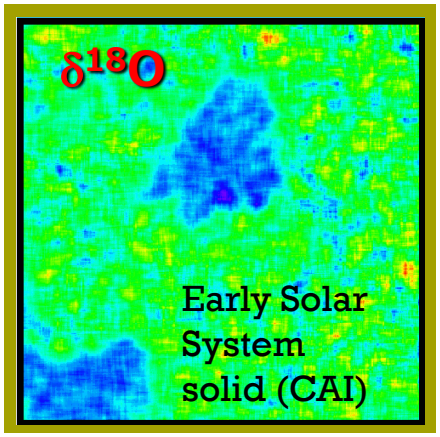
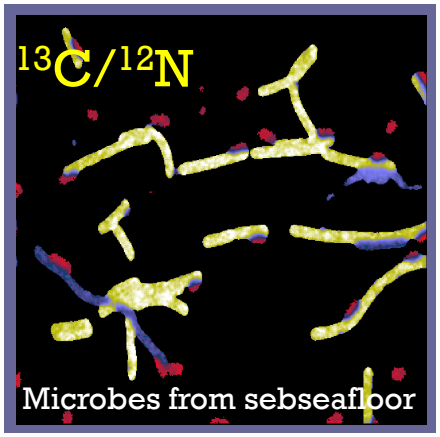
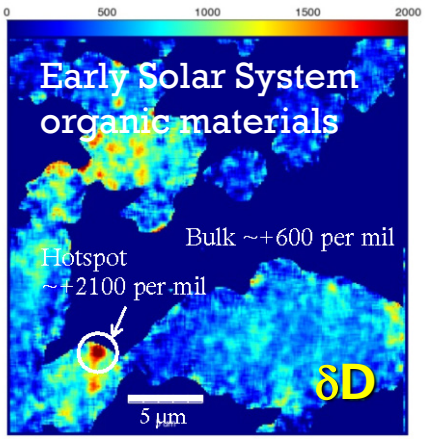
Ultra High Spatial Resolution Ion Imaging with a NanoSIMS Ion Microprobe: Applications to Astrobiology.

Motoo ITO

Kochi Institute for Core Sample research, JAMSTEC







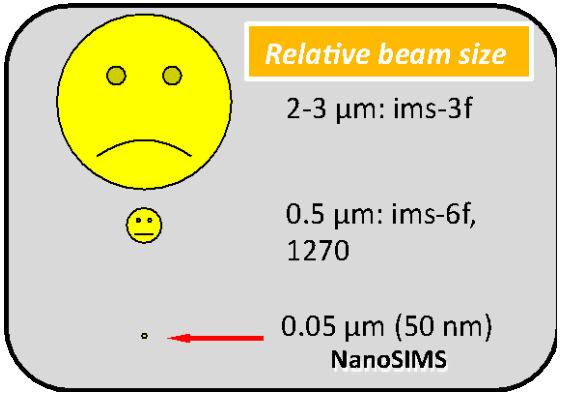
In collaboration with many scientists

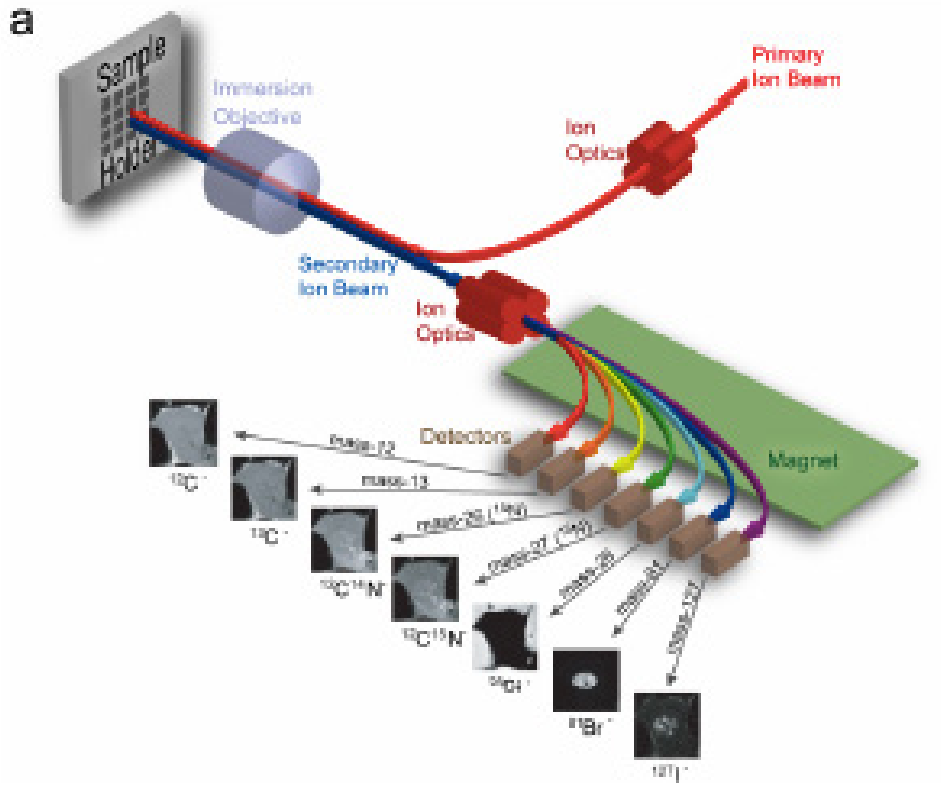
Microbiology: Y. Morono, F. Inagaki (JAMSTEC), T. Terada (MWJ)

Hayabusa Organic materials: M. Uesugi[2], H. Naraoka[3], H. Yabuta[4], F. Kitajima[3], H. Mita[5], Y. Takano[1] Y. Karouji[2], T. Yada[2], Y. Ishibashi[2], T. Okada[2] and M. Abe[2]

[1]JAMSTEC. [2]JAXA/ISAS. [3]Kyushu University. [4]Osaka University. [5]Fukuoka Inst. Tech.

A very basic of NanoSIMS Ion Microprobe





Steinhauser et al. (2012) Nature

- Ultra high spatial resolution: ~50 nm for Cs, ~200 nm for Oxygen
- Up to 7 isotopes/elements can be measured simultaneously.
  - M_{max}/M_{min} = 21 (~25.4)
- Acquire isotope/elemental images
  - Clearly see 2-D distributions in sample
- Coordinated studies with TEM, SEM, and FIB systems are becoming routine.
- Lack of molecular info.

What we can do with NanoSIMS ion imaging

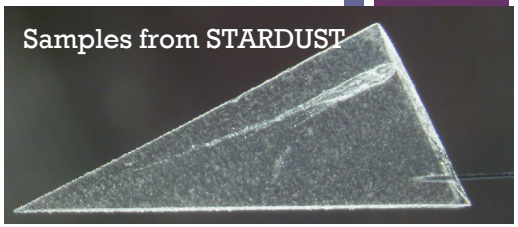
	Micro Analysis	Imaging
Cs primary ion source		
H (H, D)	N/A	~200 nm
C (^{12}C, ^{13}C)	N/A	~50 nm
O (^{16}O, ^{17}O, ^{18}O)	N/A	~50 nm
	3-5 μm	~400 nm
N (^{14}N, ^{15}N)	N/A	~50 nm
Volatile elements (H_2O, CO_2, F, Cl, S etc.)		
High-precision O isotopic measurements (~0.01%)		
Oxygen primary ion source		
^{26}Al-^{26}Mg: age dating	5-20 μm	0.2-1.5 μm
^{53}Mn-^{53}Cr: age dating	3-5 μm	N/A
^{60}Fe-^{60}Ni: age dating	~20 μm	N/A
Rare Earth Elements	8-15 μm	2 μm
Major and trace element abundances: Water in fluid inclusions, minerals and organic materials in ice		

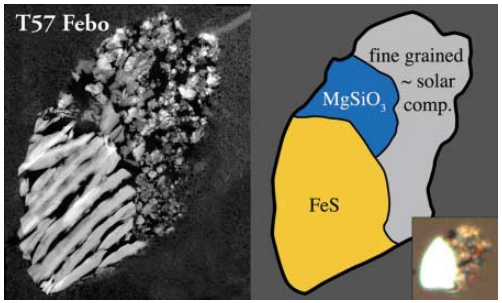
On-going project

Oxygen ion source will be upgraded to get better spatial resolution.

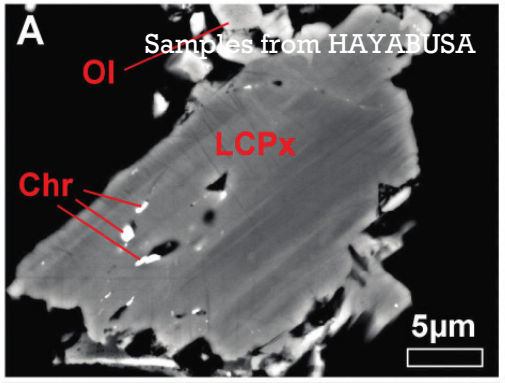
Astrobiology Samples: Organics, microbes, minerals

- We are expecting to have samples by TANPOPO (PI: Prof. Yamagishi) and Hayabusa 2 those are similar to the samples by STARDUST and Hayabusa missions.
  - Organics (carbonaceous materials)
    1. Very low temp. chemical processes in Molecular Cloud
    2. Origin of life, organics
  - Minerals (micrometeorite, asteroidal particles)
    1. Presolar materials: origin of the Solar system
    2. Water bearing minerals: origin of Earth's water
    3. High temp. processes near the Early Sun
    4. Mineral-Water interactions during planetesimals
    5. Aqueous alteration, thermal and shock metamorphism





Brownlee et al. (2006)

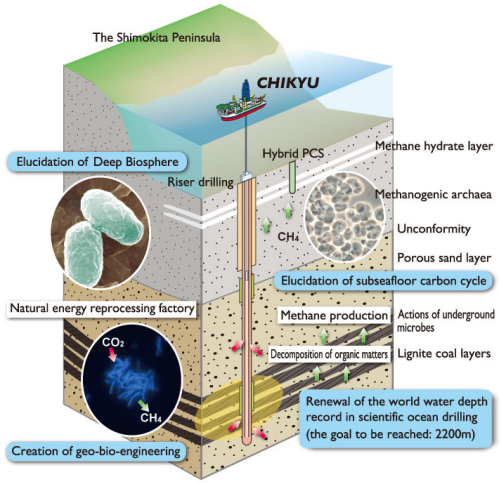


Nakamura et al. (2011)

Our analytical techniques for organics, biology and mineral samples so far

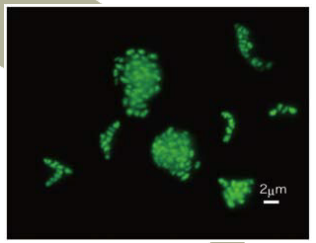
- Biology sample
  - Microbes from deep subsea floor
- Organics
  - IOMs from Carbonaceous chondrites,
  - Hayabusa category 3 organic samples

Riser drilling vessel "Chikyu"



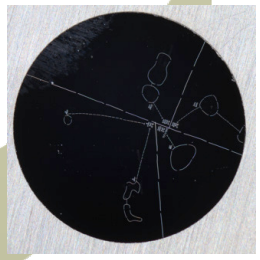
Core sediments

Incubation with ^{13}C labeled and/or ^{15}N labeled sources (e.g., glucose, amino acid)



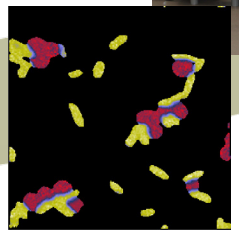
Deep subseafloor microorganism

A sequence for biology sample: From deep subseafloor to Laboratory



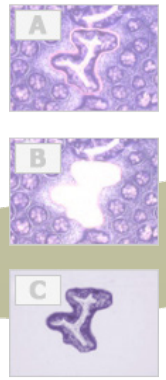
Microbes put on Carbon membrane with ITO coating

Ion imaging



^{13}C labeled Micro organisms

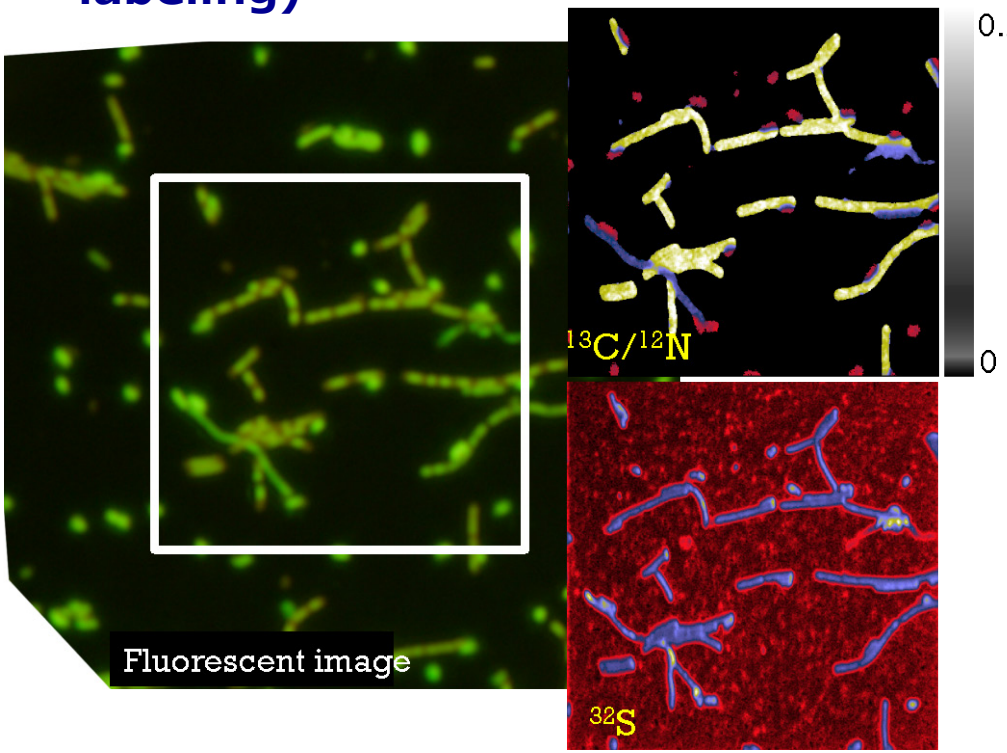
Extract DNA from the microbe that contain ^{13}C and/or ^{15}N enrichments



Laser Microdissection

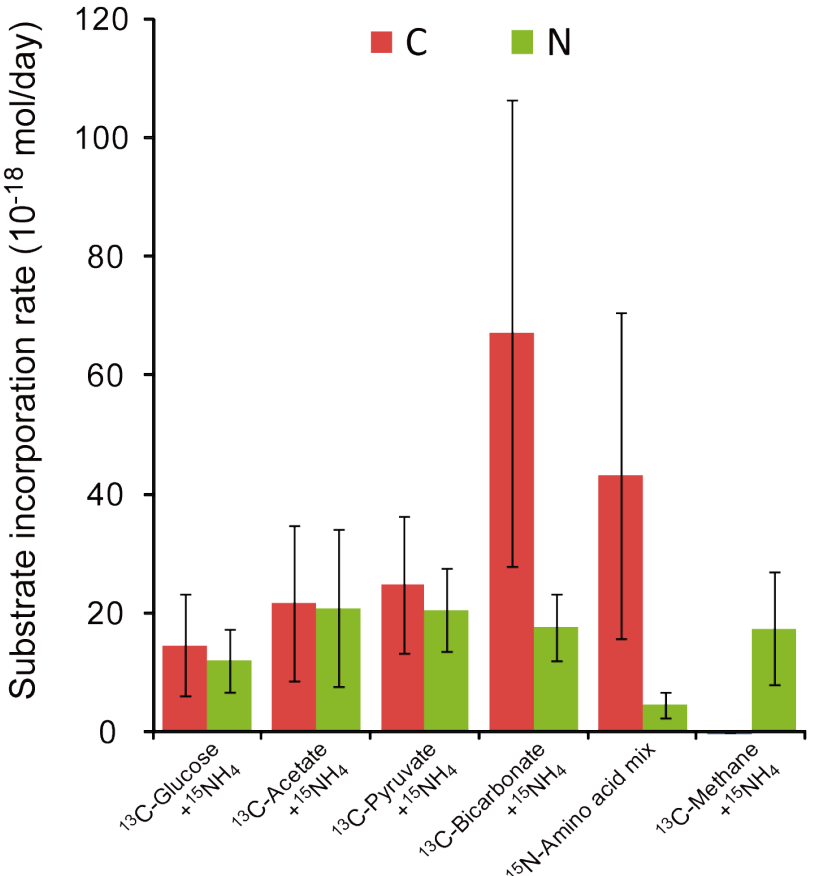
Isotope image for microbes from deep subseafloor

Stable isotope probing for activity measurement (e.g., ^{13}C, ^{15}N labeling)

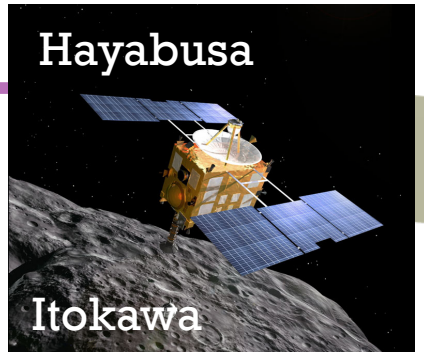


Deep sebseafloor microbes by the reactor enrichment culture using $^{13}CO_2$

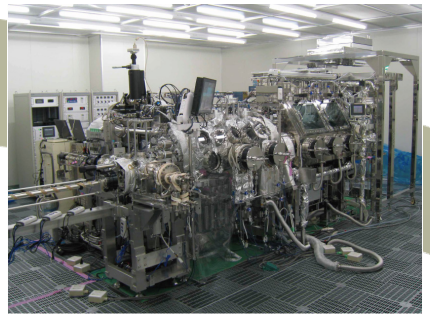
Activity can be calculated for each substrate

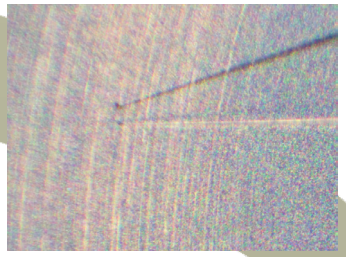


Morono et al. 2010



Sample curation @ JAXA

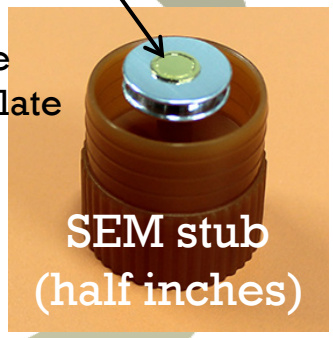




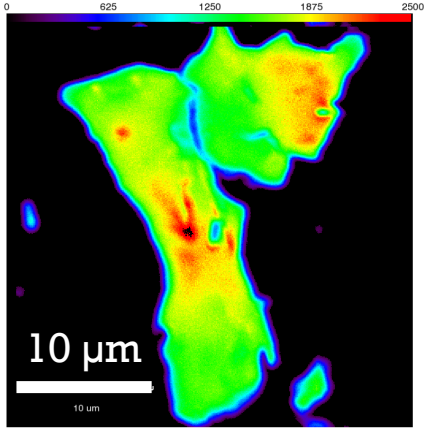
A sequence for Hayabusa Cat 3 organic sample

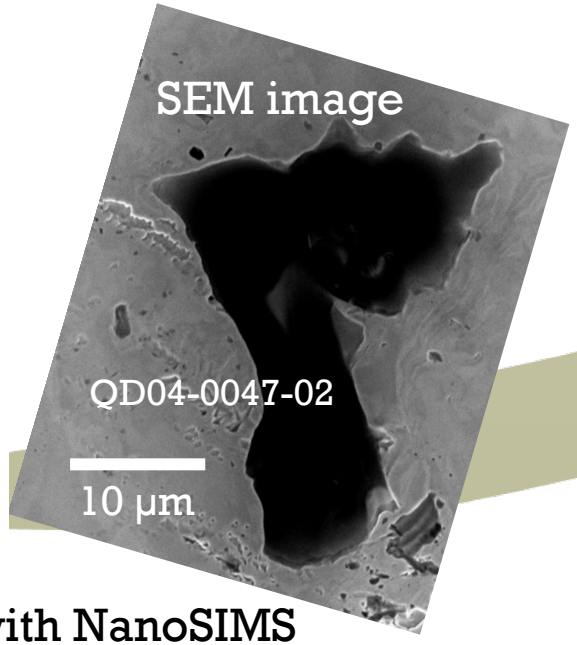
Au plate

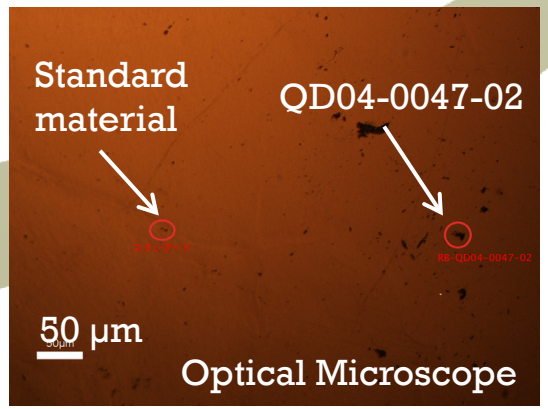
Samples were pressed on Au plate



^{12}C image





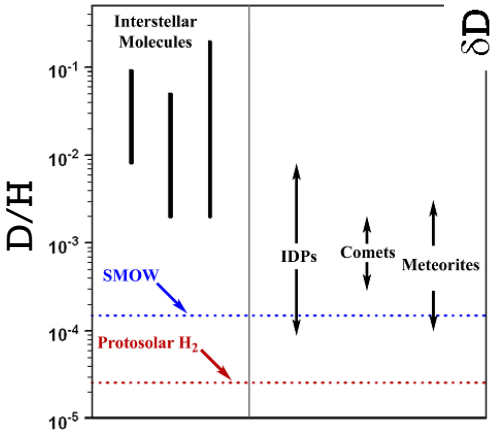


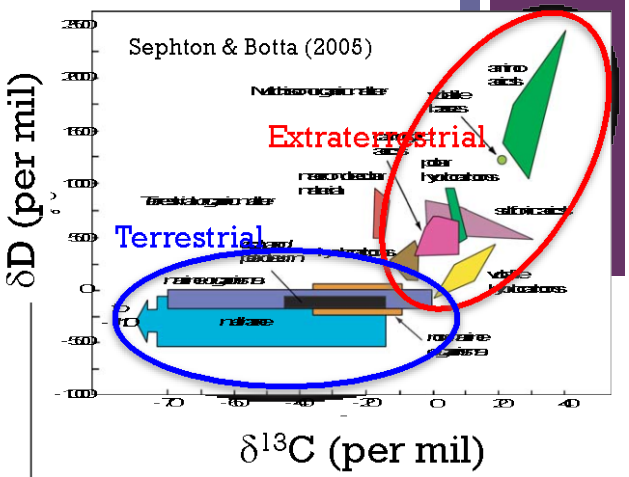
Isotope imaging with NanoSIMS

Isotopic anomalies in primitive solar system organic materials

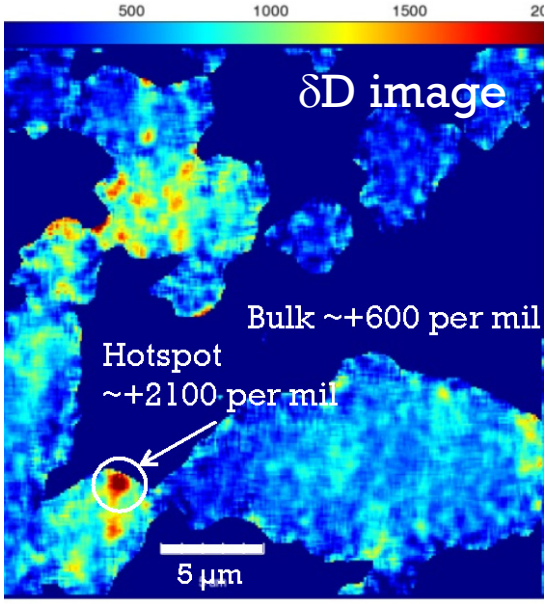
1. **Cold interstellar clouds**
   - large δD values have been observed
   - large $\delta^{15}N$ values have been predicted
2. **Outer regions of the protoplanetary disk**
   - large δD values have been predicted for gas-phase molecules.

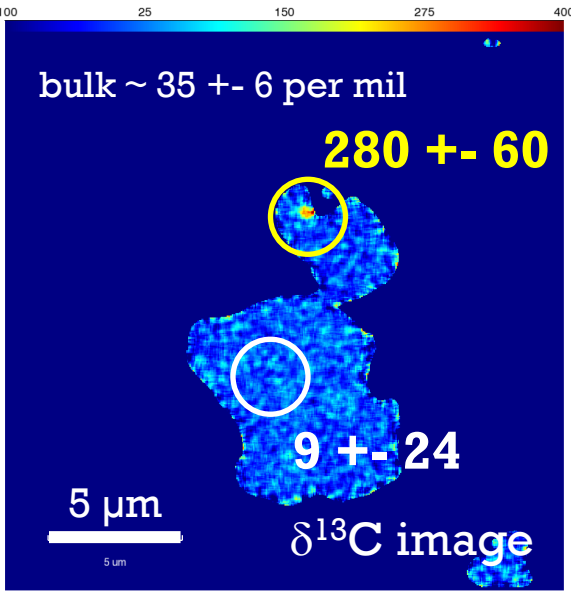
(e.g., Busemann et al., 2006)

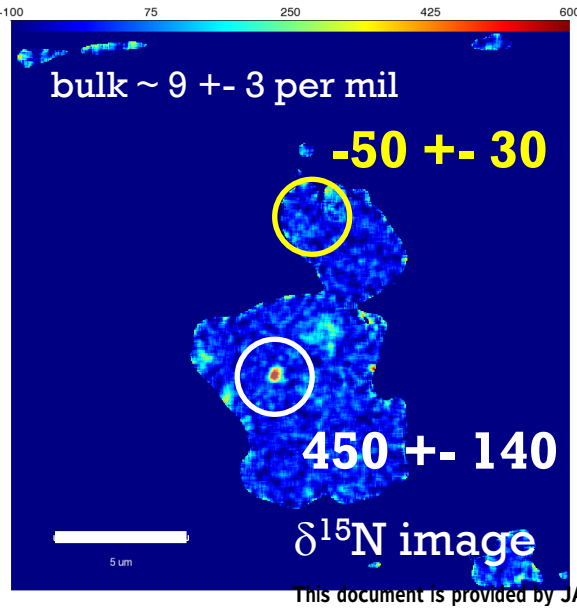




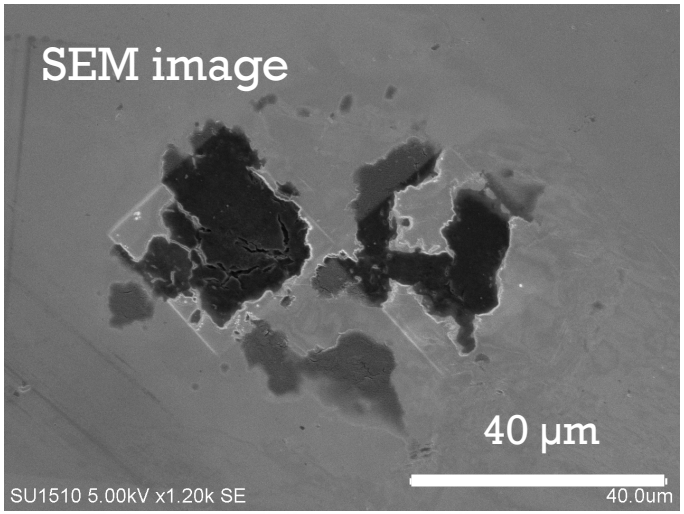
Meteorites, IDPs, and comets are D-rich, preserving some presolar organic compounds

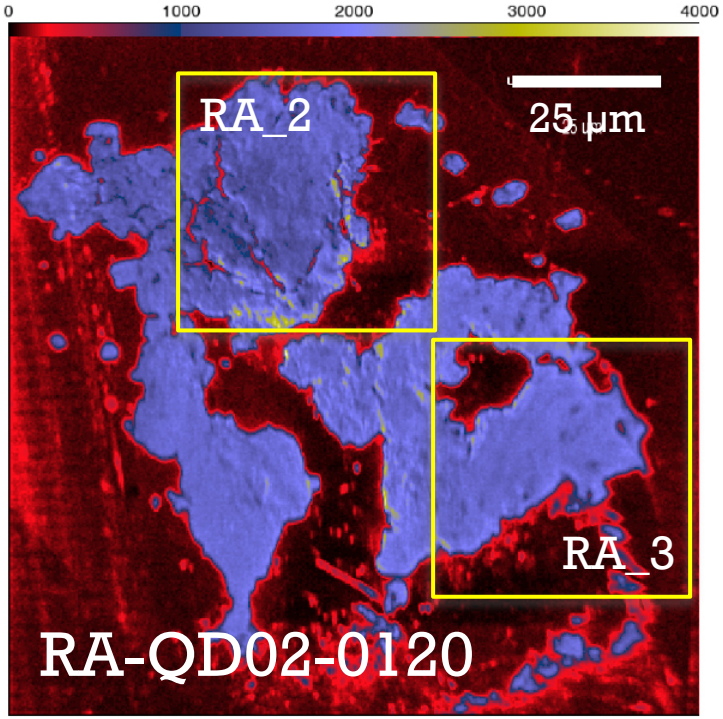






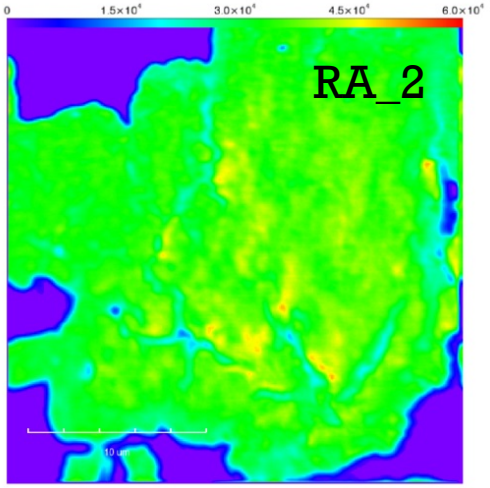
Hayabusa Category 3 organic sample

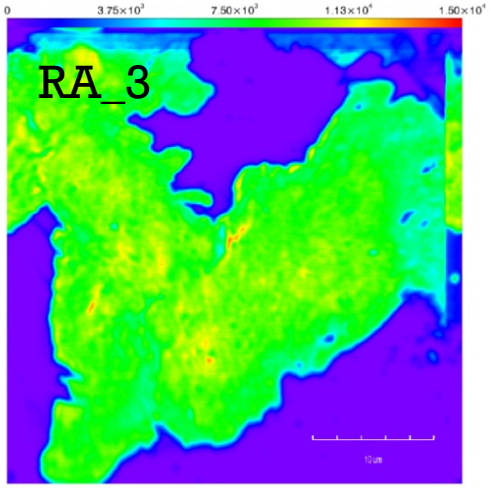




Entire image (^{12}C ^{14}N)

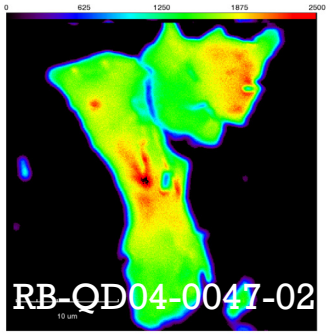
	$\delta^{13}C$ (per mil)	$\delta^{15}N$ (per mil)	δD (per mil)
RA_2	-19 +- 8	2 +- 2	81 +- 54
RA_3	-6 +- 8	0 +- 2	29 +- 47

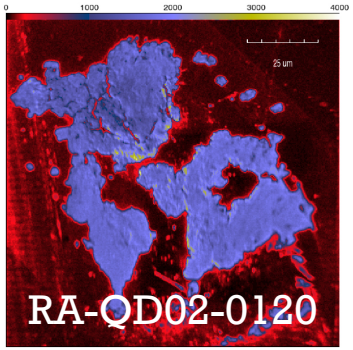


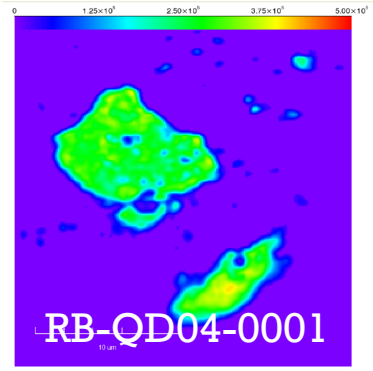


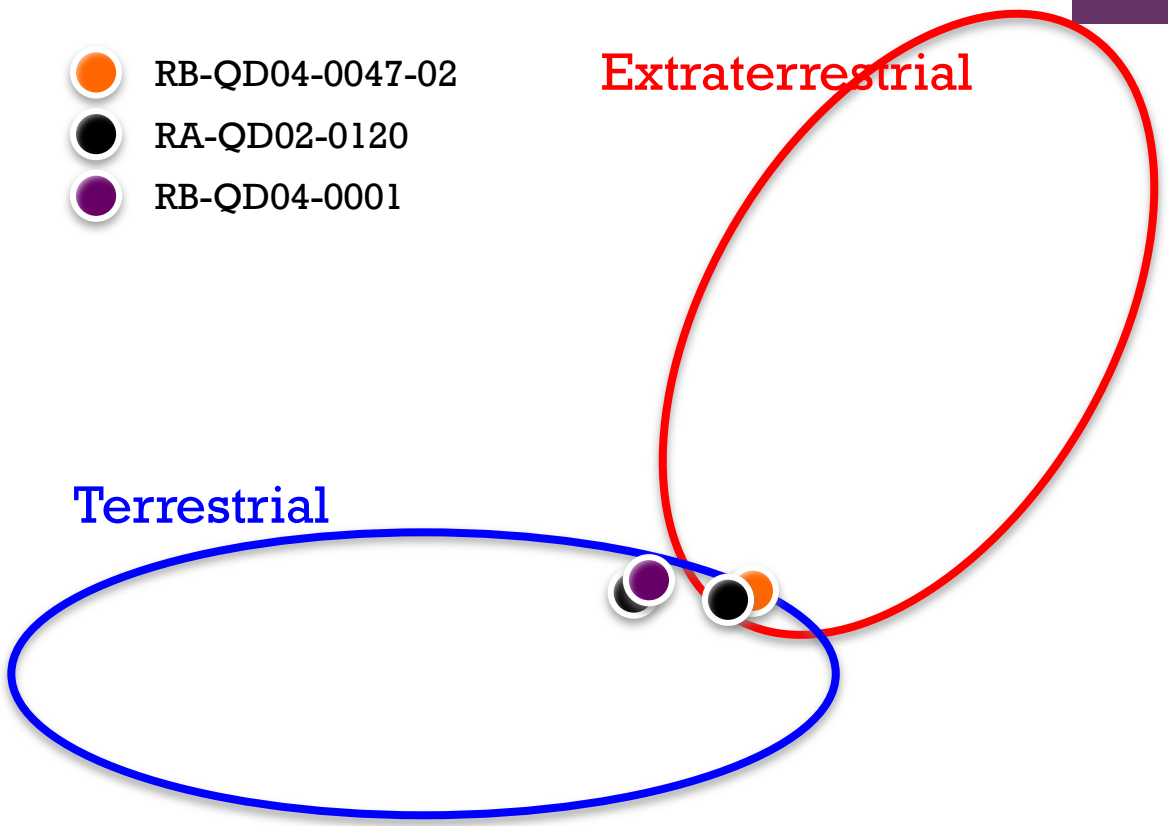
^{12}C ^{14}N image Field of view = 25 μm

H and C isotope diagram









Sephton & Botta (2005)

Conclusions:

- Sample handling system for minerals, organic materials and microbes has been developed.
- Ion imaging by SIMS is a powerful tool to visualize distributions of isotopes and elements for variety of samples, and has a potential to allow the study of processes at the sub-micron level.
- Ultra high spatial resolution & quantitative isotope/elemental images will open up "***new insight***" for Astrobiology.

High sensitivity and high spatial resolution SIMS

1. NanoSIMS
2. IMS1280HR
3. IMS6F

ADMIRAL CLUB JAMSTEC

ADVANCED MICROANALYSIS RESEARCH LABORATORY AT JAMSTEC KOCHI

Ultra high resolution TEM

1. High resolution TEM
2. FE-SEM
3. EELS, EDS, EBSD

Nano scale sample preparation system

1. FIBs
2. Micro sampling system

Next Step: Cryo-linkage system will be added.