The Stardust mission & the asteroid-comet continuum

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1. What did we know about comets before Stardust?
Comets

Rich in water – spectacular – unexpected
Dust/ice ~ 1
Cometary ices & the interstellar medium*

Interstellar Medium (ISM): Molecular clouds, molecular cloud cores, protoplanetary disk...

Bockelée-Morvan et al. 2000
D/H ratio: Link with the ISM

Compilation from Robert (2002)
IR emission of dust grains from the coma

- Detection of olivine \((\text{Mg}_2\text{SiO}_4)\) and pyroxene \((\text{MgSiO}_3)\)
- Mixture of amorphous & crystalline grains

Wooden et al. 2002
Expected cometary dust

Unprocessed dust similar to presolar grains found in the carbonaceous chondrites matrix

Nittler 2005
Comets - Summary

- Mixture (1:1) of ices and dust
  - Isotopic composition of ices link comets to the ISM
- Dust made of crystalline / amorphous olivine and pyroxene
  - High proportion of interstellar dust (small, isotopically anomalous) expected
2. Extraterrestrial matter on Earth
Most meteorites come from asteroids
Carbonaceous chondrites sample primitive asteroids

- Chondules
- Matrix
- CAIs

- olivine: $\text{Mg}_2\text{SiO}_4$
- pyroxene: $\text{MgSiO}_3$

Ca-Al oxides and silicates
Cometary origin of Orgueil?

Gounelle, Spurny & Bland *MAPS* 2006
Implications

Orgueil and other CI1 chondrites suffered intensive hydrothermal alteration

Liquid/vapour water in comets?
Micrometeorites

Interplanetary Dust Particles (Zolensky et al. 1994)

Antarctic micrometeorites (Duprat et al. ASR 2007)
3. The Stardust mission
Stardust: A cometary sample return mission

- Programme Discovery
  - 168.4 US $ (not including launch)
  - PI: Don Brownlee
- First sample return mission from a solar system primitive body
Scientific goals

Objective #1: To bring back cometary dust

Comparison with meteorites
Comparison with asteroids & comets
Cometary matter: Interstellar or solar?
Geological processes on cometary surfaces
Wild 2

Jupiter Family Comet
4.5 km diameter
Discovered 1978 (Mr. Wild)

T = 6.39 yr
Dynamical timescale ~ 10000 yr
Take off February 7th 1999 at Cape Kennedy

**Delta rocket**

- Total weight: 385 kg
- Fuel: 85 kg
- Landing module: 45.7 kg

**Diagram Description:**
- Solar arrays
- Comet and interstellar dust analyzer
- Whipple shields
- Periscope
- Star cameras
- Navigation camera
- Sample return capsule
Sample collection (2 janvier 2004)

Comet Wild 2

$\Delta V = 6.1 \text{ km/s}$
Aerogel capture

Silicon foam
99.8 % vacuum

130 aerogel parallepipeds 2 x 4 cm
Collection surface: 1000 cm²
A side: interstellar dust
B side: cometary dust
Back on Earth: January 15th 2006

Velocity entry ~ 46 400 km/h

$T_{\text{max}}: 2700 \, \text{C}$
3 days later @ Johnson Space Center

~ 1000 grains with sizes > 5 \( \mu \text{m} \)

~ 100 \( \mu \text{g} \) of cometary dust
4. Stardust: Results
Intense effort by 100’s of members of the Stardust Team
Design - launch - operation - return - recovery - analysis

Composition  Min-Pet  Isotopes  Organics  Optical  Foil Cratering
Chemical composition

Flynn et al. 2006

Difficult to obtain
Roughly solar (CI1)
Basic mineralogy

Olivine, pyroxene, sulfides, metal
Melted aerogel
Similar to what is found in primitive meteorites
Calcium-Aluminium-rich objects in comets

High T phase - important radial mixing in the Solar System
Chondrules in comets

Olivine + glass

Size of interstellar dust

Nakamura et al. 2008
More similarities with carbonaceous chondrites

McKeegan et al. 2006
Carbonates in comets

Sample# FC 3,0,2,2,1
Hugues Leroux

Field of view is 3 μm wide

Phyllosilicates not found yet
Some similarities with micrometeorites

Engrand et al. 2007

Zolensky et al. 2006
Not such a strong link to the ISM

Note all particles enriched in deuterium
Not such a strong link to the ISM

From a red giant star

Only one presolar grain found!
4. (Personal) conclusions
Conclusions 1

Similarities and differences with carbonaceous chondrites and Antarctic micrometeorites
Conclusions 2

A solar system matter
- Chemistry
- Mineralogy
- Isotopic composition

Weak interstellar heritage
Conclusions 3

Mixing in the solar system

- Stellar outflows
- Turbulence
Conclusions 4

Gounelle et al. 2008 in The Solar System beyond Neptune (Eds Barrucci et al.)

Little hydrothermal alteration in Wild 2
Some (?) secondary minerals (phyllosilicates, carbonates) in Tempel 1 (Lisse et al. 2006)

Variable amount of aqueous alteration in comets
Not all comets are the same
The *surface of one* comet was sampled
Conclusions 5

Stardust mission results support the idea there is a *continuum* between asteroids & comets

(Gounelle et al. 2006, 2008)
Final thoughts

Comets ended up in the lab!

We were surprised!

The comet-asteroid continuum yet to be characterized

Sample return missions provide long-lasting progress

Stardust was a total success

* Focused mission
* Important effort for the sample collection mechanism
* Key role of curation