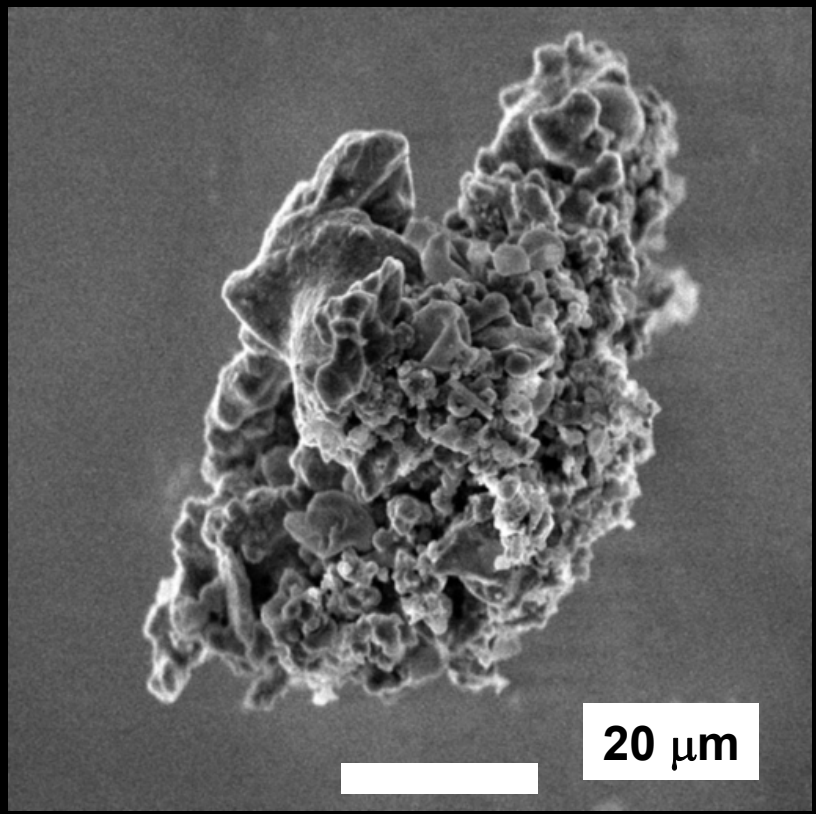
Sampling the comet-asteroid continuum

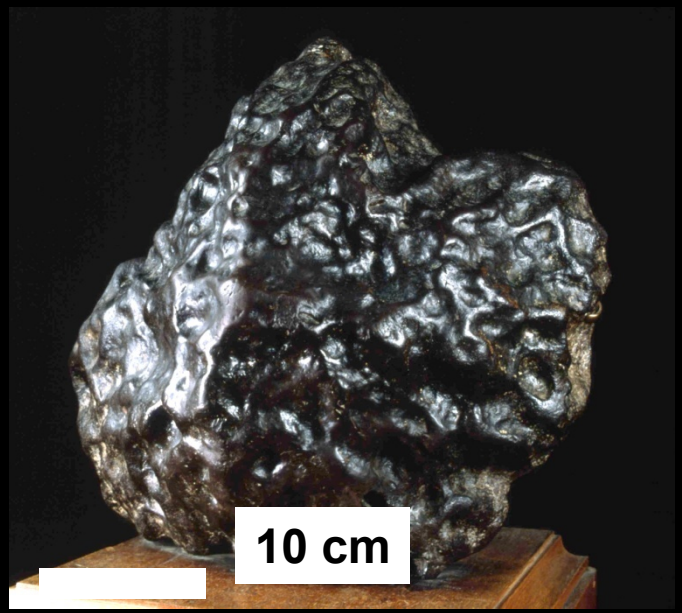
Matthieu Gounelle

Laboratoire de Minéralogie et de Cosmochimie du Muséum
UMR7202, CNRS & MNHN, Paris, France

Meteorites: Some definitions

- **Micrometeorites: size < cm**
  - **Antarctic micrometeorites (10-500 μm)**
  - **Stratospheric Interplanetary Dust Particles (IDPs, 1-40 μm)**
- **Meteorites: cm <size < 100 m (?)**



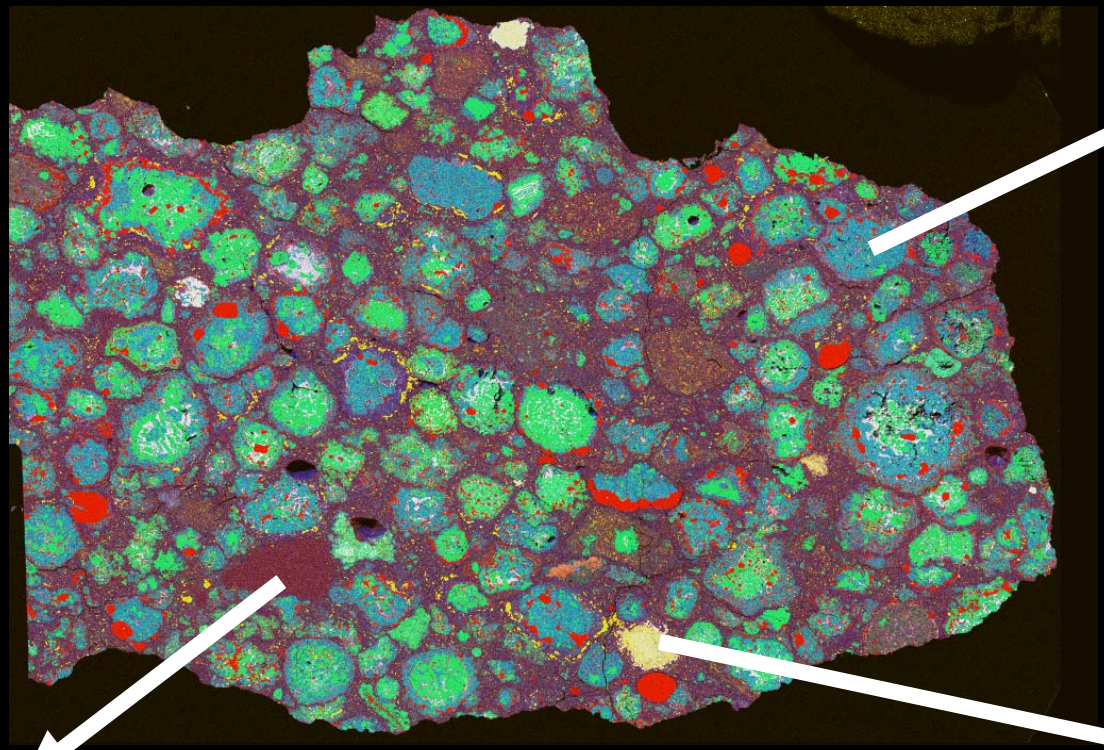


Differentiated & primitive meteorites

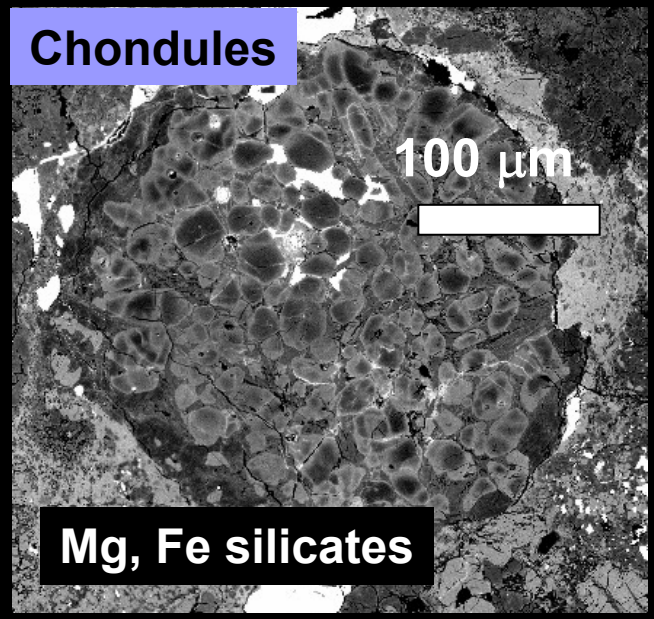
PALLASITE (DIFFERENTIATED)

CHONDRITE (PRIMITIVE)

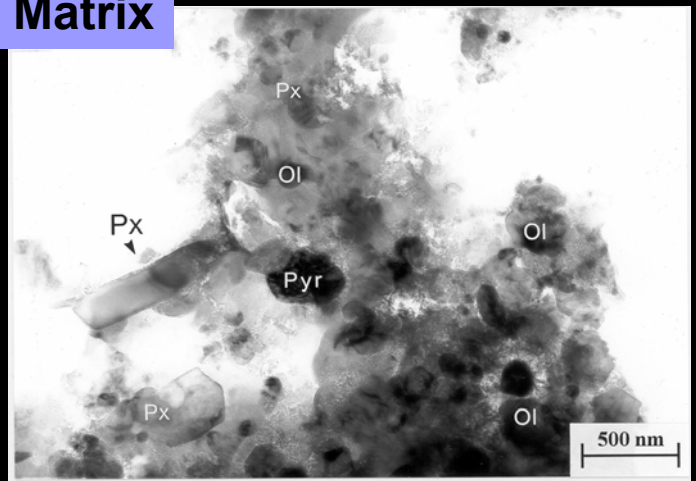
Chondrites' components



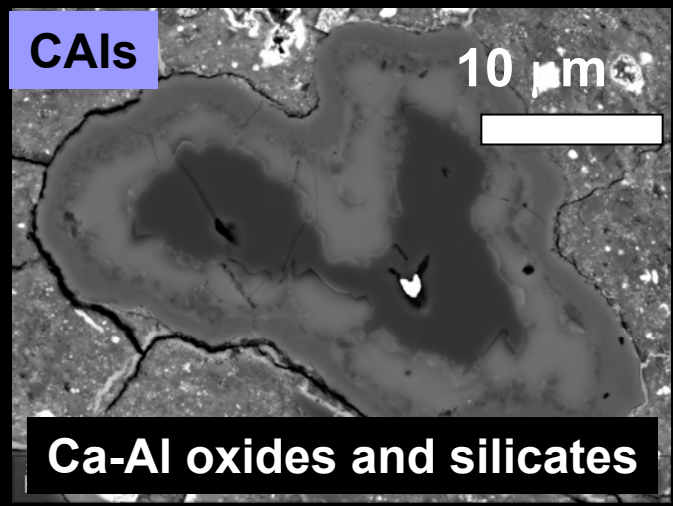
Chondules



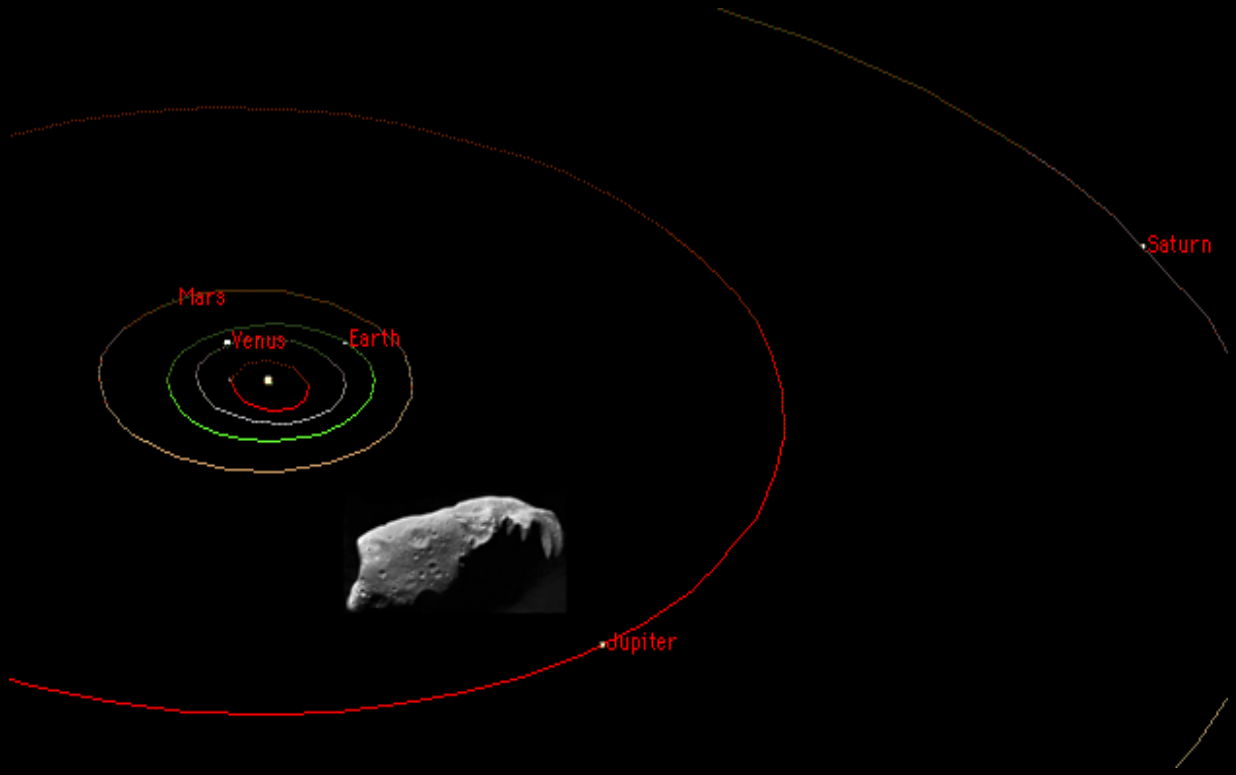
Matrix



CAIs

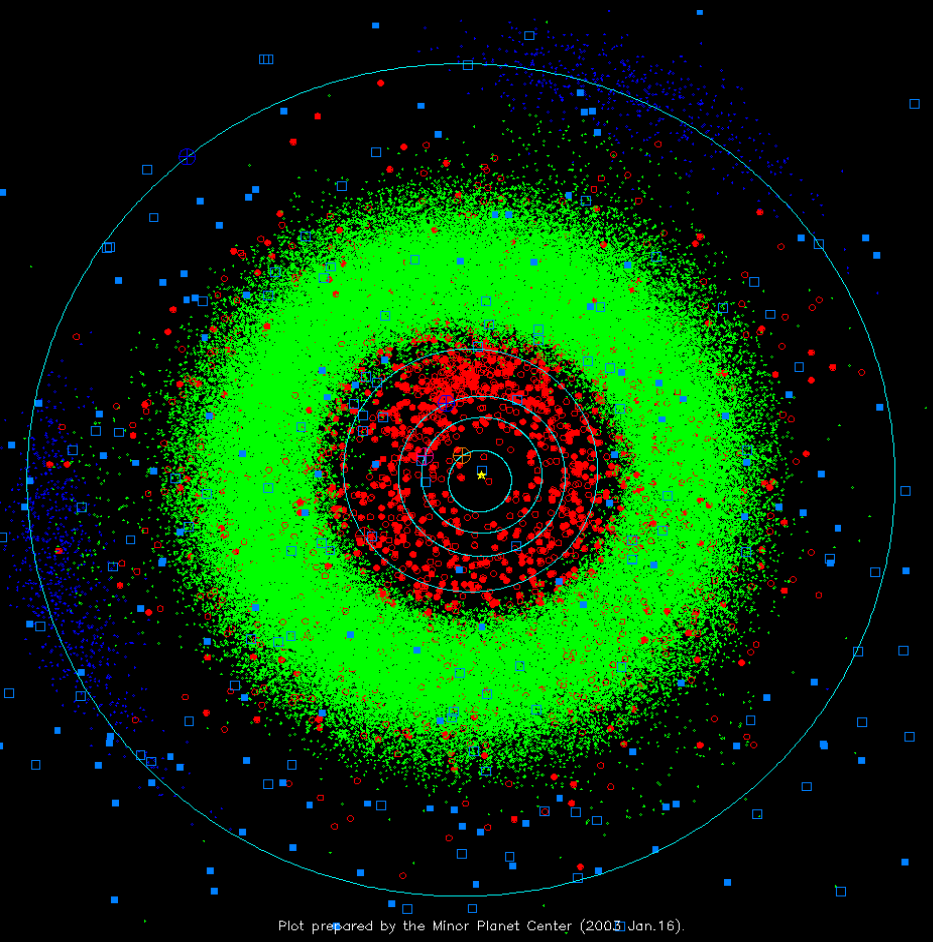


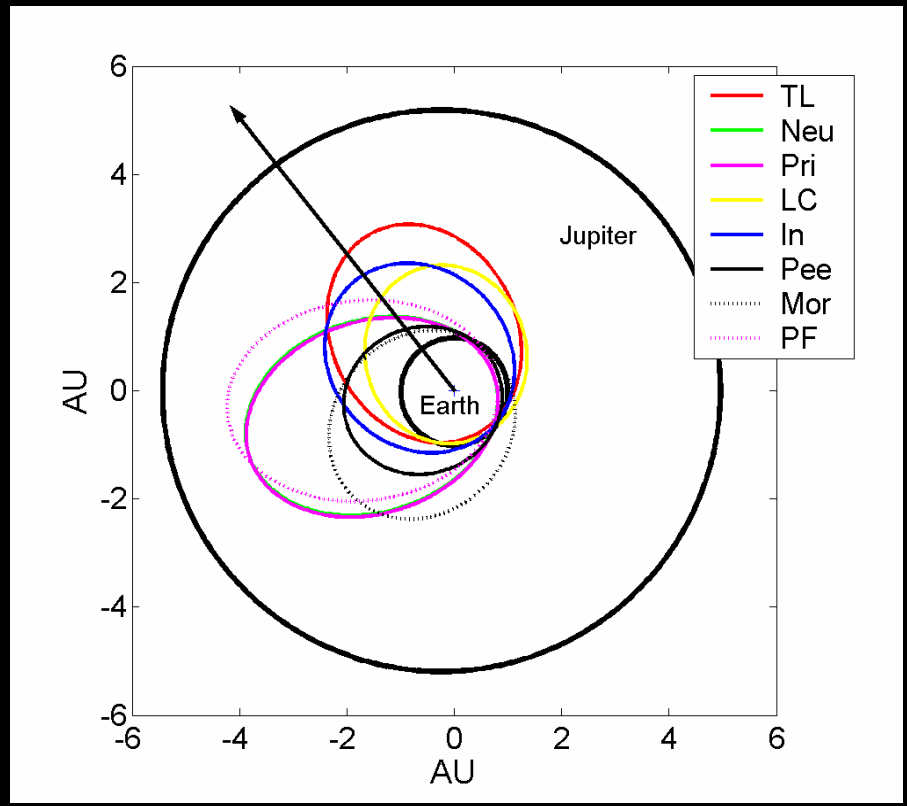
Comets & asteroids



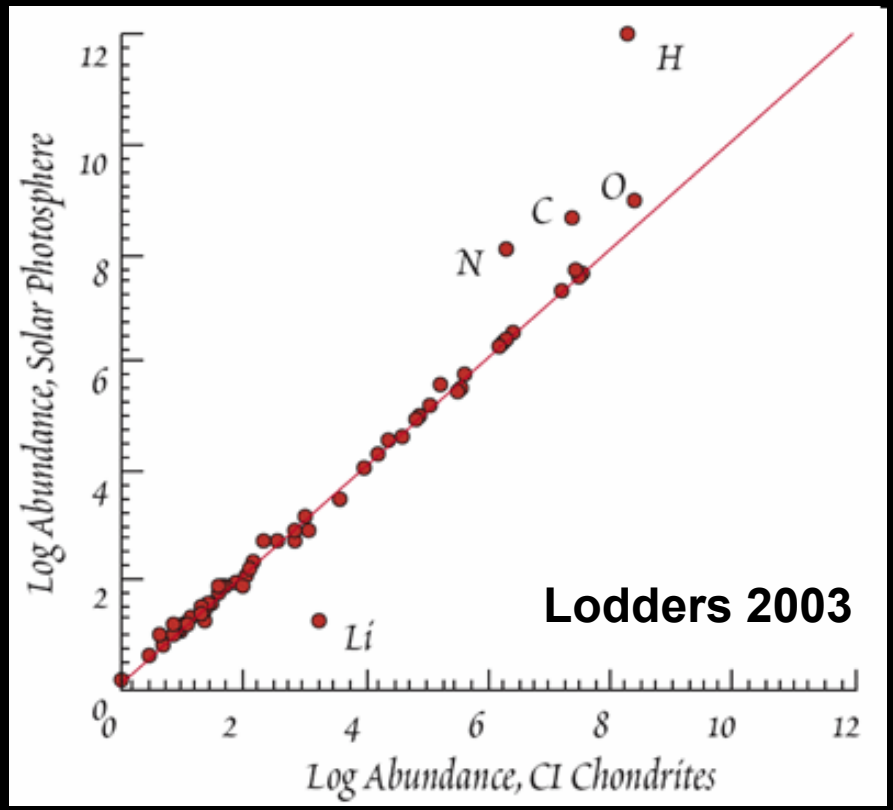
Comets formed further away and are supposed to be more primitive than asteroids (sampling <u>unprocessed</u> interstellar matter)

Most meteorites come from asteroids

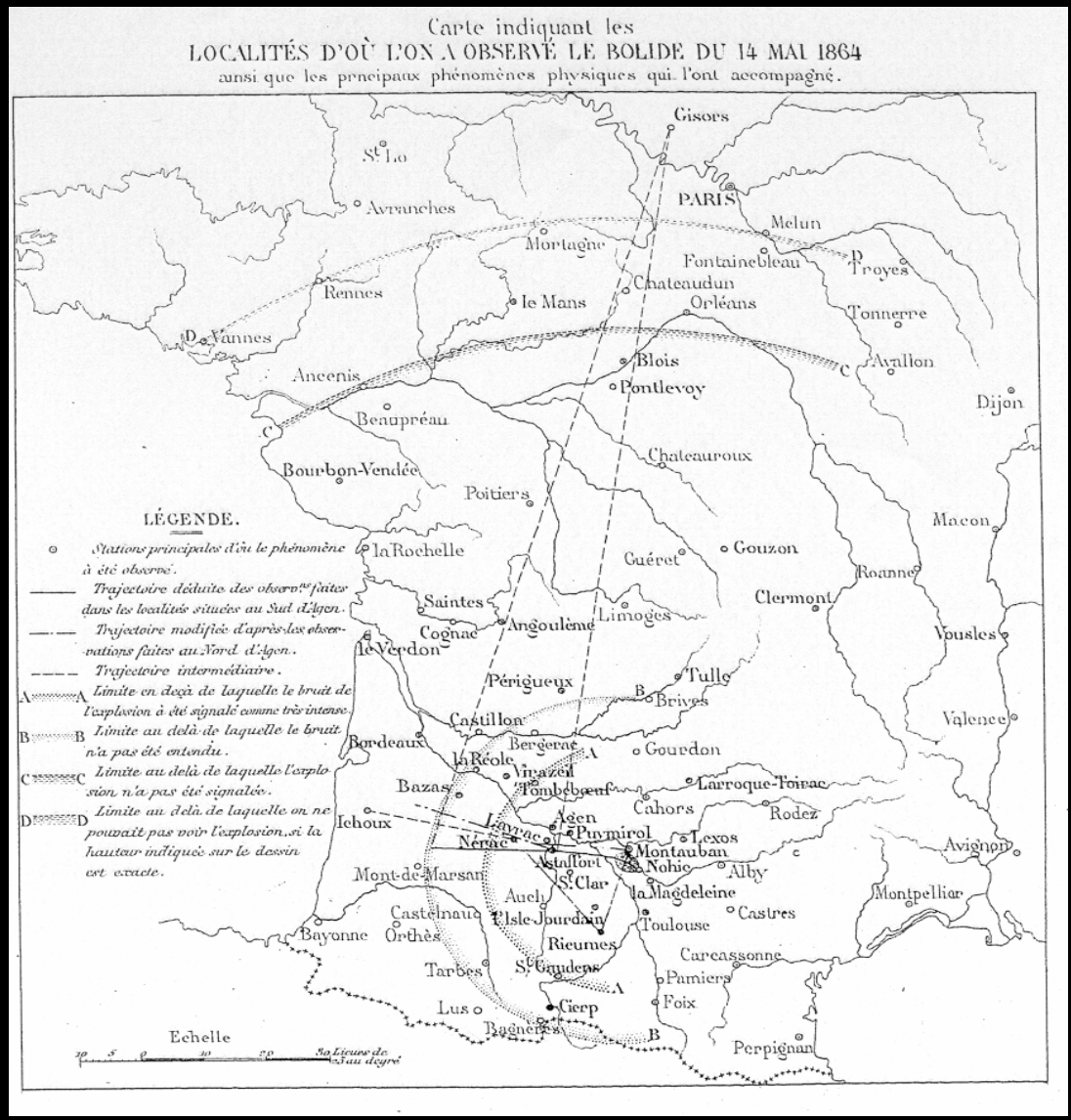




The Orgueil meteorite

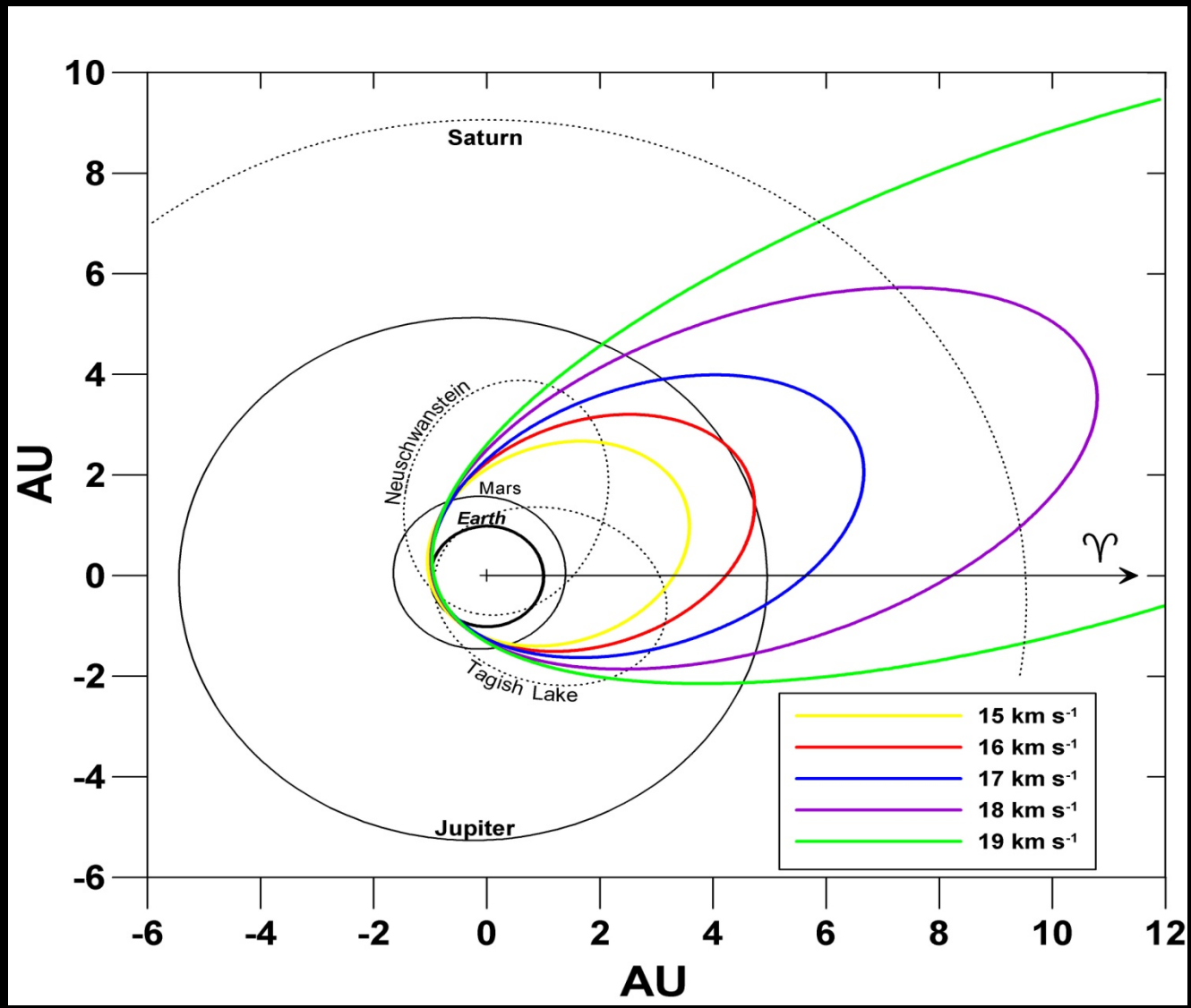


Visual observations of Orgueil – may 1864



Gounelle, Spurny & Bland *MAPS* 2006

Cometary origin of Orgueil?



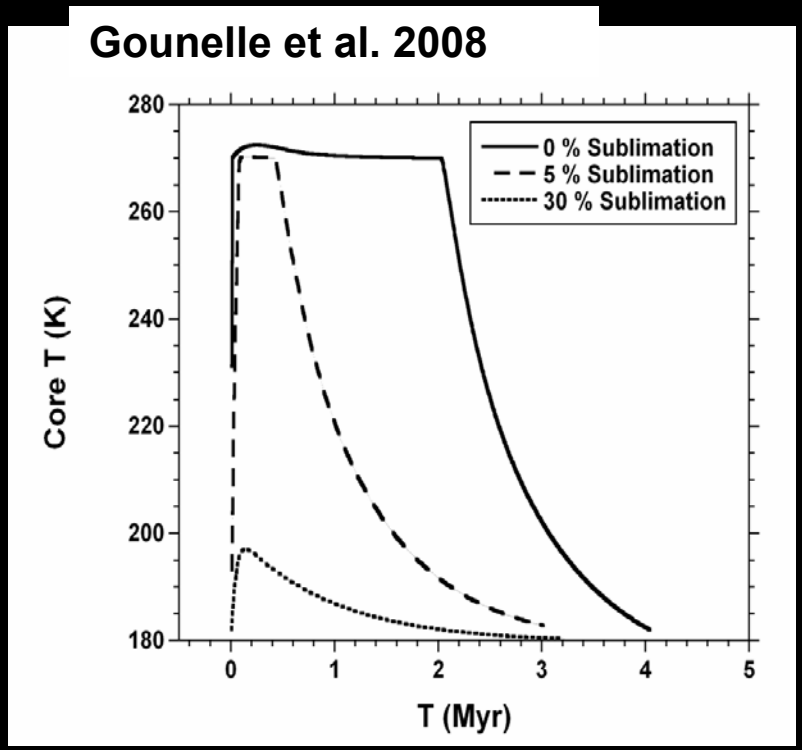
Gounelle, Spurny & Bland *MAPS* 2006

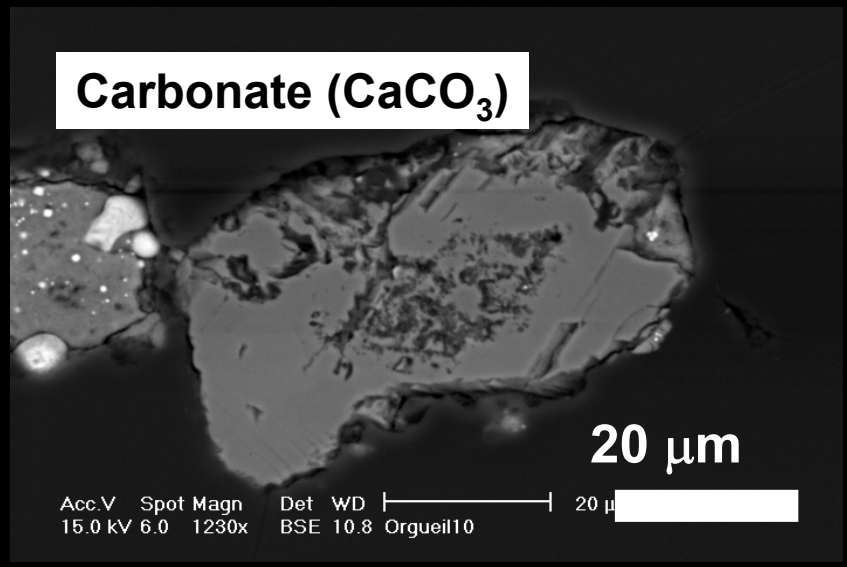
Continuum between asteroids & comets

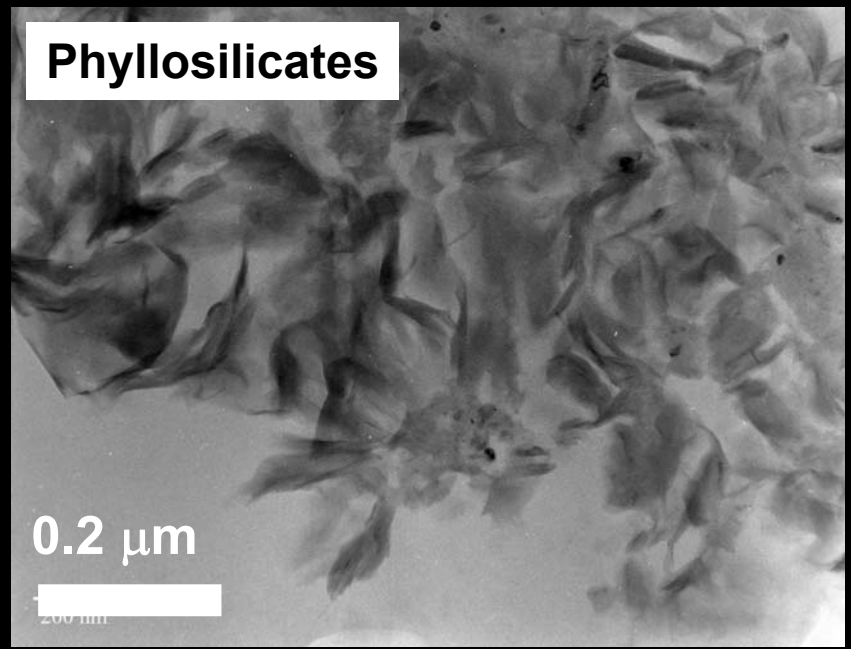
comparison to CI1 chondrites. In any case, independent of the possible cometary origin of Orgueil and the results yielded by the Stardust mission, a continuum between asteroids and comets is expected in our solar system, smoothing the possibly provocative proposition that five cometary meteorites are already present within terrestrial museums.

Gounelle, Spurny & Bland MAPS 2006

Water circulation in some comets

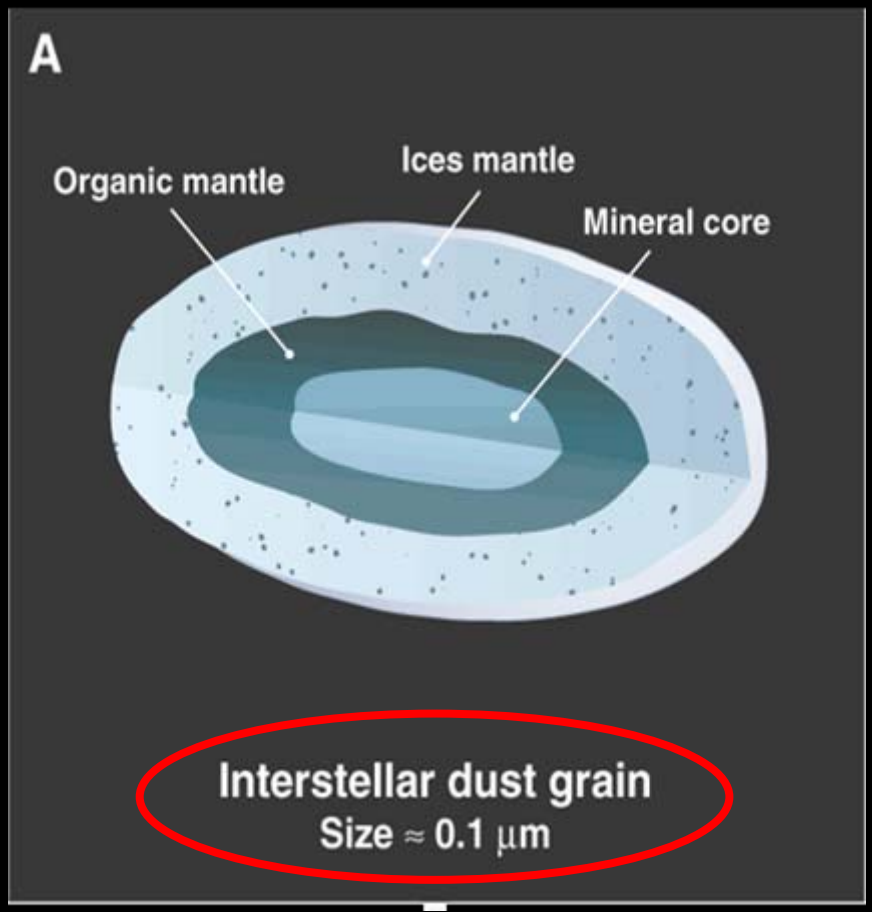


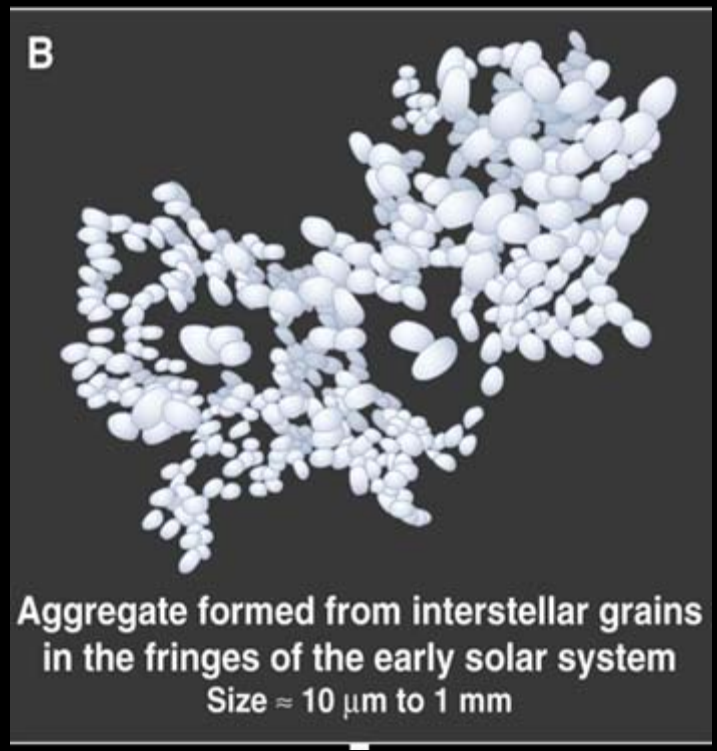




Orgueil and other CI1 chondrites suffered intensive *hydrothermal alteration*

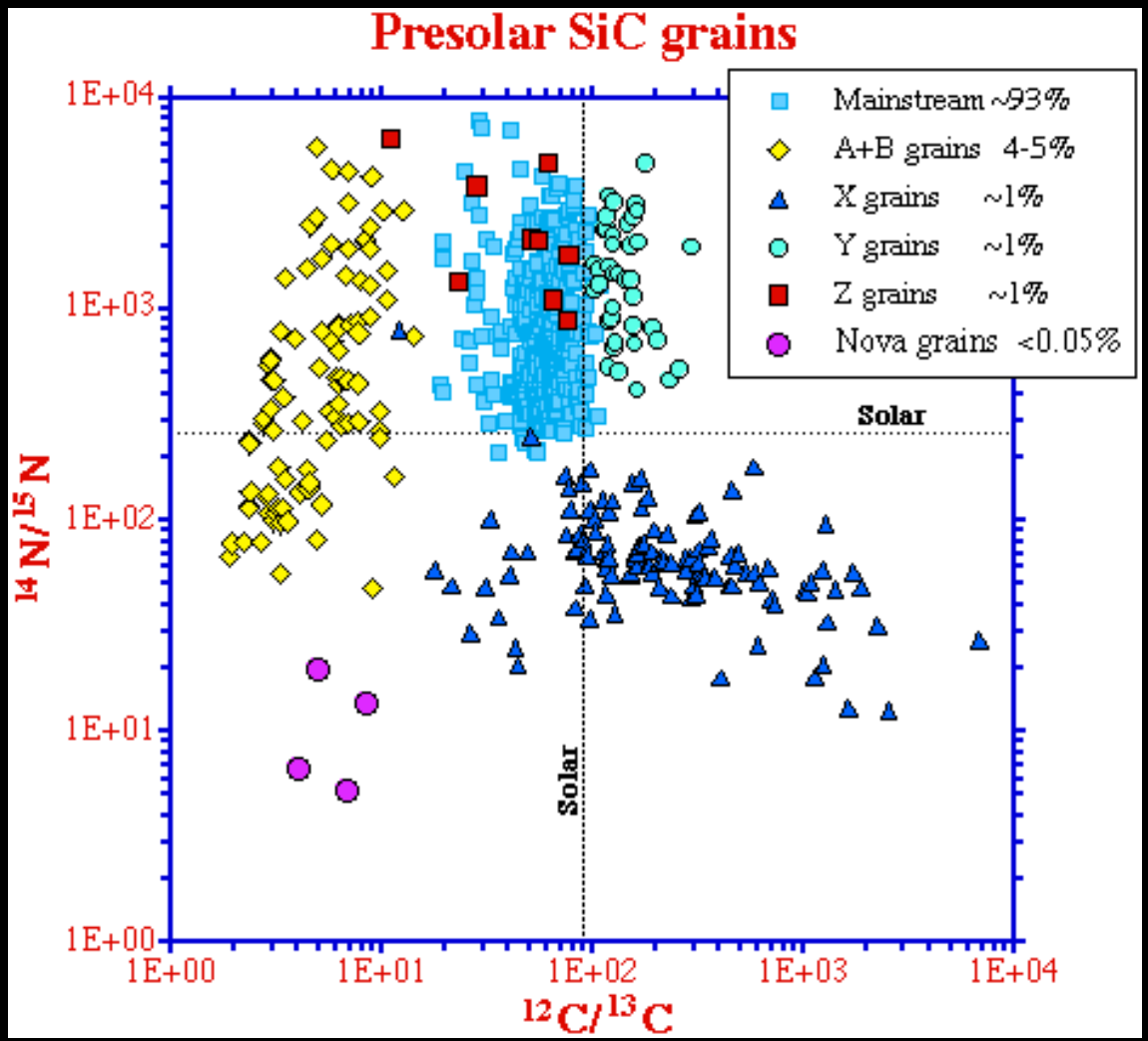
Expected cometary dust: Structure

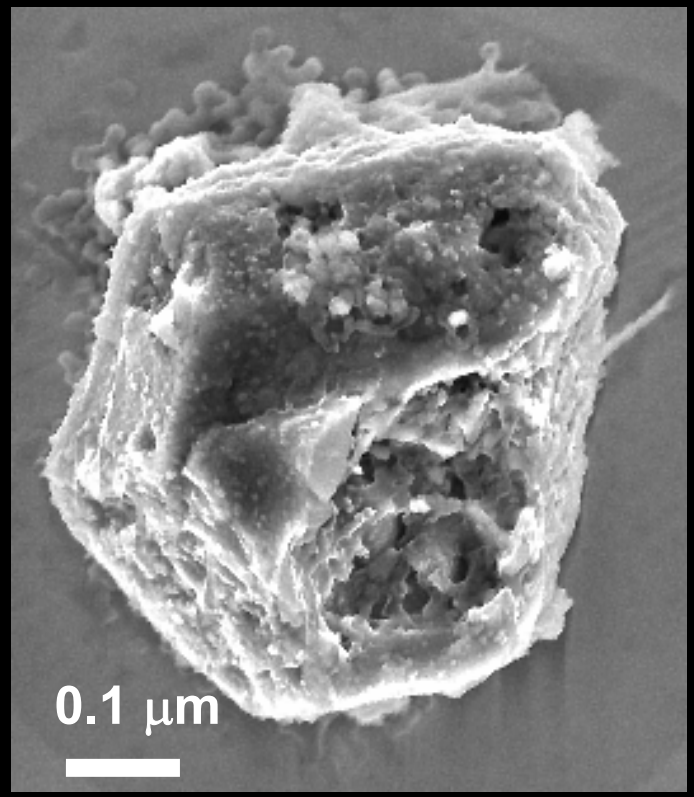




Levasseur - Regourd 2006

Expected cometary dust: Isotopic composition

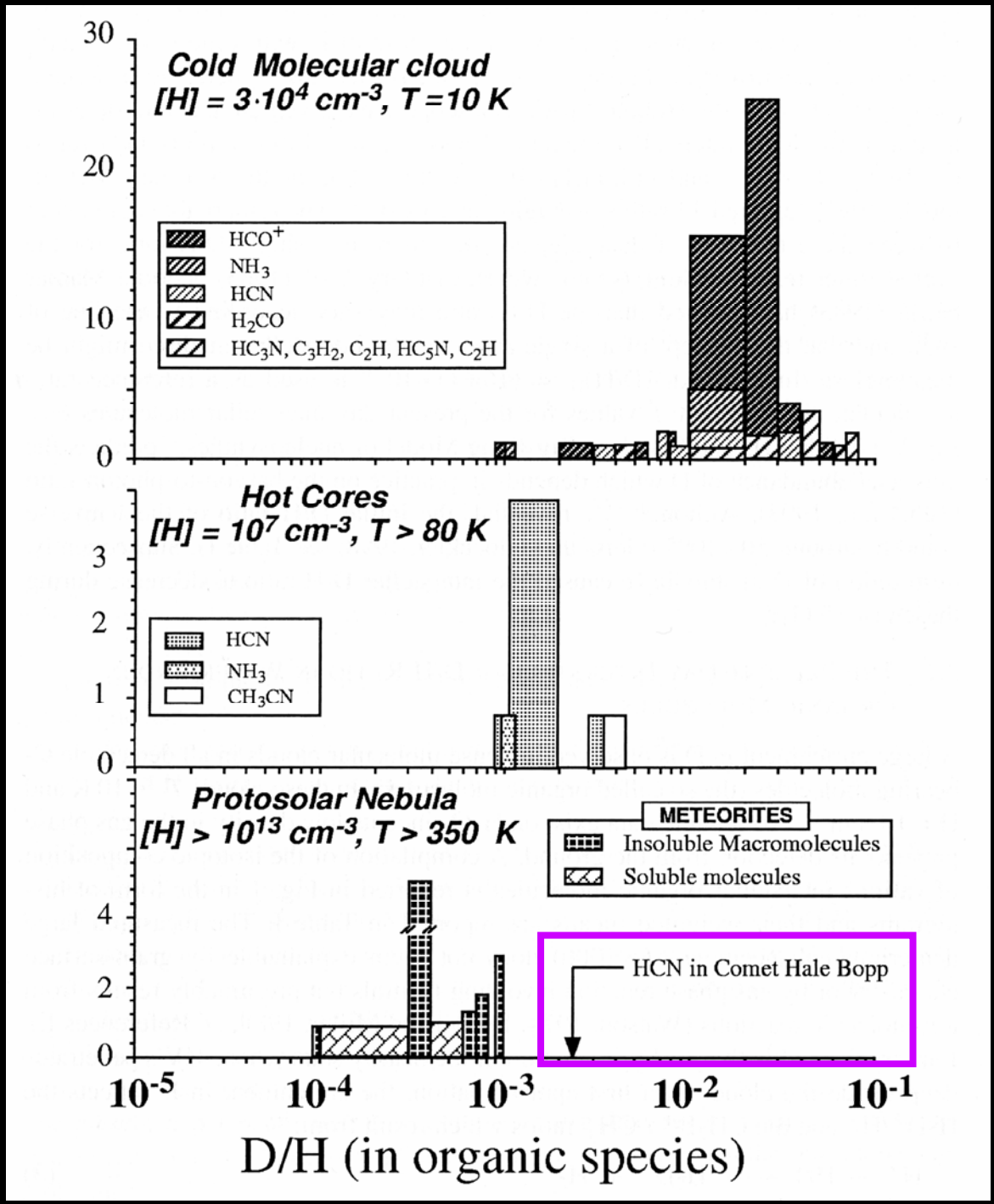




Nittler 2005

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

D/H ratio: Link with the ISM



Compilation from Robert (2002)

Stardust: A cometary sample return mission

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

Scientific goals

Objective #1: To bring back cometary dust

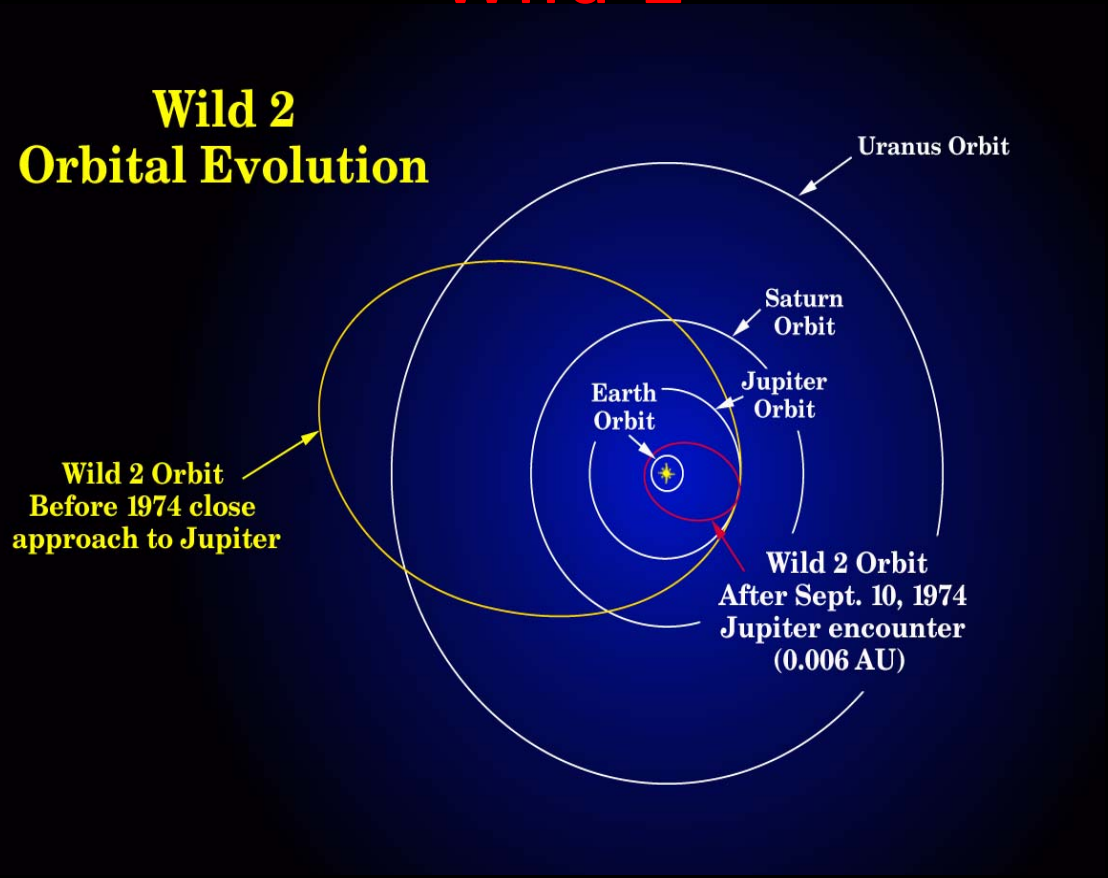
Comparison with meteorites

Comparison with asteroids & comets

Cometary matter: Interstellar or solar?

Geological processes on cometary surfaces

Wild 2



Jupiter Family Comet

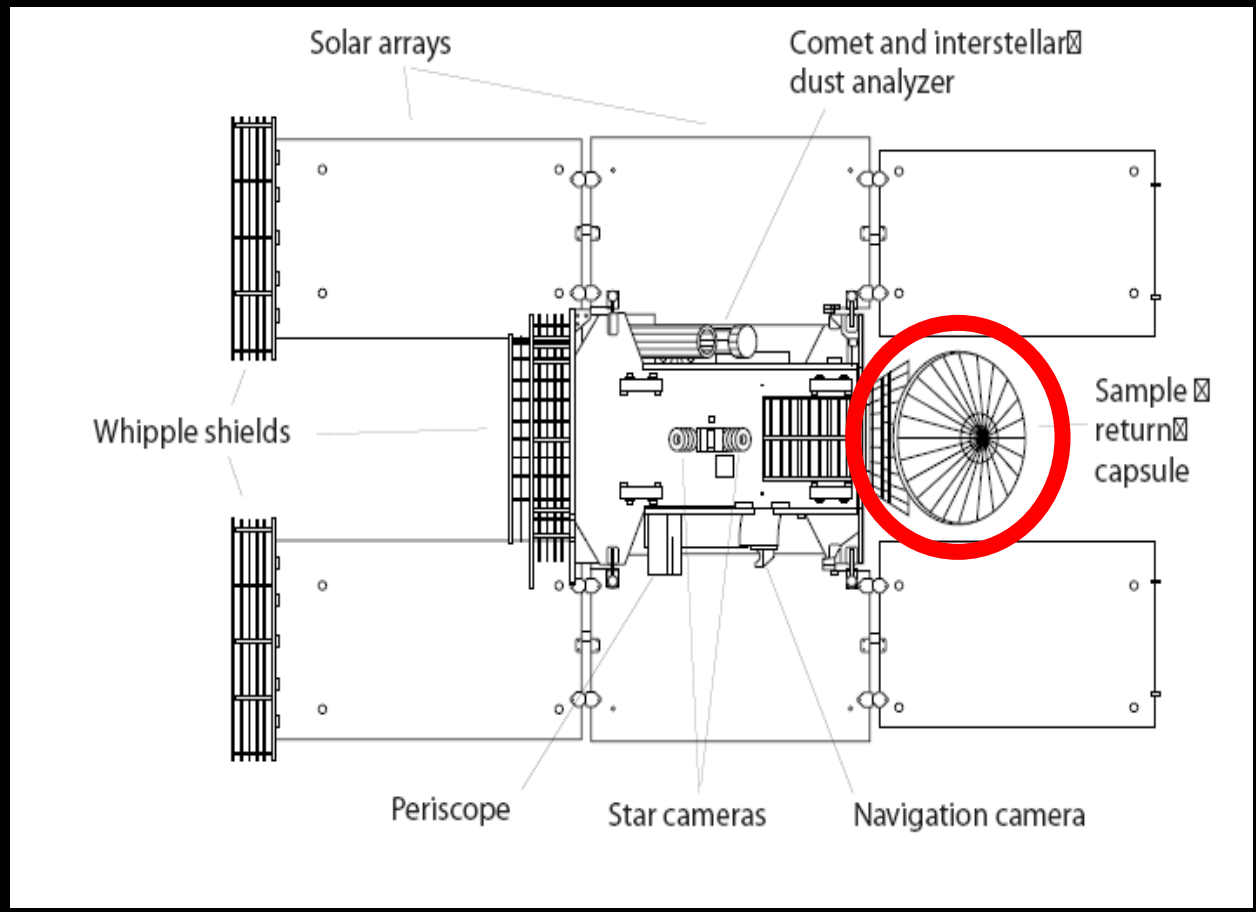
4.5 km diameter

Discovered 1978 (Mr Wild)

T = 6.39 yr

Dynamical timescale ~ 10000 yr

Take off february 7th 1999 at Cap Kennedy



Delta rocket

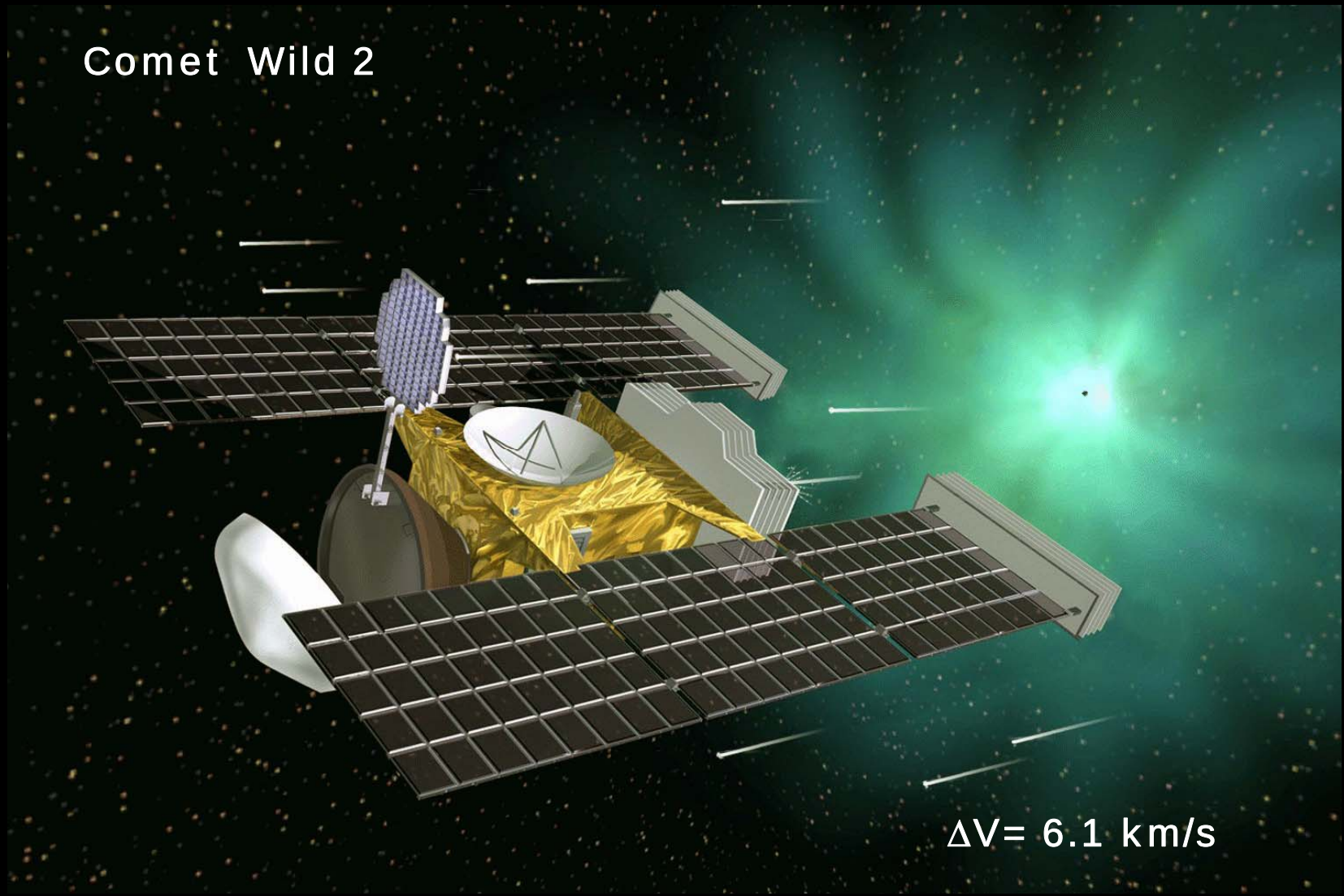
Total weight : 385 kg

Fuel 85 kg

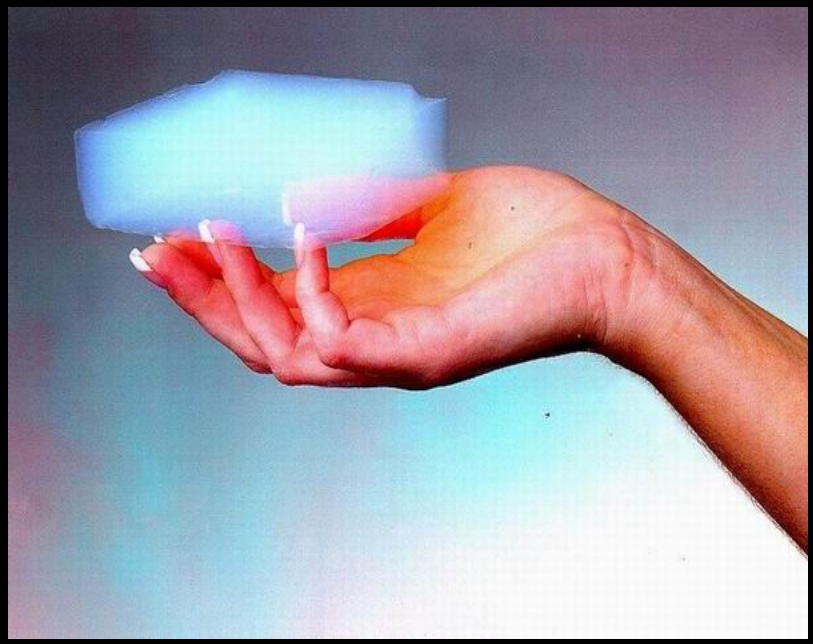
Landing module 45.7 kg

1.7 m

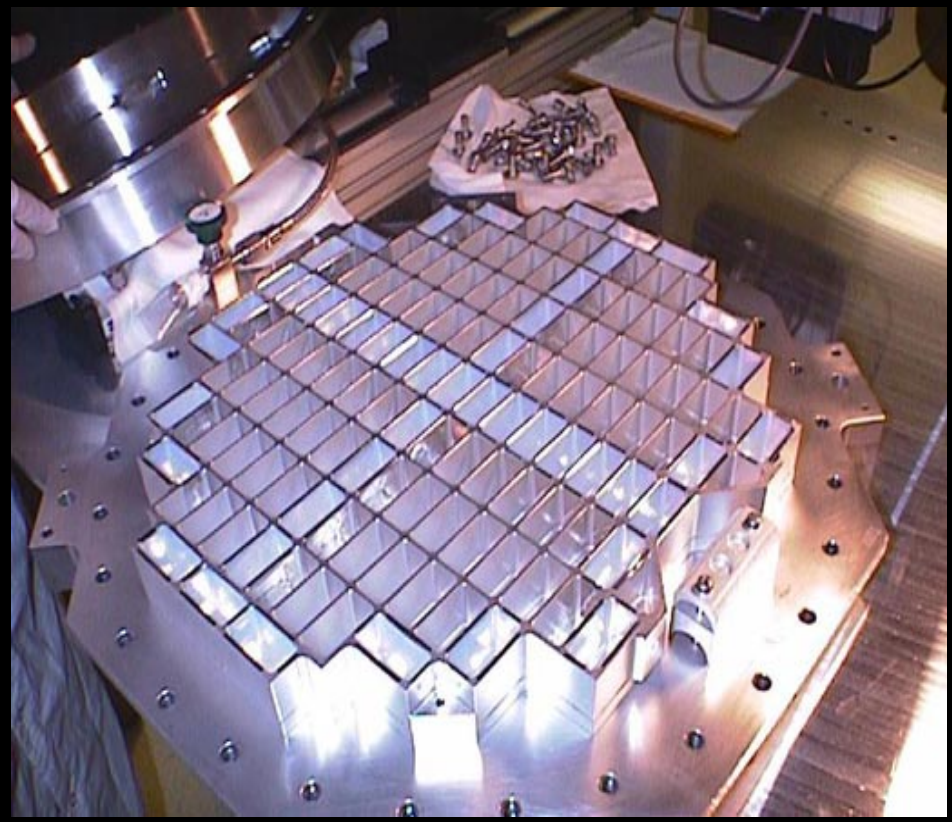
Sample collection (2 janvier 2004)



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

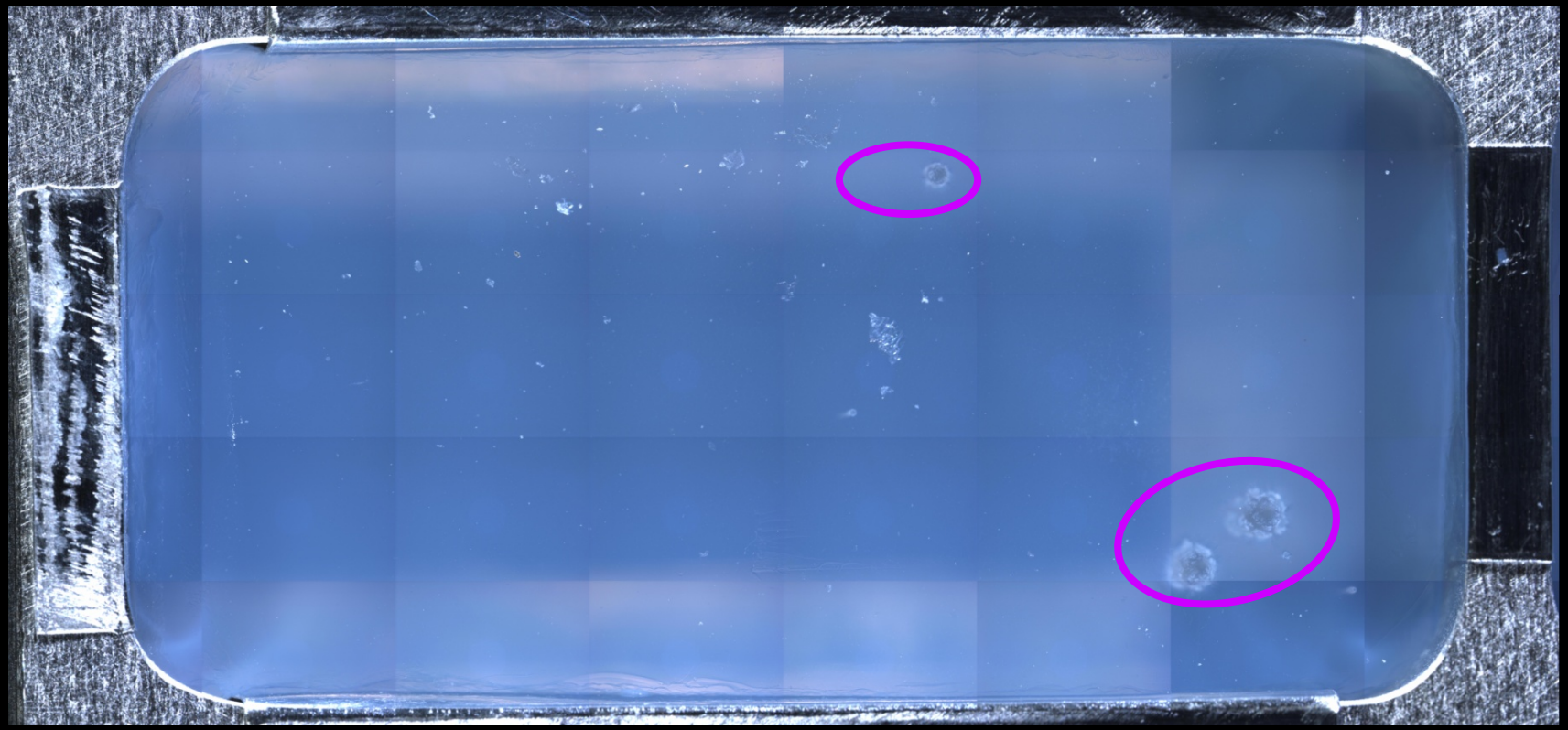
Velocity entry ~ 46 400 km/h

T_{max}: 2700 C

3 days later @ Johnson Space Center

~ 1000 grains with sizes > 5 μm

~ 100 μg of cometary dust



~ 1 cm

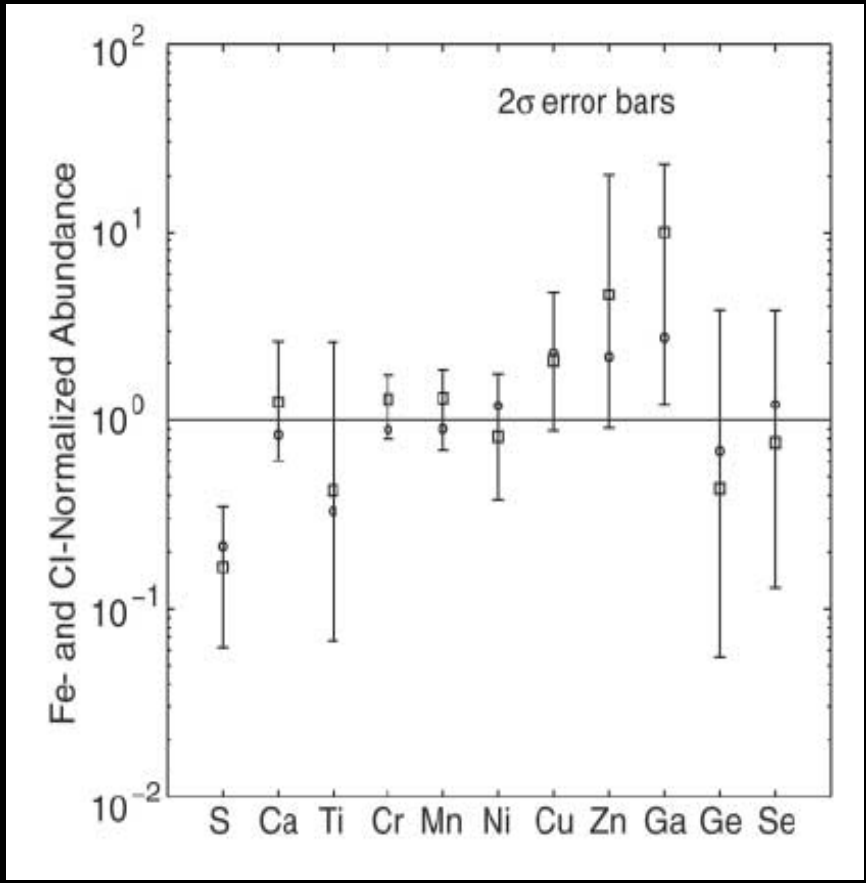
Terminal particle

Six Preliminary Examination Teams

Brownlee et al. 2006; Zolensky et al. 2006; McKeegan et al. 2006; Sandford et al. 2006; Flynn et al. 2006; Horz et al. 2006; Keller et al.2006

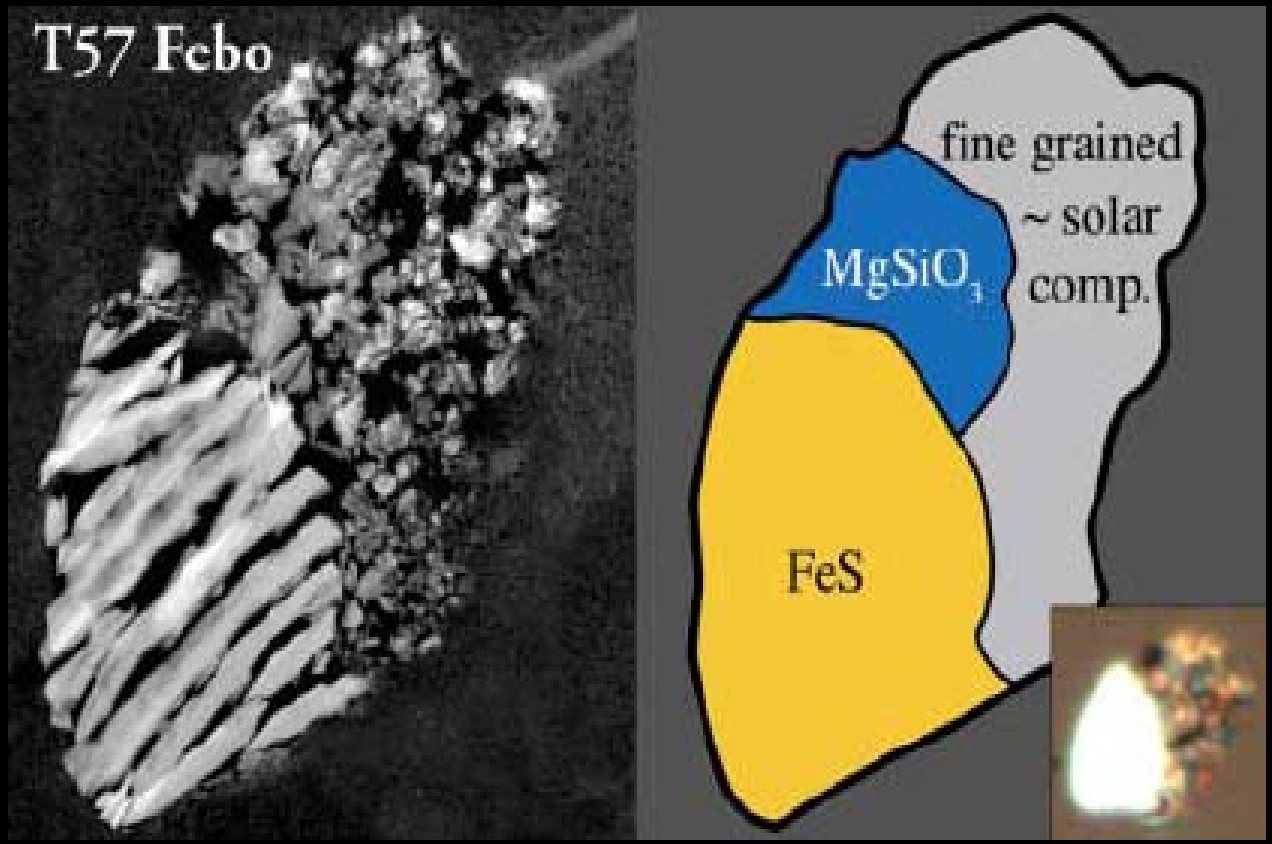
Chemical composition

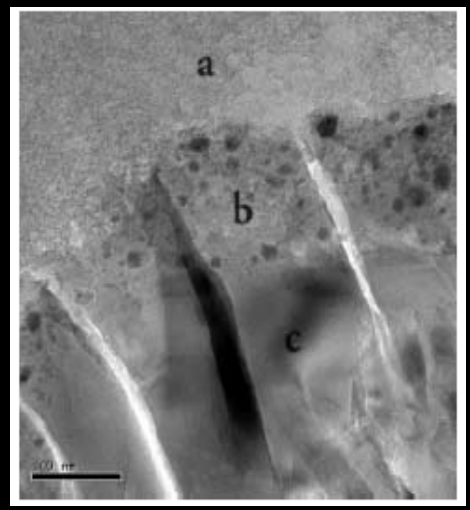
Flynn et al. 2006



Difficult to obtain
Roughly solar (CI1)

Basic mineralogy

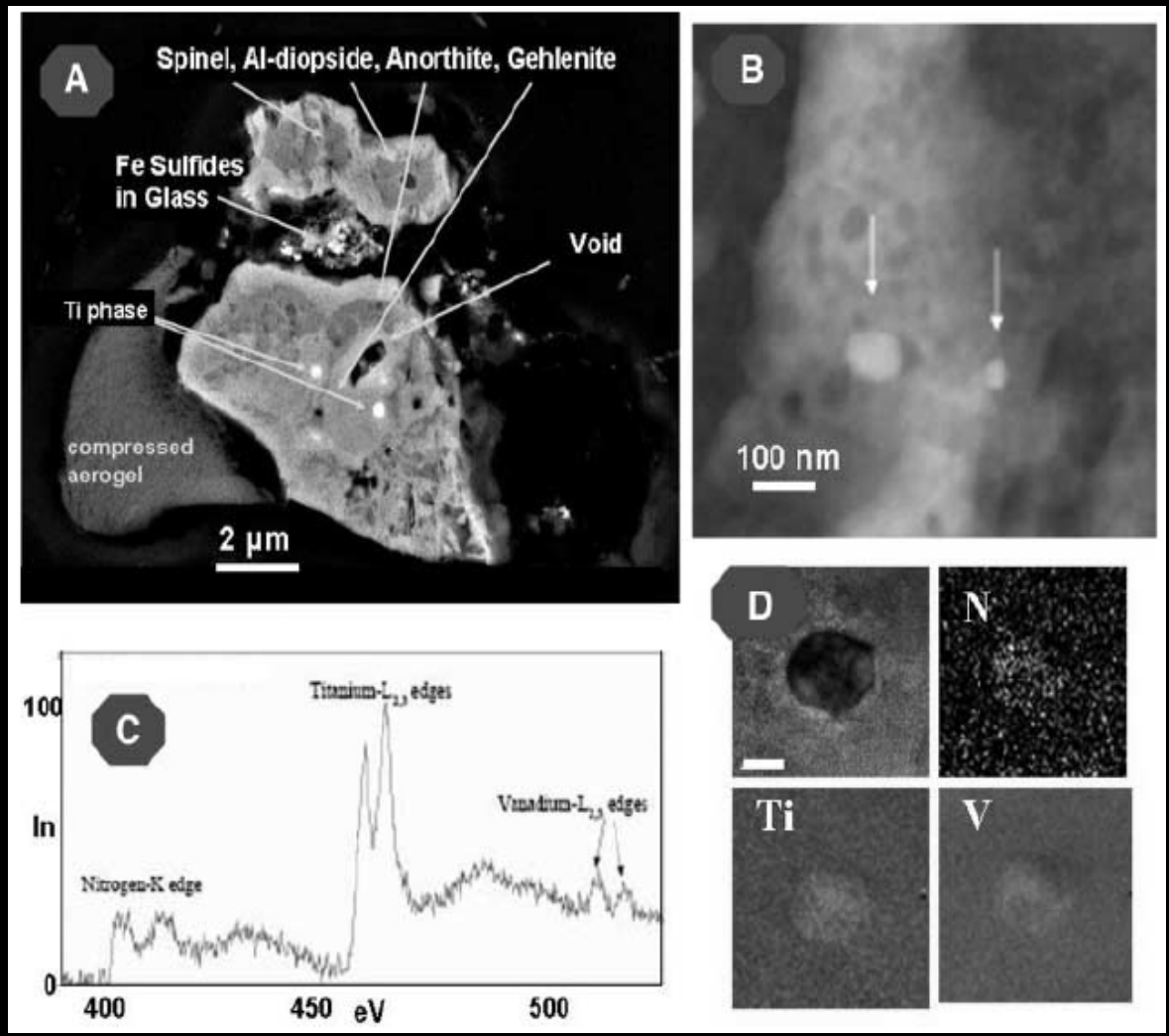




Olivine, pyroxene, sulfides, metal
Melted aerogel
Similar to what is found in primitive meteorites

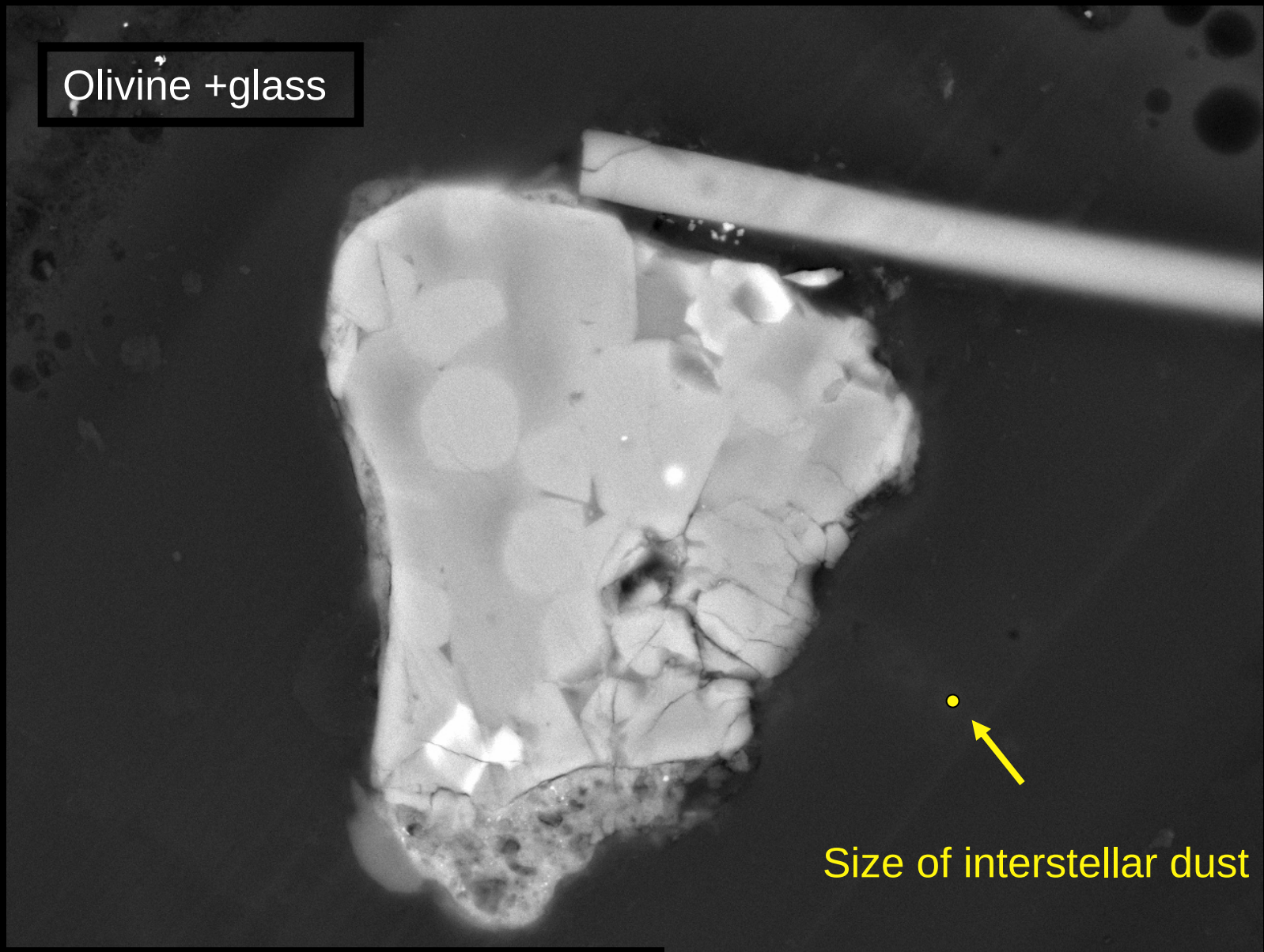
Calcium-Aluminium-rich objects in comets

Zolensky et al. 2006



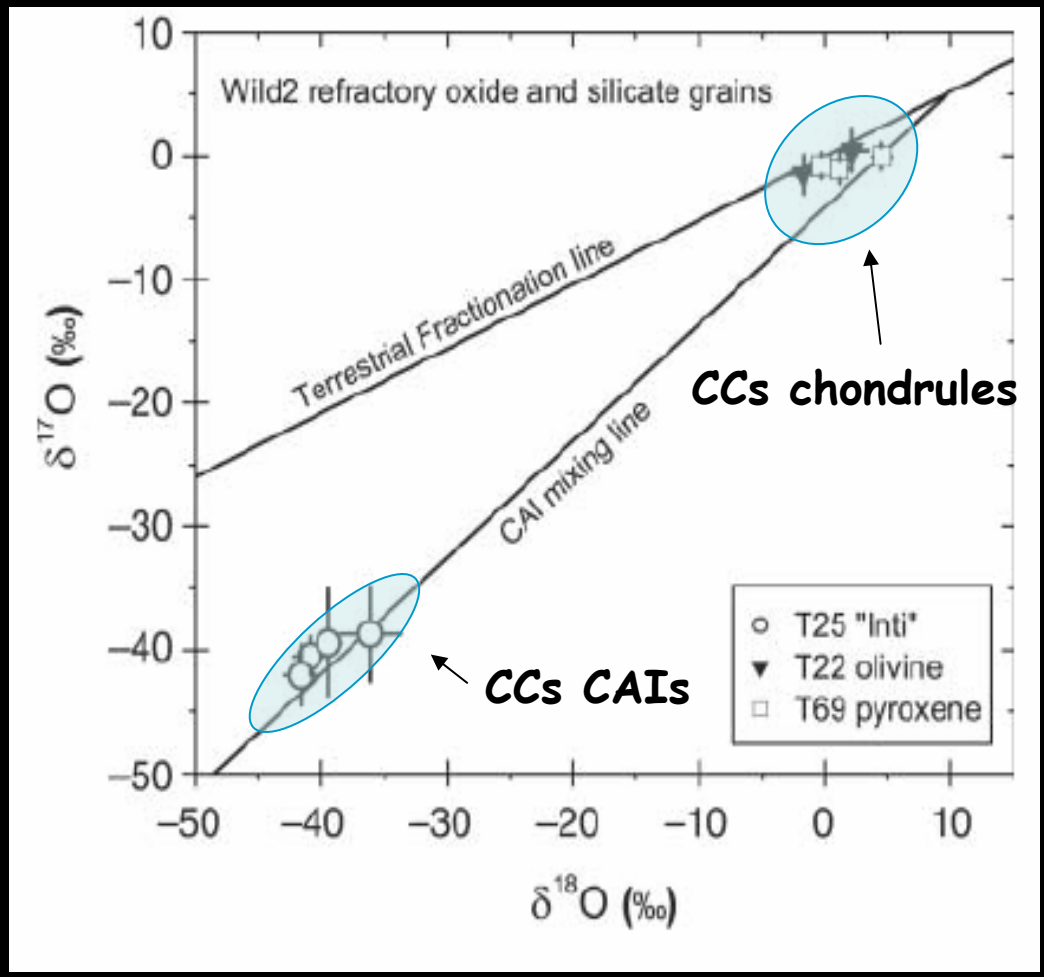
High T phase - important radial mixing in the Solar System

Chondrules in comets



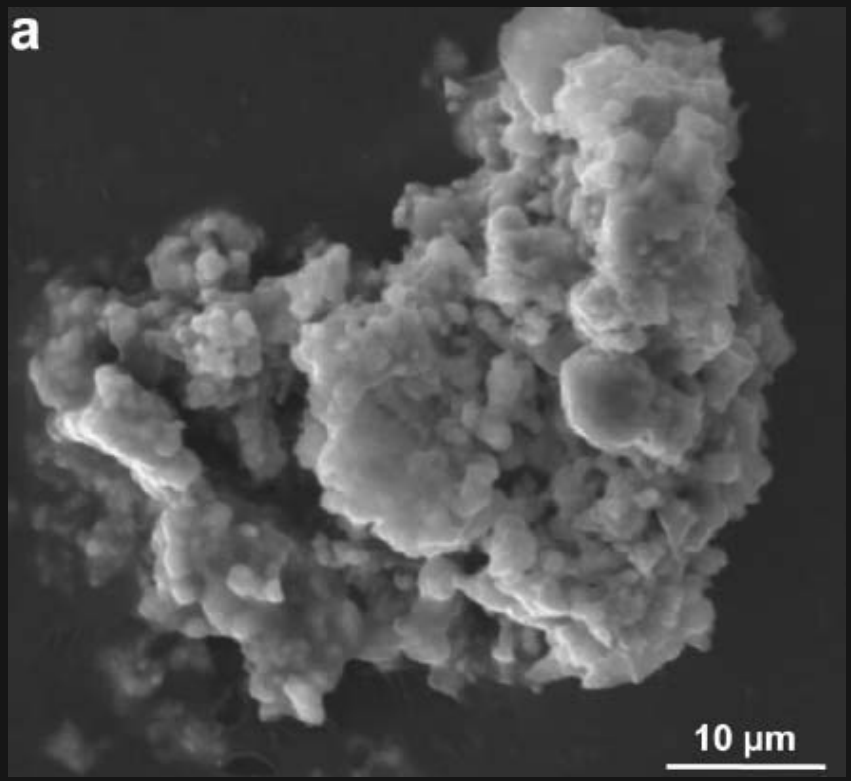
Nakamura et al. Science 2008

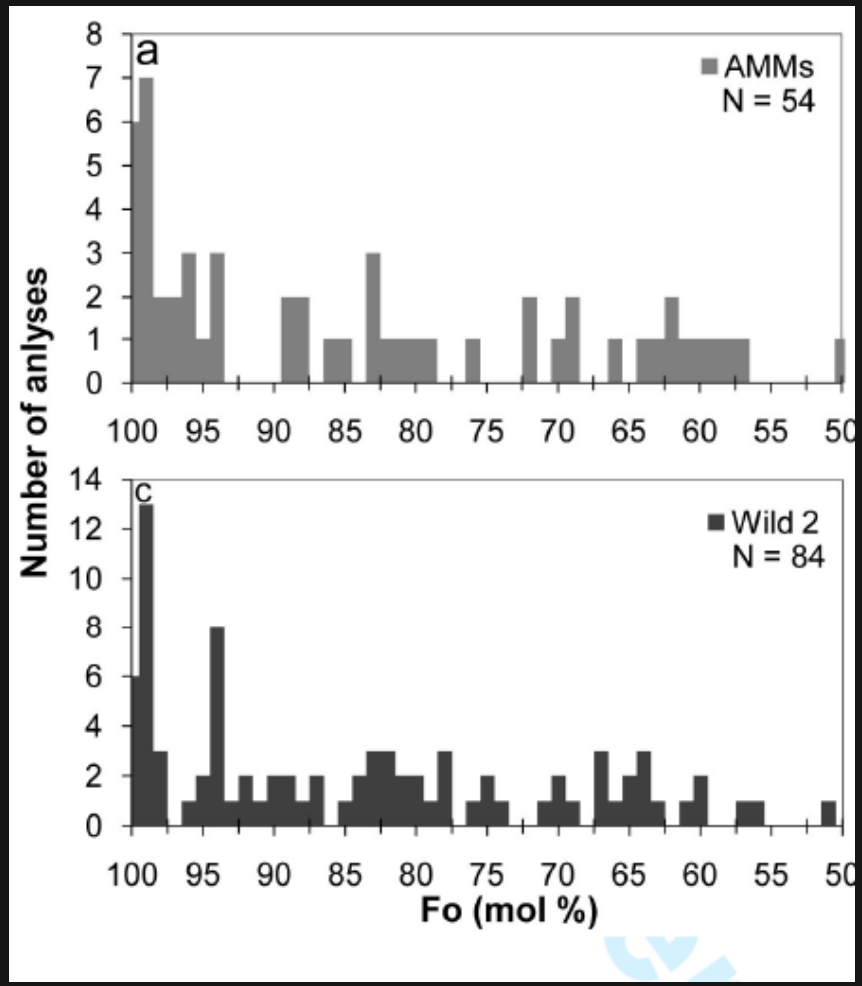
More similarities with carbonaceous chondrites



McKeegan et al. 2006

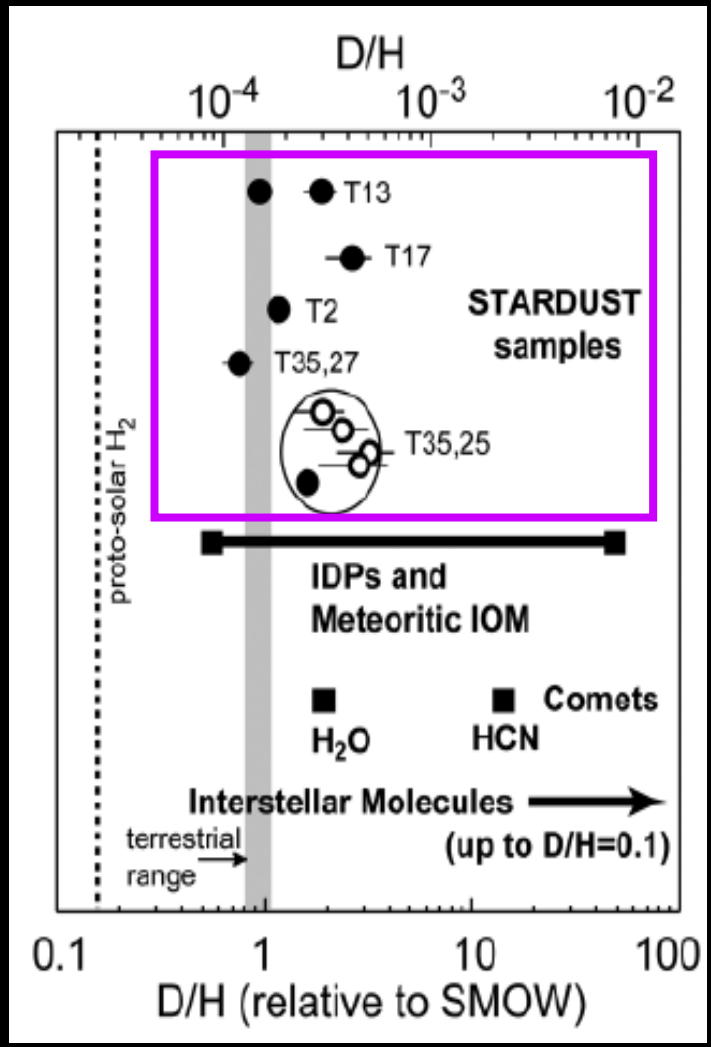
Some similarities with Antarctic micrometeorites & IDPs





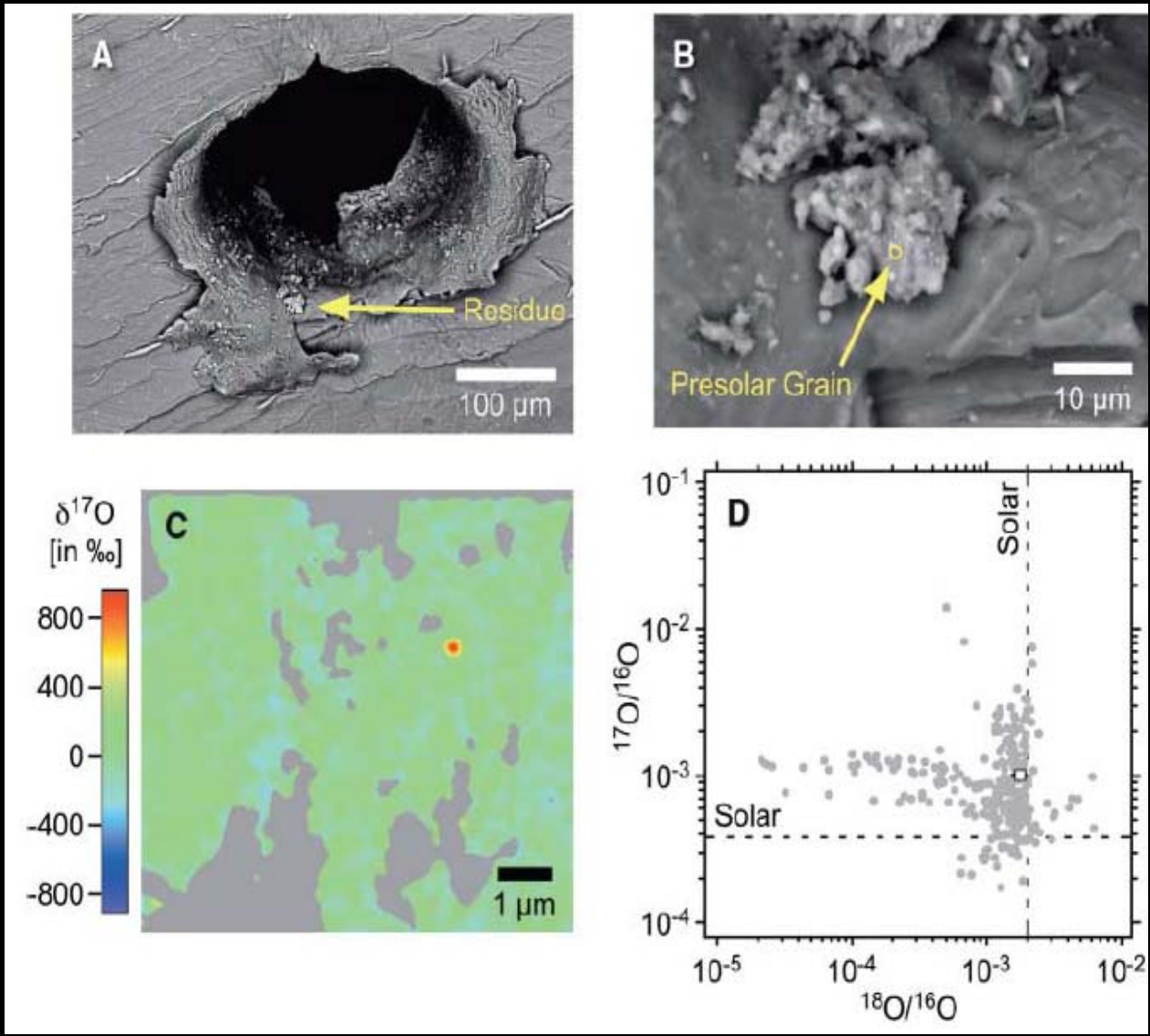
Dobrică et al. Submitted

Not such a strong link to the ISM



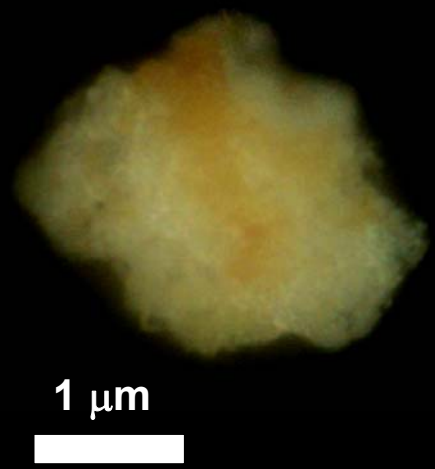
McKeegan et al. 2006

Very few presolar grains



McKeegan et al. 2006

Stardust (partial) summary

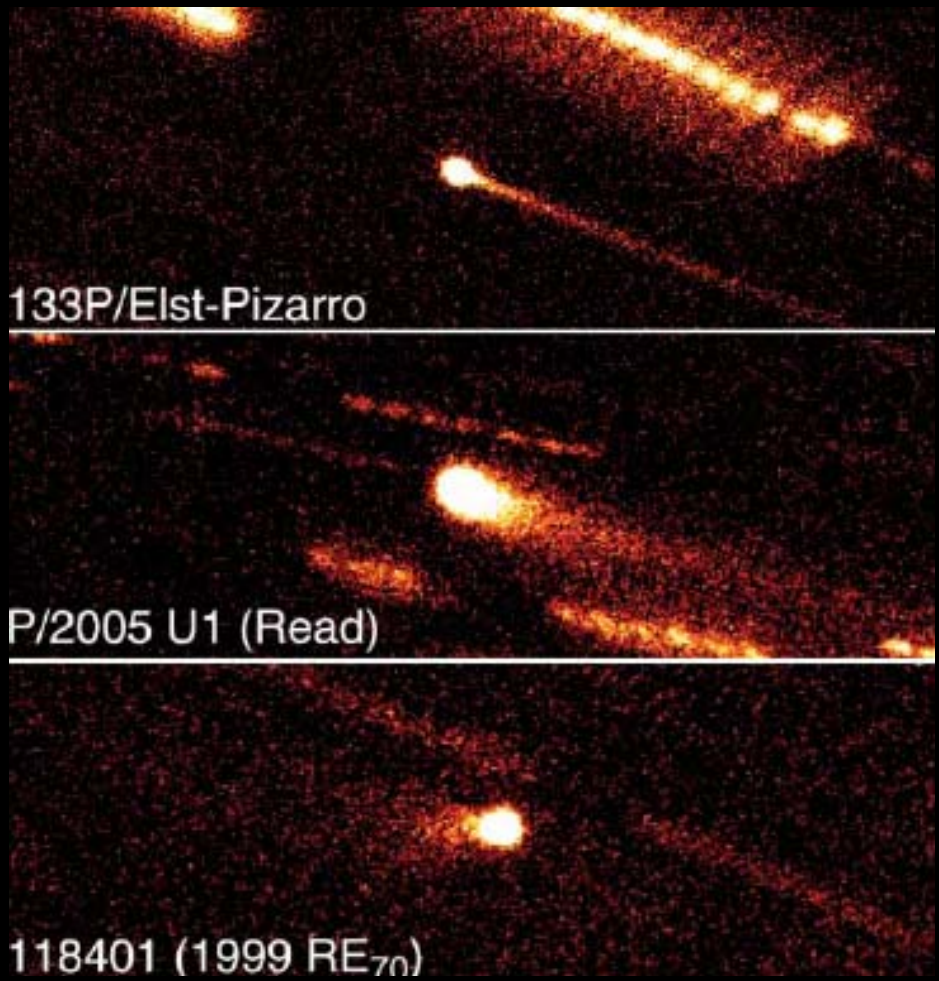


Wild 2 dust was processed in the solar system (NOT interstellar)

Wild 2 dust looks alike carbonaceous chondrites & micrometeorites:
Continuum between asteroids & comets

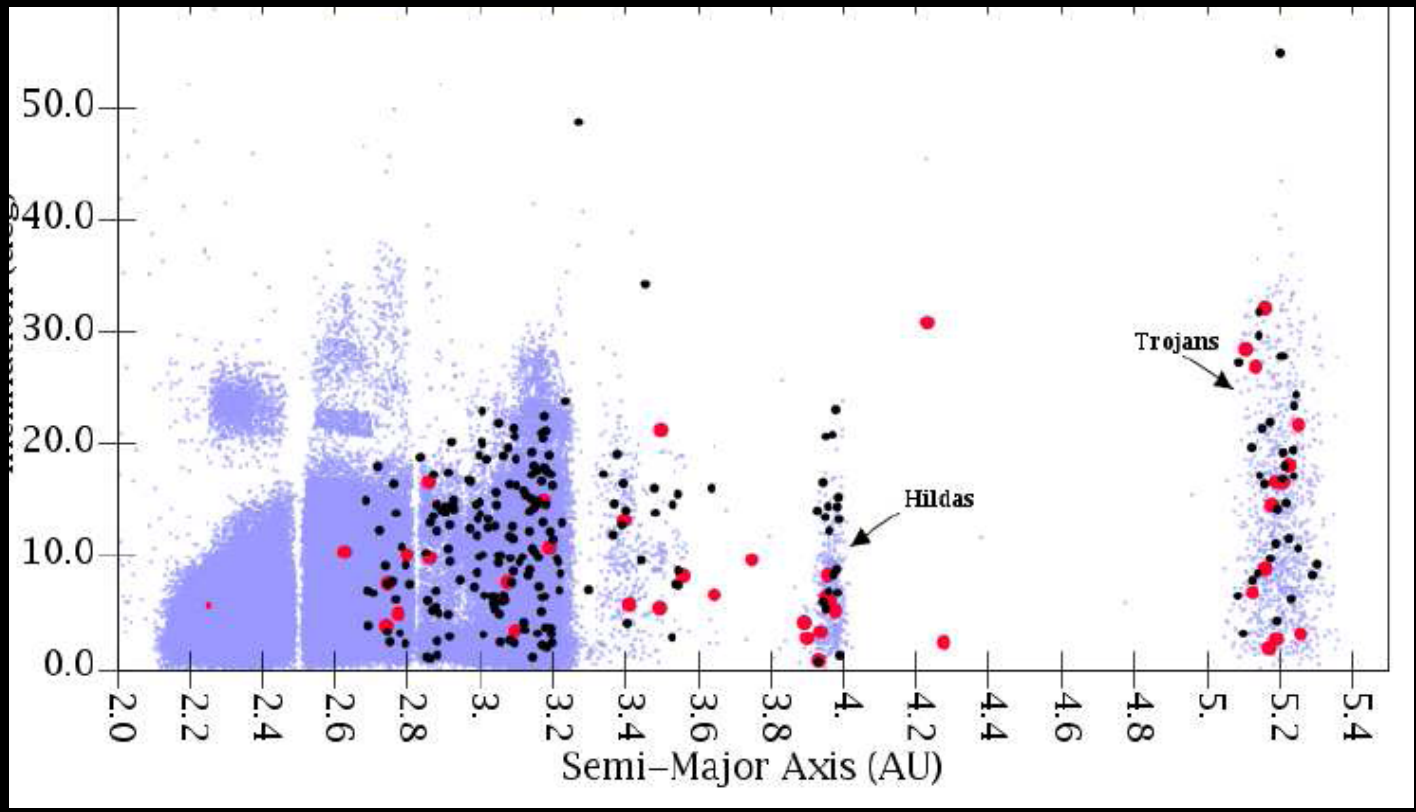
Important radial mixing between the inner & outer solar system

Main belt comets



Hsieh & Jewitt Science 2006

Embedded comets in the asteroid belt



D asteroids (black dots) are implanted comets (red dots) during the Late Heavy Bombardment

Levison et al. In press

Why sampling another body ?

1. To better characterize the comet-asteroid continuum

★Could asteroids look like comets?
★C asteroids are different from D asteroids (and comets)
★Not all comets are the same

2. What matters is to study samples of primitive [unprocessed] matter

★Meteorites are a dynamical biased sample set
★Less than a mg of Wild 2 dust : no bulk organics
★Wild 2 dust is fragmented: no petrography

Final thoughts

Comets ended up in the lab

We were surprised!

The *comet-asteroid continuum* yet to be characterized

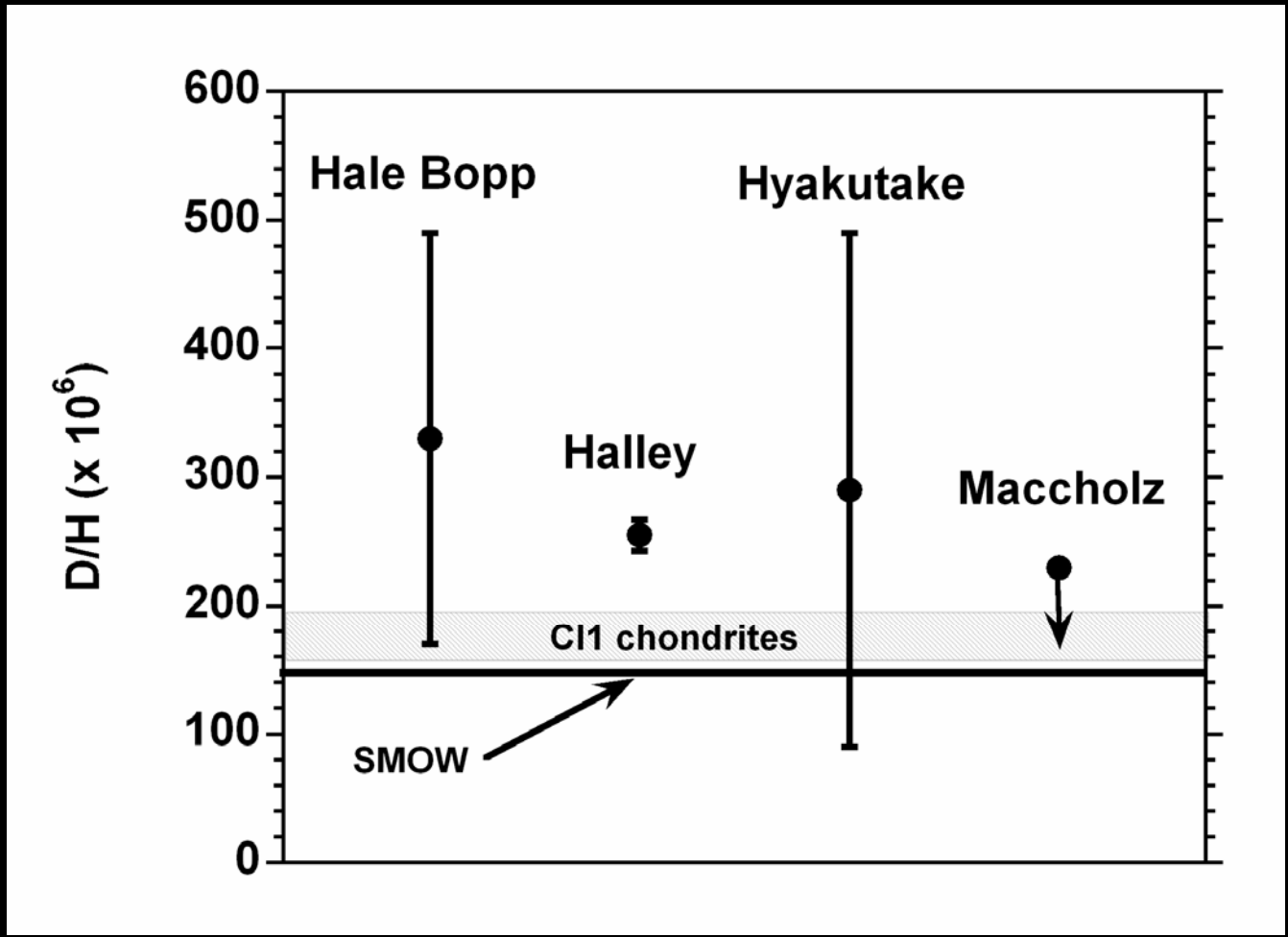
Sample return missions provide *long-lasting progress*

Primitive samples are to be found among asteroids & comets [**processes**]

5 nm

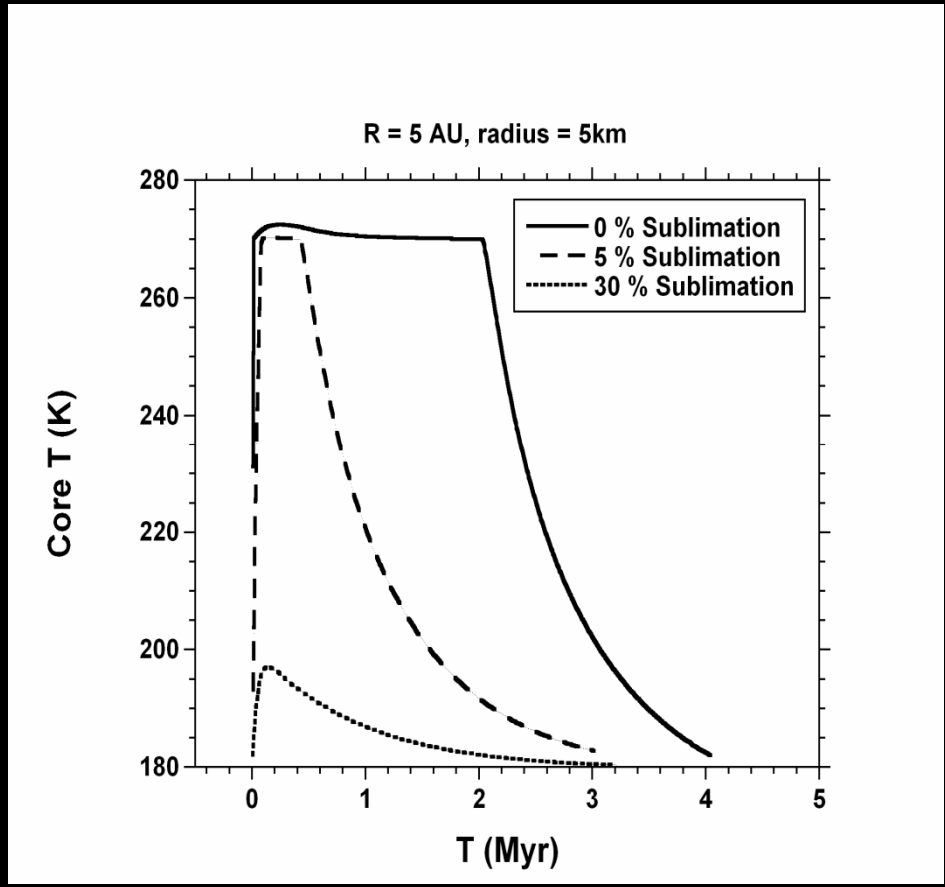
TEM image

The ISM link


600
500
400
300
200
100
0
D/H (x 10^6)
Hale Bopp
Halley
Hyakutake
Maccholz
CI1 chondrites
SMOW

Conclusions 4

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

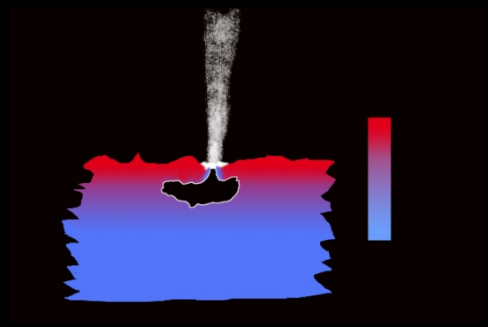


Little hydrothermal alteration in Wild 2
Some (?) secondary minerals (phyllosilicates, carbonates) in Tempel 1 (Lisse et al. 2006)

Variable amount of aqueous alteration in comets

Comment

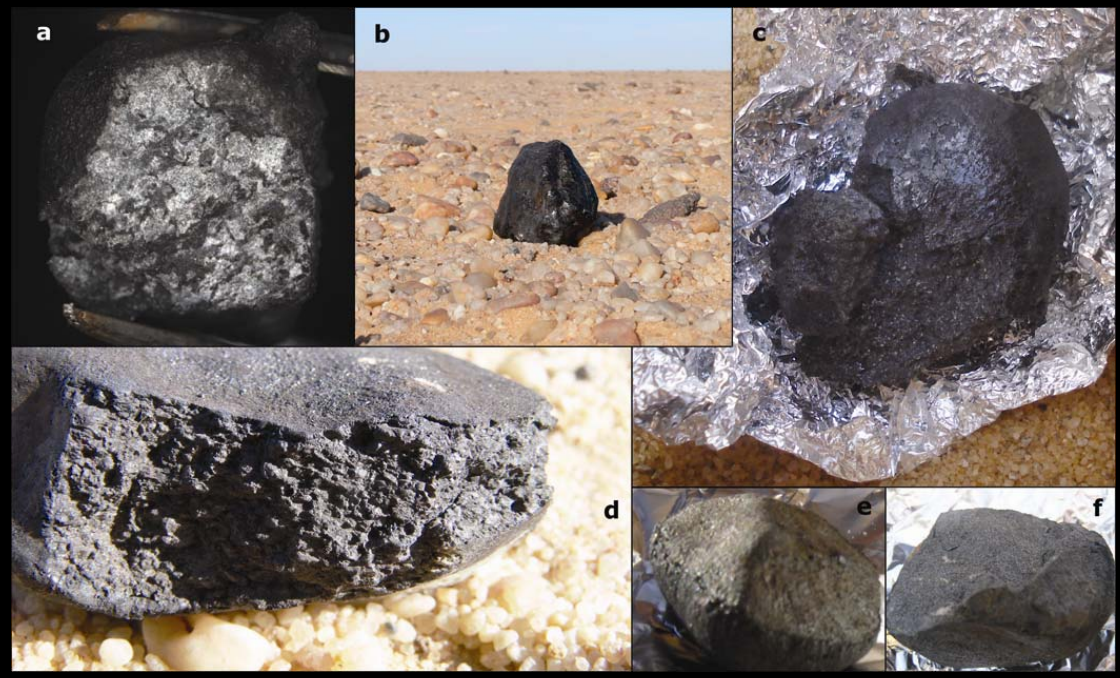
Not all comets are the same
The *surface of one* comet was sampled



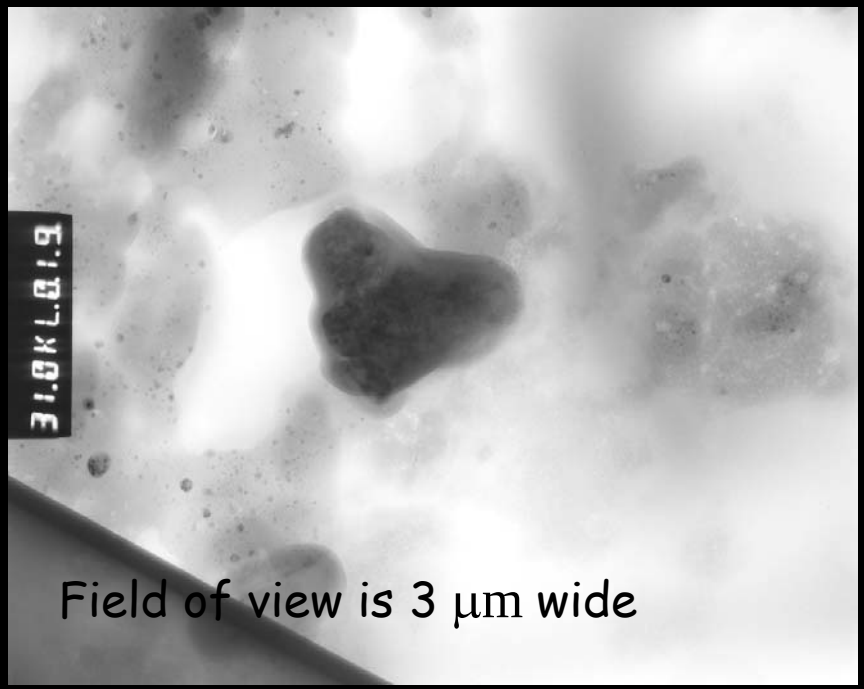
Also true for the recently recovered Almahata Sitta anomalous ureilite

Table 1 | Orbital parameters of 2008 TC_3 used to calculate the approach path

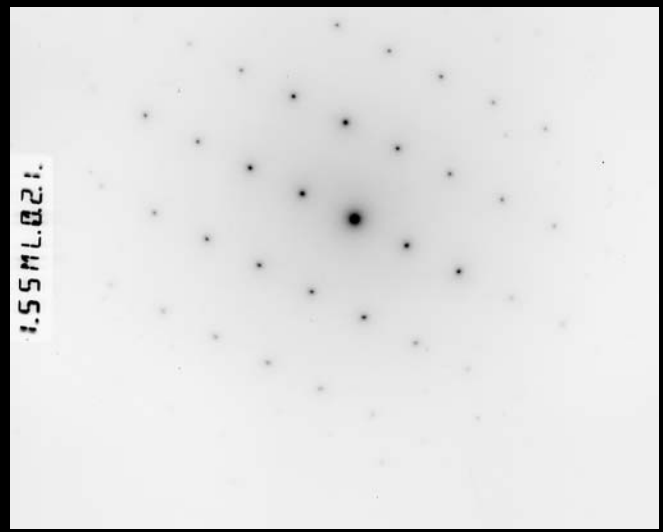
Symbol	Parameter	Value
a	Semimajor axis	1.308201 ± 0.000009 AU
q	Perihelion distance	0.899957 ± 0.000002 AU
ω	Argument of perihelion	$234.44897 \pm 0.00008^\circ$
Ω	Longitude of ascending node	$194.101138 \pm 0.000002^\circ$
i	Inclination	$2.54220 \pm 0.00004^\circ$
T_p	Perihelion time	2008 November 20.3989 ± 0.0001 UT



Carbonates in comets

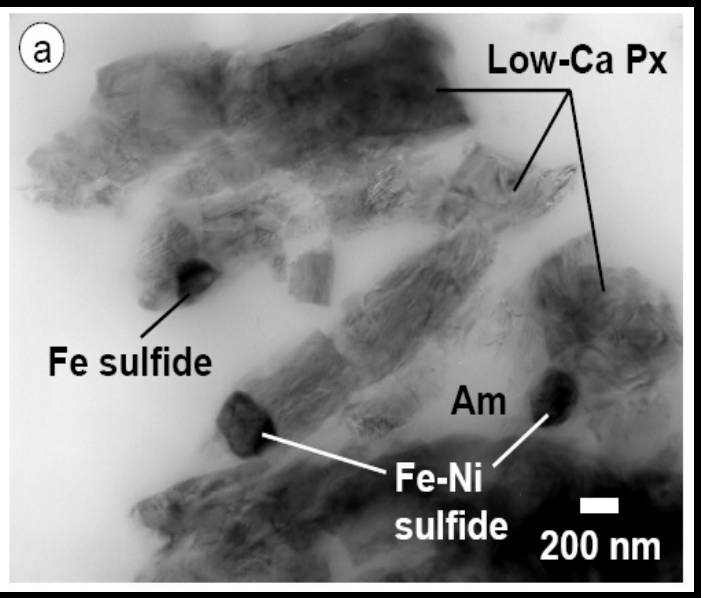


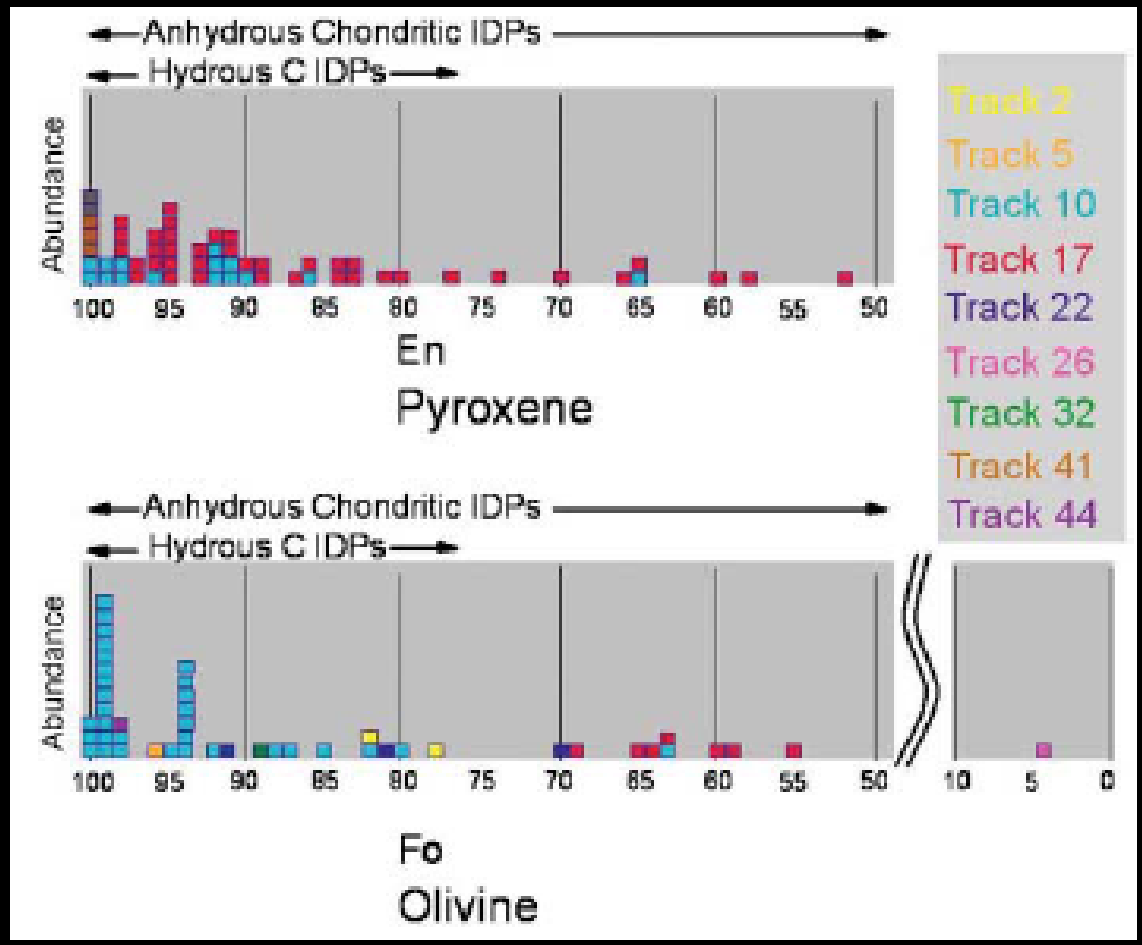
Sample# FC 3,0,2,2,1
Hugues Leroux



Phyllosilicates not found yet

Some similarities with IDPs





Zolensky et al. 2006

Brownlee et al. 2006; Zolensky et al. 2006; McKeegan et al. 2006; Sandford et al. 2006; Flynn et al. 2006; Horz et al. 2006; Keller et al.2006