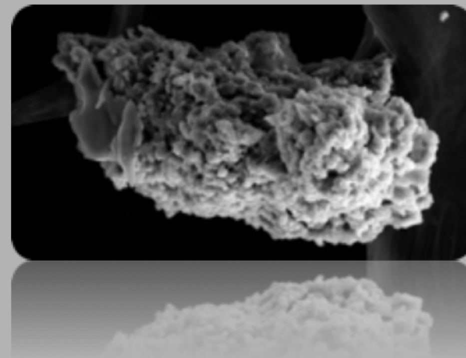
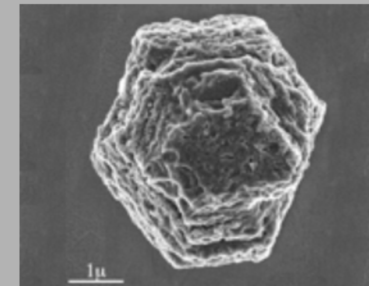
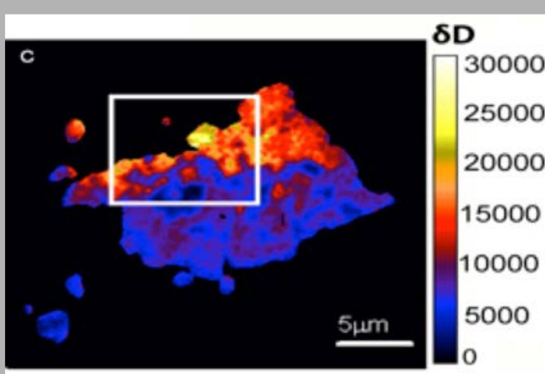


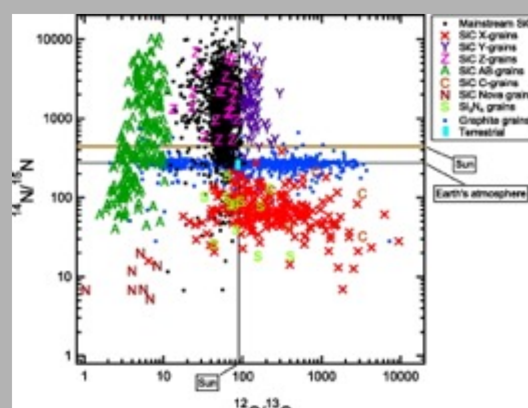


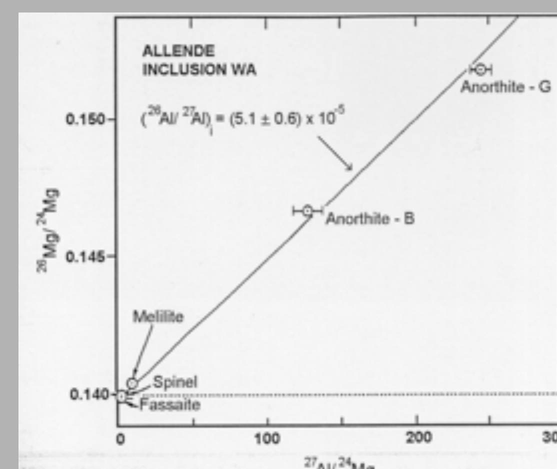
Isotopic anomalies in extra-terrestrial matter

RESANET meeting 24-08-2018

Jean Duprat
CSNSM Orsay

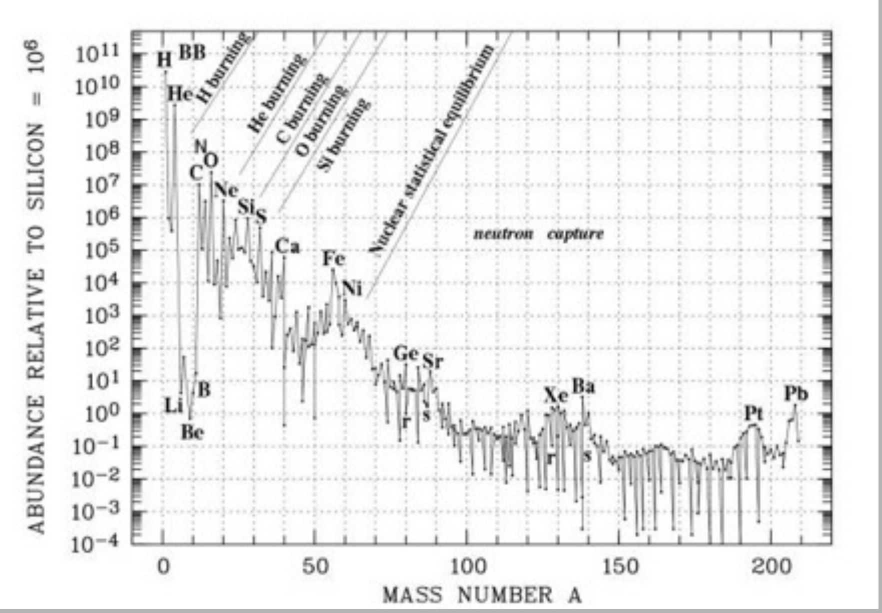


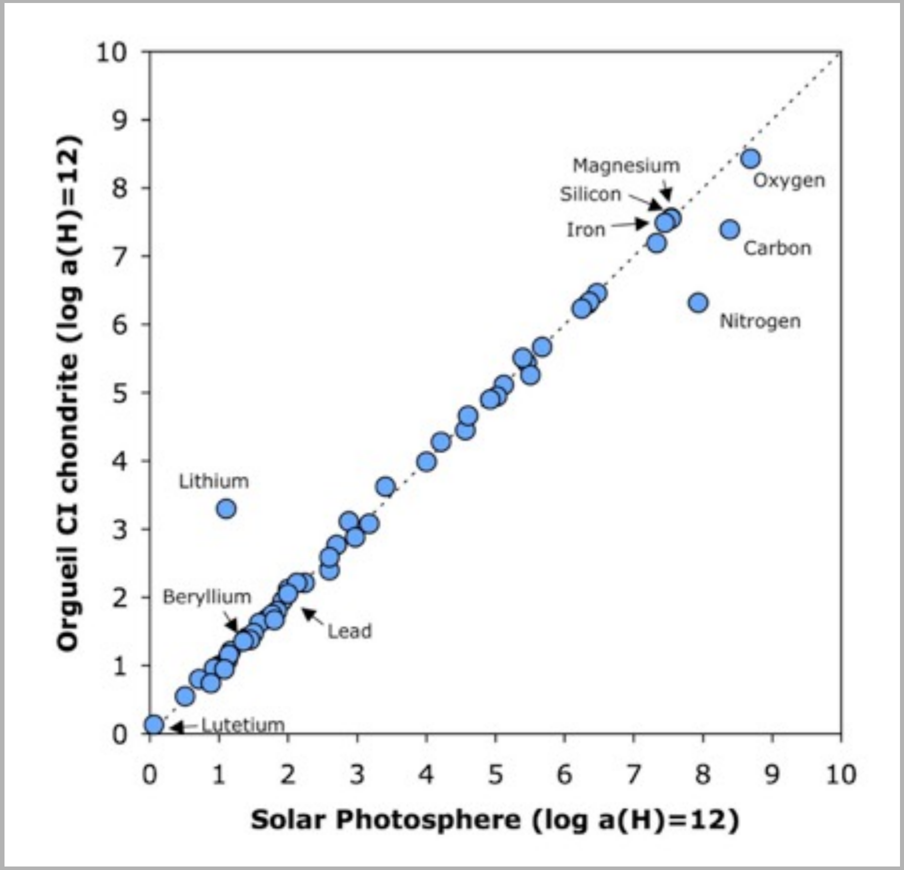




The CI reference composition

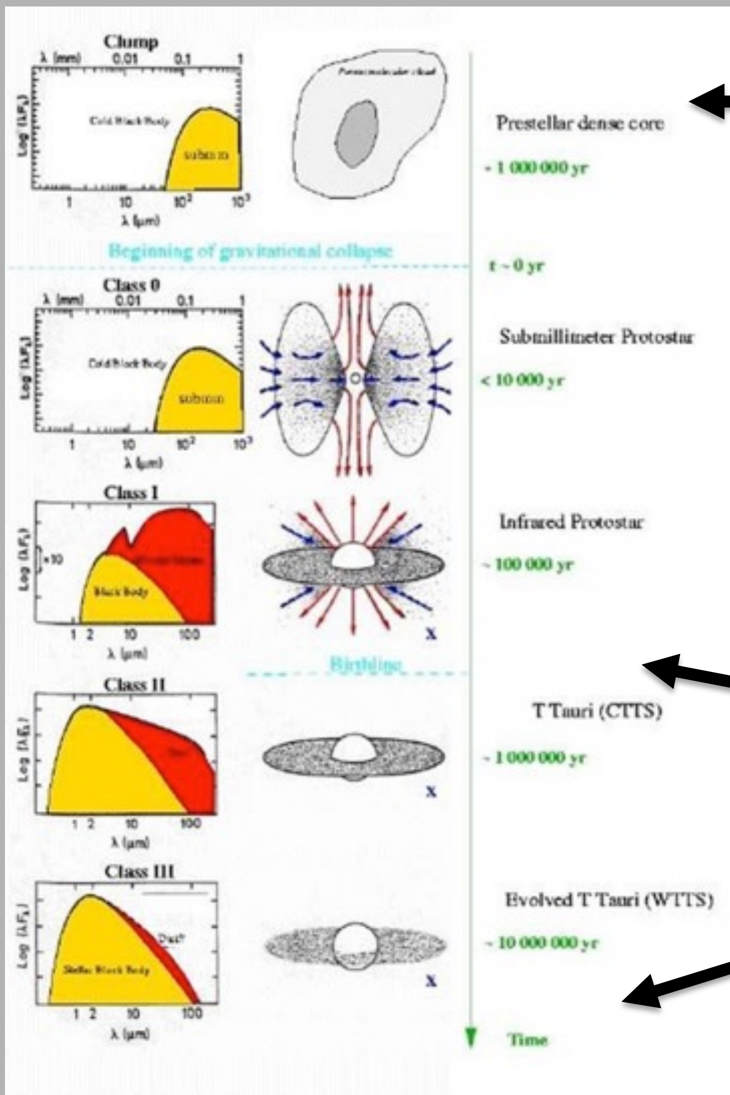
Orgueil CI meteorite





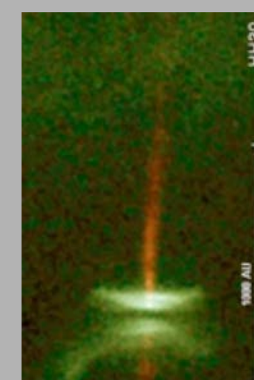
For non volatile-elements, the composition of CI meteorite is that of the Sun photosphere

Isotopic anomalies where & how ?



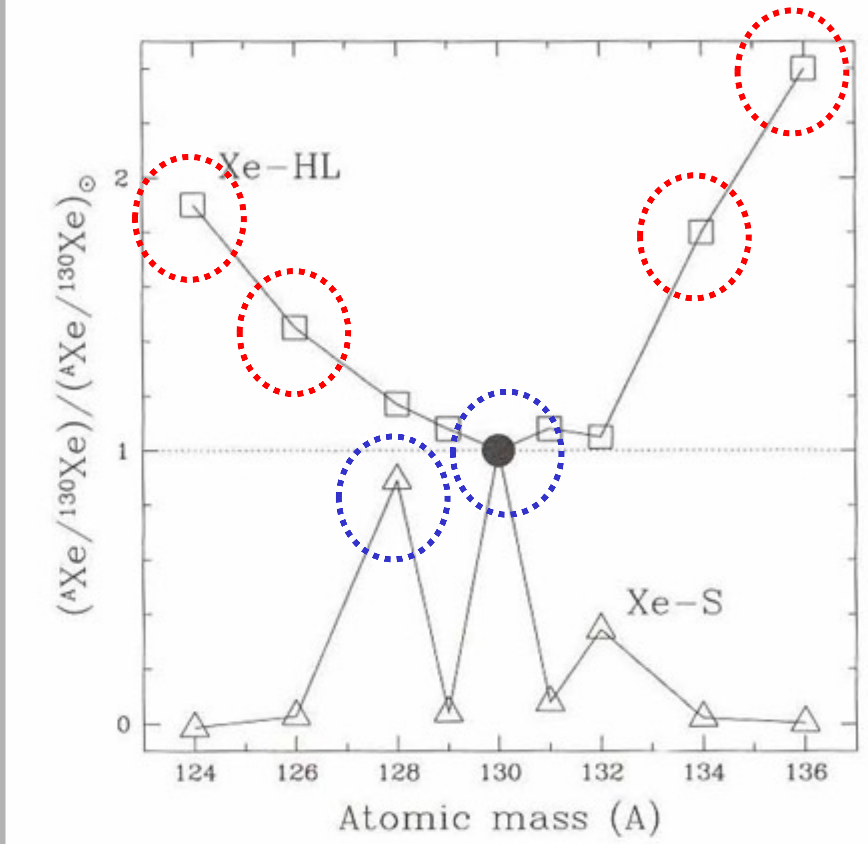
ISM heritage

- **Different types** of isotopic anomalies
- Carried by **different phases**
- **Different origins**



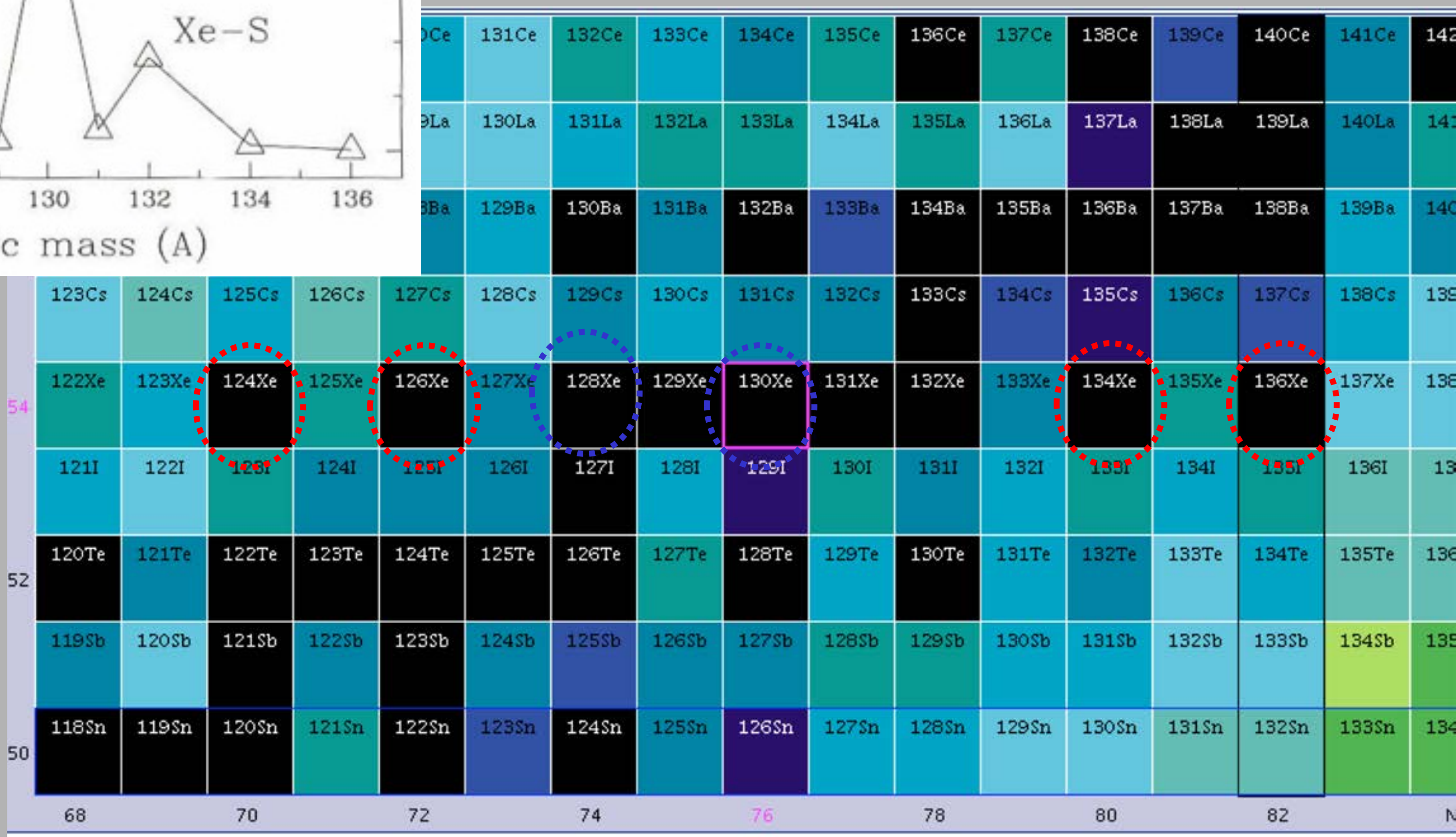
Process in the disk

Process on the parent body



The first hints : noble gases (Xe) pattern reveals strong deviations

Reynolds & Turner 1964



^{124,126}Xe : p nuclei

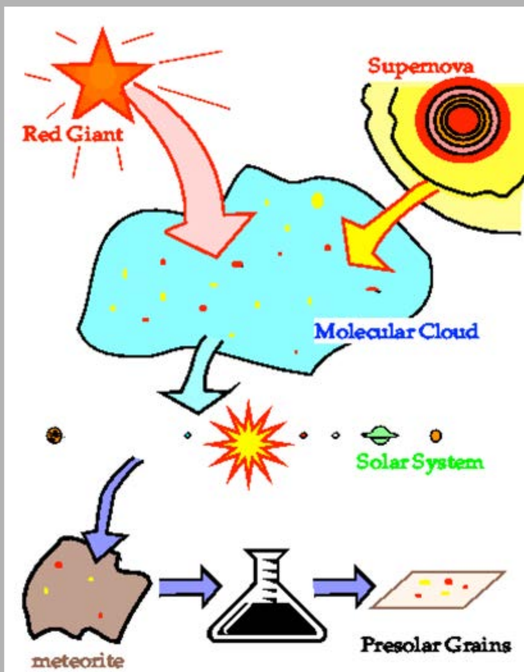
^{128,130}Xe : s nuclei

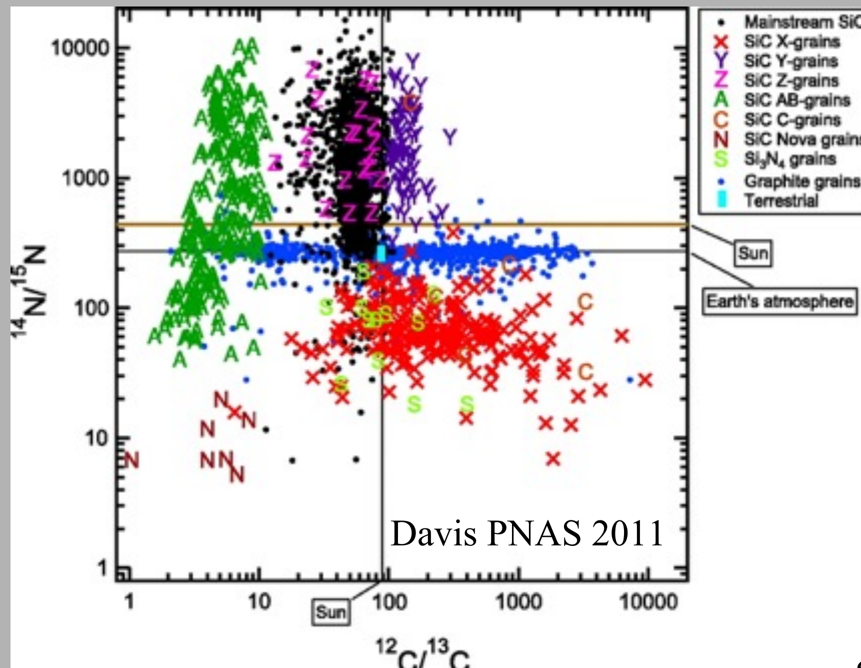
^{134,136}Xe : r nuclei

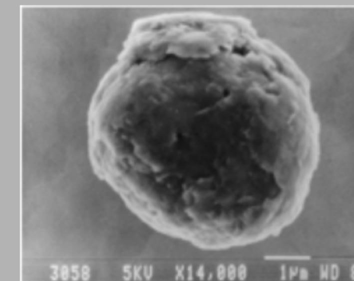
Presolar grains :

Burning down the haystack to find direct heritages from stellar envelopes
(SiC, Graphites, nano-diamants … < 10 µm)

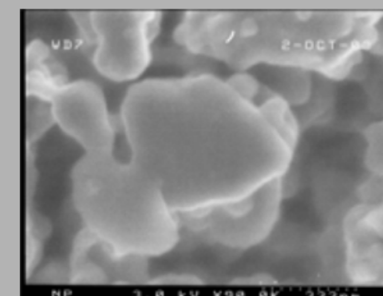
Allende meteorite



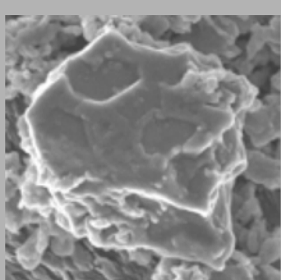


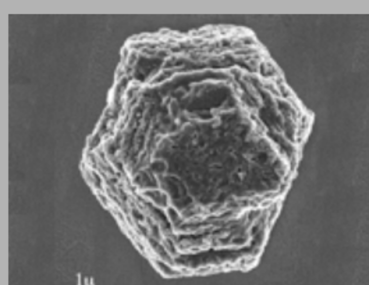


Graphite



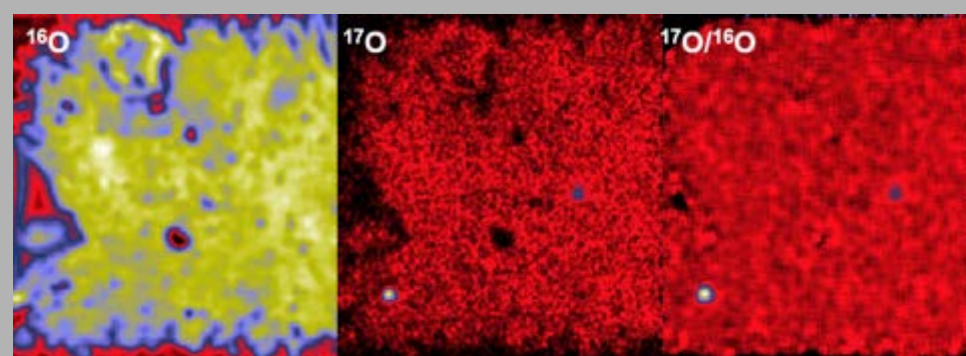
Silicates (glass, MgSiO4)





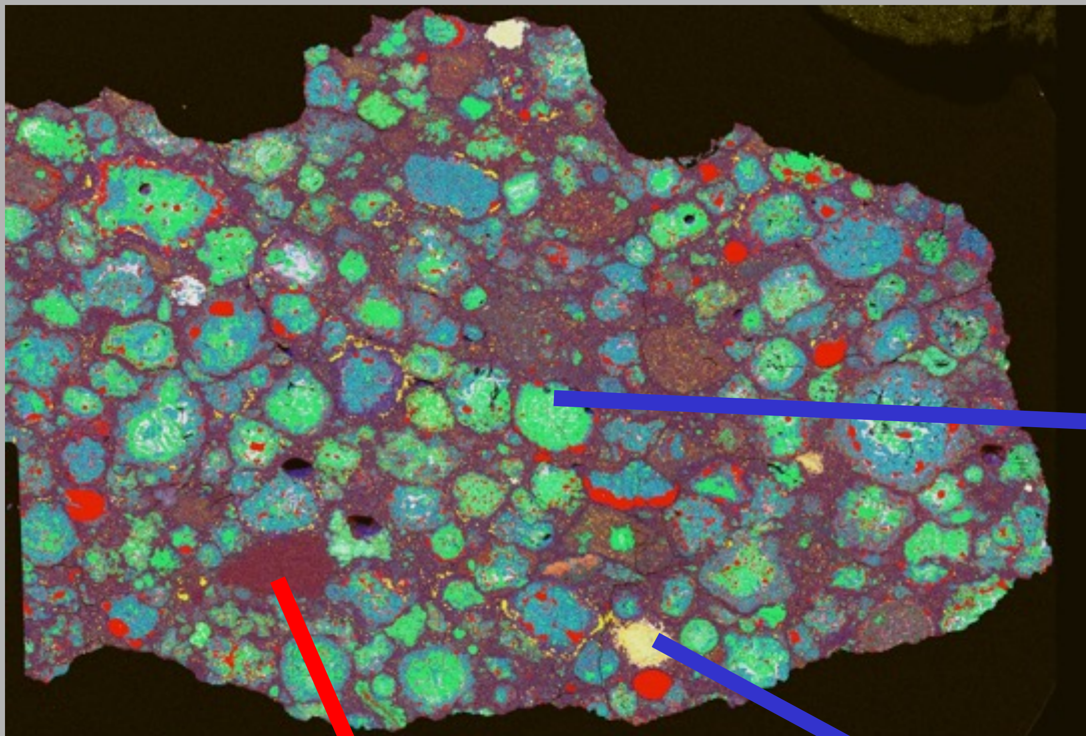
SiC

Larry Nittler,
Carnegie Institution of Washington

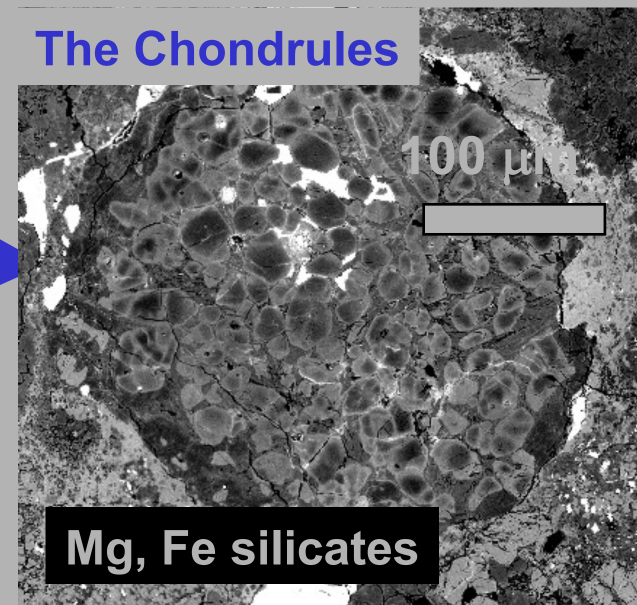


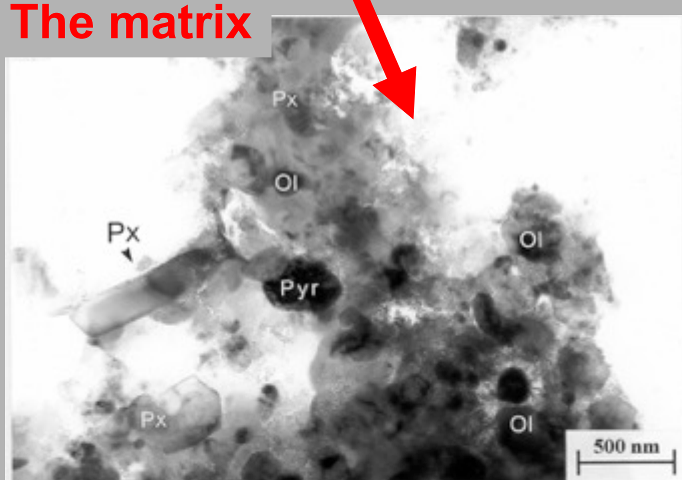
In-situ secondary ion mass image (P. Hoppe et al)

The main components in Chondrites : matrix & refractory phases

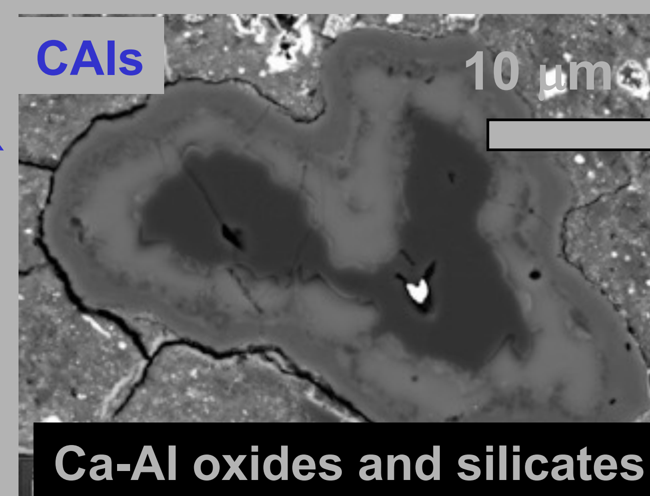


Refractory phases
the oldest solids of the solar system
Extinct radioactivities

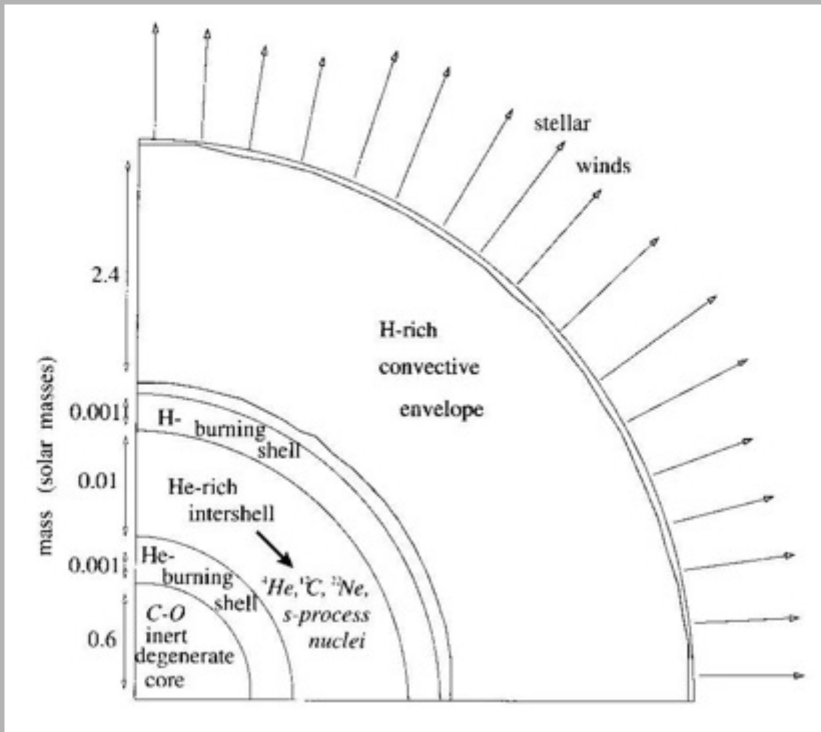


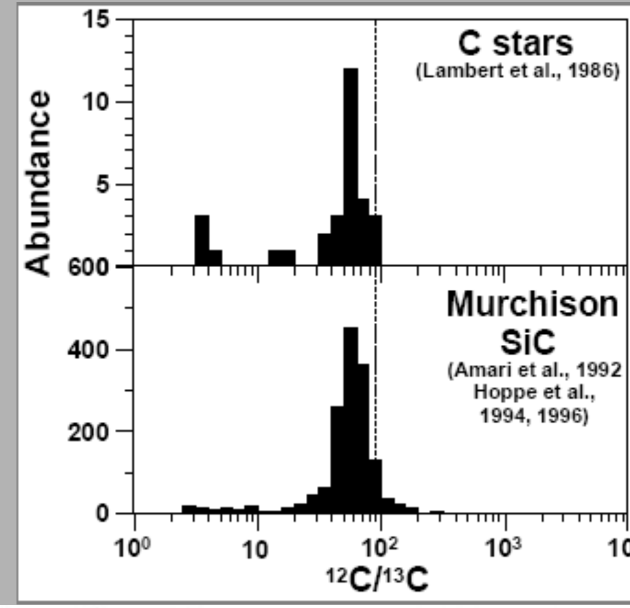


Presolar Grains
organic matter

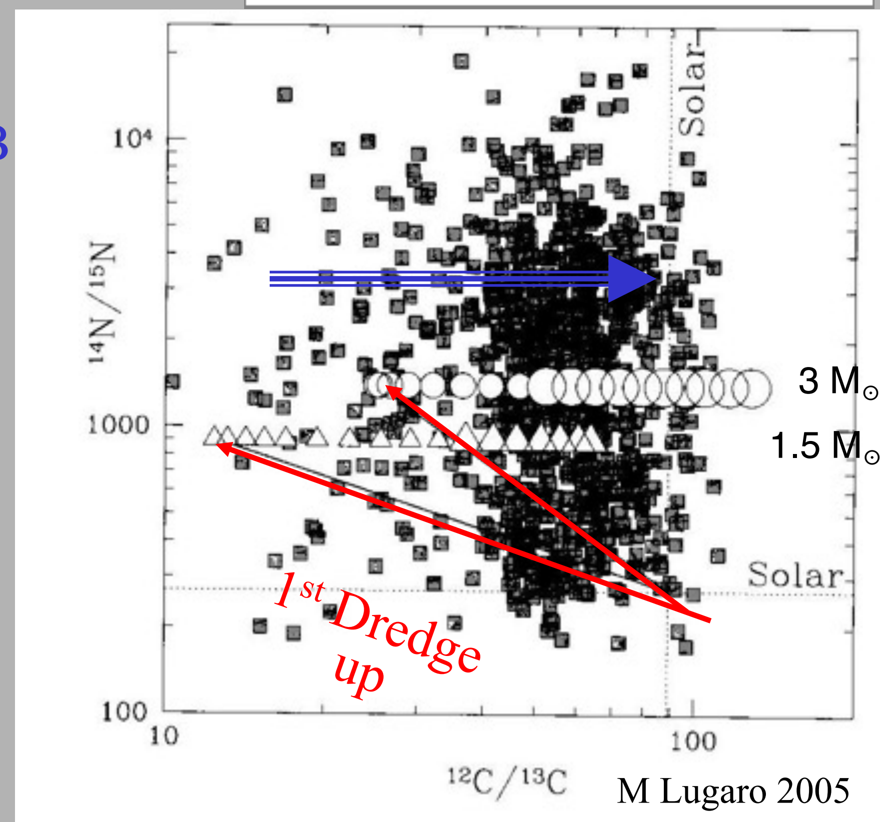


Identification of the parent type of star





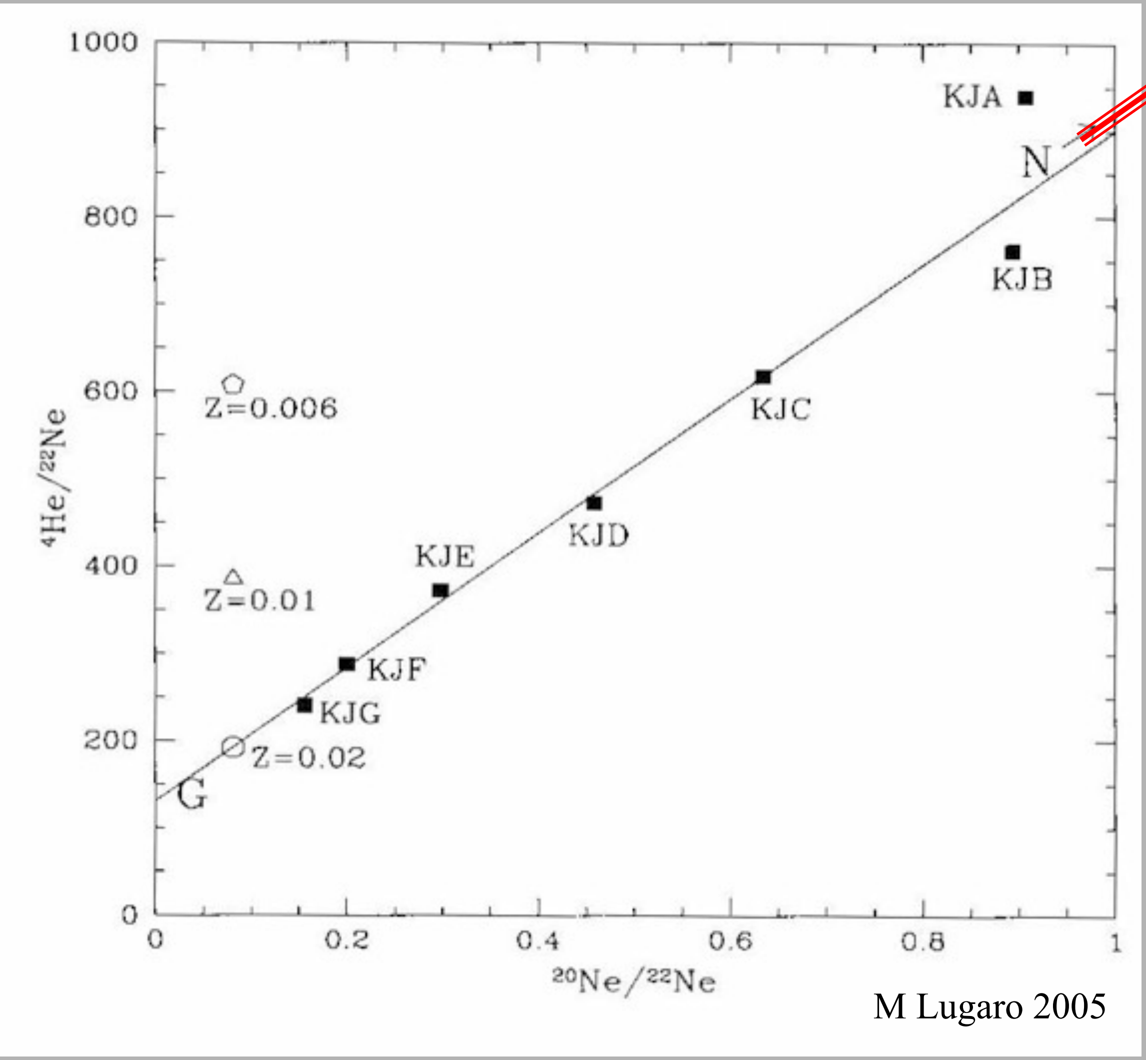
AGB
path



SiC mainstream

- Low mass star produce C-rich dust
- C-rich from He shell burning
- Rich in ^{14}N (from CNO cycle)

Ne-H in SiC



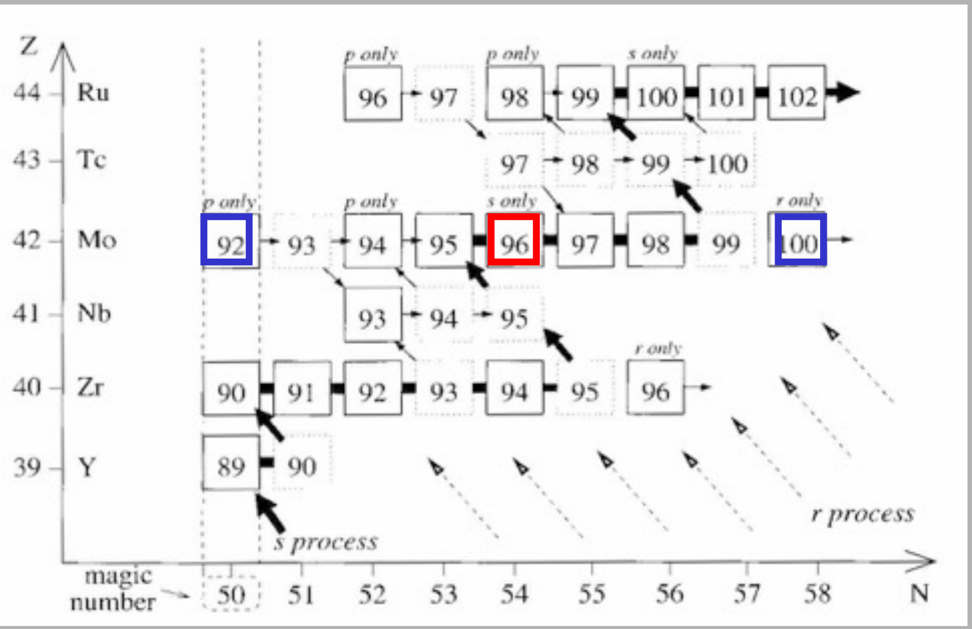
The solar end-member :

$^{4}He/^{22}Ne=2114$

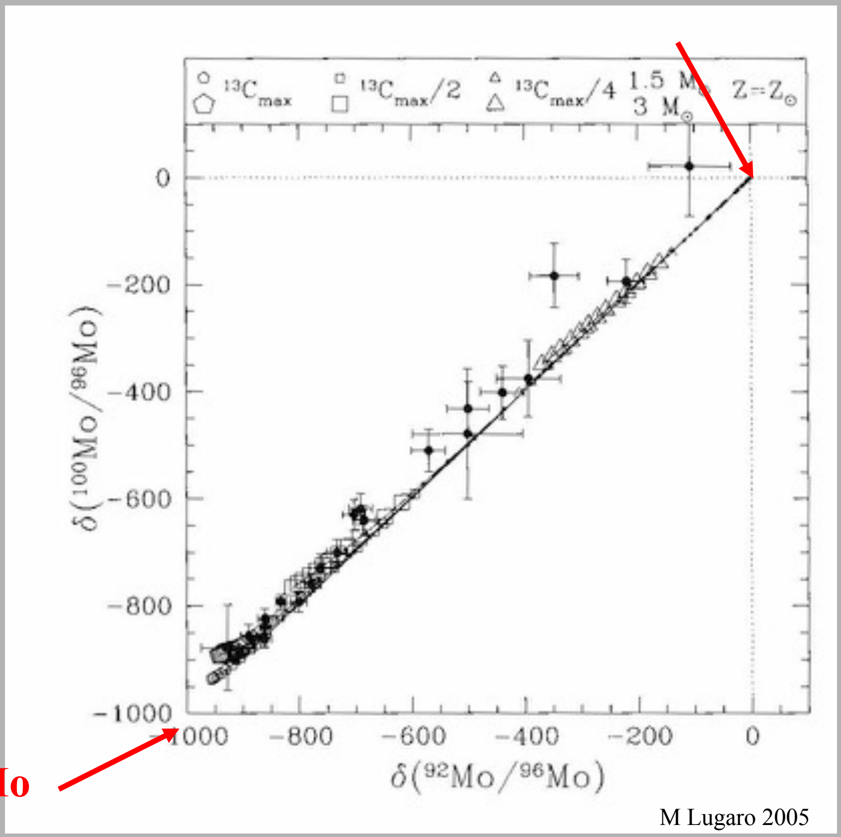
$^{20}Ne/^{22}Ne=12.4$

- The Ne is included by implantation and not condensation.
- In the He shell burning, large amount of ^{22}Ne is produced by **$^{14}N(\alpha,\gamma)^{18}O(\alpha,\gamma)^{22}Ne$**
- The linear correlation comes from a mixing between :
  - The solar end-member
  - The AGB end-member (rich in ^{22}Ne)

s-only nuclei vs. *p-only* (or *r-only)* nuclei



Solar composition (i.e. starting composition)



Mo isotopic composition in SiC

s process pure ^{96}Mo

- Mixing between a solar end-member (i.e. the star's envelope) and a pure s-process end-member
- **^{96}Mo is produced in the star (AGB) but not ^{100}Mo nor ^{92}Mo**
- **The grains are enriched in ^{96}Mo (s-only)** compared to solar
- Models taking into accounts various neutron fluxes (^{13}C pocket) for two stellar masses (1.5 and 3 $M_\odot$) can account for the data.
- The large symbols show when the condensation is possible (C/O>1)

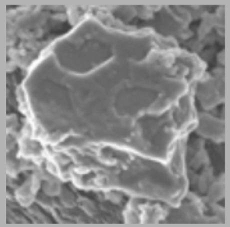
Si isotopes in mainstream SiC

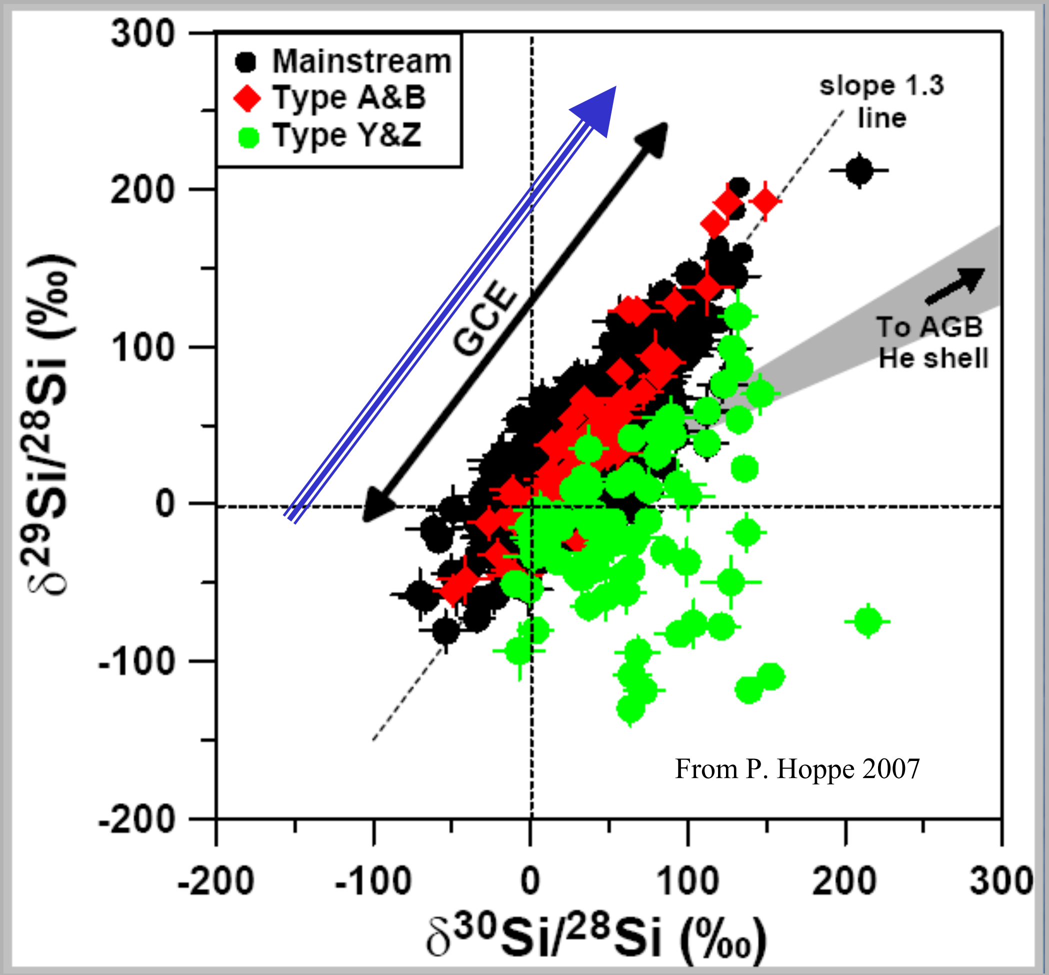
- ^{28}Si is a primary nucleus
- ^{29,30}Si are secondary nuclei

Galactic Chemical Evolution

produce heavier Si,

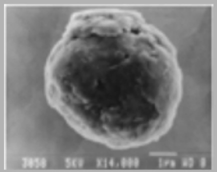
i.e. enrichments in ^{29,30}Si

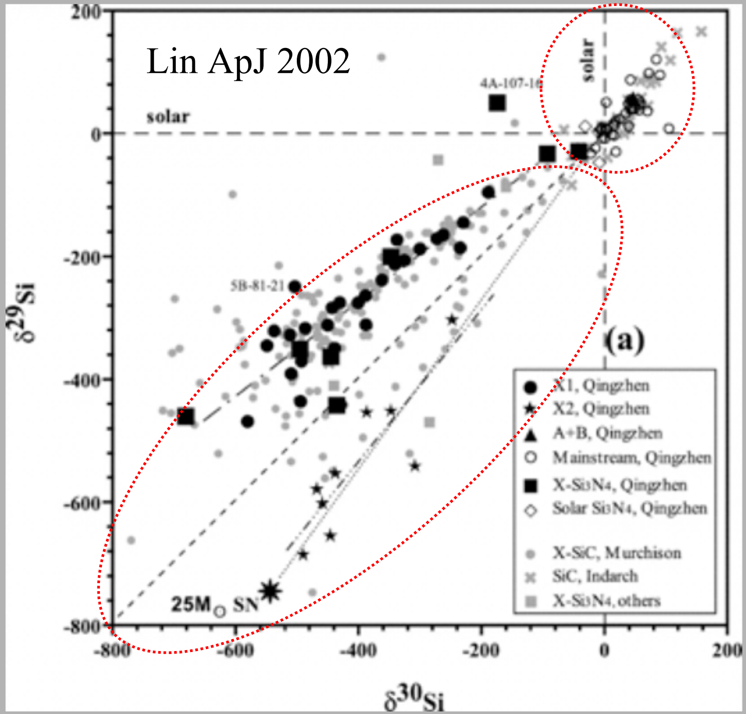


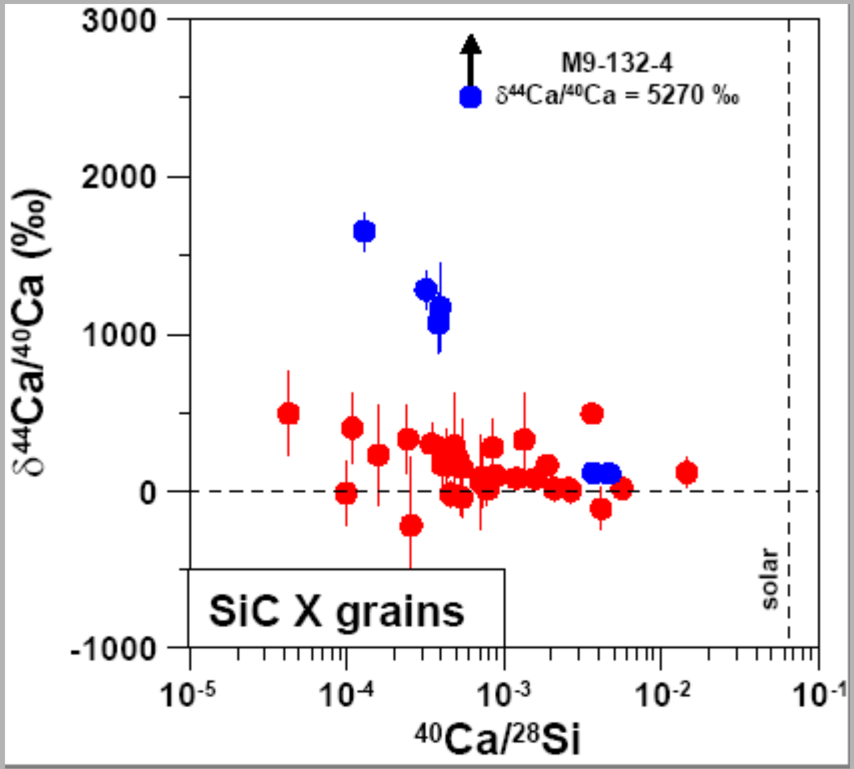


However, part of **SiC mainstream Si isotopic abundances** appears **younger than the Sun…**

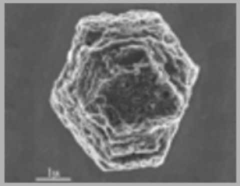
Pre-solar grains & massive stars







^{28}Si-rich SiC type X



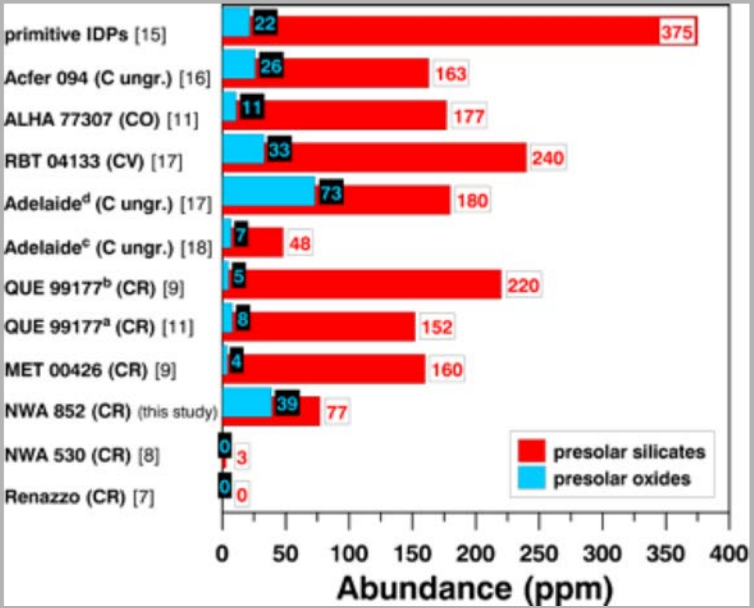
$$\delta\left(\frac{^{29}Si}{^{30}Si}\right)=\left(\left(\frac{^{29}Si}{^{30}Si}\right)_{sample}\Bigg/\left(\frac{^{29}Si}{^{30}Si}\right)_{\oplus}-1\right)\times 1000$$

^{44}Ca excesses in-situ decay of ^{44}Ti

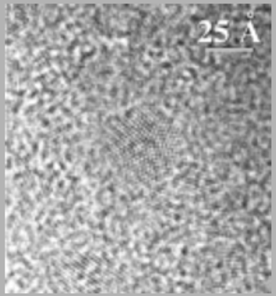
- ^{44}Ti (N=Z) $\rightarrow$ ^{44}Sc $\rightarrow$ ^{44}Ca
  - ^{44}Ti ($t_{1/2}$=60 years)

Presolar grains abundances

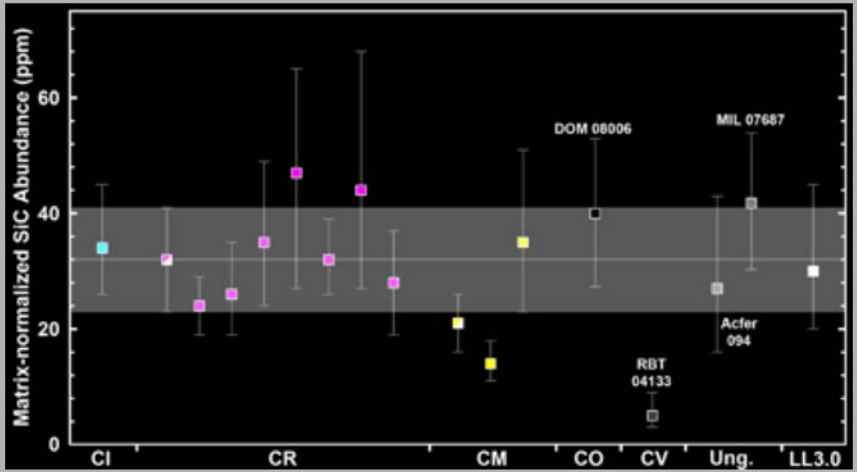
- **AGB stars** > 90% of SiC, Silicates, Oxides
- **Type II SN**, <10% of SiC, Silicates Oxides, < 50% graphite, 100% of Si3N4
- **Novae** <1% SiC, Silicates, Oxides graphite ?

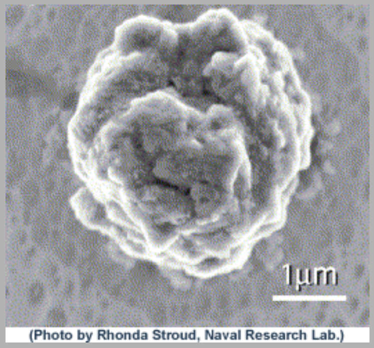


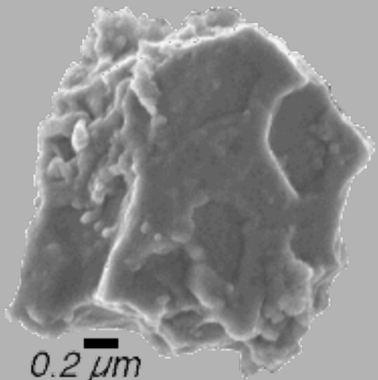
Leitner + 2010 (NIC)



SiC in Chondrites about 30 ppm

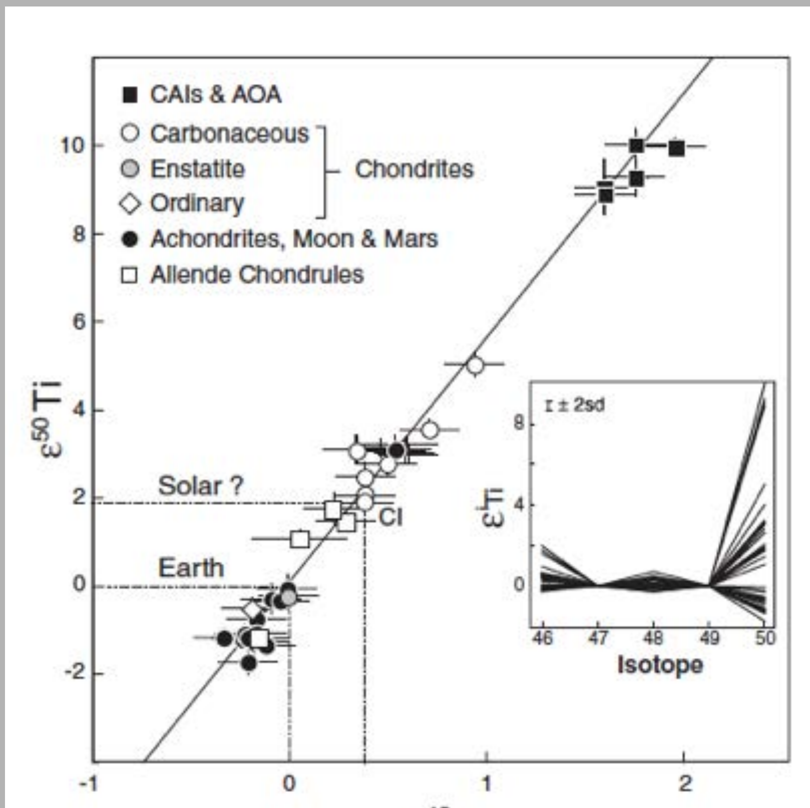




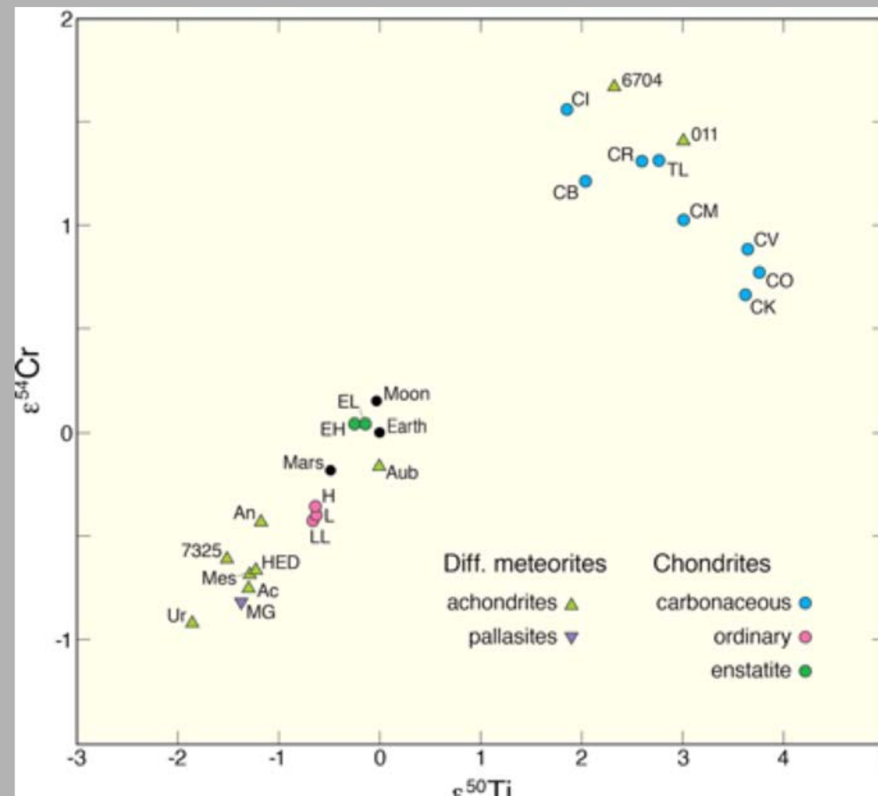


Nittler 2018 (from Davison GCA 2014)

High precision isotopic data reveals that **planets and asteroids have slightly different bulk isotopic compositions**



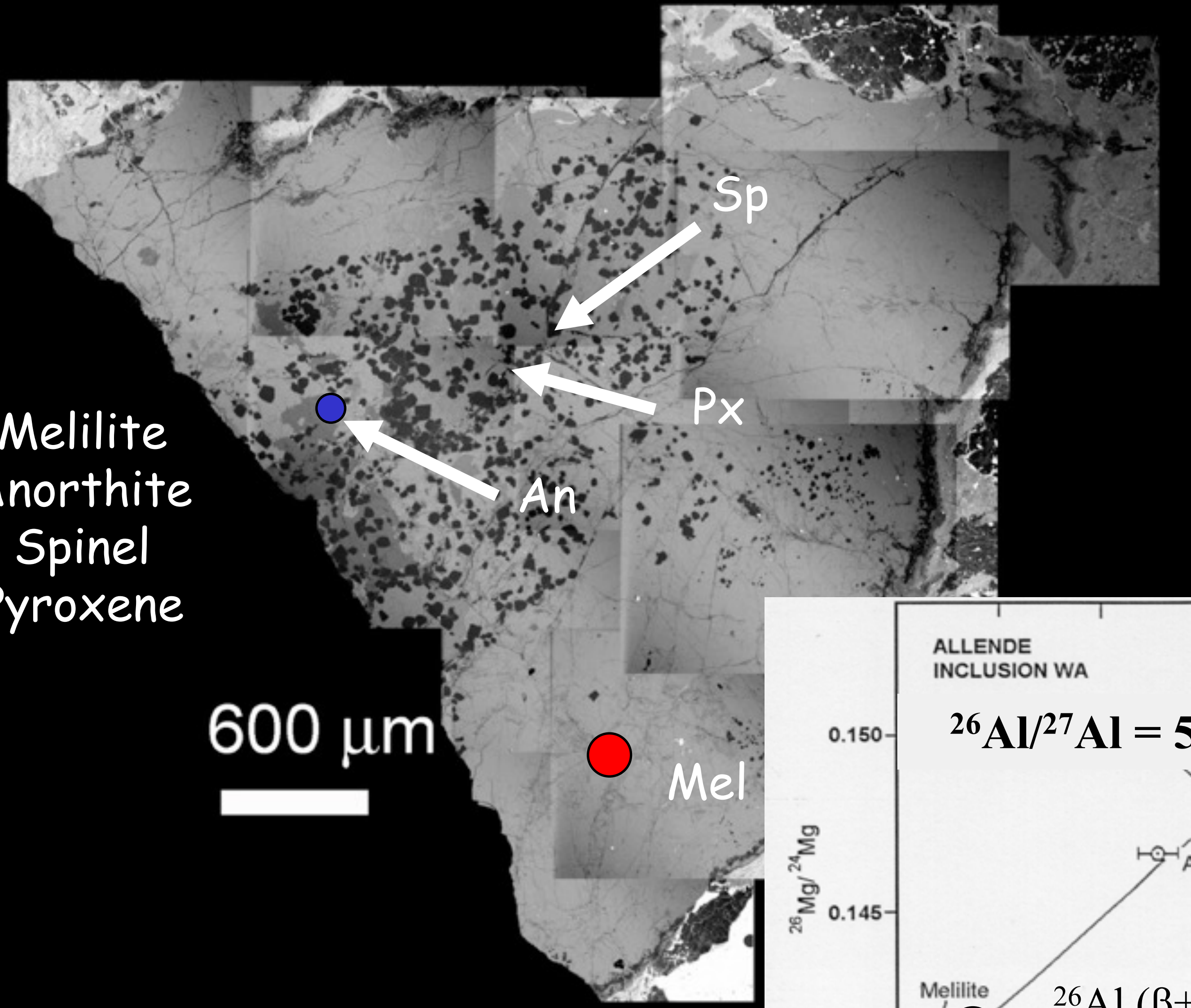
Trinquier Science 2009



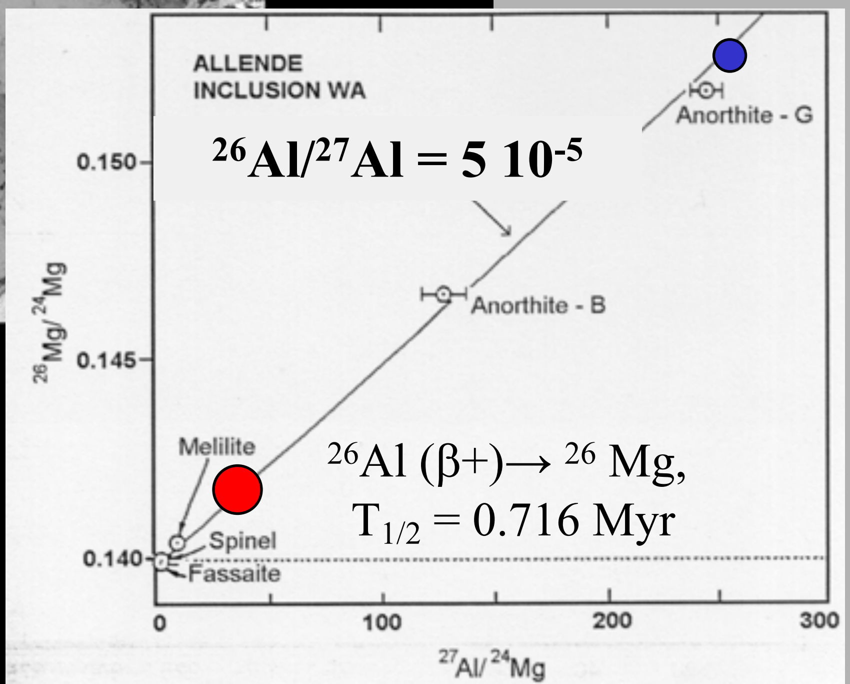
ε^{50}Ti is deviation of 10^{-4} from the Earth ^{50}Ti/ ^{47}Ti (i.e 0,01 %)

Scott et al ApJ 2018

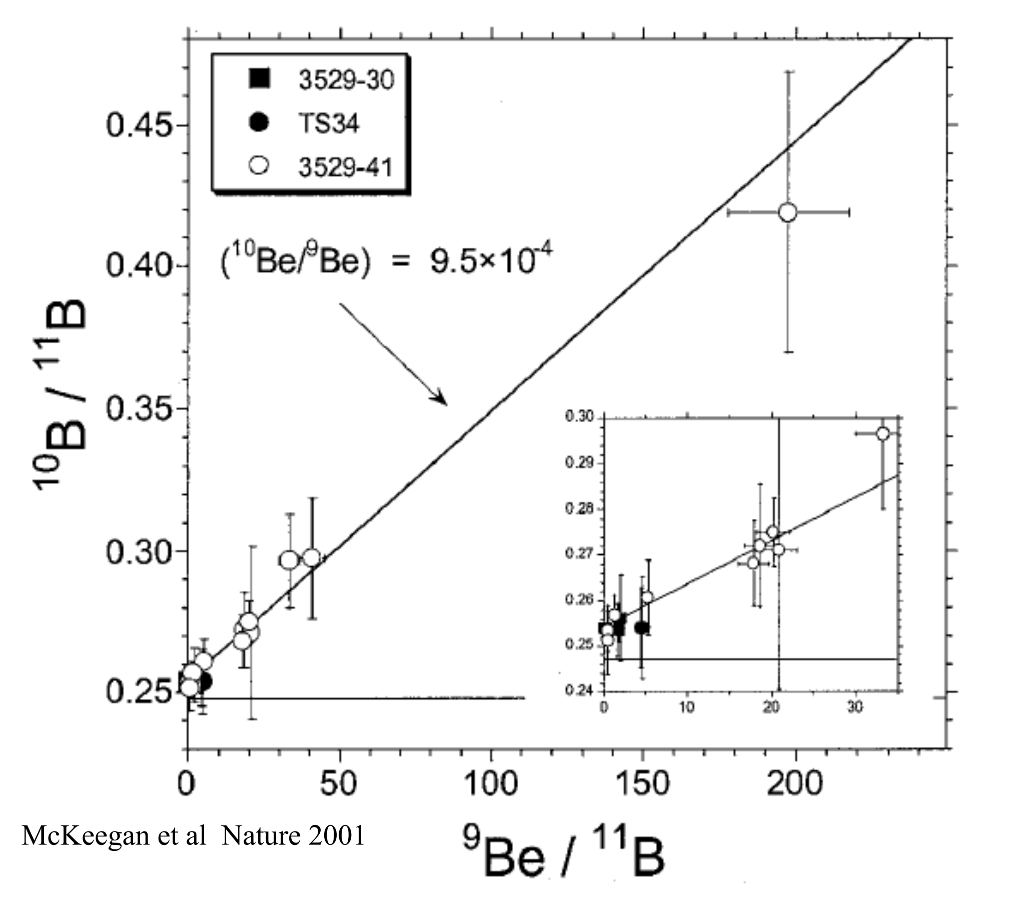
Isotopic anomalies in refractory phases



Lee et al. (1976)

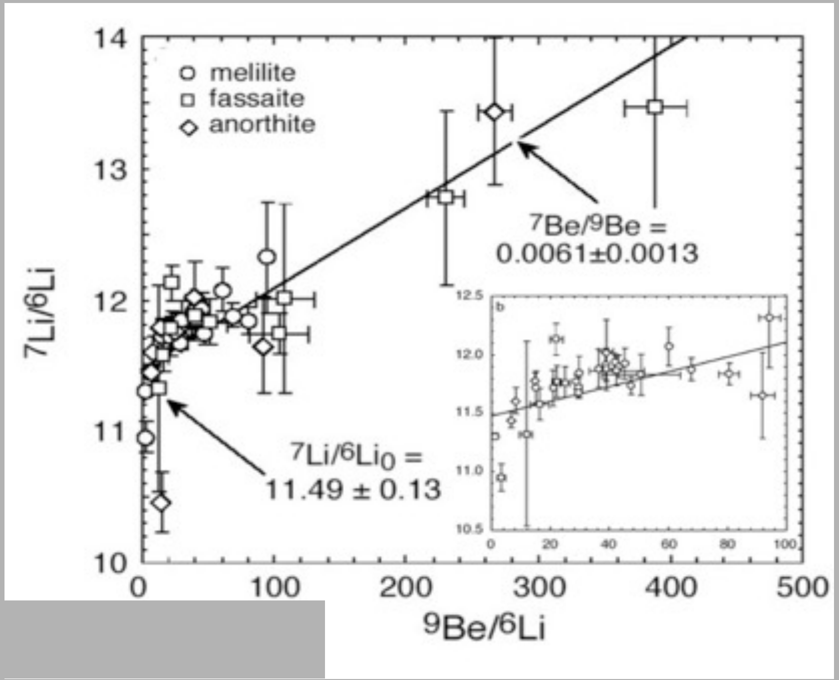


Non-thermal nucleosynthesis



McKeegan et al Nature 2001

^{10}Be (β^-) → ^{10}B, $T_{1/2}$ = 1.4 Myr



Still uncertain :

^{7}Be ($T_{1/2}$ = 53 days) → ^{7}Li, $^{7}Be/^{9}Be$ = 6 10^{-3} ?

M. Chaussidon et al 2006

^{10}Be spallation on CNO,

Irradiation by high energy particles

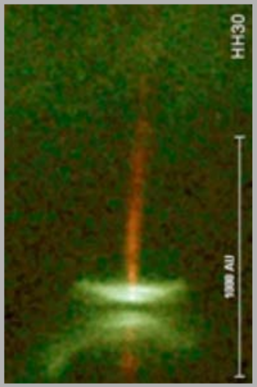
There is clear evidence for the presence of short -lived (10^5-10^6 yrs) nuclei in the protoplanetary disk

Table 1
Mean life times and abundances of short-lived nuclides, uniform production (UP) and early Solar System invento

Radioactive isotope (R)	Reference isotope (I)	Process	Mean life $\bar{\tau}_R$ (Myr)	$(N^R/N^I)_{ESS}$	$(N^R/N^I)_{UP}$ $\Delta_1 = 0$ Myr
^{238}U	^{232}Th	$r; r$	$6.45 \times 10^3; 2.03 \times 10^4$	0.438	0.388
^{235}U	^{238}U	$r; r$	$1.02 \times 10^3; 6.45 \times 10^3$	0.312	0.289
^{244}Pu	^{232}Th	$r; r$	$115; 2.03 \times 10^4$	3×10^{-3}	5.6×10^{-3}
	^{238}U	$r; r$	$115; 6.45 \times 10^3$	6×10^{-3}	1.4×10^{-2}
^{247}Cm	^{235}U	$r; r$	$22.5; 1.02 \times 10^3$	$(< 2 \times 10^{-3}; < 10^{-4})$	8.9×10^{-3}
^{182}Hf	^{180}Hf	$r; r, s$	13; stable	2.0×10^{-4}	4.5×10^{-4}
^{146}Sm	^{144}Sm	$p; p$	148; stable	1.0×10^{-2}	1.5×10^{-2}
^{92}Nb	^{93}Nb	$p; s$	52; stable	?	1.0×10^{-4}
^{135}Cs	^{133}Cs	$r, s; r, s$	2.9; stable	1.6×10^{-4}?	2.1×10^{-4}
^{205}Pb	^{204}Pb	$s; s$	22; stable	?	–
^{129}I	^{127}I	$r; r, s$	23; stable	1.0×10^{-4}	$(2–5) \times 10^{-3}$
^{107}Pd	^{108}Pd	$s, r; r, s$	9.4; stable	2.0×10^{-5}	6.2×10^{-4}
^{60}Fe	^{56}Fe	eq, exp, r	2.2; stable	$(2 \times 10^{-7}; 2 \times 10^{-6})$	5×10^{-7}
^{53}Mn	^{55}Mn	p, exp; exp	5.3; stable	$(\sim 6 \times 10^{-5}; 5 \times 10^{-6})$	$\sim 1 \times 10^{-4}$
^{41}Ca	^{40}Ca	s, exp; exp	0.15; stable	1.5×10^{-8}	2×10^{-8}
^{36}Cl	^{35}Cl	s; exp	0.43; stable	5×10^{-6}	3.8×10^{-7}
^{26}Al	^{27}Al	p; exp	1.03; stable	5×10^{-5}	$\sim 10^{-7}$
^{10}Be	^{9}Be	spallation	2.3; stable	1×10^{-3}	0

Wasserburg et al Nucl. Phys; A 2006

- **Last minute stellar nucleosynthesis**
- What was the context of the solar system birth ?
- Correlation with other anomalies (the carrier phases?)



HH30, HST, (©Burrows, STSci/ESA, WFPC2, NASA

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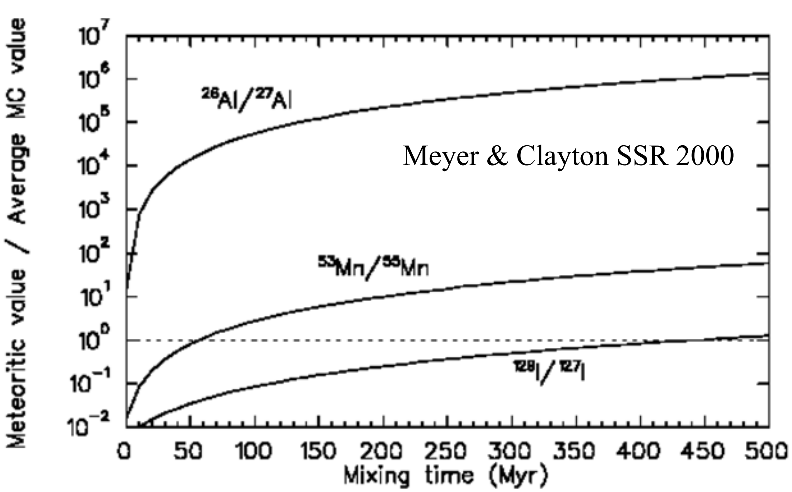
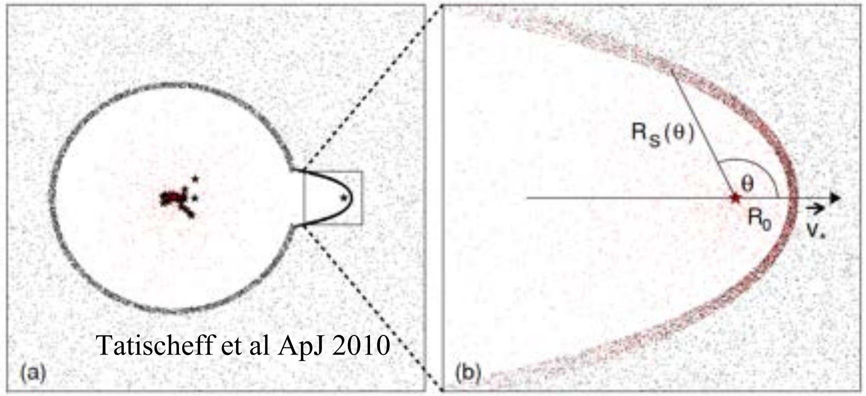
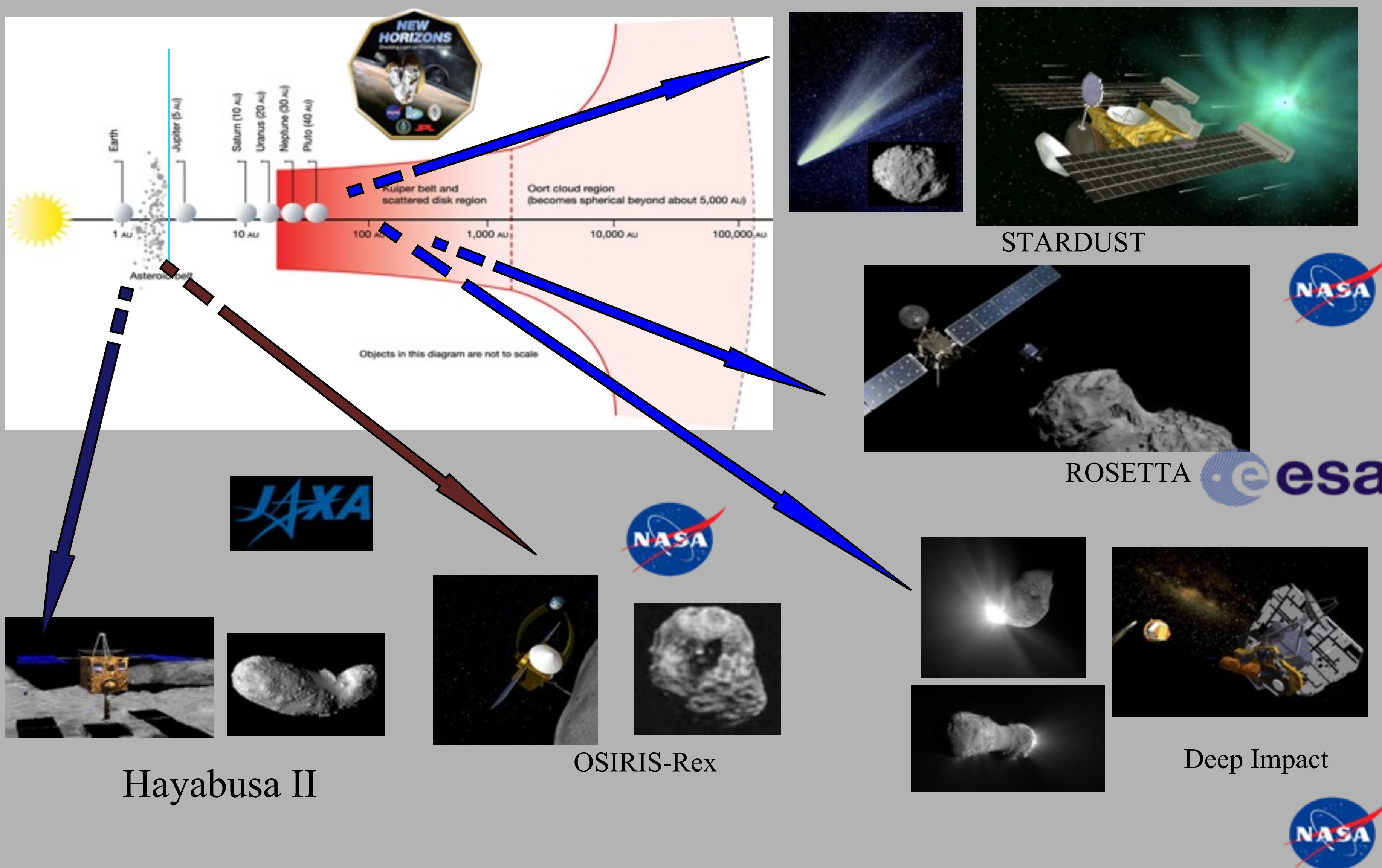


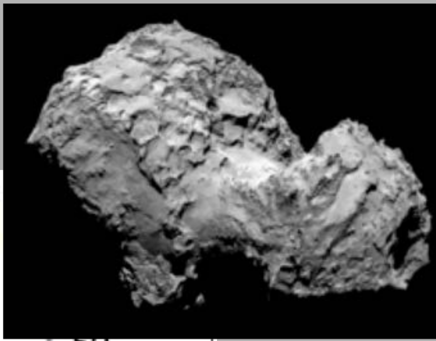


Tatischeff et al ApJ 2010

Asteroids and comets, a major goal for space missions



ROSETTA Mission



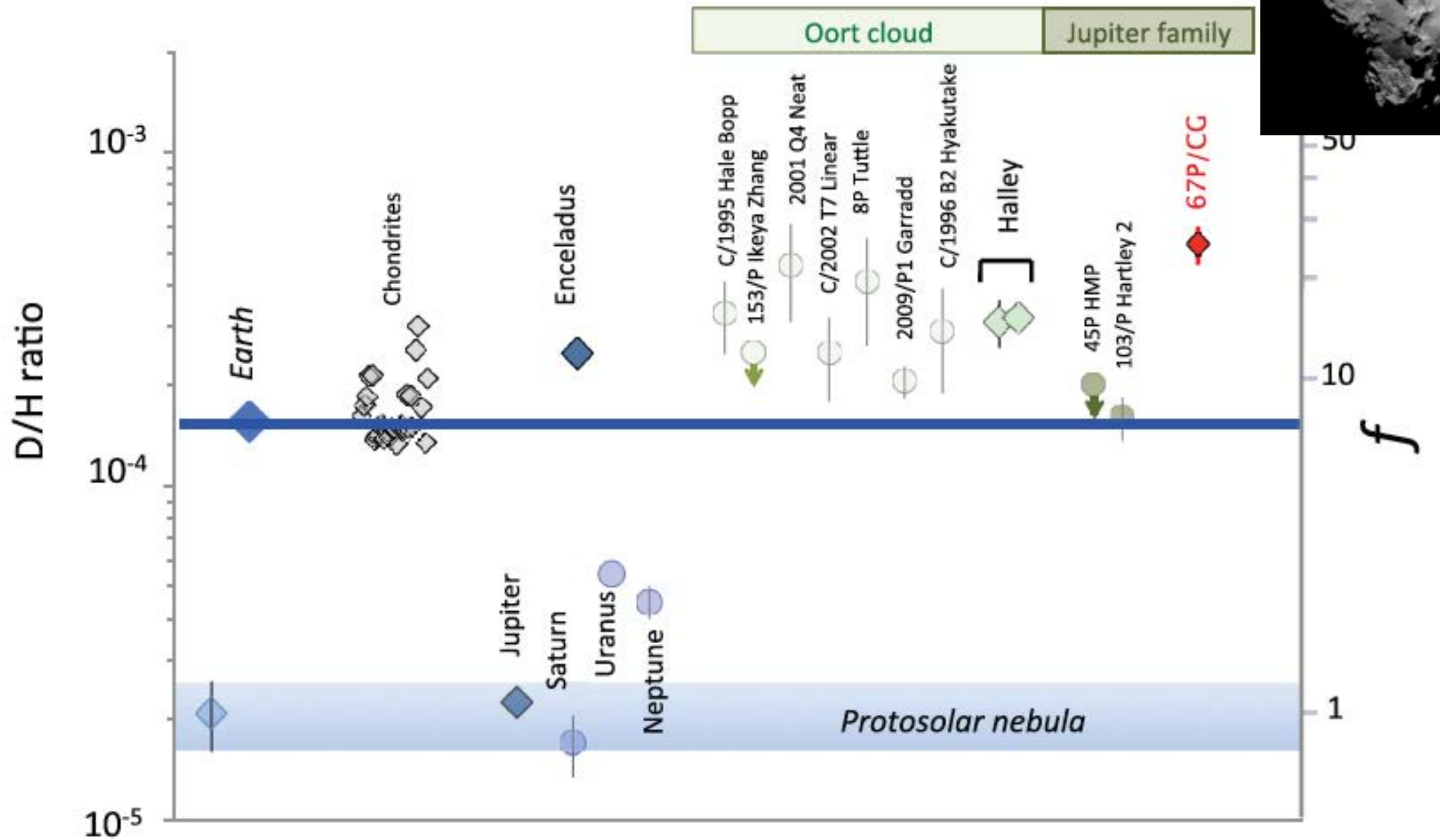
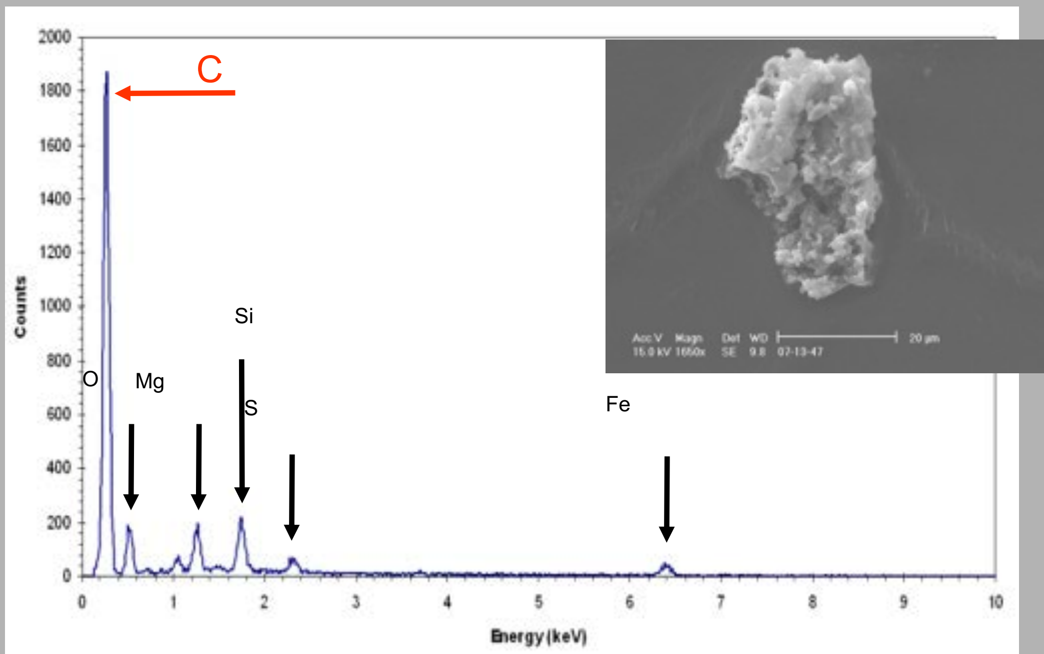


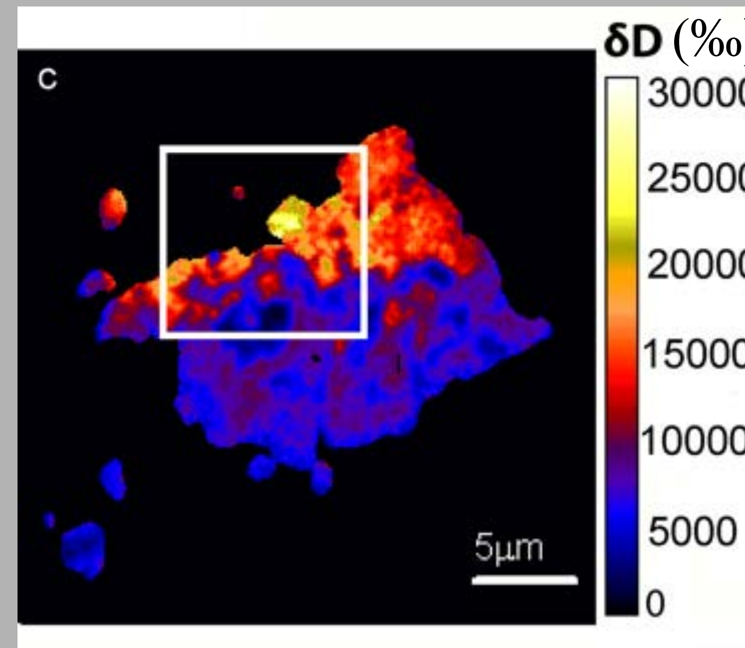
Fig. 3. D/H ratios in different objects of the solar system. Data are from (1, 2, 5–7, 26–28) and references therein. Diamonds represent data obtained by means of in situ mass spectrometry measurements, and circles refer to data obtained with astronomical methods.

K. Altwegg et al. Science 2015

A new type of interplanetary material



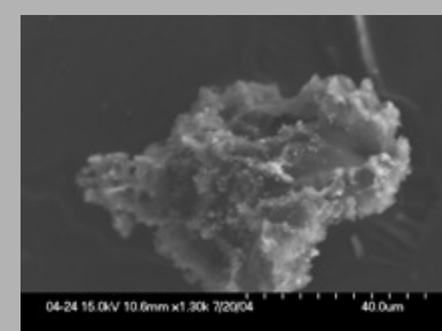
Dobrica, Engrand et al. LPSC 2008



Duprat et al. Science 2010

UltraCarbonaceous Antarctic MicroMeteorites (UCAMMs)

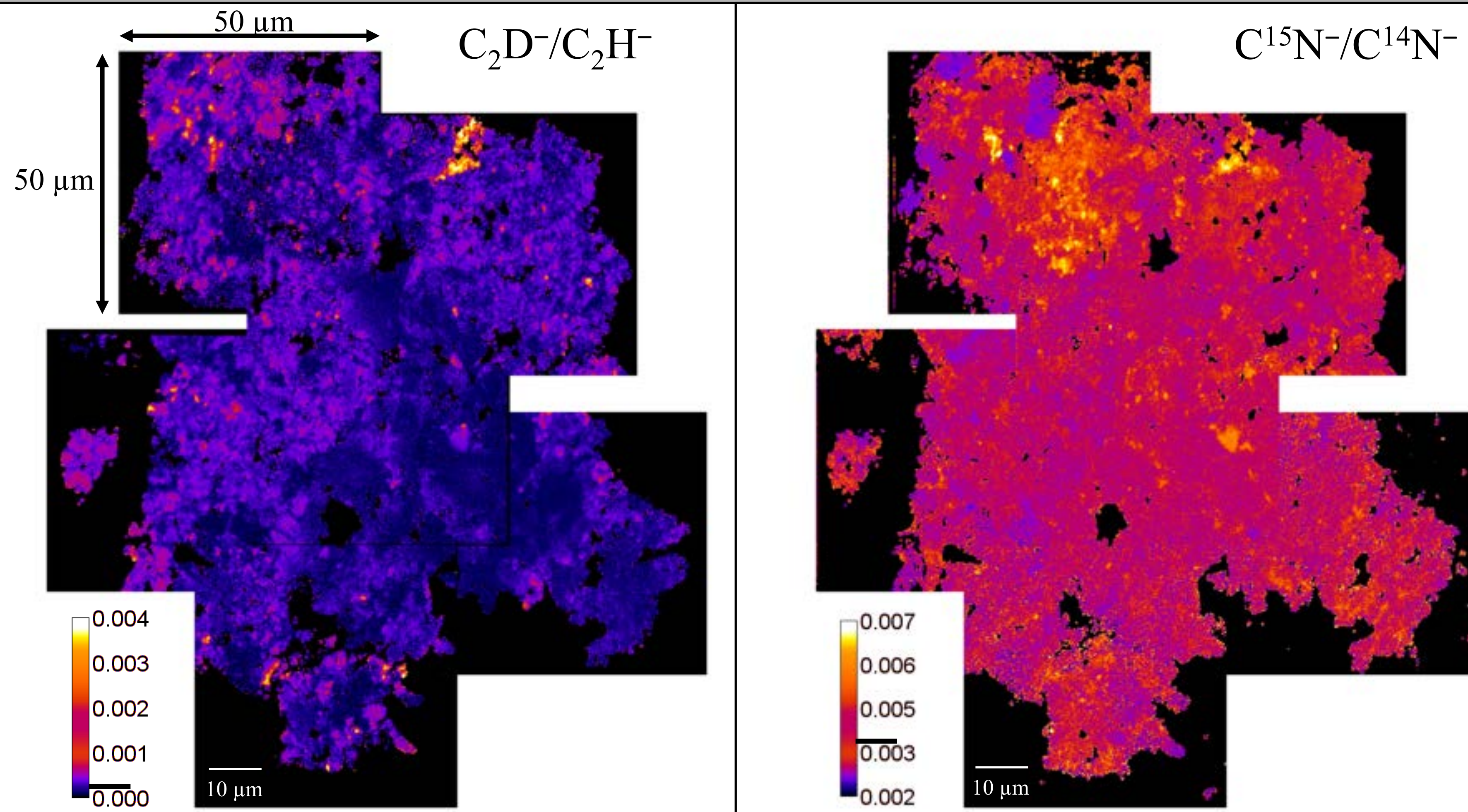
In UCAMMs, the organic matter represent more than 50 vol%



It is possible to recover cometary particles at Earth surface

C_2D^-/C_2H^- and $C^{15}N^-/C^{14}N^-$ spatial correlations on the UCAMM DC94 fragment

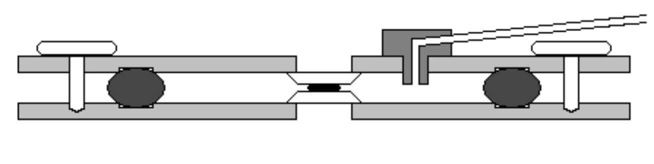
ImageJ

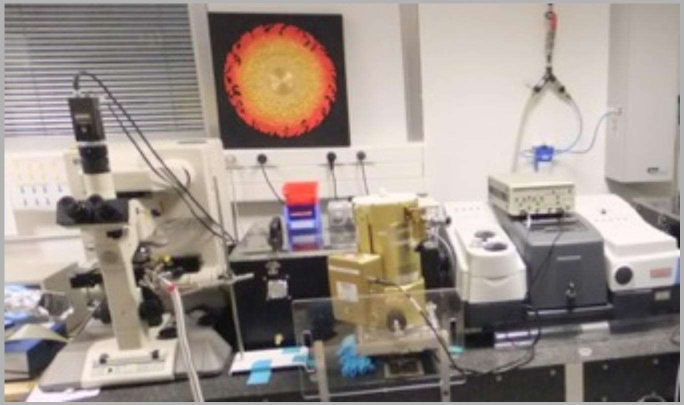


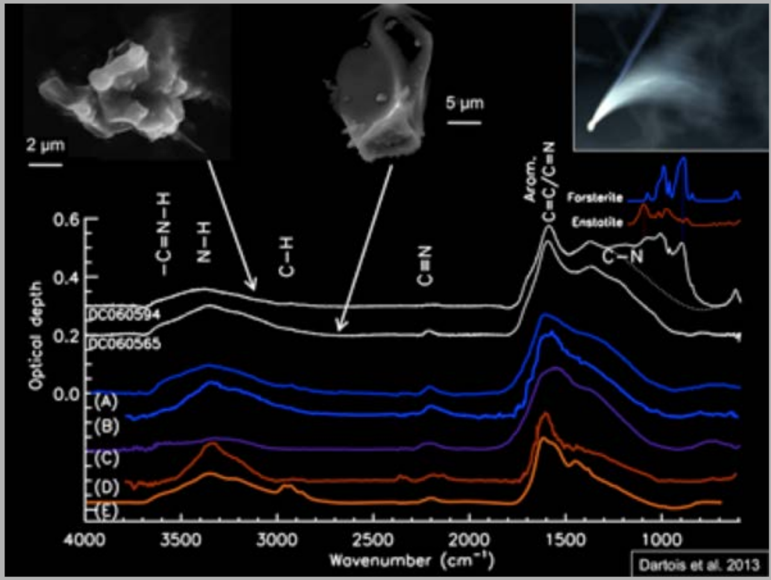
Bardin et al Metsoc 2015

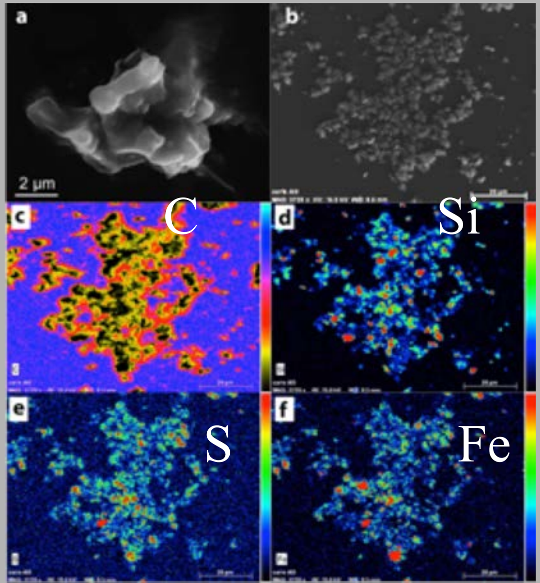
UCAMM organics are N-rich

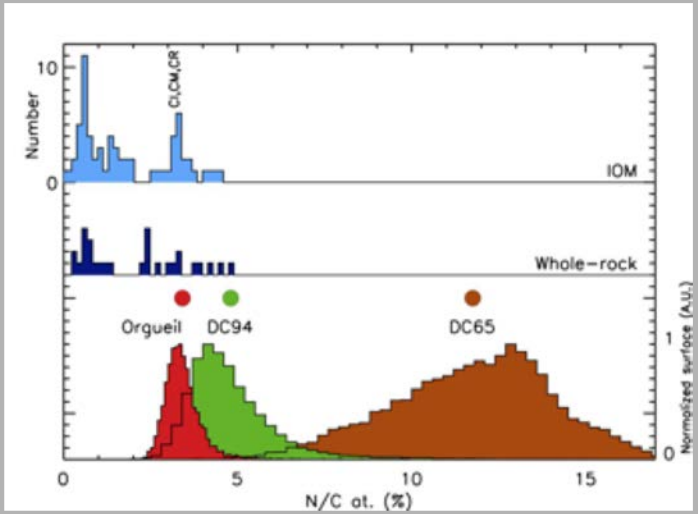
- ✓ Infra-Red transmission microanalyses @ synchrotron SOLEIL
- ✓ Elemental isotopic composition : NanoSIMS and electron microprobe





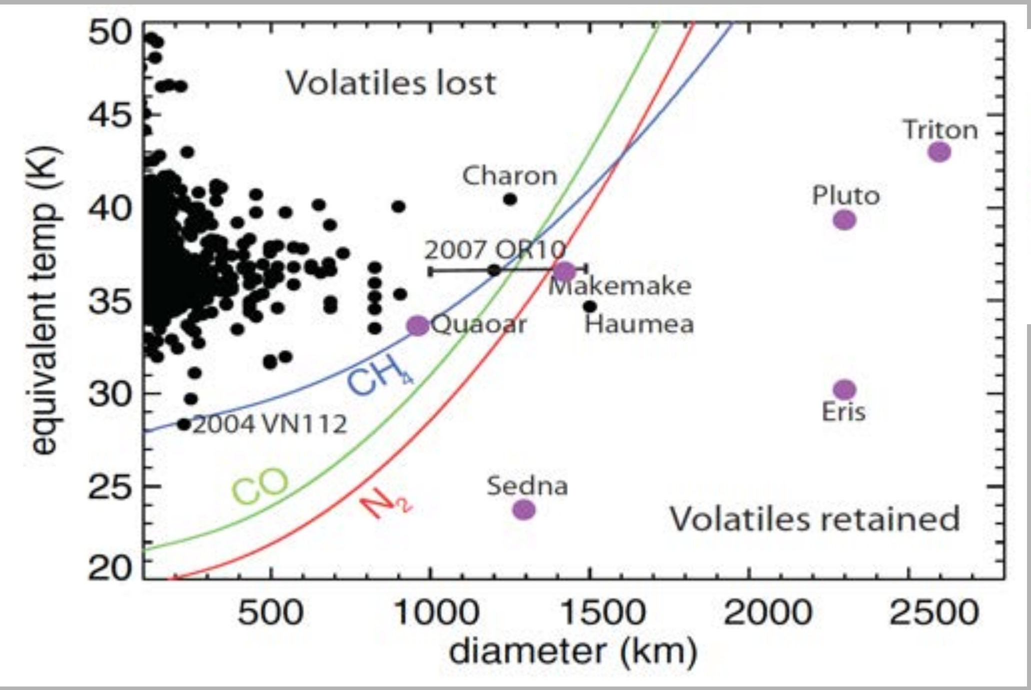




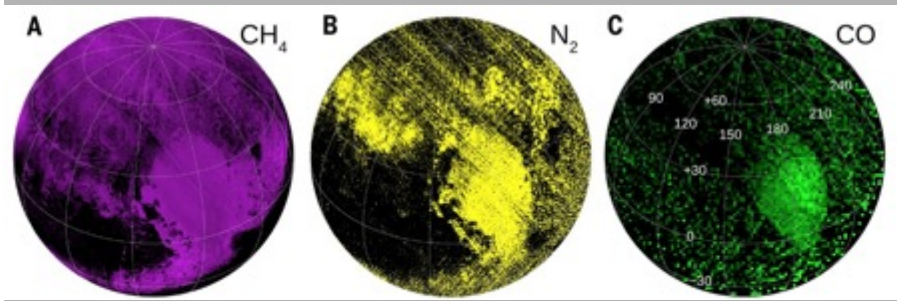


Dartois et al. Icarus 2013

N2-CH4 ices at the surface of icy bodies



Brown et al. ApJL (2011)

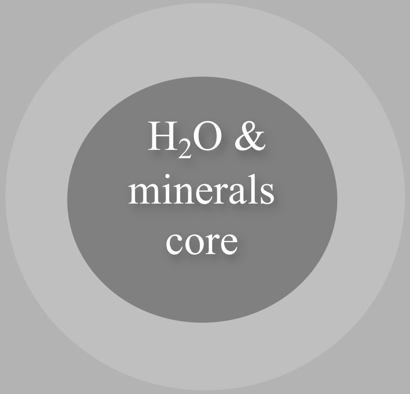


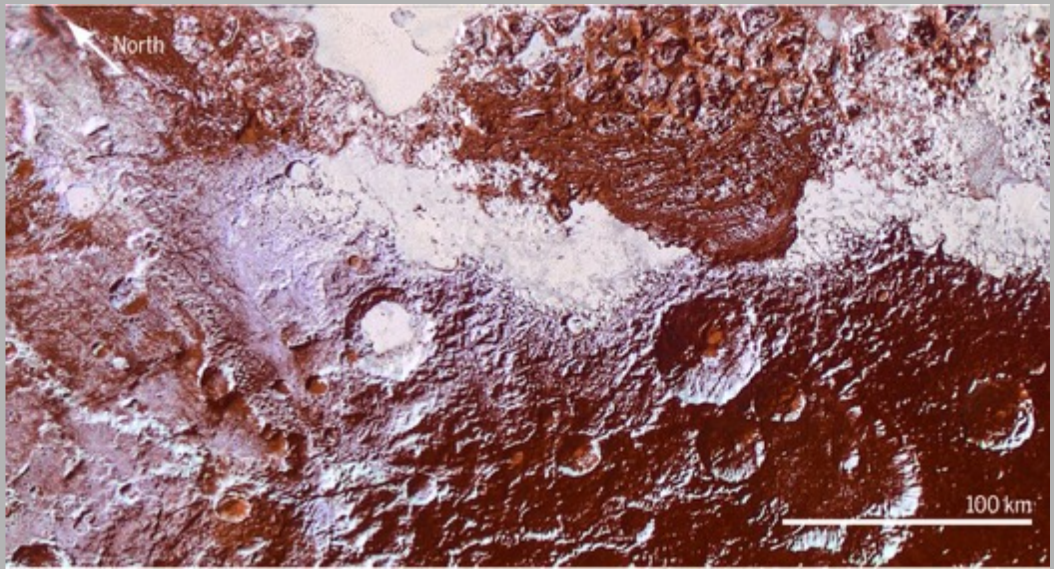
Maps of Pluto's ices CH4, N2, and CO.

Grundy et al. Science 18 march 2016

Pluto's surface
18 march 2016,
NEW HORIZONS space probe

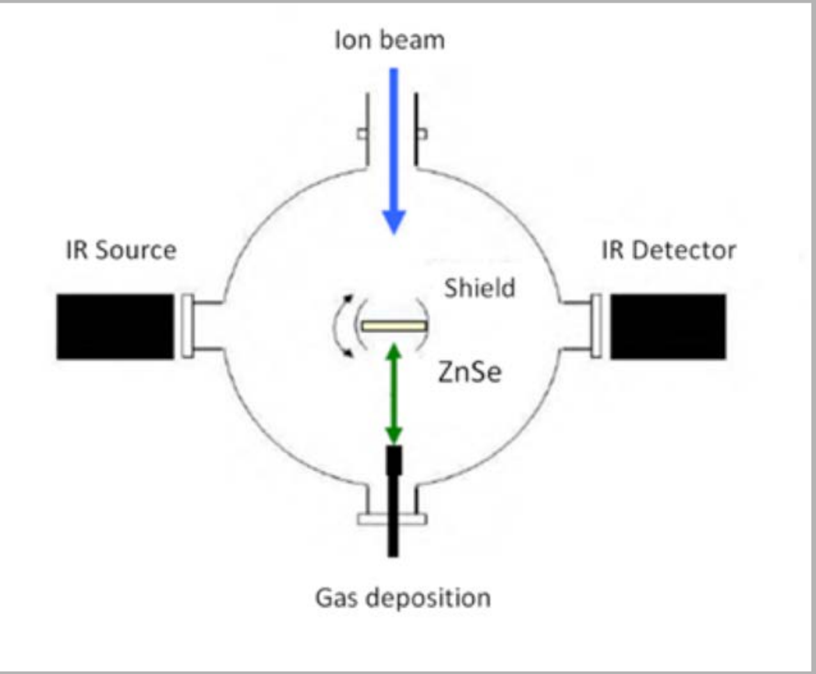
N2, NH3, CH4 icy mantle





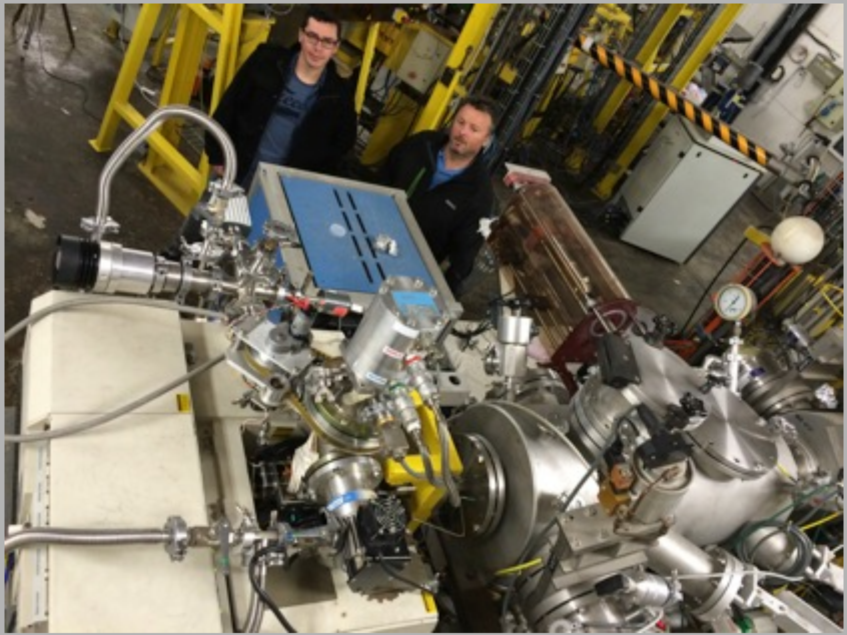
irradiation and in-situ IR analysis of ices of astrophysical interest

Ni^{11+} @44 MeV; 160 MeV
Ar^{15+}@160 MeV



Target N2-CH4 ices
(90:10; 98:2)

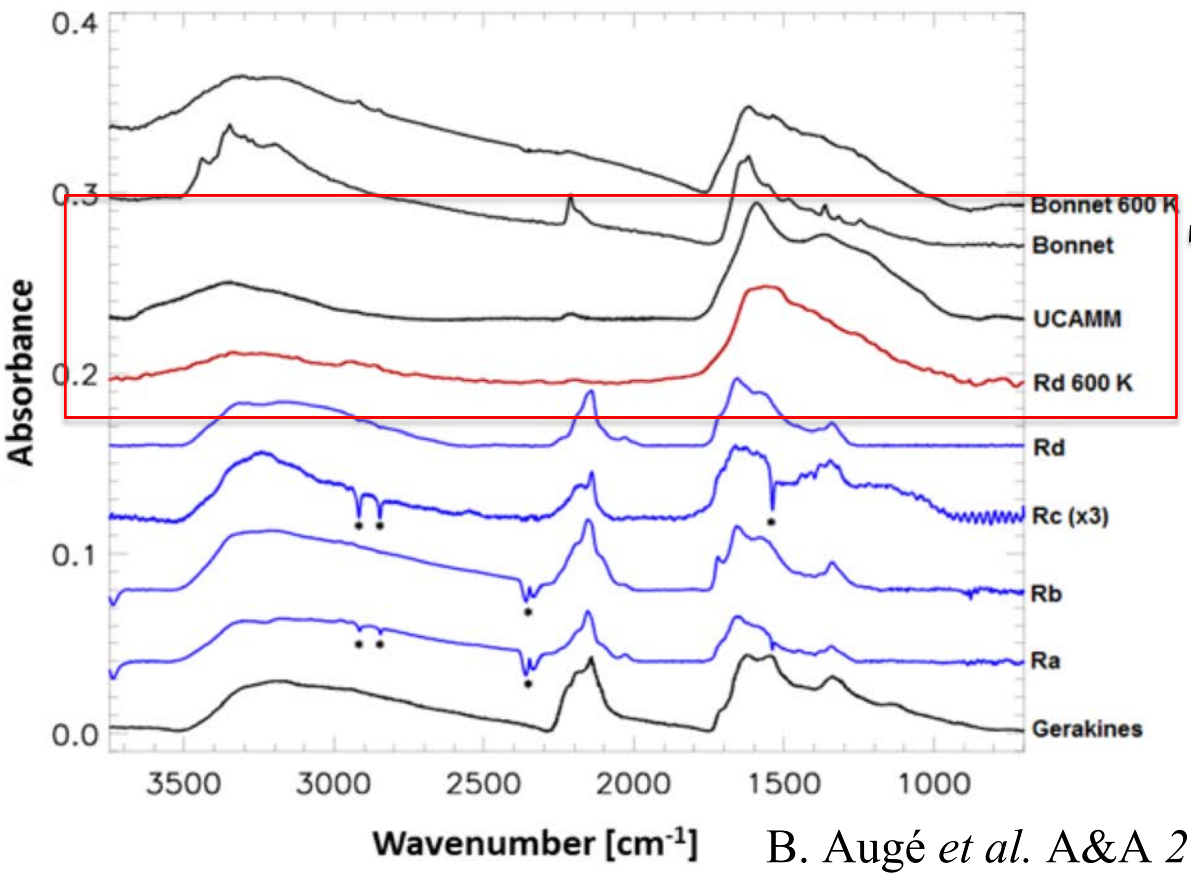
The CASIMIR set-up



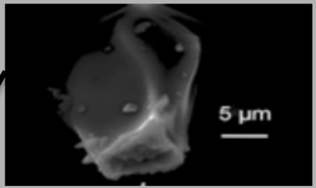
The new IGLIAS set-up

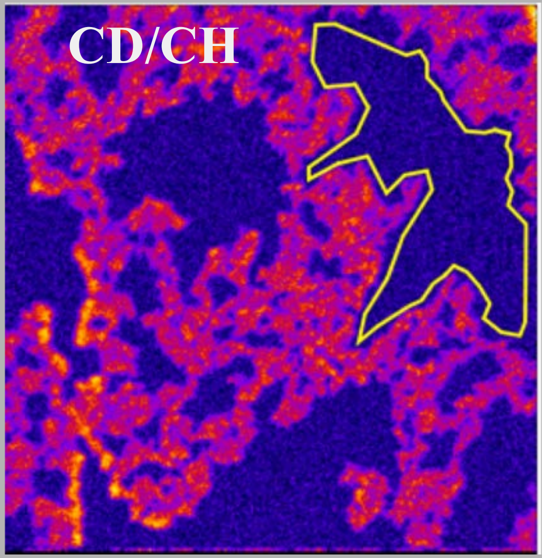
B. Augé *et al.* A&A *2016*

High energy ions irradiation of N-rich ices



B. Augé *et al.* A&A *2016*

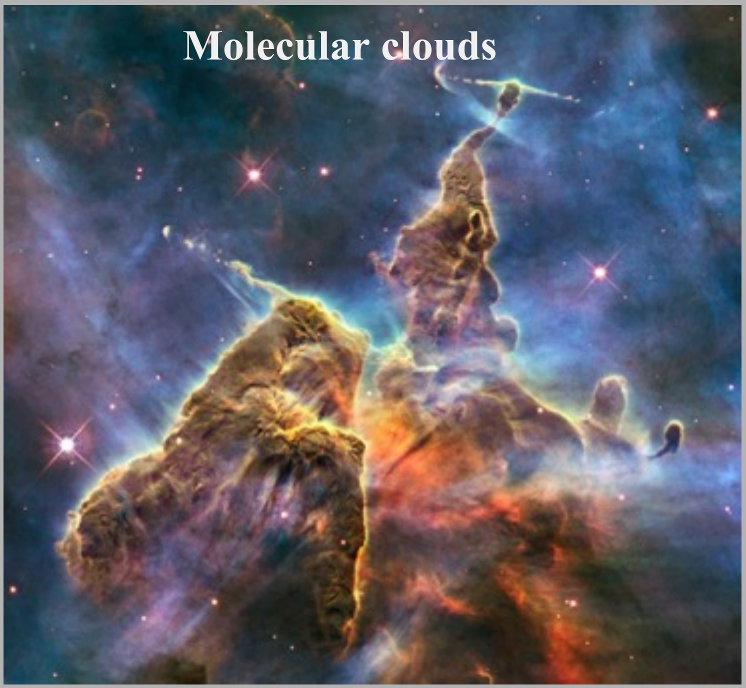


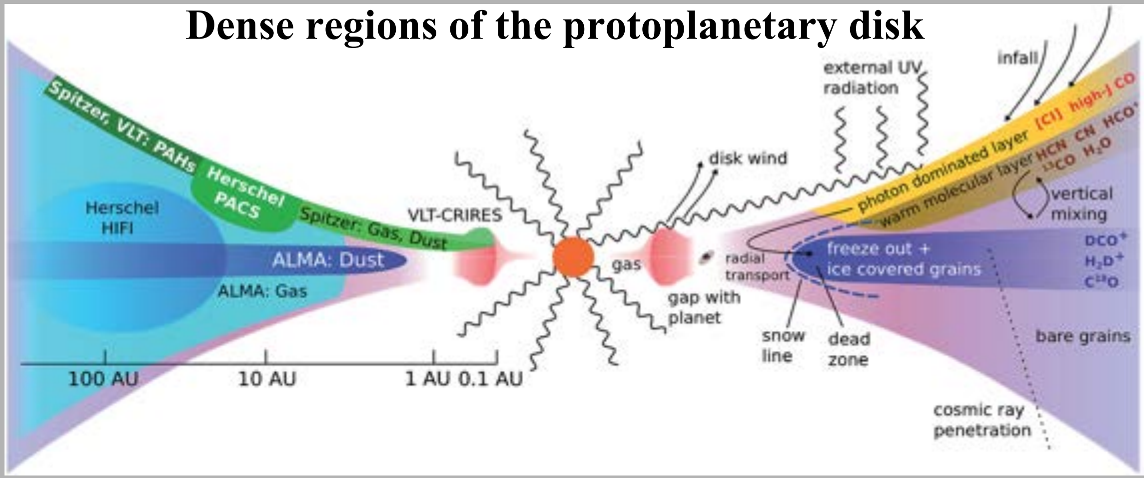


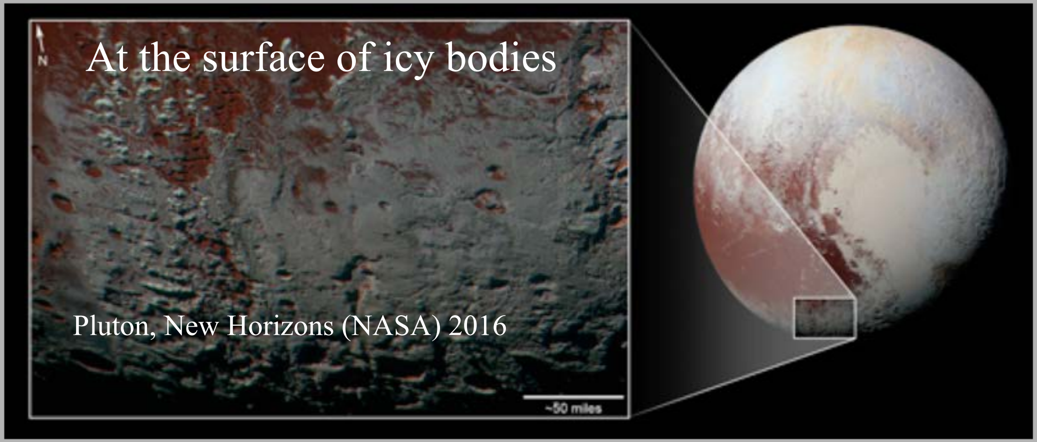
2018 : irradiation of N_2-CH_4-CD_4 produce a residue with large isotopic heterogeneities
B. Augé *et al. in prep*

2016 : **Galactic Cosmic Ray interaction with N_2-CH_4 ices** induce a refractory poly-HCN residue
that can be the precursor of the ultra-carbonaceous micrometeorites organics.

The origins of D-rich organics







Conclusions

- At the first order, the material that formed the solar system was well mixed → the meteorite **CI reference**
- **Micron-sized refractory minerals with isotopic composition radically different from CI** → the presolar grains **(PSG)**
- **Most PSG** have condensed in envelopes of **low mass stars** (i.e. AGBs)
- **Few PSG** (Type X SiC, graphites,…) originate from **massive stars**
- Planets, asteroids and (possibly) comets samples exhibits **tiny bulk isotopic differences** (slightly different initial reservoirs ? secondary processes ?)
- **Last minute nucleosynthesis (including non-thermal events)** contaminated the protoplanetary disk in **short-lived radionuclides** (^{26}Al, ^{10}Be, ^{41}Ca, ^{36}Cl,…)
- **Large isotopic anomalies** (D/H, $^{15}N/^{14}N$, …) are observed **in interplanetary organic matter**. This organics may formed in the parent molecular cloud , and/or secondary processes within the protoplanetary disk, or at the surface of icy parent bodies