Planetary Sciences

Stardust in Laboratory & Evolution of Early Solar System

Kuljeet K. Marhas

13th September 2008
Physical Research Laboratory
Elements Surrounding Us!

Solar Abundances
Cosmic Abundances = Mix from many Stellar Sources

The interstellar medium is 'ecologically' a disaster area where a large number of stellar sources pollute their environment with their garbage.

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13th September 2008
Arrival of the Solar System!

We are quite literally stardust!

Presolar Grains & Evolution of Early Solar System

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13th September 2008
Picture book of presolar grains!

Silicon carbide

Graphite grains

Corundum

Silicon Nitride

Silicate grain

Spinel grains

Presolar Grains &
Evolution of Early Solar System

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Work Horse for micron sized particle!

SIMS: Secondary Ion Mass Spectrometer
Big Brother!!

NanoSIMS: Nano Secondary Ion Mass Spectrometer
Grains are identified as presolar from their completely anomalous isotopic compositions.

The carbon and nitrogen isotopic ratios of presolar silicon carbide grains span a huge range.

**Star and Starbits!**

Presolar Grains & Evolution of Early Solar System

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13th September 2008  
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Stellar Identity!!

SiC Grain

Red Giant

Frequency

$^{12}\text{C}/^{13}\text{C}$

Presolar SiC
(Hoppe et al. 1994)

Carbon (AGB) Stars
(Lambert et al. 1986)
No Pain… No Gain…..

Probe wide range of astrophysical processes:

- Stellar Evolution
- Nucleosynthesis
- Galactic Chemical Evolution
- Stellar dust formation
Arrival of the Solar System!
FAQs!

- Is it possible to identify the stellar sources contributing to the initial mix?
- Was it a triggered the collapse?
- What was the time scale of collapse?
- What processes and time scales are involved in formation of grains and formation & differentiation of planetesimals and planets?
White Amoeba!

Allende

Calcium Aluminum Inclusion

As seen under a stereo-microscope

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Now-extinct short-lived nuclides in the Early Solar System serve as cosmic CLOCKS.

Solar System $\sim$ 4.5 billion years

so any short-lived nuclides with half life $<$100Ma present in early solar system have become extinct.

If a now-extinct nuclide was incorporated “live” into the first forming solids, its fossil records can be used to record the time of formation.
### Short-lived Now-extinct Nuclides Present in the Early Solar System

<table>
<thead>
<tr>
<th>Radio-Nuclide</th>
<th>Half-life (Ma)</th>
<th>Daughter Nuclide</th>
<th>Reference Nuclide</th>
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</thead>
<tbody>
<tr>
<td>$^{41}\text{Ca}$</td>
<td>0.10</td>
<td>$^{41}\text{K}$</td>
<td>$^{40}\text{Ca}$</td>
</tr>
<tr>
<td>$^{26}\text{Al}$</td>
<td>0.74</td>
<td>$^{26}\text{Mg}$</td>
<td>$^{27}\text{Al}$</td>
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<tr>
<td>$^{10}\text{Be}$</td>
<td>1.5</td>
<td>$^{10}\text{B}$</td>
<td>$^{9}\text{Be}$</td>
</tr>
<tr>
<td>$^{60}\text{Fe}$</td>
<td>1.5</td>
<td>$^{60}\text{Ni}$</td>
<td>$^{56}\text{Fe}$</td>
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<tr>
<td>$^{53}\text{Mn}$</td>
<td>3.7</td>
<td>$^{53}\text{Cr}$</td>
<td>$^{55}\text{Mn}$</td>
</tr>
<tr>
<td>$^{107}\text{Pd}$</td>
<td>6.5</td>
<td>$^{107}\text{Ag}$</td>
<td>$^{108}\text{Pd}$</td>
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<tr>
<td>$^{182}\text{Hf}$</td>
<td>9</td>
<td>$^{182}\text{W}$</td>
<td>$^{180}\text{Hf}$</td>
</tr>
<tr>
<td>$^{129}\text{I}$</td>
<td>16</td>
<td>$^{129}\text{Xe}$</td>
<td>$^{127}\text{I}$</td>
</tr>
<tr>
<td>$^{244}\text{Pu}$</td>
<td>81</td>
<td>Fission Xe</td>
<td>$^{238}\text{U}$</td>
</tr>
<tr>
<td>$^{146}\text{Sm}$</td>
<td>103</td>
<td>$^{142}\text{Nd}$</td>
<td>$^{144}\text{Sm}$</td>
</tr>
</tbody>
</table>
No Pain… No Gain…

Probe wide range of early solar system processes:

• Time scale of formation of first solids, formation time of different planetary objects
• Stellar sources
• Activity of early Sun
NASA’s **Stardust mission** launched in 1999 to collect dust from comet Wild 2 and return the samples to Earth.

*The first ever comet sample return mission.*

**Science objective:** to understand the materials and conditions that went into the formation of the Solar System.
Travel, travail of descent, cross examination!

230 km from nucleus
$\Delta V = 6.1 \text{ km/s}$

January 2, 2004
Caught and the catcher: Dust in the Aerogel!

Interstellar dust impacted the aerogel collector grid with a relative speed of about 20 km/s (45,000 mph).

With masses in the picogram regime, the particles should only penetrate about 100 microns into the surface of the 3 cm thick aerogel tiles, leaving behind tracks in the aerogel.

The particles are sub-micron in size and are few in number, approximately 45 in the entire collector.

The collector itself is about 1,000 cm² in area.
Creeks and cracks!

Presolar Grains & Evolution of Early Solar System

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Standing alone: presolar grain!
Unexpected truth: CAI-like particle!

- Spinel, Al-diopside, anorthite, melilite
- Fe-sulfides in glass
- Perovskite
- Compressed aerogel “cap”
- Void
**Match - Mismatch!**

- are comets mechanical agglomerations of unprocessed presolar (interstellar) materials?
- what are the relationships to isotope reservoirs in asteroidal samples? to IDPs?
- do comets provide an enhanced reservoir of circumstellar grains with distinct nucleosynthetic histories? (i.e., are grains really “stardust”?)

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**Greenberg model**
aggregate of submicron amorphous interstellar grains with core-mantle structure

**IDP model**
aggregate of submicron grains with few large xtals.
chondritic w/ high C, high D/H
there is stardust in STARDUST

- but not primarily isotopically distinctive presolar grains

limited O isotope analyses of refractory minerals (fo, CAI-minerals) consistent with other similar primitive solar system materials (CC, IDPs)

- Inti isotopically like other CAIs; derives from inner solar system reservoir
- implies large scale radial transport in nebula

Wild-2 not enhanced reservoir of presolar matter

- capture effects severe but not prohibitive
"Sure it's beautiful, but I can't help thinking about the interstellar dust out there."

M. W. FISHER