Formation of Glass With Embedded Metal and Sulfides from Shock-Accelerated Crystalline Dust in Superbubbles

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Interplanetary Dust Particles (IDPs)

- Collected in upper atmosphere
- Fluffy aggregates of relatively robust components
- Nomenclature can be a bit obscure
Presolar grain component

- Presolar grains show isotopic anomalies
- Very, very small!
- Also found in meteorites
Presolar Isotopic Anomalies

- Different presolar grains come from different astrophysical environments
- Not all GEMS show isotopic anomalies
GEMS

- Glassy particles with little bits inside them
- Different compositions
- Some have internal crystals
Relict Grain in GEMS (pyrrhotite)
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Pyrrhotite [2110]
(D$_{6h}$ – 6/mmm)
Forsterite GEMS
GEMS are unusual objects

- Some GEMS are pseudomorphs
- GEMS occur in a narrow size range (100-500nm)
- GEMS have anomalous elemental compositions
- Some, but not all, GEMS show isotopic anomalies
Amorphization

- Carrez et al., 2002
- 4 keV He ions
- Olivine (Mg$_2$SiO$_4$)
- Cosmic rays?
Inconsistent with GCR amorphization

Sharp boundary?!
Monoenergetic Amorphization

- A uniform flux of cosmic rays would not leave a relict
- An accelerated grain will experience a monoenergetic flux
Sputtering

- Fast grains in the ISM are efficiently destroyed
- Fast grains in high metallicity environment can grow!
- Experimental measurement of sputtering yields needed
- Small grains still get destroyed
Grain Acceleration

- Grains *must* be accelerated by SN shocks
- Enhancement of refractory elements
Superbubbles (or It Takes a Village)

- Low density cavity created by OB outflows & SNe
- Emerging model of CR acceleration
- 1 SN not enough
- High metallicity environment
- GEMS abundances similar

Superbubble (N 70) in the Large Magellanic Cloud (ESO Very Large Telescope Image)
GEMS Formation in Superbubbles

- Some GEMS are pseudomorphs
- GEMS abundance patterns
- Very narrow size distribution
- Isotopic anomalies

Superbubble (N 70) in the Large Magellanic Cloud (ESO Very Large Telescope Image)
Sputtering Balance

- Balance effects of sputtering & growth
- Multiple boosts from SN shocks
- Monte Carlo simulation of reacceleration
- Only a narrow range of sizes survive
GEMS as the GCR source

- SN do not accelerate their own ejecta
- SN can accelerate ejecta from other SNe
- GEMS are a highly selected sample of the GCR source
- GEMS & GCR have similar isotopic abundances
- Solar except $^{22}$Ne & $^{58}$Fe
Outstanding Questions

• Sputtering yields need to be measured
• Assumptions about superbubble magnetic field
• Inefficient mixing of metal-rich core with ISM
• Gas metallicity is not reduced by grain formation
• Predictions on GEMS amorphous rim sizes
• GEMS isotopic abundances
A Century-old puzzle

- Cosmic rays were discovered almost 100 years ago, but their origin is still uncertain
- Has the source material of cosmic rays been awaiting discovery in dust labs for decades?