Micrométéorites et formation du système solaire

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LLR 2 Février 2009

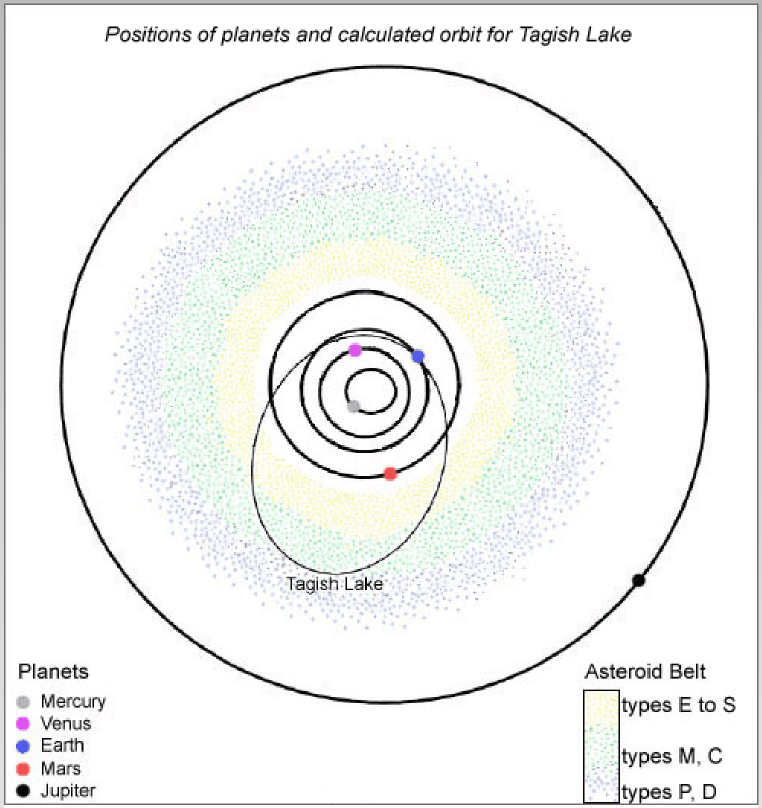
Looking for primitive solar system material : **meteorites**

+ 30,000 meteorites
USA, Japon, Italie

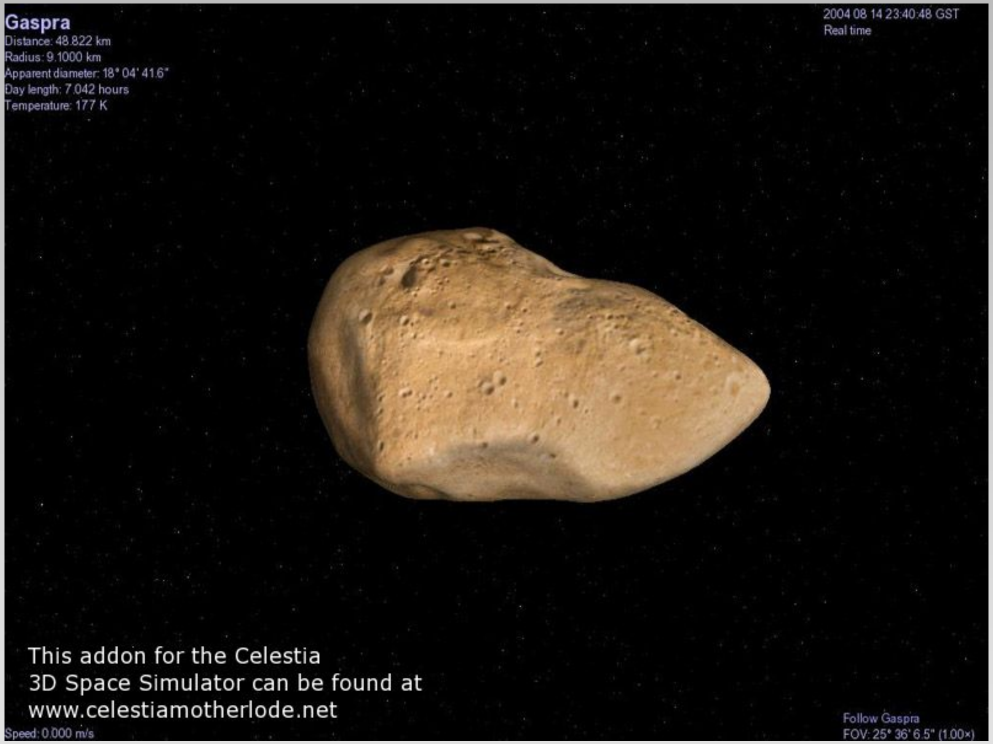
ANSMET
THE ANTARCTIC SEARCH FOR METEORITES

Antarctic Meteorite Research
PI : R. Harvey, Case Univ. US

The meteorites are coming from the asteroid belt between Mars and Jupiter



(PSRD graphic based on Brown *et al.*, 2000, *Science*, v.290, p.321.)

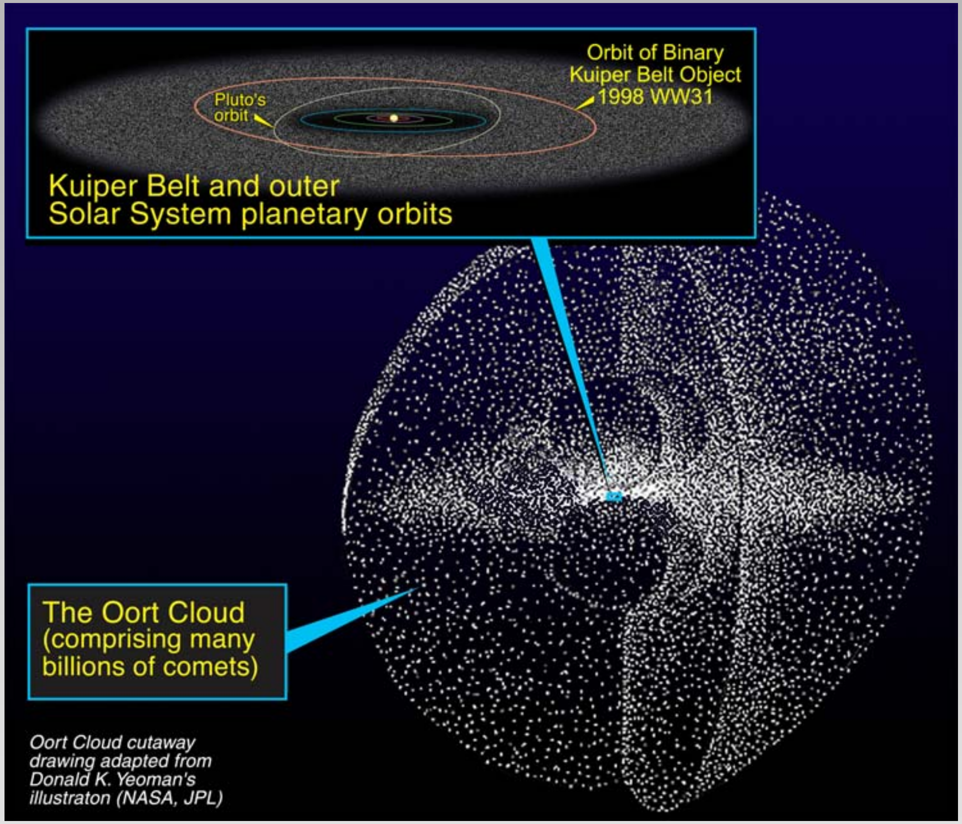


Brown et al. Science 2000

They are sampling a restricted part of **the inner solar system**

The comets

dust from the outer solar system



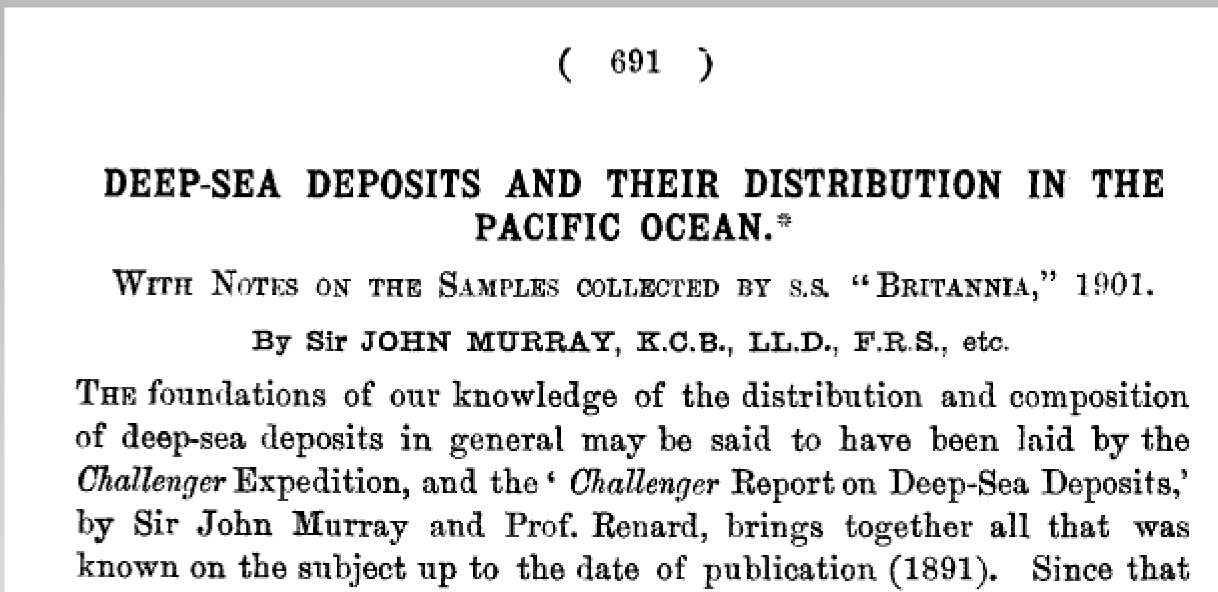
Sun-Earth : **1 UA** = 10^9 km (8 mm. c)

Pluto : 50 UA (7 hours. c)

Kuiper belt : 70 UA (10 hours.c)

Oort Cloud : 200 000 UA (3 Years. C)

The HMS *Challenger* expedition 1873-1876

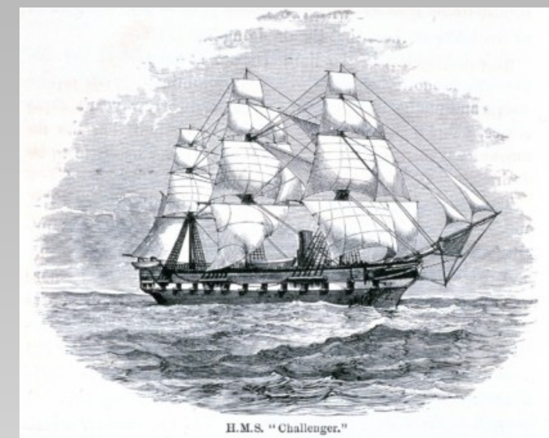

(691)

DEEP-SEA DEPOSITS AND THEIR DISTRIBUTION IN THE PACIFIC OCEAN.*

WITH NOTES ON THE SAMPLES COLLECTED BY S.S. "BRITANNIA," 1901.

By Sir JOHN MURRAY, K.C.B., LL.D., F.R.S., etc.

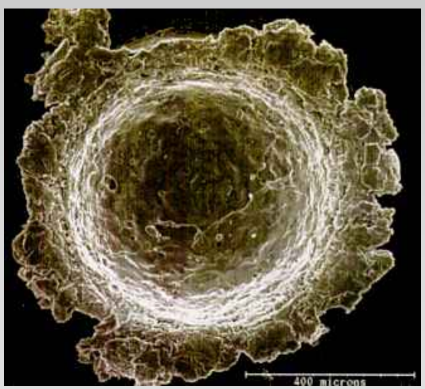
THE foundations of our knowledge of the distribution and composition of deep-sea deposits in general may be said to have been laid by the *Challenger* Expedition, and the '*Challenger* Report on Deep-Sea Deposits,' by Sir John Murray and Prof. Renard, brings together all that was known on the subject up to the date of publication (1891). Since that



Murray 1876

Les collectes spatiales et stratosphériques

Altitude 400km

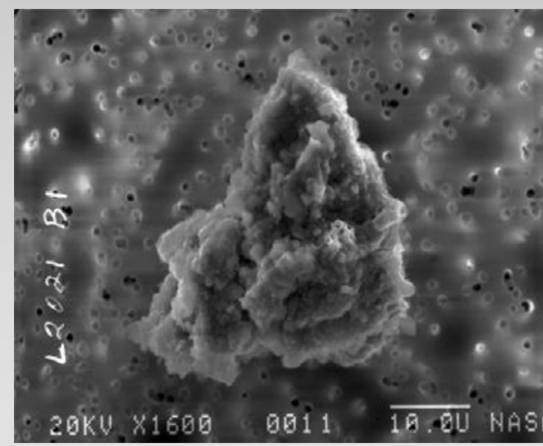


Long Duration Exposure Facility (LDEF)
Crater data

Taille 10-500 µm

e.g. Love & Bronwlee Science 1993

Altitude 15-20 km



Interplanetary Dust Particles (IDPs)
The Cosmic Dust Program (NASA)
Taille 5-40 µm

Rietmeijer in Planetary Material

Une trentaine de collections dans de multiples sédiments …

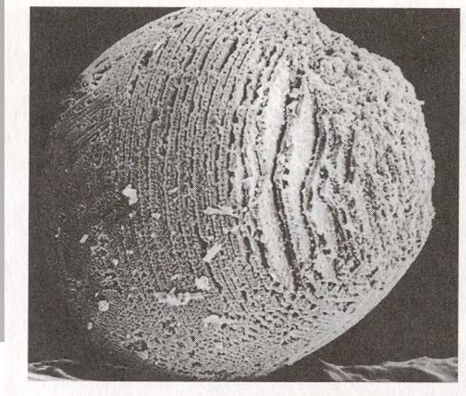
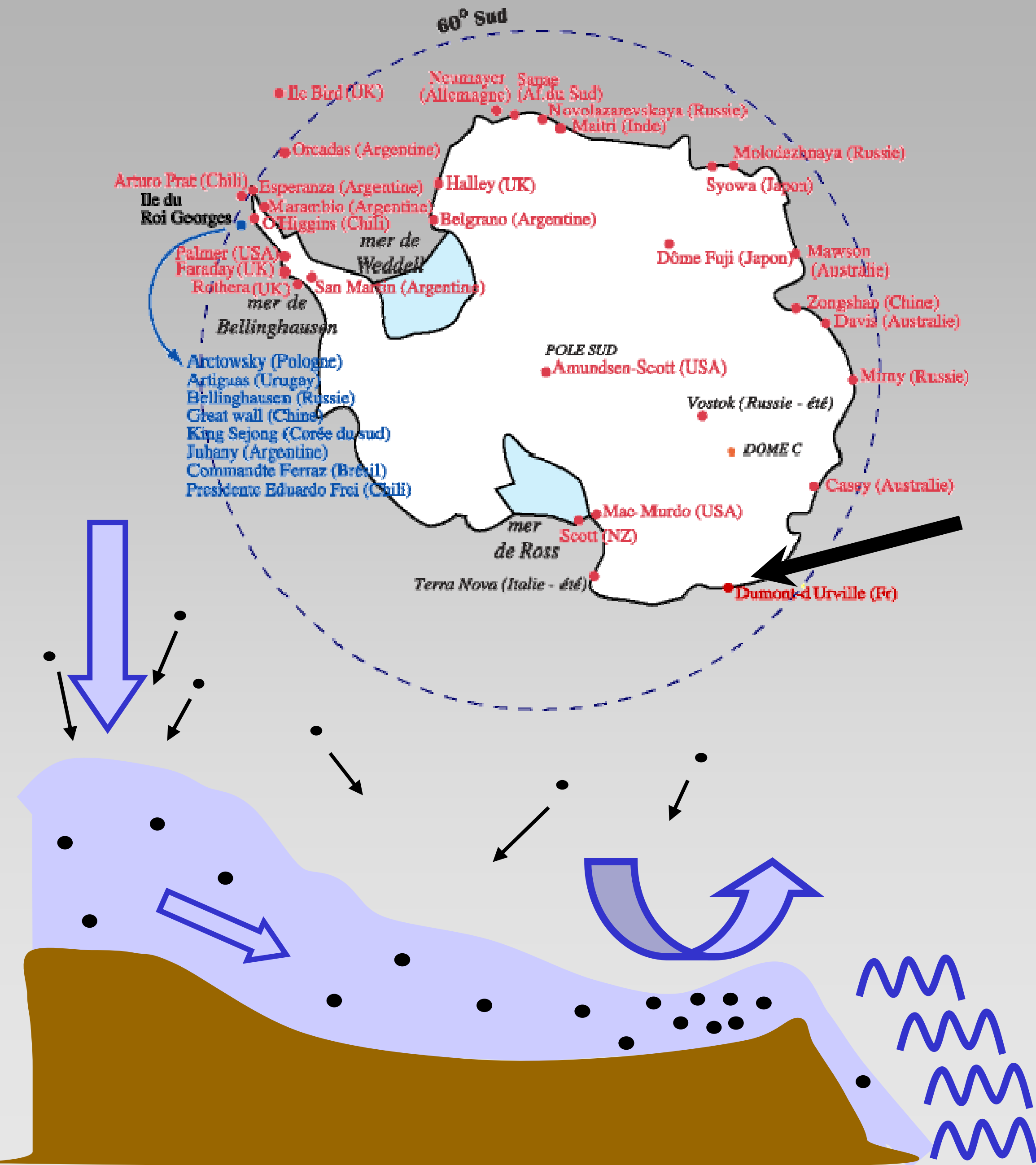


Table 1
Micrometeorite collections from sediments, sedimentary rocks, and polar deposits. The type column refers to the types of cosmic spherules recovered. When 'all' is used, both melted and unmelted micrometeorites were recovered.

Deposits	Age	Collection Technique	No. Examined	Type	Size Range (μm)	Reference
Sediments						
Deep sea	?	cores	100s	S & I	60–500	Murray and Renard, 1883, 1891
Deep sea	?	magnetic rake	>300	S & I	100–500	Brunn et al., 1955
Deep sea	<7 Ma	core from top 3 m	732	S & I	10–230	Laevastu and Mellis, 1955
Deep sea	<200 ka	magnetic sieve	4413	?	30–250	Pettersson and Fredriksson, 1958
Deep sea	?	750 kg sieved, mag. sep.	1200	I	149–351	Millard and Finkelman, 1970
Deep sea	0–100,000 yr(?)	magnetic rake	100s	S, G &I	≤5000	Brownlee et al., 1979
Deep sea	0–500,000 yr	mag. sep. box core	>700	S, G & I	100–000	Blanchard et al., 1980
Deep sea	0–700,000 yr	1 m clam shell sample	935	S & I	149–750	Murrell et al., 1980
Deep sea	0–350,000 yr	0–35 cm core, mag. sep.	258	S, G & I	50–500	Kyte, 1983
Desert sand	?	magnetic collector	32	I	30–300	Fredriksson and Gowdy, 1963
Beach sand	recent–1.6 Ma	hand magnet	?	I	80–650	Marvin and Einaudi, 1967
Sedimentary rocks						
Hardgrounds	145–185 Ma	crush and dissolve	?	I	100–300	Czajkowski et al., 1983
Hardgrounds	180 Ma	?	12	I	?	Jehanno et al., 1988
Claystones	recent–500 Ma	dissolution, magnetic sep.	?	?	<40	Crozier, 1960
Carbonates	30–40 Ma	dissolution, magnetic sep.	28	S & I	>100	Taylor and Brownlee, 1991
Salt deposits	~250 & ~400 Ma	dissolution, magnetic sep.	243	?	<40	Mutch, 1966
Sandstones	1.4 Ga	mineral separation	4	S	60–125	Deutsch et al., 1998
Polar ice and sediment						
Greenland						
Cryoconite	?	heavy liq. separation	?	S?	100–200	Wulfing, 1890
Cryoconite	0–3000 yr	suction, filter and pick	~3500	all	50–300	Maurette et al., 1987
Cryoconite	<2 ka	suction, filter and pick	>100	all	100–1000	Maurette et al., 1986
Antarctica						
Eolian deposits	<2.5 Ma(?)	sieved and hand picked	840	S	125–500	Hagen et al., 1990
Eolian deposits	0–100,000 yr(?)	wet sieved and hand picked	>100	S	64–1000	Harvey and Maurette, 1991
Ice cores	1800–1961 AD	melt and filter	?	I	15–180	Thiel and Schmidt, 1961
Ice cores	2300–100 BC	melt and filter	5	S, G, V	50–160	Yiou and Raisbeck, 1987
Ice	?	melt and filter	76	all	50–400	Maurette et al., 1991
Snow and ice	1100–1500 AD	suction bottom and filter	1600	all	50–800	Taylor et al., 1998

Review by S. Taylor & J. Lever 2001

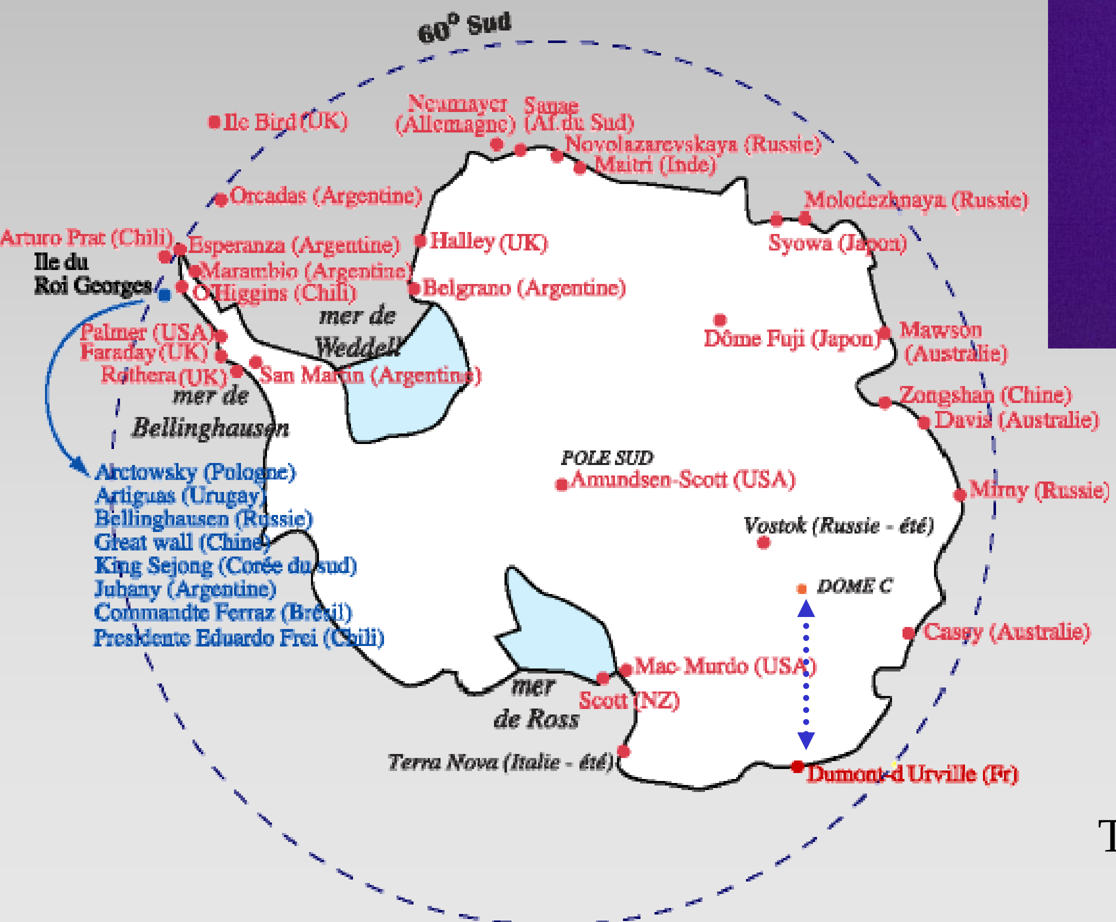
Micrometeorites in Blue Ice Fields

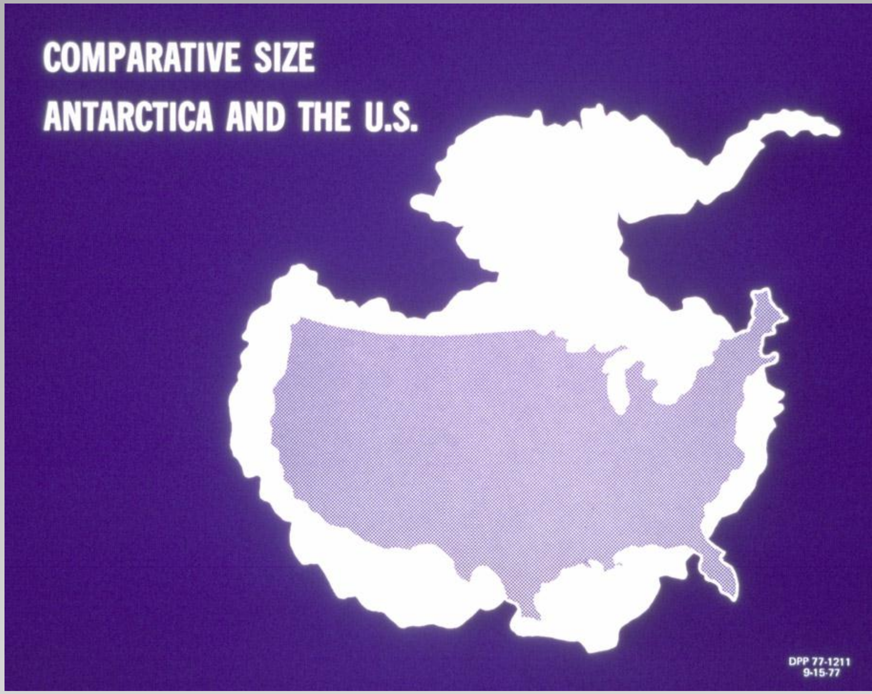


M. Maurette et al.
Nature (1991), **351**, 44-47.

The central regions of Antarctica

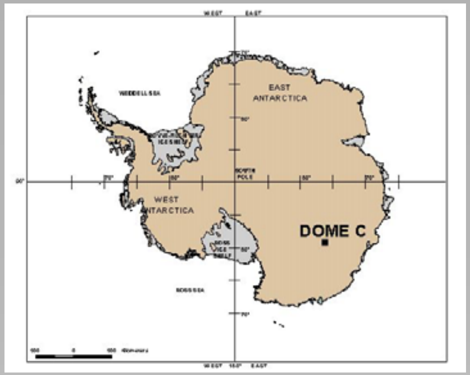
- **Amundsen-Scott base (US)**
- **Vostok (Ru)**
- **Dome Fuji (Jp)**
- **Dôme C (Fr/It)**





The French traverse DDU-DC / IPEV

The **unique advantages** of Central Antarctica Regions for Extraterrestrial Dust research



* Dome C is **extremely preserved from terrestrial dust contamination** within the MMs size range [d > 50µm] :
  – 1100 kms from the coasts of TA, 3200 m in altitude
  – The dominant wind blowing from centre to coast
  – The surface snow is separated from the bedrock by more 3,5 km of ice

  -> a **high ET/T ration** is expected, search for **new objects**

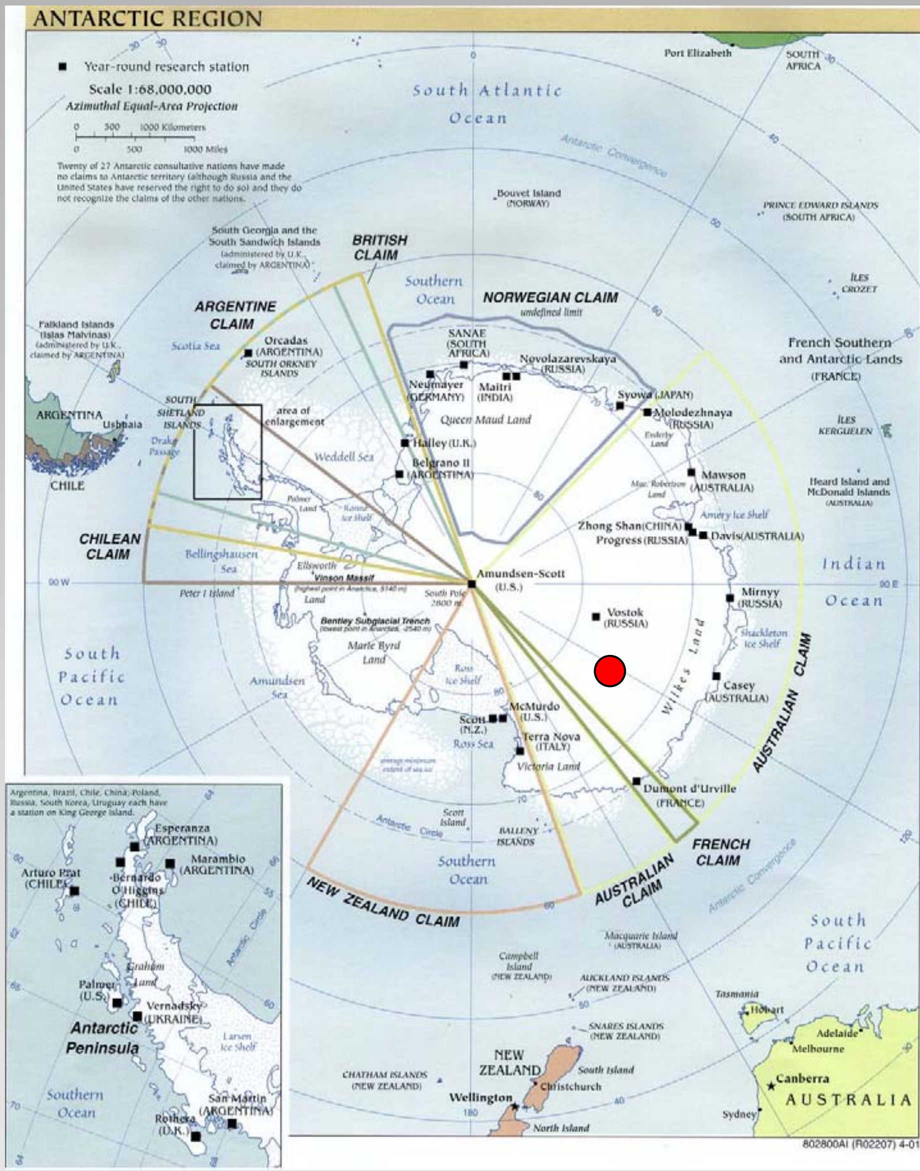
* Dome C **snow stays at low temperature** thought the year **(-70° < T<-20°)**

  -> **unique condition of preservation from terrestrial weathering** are expected

• Dome C has **very low and regular precipitation rate :**

  -> recover micrometeorites from **reasonable volume of snow** (few m^3)
  -> measure a **FLUX of ET particles/m^2/year**
  -> search for **variations in intensity/composition of the flux** in the last century

L’Institut Polaire Français (IPEV)



The Micrometeorite Program @ Dome C

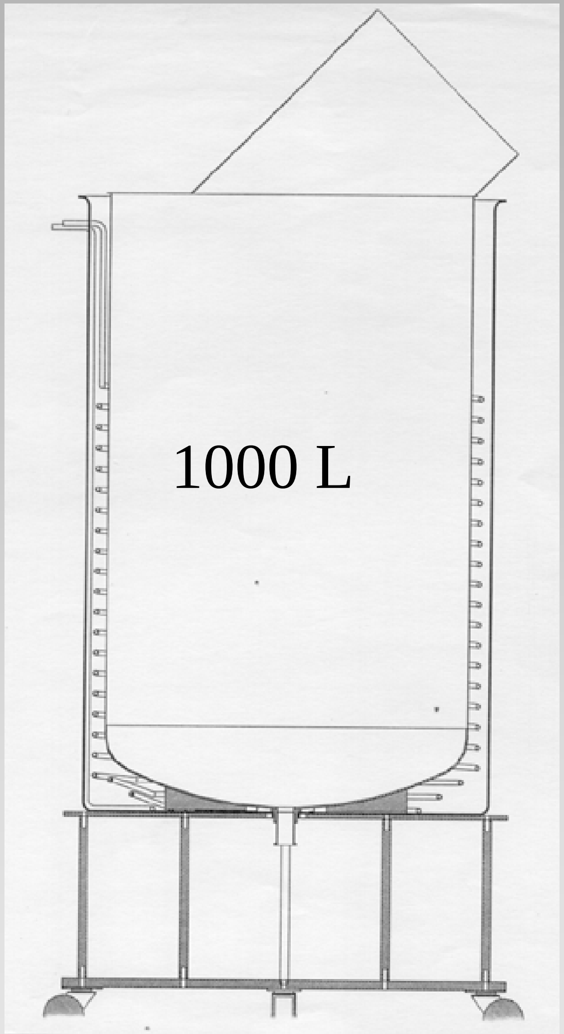
Dome C, January 2000

Surface Snow (0-80 cm)

Up to 35 km from the camp

Dôme C (75°S, 123°E)

The snow extraction procedure



Dome C, January 2006

A High efficiency 1000 L snow smelter (CSNSM)

The snow melting/sieving procedure

DOME C snow is melted in a dedicated double-tank and gravitationally sieved

The 30 μm filters are pre-analyzed in a mini-lab to control terrestrial contamination

Janvier 2000 | **Janvier 2002** | **Janvier 2006**

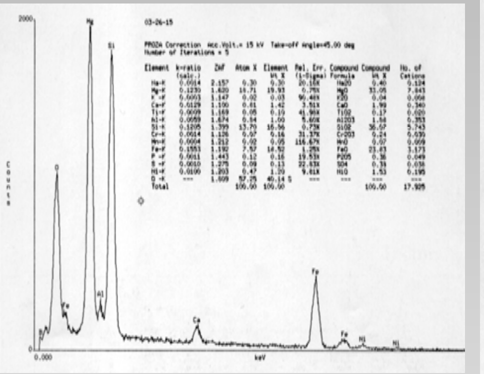
Date	Neige traitée m^3	Volume effectif m^3	Prof.	Fondoir	Temps exposition à l'eau	Efficacité	N	ET/T	Pollution
Janvier 2000	9	3	0-80 cm 2-4 m	Cuve 1 m^3	100 heures	30 %	40	1-5 %	Fibres, Glycol, poussières …
Janvier 2002	12	11	2-4 m	Double Cuve 100 L	48 heures	> 60 %	500	10-50%	Fibres textile, rares poussières
Janvier 2006	25	24	3-5 m	Double Cuve 1000 L	12 heures	> 80 %	> 1300	>50 %	Très faible

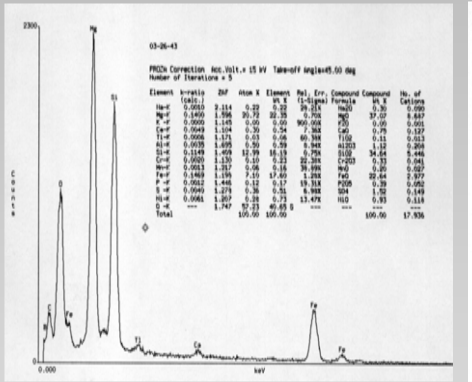
CONCORDIA Results I

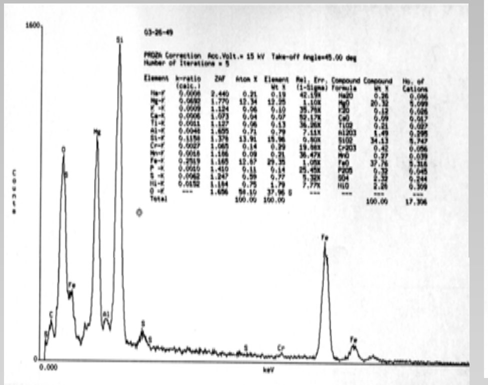
- A total of **650 micrometeorites** identified

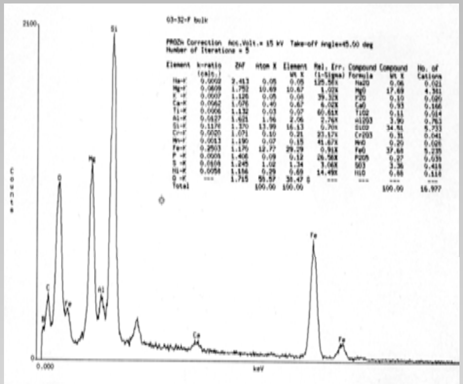
-> The **CONCORDIA Collection**

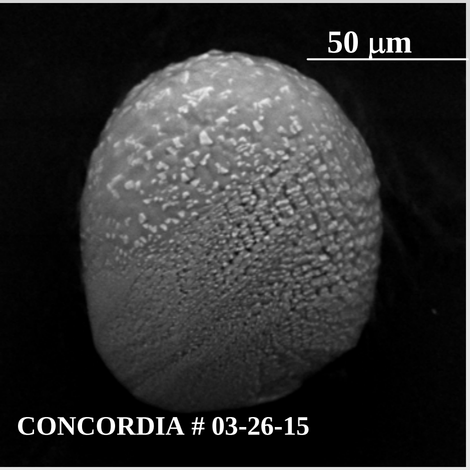
2002/2006 new protocol : ET/T ~ 1

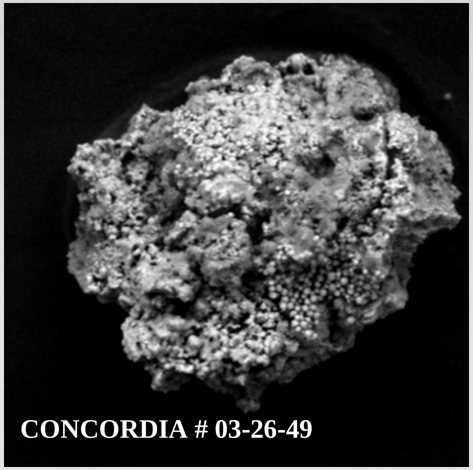


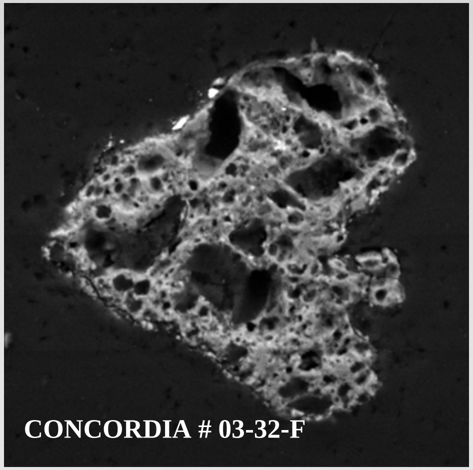










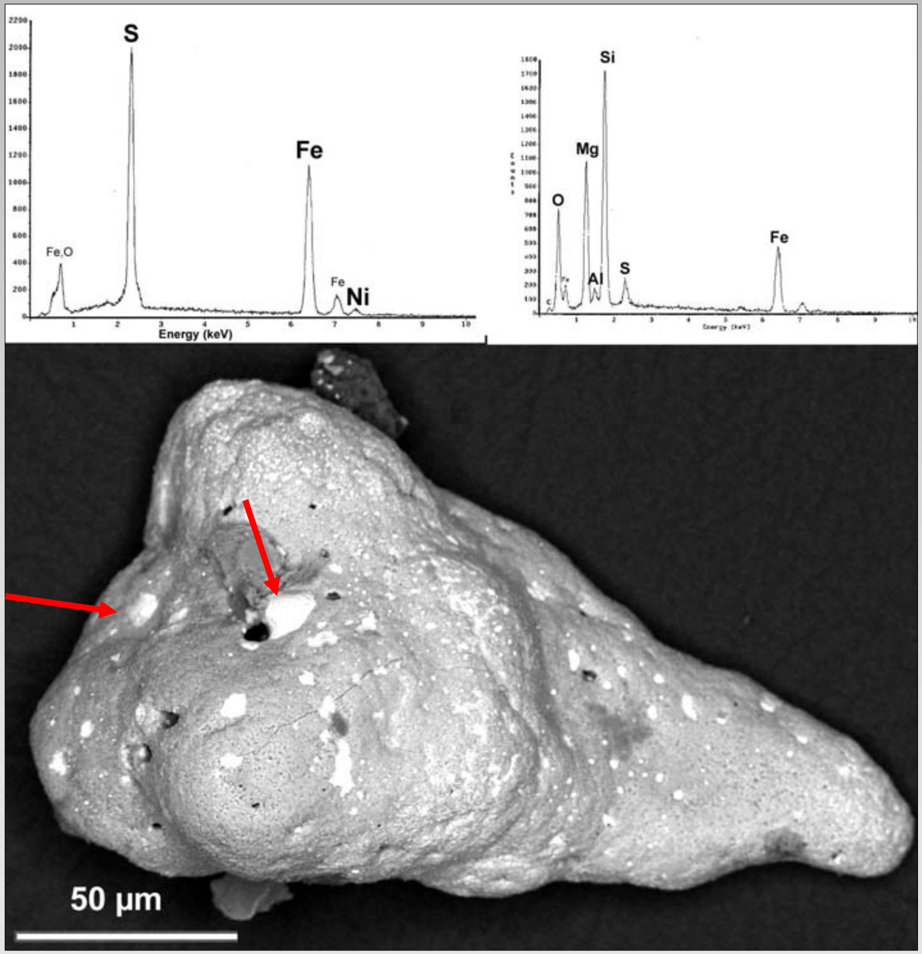


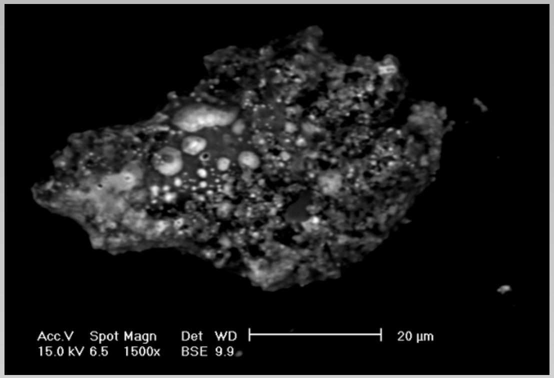
(Duprat, Engrand *et al*. LPSC, 2003)

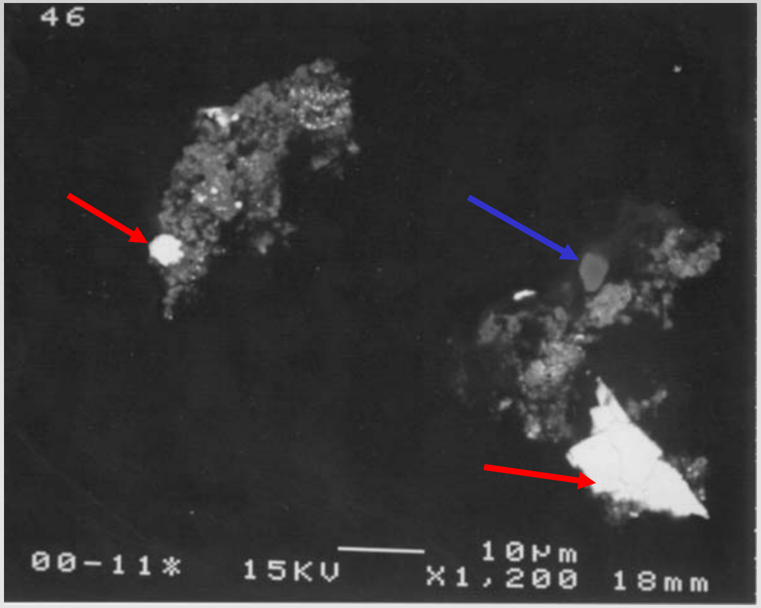
CONCORDIA Results II

Fe-Sulfide grains, a carbonate

a minimal aqueous weathering



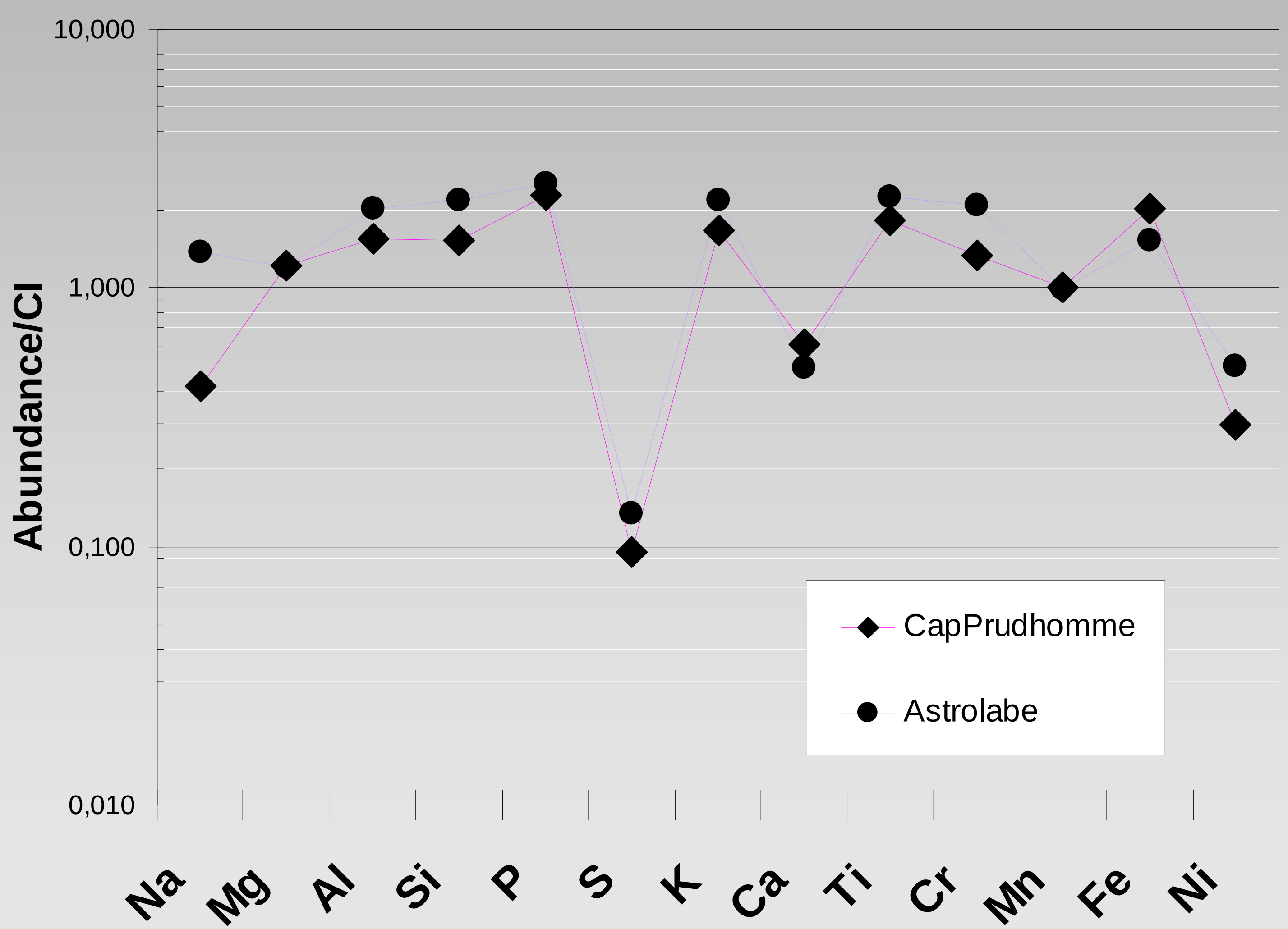




Duprat, Engrand *et al.*, *Adv. Space Sci* (2007)

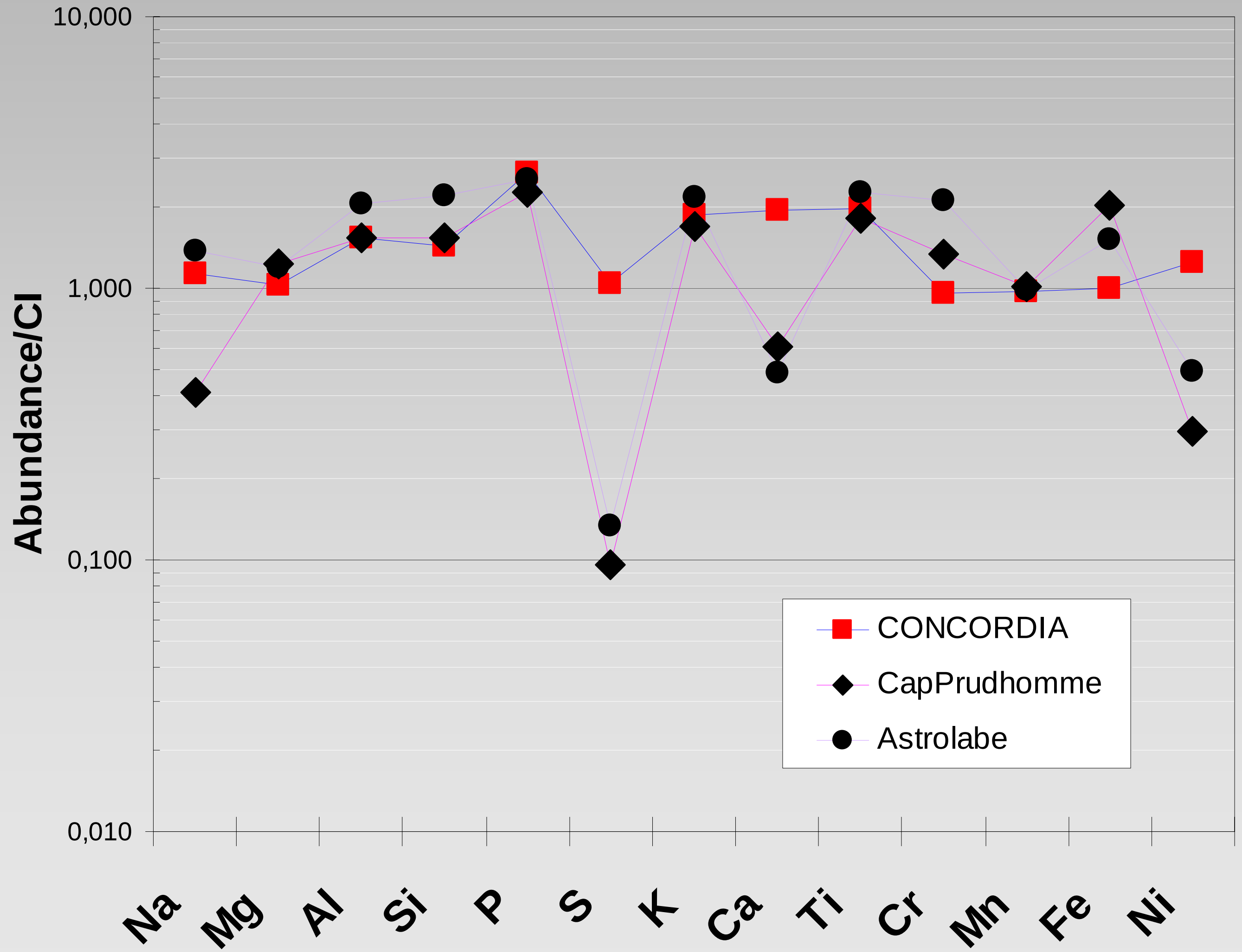
Blue Ice Field micrometeorites are depleted compared to CI Chondrites (S, Ca, Ni)

G. Kurat et al. GCA 1994



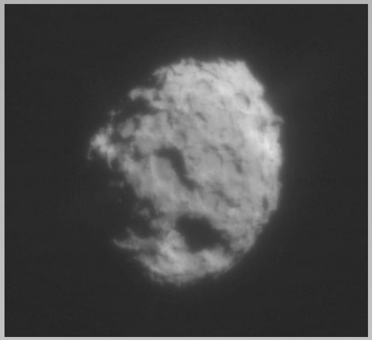
CONCORDIA Results III

an un-depleted "solar" composition



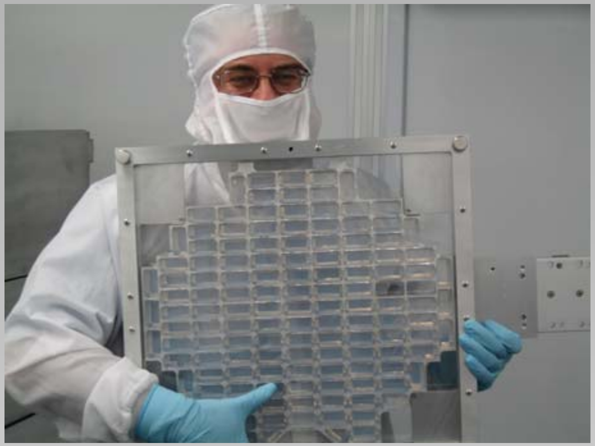
Duprat, Engrand *et al.*, *Adv. Space. Res.* (2007)

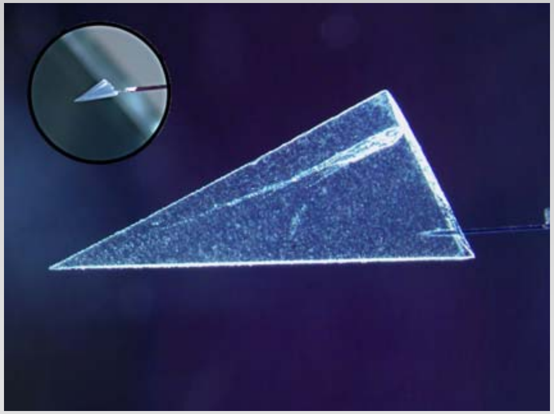
Cometary sample return : STARDUST (NASA)



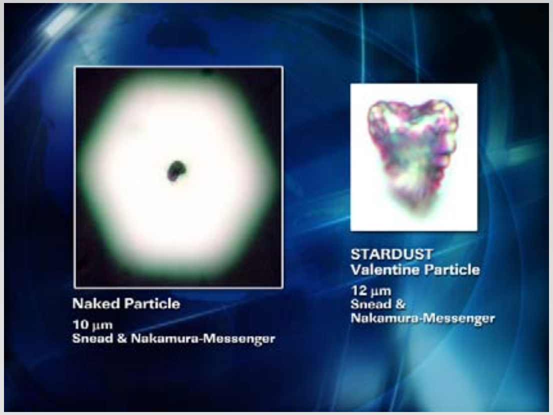
2 January 2004
Comet Wild 2

January 2006





Capture in Aerogel



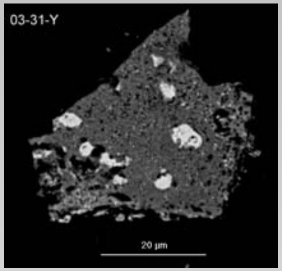
STARDUST Preliminary Examination Team (PET)

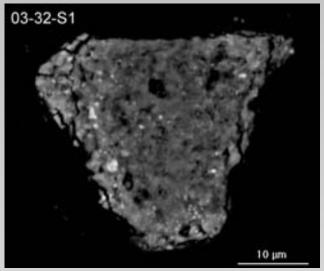
Des échantillons pour le Consortium STARDUST

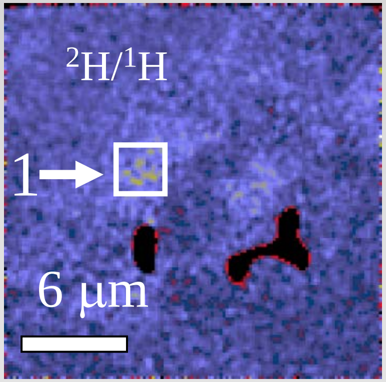
COORDINATED STUDIES OF PRISTINE CONCORDIA MICROMETEORITES.

M. Gounelle[1], P. Bleuet[2], L. Bonal[3], J. Borg[4], M. Chaussidon[5], L. d'Hendecourt[4], Z.Djouadi[4], J. Duprat[6], C. Engrand[6], T. Ferroir[7], P. Gillet[7], F. Grossemy[4], C. Le Guillou[8], L.Lemelle[7], H. Leroux[9], A. Meibom[1], G. Montagnac[7], S. Mostefaoui[1], E. Quirico[3], B.Reynard[7], F. Robert[1], J.-N. Rouzaud[8], A. Simionovici[7] and B. van de Moortèle[7].

LEME, MNHN, 75005 Paris, France.
ESRF, 38043 Grenoble, France.
LPG, 38041 Grenoble, France.
IAS, 91405 Orsay, France.
CRPG-CNRS, 54501 Vandoeuvre-lès-Nancy, France.
CSNSM, 91405 Orsay.
LST, ENS Lyon, 69007 Lyon, France.
Lab. Géol. ENS, 75231-Paris, France.
LSPES, 59655 Villeneuve d'Ascq, France.







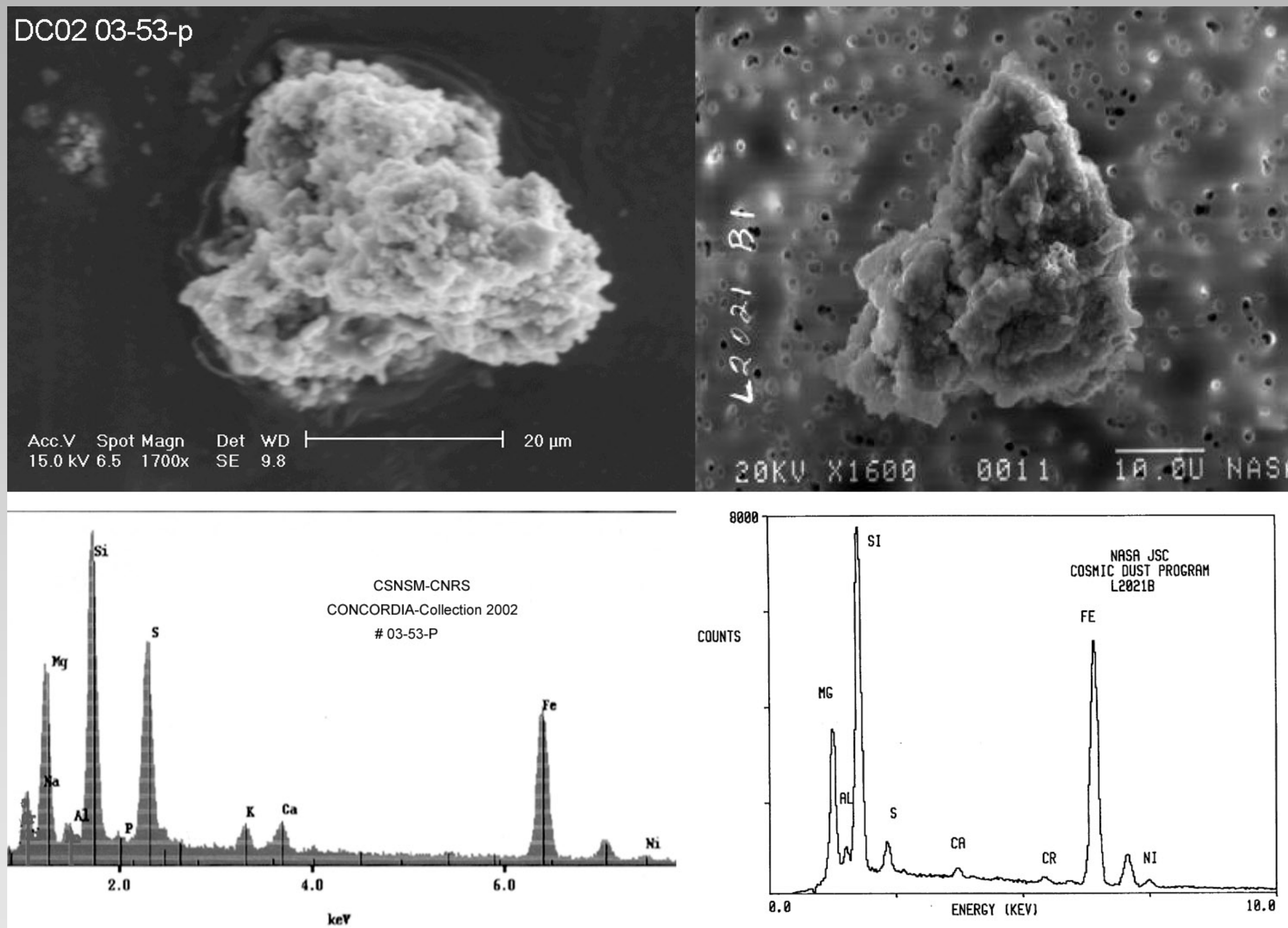
Analyses couplées :

IR, TEM, Raman, Synchrotron X-ray Fluorescence, NanoSims, Gazes Rares

Lunar & Planetary Science Conference
March 2006, League City, Texas

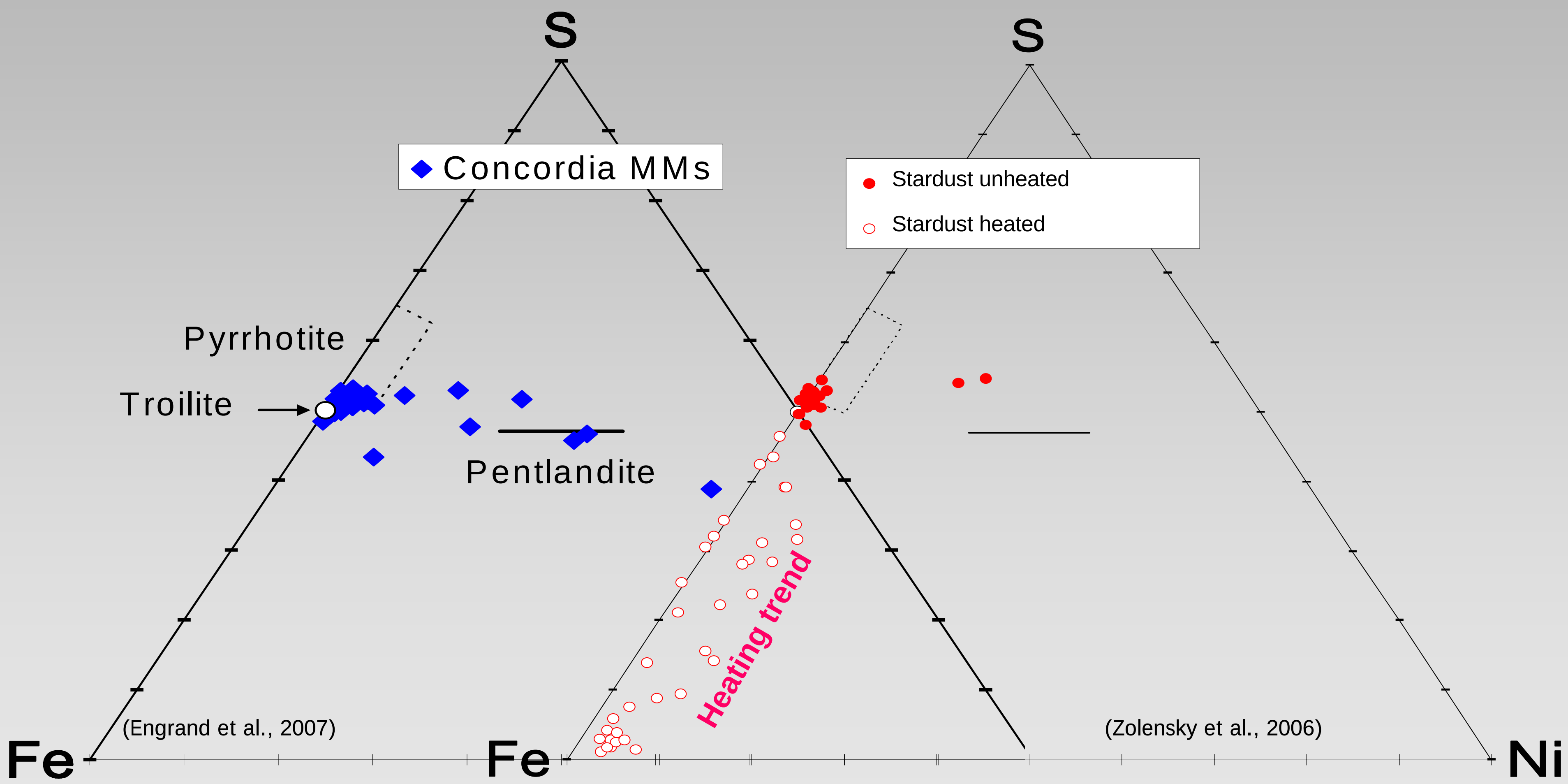
CONCORDIA results

CONCORDIA Collection IDP (NASA)



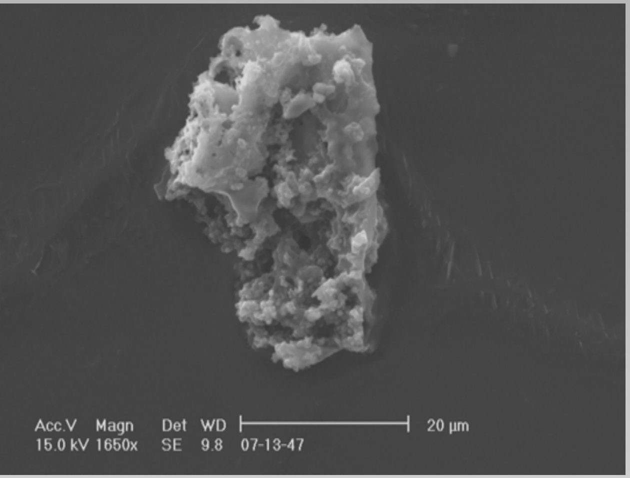
(Duprat, Engrand *et al*. LPSC, 2005)

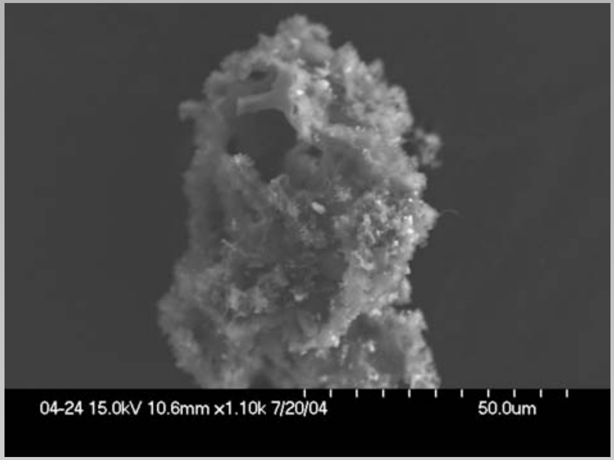
Fe-Sulphids grains
CONCORDIA / STARDUST

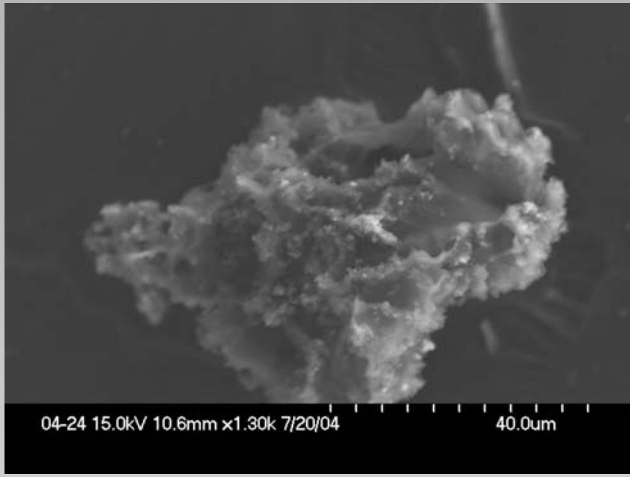


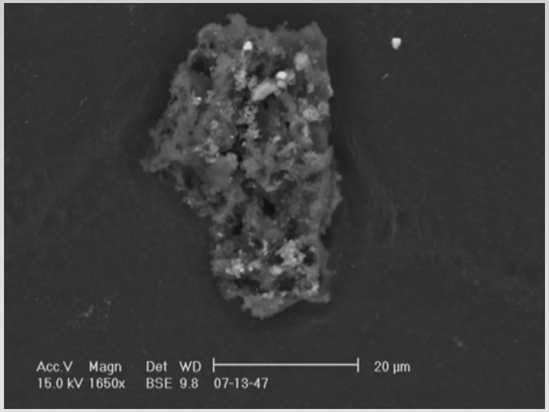
Engrand, Duprat et al LPSC 2007

Un nouveau type de matériau interplanétaire: les micrométéorites Ultracarbonées (UCAMM)

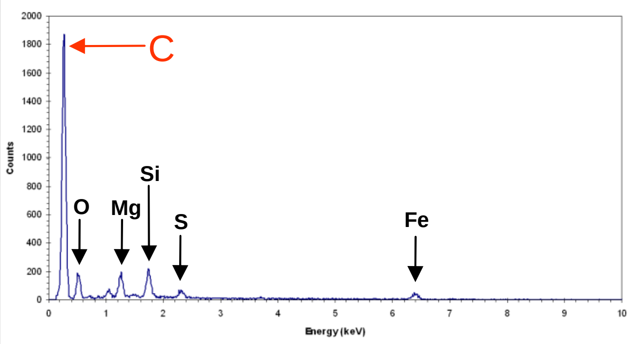








60-85vol%
Matière organique

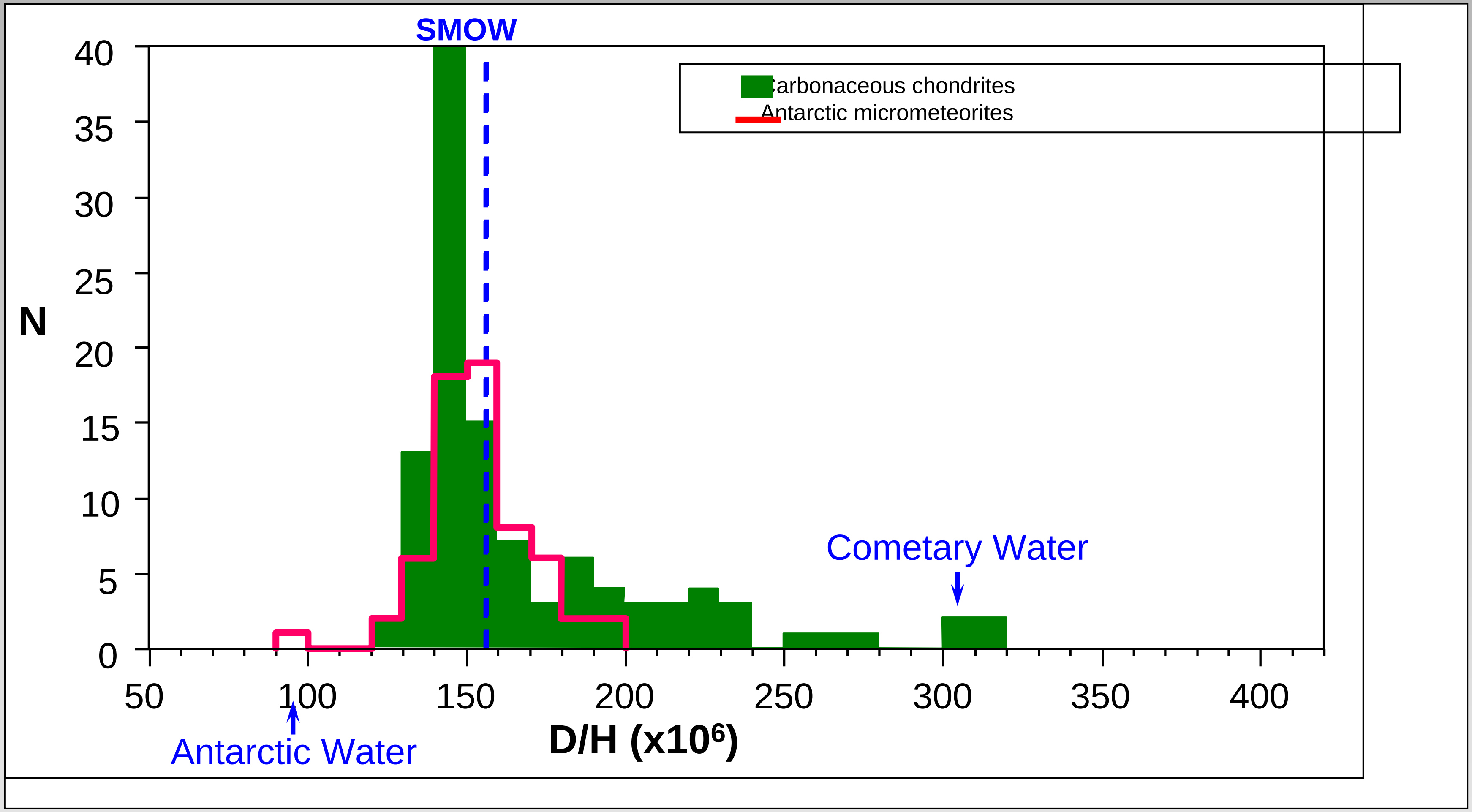


~ 3 % des AMMs sont des Utracarbonnées

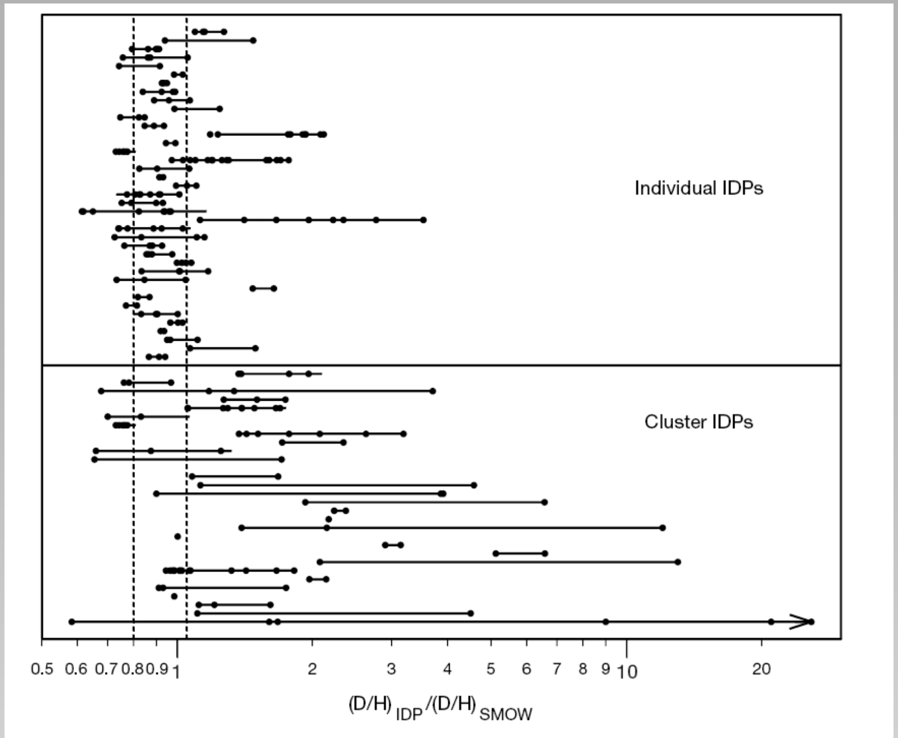
Thèse E. Dobrica (Dir. C. Engrand)

Dobrica, Engrand et al. LPSC 2008

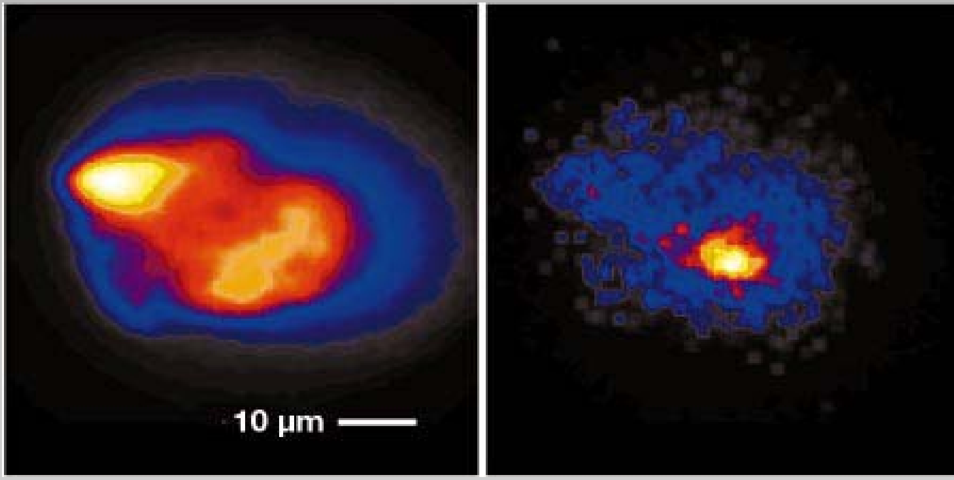
D/H in Micrometeorites … a solar value



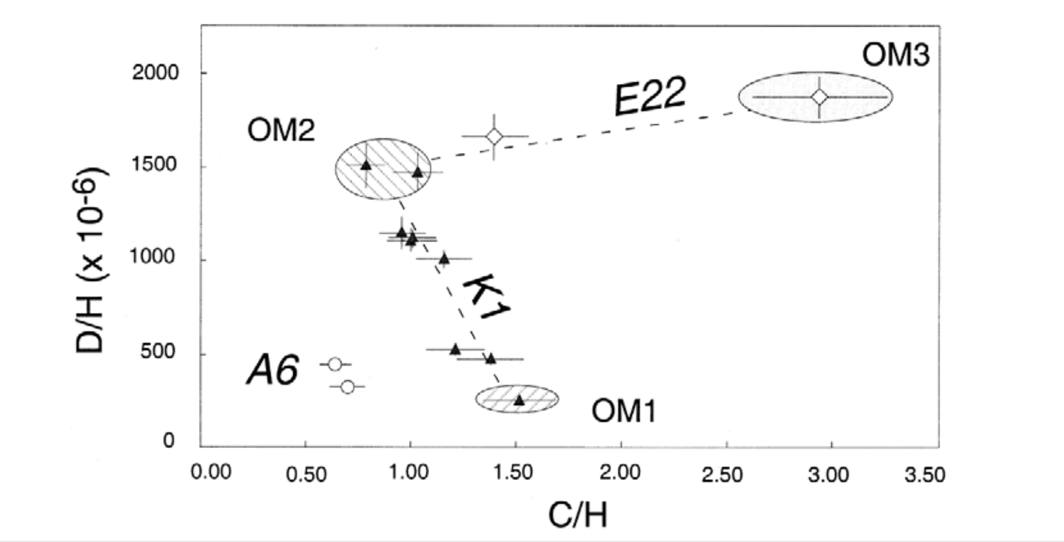
D enrichments in IDPs



Messenger, Nature 2000



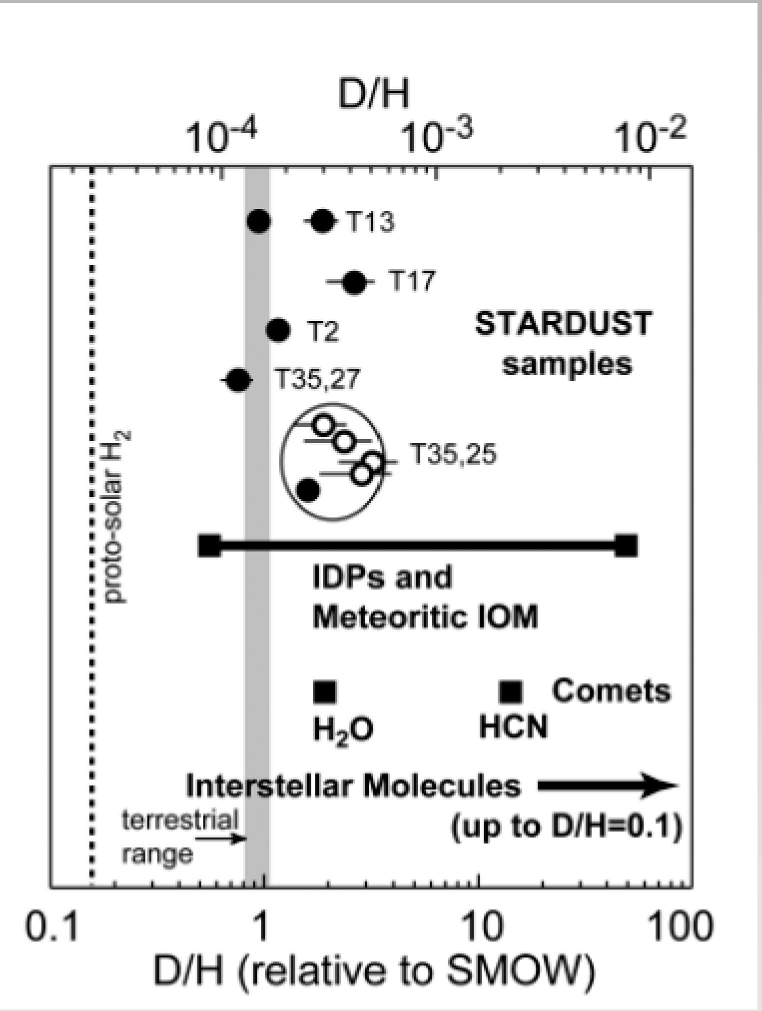
Messenger, Nature 2000



Aléon et al. GCA 2001

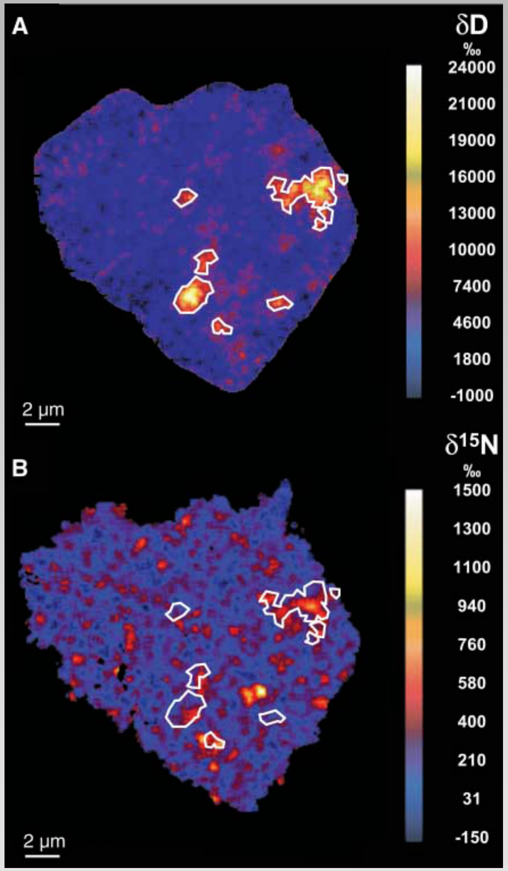
- a cometary origin
- different type of OM

Large D/H, a cometary origin

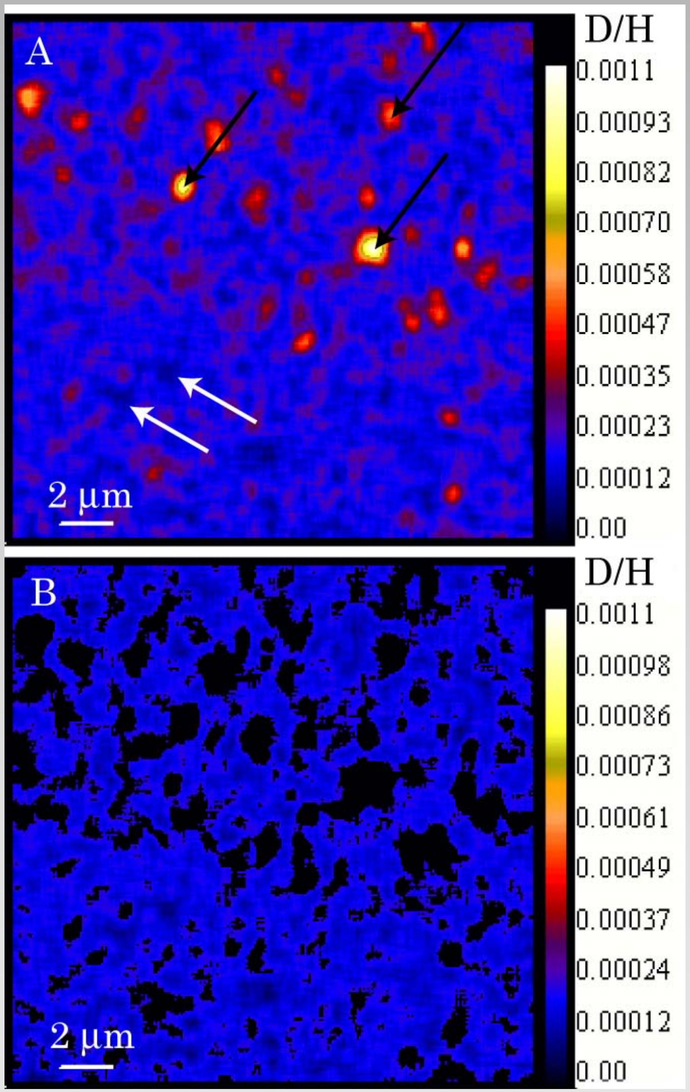


McKeegan et al Science 2006

D/H in Isoluble Organic Matter (IOM)

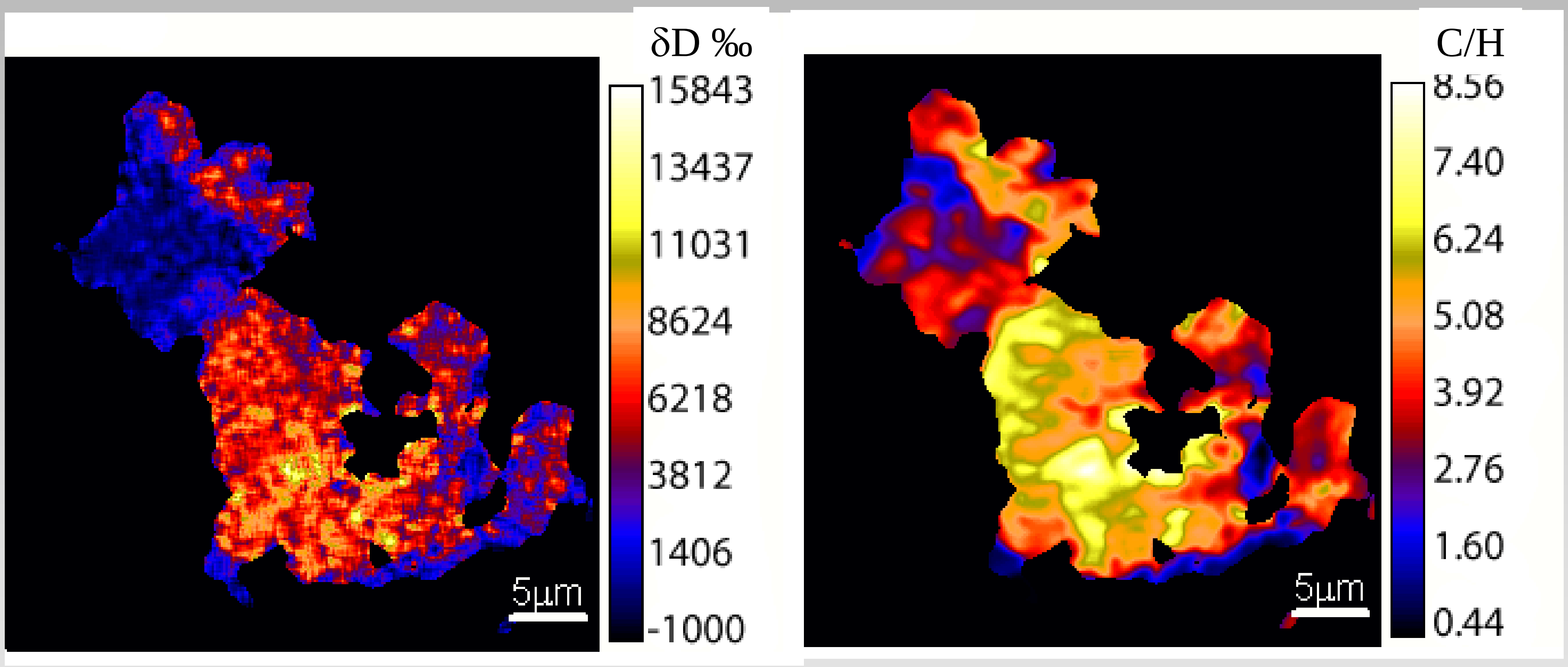


Busman et al Science 2006



Remusat et al LPSC 2008

D/H on Ultracarbonaceous micrometeorites I

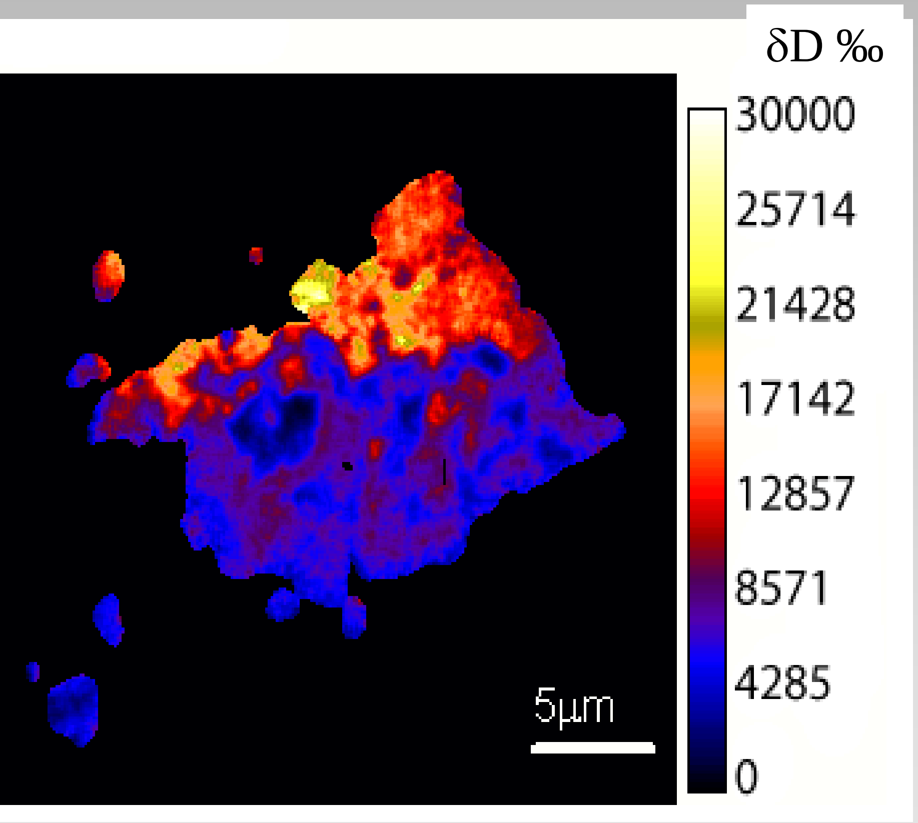


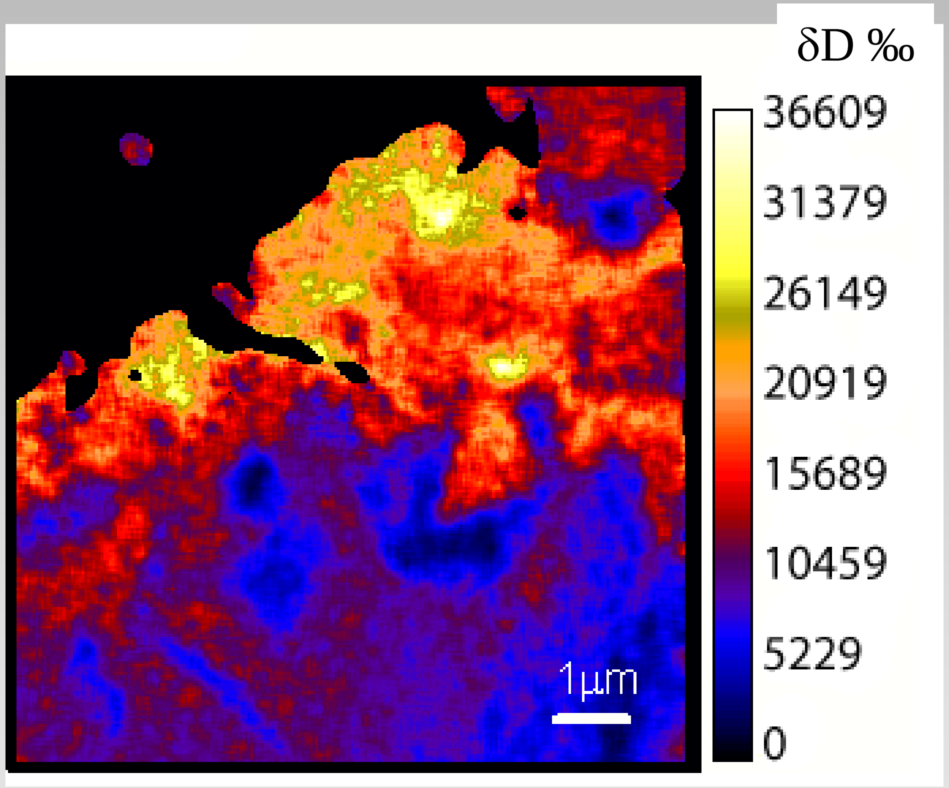
Data Nanosims 2008 CSNSM, MNHN

Duprat, Dobrica, Engrand et al. 2009

D/H on Ultracarbonaceous micrometeorites II

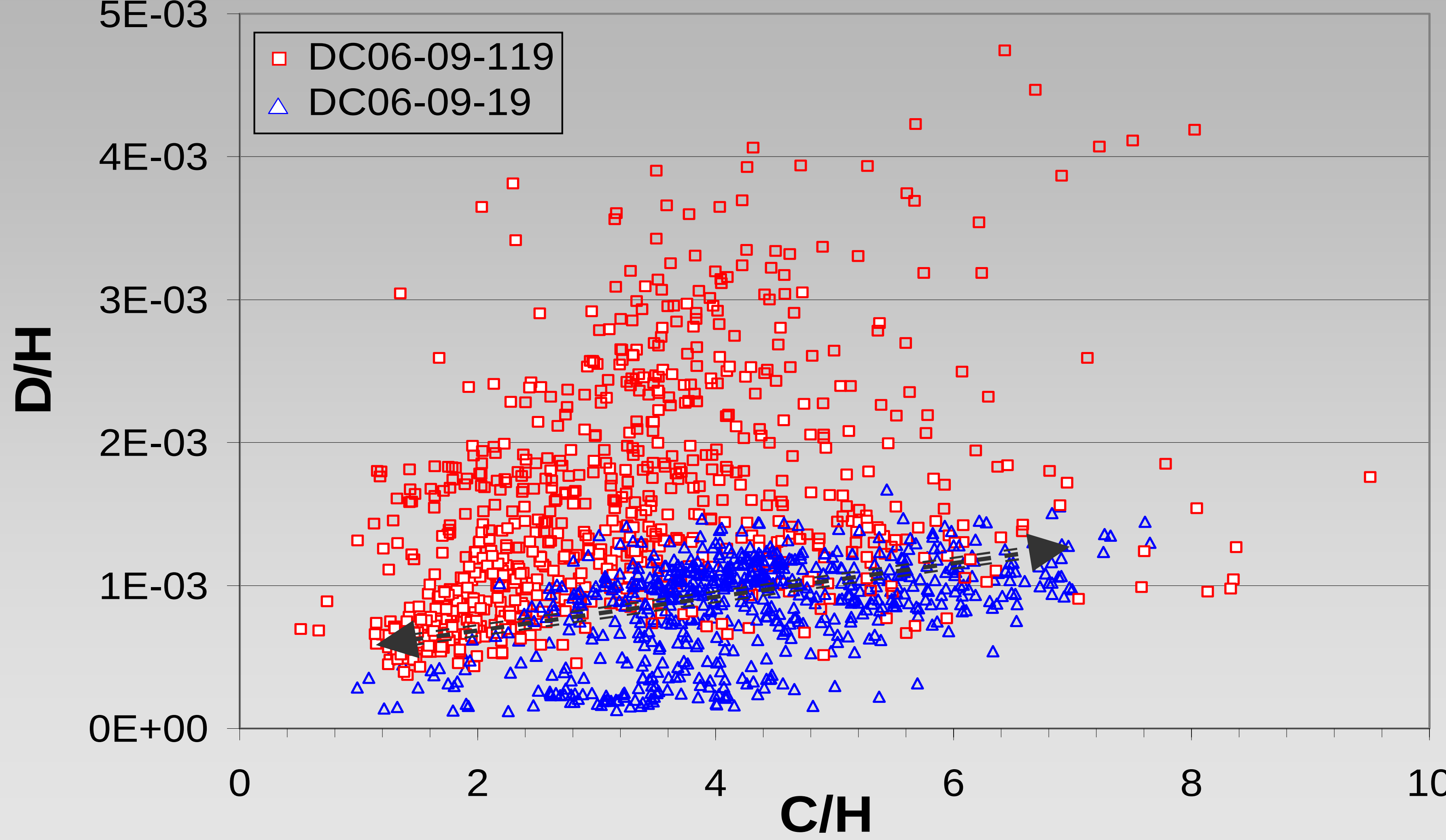
Up to 30 times the SMOW value !





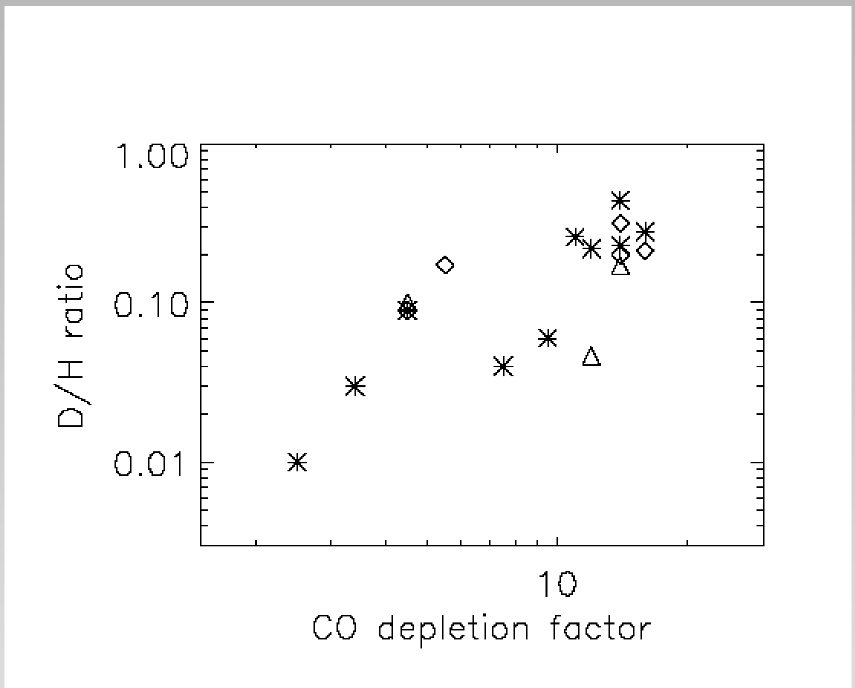
Data Nanosims 2008 CSNSM, MNHN

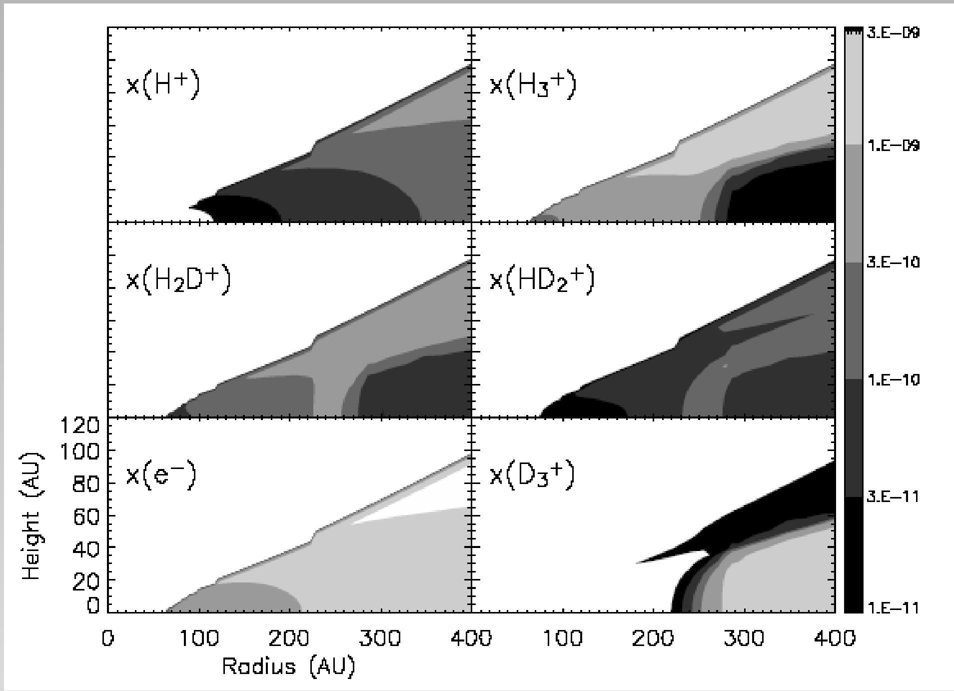
Extreme D-rich primitive organic matter



Ultracabonaceous Micrometeorites, giant cometary particles

Probing the inner part of the protoplanetary disk ?





Ceccarelli & Domonik AA 2005

Deuterated H_3^+ in proto-planetary disk

Ceccarelli et al arXiv2006

N_2D^+/N_2H^+ in prestellar cores

$$H_3^+ + HD \rightleftharpoons H_2D^+ + H_2$$

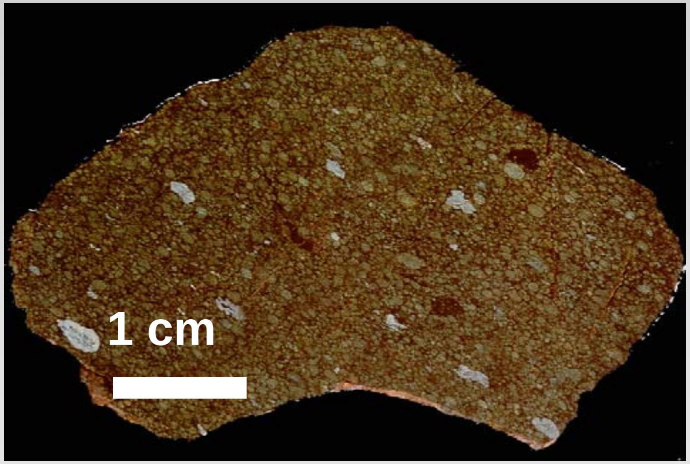
$$H_2D^+ + HD \rightleftharpoons HD_2^+ + H_2$$

$$HD_2^+ + HD \rightleftharpoons D_3^+ + H_2$$

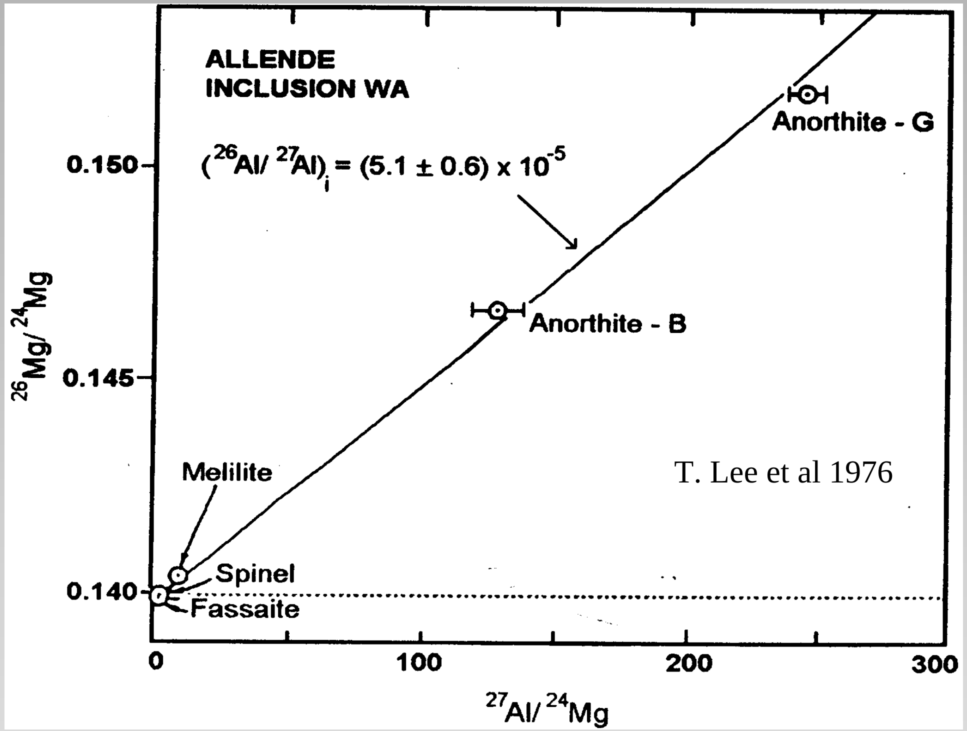
Radioactivités éteintes & Système Solaire Primitif

Meteorite Data

Nucleus	$T_{1/2}$ (My)
^{10}Be	1.51
^{26}Al	0.74
^{41}Ca	0.10
^{53}Mn	3.74
^{60}Fe	1.51

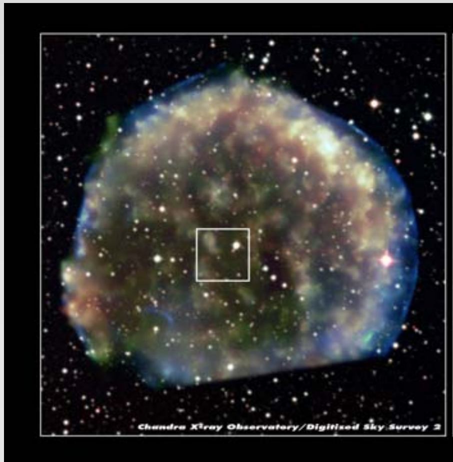


Les inclusions réfractaires de Allende (CAI, Chondres)

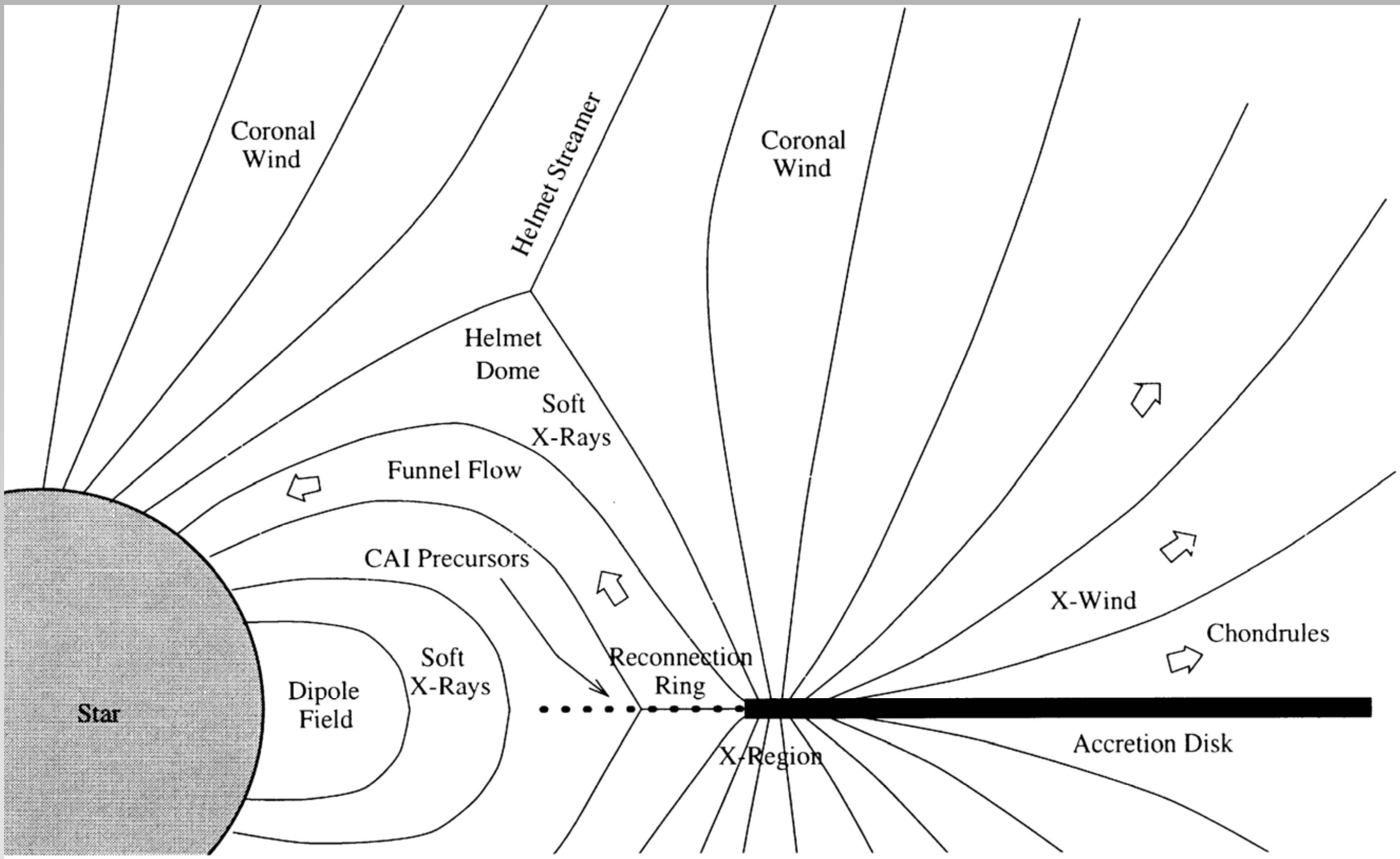


Nucléosynthèse stellaire (SNII, AGB,…)

Wasserburg et al 1998, Cameron et al. 1995, …

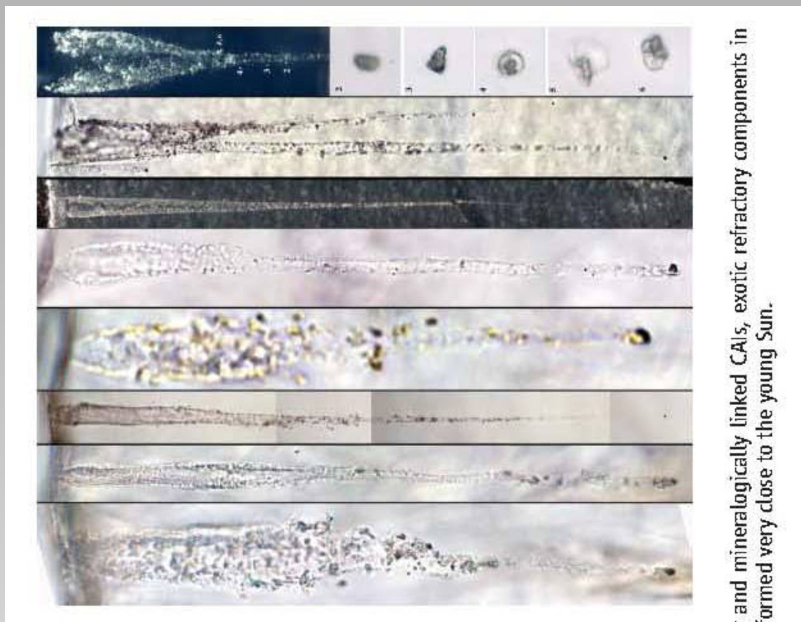


Nucléosynthèse par irradiation *in-situ* ?



T. Lee et al. ApJ 1998
Shu et al. ApJ 2001

STARDUST PET results



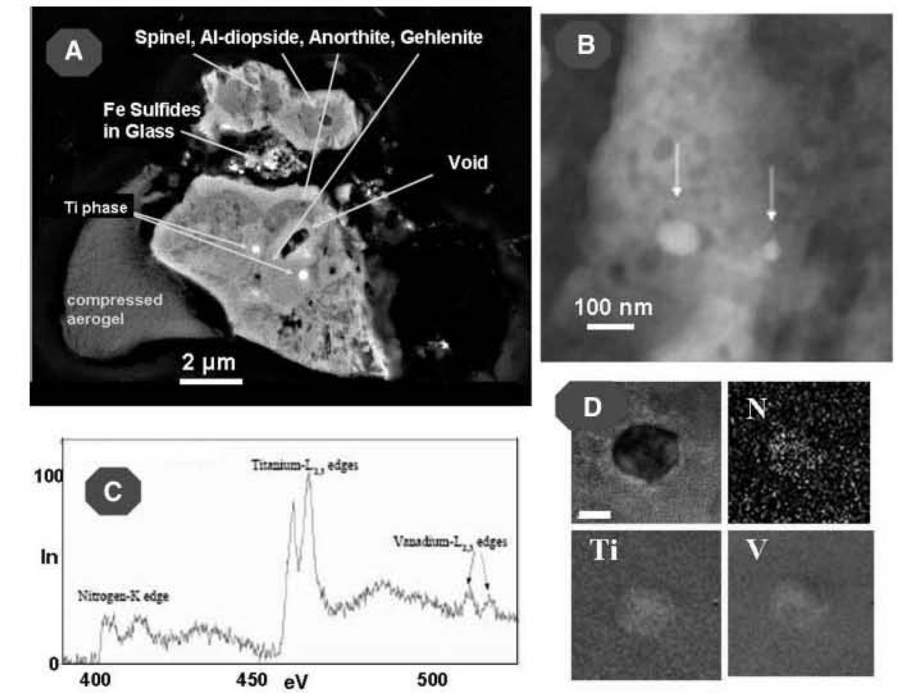


Fig. 4. The CAI-like grain from track 25. (**A**) Backscattered electron (BSE) image of the CAI-like grain from track 25, showing the gray shell of compressed-to-melted aerogel at lower left. (**B**) High-angle annular dark-field TEM image of two osbornite grains (arrows) within spinel. (**C**) EELS spectrum of an osbornite grain showing peaks for N, Ti, and V; scales represent intensity (In) and energy (in electron volts). (**D**) EELS element maps of an orbornite grain: BSE, N, Ti, and V. Scale bar, 40 nm.

- **Size 1-10 µm**
- **Aerogel capture :**
  - **Fragmentation**
  - **Heating**
  - **Mixing…**

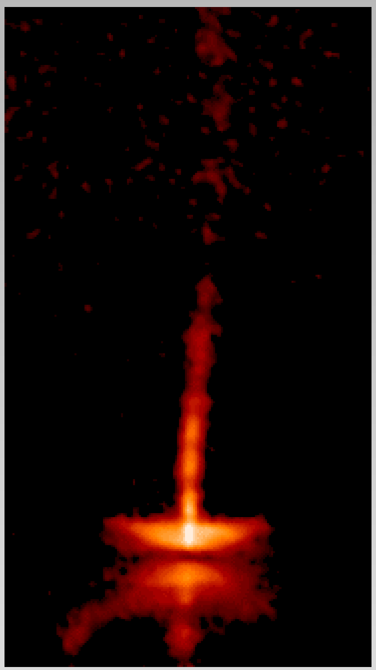
Refractory phases

Fe-Sulphides

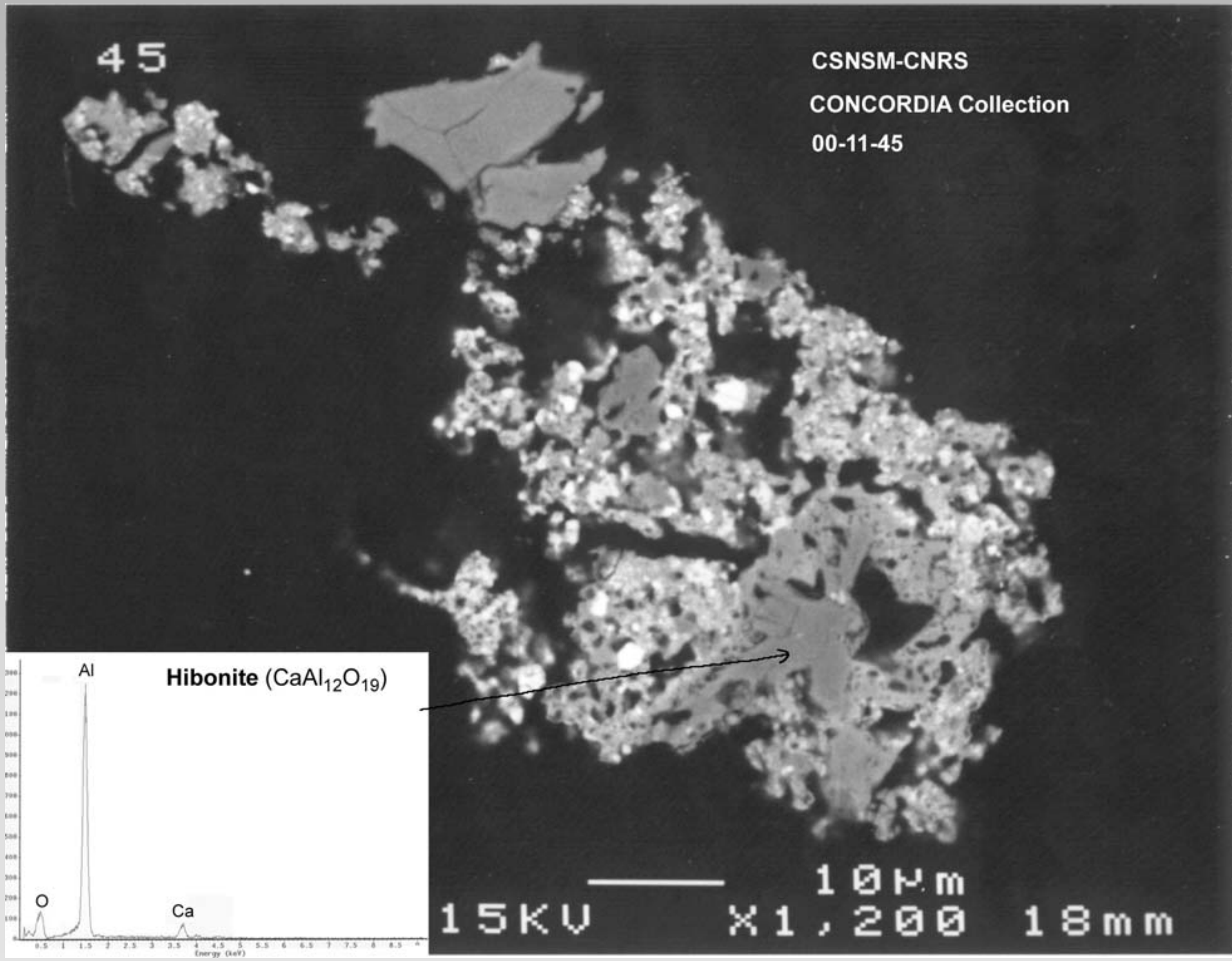
"**Remarkably enough, we have found fire and ice**"

Brownlee et al., Science 2006

Une phase réfractaire dans la collection CONCORDIA

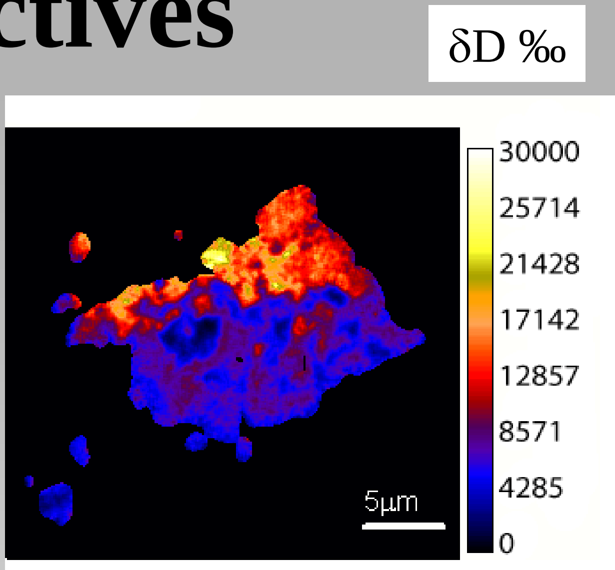


HH 30
Télescope Hubble
V= 500 000 km/h
Disk = 64 10^9 km = 500 UA



J. Duprat, CSNSM-IN2P3-CNRS

Conclusion / Perspectives



La Collection CONCORDIA

- > 2000 particules
- Un rapport signal sur bruit très élevé (ET/T ~ 1)
- Une valeur du flux contemporain
- Une altération terrestre minimale
- Des particules friables uniques
- Des micrométéorites Ultra-carbonées
- Des enrichissements extrêmes en Deutérium

- **Des grains cométaires géants**
  - Comparaison STARDUST
  - Des échantillons des régions froides du disque protoplanétaire
  - Test de la chronologie isotopique du système solaire

Les régions centrales antarctiques représente un collecteur unique de matériau cométaire