Nucleosynthesis of Proton-Rich Nuclides

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Outline

1. Overview of Nucleosynthesis
2. Nuclear Physics of p-process
3. Type II Supernova
4. Facilities
What are we made of?
and where does it come from?
Star Lifecycle
### p-nuclides

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<th>Nucleus</th>
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<th>Error (%)</th>
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p-process Reactions

- $\beta^+ \rightarrow (\gamma, \alpha)$
- $(\gamma, n) \rightarrow (\gamma, p)$
- $(p, \gamma)$

Diagram showing nuclear processes with labels and reactions.
Reaction Rate:

$$\lambda(T) = \int_0^\infty c \, n_\gamma(E, T) \, \sigma_{(\gamma,x)} \, dE$$

Thermal photon flux:

$$n_\gamma(E, T) = \left( \frac{1}{\pi} \right)^2 \frac{1}{\hbar c} \frac{E^2}{\exp(E/kT) - 1}$$
Gamow Window

- Gamow window where integral significantly different from zero
- $(\gamma, n)$ Gamow window just above threshold
- $(\gamma, \alpha)$ Gamow window changes significantly with temperature
- Ratio of $\lambda_{(\gamma,n)}/\lambda_{(\gamma,\alpha)}$ determines branch points
Modeling p-process

- Involves 20,000 reactions linking 2000 nuclei
- Most pertinent rates are unknown due to involving unstable isotopes
- $\beta$-decay rates from mass predictions
- Photodisintegration rates calculated with statistical model
- Need to known level densities, gamma-ray strength functions, and optical model potentials
Type II Supernova
Lifecycle of Massive Stars

Red Giant Star

Nuclear burning occurs at the boundaries between zones

Example of nuclear reactions that build neutron-rich isotopes

Massive star near the end of its lifetime has an "onion-like" structure just prior to exploding as a supernova

H, He
He, N
He, C, ²²Ne
O, C
O, Ne, Mg
Si, S
Fe, Ni core

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Considerations

Side factors

- Highly sensitive to temperature
- Neutrinos present - weak interactions
- Large number of protons - \((p, \gamma)\) significant
- Neutrons present - reverse flow

p-process conditions

- Seed nuclei
- High-T (on order of \(2 \times 10^9\) Kelvin)
- Short time scale (a few seconds)
Known Cross Sections

\[ ^{148}\text{Gd}(\gamma,n)^{147}\text{Gd} \]
\[ S_n = 8.984 \text{ MeV} \]

\[ ^{148}\text{Gd}(\gamma,\alpha)^{144}\text{Sm} \]
\[ S_\alpha = -3.271 \text{ MeV} \]
Overview of Nucleosynthesis

Nuclear Physics of p-process

Type II Supernova Facilities
Conclusions

• sensitive test for stellar model
• models are incomplete
• not many measurements made for nuclear physics
• A lot of work to be done!
Acknowledgements