Zirconium Isotope Abundances in Single Mainstream SiC Grains and the $^{13}$C Pocket Structure in AGB Models

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Introduction

AGB Model Uncertainties
- Nuclear inputs
  - Neutron capture cross sections
    - Maxwellian Averaged Cross Sections (MACS)
    - $^{23}$Ne(a,$n$)$^{28}$Mg reaction rate
    - A factor of 4 uncertainty at relevant AGB stellar T
- Stellar model
  - $^{13}$C pocket formation
    - Uncertain mixing processes occurred during and/or after formation.
  - Fig. 3 of Lugaro et al. (2014)
    - Black dots: presolar SIC from Nicolussi et al. (1997) & mainstream SIC, Barzyk et al. (2007)
    - Red dots: presolar graphite, Nicolussi et al. (1998)
    - Colored lines with symbols: their AGB model predictions for carbon-rich phase;
    - Colored lines without symbols: predictions for oxygen-rich phase.

AGB Model Predictions for Zr Isotopes
(Lugaro et al. 2014)
- New n-TOF cross sections
- Stellar model (Karakas 2010)
- Failed to explain mainstream
  - Grains with $\delta^{(28/29/30)Zr} > -50\%$

Grain Data & Torino AGB Model

Previous RIMS Data
- Nicolussi et al. (1997) & Barzyk et al. (2007), delta-notation with $2\sigma$ errors

A Parameterized $^{13}$C Pocket

Previous Constraints (Liu et al. 2014a)
- Constraints on the $^{13}$C pocket
  - $^{6}$Ba $> -400\%$, $< -400\%$
  - $^{13}$C profile
    - Three-zone
    - Zone-II
  - $^{13}$C mass fraction
    - D3–U1.3
    - Around ST
  - $^{13}$C pocket mass upper-limit
    - $18.6 \times 10^{-4} M_{\odot}$
  - $^{13}$C pocket mass lower-limit
    - $7.4 \times 10^{-4} M_{\odot}$

K$^4K$–K$^4K$ (K$^4K$:lower-limit by Käppeler et al. 1994)

New n-TOF Zr neutron capture cross-section($\sigma_{asc}$)

Result & Discussion

Effect of the $^{13}$C Pocket Structure
- Why are $^{80/81/82}$Zr predictions affected by the $^{13}$C pocket?
  - $^{80/81/82}$Zr: neutron magic, the bottleneck of the $s$-process path;
  - $^{81/82}$Zr: MACS values deviate from the 1/$v_T$ rule by 30% while that of $^{82}$Zr closely follows this rule.
- What is the effect of the $^{82}$Zr predictions? $^{82}$Zr predictions are shifted by 100%; better match with the grain data can be achieved;
- Better determination of $^{82}$Zr MACS is needed to evaluate the necessity of Zone-II models.

Effect of the $^{13}$C Pocket Mass
- To summarize, Sr, Zr and Ba isotopes in mainstream grains all consistently point towards a smaller $^{13}$C pocket;
- Different $^{13}$C pocket structures should be a result of different degrees of mixing during or after the formation of the $^{13}$C pocket;
- For the first time, we discovered the smoking guns of the $^{13}$C pocket (Sr, Zr and Ba); the derived constraints will guide future simulations of $^{13}$C pocket formation;
- Correlated Sr, Zr and Ba isotope measurements in acid-cleaned presolar SiC grains will be done soon with CHILI.

Conclusion

References