Presolar Grains: Observational constraints on nucleosynthesis from the laboratory

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Special thanks to: Jordi Jose, Sergio Cristallo, and Ernst Zinner
A brief note on terminology

presolar = circumstellar = stardust ≠ STARDUST*

*Although, there is some stardust in STARDUST
What Can We Learn from Presolar Grains?

- Nucleosynthesis and stellar evolution:
  - AGB/RGB Stars
  - Novae
  - Type II Supernovae

- Galactic Chemical Evolution

- Interstellar medium residence times

- What types of solids condense in circumstellar outflows

- Circumstellar grain formation conditions (e.g., temperature, pressure, etc.)
Where do presolar grains come from & what are they?

Note: Meteorites are busted up pieces of asteroids that traveled for millions of years and finally hit Earth.
How do we know they’re presolar?

• Measure isotopes with a mass spectrometer while comparing them to Solar System material & theoretical models

• Typically use secondary ion mass spectrometers
How do we know they’re presolar?

All SS materials
How do we know they’re presolar?
How do we know they’re presolar?
Types of Presolar Grains

- SiC
- Graphite
- Nanodiamonds
- Oxides
  - Corundum \((\text{Al}_2\text{O}_3)\)
  - Spinel \((\text{MgAl}_2\text{O}_4)\)
  - Hibonite \((\text{CaAl}_{12}\text{O}_{19})\)
- Silicates
  - Pyroxene \((\text{MgSiO}_3)\)
  - Olivine \((\text{Mg}_2\text{SiO}_4)\)
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What Can We Learn from Presolar Grains?

- Nucleosynthesis and stellar evolution:
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  - Type II Supernovae
  (See Marco’s talk after lunch!)

- Galactic Chemical Evolution

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Classical Novae

(Nuclear runaway caused by accretion of H-rich material onto a White Dwarf)

Accretion Disk

Large Main Sequence Star

White Dwarf

\[ \sim 10^{-4} \, M_\odot \] ejected in explosion; only \( \sim 5\% \) of accreted material required for the event

Multiple nova explosions can occur due to continued accretion
Hot CNO Cycle

CNO: $T < 10^8$ K  
Hot CNO: $10^8 K < T < 10^9$ K  
rp-process: $T > 1 \times 10^9$ K
Can we find isotopic signatures of novae in presolar grains?

• “Hot” CNO cycle produces large amounts of: 
  $^{13}\text{C}$, $^{15}\text{N}$, $^{17}\text{O}$, $^{18}\text{O}$, $^{25}\text{Mg}$, $^{26}\text{Al}$, $^{30}\text{Si}$

• SiC from ONe novae?
  Very **LOW** $^{12}\text{C}/^{13}\text{C}$ & $^{14}\text{N}/^{15}\text{N}$ and **HIGH** $^{30}\text{Si}/^{28}\text{Si}$ & $^{26}\text{Al}/^{27}\text{Al}$
  **HOWEVER:** Ti measurements may hint at SN origin

• O-rich grains from CO novae?
  $^{17}\text{O}/^{16}\text{O} > 4.4 \times 10^{-3}$ & $\delta^{25}\text{Mg}/^{24}\text{Mg}$ up to 1000 ‰
Where does nova nucleosynthesis end?

• ONe novae: Ca is nucleosynthetic endpoint
  -> In very extreme and rare conditions nucleosynthesis can continue up to Ti
  -> By decreasing WD luminosity or by accretion of metal-poor material this may be possible

• CO novae: Si is nucleosynthetic endpoint
  -> NO further nuclear processing possible
What types of dust come from novae?

<table>
<thead>
<tr>
<th>Nova</th>
<th>Year</th>
<th>Dust</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1229 Aql</td>
<td>1970</td>
<td>C</td>
</tr>
<tr>
<td>V1301 Aql</td>
<td>1975</td>
<td>C</td>
</tr>
<tr>
<td>V1500 Cyg&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1975</td>
<td>-</td>
</tr>
<tr>
<td>NQ Vul</td>
<td>1976</td>
<td>C</td>
</tr>
<tr>
<td>V4021 Sgr</td>
<td>1977</td>
<td>C</td>
</tr>
<tr>
<td>LW Ser</td>
<td>1978</td>
<td>C</td>
</tr>
<tr>
<td>V1668 Cyg</td>
<td>1978</td>
<td>C</td>
</tr>
<tr>
<td>V1370 Aql&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1982</td>
<td>C, SiC; SiO&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td>GQ Mus</td>
<td>1983</td>
<td>no dust</td>
</tr>
<tr>
<td>PW Vul</td>
<td>1984 #1</td>
<td>C</td>
</tr>
<tr>
<td>QU Vul&lt;sup&gt;a&lt;/sup&gt;,&lt;sup&gt;f&lt;/sup&gt;</td>
<td>1984 #2</td>
<td>SiO&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td>OS And&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1986</td>
<td>C?</td>
</tr>
<tr>
<td>V1819 Cyg&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1986</td>
<td>no dust</td>
</tr>
<tr>
<td>V842 Cen</td>
<td>1986</td>
<td>C, SiC; HC</td>
</tr>
<tr>
<td>V827 Her&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1987</td>
<td>C</td>
</tr>
<tr>
<td>V4135 Sgr</td>
<td>1987</td>
<td>-</td>
</tr>
<tr>
<td>QV Vul</td>
<td>1987</td>
<td>C, SiO&lt;sub&gt;2&lt;/sub&gt;; HC</td>
</tr>
<tr>
<td>LMC 1988 #1</td>
<td>1988 #1</td>
<td>C?</td>
</tr>
<tr>
<td>LMC 1988 #2</td>
<td>1988 #2</td>
<td>-</td>
</tr>
<tr>
<td>V2214 Oph</td>
<td>1988</td>
<td>-</td>
</tr>
<tr>
<td>V838 Her&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1991</td>
<td>C</td>
</tr>
<tr>
<td>V1974 Cyg&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1992</td>
<td>no dust</td>
</tr>
<tr>
<td>V705 Cas</td>
<td>1993</td>
<td>C; HC; SiO&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td>Aql 1995&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1995</td>
<td>C</td>
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Both C-rich & O-rich dust observed in IR spectra.

However, most nova models predict O/C > 1. Detection bias?
Presolar grains from novae

<table>
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<th>C-rich grains</th>
<th>O-rich grains</th>
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<td>Total number ~ 11,000</td>
<td>Total number ~ 1200</td>
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Total numbers of grains from the current Presolar Database

http://presolar.wustl.edu/~pgd/
Presolar grains from novae

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<td>Nova candidates</td>
<td>≤ 8</td>
</tr>
</tbody>
</table>

Upper limit: some may be SN condensates

17O/16O > 0.006 by 2σ
### Presolar grains from novae

#### C-rich grains
- **Total number**: \( \sim 11,000 \)
- **Nova candidates**: \( \lesssim 8 \)
- **Relative nova abundance**
  - Uncorrected: 0.07 %
  - Corrected*: 0.01 %

#### O-rich grains
- **Total number**: \( \sim 1200 \)
- **Nova candidates**: \( \lesssim 16 \)
- **Relative nova abundance**: \( \sim 1.3 \) %

* Total number of grains extrapolated from number of X grains found in literature
$^{17}\text{O}/^{16}\text{O}$ too high for single AGB star

1st & 2nd Dredge-up
Where does the forbidden region come from?
Where does the forbidden region come from?

$^{17}\text{O}/^{16}\text{O}$ too high for single AGB star
New 1\textsuperscript{st} dredge-up model results

Updated CNO reaction rates\,*:

\[ ^{14}\text{N}(p,\gamma)^{15}\text{O} \ (2x\downarrow) \]
\[ ^{15}\text{N}(p,\alpha)^{12}\text{C} \ (0.96x\uparrow) \]
\[ ^{15}\text{N}(p,\gamma)^{16}\text{O} \ (2x\downarrow) \]

*Adelberger et al. 2010
New reaction rates for Hot CNO

- New nucleosynthesis models computed with updated nuclear reaction rates
- New measurements of $^{17}\text{O}(p,\gamma)^{18}\text{F}$ and $^{18}\text{F}(p,\gamma)^{19}\text{Ne}$ reaction rates predict lower $^{18}\text{O}$ abundances than José et al. (2004) models
Before new rates
After the new rates
New nova model O predictions

- Mixing with solar material is required
- Required also for SiC (Amari et al. 2001)
New Nova model Mg Predictions

- Mixing with solar material is required
Conclusions & future work

• Perform automated searches to locate/identify more nova candidate grains, both O-rich & C-rich
• Further investigate parameter space of updated nova models
  -> Look in detail at compositions of individual shells
  -> Perform 2D and 3D simulations
• Search for hibonite ($\text{CaAl}_{12}\text{O}_{19}$) grains with large $^{17}\text{O}$ excesses!
  -> May show Ca isotopic signatures of ONe novae