ULTRACARBONACEOUS ANTARCTIC MICROMETEORITES: A NEW WINDOW ON THE SOLAR SYSTEM ORIGIN
Plan

- The protoplanetary disk
- Micrometeorites
- The CONCORDIA collection
- Ultracarbonaceous micrometeorites
  - principal properties
  - cometary origin
  - a new window on the protoplanetary disk
Solar system formation

- Dust grains
- Undifferentiated planetesimals
- Differentiated planetesimals
- Planets

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The first 10 Myr: astrophysics
The first 10 Myr: cosmochemistry

First solids in the solar system: CAIs and chondrules

McSween & Huss 2010
Chronology of planet formation

Molecular clouds and unstable cores
(Bltz et al. 2006; Alves et al. 2001)

Embedded protostars
Jets and outflows common
(Bally et al. 2006; Ray et al. 2008)

Massive accretion disks
Taurus– Auriga (age spread) 0–4 Myr
Radial disk structures and gaps detected
(IC 348 and Chamaeleon I star-forming regions)
2 Myr, warm dust disks around ~50–65% of stars
(Luhman 2006)

Low-mass disks with evolved dust
Upper Scoeius Association
(5 ± 3 Myr, iso: Siesnick et al. 2008)
Warm dust around ~10% of young stars
Eta Cha association
(12 ± 6 Myr, Li: Mentuch et al. 2008)
TW Hya associations
(12 ± 6 Myr, Li: Mentuch et al. 2008;
8 ± 1 Myr, dyn: de la Reza et al. 2006)
Debris disks (Meyer et al. 2007, Wyatt et al. 2008)
Beta Pic Group (11 Myr, dyn: de la Reza et al. 2008)
H₂ gas mass < 1 Jupiter mass (Pascucci et al. 2007)
Tuco–Hor Group
(27 ± 11 Myr, Li: Mentuch et al. 2008)
AB Dor Group
(> 45 Myr, Li: Mentuch et al. 2008;
119 ± 20 Myr, dyn: Ortega et al. 2007)
Planets around >10–30% stars
(Udry & Santos 2007, Mayor et al. 2009)

$T_0$ – 1: Supernova injects radionuclides
$^{36}$Ar, $^{54}$Cl, $^{44}$Ca, $^{65}$Mn, $^{60}$Fe initial SS abundances
(Quetle et al. 2007; Mosteloul et al. 2005)

$T_0$: Earliest CAI formation
Pb–Pb ages of Efremovka CAIs: 4567.2 ± 0.6 Ma
(Amelin et al. 2002)

$T_0$ + 0.1: Latest CAI formation
Pb–Pb ages of Allende CAIs: 4567.1 ± 0.2 Ma
(Connely et al. 2008)

$T_0$ + 1: Formation of magmatic iron meteorites
$^{183}$Os: 1.5 ± 0.2 Myr younger than CAI
(Bizzarro et al. 2005; Qin et al. 2008)

$T_0$ + 2: Peak of chondrule formation
$^{26}$Al: 2 ± 1 Myr younger than CAI (Kita et al. 2005)
Pb–Pb of Acfer 094 chondrules: 4564.7 ± 0.6 Ma (Amelin et al. 2002)

$T_0$ + 3: Formation of basaltic eucrites (Asteroid Vesta)
$^{26}$Al: 3.1 ± 0.2 Myr younger than CAI
(Bizzarro et al. 2005)

$T_0$ + 4: Latest chondrule formation
Pb–Pb ages of CB chondrite chondrules: 4562.8 ± 0.9 Ma
(Not et al. 2005)

$T_0$ + 10: Formation of basaltic angrites
Pb–Pb: 4568.6 ± 0.2 Ma (Amelin 2007)
$^{54}$Mn: 10 ± 2 Myr younger than CAI (Yin et al. 2003)

$T_0$ + 13: Formation of Mars
$^{183}$Os: 13 ± 2 Myr younger than CAI (Kleine et al. 2002)

$T_0$ + 60: Formation of Earth–Moon system
$^{183}$Os: 6 ± 0.5 Myr younger than CAI (Touboul et al. 2007)
What are micrometeorites

Zodiacal cloud particles accreted by the Earth

IDPs

Micrometeorites

Meteorites

Bradley, 2005

Paris (CM)
Micrometeorites in the solar system

mass distribution in the inner solar system

Grun et al. 1985

Flynn et al. 2004
Micrometeorites in the solar system
Micrometeorites in the solar system

mass distribution in the inner solar system

ET matter entering the Earth atmosphere

Grun et al. 1985

Love & Brownlee 1993

Flynn et al. 2004

Micrometeorites in the solar system

mass distribution in the inner solar system

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Love & Brownlee 1993

Flynn et al. 2004
Micrometeorites

Classification: effects of the interaction with the Earth's atmosphere

totally melted micrometeorites
cosmic spherules

partially melted micrometeorites: scoriaceous micrometeorites

unmelted micrometeorites
Dome C - Concordia

- 1100 km from the coast (S 75°, E 123°)
- no terrestrial dust thanks to catabatic winds
- collection in surface snow (down to 4 m depth)
- snow isolated from the bedrock by >3 km of ice
- no terrestrial aqueous alteration
- snow melting: 1 – 20 hours
Fine-grained fluffy micrometeorites

Dobrica et al. 2008

Duprat et al. 2007

DC02 03-53-p
UCAMMs

Rare micrometeorites: 2% of the CONCORDIA collection

Carbon content up to 80% in volume.

Dobrica et al 2008

Dobrica et al 2012
UCAMMs

Unmetamorphosed organic matter

Dobrica et al. 2011
UCAMMs

Raman spectroscopy of carbonaceous matter

- Observation of the cyanide (-CN) functional group
- Cyanides commonly observed in ISM and comets
- Low abundances in chondritic organic matter

UCAMMs avoided hydrothermal alterations

Dobrica et al. 2011
UCAMMs

Hydrogen isotopic composition

\[
\delta D = \left( \frac{D / H}{D / H_{SMOW}} - 1 \right) \times 1000
\]

\[D / H_{SMOW} = 1.5 \times 10^{-6}\]

Robert 2001

Alexander et al. 2010

Duprat et al. 2010
UCAMMs

Possible cometary origin

- High carbon content
- Unmetamorphosed carbonaceous matter
- Detection of the –CN group
- High D enrichments
UCAMMs

Possible cometary origin

- High carbon content
- Unmetamorphosed carbonaceous matter
- Detection of the –CN group
- High D enrichments
- Anhydrous mineralogy
- GEMS-like inclusions
UCAMMs

Mineralogy dominated by olivine and pyroxene, phyllosilicate content < 1%.

\[
\text{Olivine: } \text{Mg}_2\text{SiO}_4, (\text{Mg,Fe})_2\text{SiO}_4
\]

\[
\text{Pyroxene: } \text{MgSiO}_3, (\text{Mg,Fe})\text{SiO}_3
\]
UCAMMs

GEMS
Glass with Embedded Metals and Sulfides

Keller & Messenger 2011

GEMS may account for as much as half of the mass of some IDPs
UCAMMs

GEMS
Glass with Embedded Metals and Sulfides

GEMS have been detected in UCAMMs, but never in meteorites
GEMS: an interstellar origin?

- GEMS-rich CP IDP
- comet Halley
- comet Hale-Bopp
- late stage Herbig Ae/Be star

Si-O stretch band

- GEMS in one IDP
- Elias 16 mol. cloud
- Trapezium mol. cloud
- T Tauri YSO
- M-type supergiant

Bradley 2003
UCAMMs and the protoplanetary disk

Organic matter in UCAMMs
- formed at low temperature
- never altered

Low-temperature phases in UCAMMs attest they are samples from the outer solar system.
UCAMMs and the protoplanetary disk

Association at very small scale of carbonaceous and mineral components

Dobrica et al. 2012
UCAMMs and the protoplanetary disk

Association at very small scale of carbonaceous and mineral components

--> What mineral phases were present when comet accreted?
UCAMMs and the protoplanetary disk

Association at very small scale of carbonaceous and mineral components

--> What mineral phases were present when comet accreted?

--> Crystalline silicates in cometary matter require transport in the protoplanetary disk
UCAMMs and the protoplanetary disk

How much of the cometary matter is a direct interstellar heritage?

1) presolar grains

Hoppe 2009
UCAMMs and the protoplanetary disk

How much of the cometary matter is a direct interstellar heritage?

1) presolar grains

Busemann et al, 2009
UCAMMs and the protoplanetary disk

How much of the cometary matter is a direct interstellar heritage?

2) GEMS

First measurements of O isotopic composition in GEMS from one UCAMM: ~solar composition

Dobrica et al. 2012
Conclusions

- UCAMMs: tiny extraterrestrial samples with huge amount of information on the protoplanetary disk
  - samples from the outer solar system
  - pristine low temperature and high temperature phases
  - sampling not ONE comet, but a population of comets
  - new constraints on the mixing processes in the protoplanetary disk
Origin of micrometeorites

Zodiacal cloud dust bands: IRAS observations at 25 µm.


Best fit:
\[ \alpha_{JFC} = 0.97, \ \alpha_{OCC} = 0.03, \]
\[ D = 100 \mu m, \ and \ t_{JFC} = 12000 \ yr \]

JFC particles represent ~ 85% of the total mass influx in the Earth's atmosphere
Identification