

<u>Giacomo Briani</u> Cécile Engrand, Jean Duprat, Elena Dobrică

Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse Université Paris Sud – CNRS

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



© http://oz.plymouth.edu/~sci_ed/Turski/Courses/Earth_Science/Intro.html



dust grains

undifferentiated planetesimals







differentiated planetesimals

planets



The first 10 Myr: astrophysics



The first 10 Myr: cosmochemistry

NWA 2086

8 9 10

Ca

Al

1 mm

PCA 91082, CR

CAI

5 6

Krot et al. 2009

7

First solids in the solar system: CAIs and chondrules



Chronology of planet formation

[Myr]		
Molecular clouds and unstable cores (Biltz et al. 2006; Alves et al. 2001) Embedded protostars Jets and outflows common (Bally et al. 2006; Ray et al. 2006)	0	T ₀ - 1: Supernova injects radionuclides ²⁸ Al, ³⁸ Cl, ⁴¹ Ca, ⁴³ Mn, ⁴⁰ Fe initial SS abundances (Oulette <i>et al.</i> 2007; Mostefacui <i>et al.</i> 2005) T ₀ : Earliest CAI formation Pb-Pb ages of Efremovka CAIs: 4567.2 ± 0.6 Ma (Amelin <i>et al.</i> 2002) T ₀ + 0.1: Latest CAI formation Pb-Pb ages of Allende CAIs: 4567.1 ± 0.2 Ma
Massive accretion disks	0.5	(Connely et al. 2008)
Taurus–Auriga (age spread) 0 – 4 Myr Radial disk structures and gaps detected	1	T ₀ + 1: Formation of magmatic iron meteorites ¹⁸² Hf: 1.5 ± 0.2 Myr younger than CAI (Bizzaro et al. 2005: Cin. et al. 2006)
IC 348 and Chamæleon I star-forming region 2 Myr, warm dust disks around ~50–65% of s (Luhman 2008)	ns stars	T ₀ + 2: Peak of chondrule formation ²⁶ Al: 2 ± 1 Myr younger than CAI (Kta <i>et al.</i> 2005) Pb-Pb of Acter 094 chondrules: 4564.7 ± 0.6 Ma (Amelin <i>et al.</i> 2002) T ₀ + 3: Formation of basaltic eucrites (Asteroid Vesta)
Low-mass disks with evolved dust Upper Scorpius Association (5 ± 3 Myr, iso: Slesnick <i>et al.</i> 2008) Warm dust around - 10% of young stars Eta Cha association (12± 6 Myr, Li: Mentuch <i>et al.</i> 2008)	5	 ²⁶AI: 3.1 ± 0.2 Myr younger than CAI (Bizzaro <i>et al.</i> 2005) T₀ + 4: Latest ch on drule form ation Pb-Pb ages of CB chondrite chondrules: 4562.8 ± 0.9 Ma (Krot <i>et al.</i> 2005)
TW Hya associations (12±8 Myr, Li: Mentuch <i>et al.</i> 2008; 8±1 Myr, dyn: de la Reza <i>et al.</i> 2006) Debris disks (Meyer <i>et al.</i> 2007, Wyatt <i>et al.</i> Beta Pic Group (11 Myr, dyn: de la Reza <i>et al.</i>	10 2008) 2006)	L T ₀ + 10: Formation of basaltic angrites Pb-Pb: 4558.6 ± 0.2 Ma (Amelin 2007) [™] Mn: 10 ± 2 Myr youngerthan CAI (Yin <i>et al.</i> 2007) T ₀ + 13: Formation of Mars
H _g gas mass < 1 Jupiter mass (Pascucci <i>et a</i> Tuc–Hor Gnoup: (27±11 Myr, Li: Mentuch <i>et al.</i> 2008)	1. 2007)	¹⁴² Hf: 13 ± 2 Myr younger than CAI (Kleine <i>et al.</i> 2002)
AB Dor Group (>45 Myr, Li: Mentuch <i>et al.</i> 2008; 119± 20 Myr, dyn: Ortega <i>et al.</i> 2007)	50	To + 60: Formation of Earth–Moon system ¹⁶² Hf: 62 ⁺⁶⁰ / _{-∞} Myr younger than CAI (Touboul <i>et al.</i> 2007)
Planets aro und >10-30% stars (Udry & Santos 2007, Mayor <i>et al.</i> 2009)	100	

Apai & Lauretta, 2010

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



Micrometeorites in the solar system

0 10-15

Daniel López cielosdelteide.com

Micrometeorites in the solar system

mass distribution in the inner solar system



Micrometeorites

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



totally melted micrometeorites cosmic spherules



partially melted micrometeorites: scoriacous 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





Rare micrometeorites: 2% of the CONCORDIA collection



Dobrica et al 2008



Unmetamorphosed organic matter





Dobrica et al 2011



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



Hydrogen isotopic composition



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



Alexander et al 2010

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

D

Duprat et al 2010



 C/H
 8.5

 7.40
 6.24

 5.08
 3.92

 2.76
 1.60

 0.44
 0.44

10459

5229



Possible cometary origin



- High carbon content
- Unmetamorphosed carbonaceous matter



- Detection of the –CN group
- High D enrichments



Possible cometary origin



- High carbon content
- Unmetamorphosed carbonaceous matter



- Detection of the –CN group
- High D enrichments



- Anhydrous mineralogy
- GEMS-like inclusions



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





GEMS Glass with Embedded Metals and Sulfides



Keller & Messenger 2011

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



GEMS Glass with Embedded Metals and Sulfides



Keller & Messenger 2011

Dobrica et al. 2012

GEMS have been detected in UCAMMs, but never in meteorites

GEMS: an interstellar origin?



Organic matter in UCAMMs formed at low temperature never altered



Low-temperature phases in UCAMMs attest they are samples from the outer solar system

Association at very small scale of carbonaceous and mineral components





Dobrica et al. 2012

Association at very small scale of carbonaceous and mineral components

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



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

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

1) presolar grains



Hoppe 2009



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

1) presolar grains



Busemann et al, 2009

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

PLUS

Origin of micrometeorites

Zodiacal cloud dust bands: IRAS observations at $25 \,\mu$ m.





 $\alpha_{JFC} = 0.97, \ \alpha_{OCC} = 0.03,$ D = 100 µm, and $t_{JFC} = 12000 \ yr$

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

Identification

