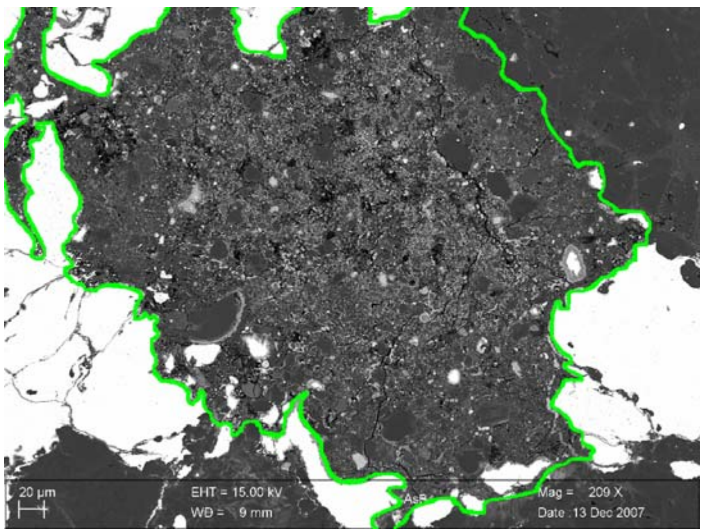
International Symposium Marco Polo
Paris, May 19th, 2009

A primordial xenolith with unaltered organic matter in the chondrite Isheyevo: memory from the solar nebula



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[3]Laboratoire de Planétologie de Grenoble, Université Joseph Fourier, CNRS/INSU, Grenoble, France
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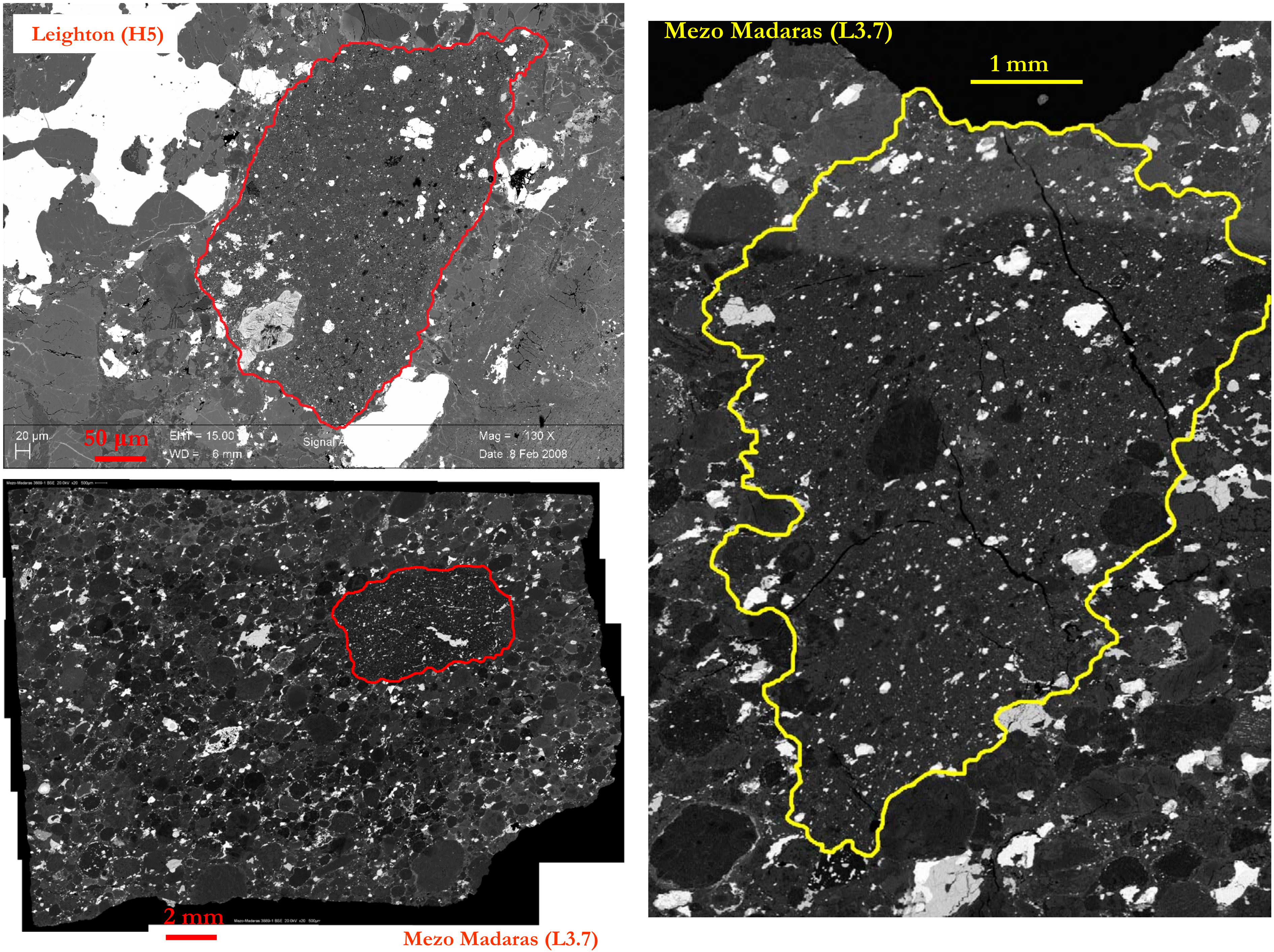
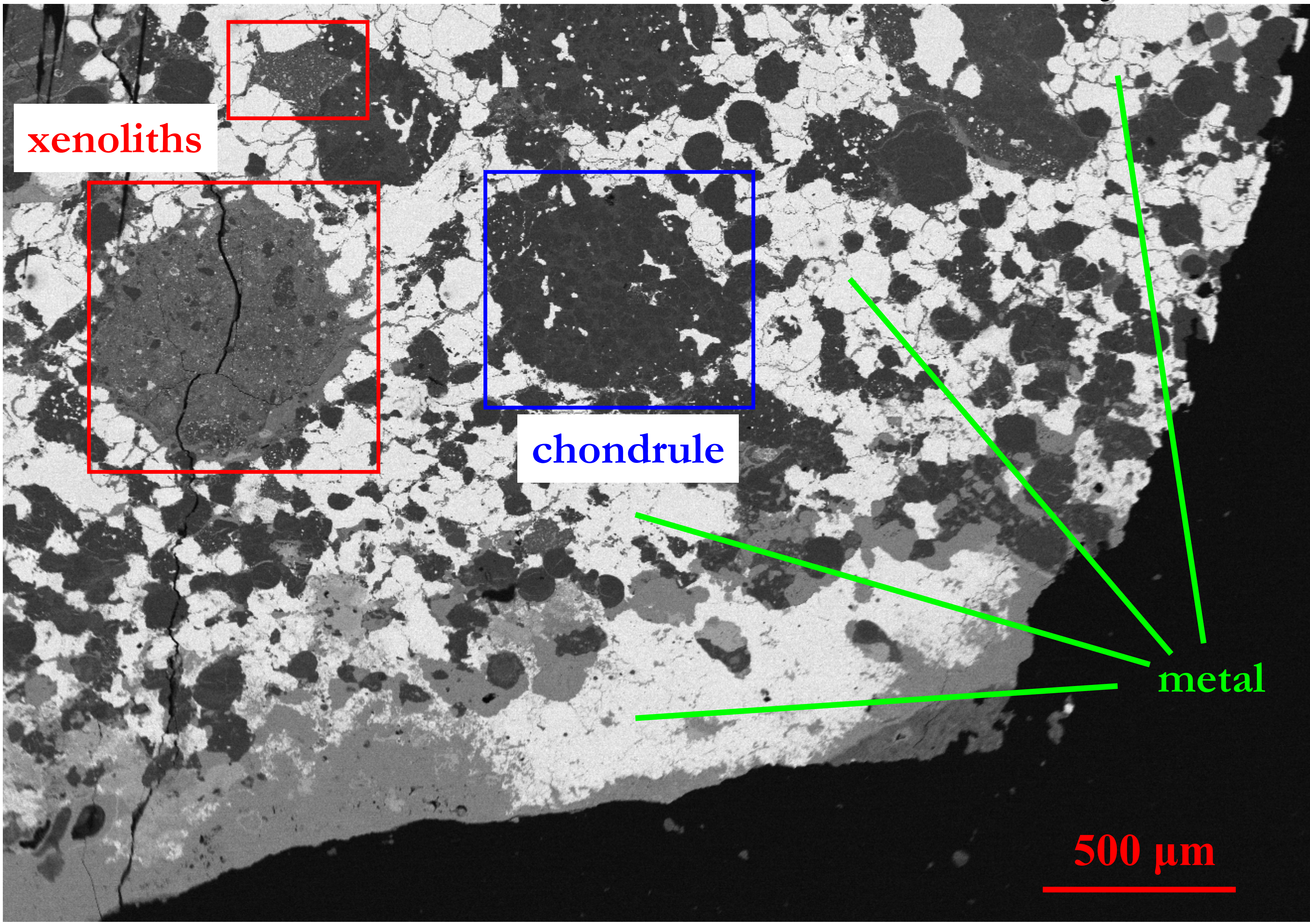
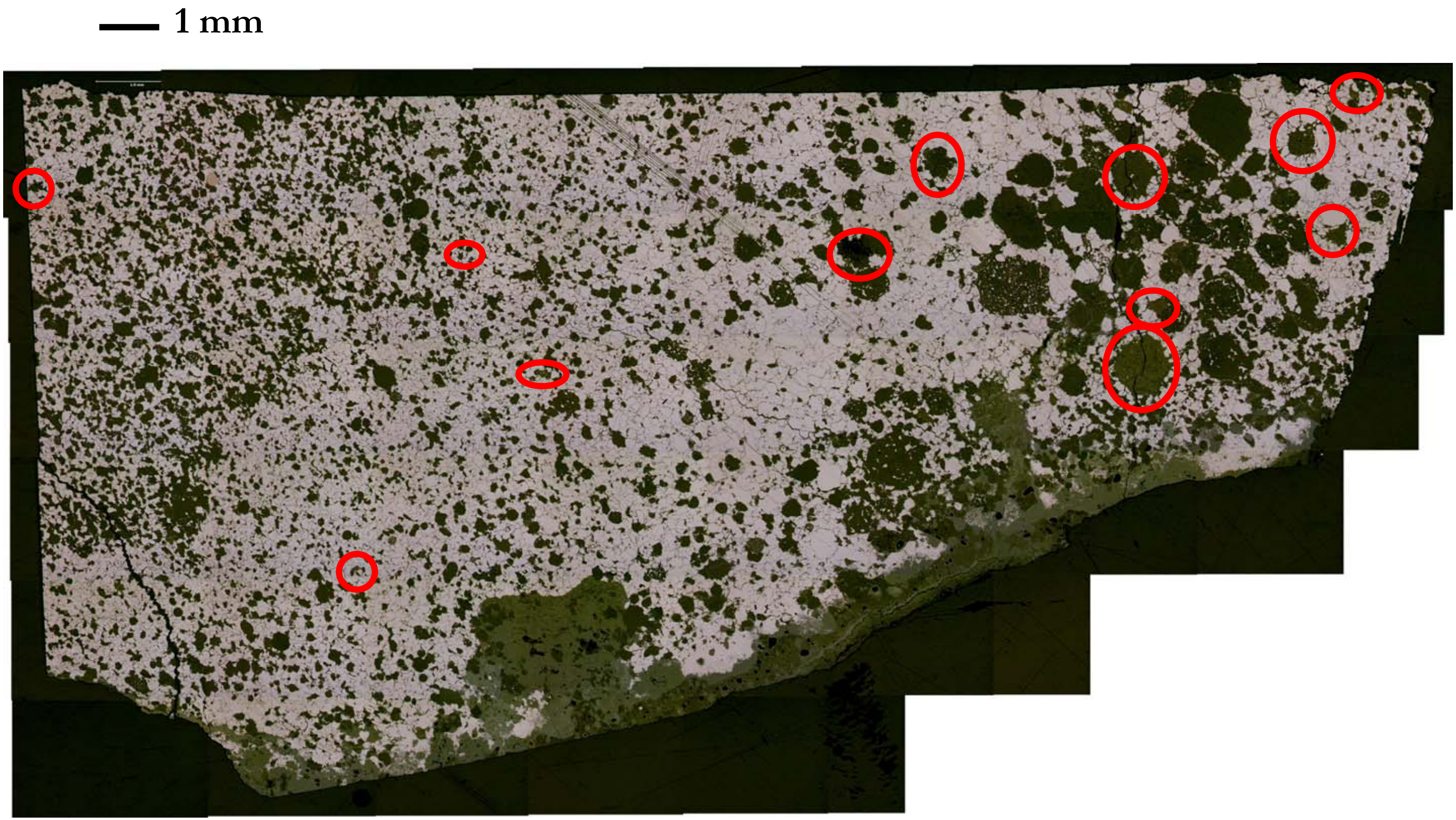


Leighton (H5)
20 µm
50 µm
EHT = 15.00
WD = 6 mm
Signal A
Mag = 130 X
Date :8 Feb 2008
Mezo Madaras (L3.7)
1 mm
2 mm
Mezo Madaras (L3.7)

The carbonaceous chondrite Isheyevo



The carbonaceous chondrite Isheyevo

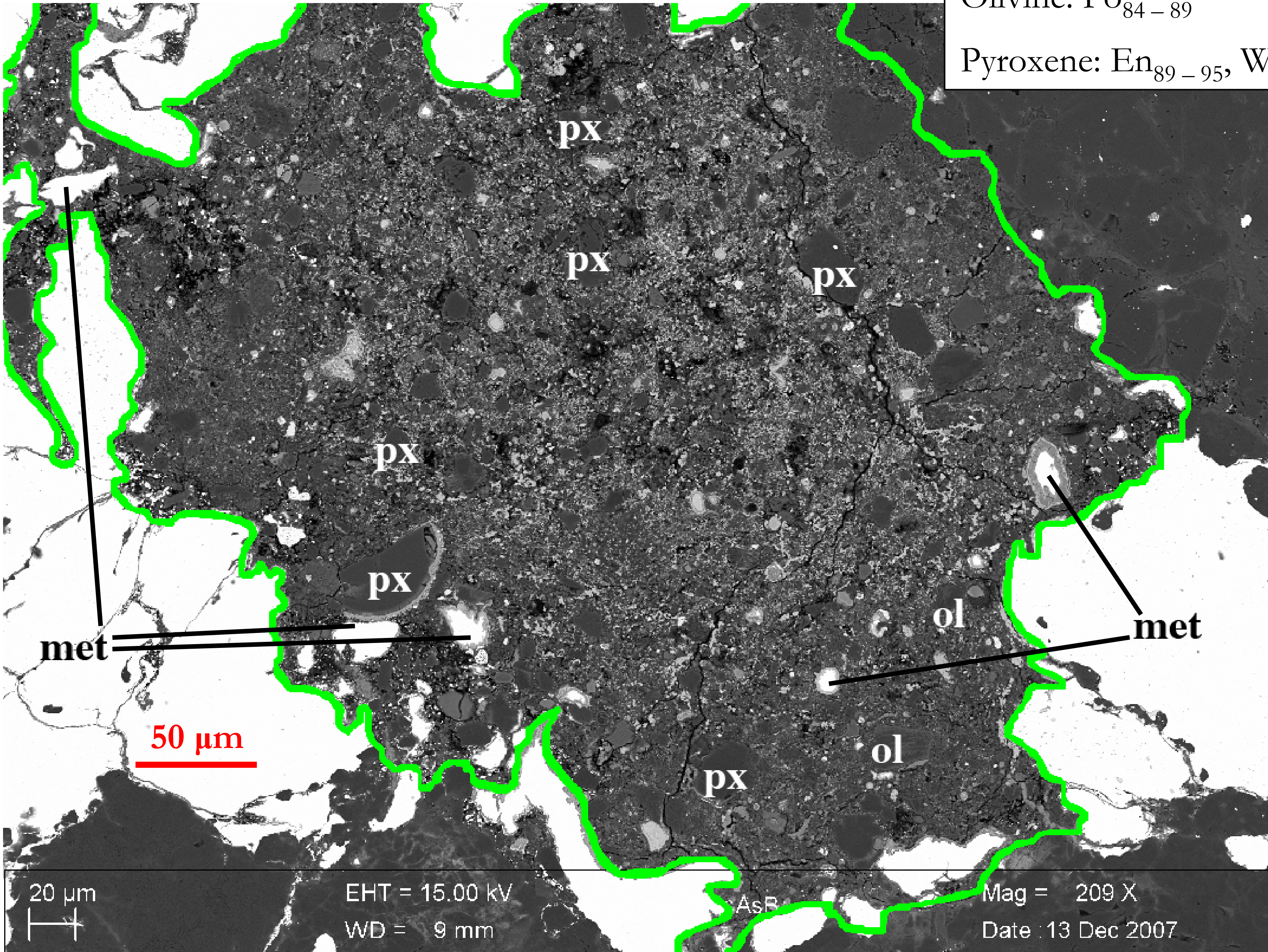


2 sections, ~ 10×20 mm^2 each, more than 100 xenoliths

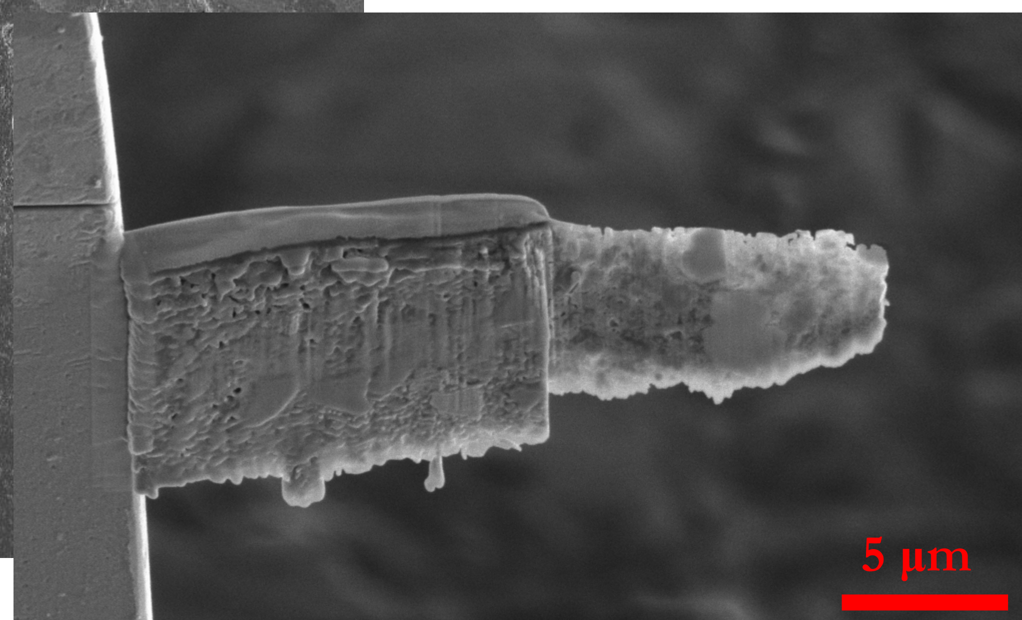
Primordial Xenolith #18

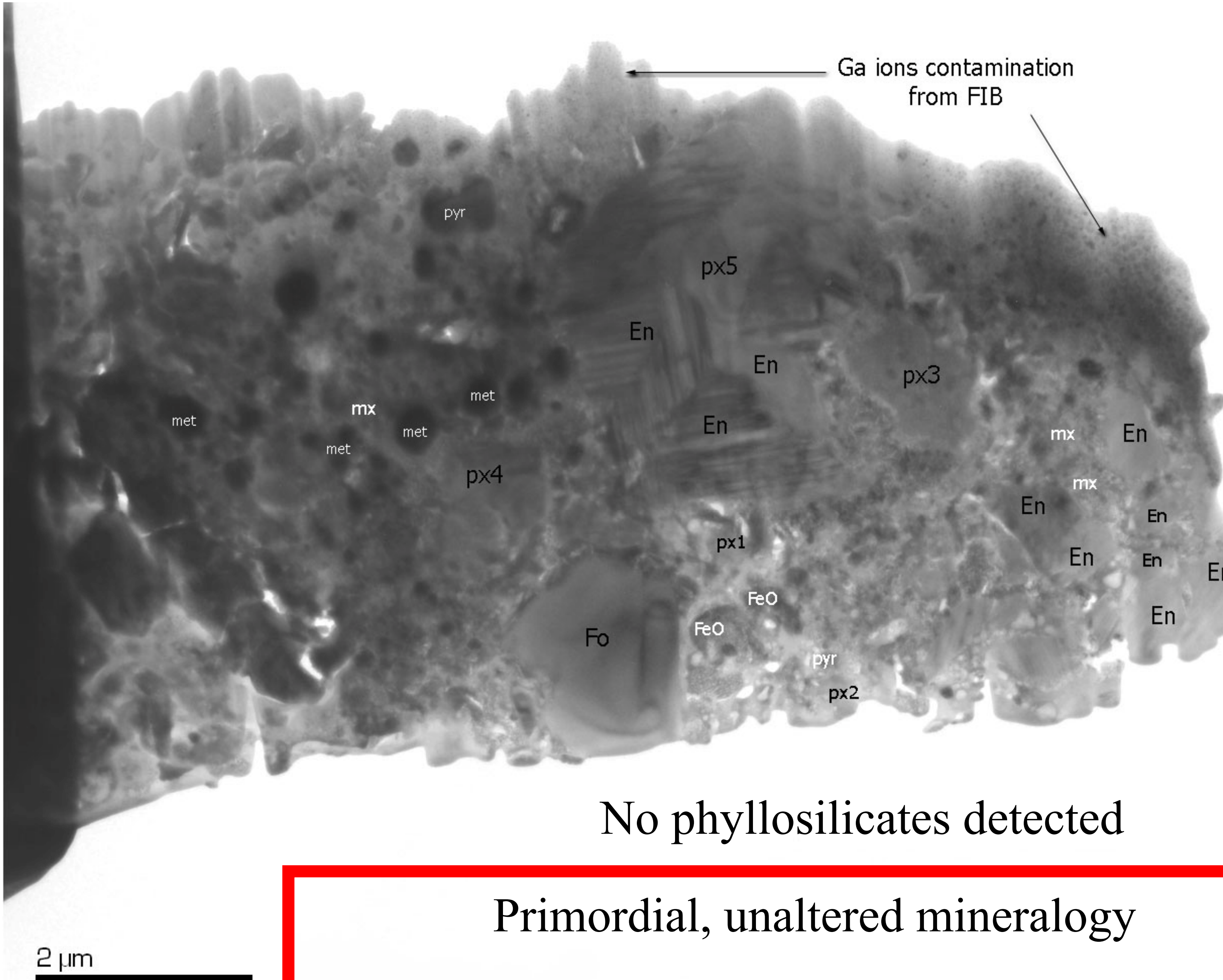
Olivine: Fo_{84-89}

Pyroxene: En_{89-95}, Wo_{0-4}



TEM sections preparation by Focused Ion Beam





No phyllosilicates detected

Primordial, unaltered mineralogy

similar to anhydrous CP IDPs and Wild2 samples

NanoSIMS measurements

First session

5 Isheyevo xenoliths

$^{1}H^{-}$

$^{2}H^{-}$ → **D/H**

Second session

4 Isheyevo xenoliths

$^{12}C^{-}$

$^{13}C^{-}$ → **$^{13}C/^{12}C$**

$^{12}C^{14}N^{-}$

$^{12}C^{15}N^{-}$ → **$^{15}N/^{14}N$**

Primary beam: Cs^{+}

~ 4 pA for 40×40 μm images

~ 1 pA for 10×10 μm images

Spatial resolution: ~ 100 – 200 nm

Mass resolution:

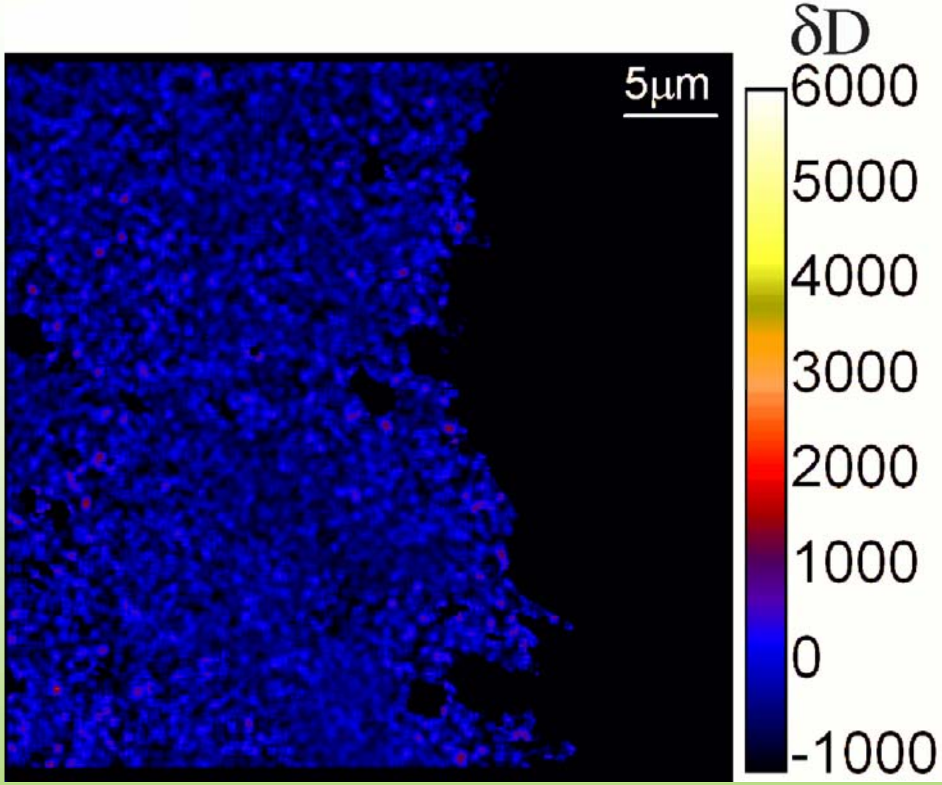
~ 2000 for D/H

~7500 – 8000 for C and N

Standards: kerogene type III

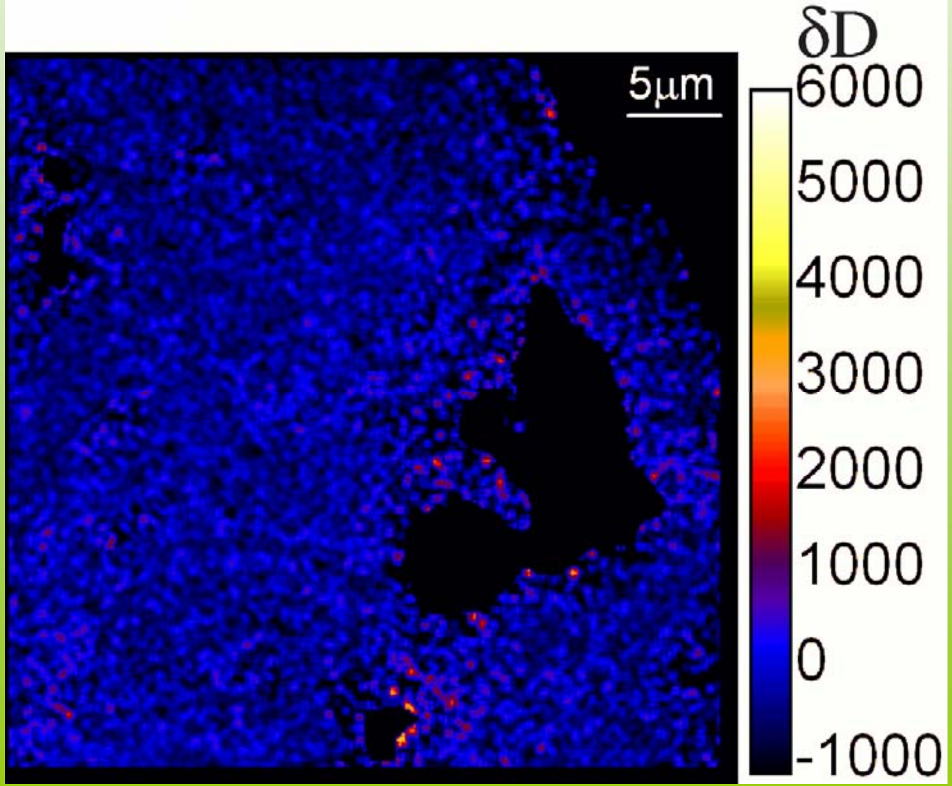
256x256 pixels images

Isotopic composition: H

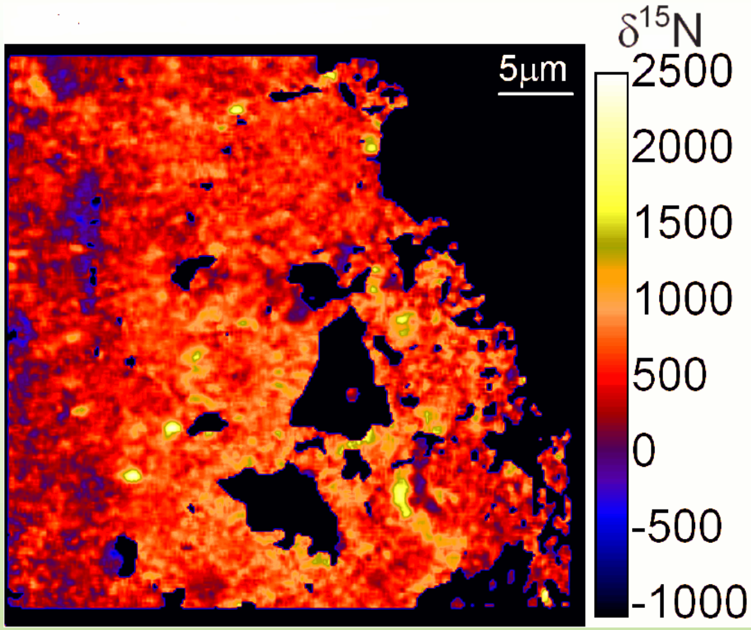


No D enrichment

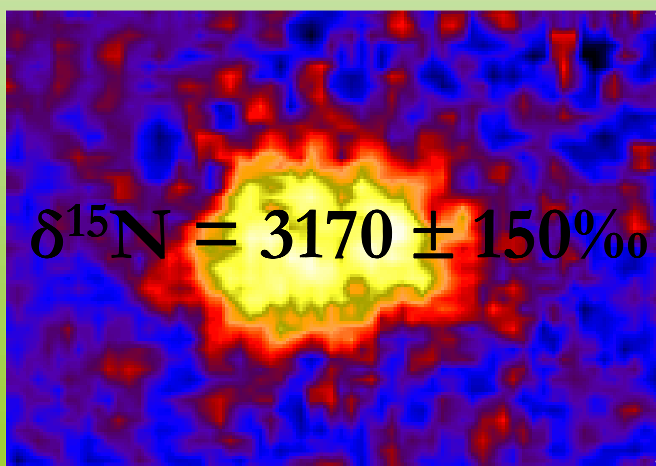
$$\delta D = \left(\frac{D/H}{(D/H)_{SMOW}} \right) \times 1000$$



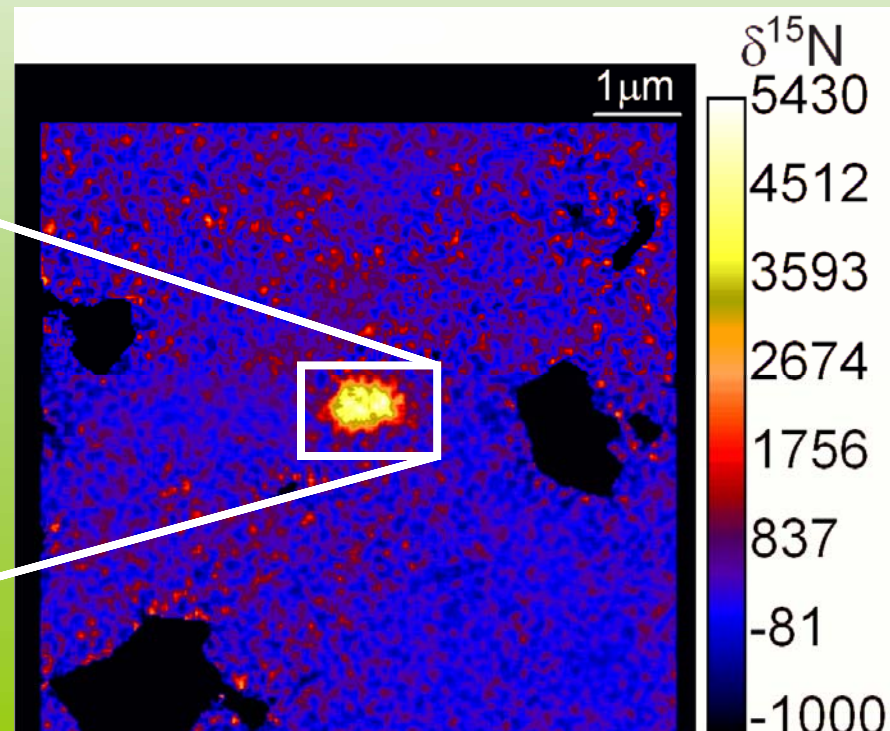
^{15}N enrichments in PX-18



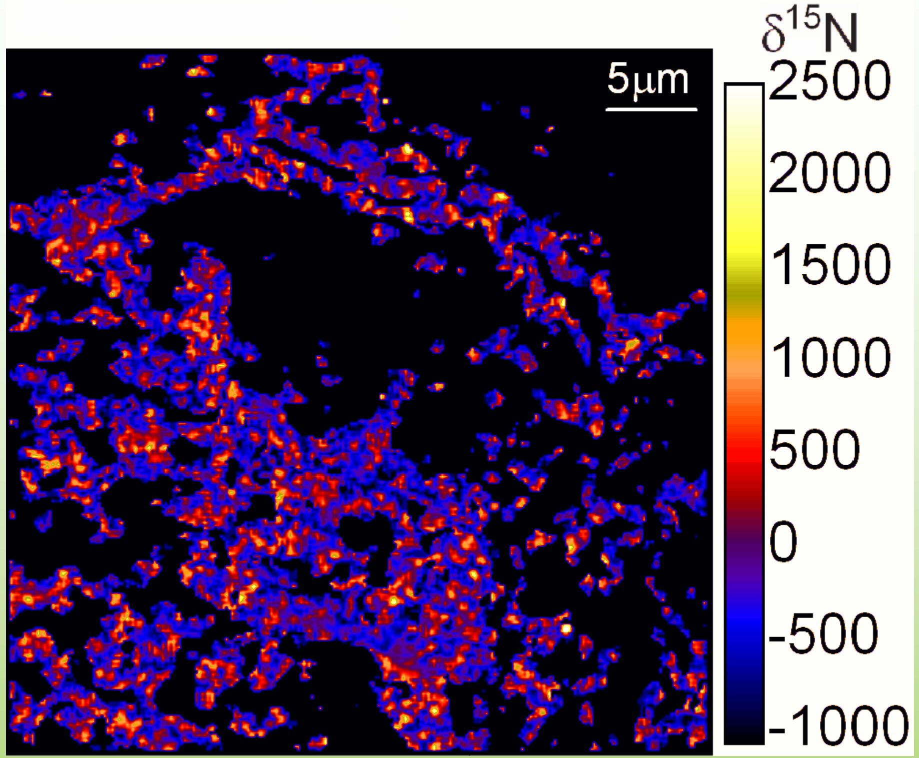
$$\delta^{15}N = \left(\frac{^{15}N/^{14}N}{\left(^{15}N/^{14}N\right)_{AIR}} \right) \times 1000$$

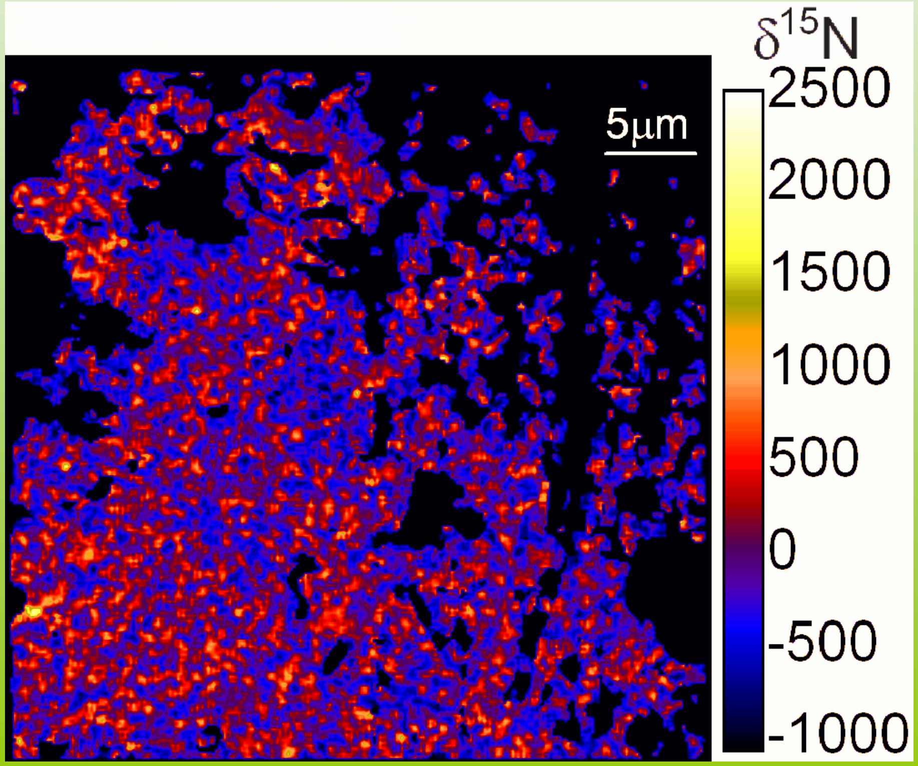


$\delta^{15}N = 4900 \pm 300$‰

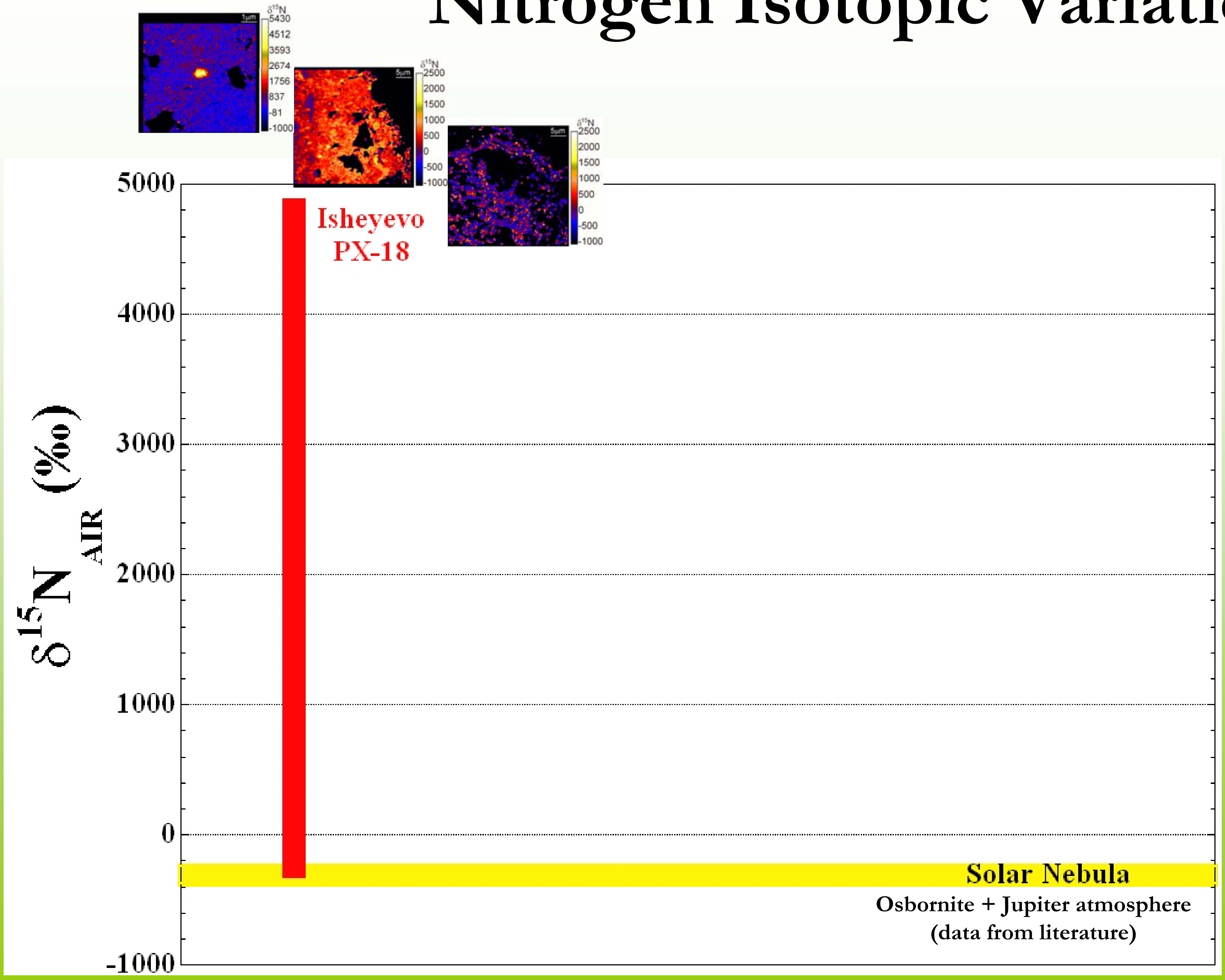


Areas with $\delta^{15}N < 0$ ‰

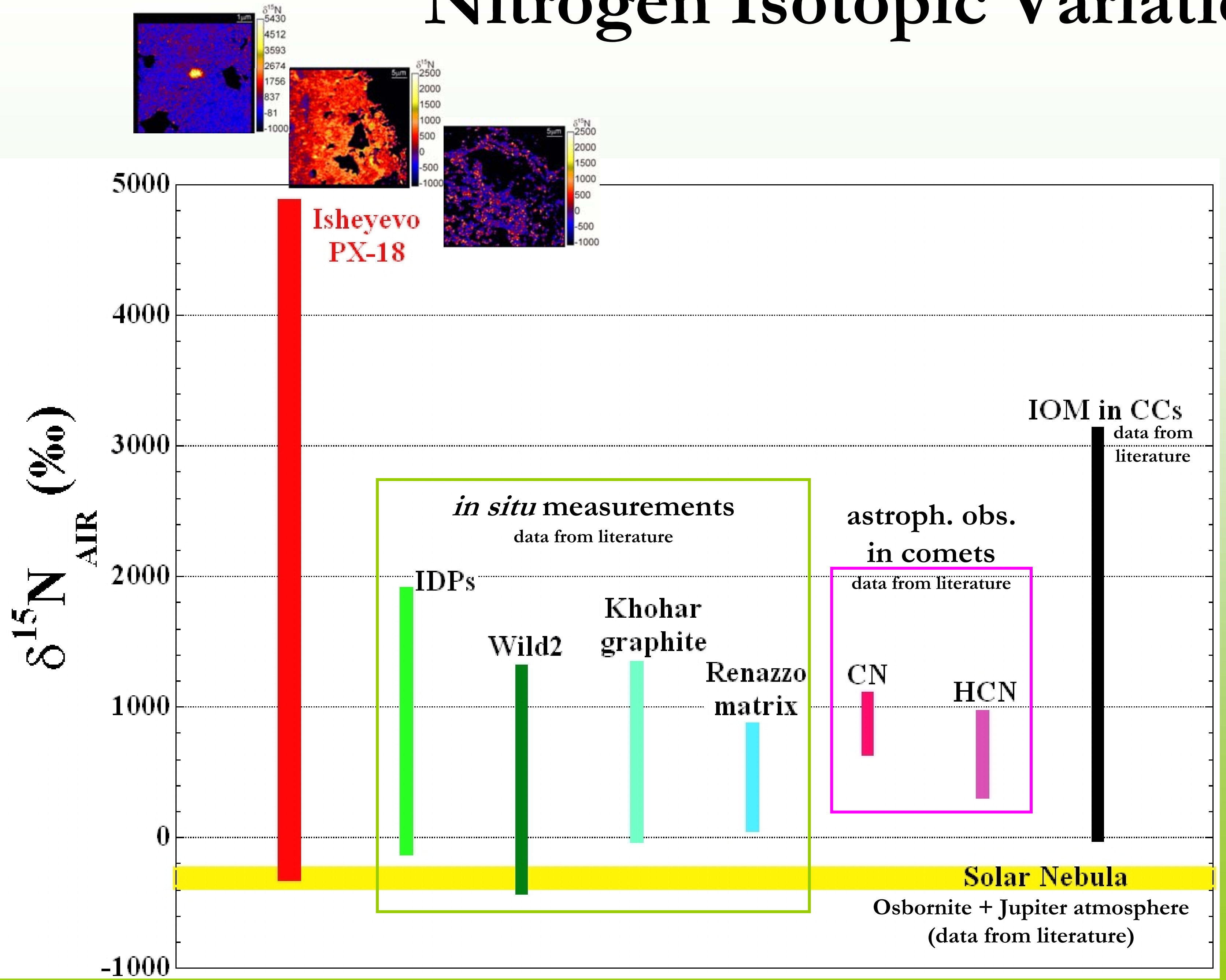




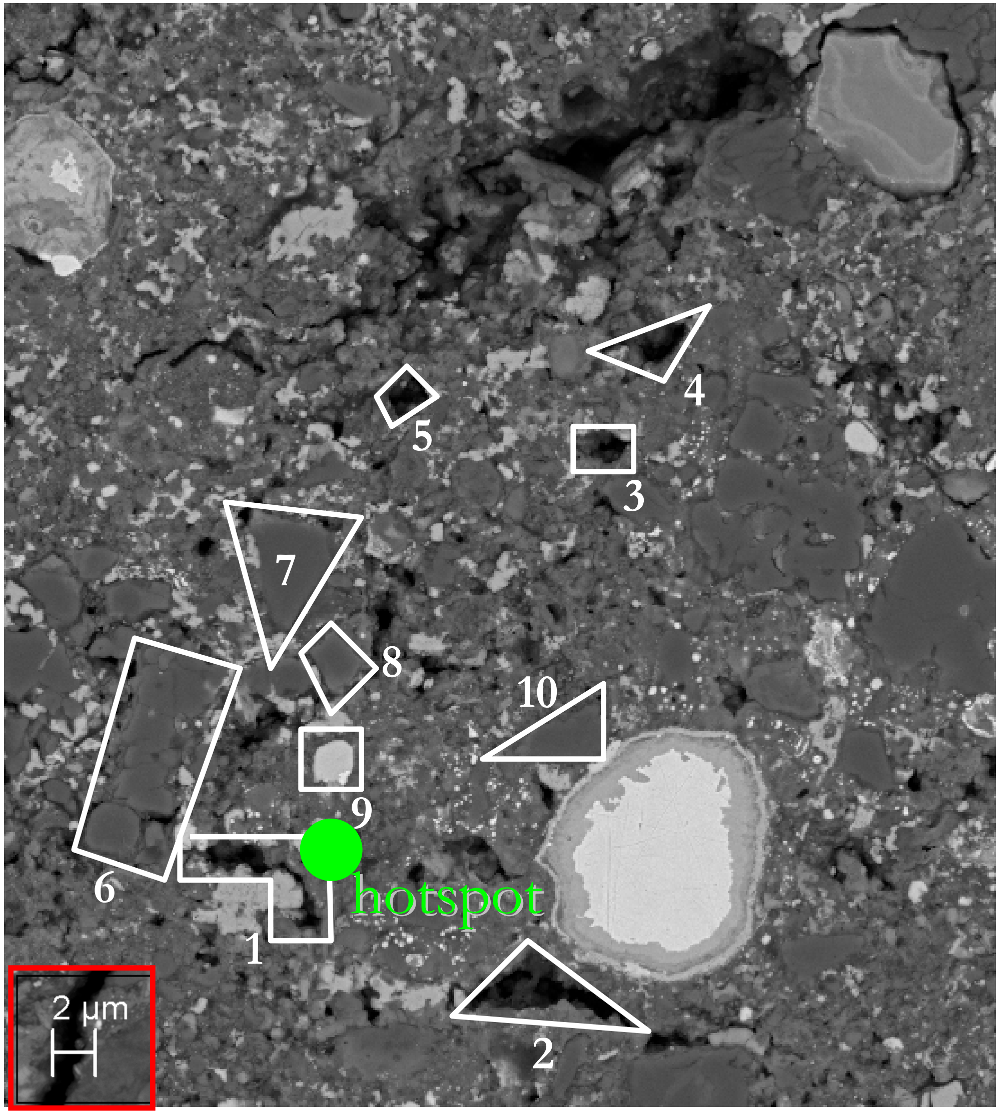
Nitrogen Isotopic Variation

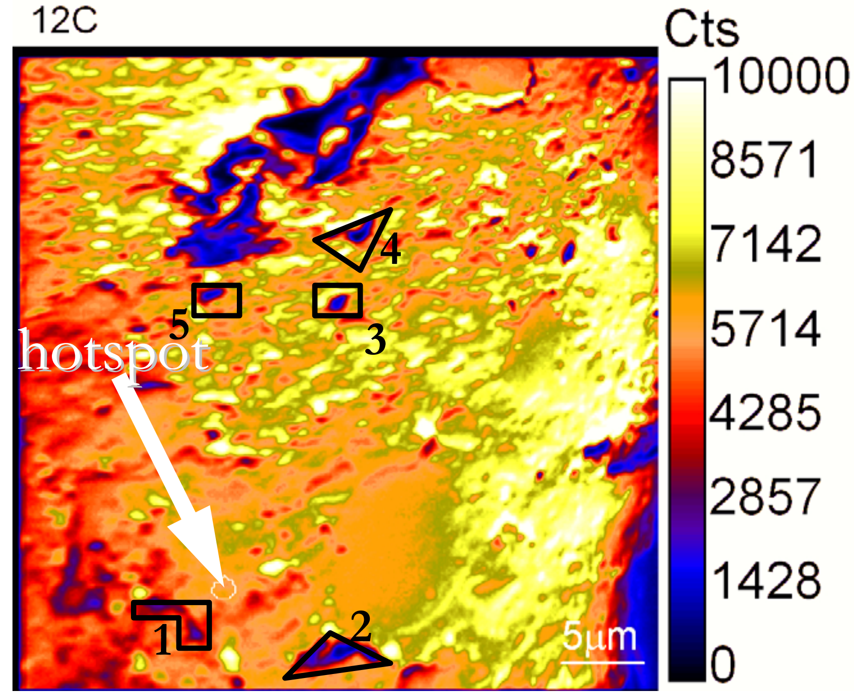


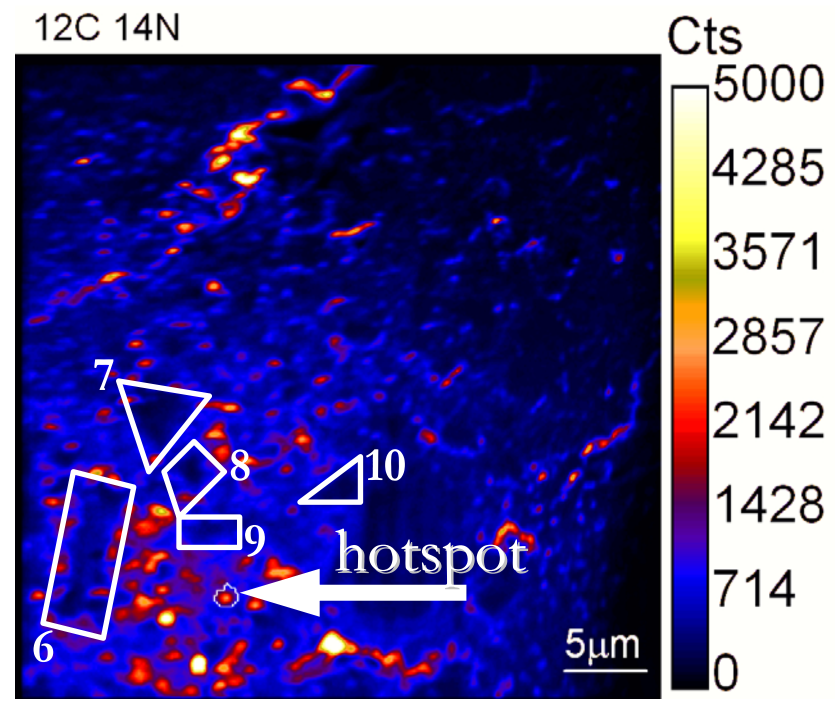
Nitrogen Isotopic Variation

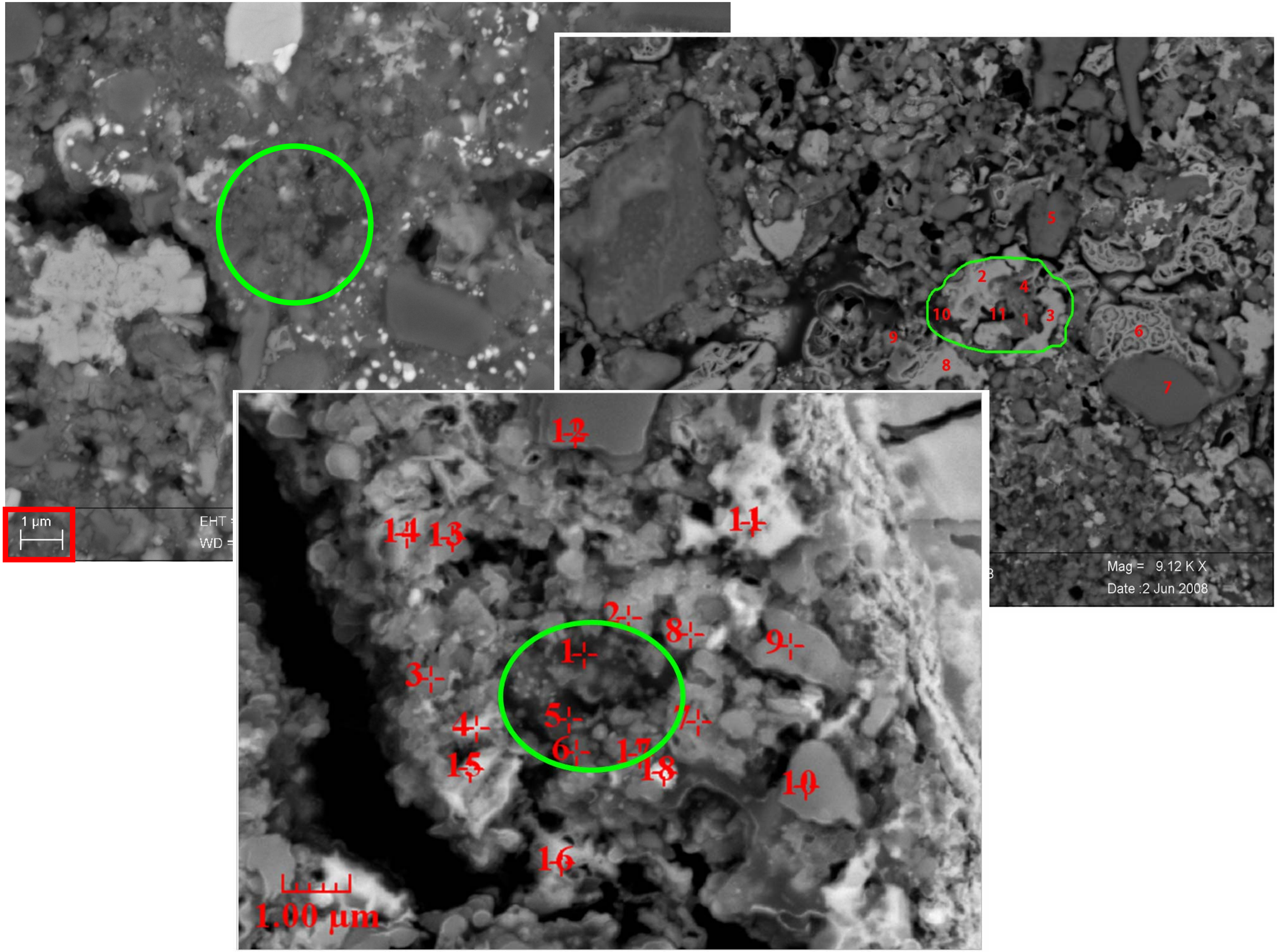


What are hotspots ?








1 μm
Mag = 9.12 K X
Date :2 Jun 2008
1.00 μm

What is the ^{15}N enrichments carrier phase?

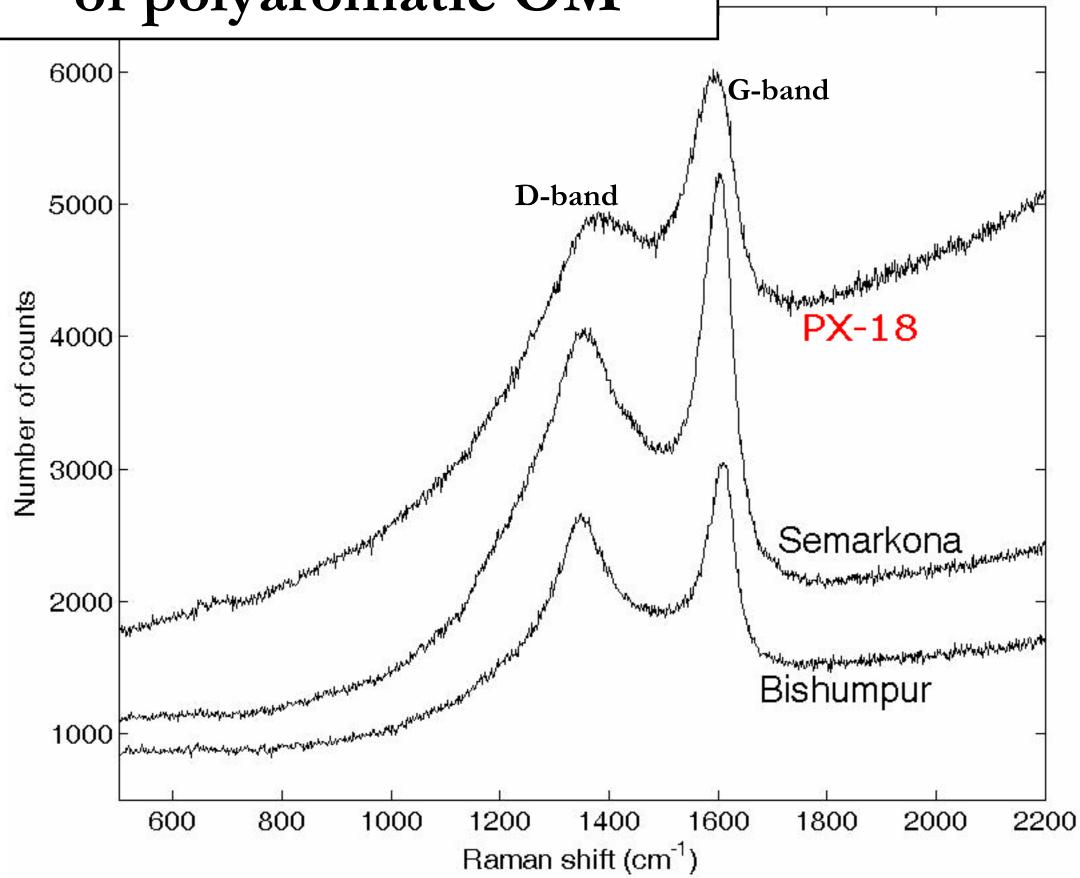
- Hotspots larger than mineral phases they correspond.
- No single phases common to all hotspots.
- Large areas with diffuse ^{15}N enrichments.

^{15}N enrichments are probably carried by macromolecular organic matter

cf Aléon et al 2003; Busemann et al 2006; Floss et al 2006.

Organic Matter in PX-18

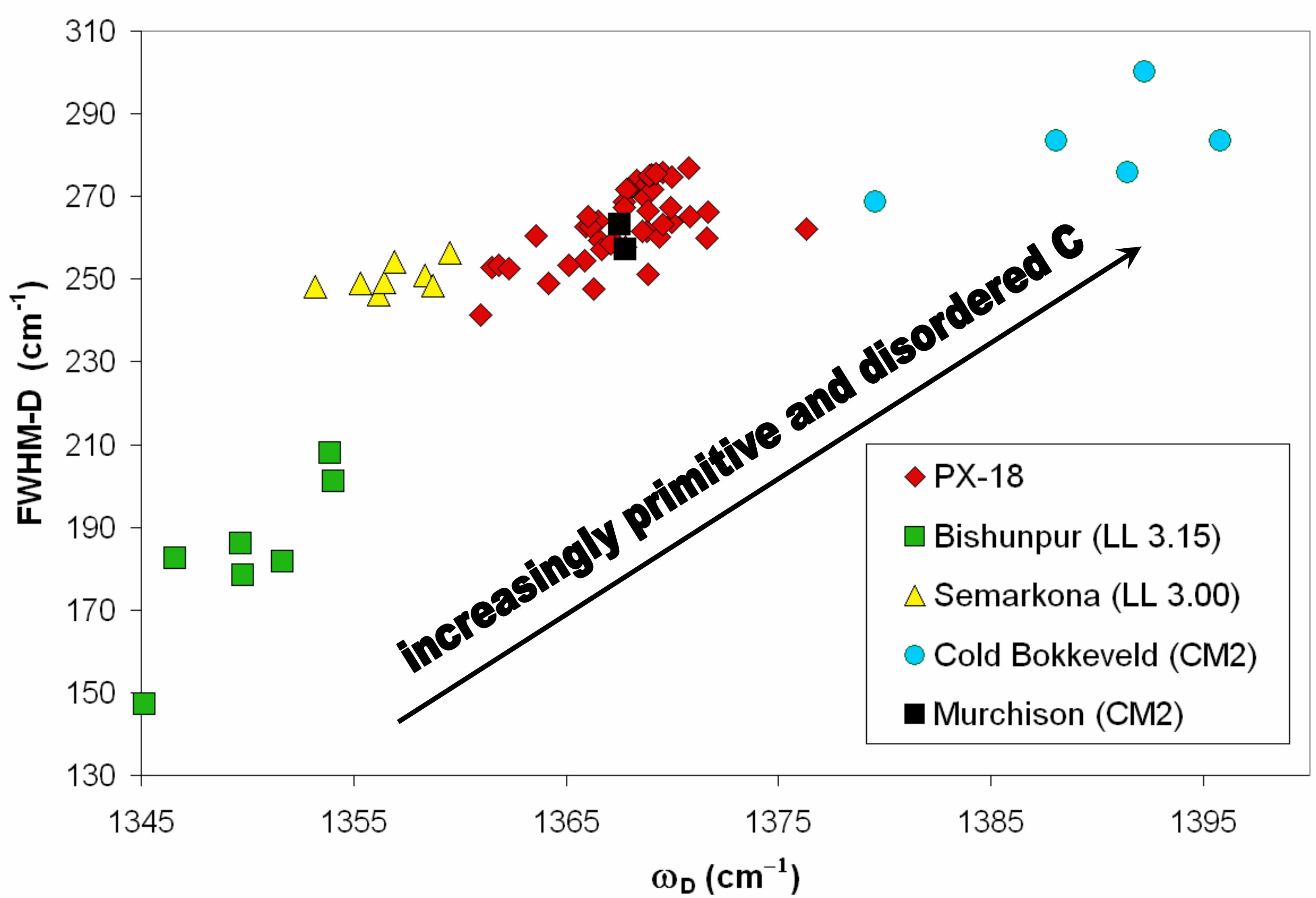
First-order carbon bands of polyaromatic OM



Experimental set-up
Spectrometer: JOBIN YVON – LABRAM HR800
Ar-ion laser, λ = 514.5 nm
Grating: 600 g/mm
Power on the sample = 400 μW
Spot size ≈ 5 μm

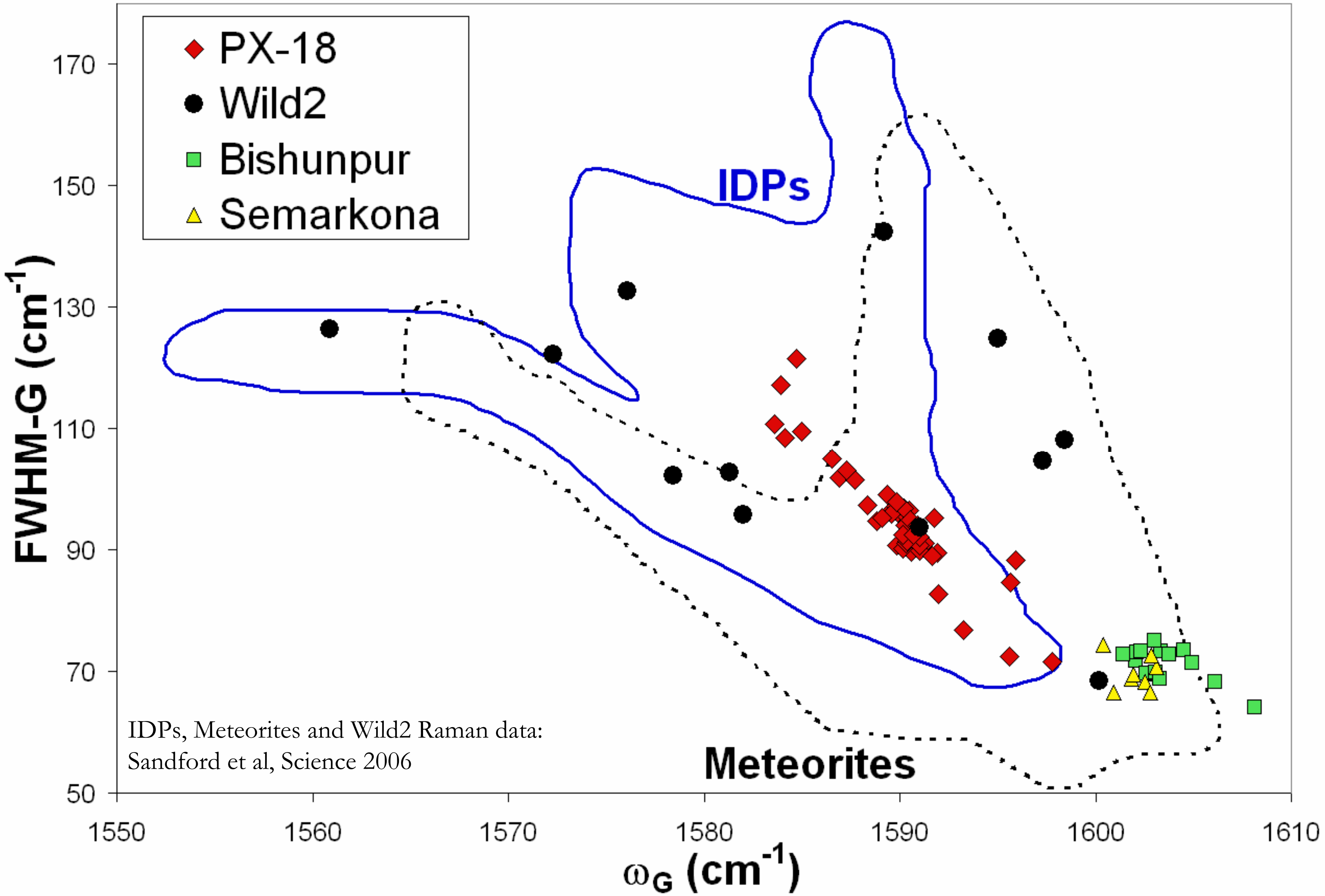
Organic Matter in PX-18

D-diagram: low thermal metamorphism



Organic Matter in PX-18

G-diagram: disordered carbon



Fractionation of light elements

Isheyevo xenolith 18: extreme N fractionation, no D enrichment

N fractionation

Low temperature ion-molecule reactions in dense cloud cores

Rodgers & Charnley 2008

$\delta^{15}N \geq 3000‰$

$n_{H_2} \sim 10^6\ cm^{-3}$ T = 7 K   CO depletion

$D/H \geq 0.3$
(Roberts et al 2003)

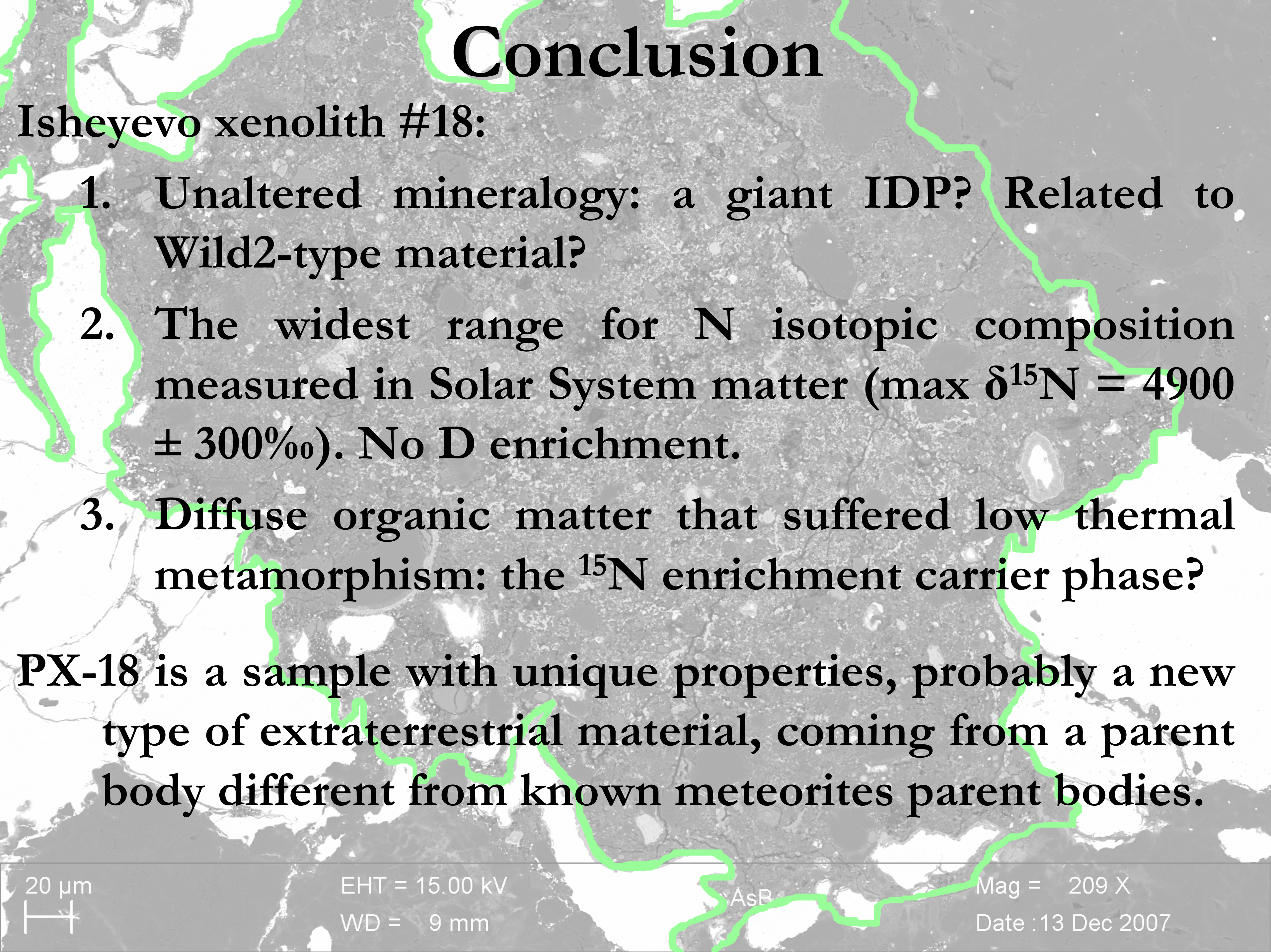
N fractionation by self-shielding in the solar nebula?

Conclusion

Isheyevo xenolith #18:

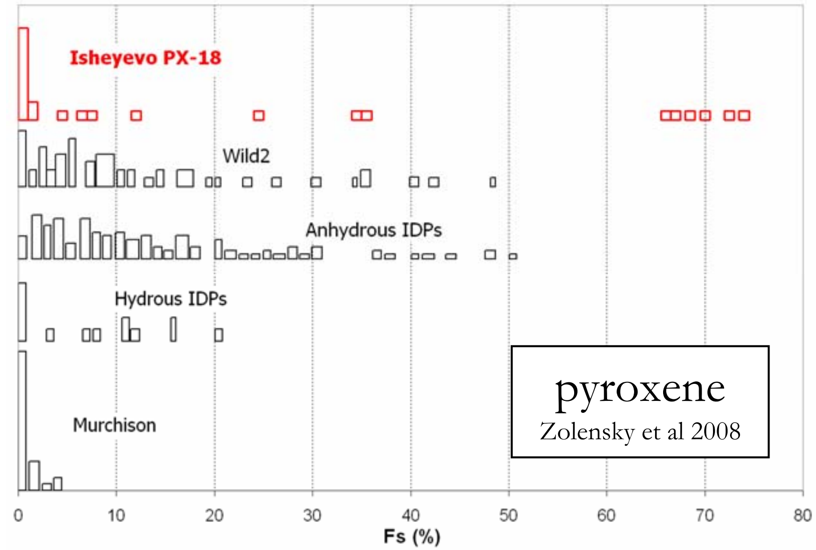
1. Unaltered mineralogy: a giant IDP? Related to Wild2-type material?
2. The widest range for N isotopic composition measured in Solar System matter (max $\delta^{15}N = 4900 \pm 300‰$). No D enrichment.
3. Diffuse organic matter that suffered low thermal metamorphism: the ^{15}N enrichment carrier phase?

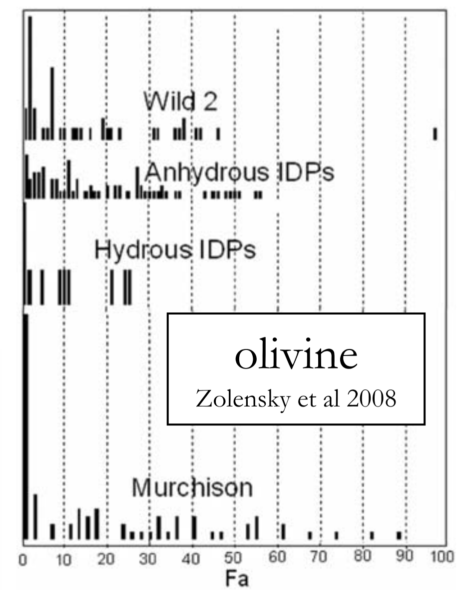
PX-18 is a sample with unique properties, probably a new type of extraterrestrial material, coming from a parent body different from known meteorites parent bodies.



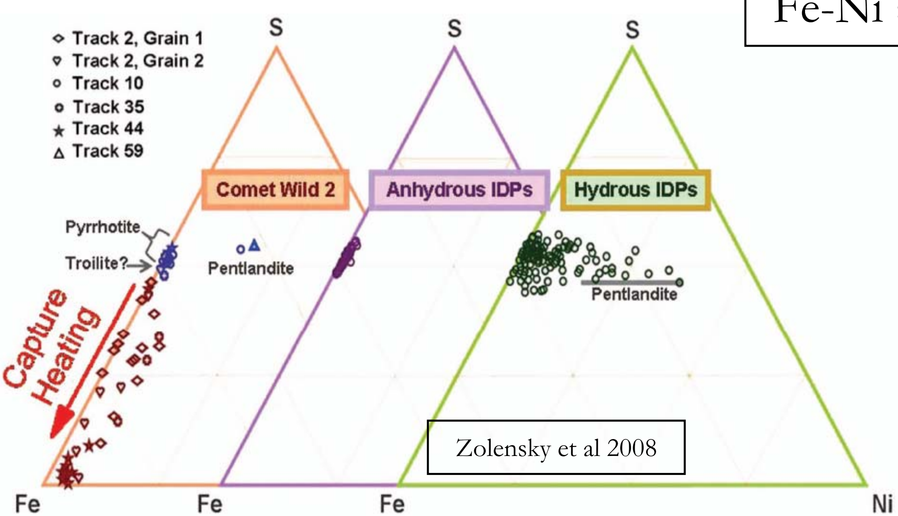
PLUS

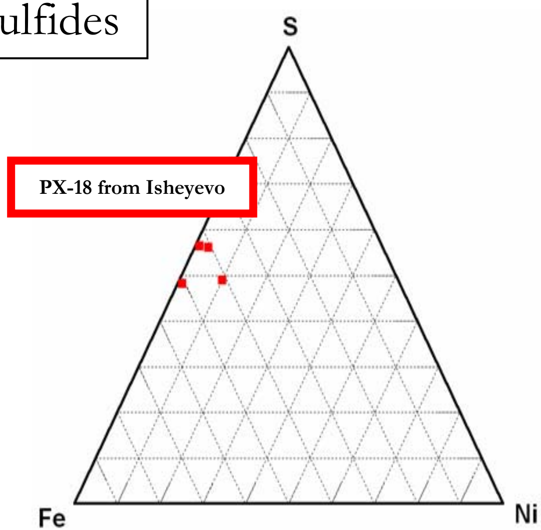
- Wild2 grains (Zolensky et al 2006 and 2008) CP IDPs (Bradley 2004) have no phyllosilicates.
- En and Fo are the most common silicate in CP IDPs (Bradley et al 2004)





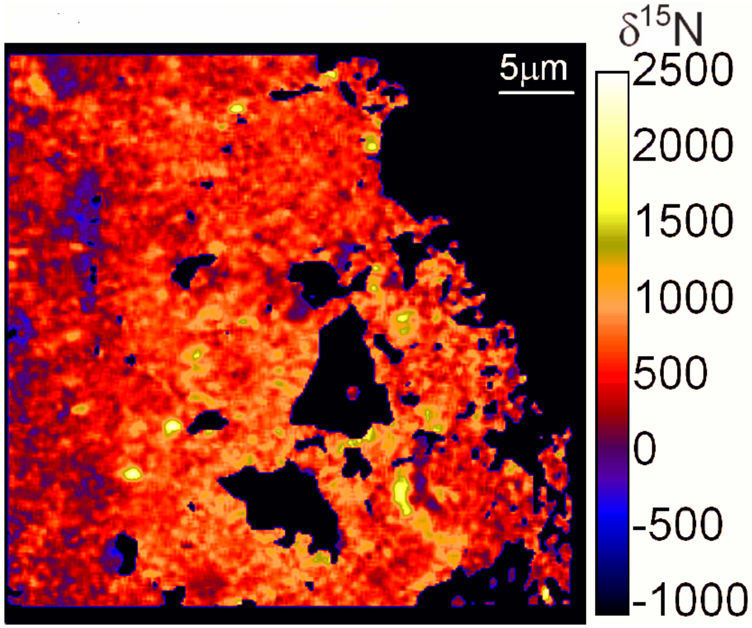
Fe-Ni sulfides



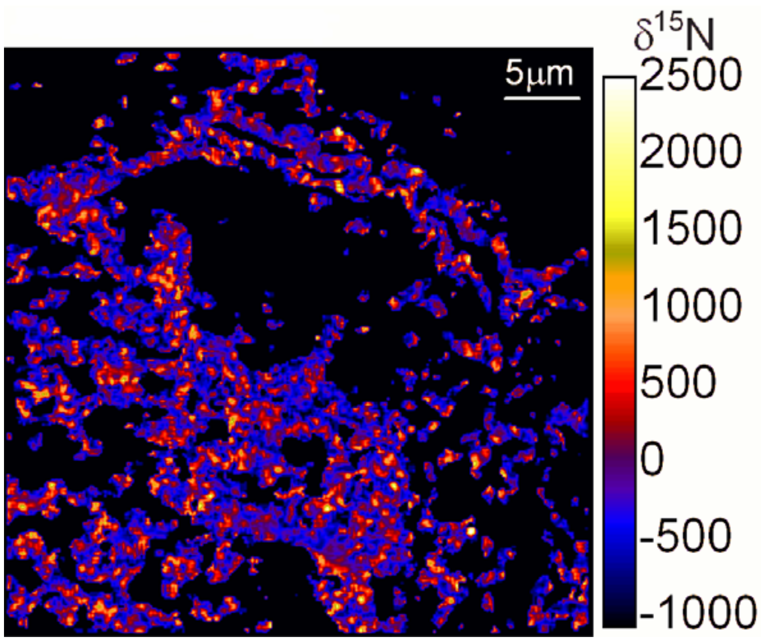


Isheyevo PX-18
Fa_{2-16}
mean: Fa_{11}

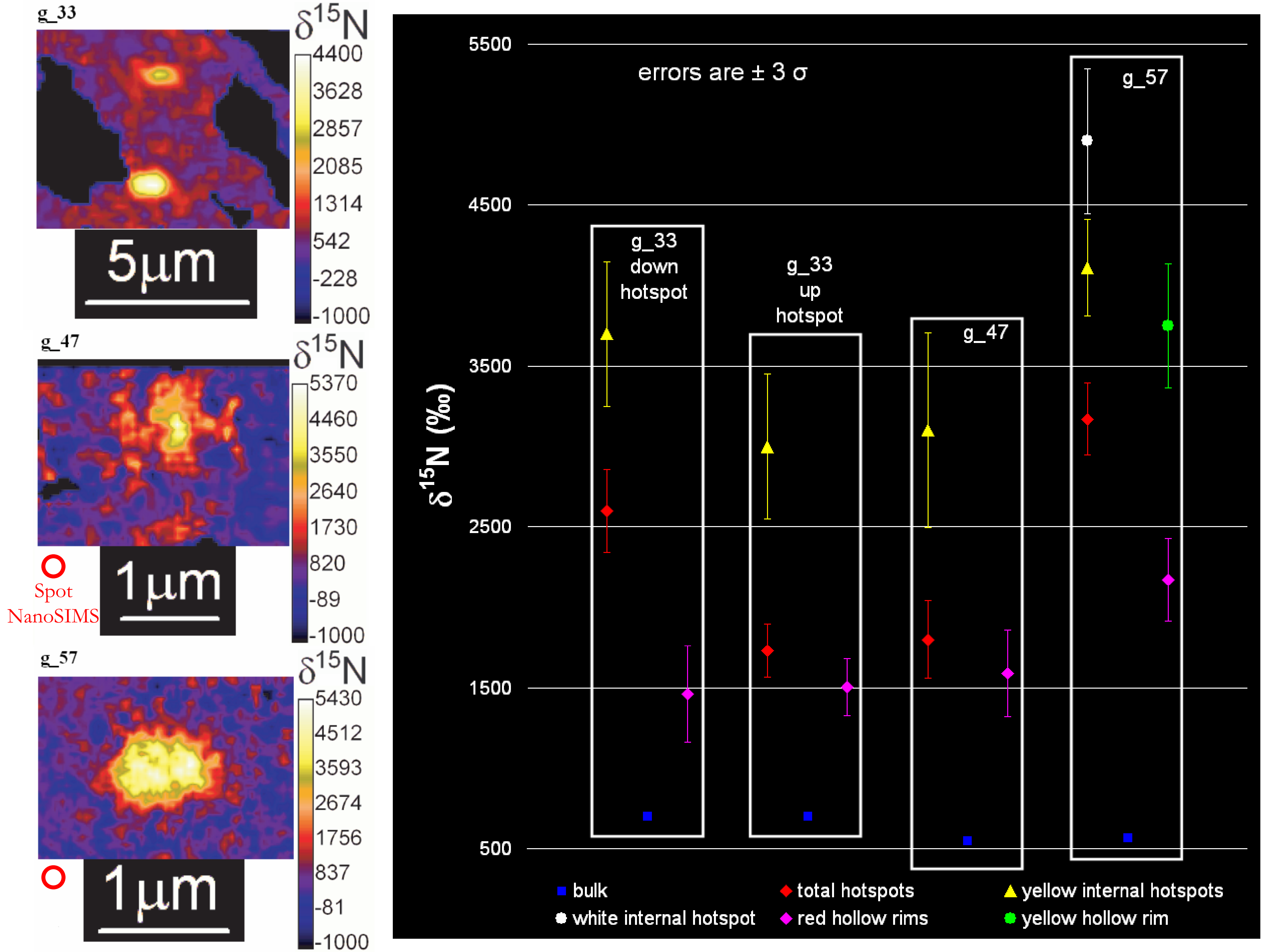
^{15}N variations in PX-18



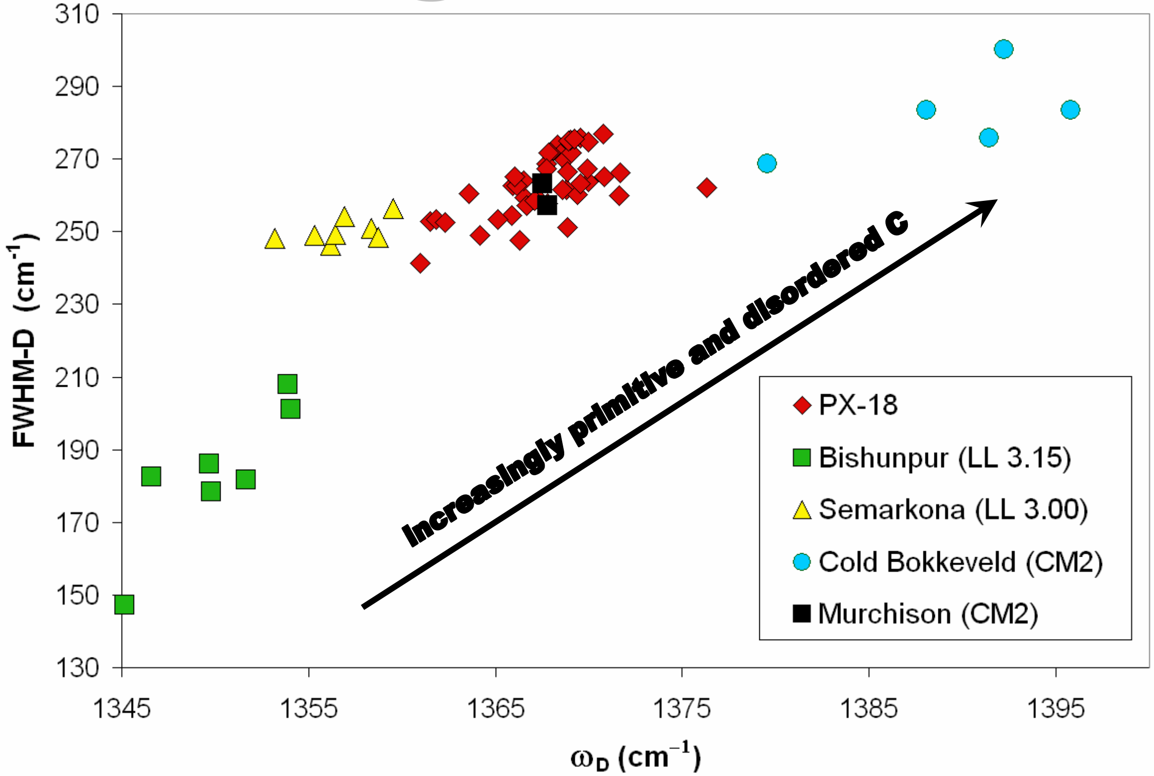
40×40 µm² image	area (µm²)	$\delta^{15}N_{mean}$ (‰)	$\delta^{15}N$ > 250‰ (% area)	hotspots
g_31	394.6	140 ± 13	34.26	3
g_32	541.2	630 ± 20	92.63	10
g_33	507.6	700 ± 17	95.76	2
g_41	1218.9	220 ± 9	35.89	7
g_42	1082.1	640 ± 11	89.67	16
g_48	888.6	110 ± 20	23.48	7
g_49	601.4	30 ± 22	28.78	0
g_53	995.8	80 ± 17	28.26	1



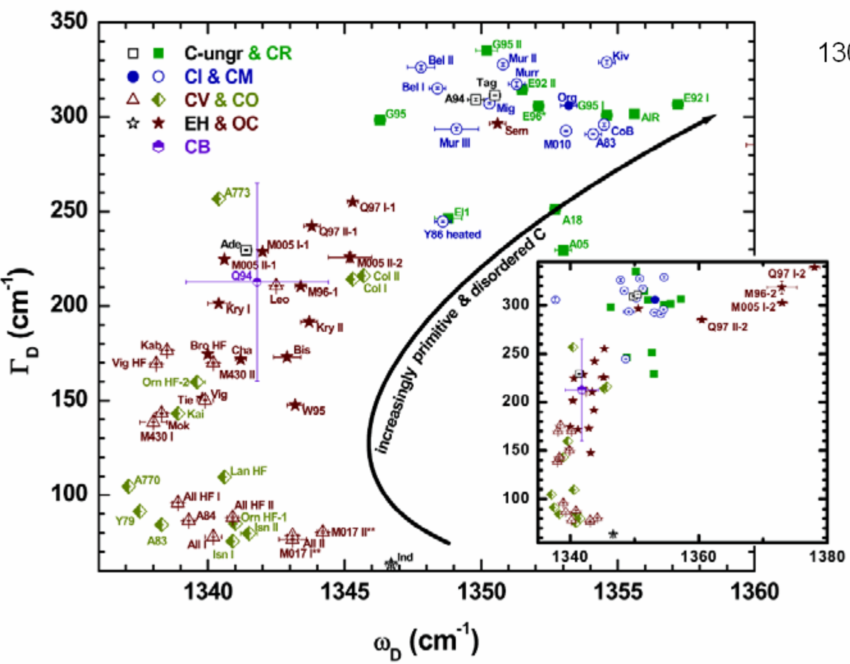
40×40 µm² image	area (µm²)	$\delta^{15}N_{mean}$ (‰)	$\delta^{15}N$ < 0‰ (% area)
g_31	394.6	140 ± 13	27.42
g_32	541.2	630 ± 20	1.05
g_33	507.6	700 ± 17	0.79
g_41	1218.9	220 ± 9	29.95
g_42	1082.1	640 ± 11	1.45
g_48	888.6	110 ± 20	43.18
g_49	601.4	30 ± 22	52.63
g_53	995.8	80 ± 17	46.67


g_33
δ15N
4400
3628
2857
2085
1314
542
-228
-1000
5µm
g_47
δ15N
5370
4460
3550
2640
1730
820
-89
-1000
1µm
Spot
NanoSIMS
g_57
δ15N
5430
4512
3593
2674
1756
837
-81
-1000
1µm
errors are ± 3 σ
δ15N (‰)
5500
4500
3500
2500
1500
500
g_33
down
hotspot
g_33
up
hotspot
g_47
g_57
bulk
total hotspots
yellow internal hotspots
white internal hotspot
red hollow rims
yellow hollow rim

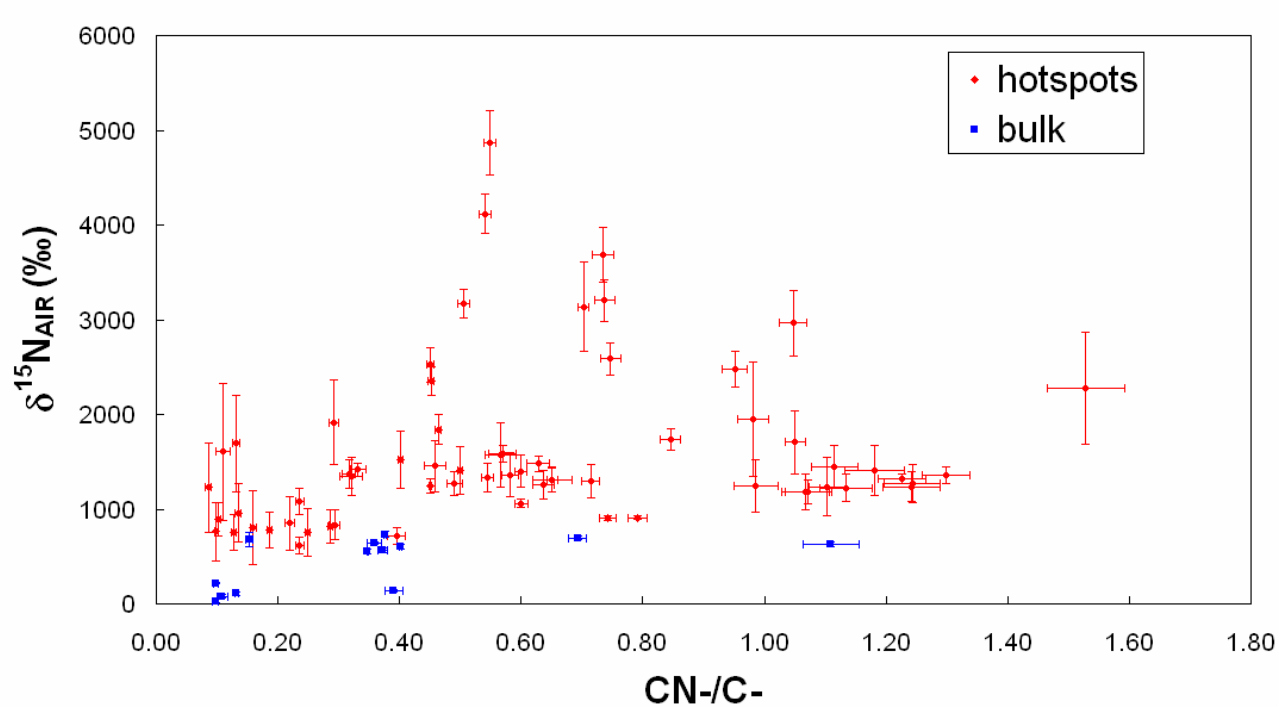
Raman spectra of Organic Matter



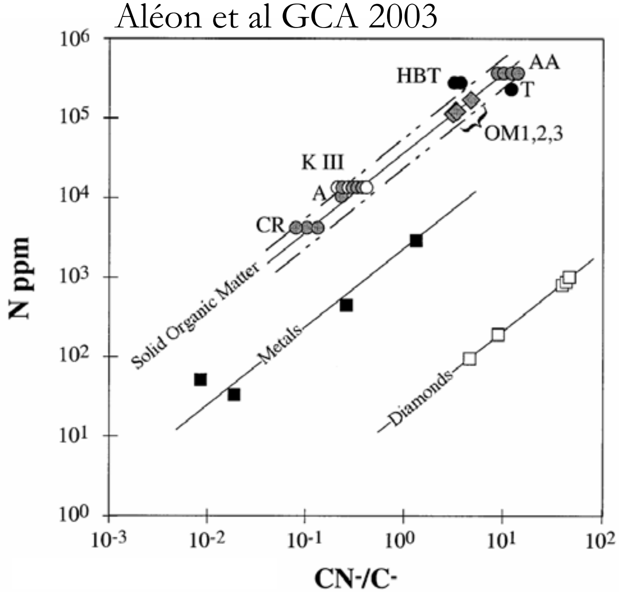
Busemann et al. 2007



Organic Matter in PX-18: row evaluation of N content



Aléon et al GCA 2003



PX-18 hotspots:

0.3 < N (wt%) < 5.5

(~ the same range found in ^{15}N-rich hotspots in IDPs by Floss et al 2006)

⇒ organic compounds with amine and nitrile functionalities?

Pre-solar grains

C and N isotopic composition would indicate an abundant amount of SiC-X rare grains

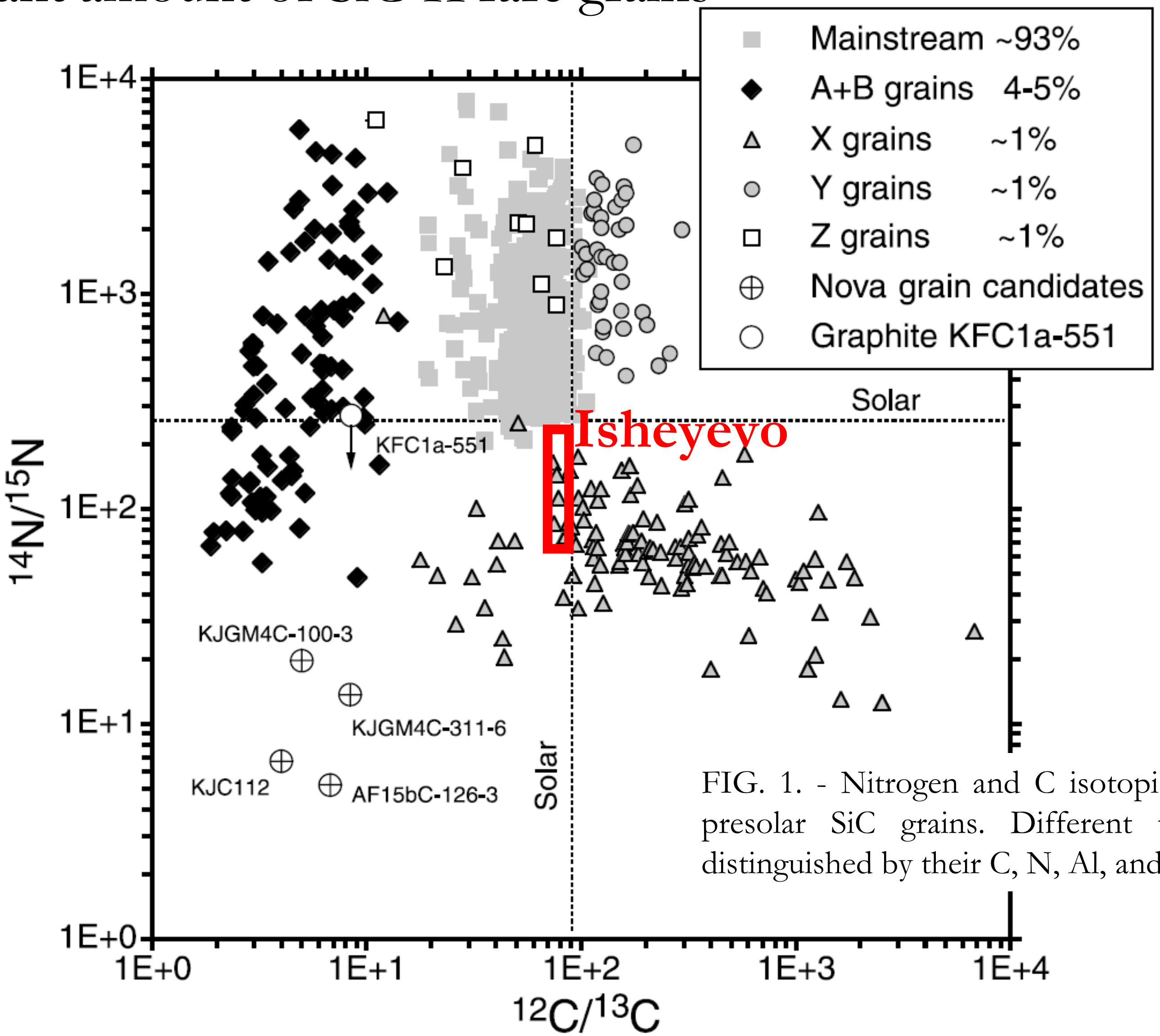
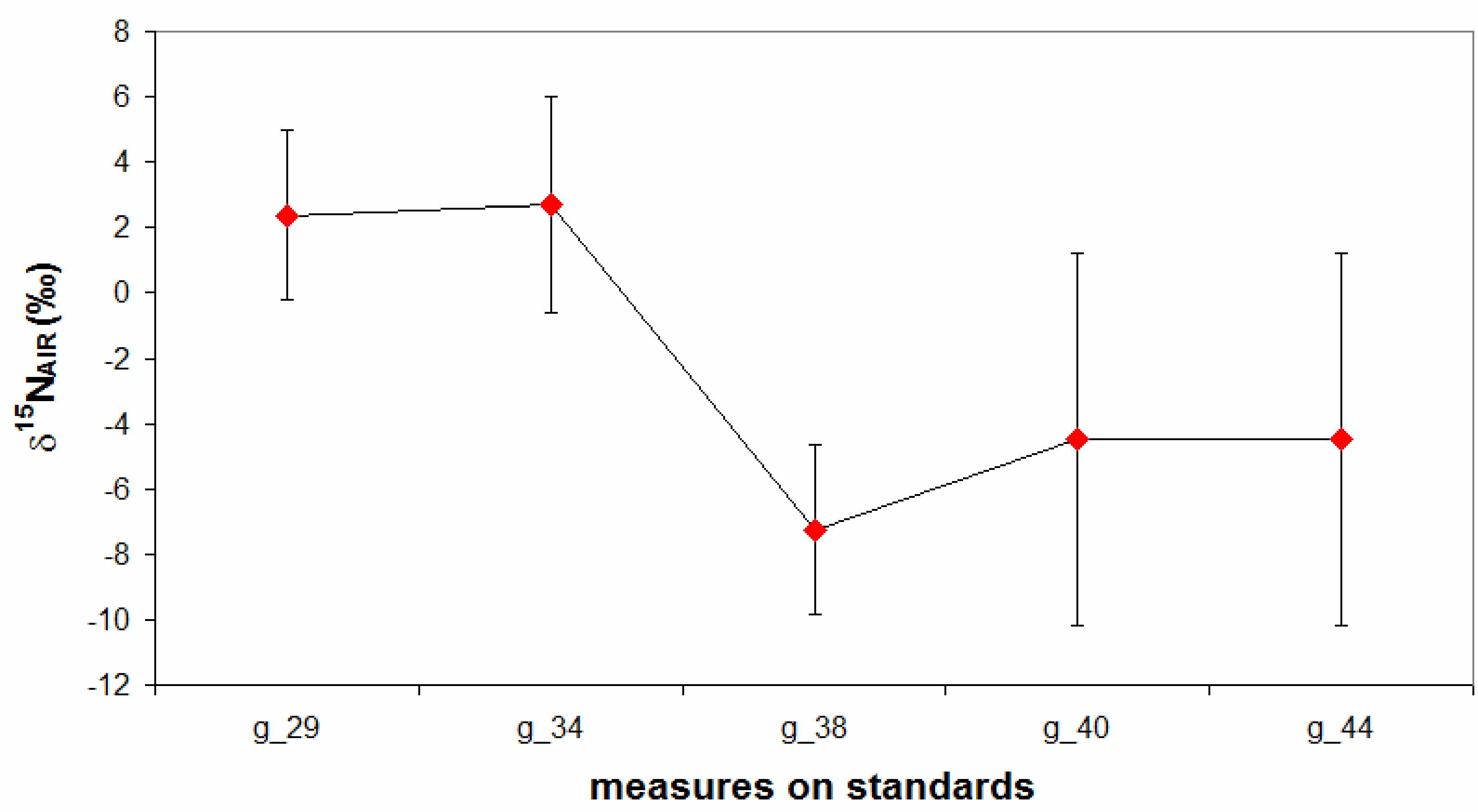
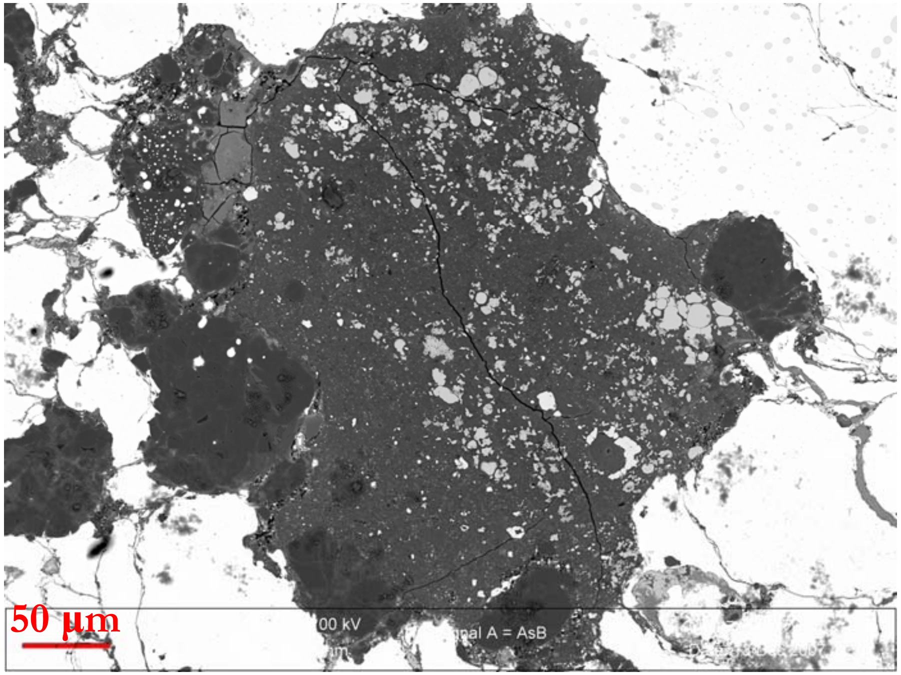


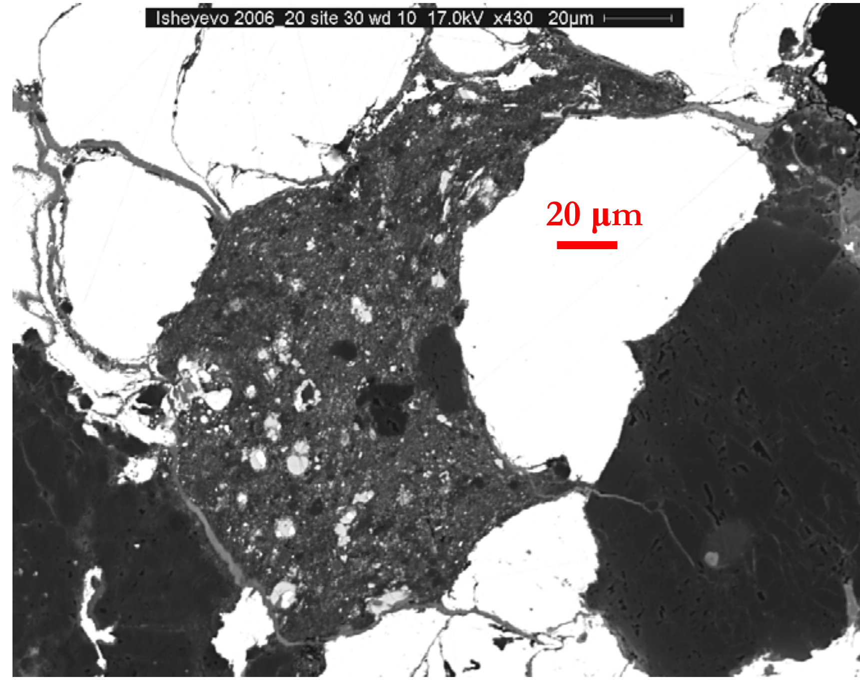
FIG. 1. - Nitrogen and C isotopic ratios of individual presolar SiC grains. Different types of grains are distinguished by their C, N, Al, and Si isotopic ratios.

Amari et al (2001)

NanoSIMS standard measurements: Nitrogen





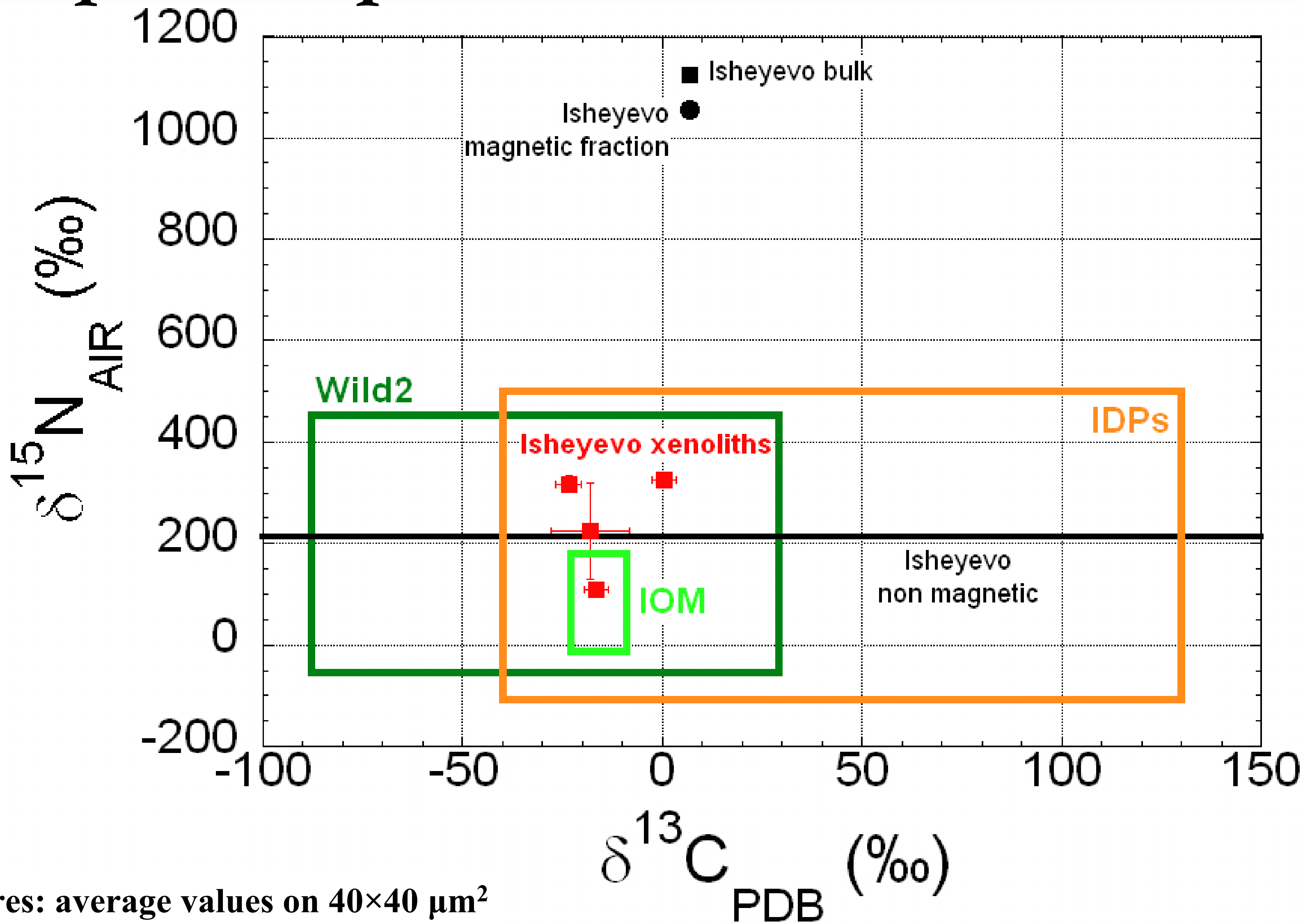


xenoliths CR-CI – like

xenoliths CM – like

xenoliths CR-CI – like	xenoliths CM – like
Olivine rare (Fo% = 97)	Olivine: common (Fo% = 73 – 98)
Pyroxene: common (En% = 90-95, Wo% = 1-4)	Pyroxene: common (En% = 77-91, Wo% = 0.2 – 4)
Carbonate: rare (calcite)	Carbonate: no
Magnetite: very abundant	Magnetite: rare
Fe-Ni sulfide: no	Fe-Ni sulfide: common (pyrrhotite)
Metal: common	Metal: common
Matrix: phyllosilicates	Matrix: phyllosilicates

Isotopic composition: bulk C and N



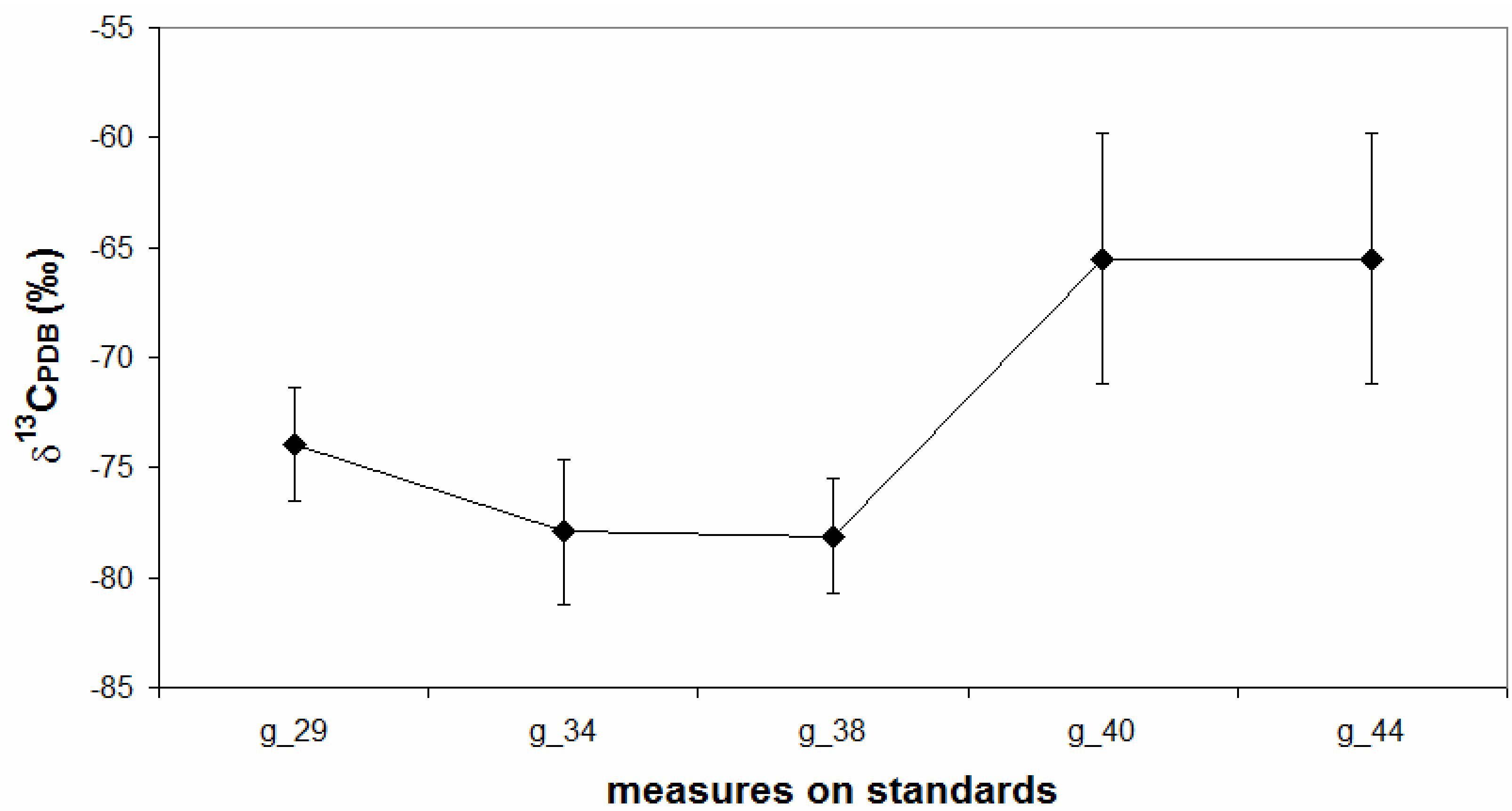
Isheyevo measures: average values on 40×40 μm^2

Isheyevo bulk, magnetic and non-magnetic fraction: Ivanova et al. (2007) MAPS, 42, A75, #5164

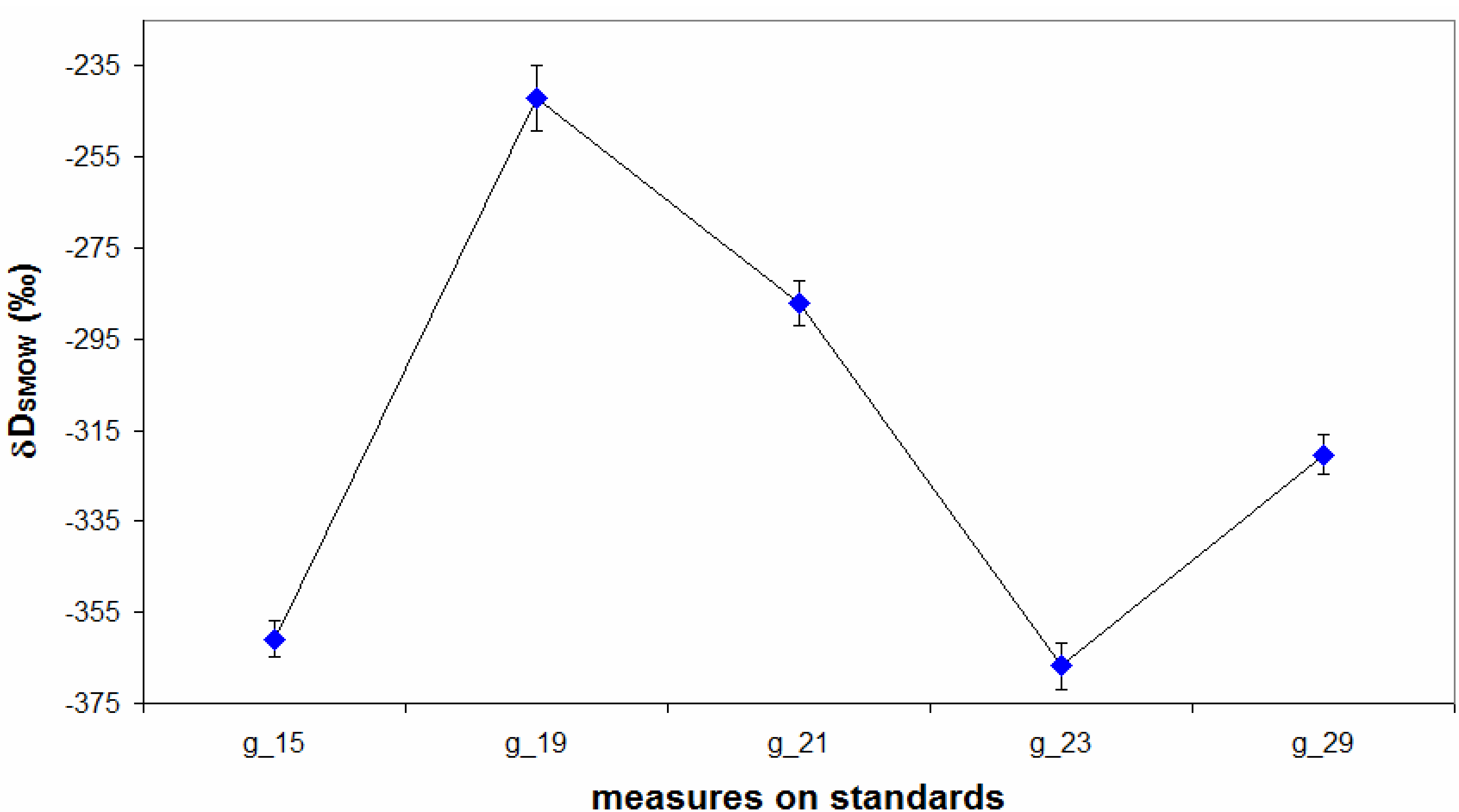
IDPs: Floss et al, GCA, 70, 2371, 2006 **Wild2: McKeegan et al, Science, 314, 1724, 2006**

Insoluble Organic Matter: Busemann et al, Science, 312, 727, 2006

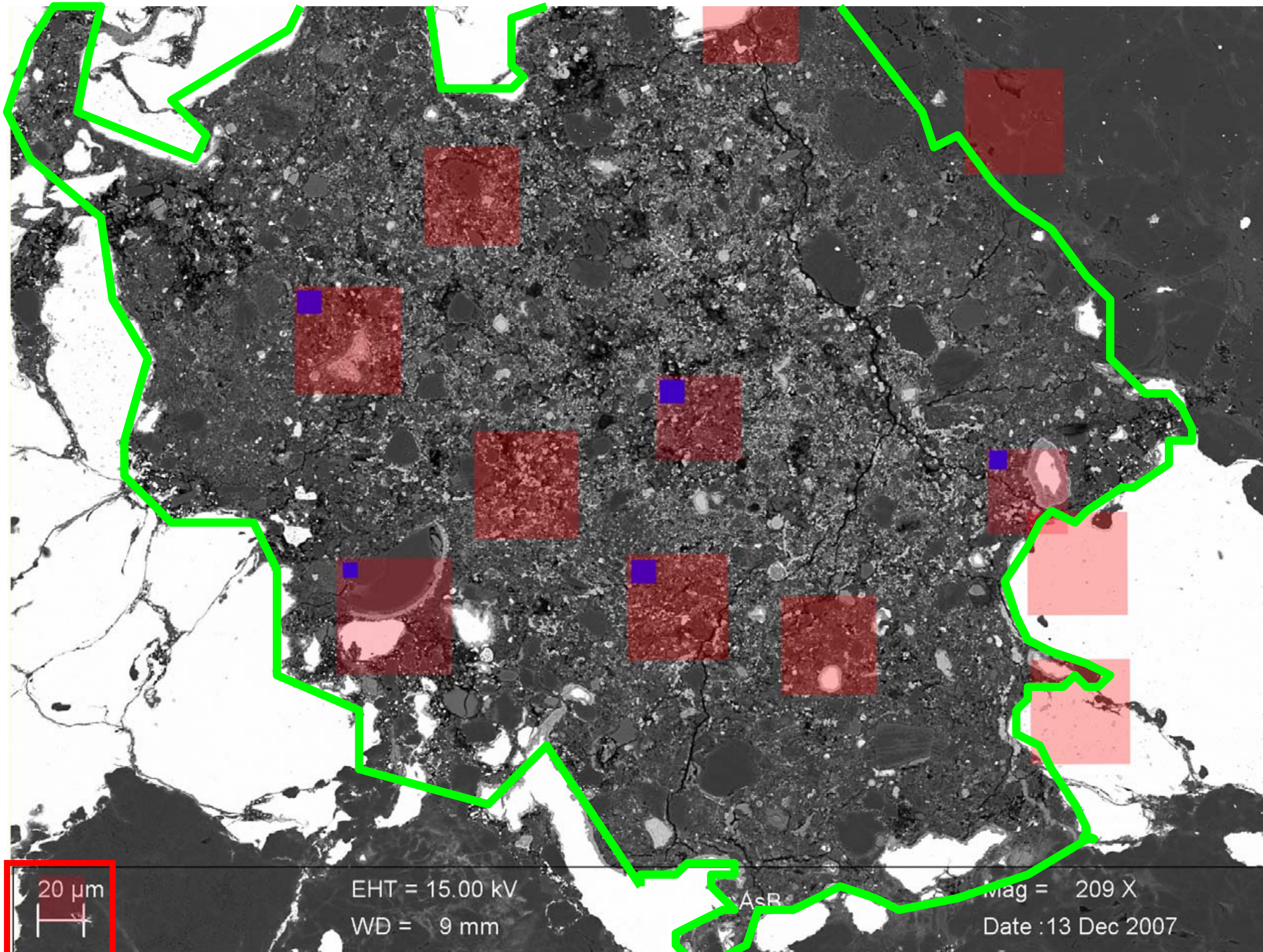
NanoSIMS standard measurements: Carbon



NanoSIMS standard measurements: Hydrogen



The ^{15}N-rich xenolith #18



Fractionation of light elements

N fractionation

- Low temperature ion-molecule reactions → Rodgers & Charnley 2008: $\delta^{15}N \geq 3000‰$
- Self-shielding (?)

H fractionation (Sandford et al. 2001)

- Low temperature gas phase ion-molecule reactions

However, this process only operates on molecules in the gas phase, and the majority of species are condensed onto grains at the low temperatures where fractionation is significant. Thus, while ion-molecule reactions clearly contribute to D fractionation in the interstellar medium, they may not be the main contributor to the bulk fractionation of D in dense clouds.

- Low temperature gas-grain reactions

Since the grain mantles in dense clouds represent a much larger fraction of the total reservoir of material than does material in the gas phase (H_2 excepted), grain surface processes are likely to be far more important for the total D fractionation in dense clouds than ion-molecule reactions.

- Gas phase unimolecular photodissociation
- UV photolysis in D-rich ice mantles

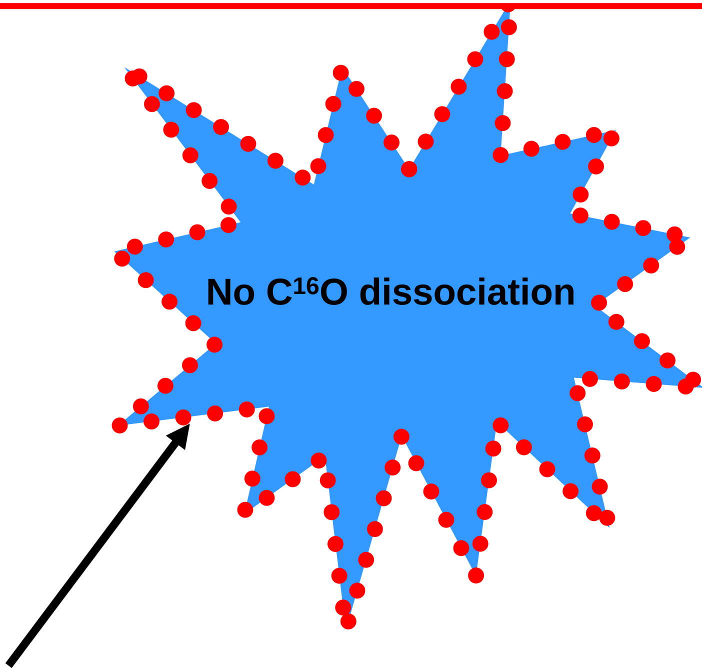
The mechanism of self-shielding

(coutesy of Matthieu Gounelle)

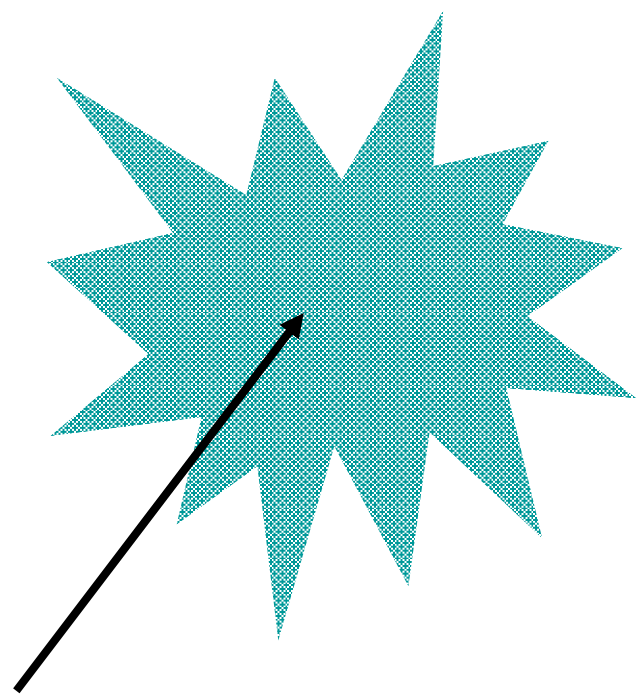
- For a given UV flux, photoabsorption takes place until a certain distance within the molecular cloud (depends on the column density)

- $C^{16}O$ being the most abundant molecule, photoabsorption takes place only in the outside skin of the molecular cloud [UV flux at specific wavelengths is totally absorbed] : *self-shielding!*

$C^{16}O$ self-shielding in a molecular cloud

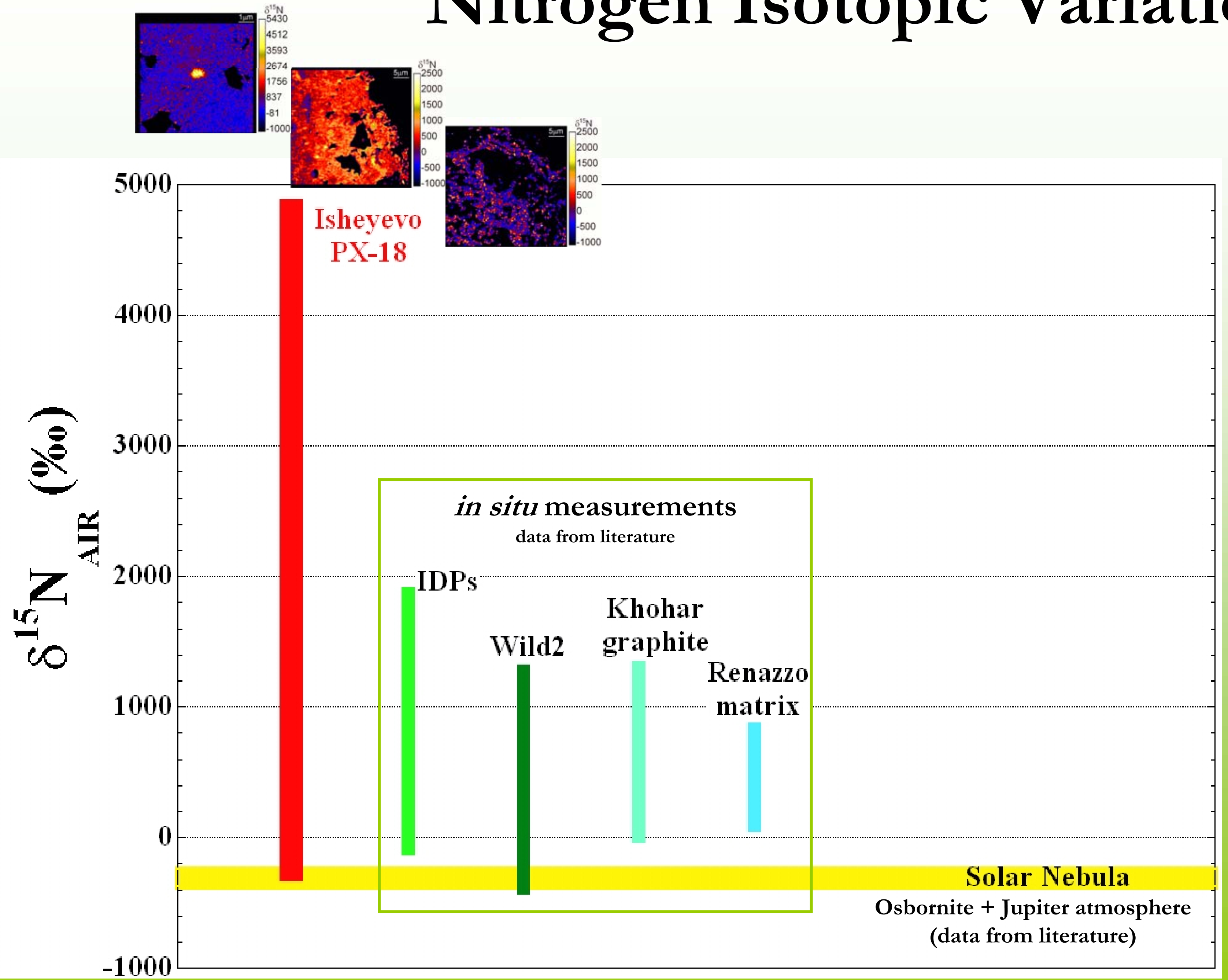


$C^{16}O$ dissociation in an outer skin



$C^{17}O$ and $C^{18}O$ dissociation inside the whole MC

Nitrogen Isotopic Variation



Nitrogen Isotopic Variation