamos National Laboratory, March 2020
[5] Battino U, Pignatari M, Travaglio C, Lederer-Woods C, Denissenkov P, Herwig F, Thielemann F, Rauscher T. Heavy elements nucleosynthesis on accreting white dwarfs: building seeds for the p-process. Monthly Notices of the Royal Astronomical Society. 2020 Oct;497(4):4981-98