MICROMÉTÉORITES : ANALYSES ISOTOPIQUES DE POUSSIÈRES INTERPLANÉTAIRES

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CSNSM Orsay

Ecole Internationale Joliot-Curie, Septembre 2008

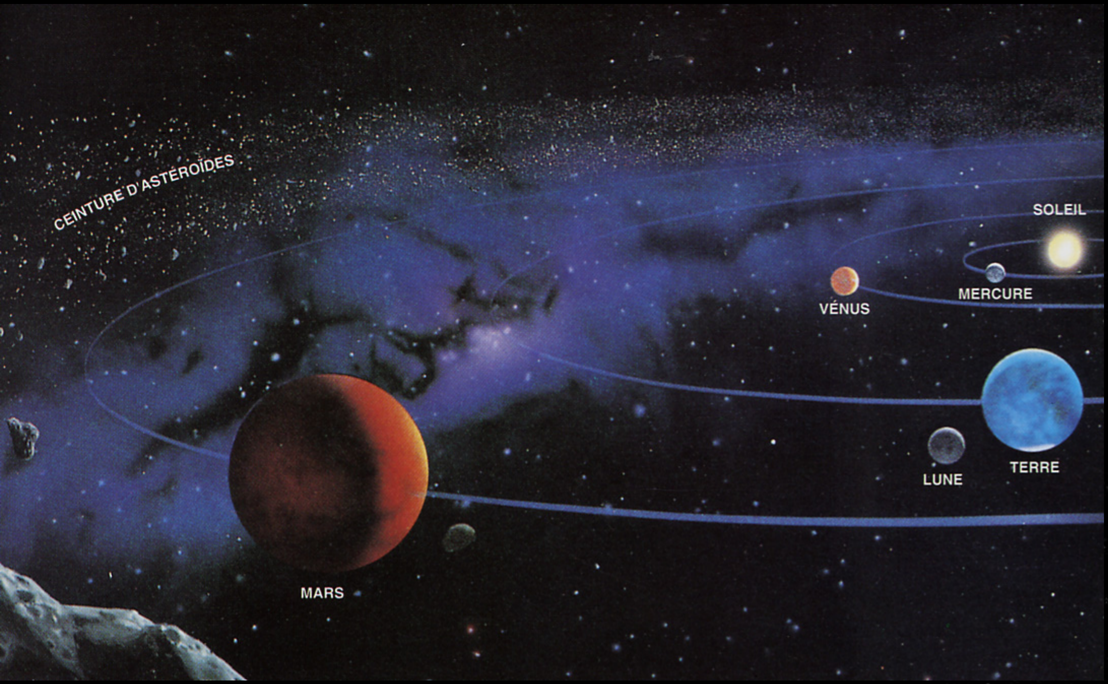
Météorites & Antarctique

+ 30,000 meteorites
USA, Japan, Italy

ANSMET
THE ANTARCTIC SEARCH FOR METEORITES

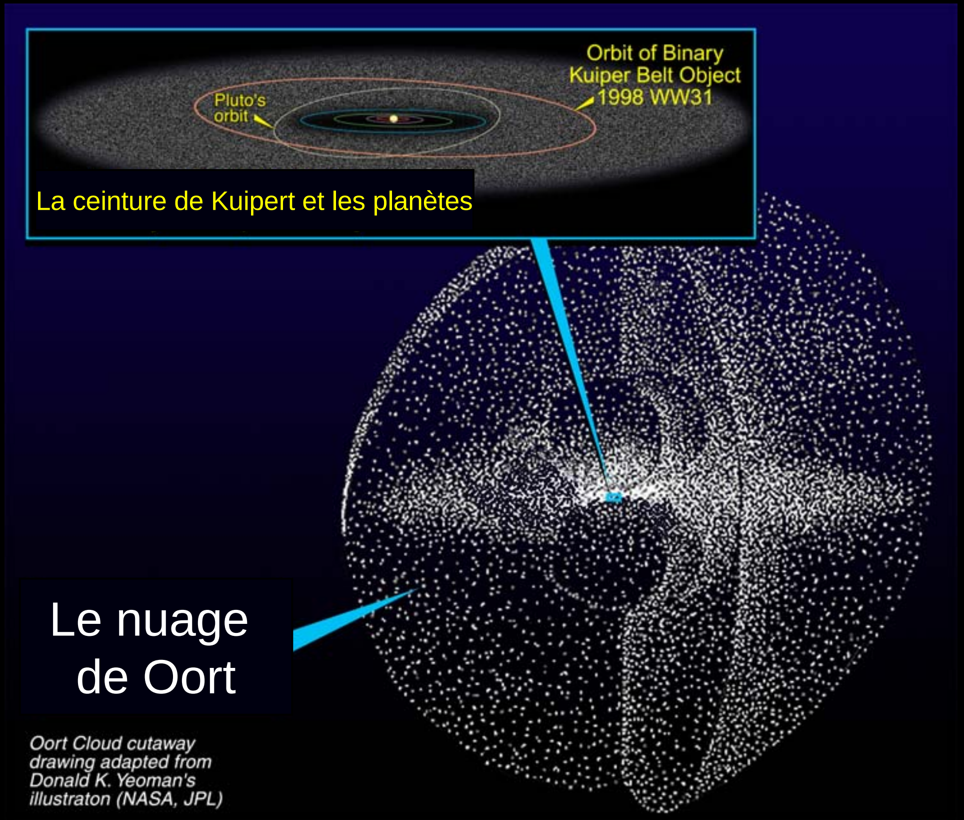
Antarctic Meteorite Research
PI : R. Harvey, Case Univ. US

D’où viennent les météorites ?



Entre Mars et Jupiter, les astéroïdes…
un échantillonnage restreint !

Au confins du système solaire…
les comètes



Terre soleil : **1 UA** = 10^9 km (8 minutes. c)

Pluton : 50 UA (7 heures. c)

La ceinture de Kuiper : 70 UA (10 heures .c)
Le Nuage Oort : 200 000 UA (3 ans. C)

The HMS *Challenger* expedition 1873-1876

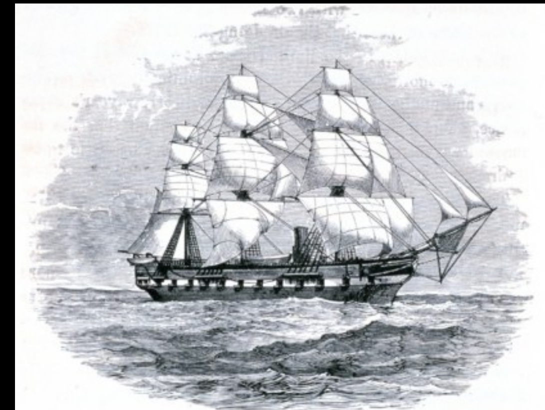
(691)

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



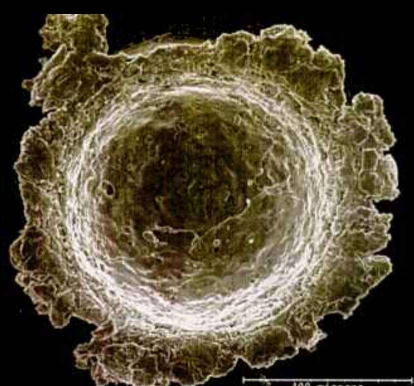
H.M.S. "Challenger."

Murray 1876

Les collectes spatiales et stratosphériques

Altitude 400km

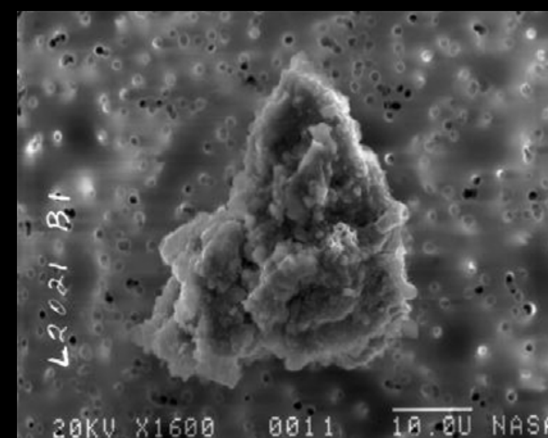
Altitude 15-20 km



Long Duration Exposure Facility (LDEF)
Crater data

Taille 10-500 μm

e.g. Love & Bronwlee Science 1993



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 …

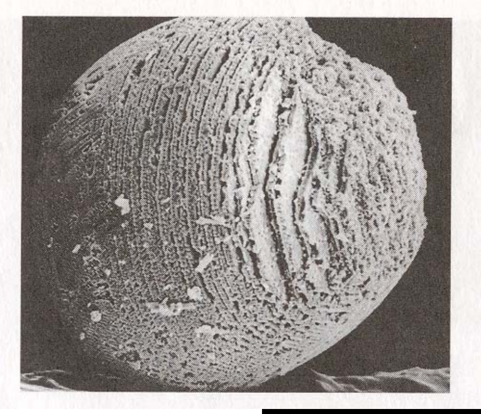
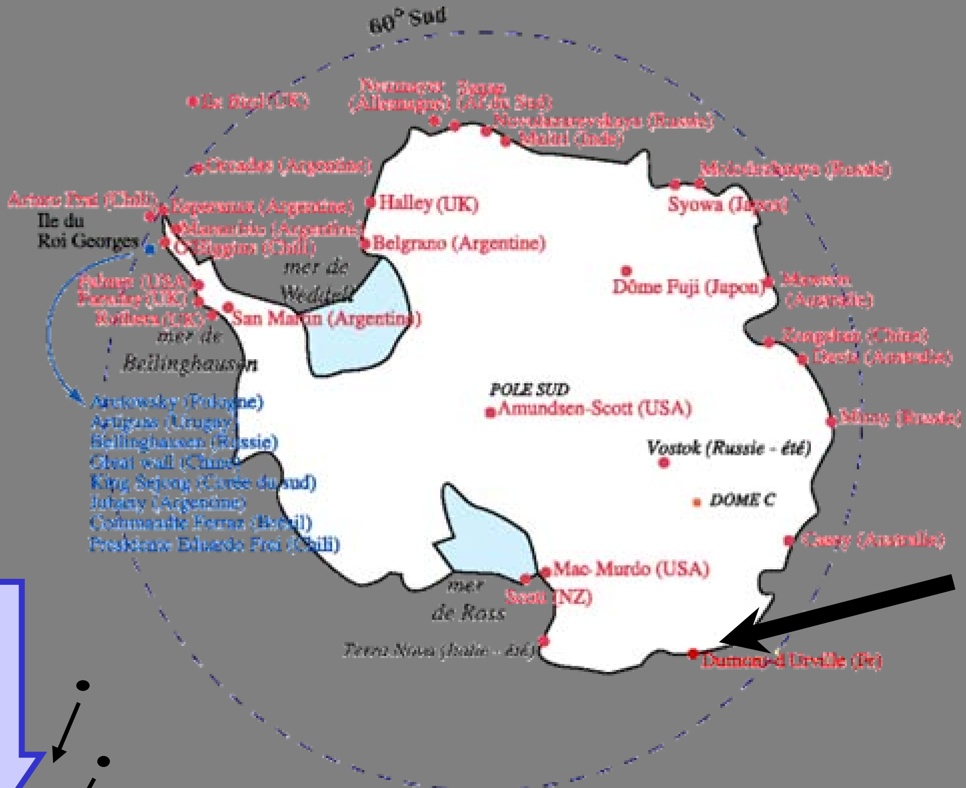


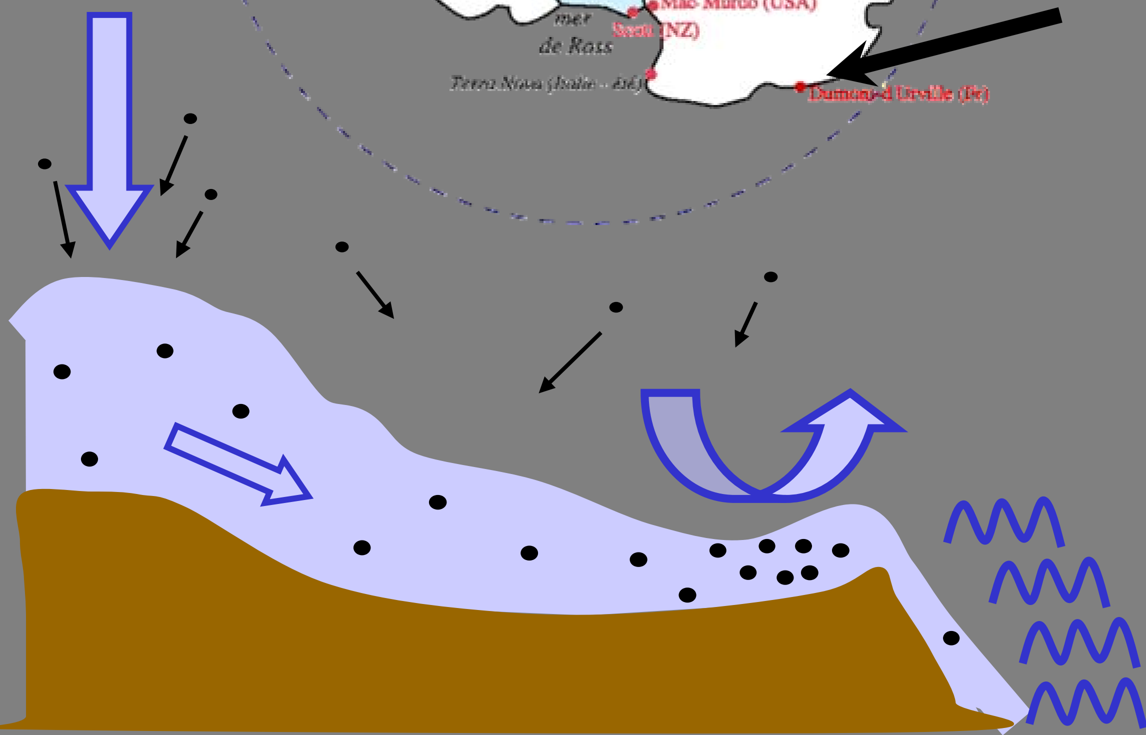
Table 1
Micrometeorite collections from sediments, sedimentary rocks, and polar deposits. The type column refers to the types of cosmic spherules recovered. When 'all' is used, both melted and unmelted micrometeorites were recovered.

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

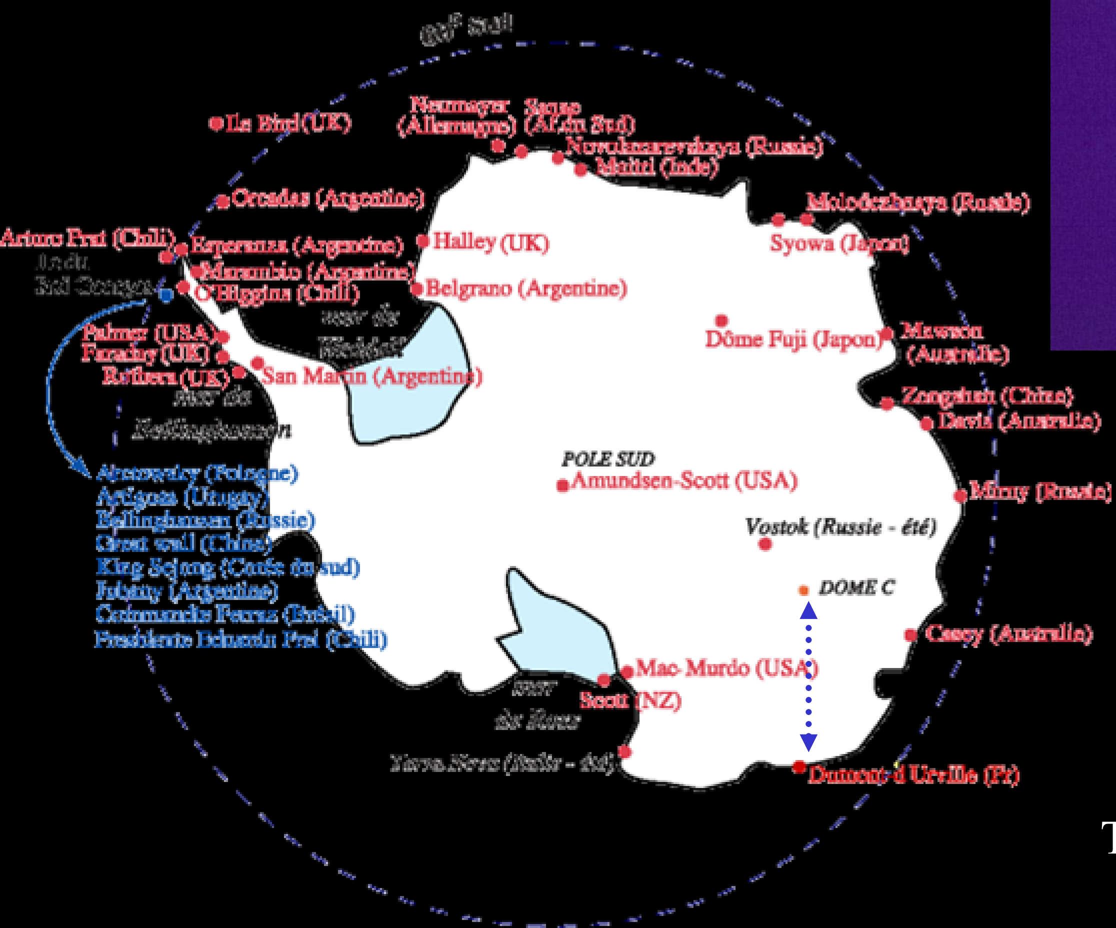


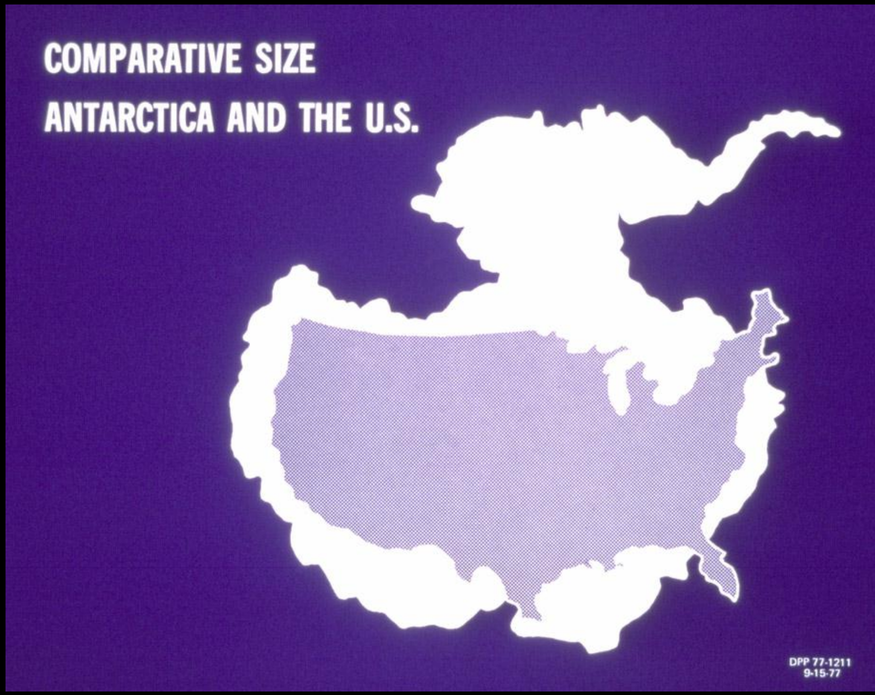


M. Maurette et al.
Nature (1991), **351**, 44-47.

The central regions of Antarctica

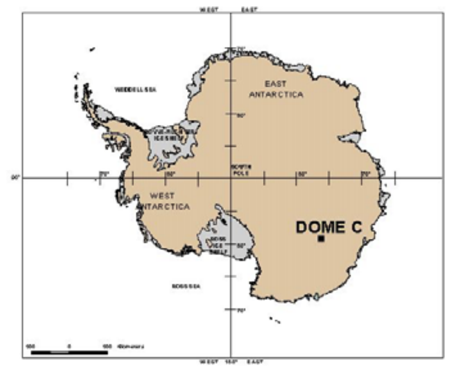
- Amundsen-Scott base (US)
- Vostok (Ru)
- Dome Fuji (Jp)
- Dôme C (Fr/It)





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 :**

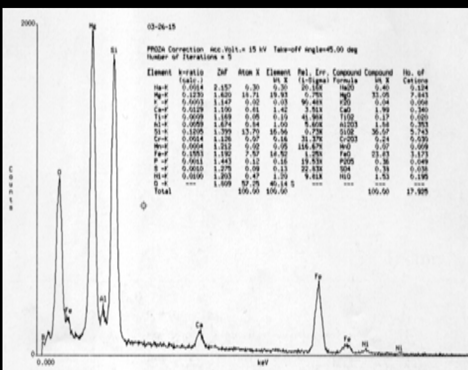
-> recover micrometeorites from **reasonable volume of snow** (few m^3)
-> measure a **FLUX of ET particles/m^2/year**
-> search for **variations in intensity/composition of the flux** in the last century

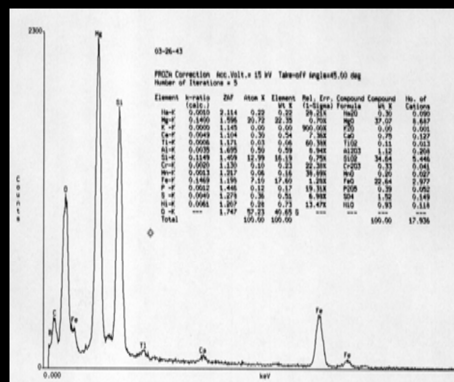
CONCORDIA Results I

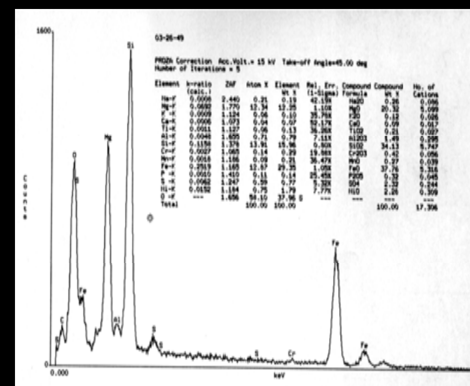
- A total of **500 micrometeorites** identified from 11 m^3 of snow

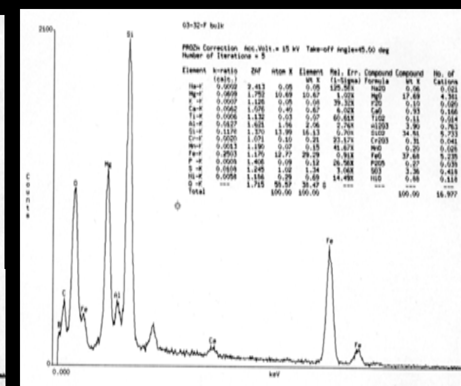
-> The **CONCORDIA Collection**

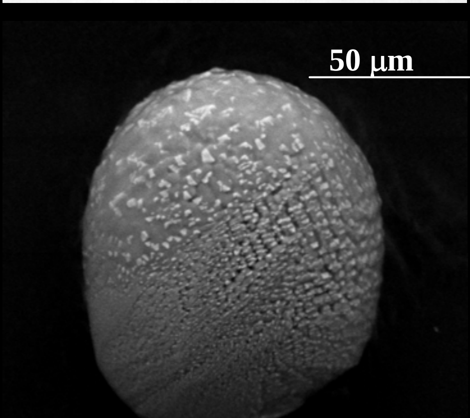
in 2006 new protocol : ET/T ~ 1



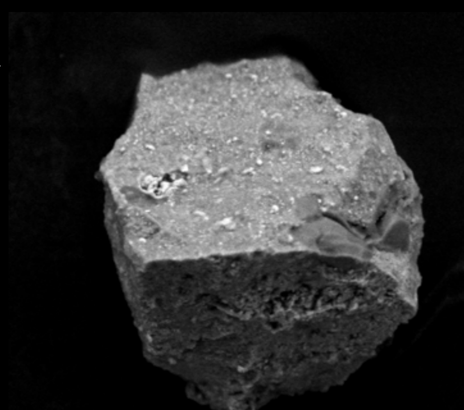




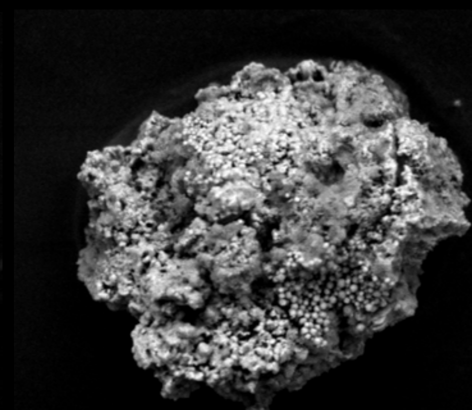




CONCORDIA # 03-26-15



CONCORDIA # 03-26-43



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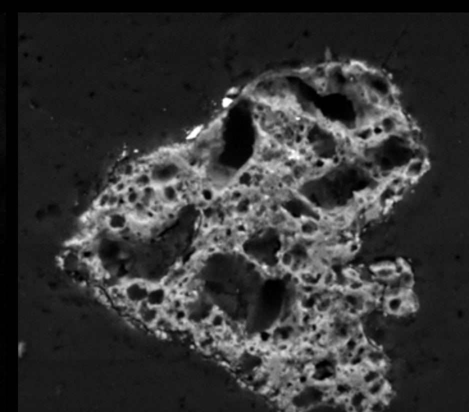
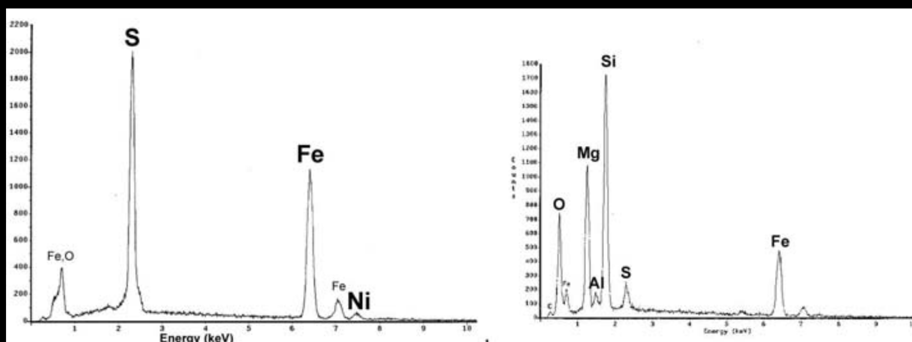


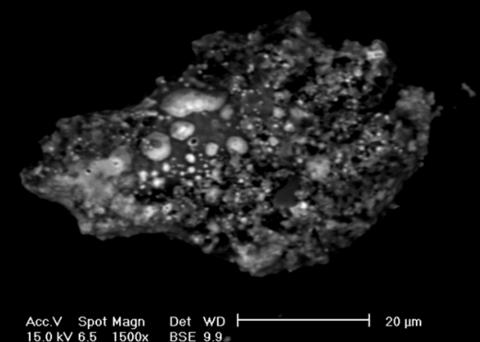
CONCORDIA # 03-32-F

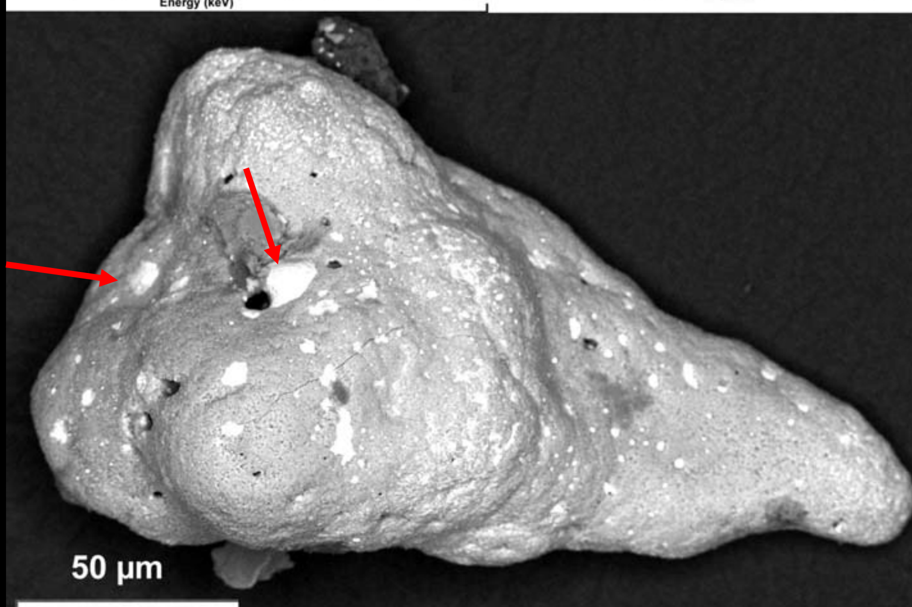
(Duprat, Engrand *et al*. LPSC, 2003)

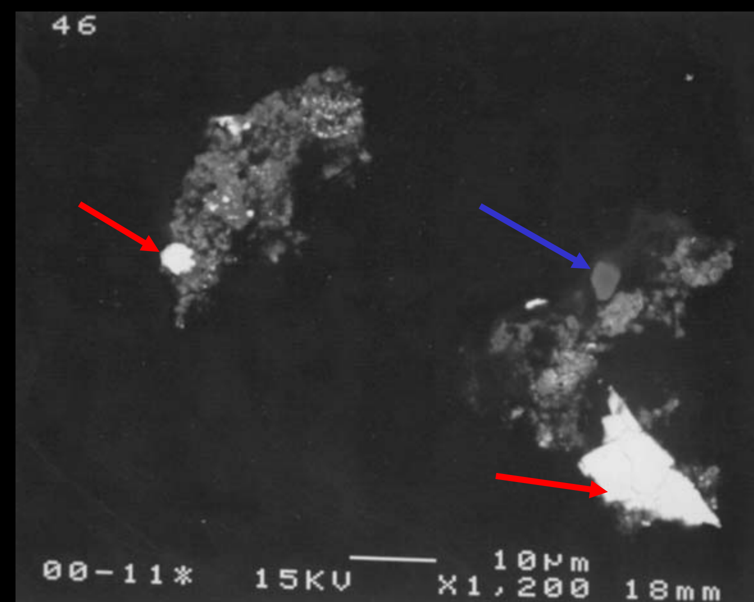
CONCORDIA Results II

Fe-Sulfide grains, carbonates



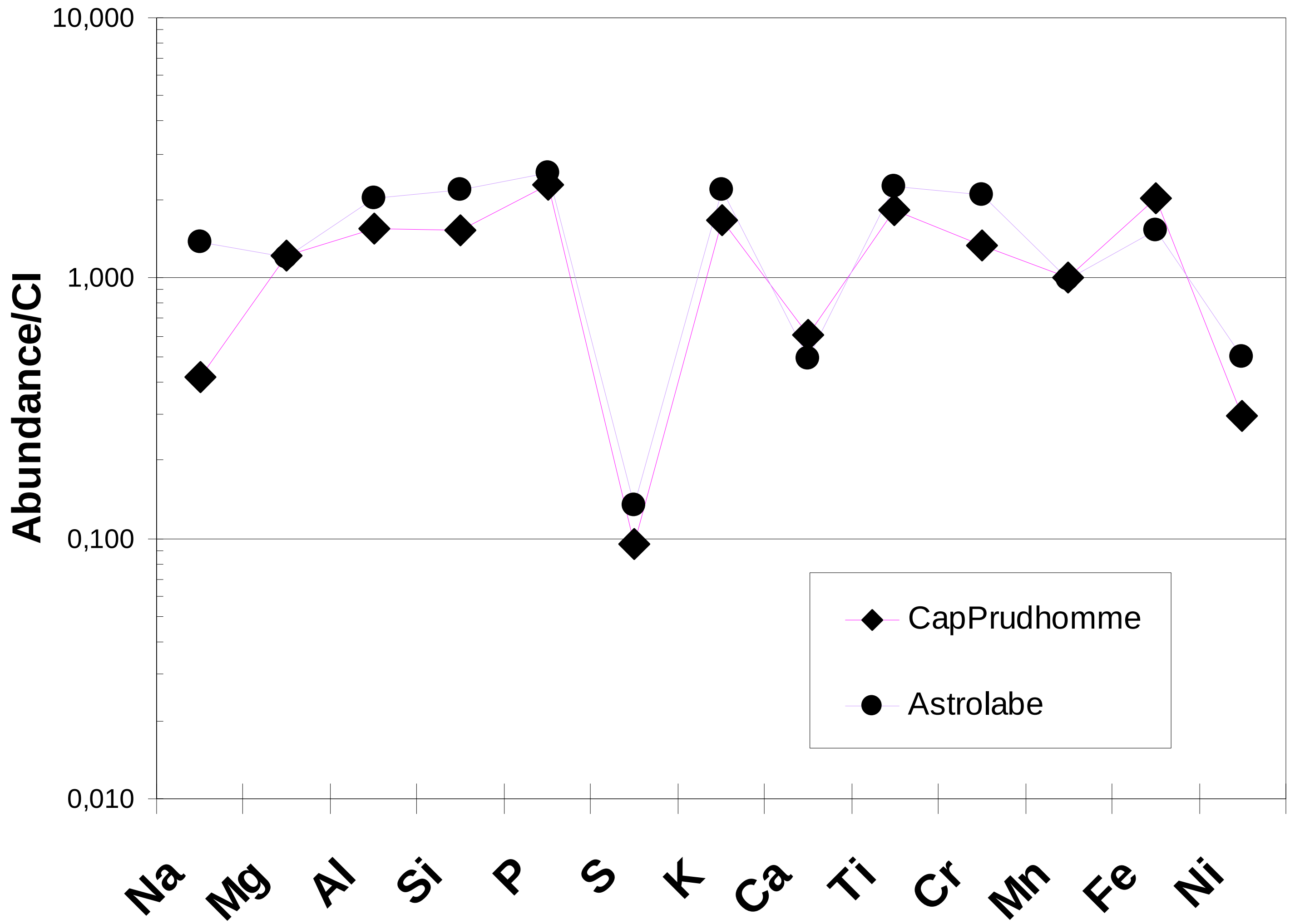






Duprat, Engrand *et al.*, *Adv. Space Sci* (2007)

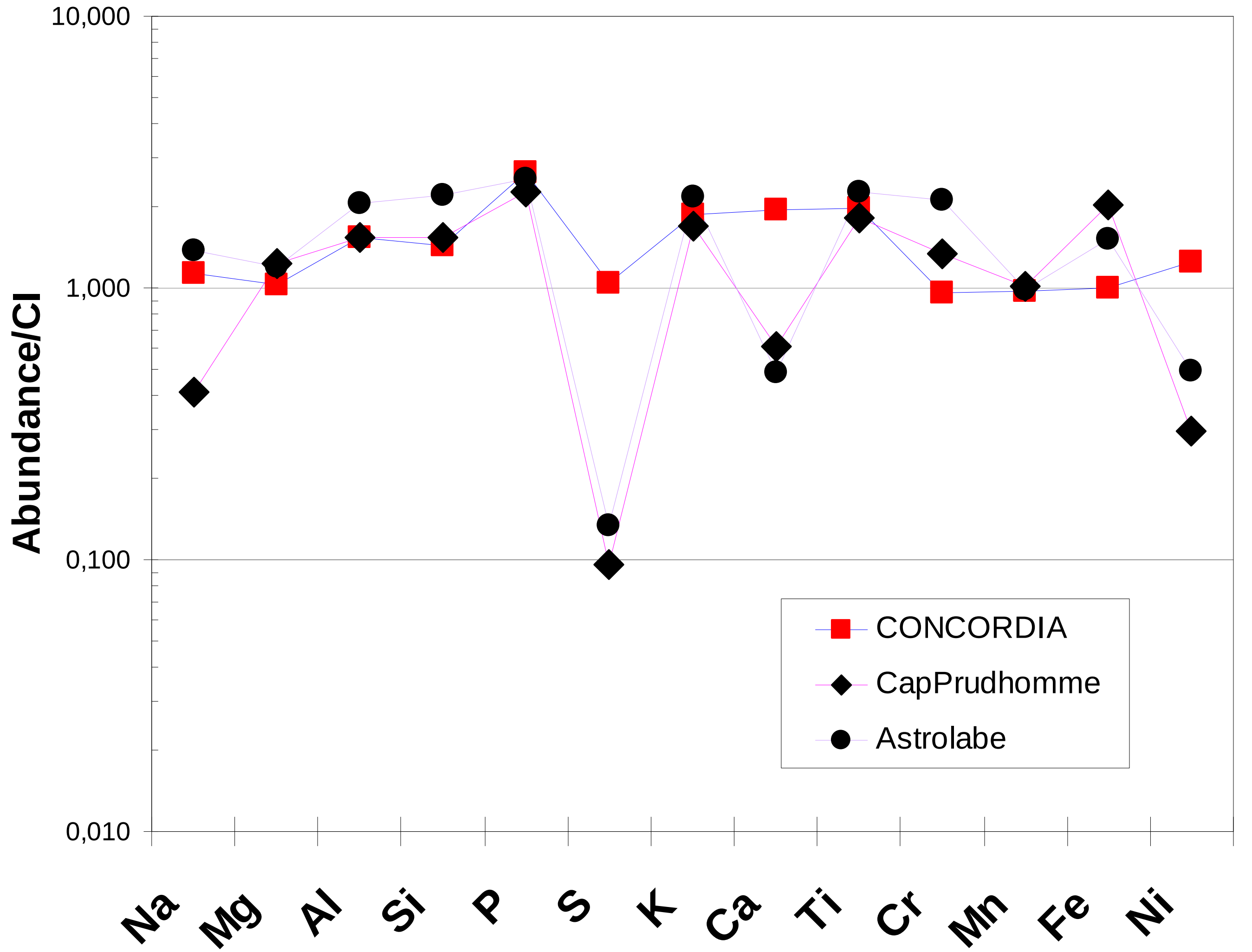
Blue Ice Field micrometeorites are depleted compared to CI Chondrites (S, Ca, Ni)



G. Kurat et al. GCA 1994

CONCORDIA Results III

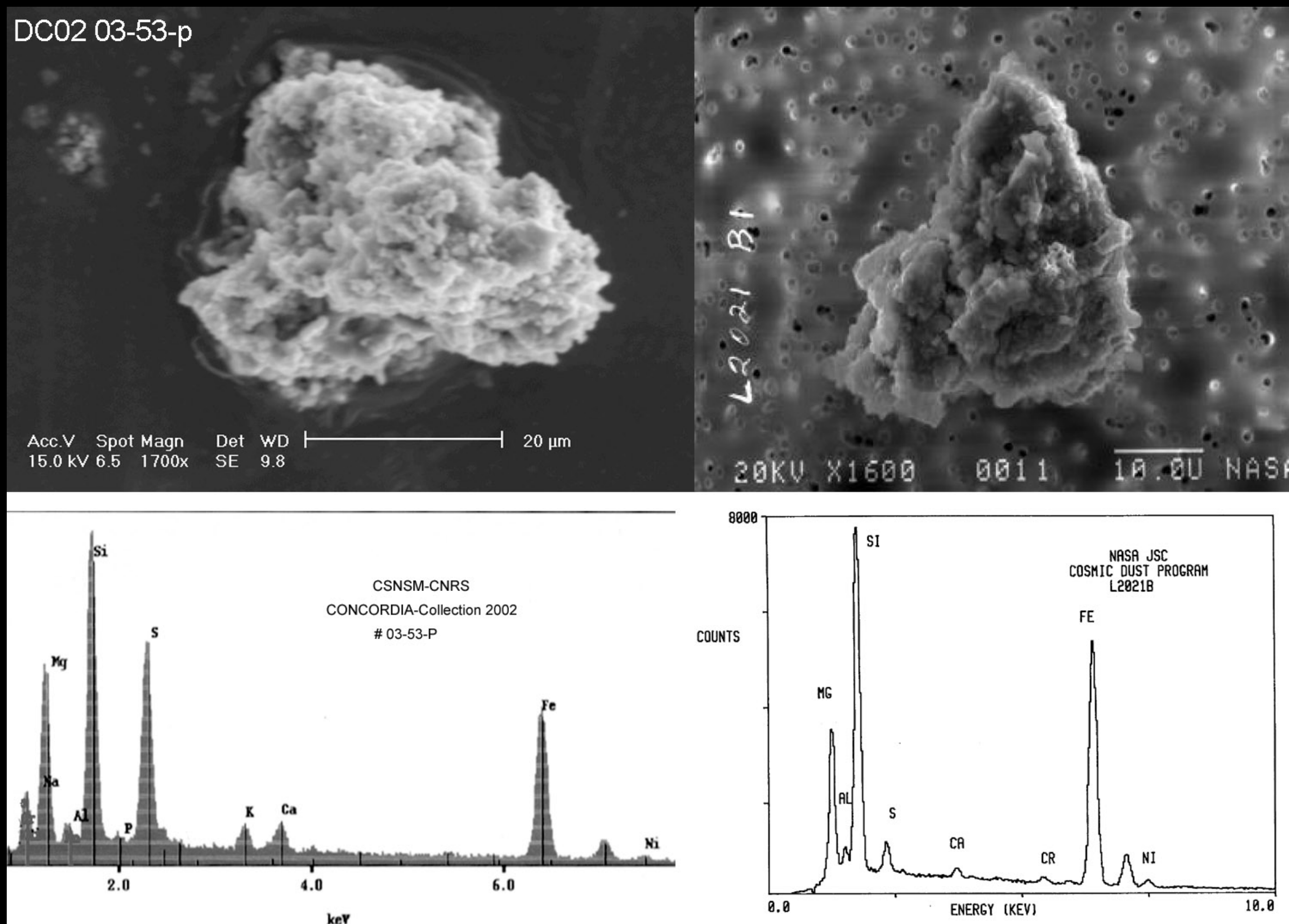
an un-depleted "solar" composition



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

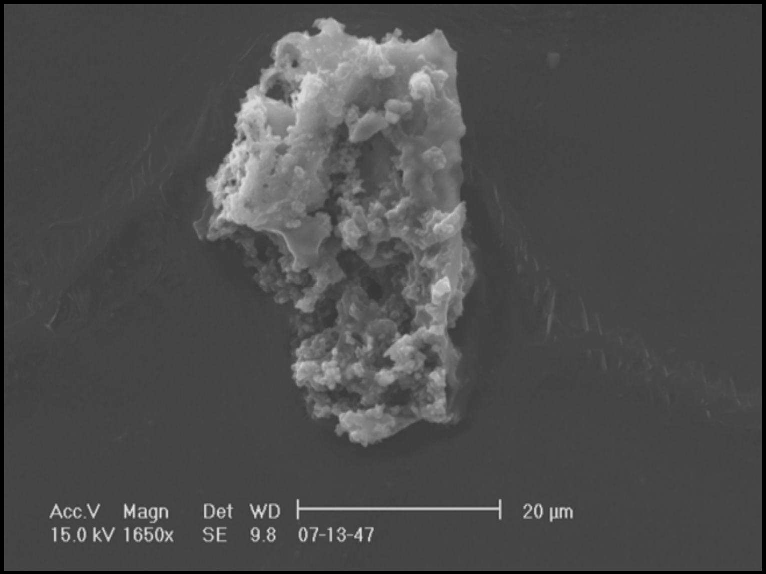
CONCORDIA Results IV

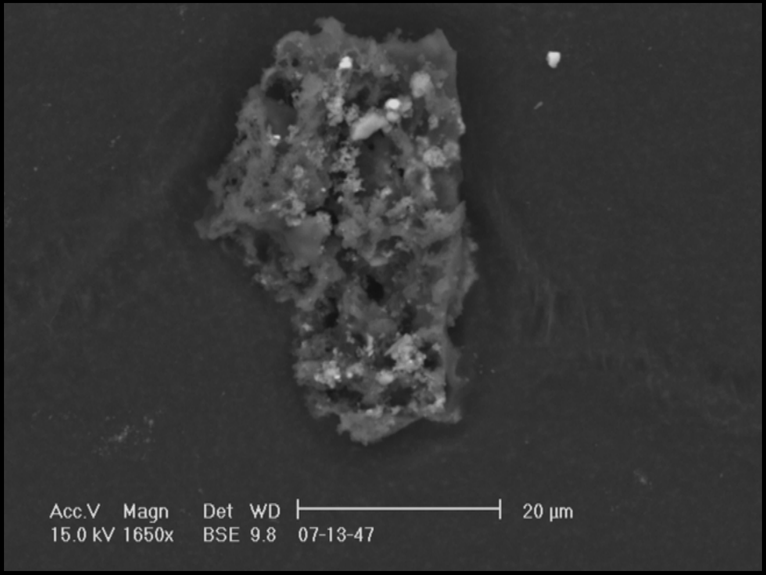
CONCORDIA Collection IDP (NASA)

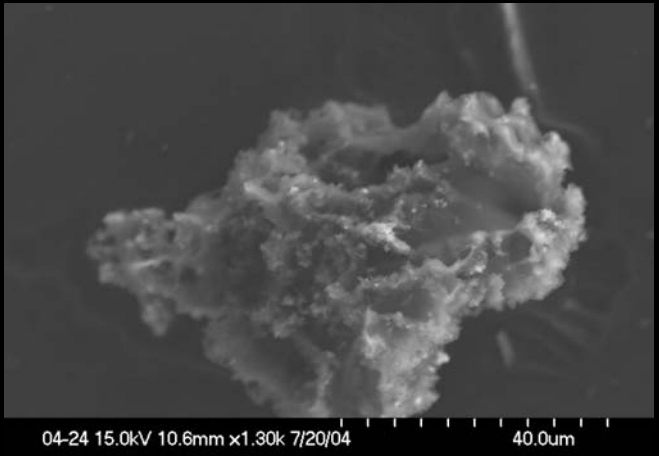


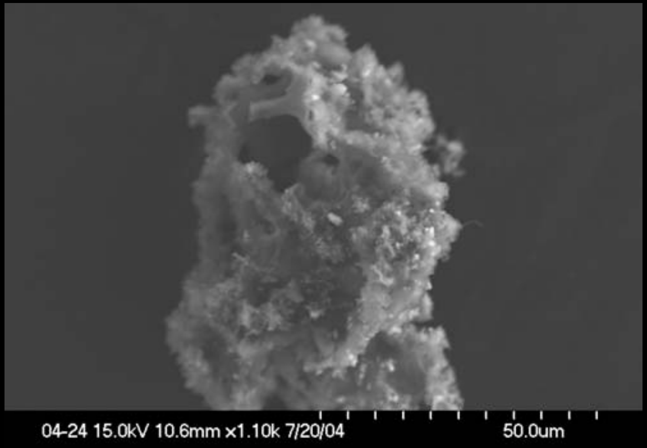
(Duprat, Engrand *et al*. LPSC, 2005)

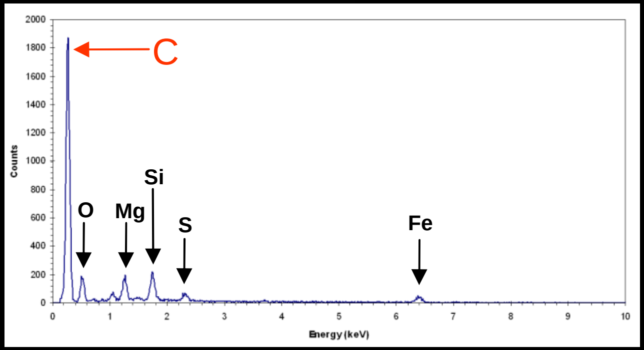
ULTRACARBONACEOUS MICROMETEORITES - UCAMMs







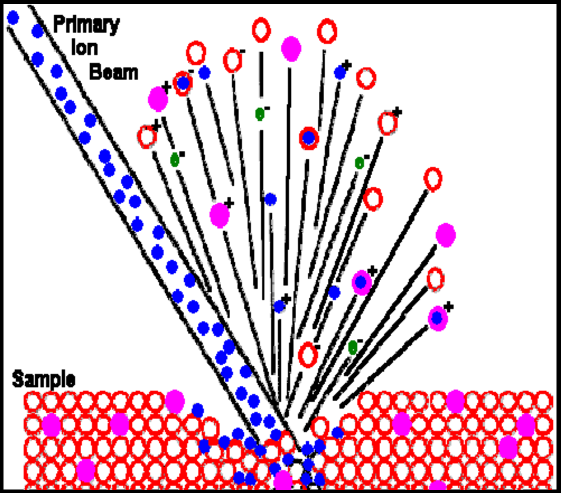


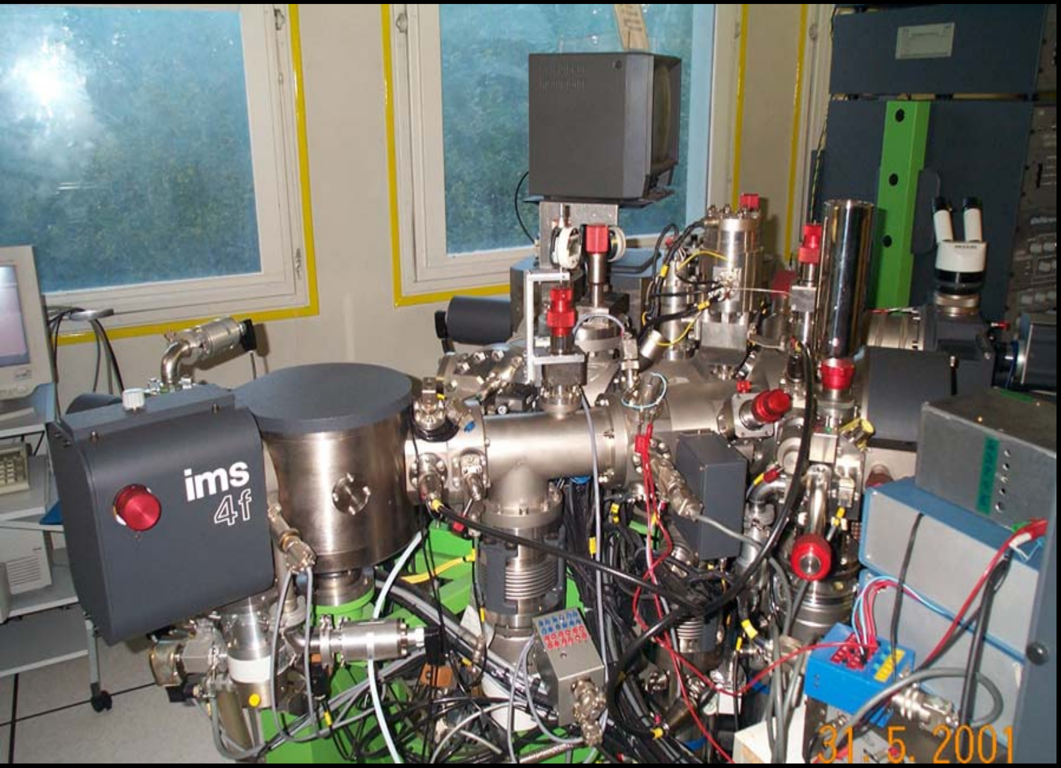


60-85 vol% carbonaceous material

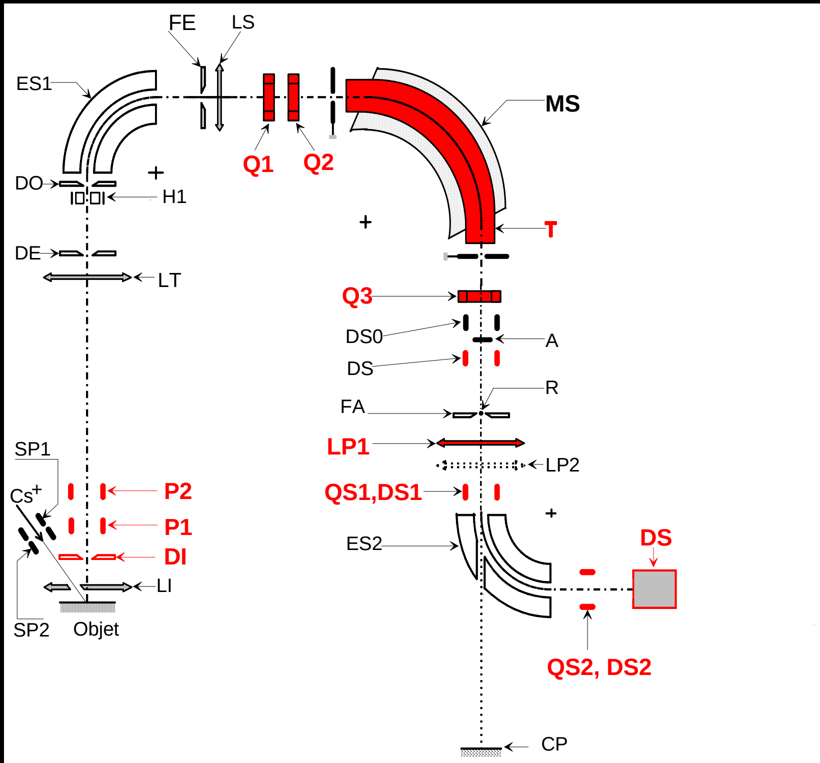
Dobrica, Engrand et al LPSC 2008

Spectroscopie de Masse
CSNSM ORSAY

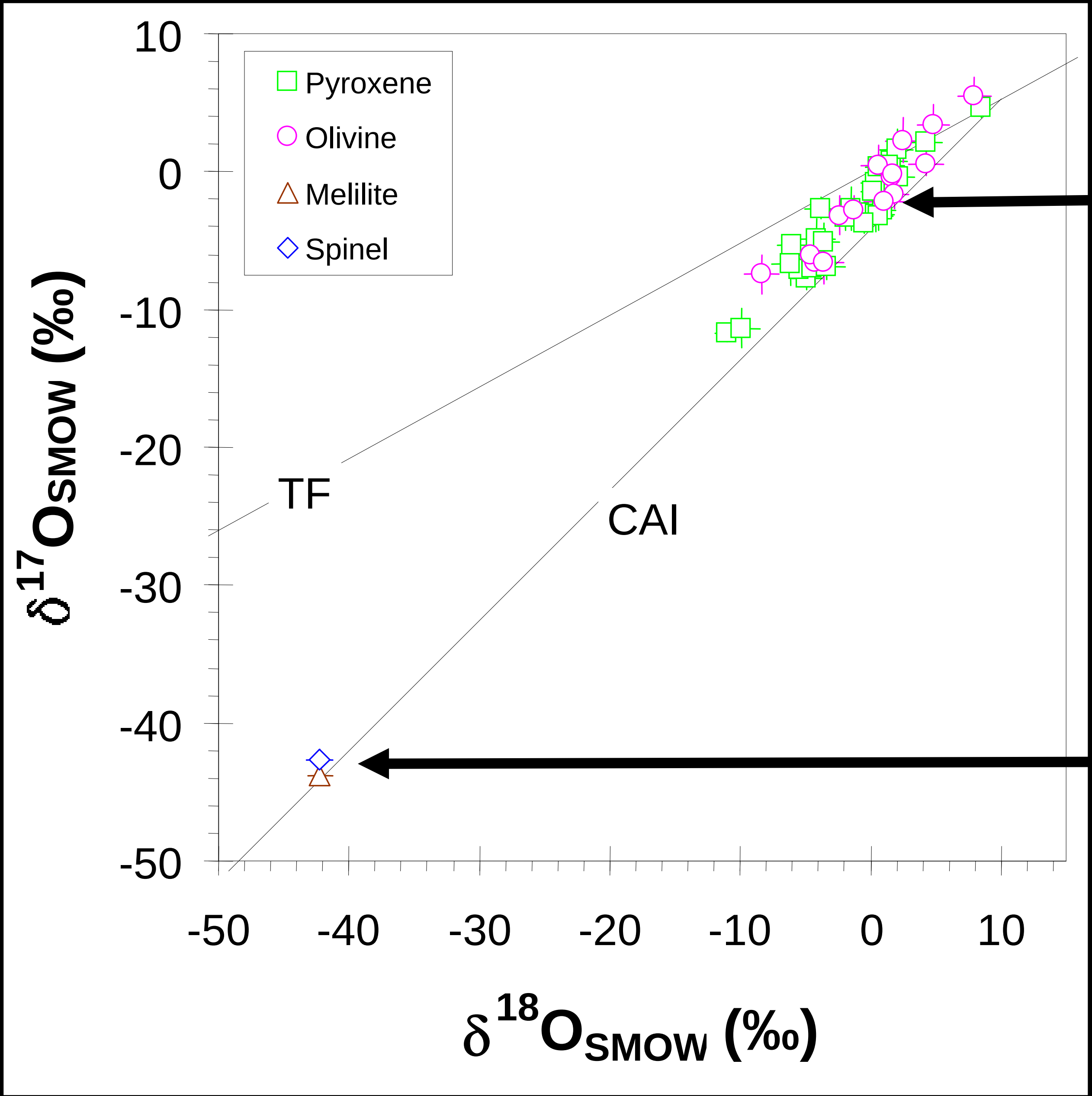


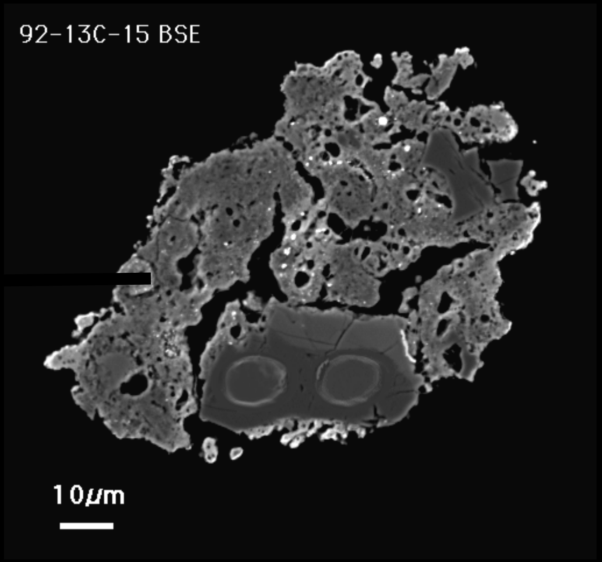


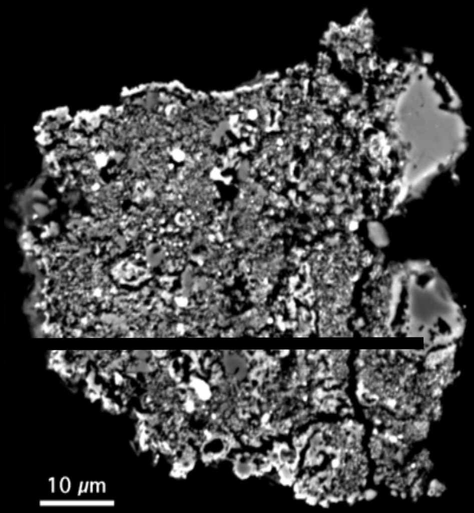
The **IMS-Orsay** ion micro-probe



Micrometeorites *in-situ* isotopic analysis

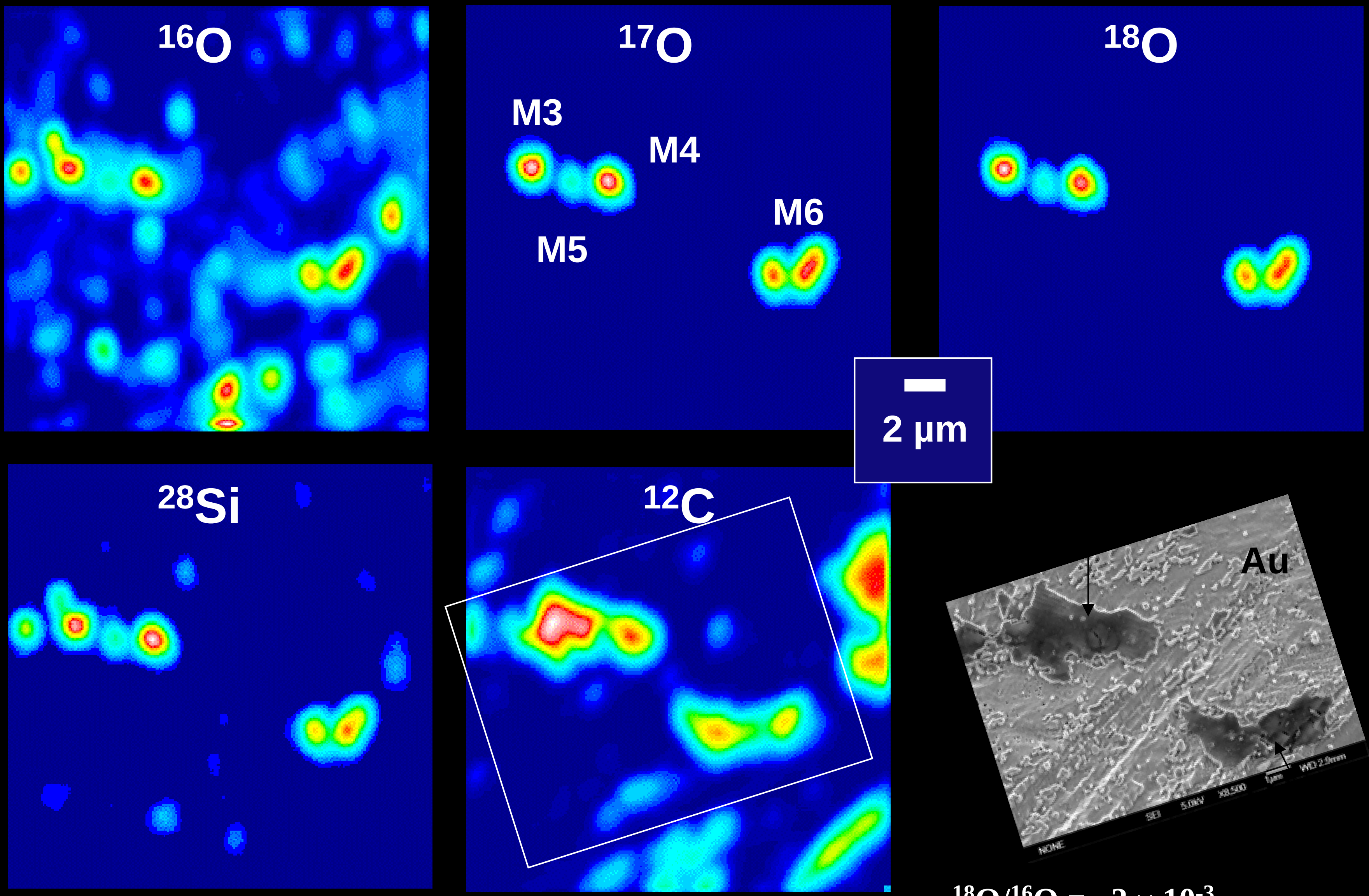






Engrand et al, 1999

« Hotspots » IOM in Murchison Meteorite



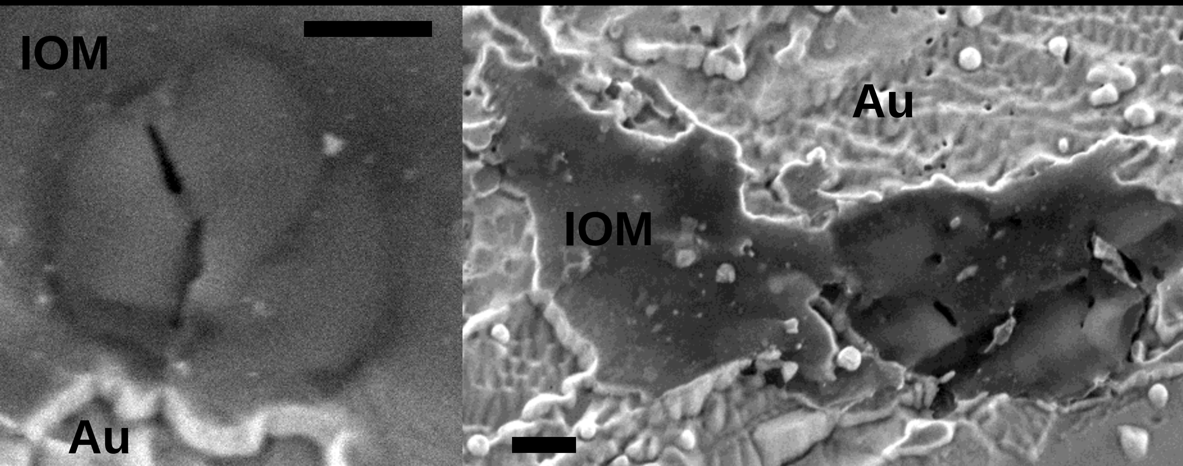
$^{18}O/^{16}O = 2 \times 10^{-3}$

$^{17}O/^{16}O = 3.8 \times 10^{-4}$

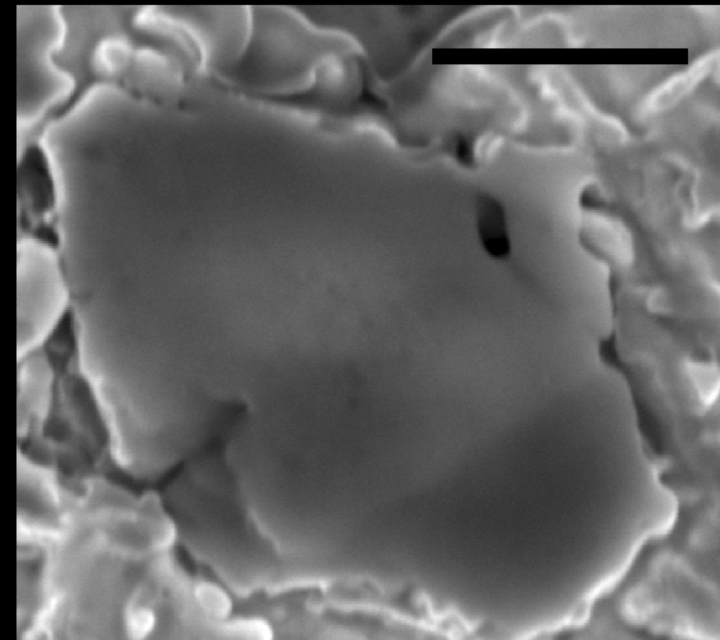
1270 CRPG microprobe data, J. Aleon et al. LPSC 2005

SiO_2-rich grains embedded in IOM

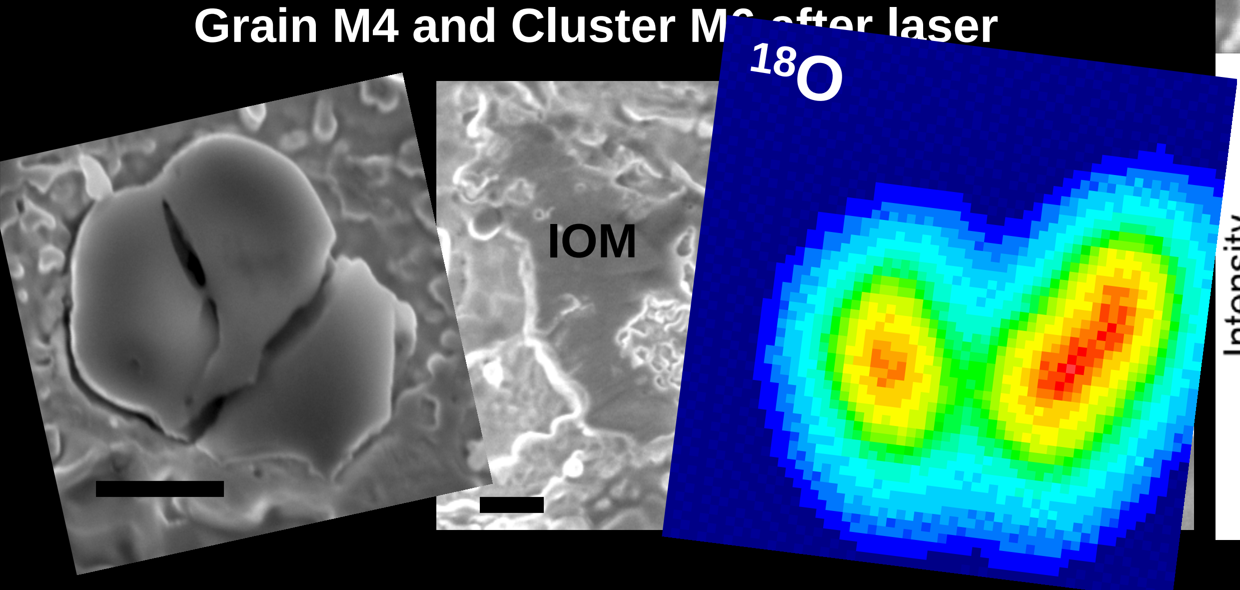
IOM pellets before laser

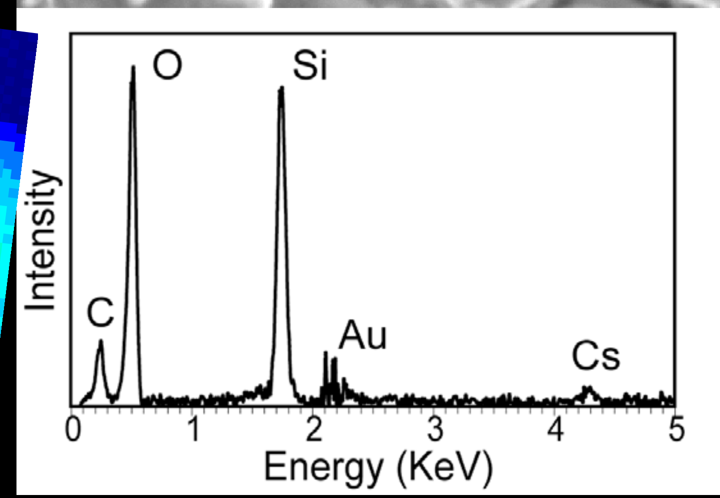


Grain M3

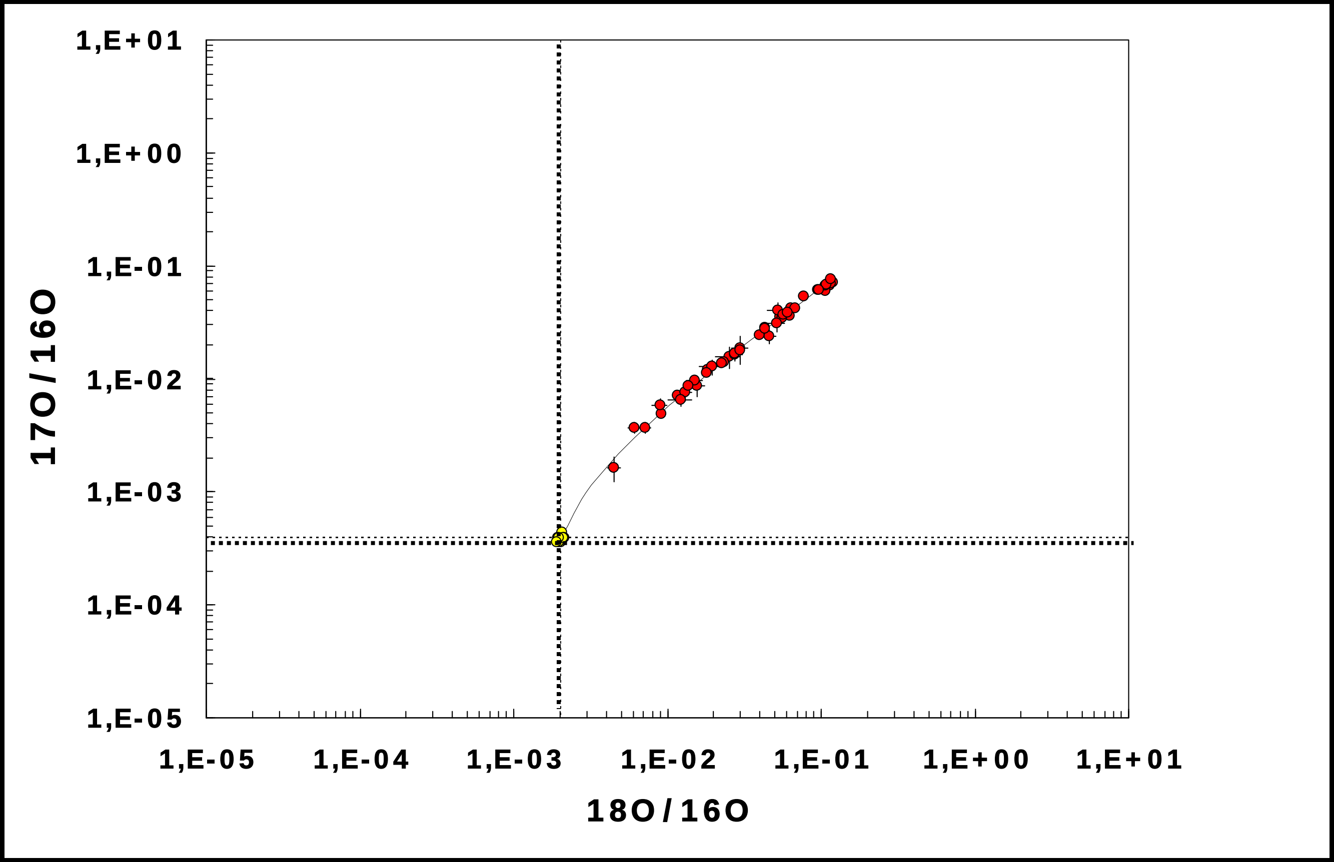


Grain M4 and Cluster M after laser





Oxygen isotopic composition of Si-rich grains



31 grains (now 36)

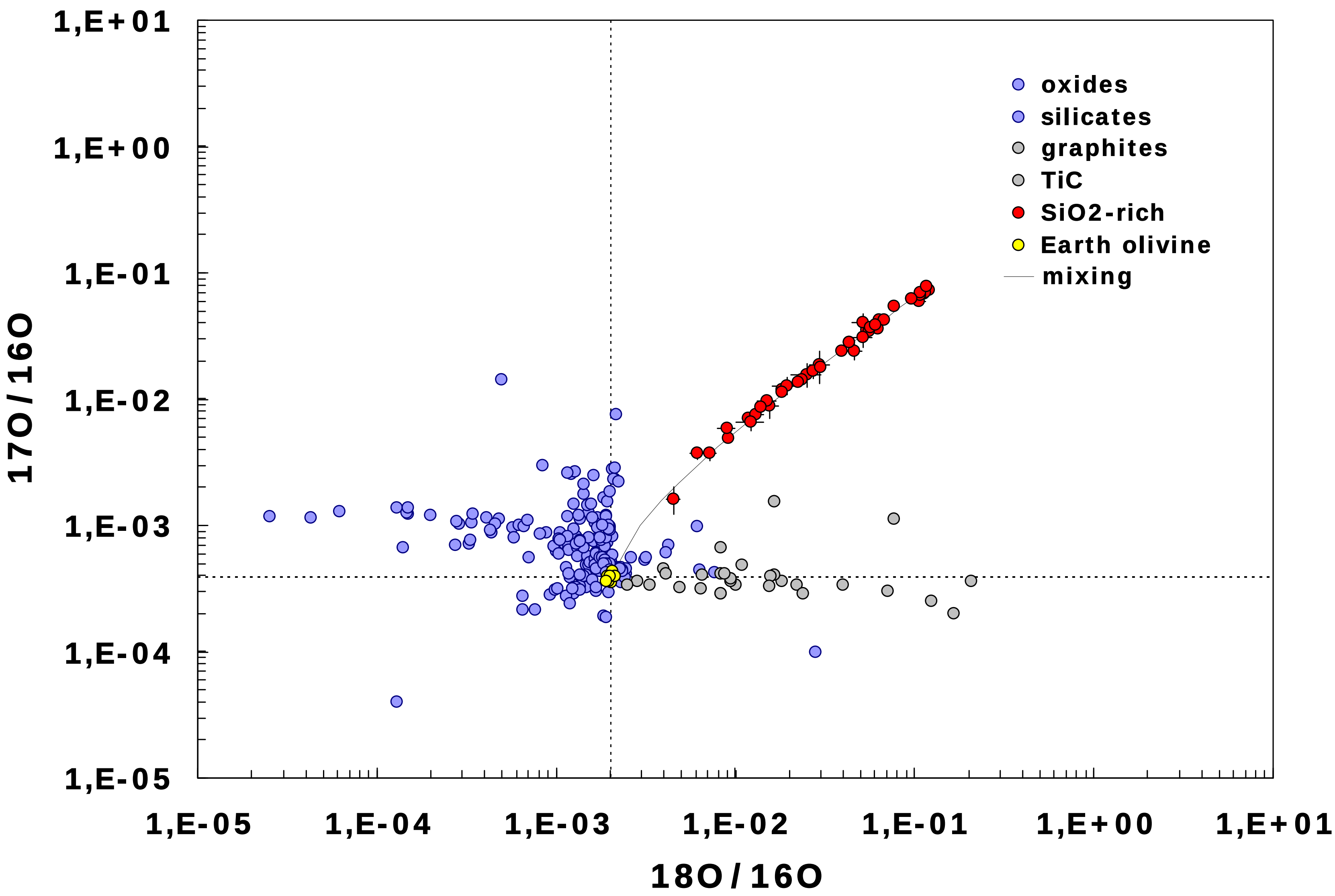
All Si-rich

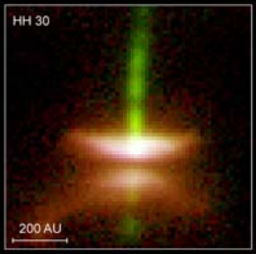
$^{18}O/^{16}O$ up to 1.2×10^{-1}
$^{17}O/^{16}O$ up to 7.7×10^{-2}
$^{18}O/^{17}O \sim 1.6$

A single mixing line

870 ppb

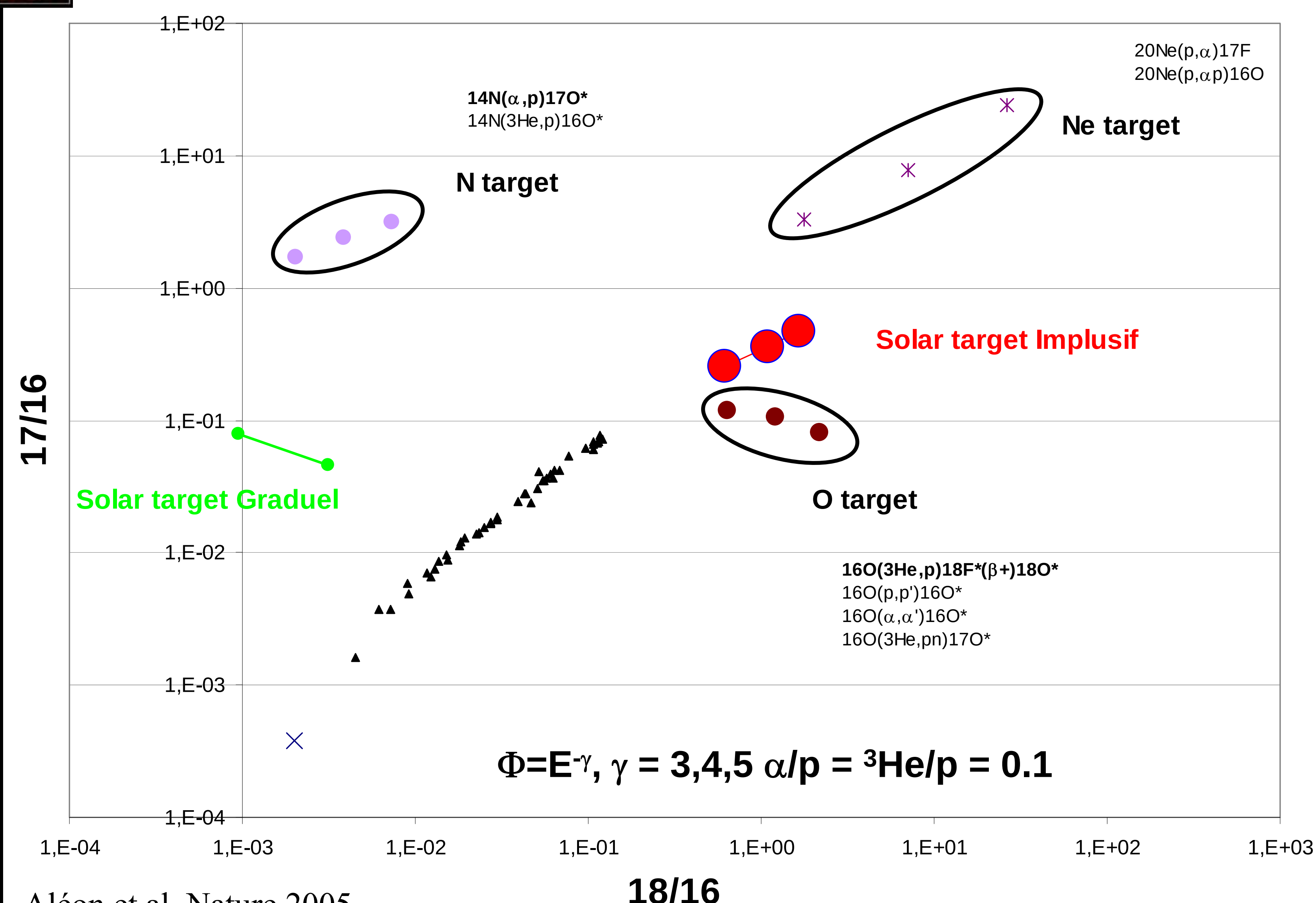
Presolar grains ?





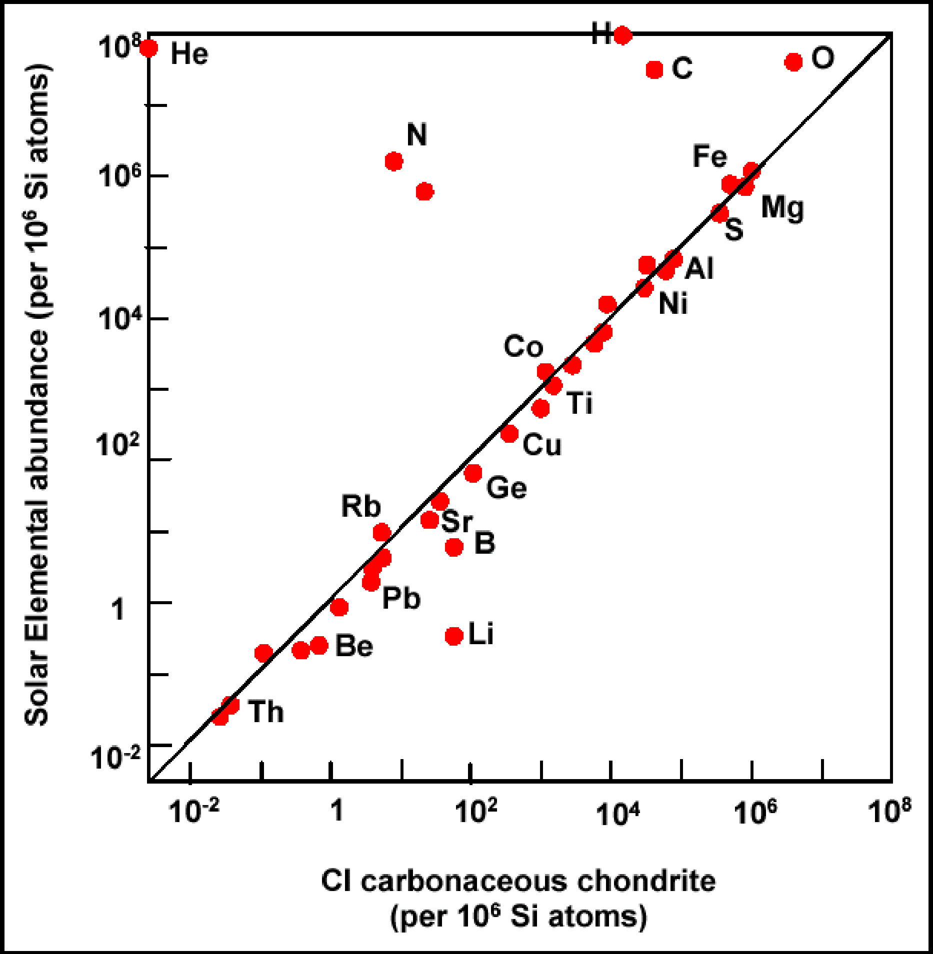
Irradiation of circumsolar gas ?

=> A fast recoiling nuclear-induced O* reservoir



Aléon et al. Nature 2005

The chondrites, primitive objets…



Orgeuil meteorite,
Carbonaceous Chondrite

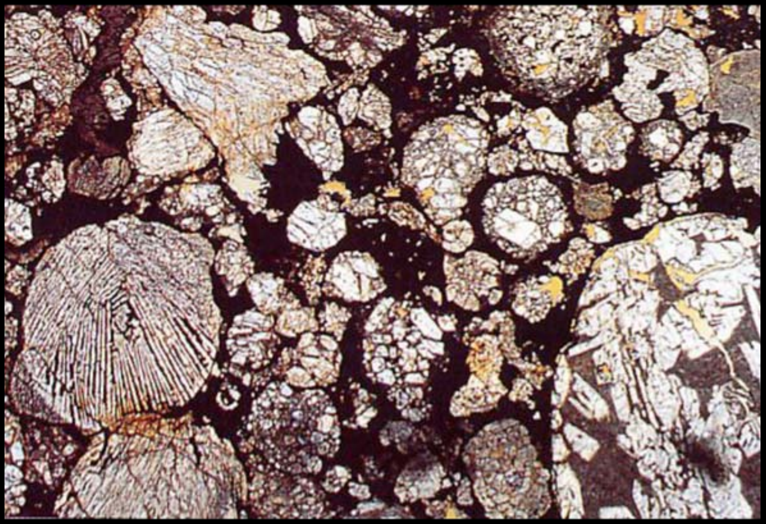
Chondres et Inclusions réfractaires

ALLENDE, CV3, MEXICO

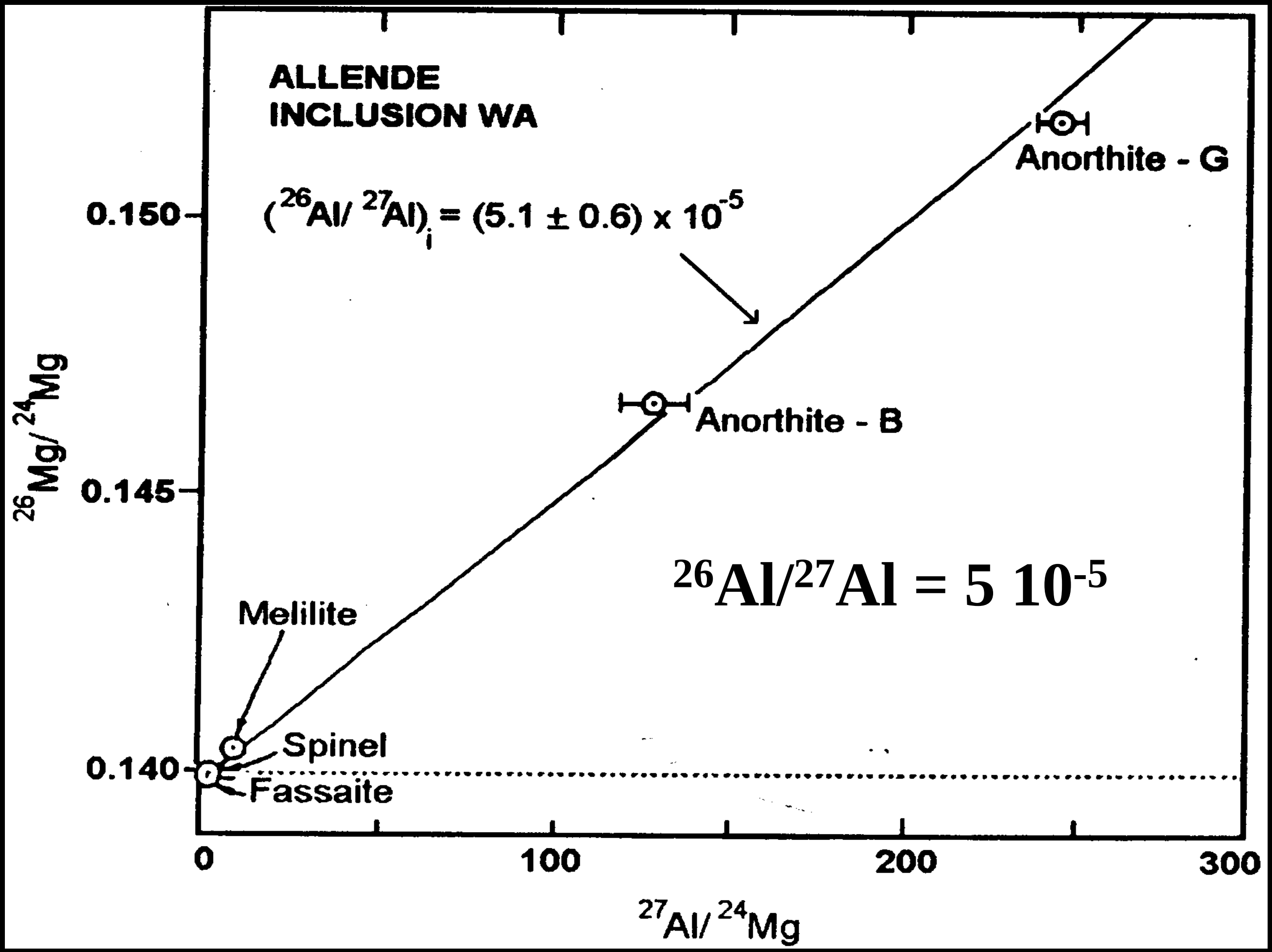
Photo & Collection
Harald Stehlik

Les premiers solides du Système Solaire Primitif (T = 4.5 Gyrs) :

- CAI (Ca-Al Rich Inclusions)
- Chondres



^{26}Al dans le système solaire primitif

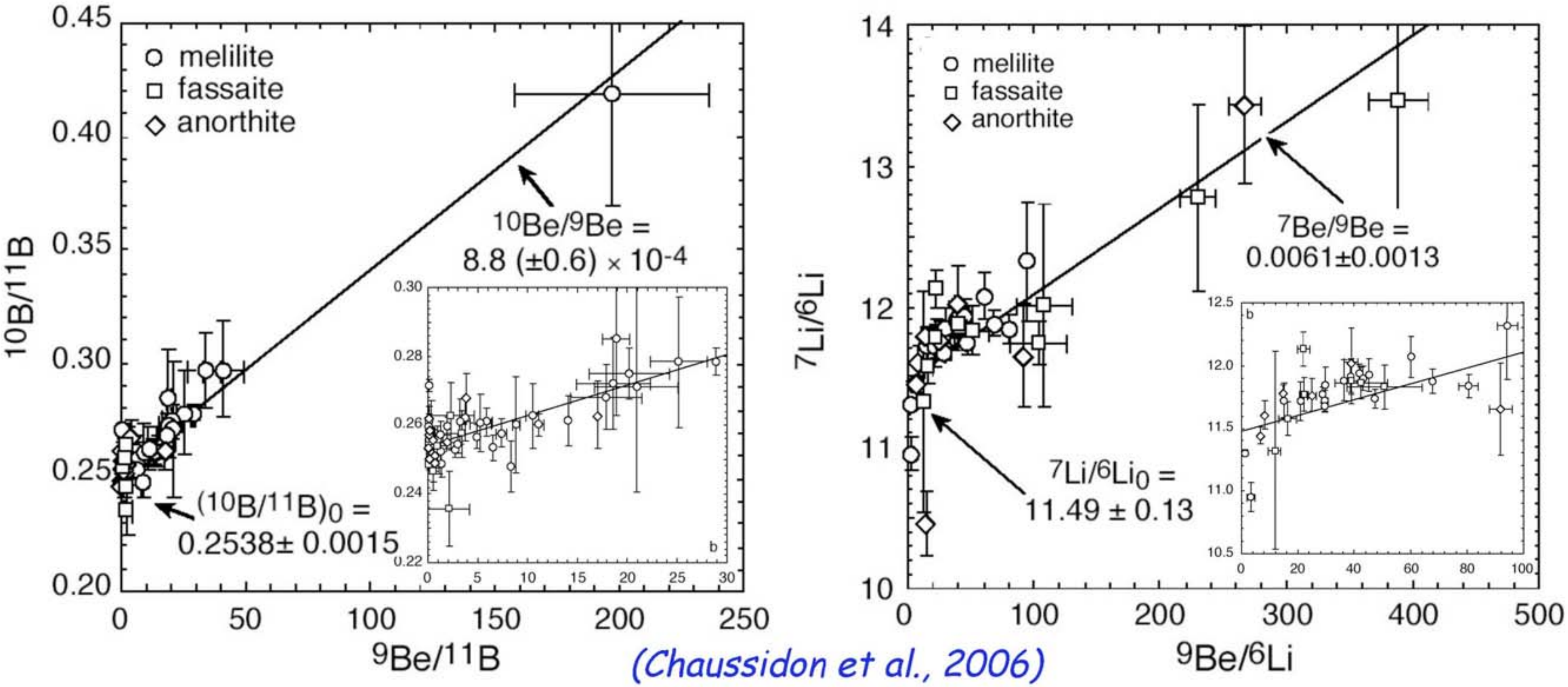


$^{26}Al\ (\beta+) \rightarrow\ ^{26}Mg,\ T_{1/2} = 0.716$ Myr

T. Lee et al 1976

The Be case

Evidence for ^{10}Be ($T_{1/2}$ = 1.5 Ma) and ^{7}Be ($T_{1/2}$ = 53 days)



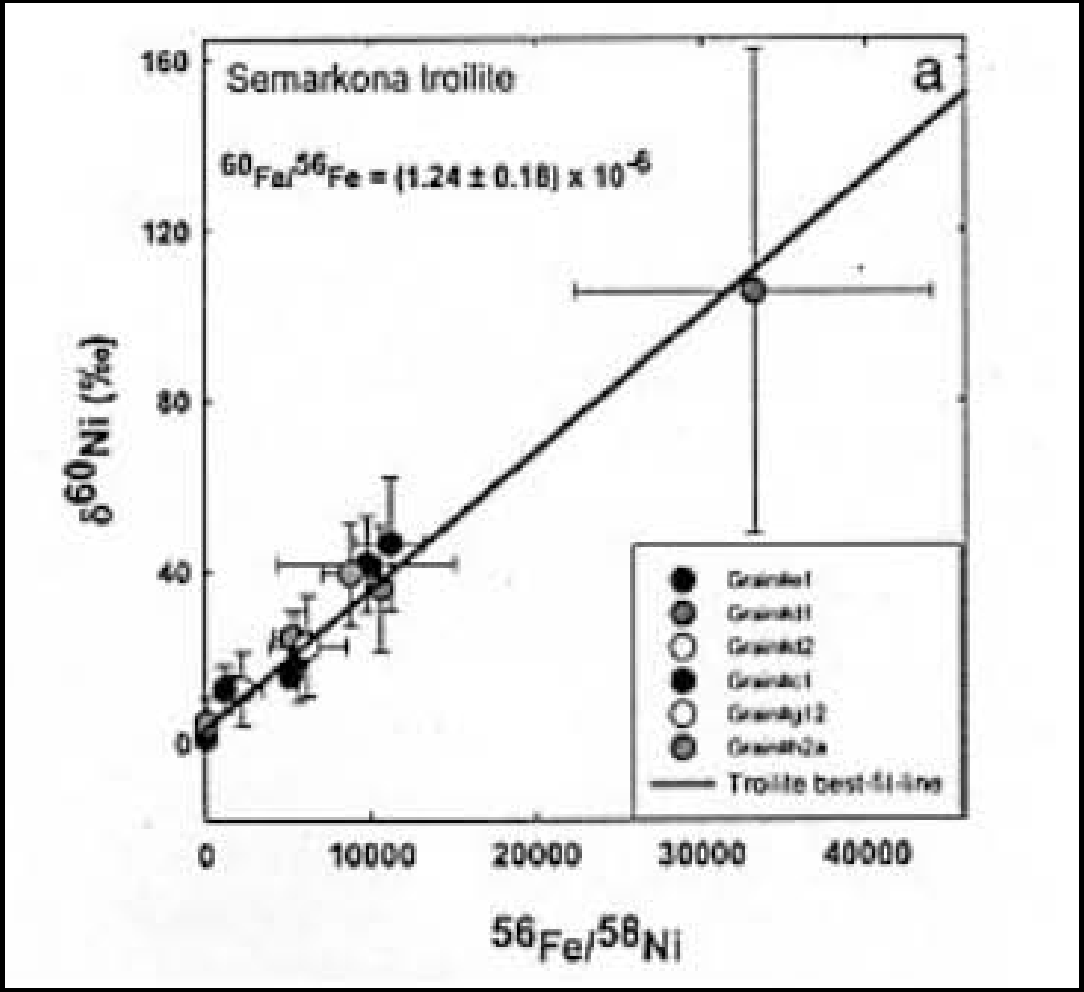
(Chaussidon et al., 2006)

$^{10}Be/^{9}Be \approx 1 \times 10^{-3}$

$^{7}Be/^{9}Be \approx 6 \times 10^{-3}$

(McKeegan et al., 2000 ; Sugiura et al., 2001 ; MacPherson et al.,2003 ; Chaussidon et al., 2004)

$^{60}Fe(\beta^-) \rightarrow {}^{60}Co(\beta^-) \rightarrow {}^{60}Ni$ $T_{1/2}$ = 1.5 Myr

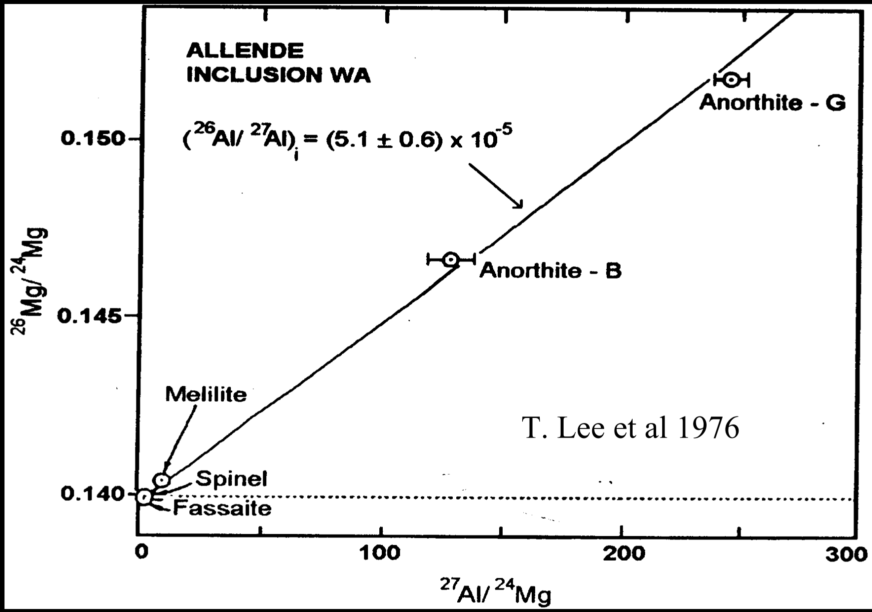


$^{60}Fe/^{56}Fe = 1.2\ 10^{-6}$

Mostefaoui et al 2004

What is the nucleosynthetic origin of the Short-Lived-Radionuclei in the early solar system ?

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

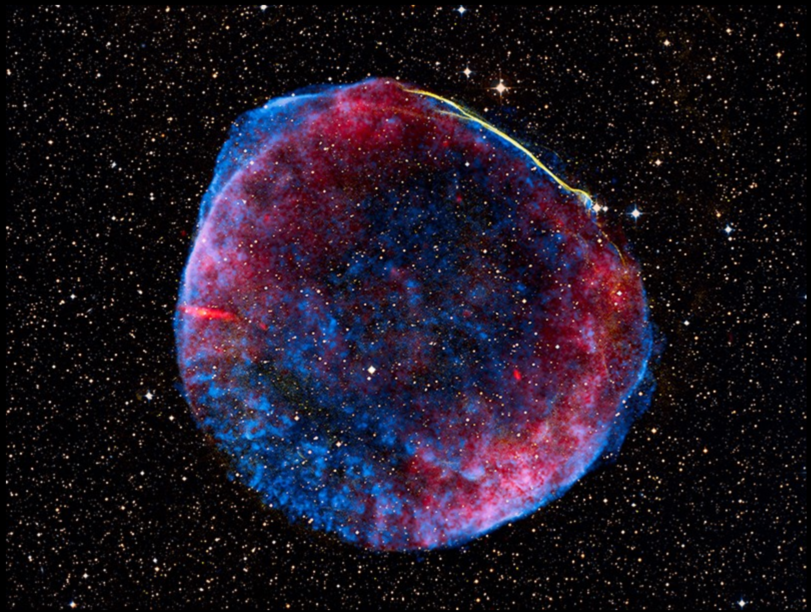


Meteorite Data

Implications for :

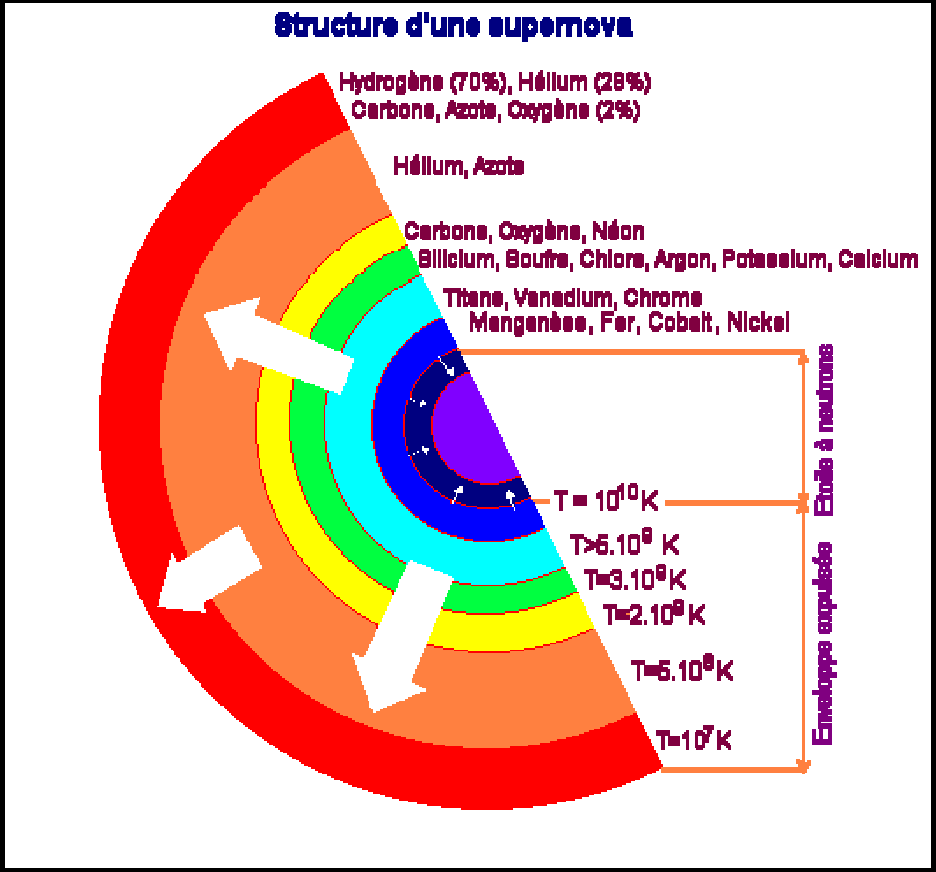
- the astrophysical context of the solar system birth
- the chronology of the first Myrs
- the planetary formation and differentiation

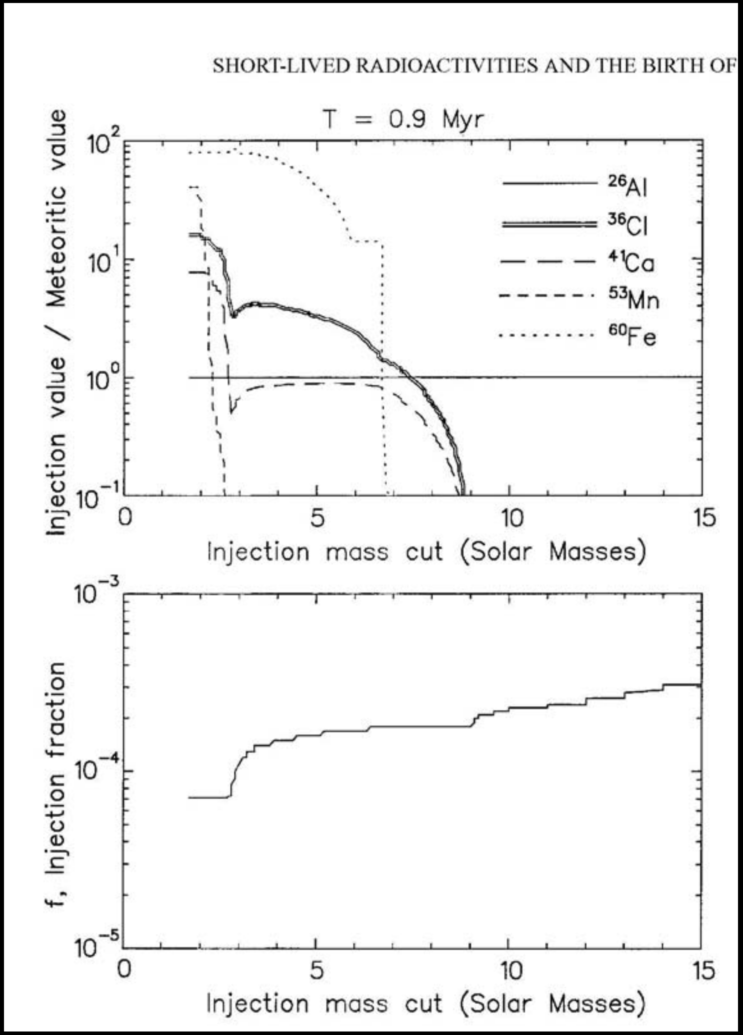
La nucléosynthèse stellaire



SN 1006, 7 kAL, D = 60 AL,
Composite view, blue : X-ray (chandra), yellow : optical, red : radio.

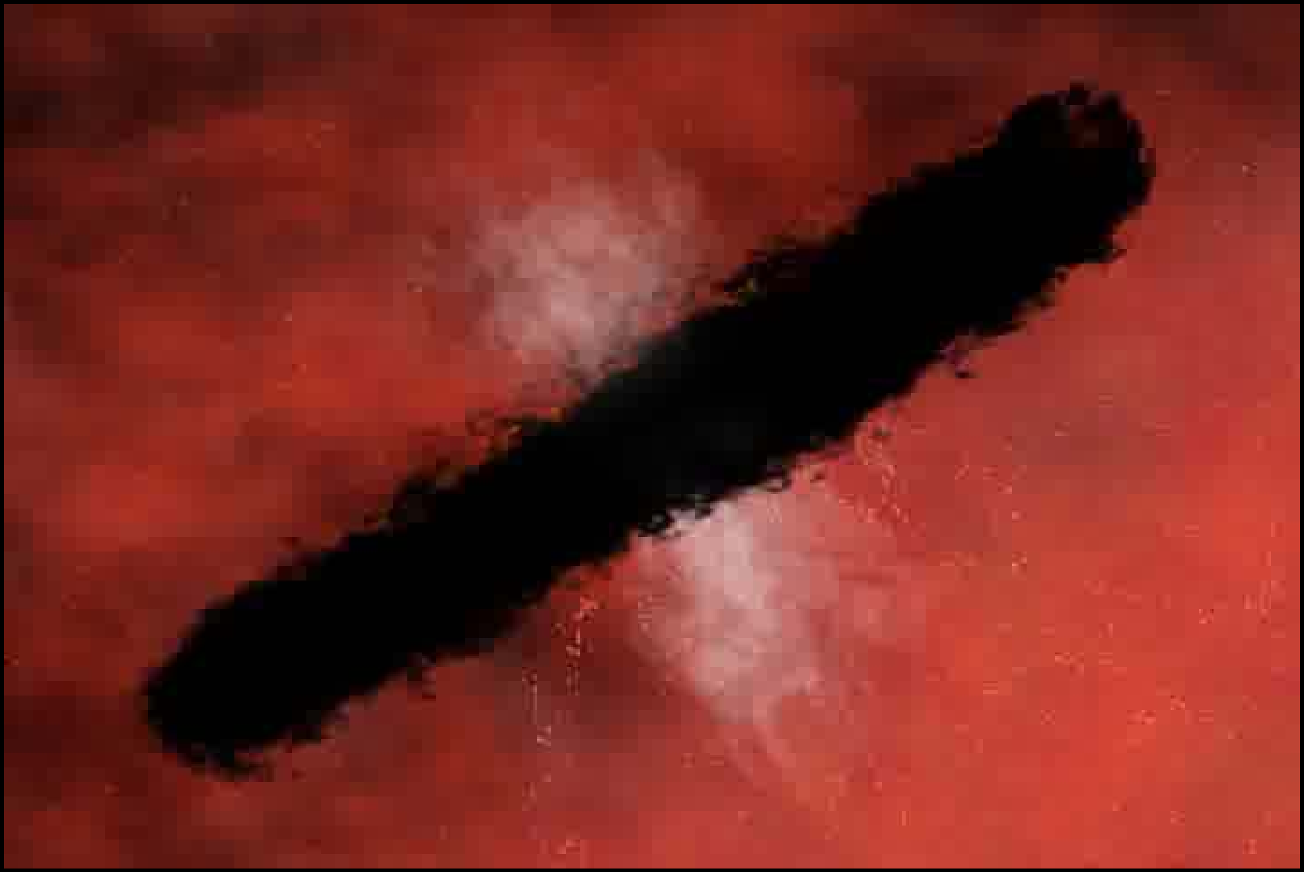
La modélisation …





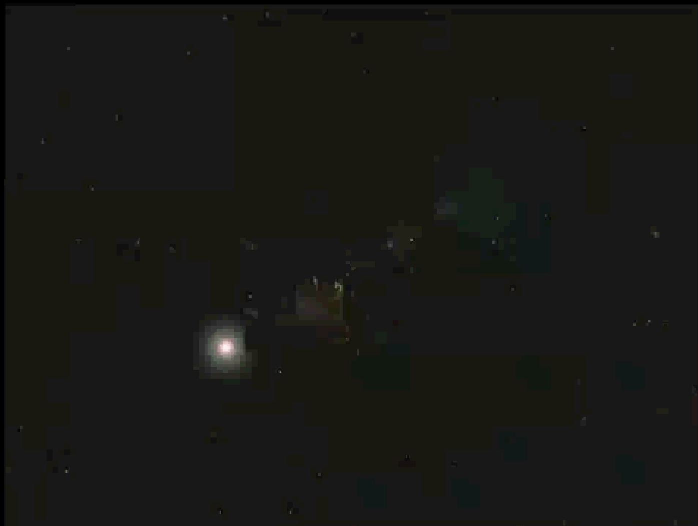
Meyer & Clayton SSR 2000

Flares in Young Stellar Objects

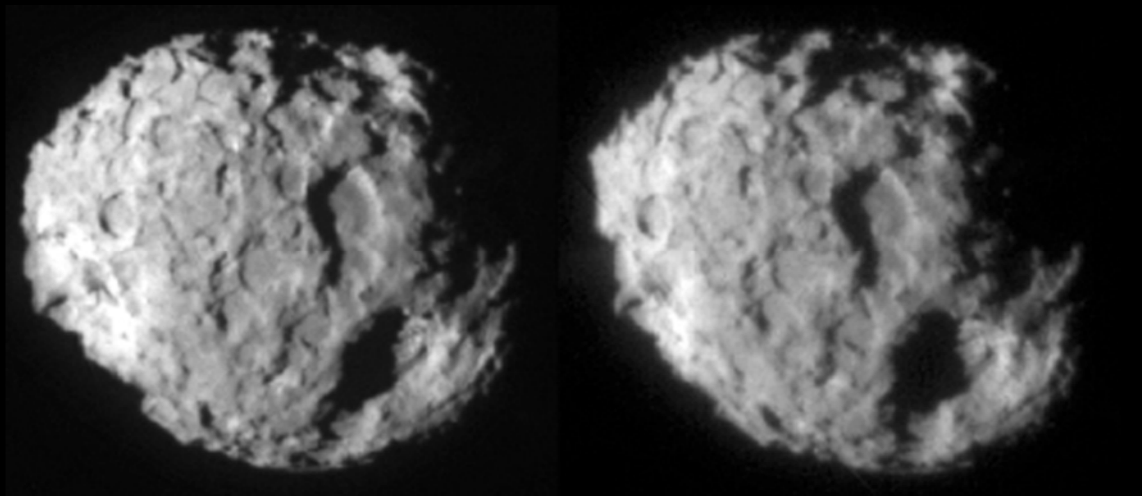


Artiste view
Chandra web site

STARDUST Janvier 2006



NASA Space mission



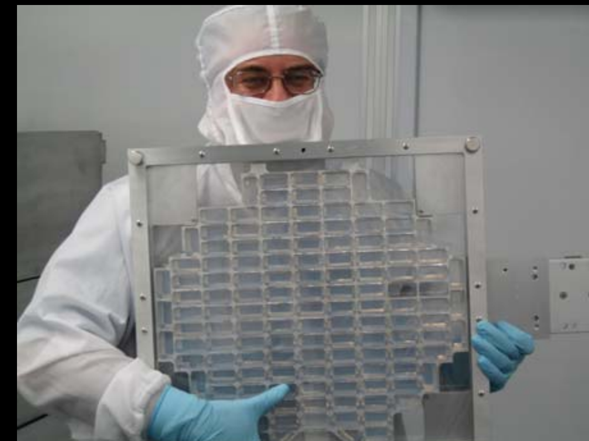
Lancé Février 1999, Rencontre Janvier 2004
Comet WILD2 D = 1.86 UA = 280 10^6 kms
Dapproch = 300 km

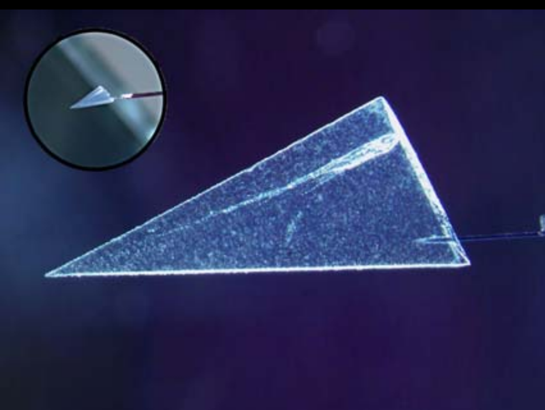
Janvier 2006 :
Quelques centaines de particules de 1-10 μm

STARDUST (NASA)

2 Janvier 2004
Comet Wild 2

Janvier 2006

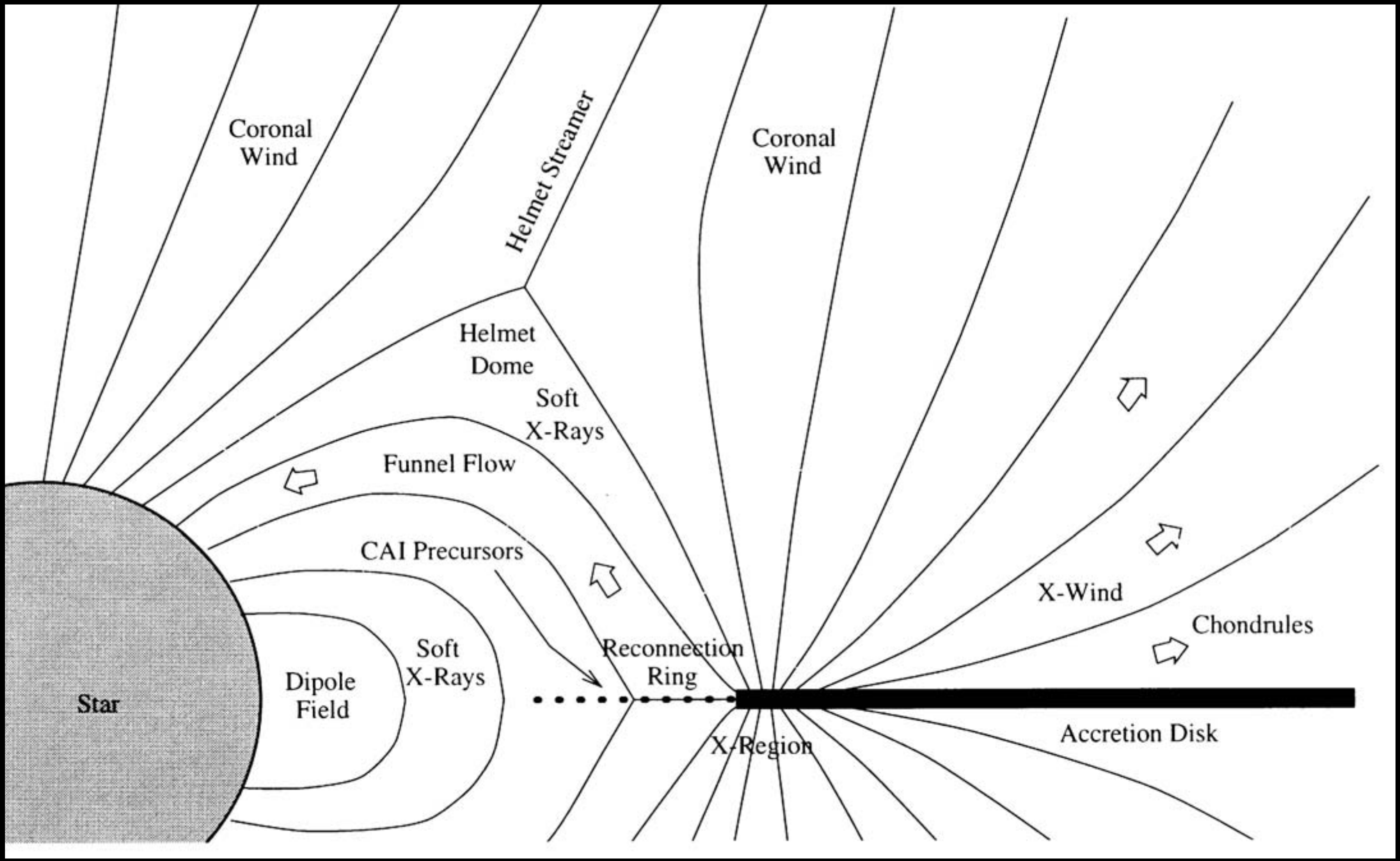


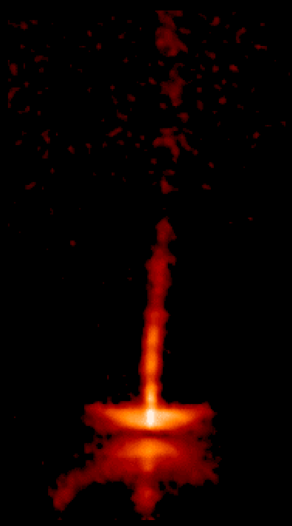


- **N > 10-20 μm ?**
- **Fragmentation**
- **Chauffage ?**
- **Aérogel ?**

"Remarkably enough, we have found fire and ice,"
Don Brownlee *et al* Science (2006)

Irradiation in YSO

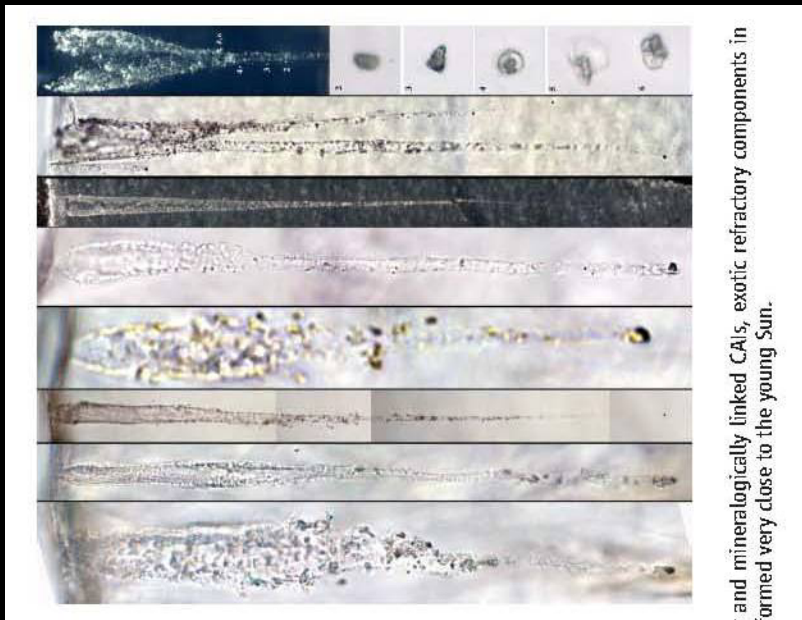




Shu et al. Science 1996, Shu et al ApJ 2001

CAI and Chondrules are formed at close distance from the star (the reconnection ring : R=0.06 AU) then transported at several AU over the disk by the x-wind…

Refractory phases in cometary material



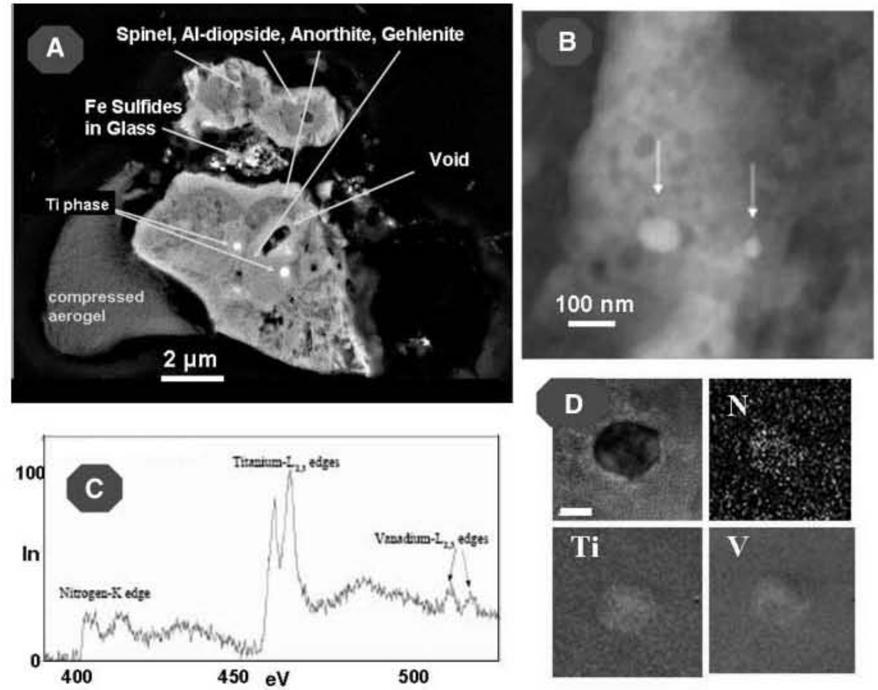


Fig. 4. The CAI-like grain from track 25. **(A)** Backscattered electron (BSE) image of the CAI-like grain from track 25, showing the gray shell of compressed-to-melted aerogel at lower left. **(B)** High-angle annular dark-field TEM image of two osbornite grains (arrows) within spinel. **(C)** EELS 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.

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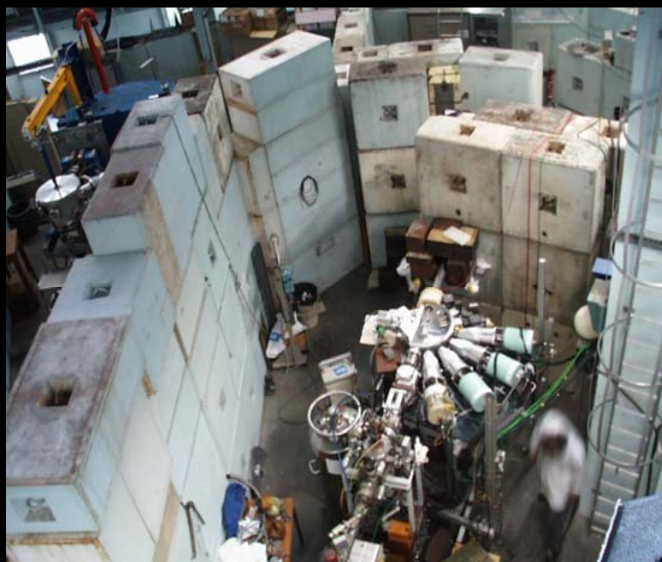
"Remarkably enough, we have found fire and ice"

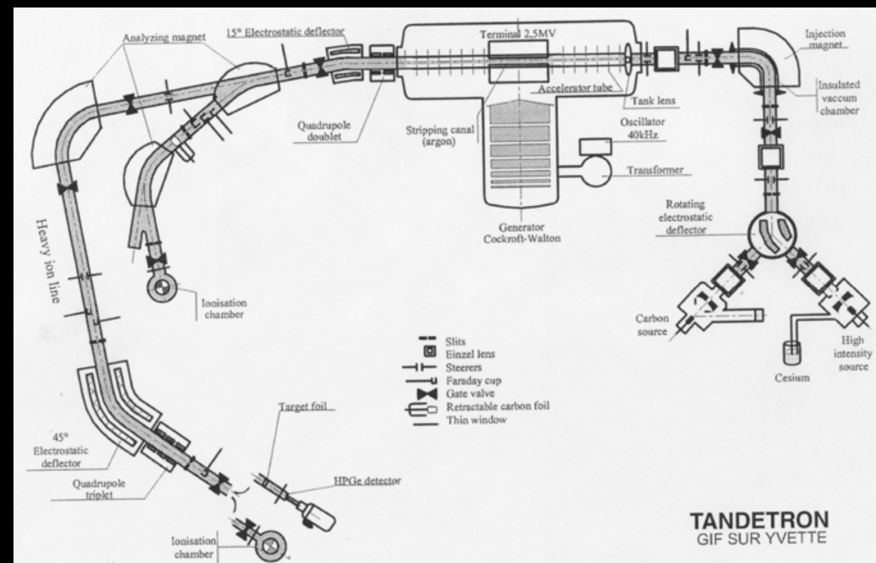
Stardust PI (D. Brownlee)

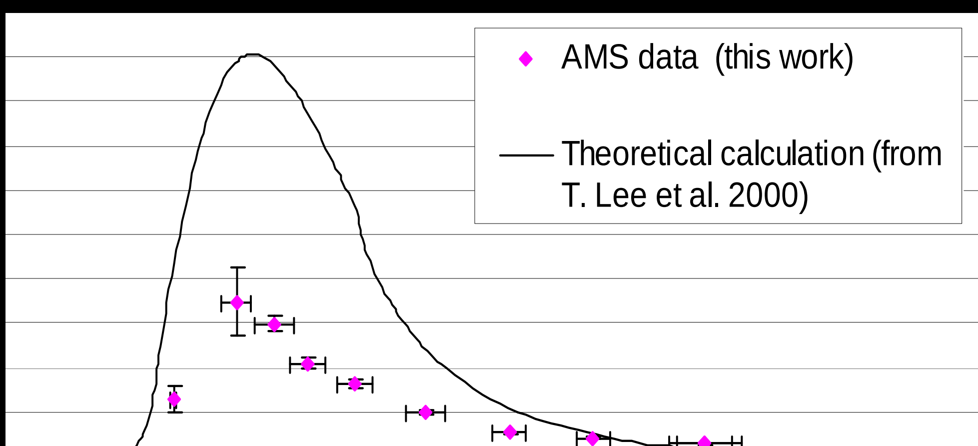
«…Their presence in a comet proves that the formation of the solar system included mixing on the grandest scales…» Brownlee et al. Science 2006

Mesure SMA : $^{24}Mg(^{3}He,p)^{26}Al$

Collaboration : Astro. Sol. + Astro. Nucl. + SMA + IPNO







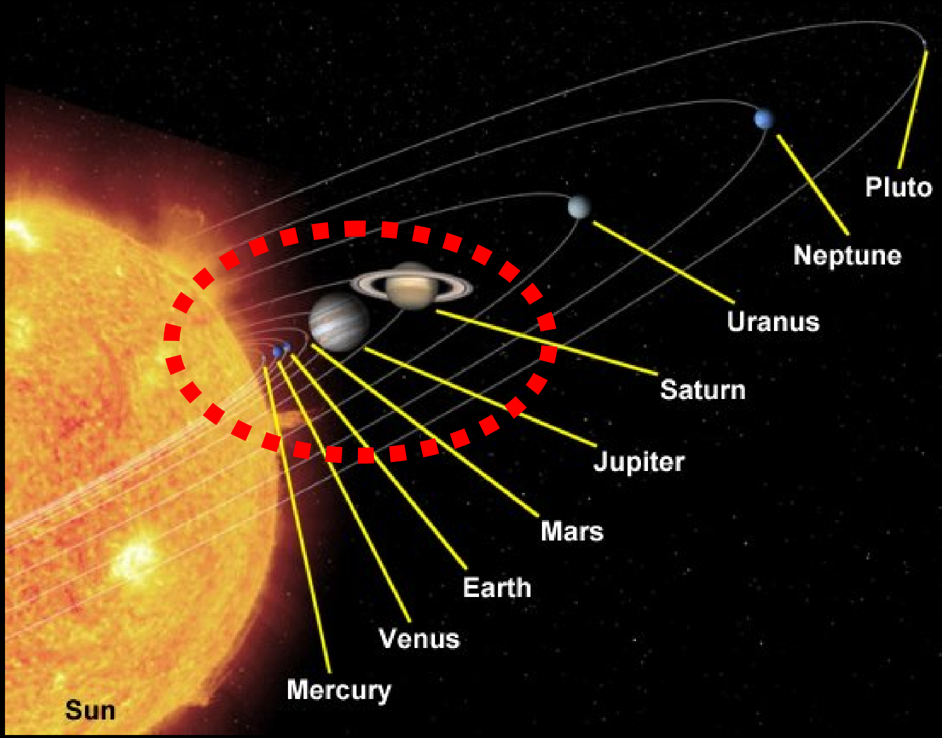
^{26}Al dans le Système Solaire Primitif

Fitoussi, Duprat, Tatischeff, et al.
LPSC 2004 et en préparation

^{3}He dans les flares solaires

Tatischeff, Duprat, Kiener, et al.
Phys ReV C 2003

The Minimum Mass Solar Nebulae



The minimum amount of material to make the planets …
Hayashi 1985,

$= 0.01\text{-}0.02\ M_{\odot}$ (gas + rock)

$= 25\text{-}50\ M_{\oplus}$ (rock)

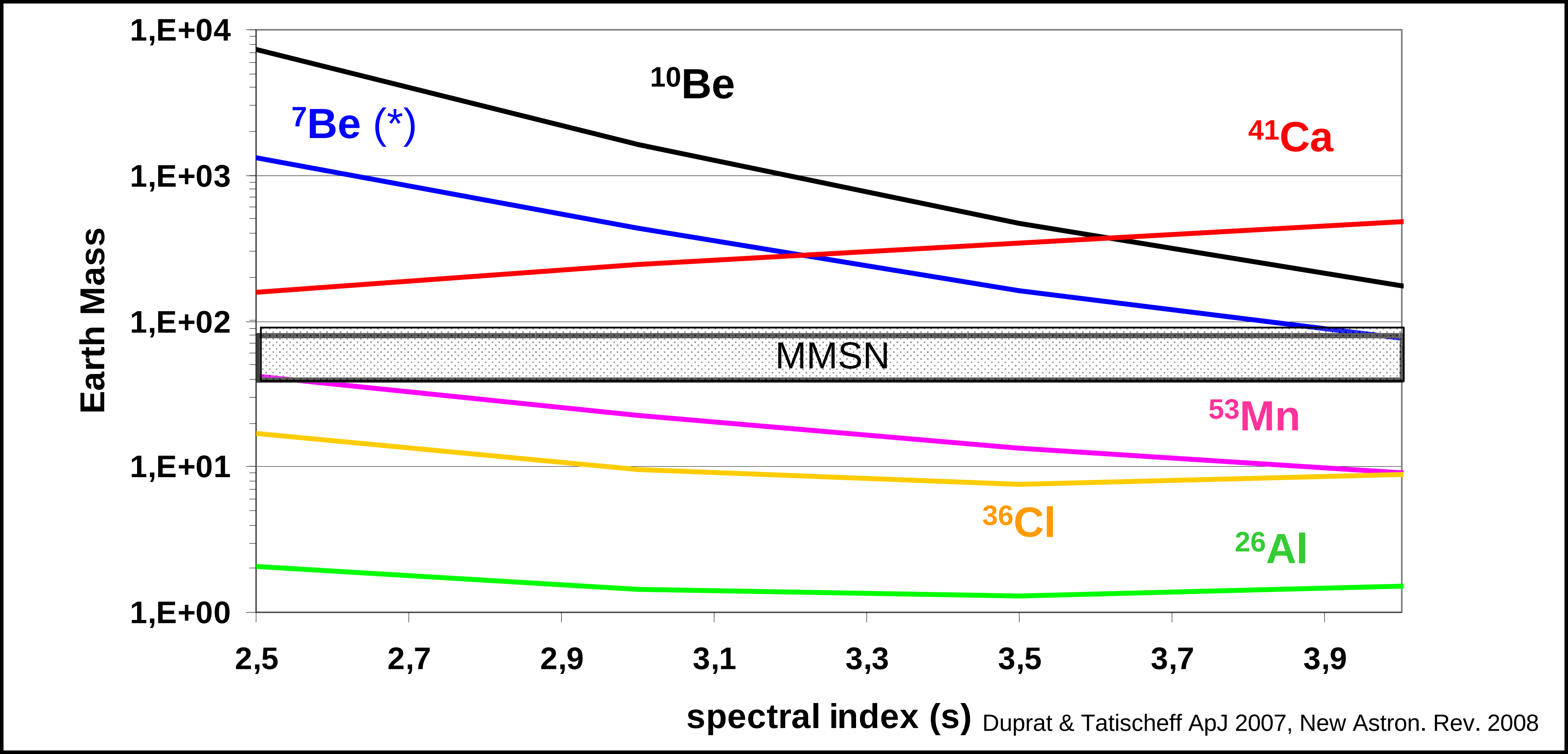
(gas/dust = 0.01, Rudden 1999)

- **Can irradiation provide a homogeneous SLR distribution over the MMSN ?**

- **Which SLR can we find in comets ?**

Duprat & Tatischeff ApJ 2007, NAR 2008

Upper limits on irradiation-induced SLR in the early solar system

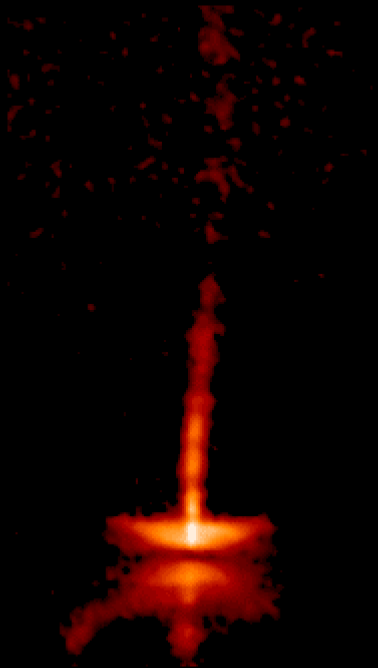


^{10}Be, ^{41}Ca can be produced over the MMSN

^{53}Mn, ^{36}Cl and ^{26}Al cannot be produced at a satisfactory level.

The early solar system 26Al budget comes from stellar nucleosynthesis

Les premières phases minérales du Système Solaire



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