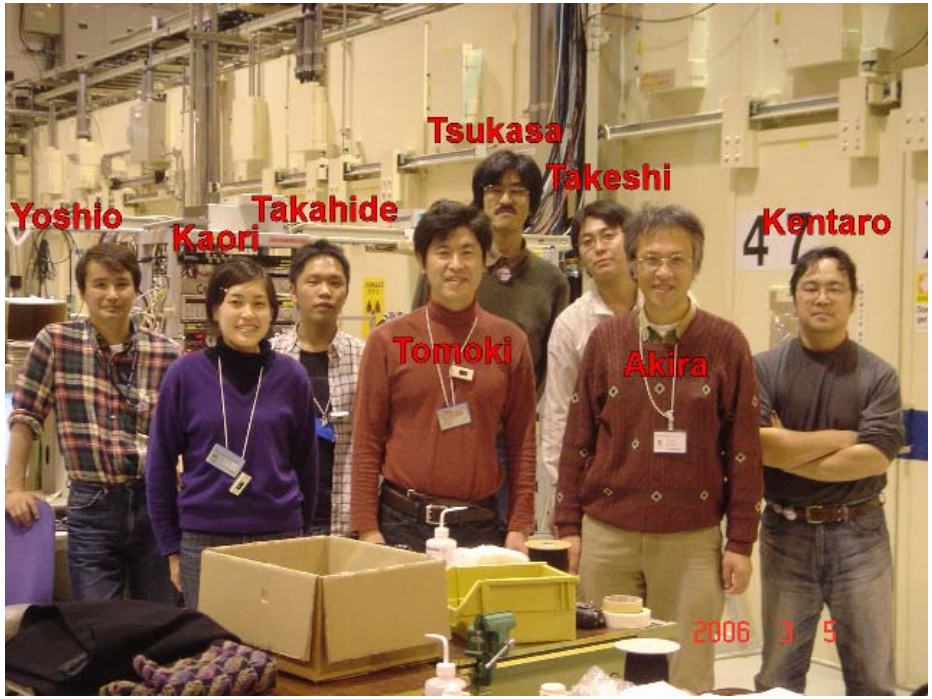
X-ray tomographic studies of Stardust samples: a track and individual particles

A. Tsuchiyama[1], K. Uesugi[2], T. Nakano[3], T. Okazaki[1], T. Nakamura[4], A. Takeuchi[2], Y. Suzuki[2], and M. Zolensky

[1] Department of Earth and Space Science, Osaka Univ.
[2] SPring-8/JASRI, [3] GSJ/AIST
[4] Department of Earth and Planetary Sciences, Kyushu Univ., [5] JSC/NASA



Two types of tomographic studies at BL47XU/SPring-8

1. 3-D structures of impact tracks
   SUBTEAM: Bulk-composition
   Projection tomography (high resolution)
   Resolution: 0.5 or 0.195 μm/pixel
   Samples: 4 tracks* in keystones
   with XRF (T. Nakamura)

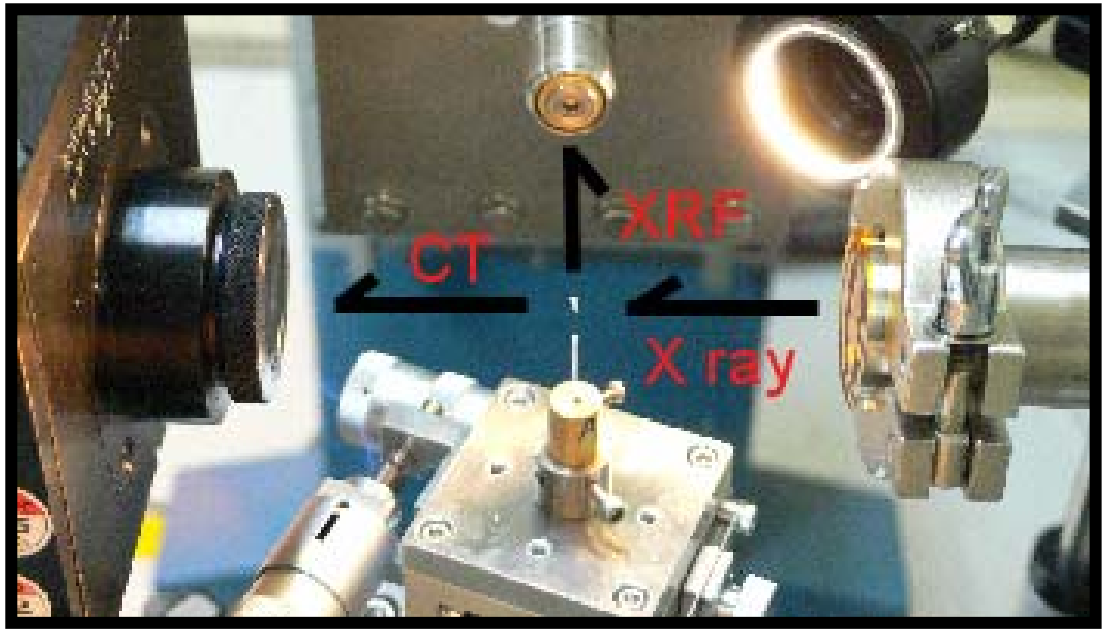
2. 3-D structures of individual particles
   SUBTEAM: Mineralogy-Petrology
   Imaging tomography (ultra-high resolution)
   Resolution: 0.0425 μm/pixel
   Samples: 4 particles removed from 2 tracks*
   with XRD at BL17/PF (T. Nakamura)

* Different tacks

3D structures of impact tracks

Projection tomography (0.5 or 0.195 μm/pixel)
Samples: 4 tracks (C2126,2,68,0; 32,0; 67,0; 47,0)
Photon energy: 10 keV
No. of projection: 1500
3-D image: 2000x2000 matrix, 1312 slices

XRF
Photon energy 15 keV
Beam size:
40x40 to 400x260 μm



Procedure

(1) Optical microscopy

(2) Radiography

Whole 2-D image of keystone

(3) XRF

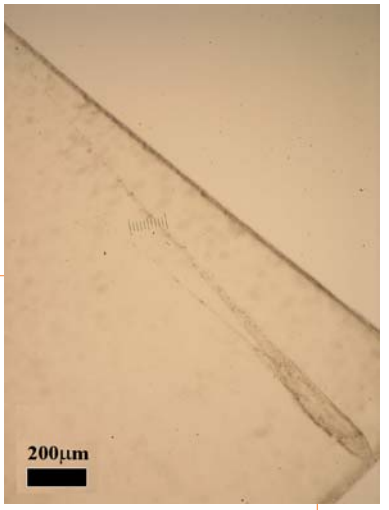
Coarse mode: cover whole track

Fine mode: individual particles

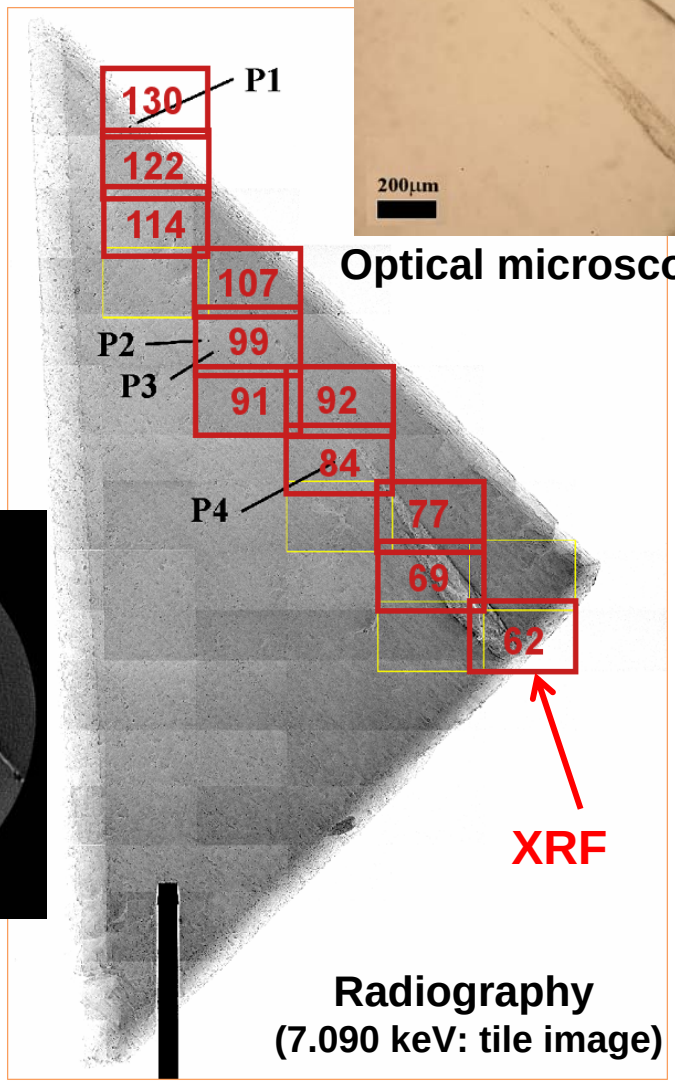
(4) Tomography

Coarse mode: cover whole track

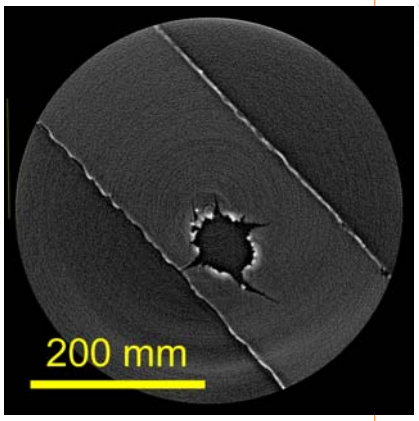
Fine mode: details of a track



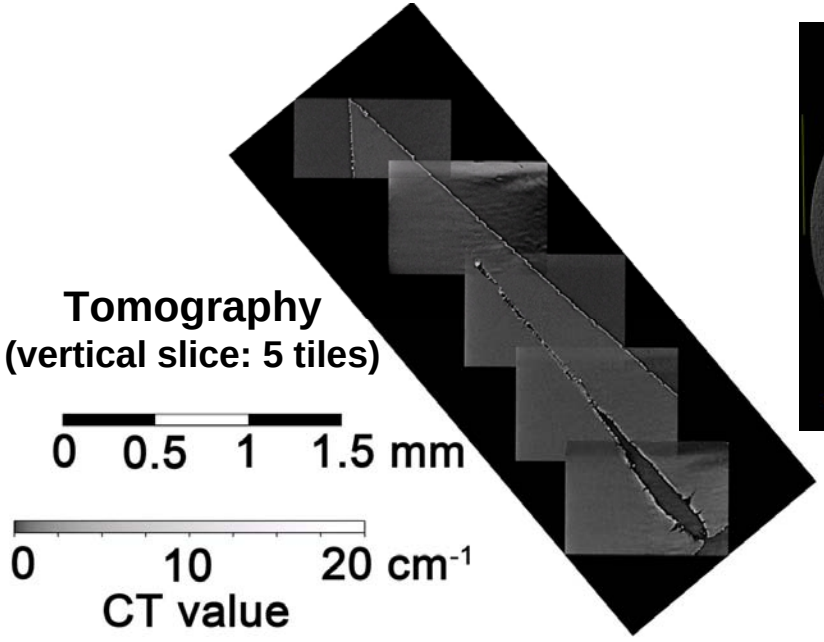
Optical microscopy



Radiography
(7.090 keV: tile image)



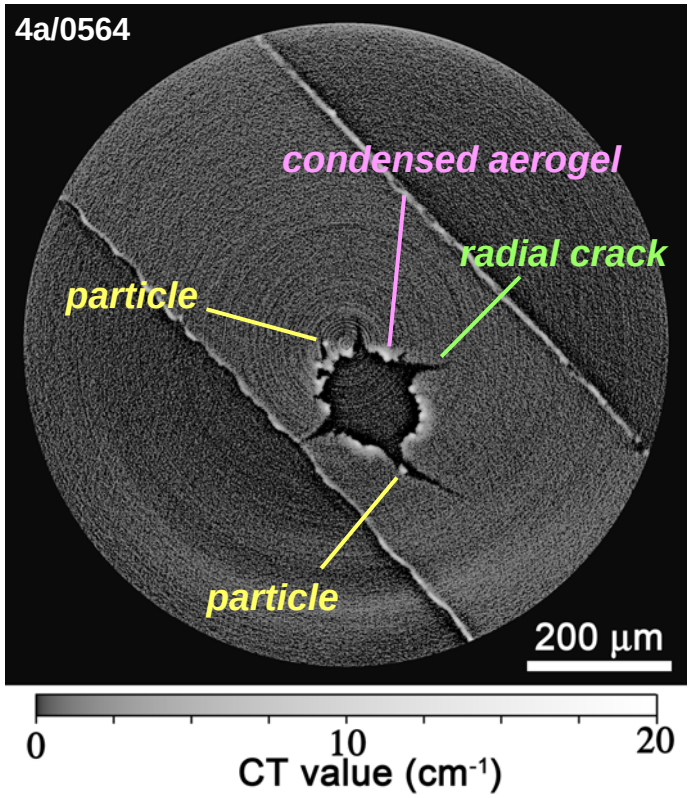
Tomography
(CT slice)

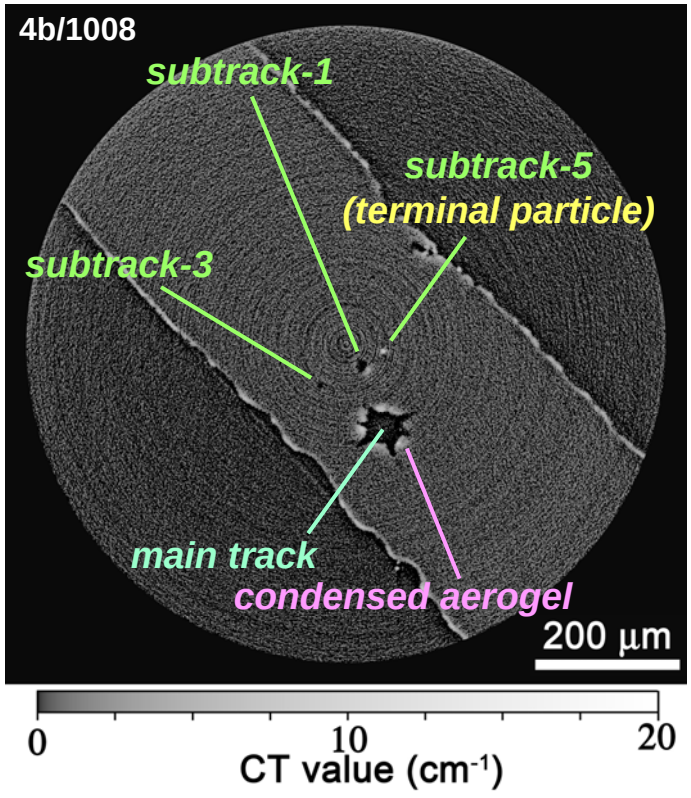


Tomography
(vertical slice: 5 tiles)

Sample: C2126,2,68,0

CT slice images (C2126,2,68,0)

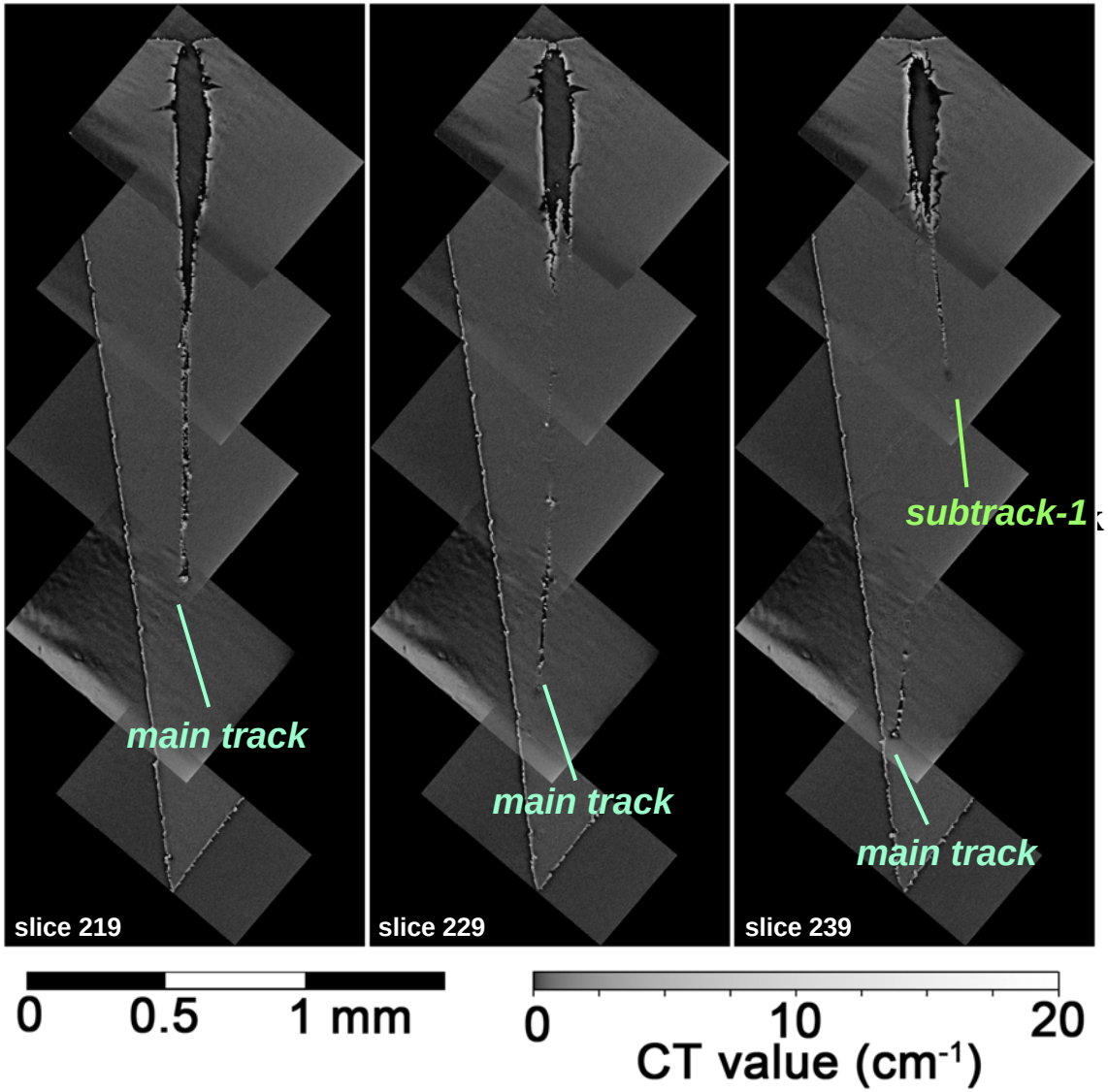


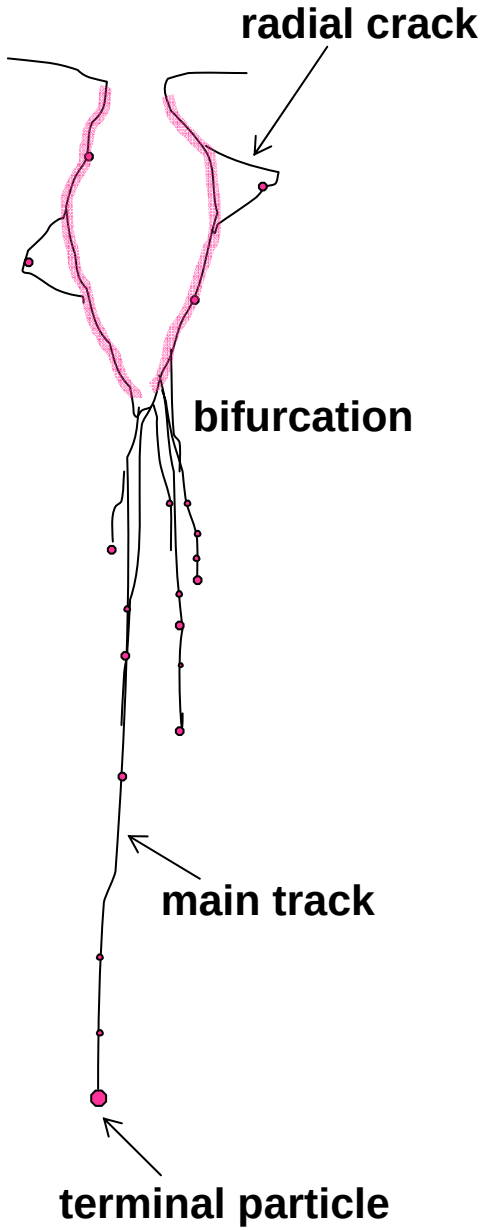


Dark space: track hole with radial cracks
Bright wall: condensed aerogel (melted?) with very fine particles?
White: captured particles

Track is bifurcated into main and sub-tracks.
Particles are present along tracks and radial cracks as well as the main track terminal.

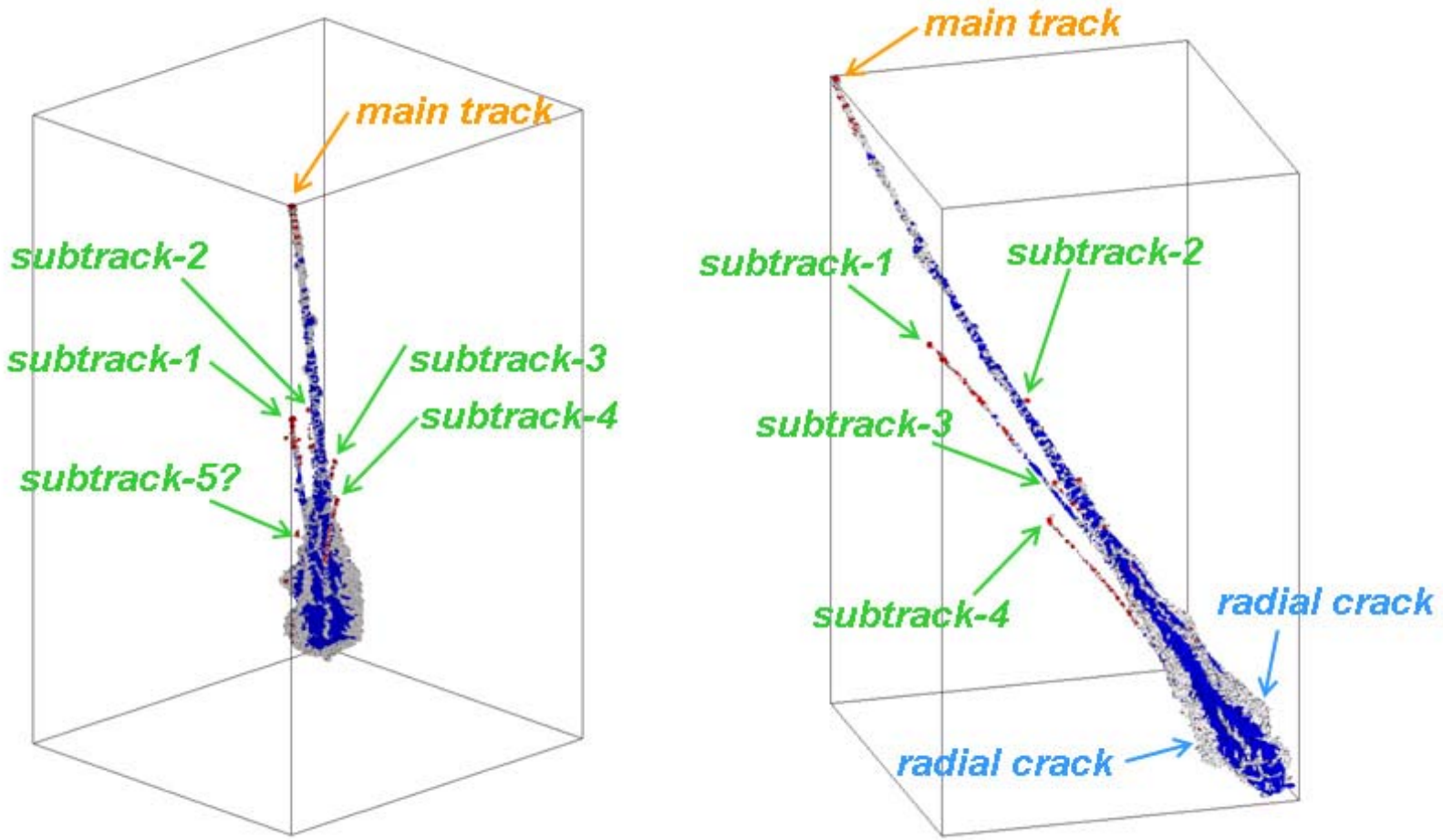
CT images parallel to the track (C2126,2,68,0)





Many particles are present along the main and subtrack-1.

Track: Bird's eye view (C2126,2,68,0)



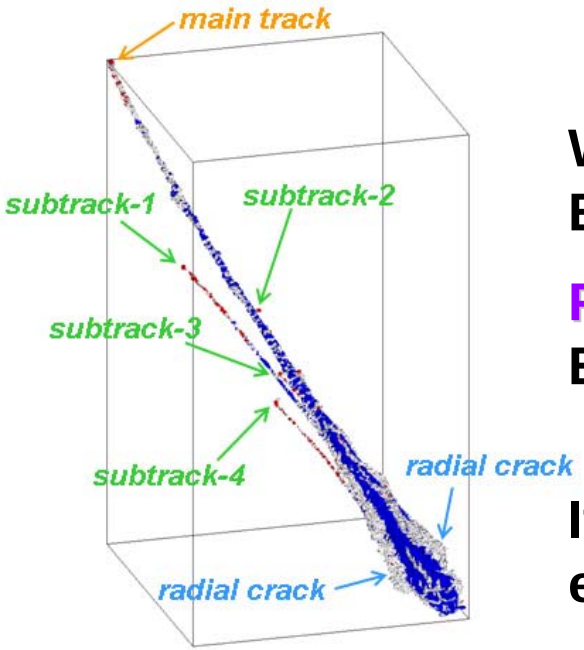
Gray: track hole and radial cracks
Blue: condensed aerogel
Red: captured particles

Track is bifurcated into 5 or 6.
Main and subtracks have terminal particles, respectively.
Many particles are present along the bifurcated tracks.

Track size *vs*. XRF data (C2126,2,68,0)

	volume (μm^3)	mode(%)
track	7.788E+06	78.75
particles	3.155E+04	0.32
condensed aerogel	2.070E+06	20.93
total	9.889E+06	100.00

	diameter (μm)
entrance	79.9x60.5
	length (μm)
main track	2484
subtrack-1	1672
subtrack-2	1353
subtrack-3	1107
subtrack-4	1027
subtrack-5(?)	756



Whole Fe mass: 6.66×10^{-11} g XRF data

Estimated mass (whole grain): 7.6×10^{-10} g

Fe mass/track volume: 8.56×10^{-6} g/cm^3

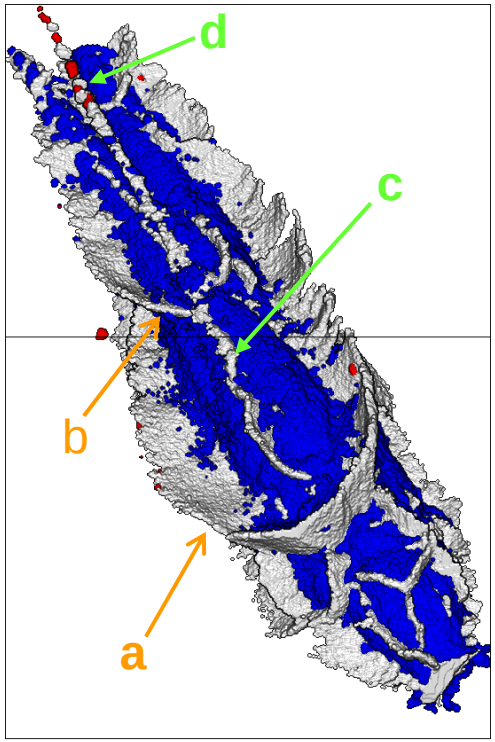
Estimated whole mass/track volume: 9.7×10^{-5} g/cm^3

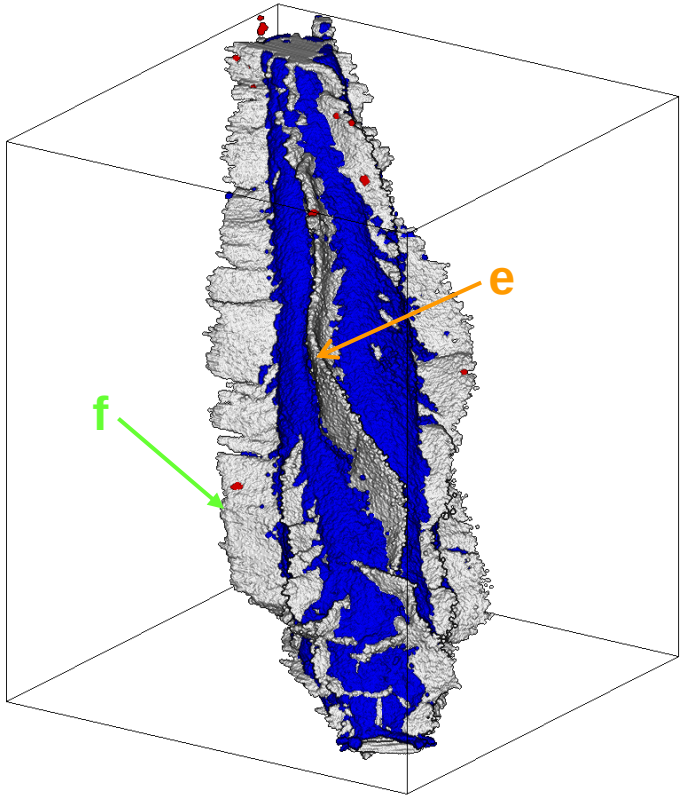
if density=1 g/cm^3 : 0.01 vol.%

If track volume is proportional to mass, we may evaluate volatile/solid ratio among different tracks.

track volume ↔ kinetic $E = 1/2mv^2$ (v ~const.)

Track bulb: Bird's eye view (C2126,2,68,0)





U-shaped radial crack (main: arrow-a and sub: arrow-b)

Crack along the central axis of the U-shaped crack: arrow-c

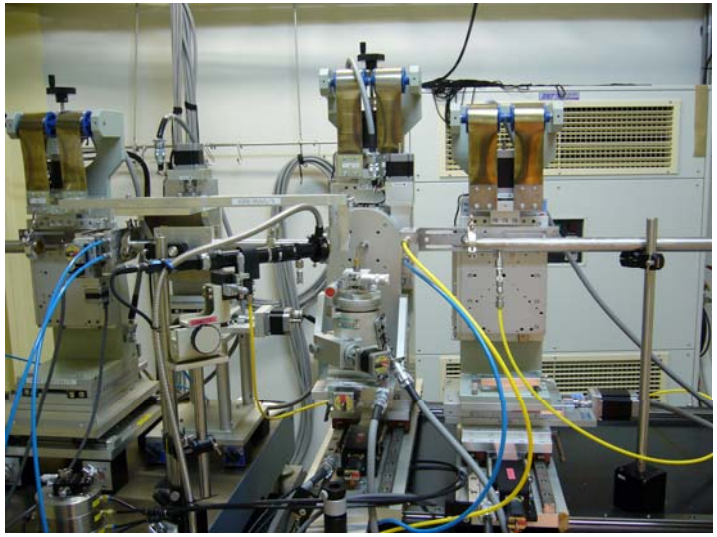
Subtrack-4 grows from the central crack: arrow-d
(each subtrack seem to grow from a crack)

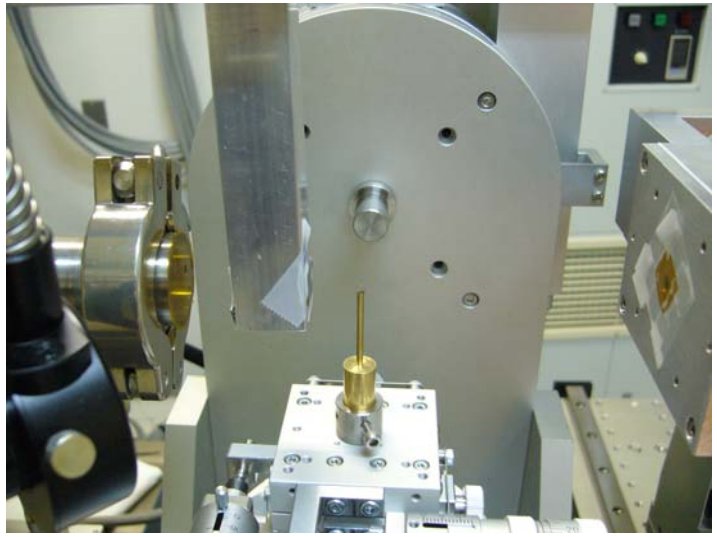
Wavy radial crack: arrow-e

Some particles are in radial cracks: arrow-f

3D structures of individual particles

Imaging tomography (0.0425 μm/pixel)
Samples: 4 particles (C2004.1.44.3, C2054.0.35.6; .5,; .4)
Photon energy: 8 keV
No. of projection: 3600
3-D image: 2000x2000 matrix, 1312 slices





XRD
BL17/Photon Factory, Japan

The results are presented by T.Nakamura

Conclusions

- **Whole dust particle**
  less fragile particles + fragile aggregate of fine particles
  ← **3-D structure of track**
  ← **3-D structures of individual particles**
  less fragile particles: crystalline
  fragile aggregate: amorphous-rich (mixture with aerogel)
- **Not easy to reconstruct whole dust particle texture completely by tomography alone**
- **Fe mass/track volume**
  → **whole dust particle/track volueme: ~ 0.01 vol.%**
  → **may estimate volatile/solid ratios of whole dusts particles among tracks**
- **Crystalline particles**
  evidence of melting? (SEM/EBSD or TEM study required)
  fractured surface