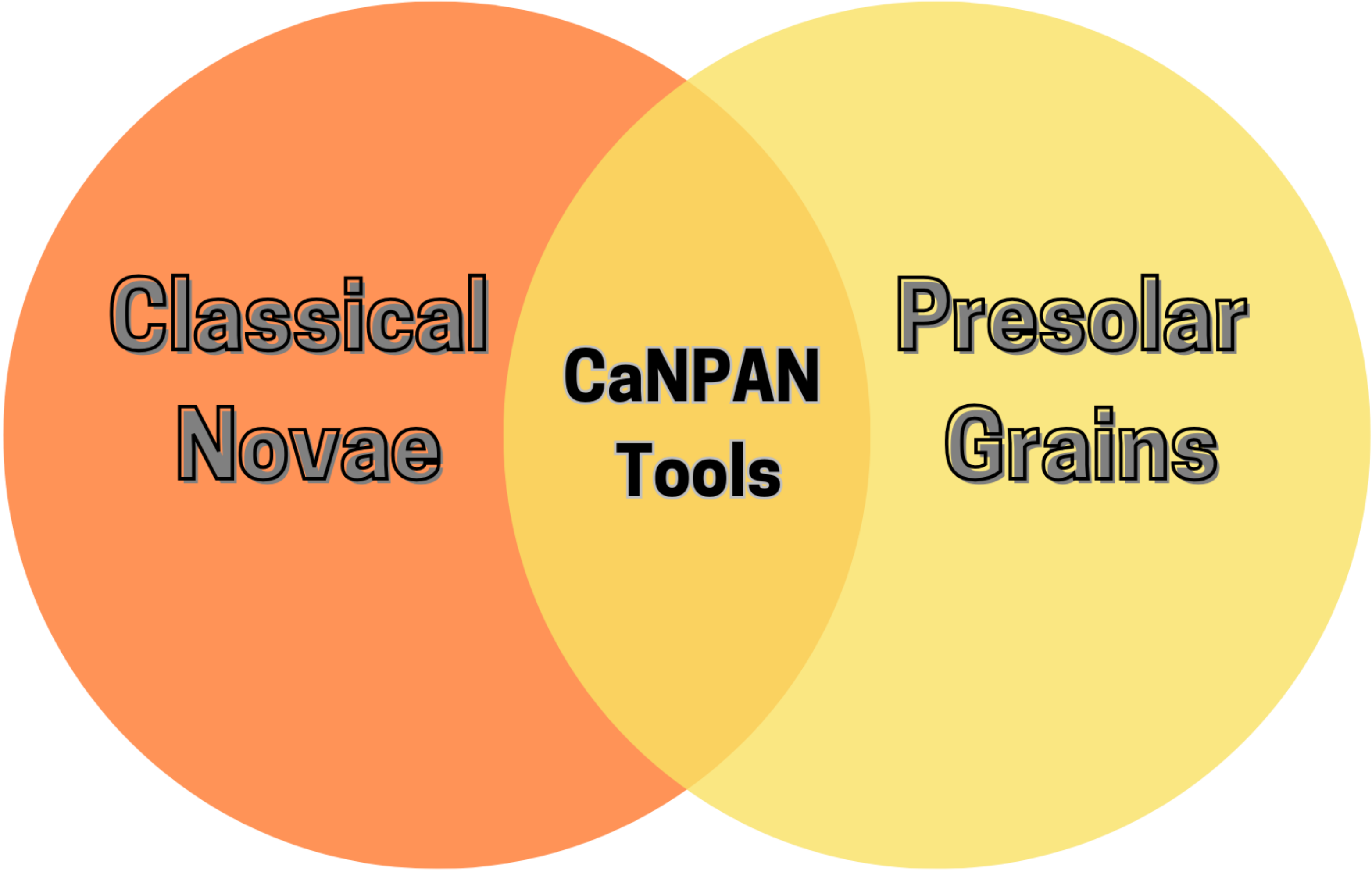
Illuminating Nuclear Physics Uncertainties in Astrophysics With CaNPAN Tools

Mallory Loria
University of Victoria/TRIUMF
05/01/24



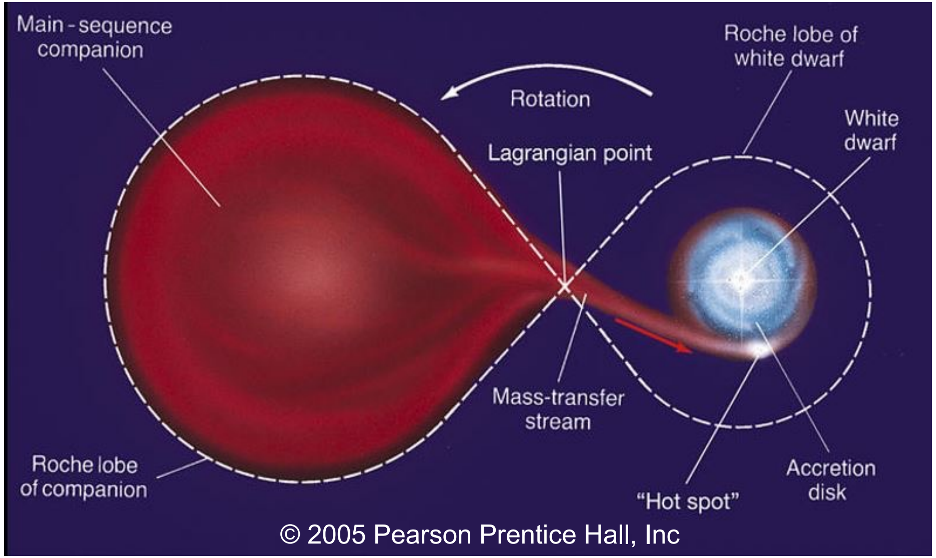
Classical Novae

CaNPAN Tools

Presolar Grains

Classical Novae

- Explosive events where a white dwarf (WD) accretes material from a low-mass, main-sequence companion (Chomiuk+ 21)
- One of the most common types of explosions in our galaxy (20 – 70 per year)
- Important to study because they offer insights into explosive nucleosynthesis processes that we can then study in the laboratory (Lovely+ 21)



Nova models for heavy element production

- Performed multi-zone post-processing nucleosynthesis simulations (NuGrid MPPNP) on five Modules for Experiments in Stellar Astrophysics (MESA) nova models
- Gathered abundances from nine observed novae that report Ca abundance

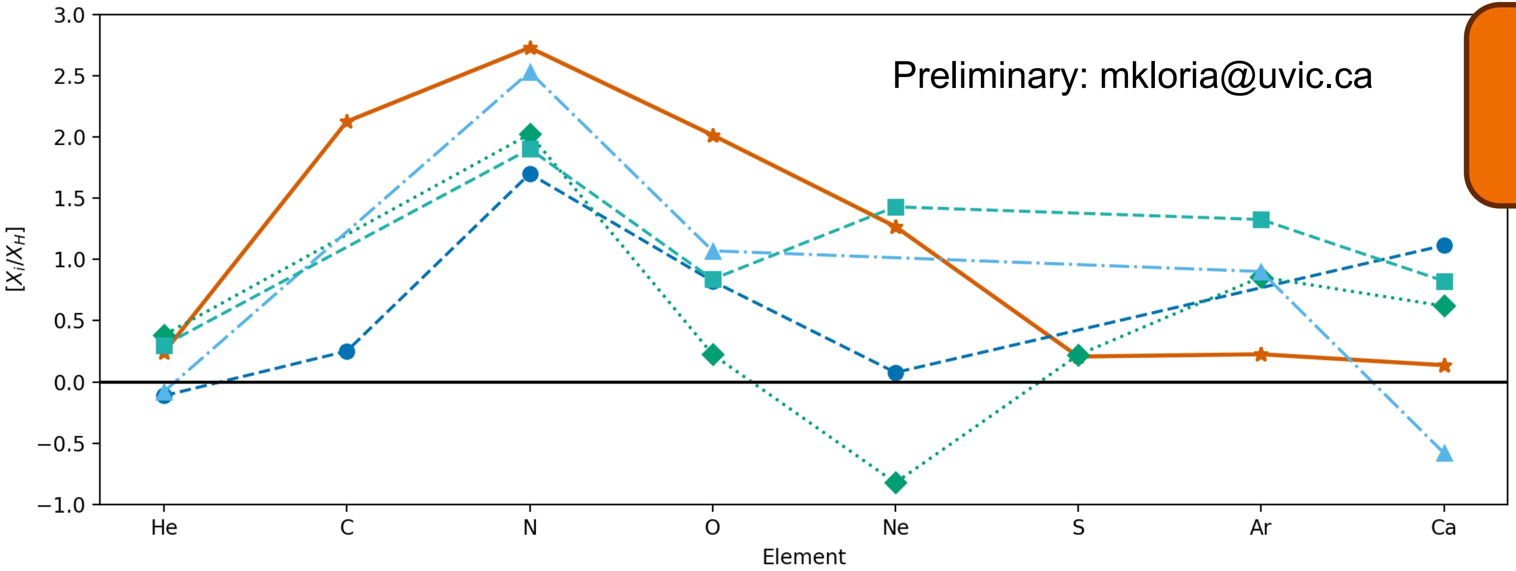
Preliminary!

The hotter and more extreme the nova, the greater the production of heavy elements!

Table 1: MESA nova model parameters, similar to Denissenkov+ 14

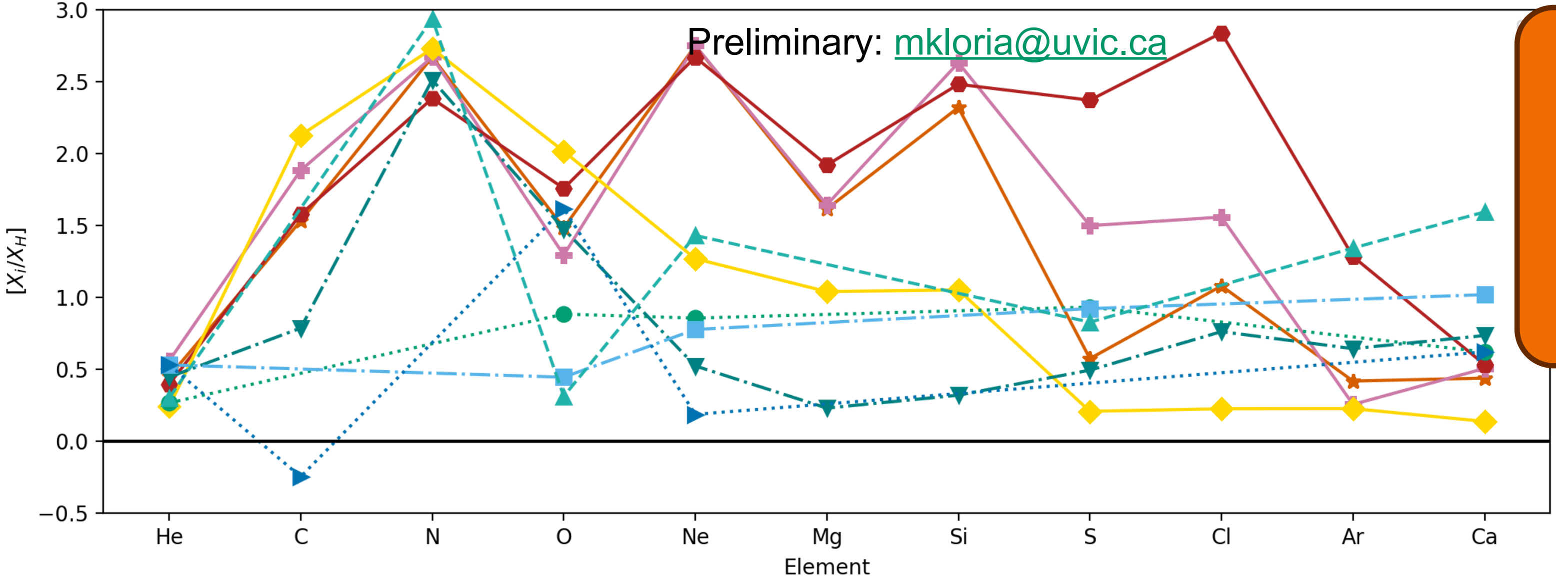
Ca overabundance in observed novae

$[X_i/X_H] = \log_{10}(X_i/X_H)_{\text{nova}} - \log_{10}(X_i/X_H)_\odot$



Ca overabundance in observed novae

$[X_i/X_H] = \log_{10}(X_i/X_H)_{nova} - \log_{10}(X_i/X_H)_{\odot}$



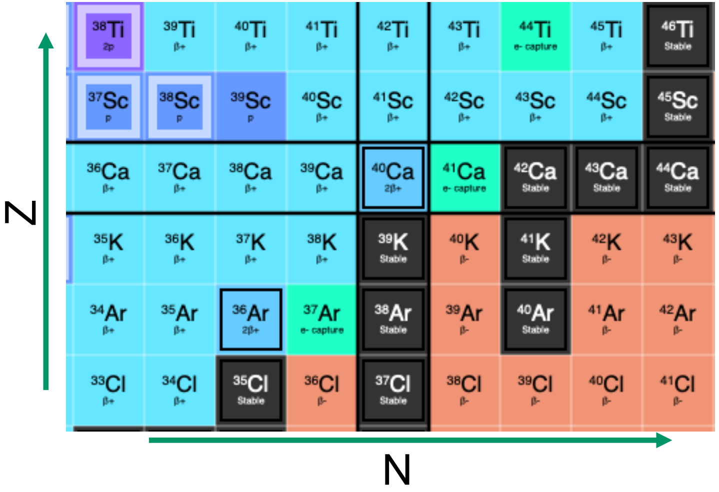
Preliminary: mkloria@uvic.ca

What causes this discrepancy?

- Could it be the nuclear physics uncertainties in our models?
  - Certain reactions are not well studied thus the uncertainties in their rates are large

- Performed Monte Carlo (MC) simulations of single-zone post-processing (NuGrid PPN) nucleosynthesis that vary nuclear reaction rates by a factor of 10 up and down
  - (p, γ), (p, α), (α, γ), (α, p)
  - ^{33}Cl to ^{41}Cl and up to ^{38}Ti to ^{46}Ti

- Calculate Pearson correlation coefficients to get the important reactions for element production



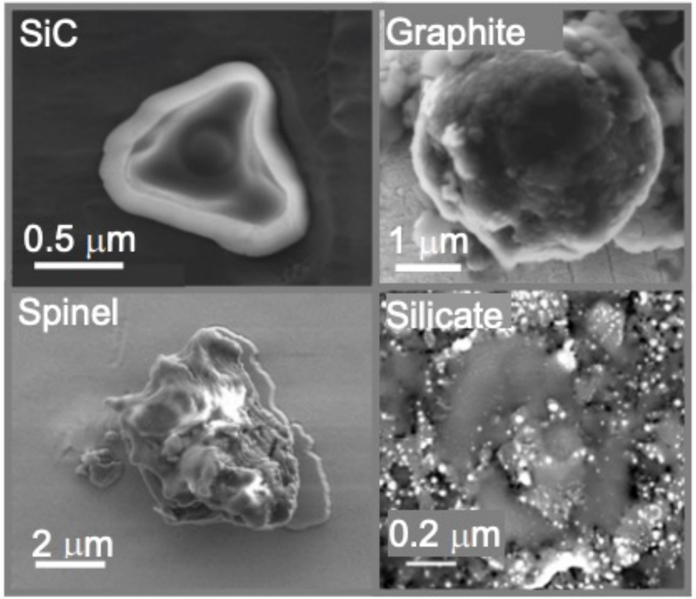
Impact of varied nuclear reaction rates on Ca production

- **^{39}K(p, γ)^{40}Ca** and **^{38}K(p, γ)^{39}Ca** identified as the most correlated to the production of Ca in *all* nova models

- ^{39}K(p, γ)^{40}Ca rate increased by a factor of 13 (Fox+ 24)

- Changed only reaction rate of ^{39}K(p, γ)^{40}Ca by a factor of 10 for our hottest nova model → minimal increase in Ca

NUCLEAR PHYSICS UNCERTAINTIES CANNOT ACCOUNT FOR THIS DISCREPANCY



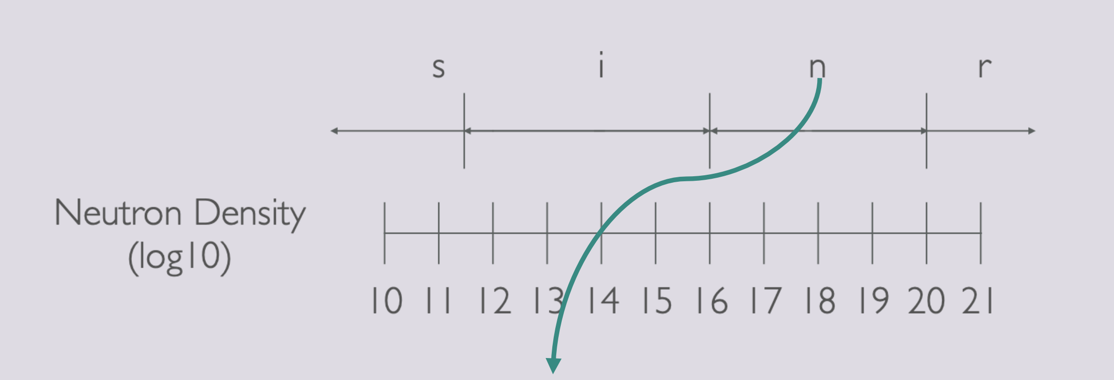
Max Planck Institute for Chemistry

Presolar Grains

- Specs of interstellar dust formed by stars that died before the solar system formed (Clayton & Nittler 2004)
- Typically formed in asymptotic giant branch (AGB) stars and core-collapse supernovae (CCSNe) (Pignatari+ 2018, Lugaro+ 2018)
- They are important to study because their isotopic abundances can tell us about the nucleosynthesis of their parent star

Can we identify presolar grains as coming from an i or n-process site?

B. Cropmvoets 2021



<u>i-process</u>

Rapidly Accreting White Dwarfs:

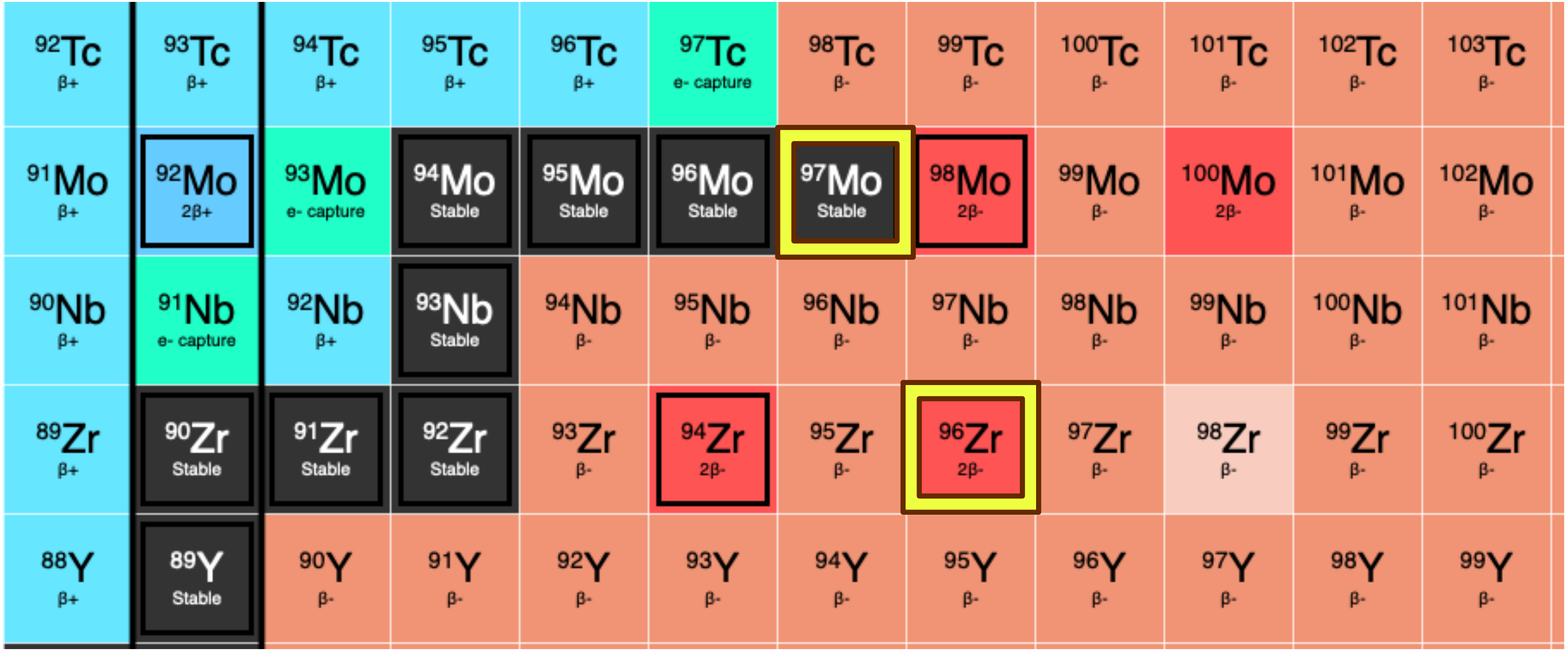
$^{12}C(p, \gamma)^{13}N \rightarrow {}^{13}N(\beta +)^{13}C \rightarrow {}^{13}C(\alpha, n)^{16}O$

(Denissenkov + 2019)

<u>n-process</u>

Core Collapse Supernovae: $^{22}Ne(\alpha,n)^{25}Mg$

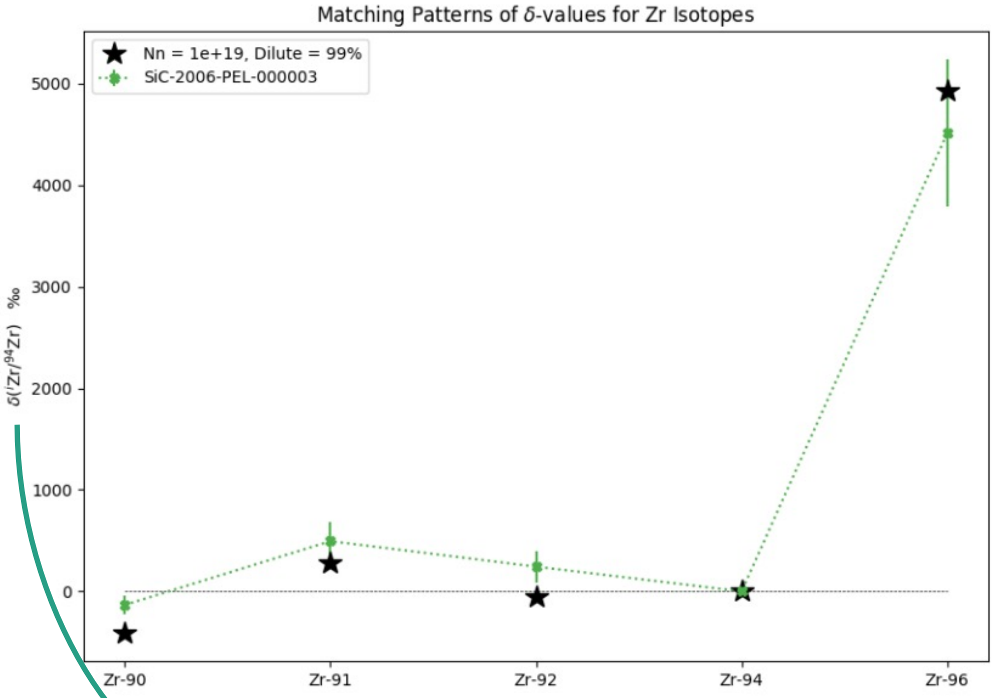
(Pignatari + 2018)



^{92}Tc β+	^{93}Tc β+	^{94}Tc β+	^{95}Tc β+	^{96}Tc β+	^{97}Tc e- capture	^{98}Tc β-	^{99}Tc β-	^{100}Tc β-	^{101}Tc β-	^{102}Tc β-	^{103}Tc β-
^{91}Mo β+	^{92}Mo 2β+	^{93}Mo e- capture	^{94}Mo Stable	^{95}Mo Stable	^{96}Mo Stable	^{97}Mo Stable	^{98}Mo 2β-	^{99}Mo β-	^{100}Mo 2β-	^{101}Mo β-	^{102}Mo β-
^{90}Nb β+	^{91}Nb e- capture	^{92}Nb β+	^{93}Nb Stable	^{94}Nb β-	^{95}Nb β-	^{96}Nb β-	^{97}Nb β-	^{98}Nb β-	^{99}Nb β-	^{100}Nb β-	^{101}Nb β-
^{89}Zr β+	^{90}Zr Stable	^{91}Zr Stable	^{92}Zr Stable	^{93}Zr β-	^{94}Zr 2β-	^{95}Zr β-	^{96}Zr 2β-	^{97}Zr β-	^{98}Zr β-	^{99}Zr β-	^{100}Zr β-
^{88}Y β+	^{89}Y Stable	^{90}Y β-	^{91}Y β-	^{92}Y β-	^{93}Y β-	^{94}Y β-	^{95}Y β-	^{96}Y β-	^{97}Y β-	^{98}Y β-	^{99}Y β-

Neutrons →

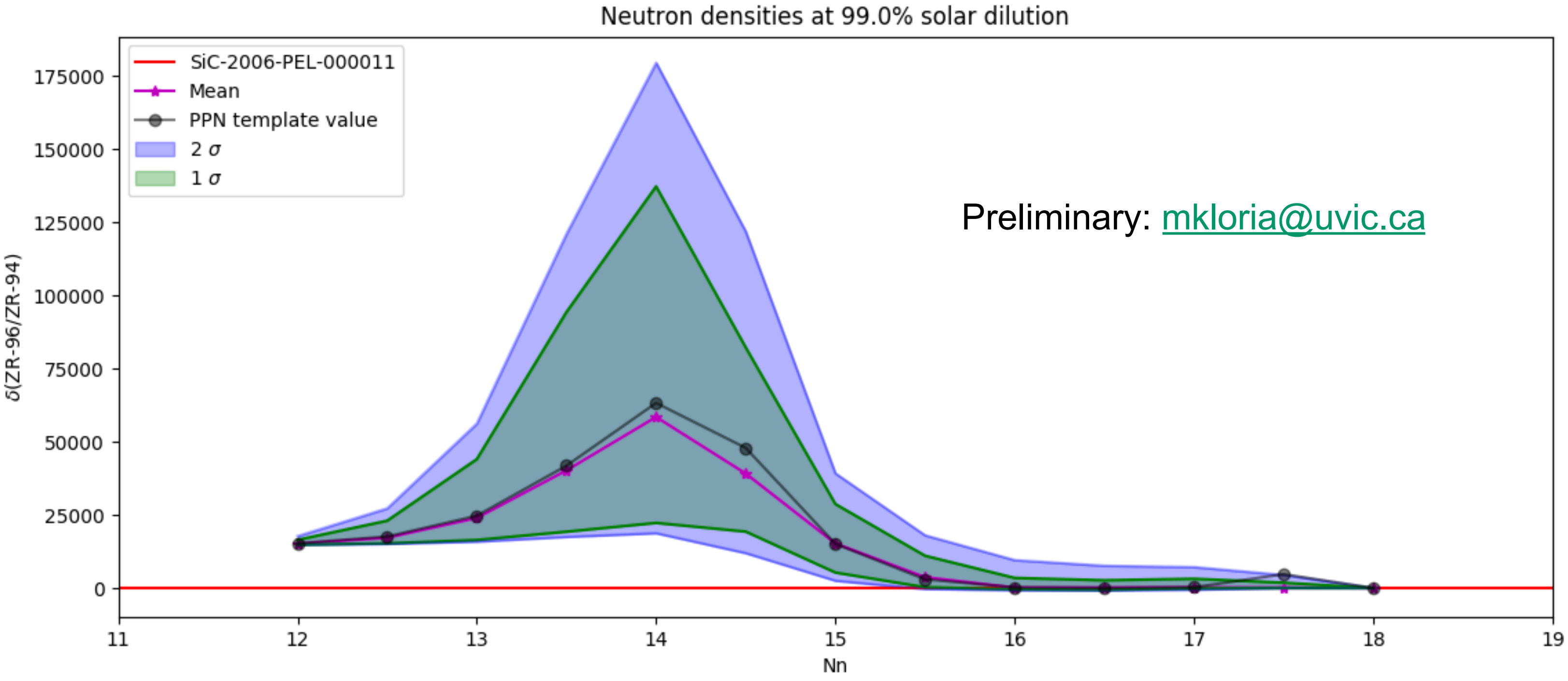
SiC grains showing i-process signatures



$$\delta\left(\frac{X}{Y}\right) = \left(\frac{\frac{X}{Y}_G}{\frac{X}{Y}_\odot} - 1\right) \times 1000$$

- 9 grains were identified
  - B. Crompvoets 2021
- Used Zr and Mo → "first peak" elements that are assumed to be produced in the i-process
- Grains are usually diluted 99% to 1% solar material to pre-solar origins

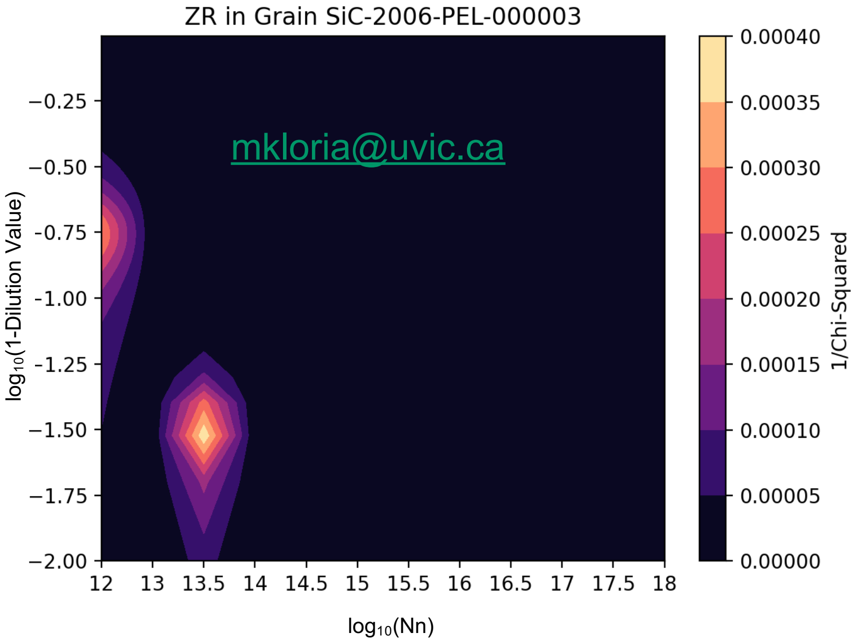
- MC sims varying the (n, γ) reaction rates for constant neutron density PPN runs
- Variation factors were calculated using Hauser-Feshbach computations

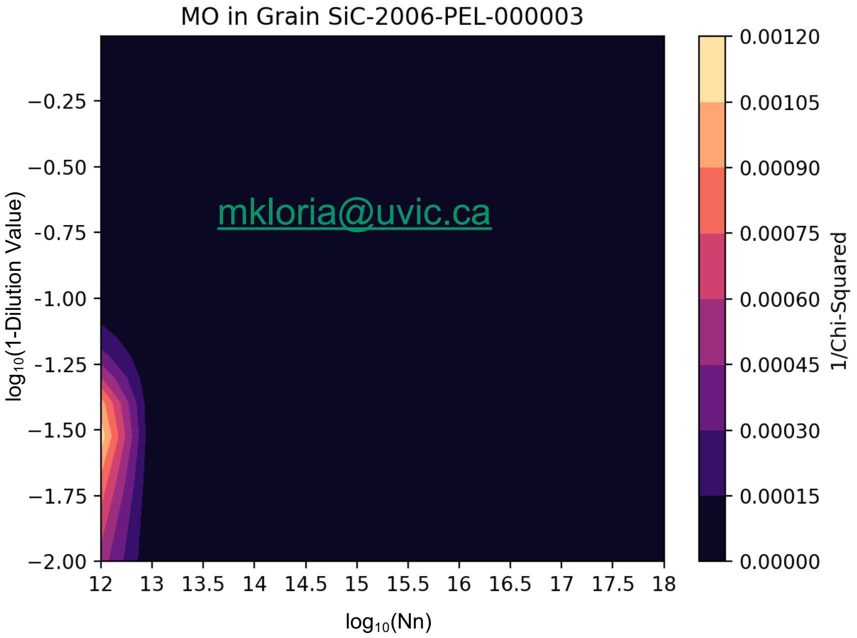


Preliminary: mkloria@uvic.ca

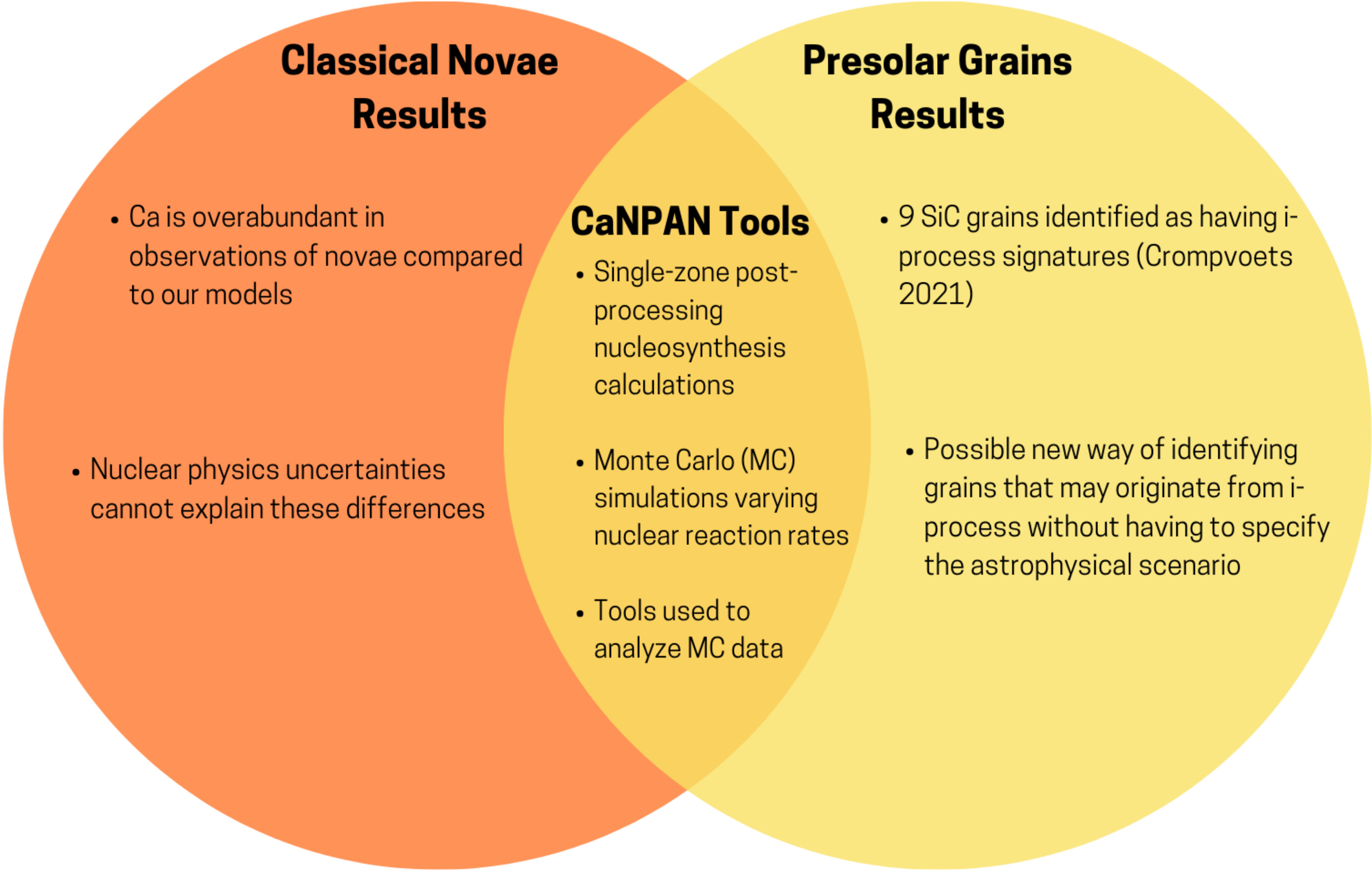
Finding the best fit between observations and models

Preliminary: mkloria@uvic.ca


ZR in Grain SiC-2006-PEL-000003


MO in Grain SiC-2006-PEL-000003

Create χ^2 maps → by finding the smallest value of χ^2 between model and observation for a given neutron density and dilution coefficient



Classical Novae Results

- Ca is overabundant in observations of novae compared to our models
- Nuclear physics uncertainties cannot explain these differences

CaNPAN Tools

- Single-zone post-processing nucleosynthesis calculations
- Monte Carlo (MC) simulations varying nuclear reaction rates
- Tools used to analyze MC data

Presolar Grains Results

- 9 SiC grains identified as having i-process signatures (Crompvoets 2021)
- Possible new way of identifying grains that may originate from i-process without having to specify the astrophysical scenario