Presolar grains in meteorites and IDPs: opportunities for astrophysics

U. Ott
Prag, August 21, 2006
almost twenty years since identification of presolar grains in meteorites

Evidence for interstellar SiC in the Murray carbonaceous meteorite

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Nature, 24/31 December 1987

Interstellar diamonds in meteorites

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Nature, 12 March 1987

Large isotopic anomalies of Si, C, N and noble gases in interstellar silicon carbide from the Murray meteorite

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Nature, 24/31 December 1987
at once and / or soon after: variability → many stellar sources

Interstellar SiC in the Murchison and Murray meteorites: Isotopic composition of Ne, Xe, Si, C, and N

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S-process krypton of variable isotopic composition in the Murchison meteorite

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Nature, 21 April 1988

or trace elements like the noble gases
Stellar nucleosynthesis and formation of dust grains

Formation of solar system

Meteorites

Chemical & physical separation of dust grains

Laboratory analyses

new: in-situ detection / investigation (Nano-SIMS - silicates)
<table>
<thead>
<tr>
<th>mineral</th>
<th>isotopic signatures</th>
<th>stellar source</th>
<th>contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>diamond</td>
<td><strong>1500 ppm</strong> Kr-H, Xe-HL, Te-H</td>
<td>supernovae</td>
<td>?</td>
</tr>
<tr>
<td>silicon carbide</td>
<td>enhanced $^{13}$C, $^{14}$N, $^{22}$Ne, s-process elements</td>
<td>AGB stars</td>
<td>&gt; 90 %</td>
</tr>
<tr>
<td></td>
<td>low $^{12}$C/$^{13}$C, often enhanced $^{15}$N</td>
<td>J-type C stars (?)</td>
<td>&lt; 5 %</td>
</tr>
<tr>
<td></td>
<td>enhanced $^{12}$C, $^{15}$N, $^{28}$Si; extinct $^{26}$Al, $^{44}$Ti</td>
<td>Supernovae novae</td>
<td>1 %</td>
</tr>
<tr>
<td></td>
<td>low $^{12}$C/$^{13}$C, low $^{14}$N/$^{15}$N</td>
<td></td>
<td>0.1 %</td>
</tr>
<tr>
<td>graphite</td>
<td>enhanced $^{12}$C, $^{15}$N, $^{28}$Si; extinct $^{26}$Al, $^{41}$Ca, $^{44}$Ti</td>
<td>SN (WR?)</td>
<td>80 %</td>
</tr>
<tr>
<td></td>
<td>Kr-S</td>
<td>AGB stars</td>
<td>&lt; 10 %</td>
</tr>
<tr>
<td></td>
<td>low $^{12}$C/$^{13}$C</td>
<td>J-type C stars (?)</td>
<td>&lt; 10 %</td>
</tr>
<tr>
<td></td>
<td>low $^{12}$C/$^{13}$C; Ne-E(L)</td>
<td>novae</td>
<td>2 %</td>
</tr>
<tr>
<td>corundum/spinel/hib.</td>
<td>enhanced $^{17}$O, moderately depleted $^{18}$O</td>
<td>RGB and AGB</td>
<td>&gt; 70 %</td>
</tr>
<tr>
<td>silicates</td>
<td>enhanced $^{17}$O, strongly depleted $^{18}$O</td>
<td>AGB stars</td>
<td>20 %</td>
</tr>
<tr>
<td></td>
<td>enhanced $^{16}$O</td>
<td>supernovae</td>
<td>1 %</td>
</tr>
<tr>
<td></td>
<td>similar to oxides above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>silicon nitride</td>
<td>enhanced $^{12}$C, $^{15}$N, $^{28}$Si; extinct $^{26}$Al</td>
<td>supernovae</td>
<td>100 %</td>
</tr>
<tr>
<td></td>
<td>&gt; 100 ppm in meteorites (more in IDPs)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
opportunities for astrophysics

are being exploited to more or less extent

- can be classified along the lines of the three following sessions

1. nucleosynthesis and GCE

   has generally received most attention by analysts, because (isotopic) composition is the key for establishing a grain as pre-solar

2. grain formation

3. grain history

   will give a few examples in this introductory talk - mark in red examples that (I think) may not be addressed by following talks
1. **nucleosynthesis and GCE**

- watch effects of well-established processes under special conditions, e.g. H burning in HBB / CBP
- oxygen isotopes in oxides / silicates from Red Giants

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**Zinner, 1998, Annu. Rev. Earth Planet. Sci.**
constrain conditions under which well-known process operates, e.g. via branchings of s-process

branchings record neutron density, temperature and, in some cases, (e.g. $^{163}$Dy) density

Savina et al., 2003, GCA

closed neutron shell → neutron exposure
may indicate “new processes”
B²FH: 8 basic processes, among them 3 (r,s,p) for heavy elements beyond Fe

(17%)
+ normal (83%)

measured

mass number

(except for p-isotopes) best explained as mixture 83% solar Mo + 17% “neutron burst” (Meyer et al., 2000; ApJ) Mo

originally devised for: Xe-H in presolar diamonds

e.g., X (= supernova) SiC grain 209-1 (Pellin et al., LPSC 2000, 2006)
however: same scheme may not work for Ba in X grains (??)

complex: maybe mix more s-process rich "normal Ba" (GCE?) with Cs/Ba fractionated (after ~ 1 a?) n burst material, in different mixing ratio → topic of grain formation

burst Meyer (complete decay)
halflife of $^{135}$Cs = 2 Ma
2. grain formation

- composition, sizes, crystallinity, microstructure → p, T, C/O at formation and cooling rates
  
  - cubic (β-SiC)
  - hexagonal (α-SiC)

- ~ 80% 3C + ~ 20% (2H + 3C/2H intergrowths): lowest T polymorphs → formation temperature

Daulton et al. 2003), GCA: stacking sequences of bilayers

- e.g., SiC
bulk SiC pattern:
- relative abundances of elements with similar volatility = production ratios
- “volatile” Ba and Sm, Eu, Yb = deficient
- “pre-condensation” of highly refractory elements
- looking at single grains  
  (Amari et al., 1995, Meteoritics; Marhas et al., 2006, in prep.)

- nicely correlated “volatile” Ba and Sr
- no correlation of Ba with refractory Zr
- large grain-to-grain variation in absolute abundances
timescales for grain formation

supernova (X) SiC grains form within a year or so after SN explosion (Hoppe and Besmehn, 2002, ApJ); cf. also earlier Ba data
3. grain history

- the basic observation: which type of grains have survived and in which abundance relative to (expected) production

- further: what are their properties? signs for being processed (crystallinity ?, radiation damage ?)

- note: we probably look at a biased sample

- pristine (no chemistry for isolation) SiC: little to no evidence for surface sputtering or cratering thought to occur in ISM (Bernatowicz et al., 2003, GCA)
a fundamental question: what is the age?
analytically extremely difficult

important long lived chronometers:
trace elements - maybe chance only for SiC, however even there:

\[
\begin{align*}
{^{147}}\text{Sm} &\rightarrow {^{143}}\text{Nd} + {^4}\text{He} & 1.06 \times 10^{11} \text{ a} \\
{^{87}}\text{Rb} &\rightarrow {^{87}}\text{Sr} + e^- & 4.88 \times 10^{10} \text{ a} \\
{^{187}}\text{Re} &\rightarrow {^{187}}\text{Os} + e^- & 4.4 \times 10^{10} \text{ a} \\
{^{232}}\text{Th} &\rightarrow {^{208}}\text{Pb} + 6 {^4}\text{He} & 1.40 \times 10^{10} \text{ a} \\
{^{238}}\text{U} &\rightarrow {^{206}}\text{Pb} + 8 {^4}\text{He} & 4.47 \times 10^{9} \text{ a} \\
{^{235}}\text{U} &\rightarrow {^{207}}\text{Pb} + 7 {^4}\text{He} & 7.04 \times 10^{8} \text{ a} \\
{^{40}}\text{K} &\rightarrow {^{40}}\text{Ca} + e^- & 1.28 \times 10^{9} \text{ a} \\
&\rightarrow {^{40}}\text{Ar} & 1.1 \times 10^{10} \text{ a}
\end{align*}
\]

max. 2% in 10 Ga
volatile parent
difficult
nucleosynthesis
r-only parents
\( \rightarrow \) X grains?
U, Th extremely rare; U isotope ratio?
volatile parent
possible alternative
GCR spallation → "pre-solar" exposure age
→ contributions to rare elements (in "rocks") - noble gases

also problematic:
  a) GCR spectra / intensity → production rate
  b) recoil loss from small grains of products

-most consistent
(tentative) solution for
bulk SiC grain size
fraction data of Lewis et al. (1994, GCA)
-zero age coupled with
ratio $^{124}$Xe/$^{126}$Xe of p-only isotopes ~5 % lower than solar
-maybe best: go for Ne in single big grains (how representative?)
but maybe in the enigmatic diamonds

now on to the details......