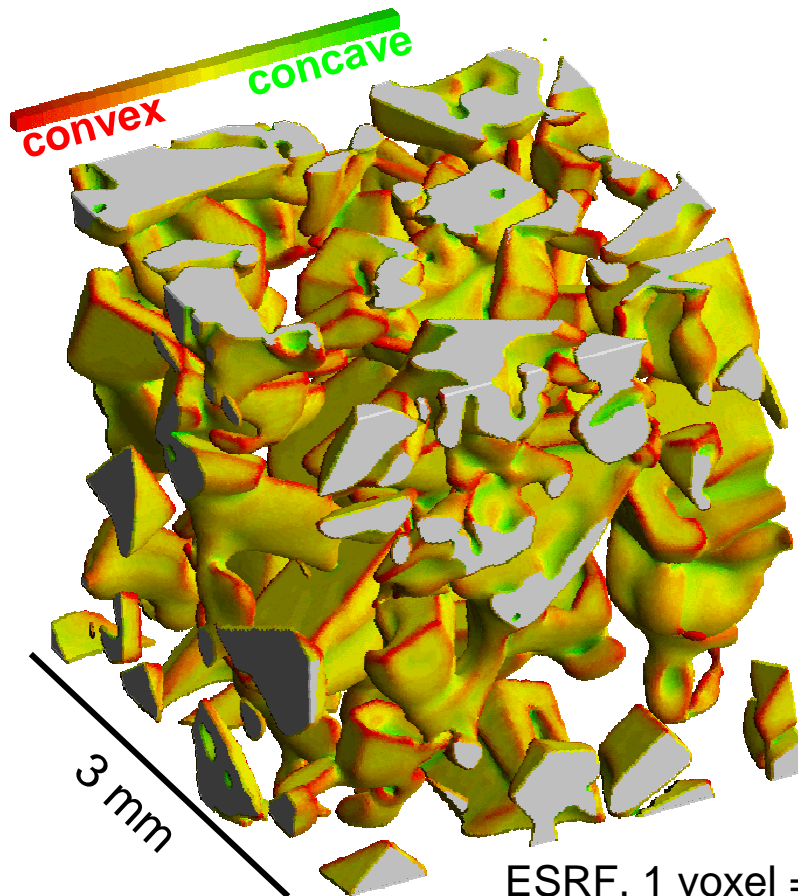


Tomographie de la neige et de la glace à Grenoble

A. Philip et F. Flin

Tomographie dans un environnement à température ambiante

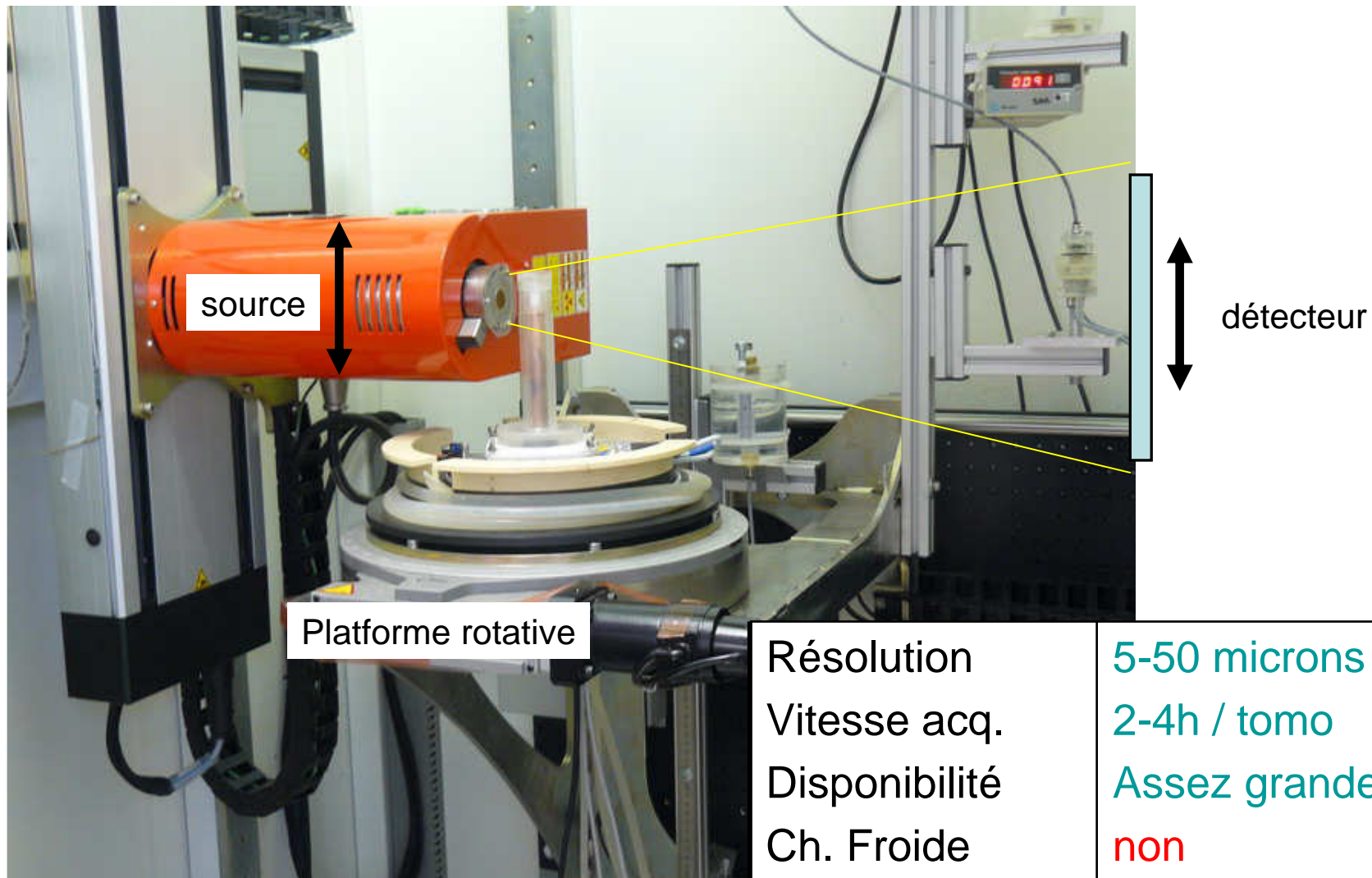


- 1. Instruments
 - 1.1. 3SR : Microtomographe
 - 1.2. SIMaP : Nanotomographe
 - 1.3. ESRF (ID19...) : Nano, microtomographie et autres techniques

- 2. Cellules froides
 - 2.1. Cellules CEN (3SR)
 - 2.2. Cellules LGGE (ESRF)

NB: Certaines informations quantitatives (résolution, dimensions, coût...) sont très approximatives ou fortement sujettes au contexte (expérimental, administratif) et mériteraient idéalement une validation (ou une rectification) par les responsables des dispositifs concernés.

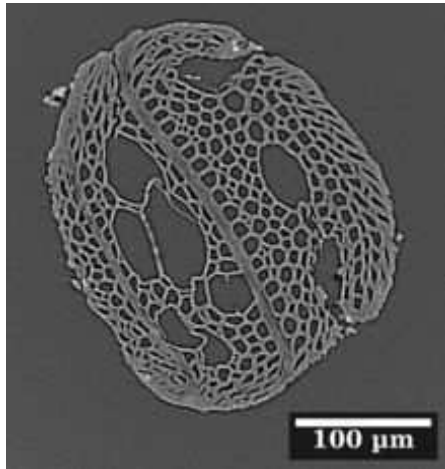
1.1. Instruments – Microtomographe 3SR



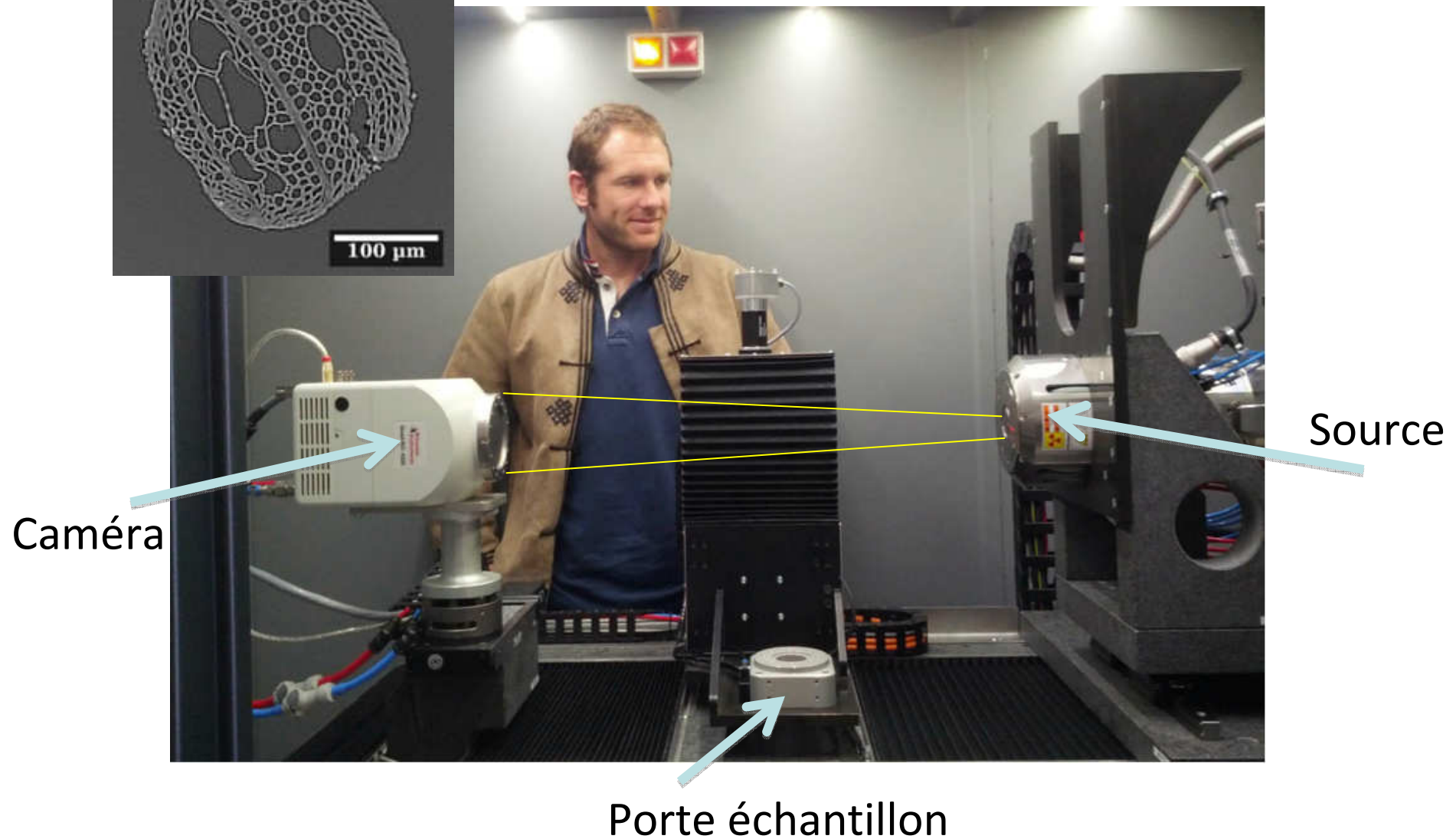
Résolution	5-50 microns
Vitesse acq.	2-4h / tomo
Disponibilité	Assez grande
Ch. Froide	non
Espace cabine	Grand
Coût	500 E/jour
Particularité	Plateau traversant

1.2. Instruments – Nanotomo SIMaP – EASYTOM XL Nano

Section d'un cure-dent en bois après reconstruction



Sur cette photo, il manque le tube « micro foyer »



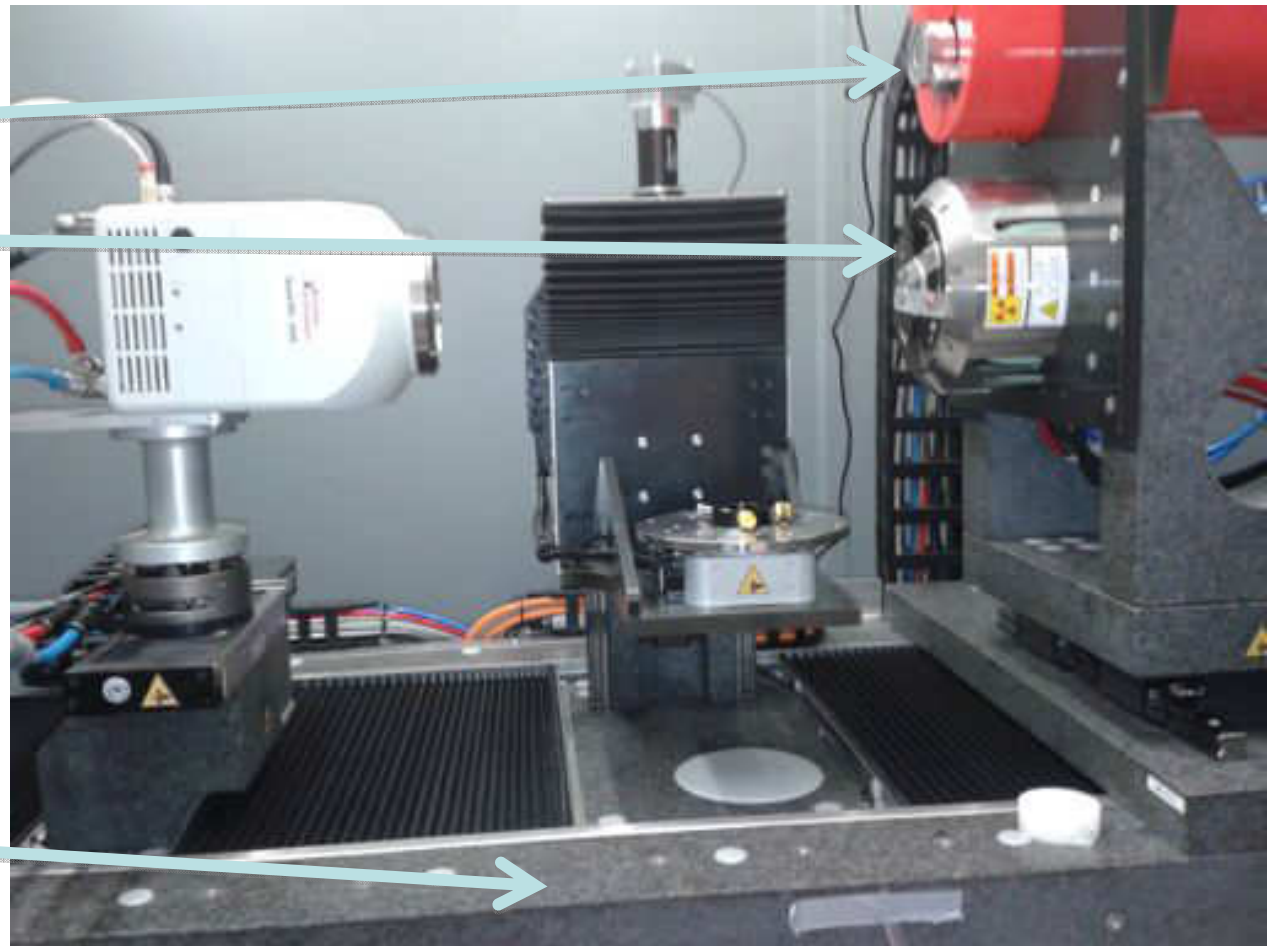
1.2. Instruments – Nanotomo SIMaP – EASYTOM XL Nano

Tube microfoyer

Tube nanofoyer

Marbre

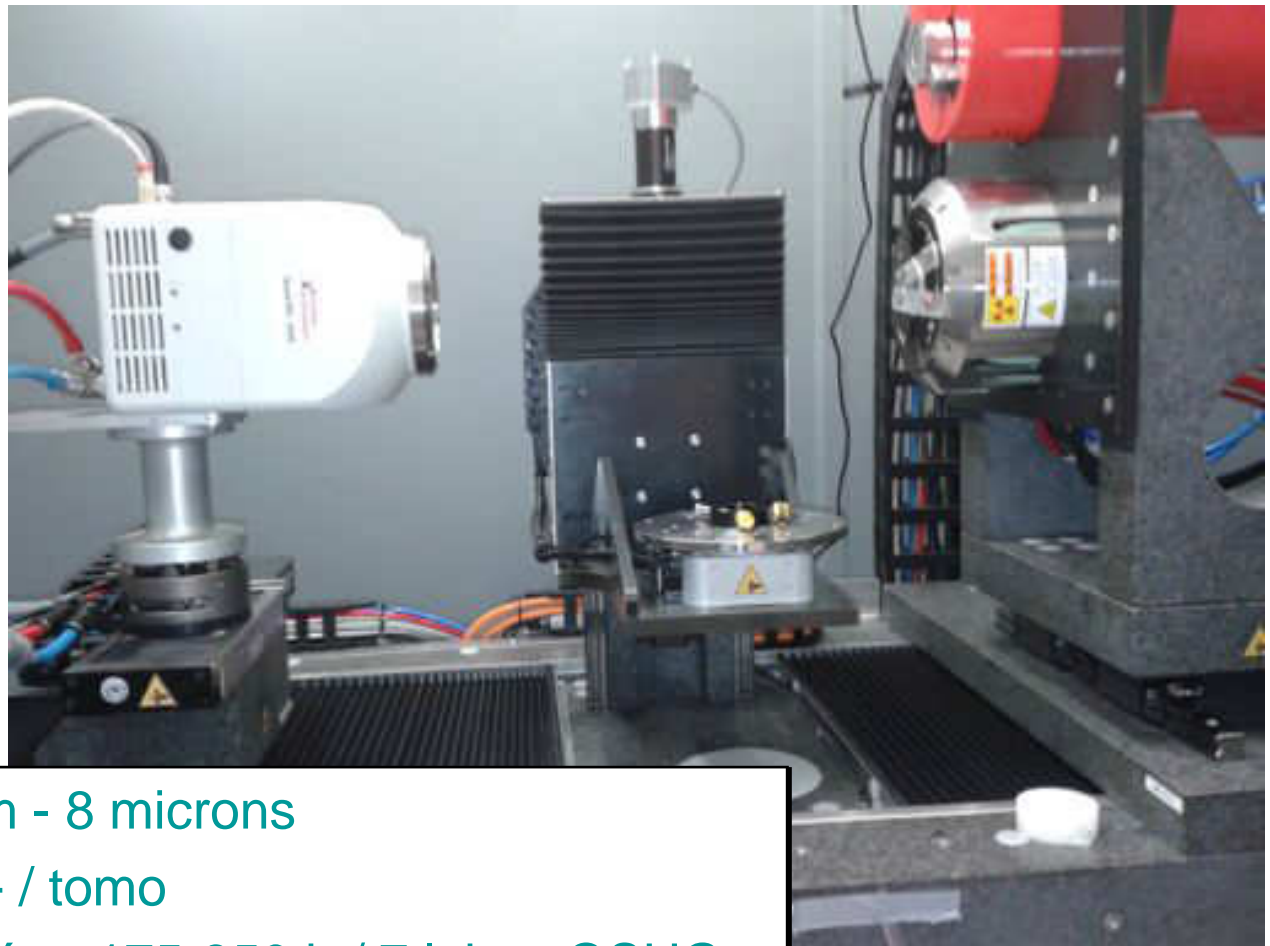
→ grande stabilité



Possibilité d'utiliser:

- soit la source microfoyer : Résolution d'environ **5 μm**
- soit un filament W : Résolution d'environ **1 μm**
- soit un filament LaB6 : Résolution maximale de **250 nm**

1.2. Instruments – Nanotomo SIMaP – EASYTOM XL Nano

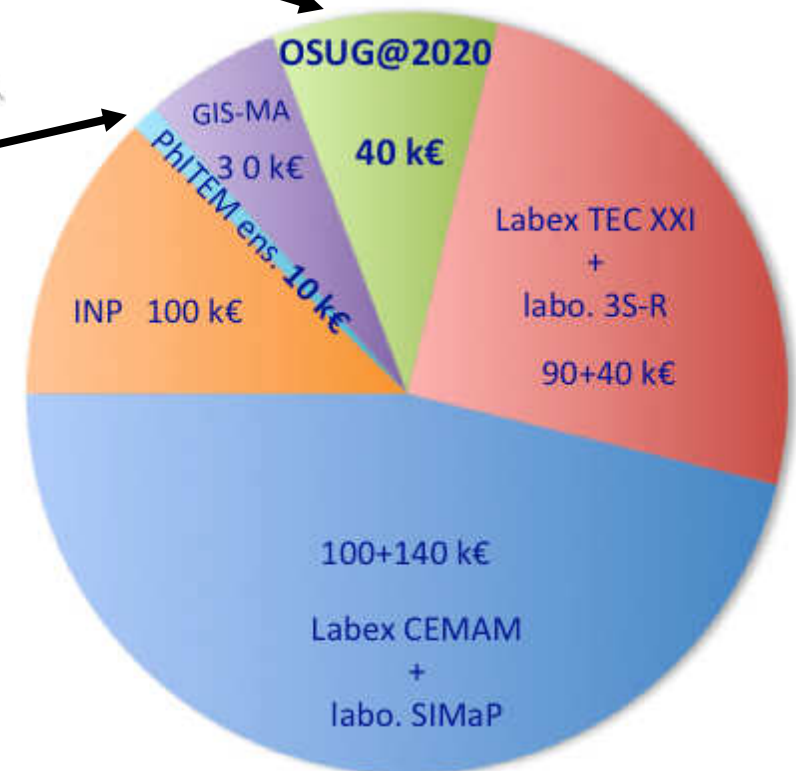


Résolution	250 nm - 8 microns
Vitesse acq.	4h et + / tomo
Disponibilité	Modérée : 175-350 h / 7 labos OSUG
Ch. Froide	non
Espace cabine	Assez grand
Coût	500 E/jour
Particularité	Pas de plateau traversant

1.2. Instruments – Nanotomo SIMaP – EASYTOM XL Nano

Financement

Les financeurs du nouveau tomographe



Coût total: 550 K€

1.2. Instruments – Nanotomo SIMaP – EASYTOM XL Nano

Fonctionnement

1 créneau = 1 matin, après-midi ou nuit

OSUG : 35 créneaux

PHITEM : 9 créneaux



7 labos **CEN, IPAG, IRSTEA, ISTERre, LECA, LGGE ,LTHE**

A mettre en place **Cours Master et Ecole doctorale**

forfait de 50€ par créneau réservé

Puis Recherche

- 20€/h de faisceau tube microfoyer
- 40€/h de faisceau tube nanofoyer filament W
- 60€/h de faisceau tube nanofoyer filament LaB6

Coefficient multiplicateur de :

- 1 pour les partenaires
- 2 pour les collaborations universitaires
- 3 pour les extérieurs (prestation, industriel...)

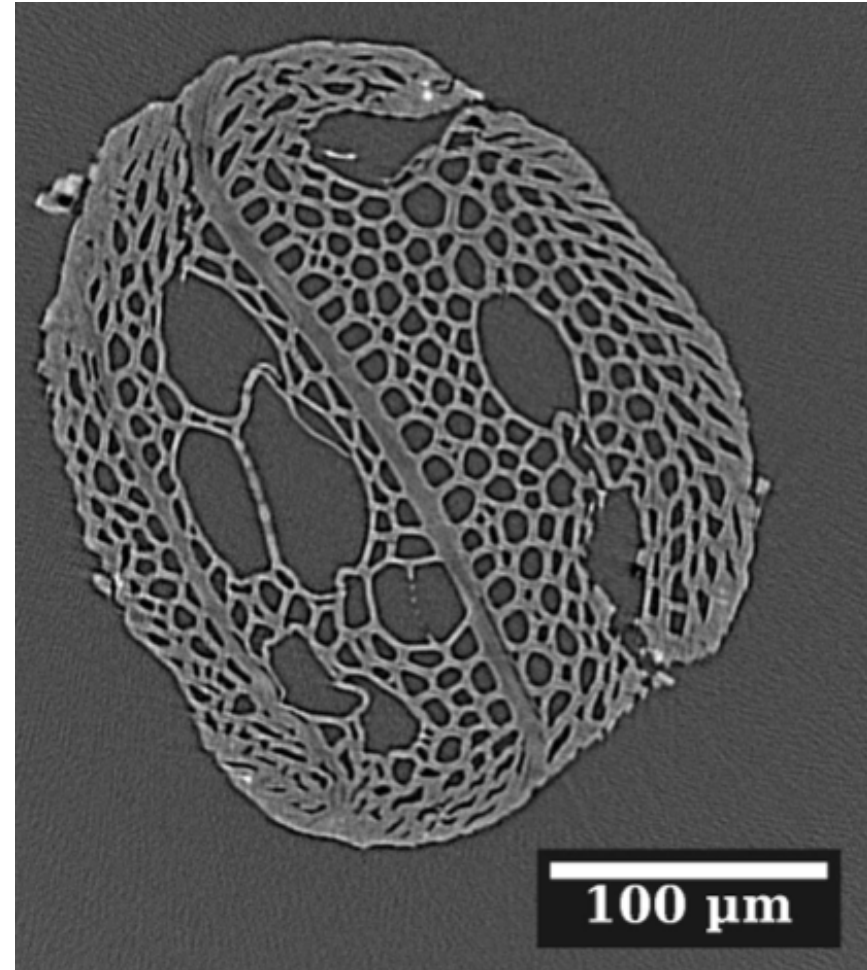
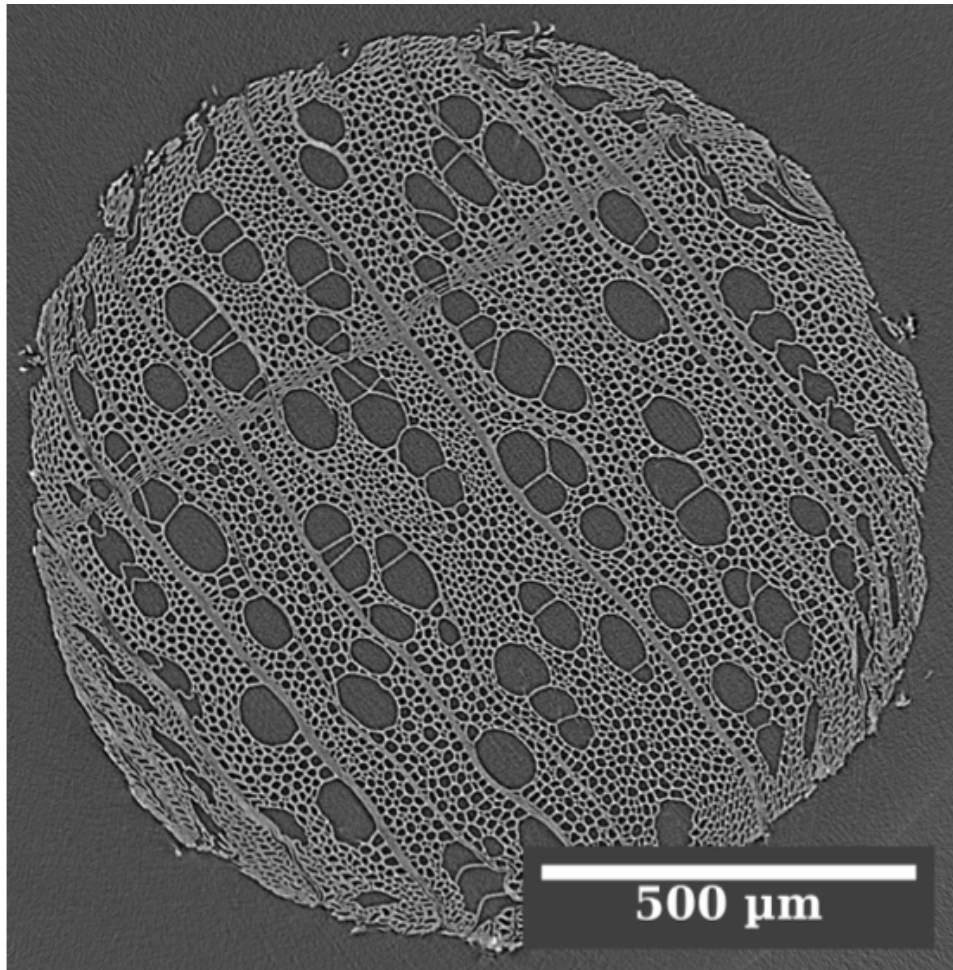
Pour enseignement

- pas de frais de faisceau , 50€ par créneau seulement 😊

1.2. Instruments – Nanotomo SIMaP – EASYTOM XL Nano

un cure dent en peuplier

Crédit Tomographe EASYTOM XL Nano



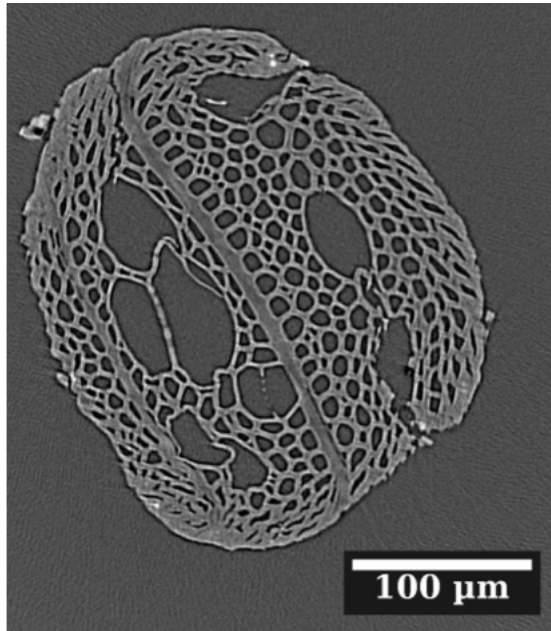
Taille de pixel 1 μm (1600 proj, 2s)
un peu plus d'une heure

Taille de pixel 0.3 μm (2000 proj, 6s)
Environ 4h

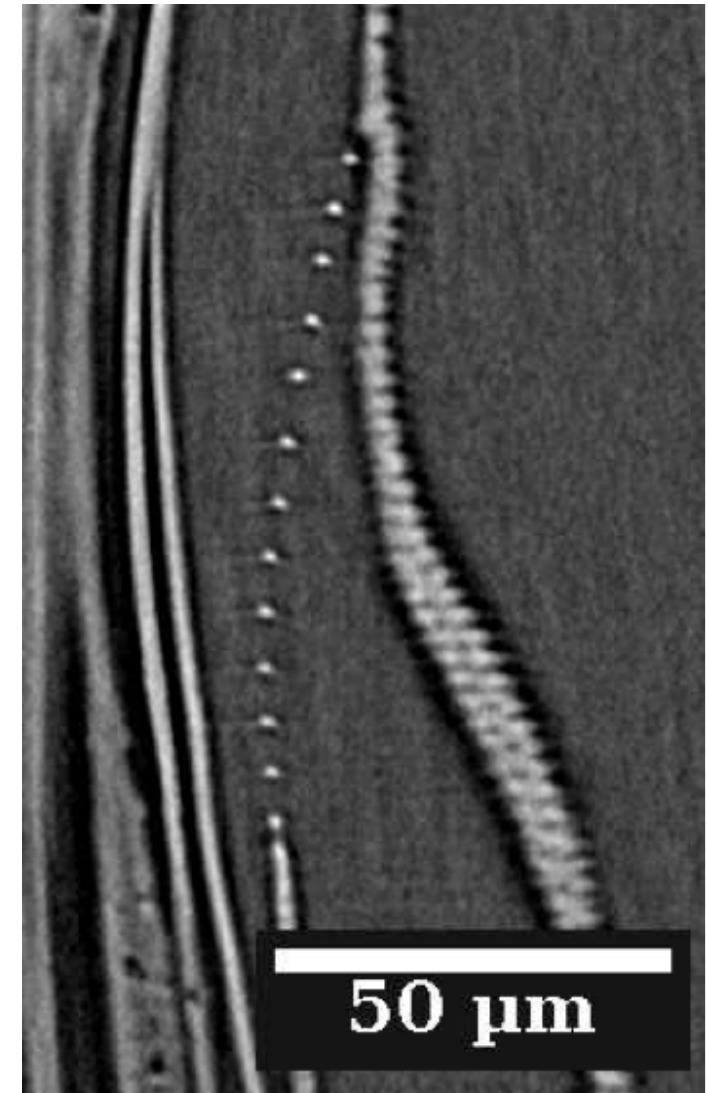
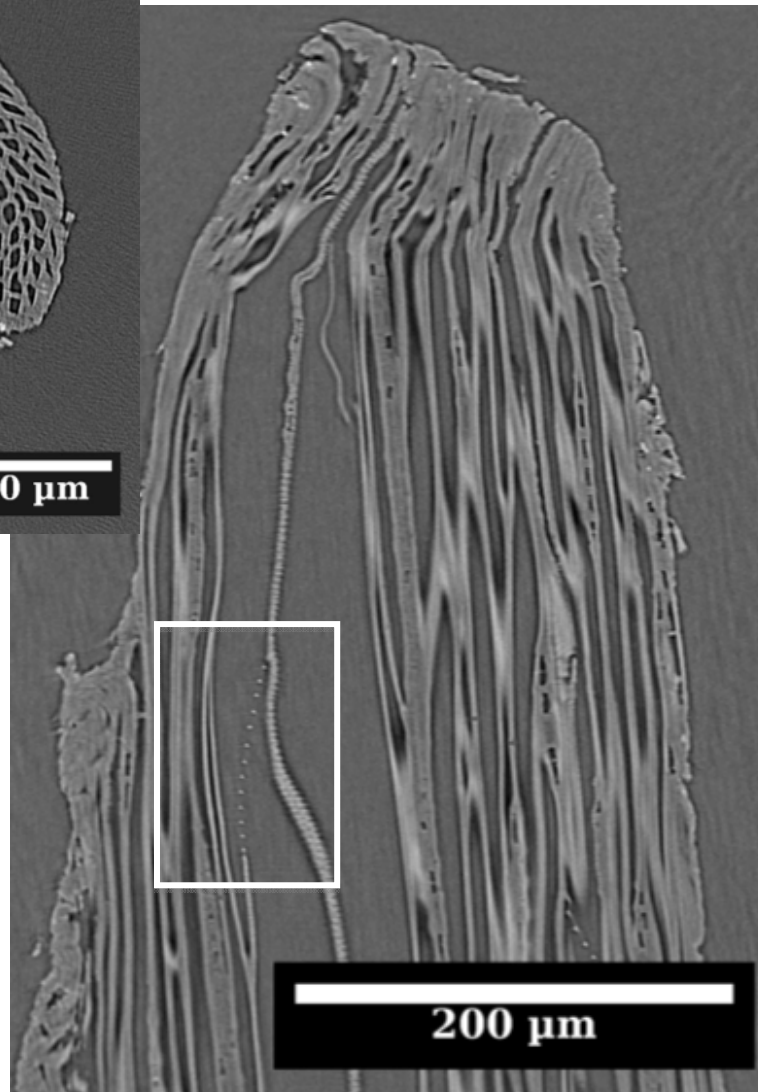
1.2. Instruments – Nanotomo SIMaP – EASYTOM XL Nano

Taille de pixel $0.3 \mu m$ (2000 proj, 6s)
Environ 4h

Crédit Tomographe EASYTOM XL Nano



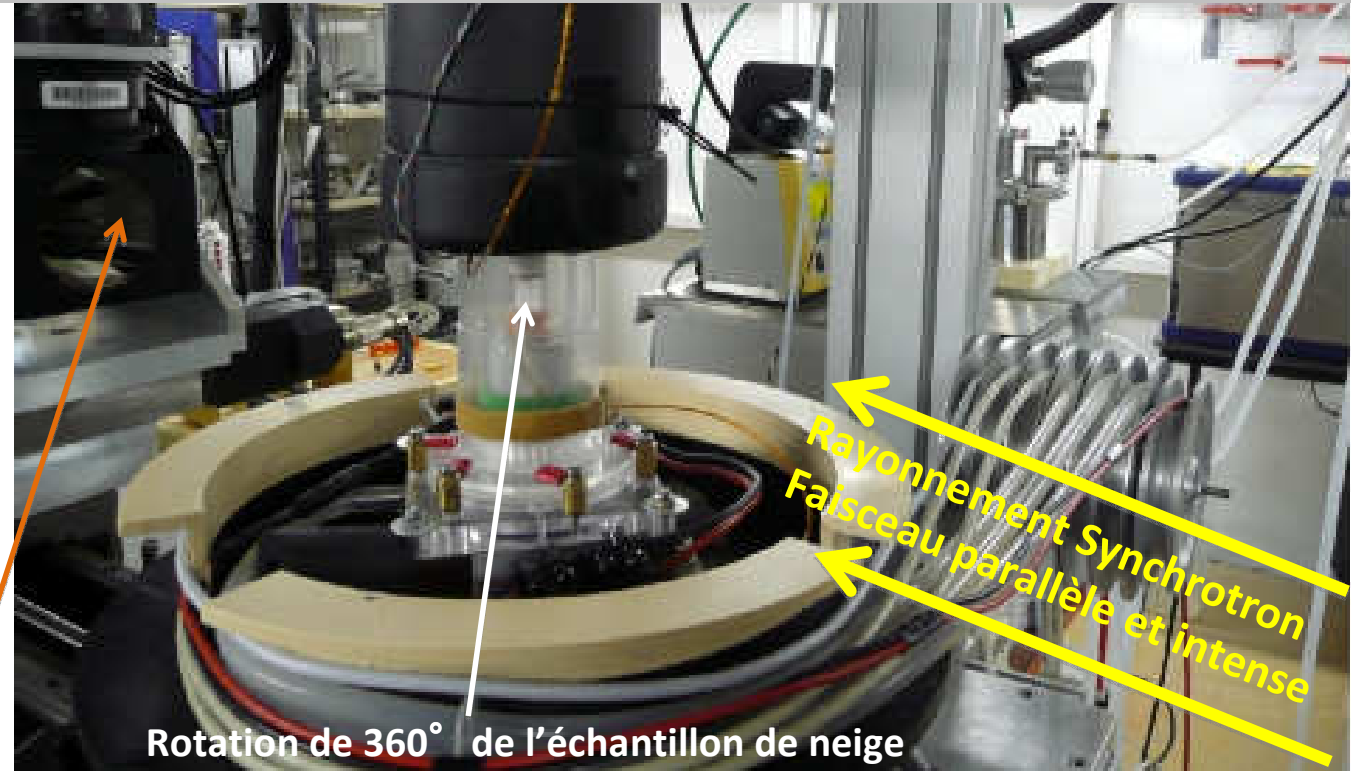
Cure dent



1.3. Instruments – ESRF : nano-, micro-tomographie et DCT



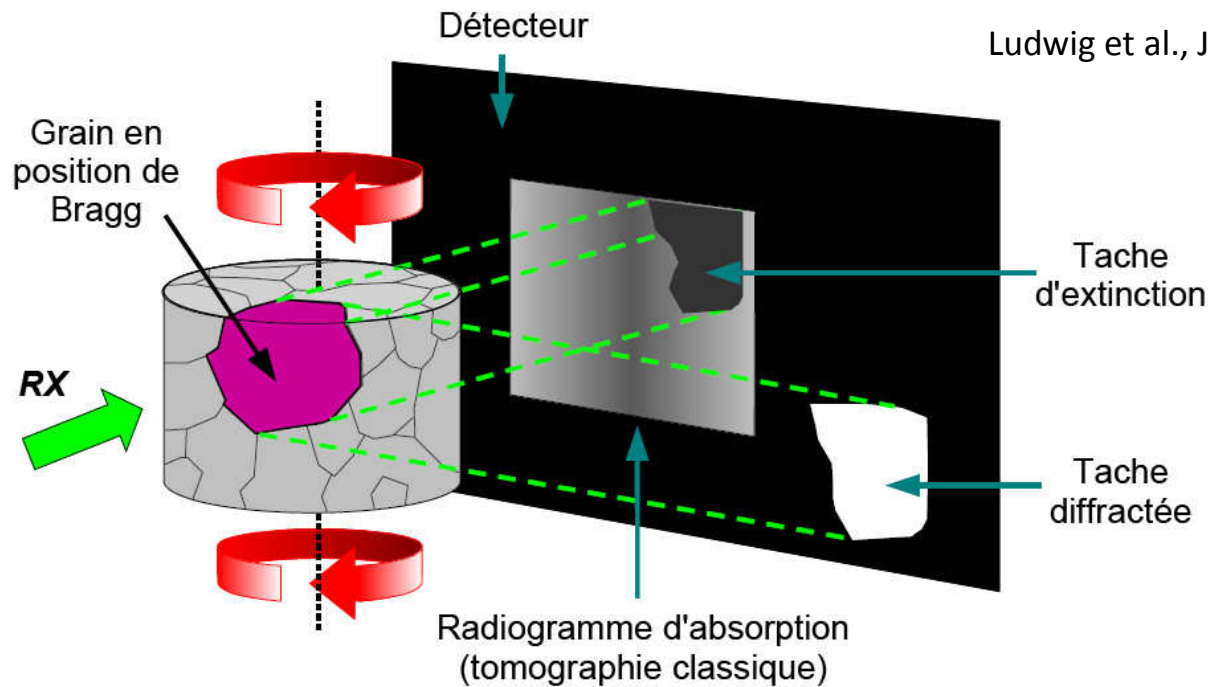
Détecteur
CCD



Résolution	20 nm - 20 microns
Vitesse acq.	Quelques secondes et + (fonction du dispositif exp.) / tomo
Disponibilité	Assez faible - proposal
Ch. Froide	non
Espace cabine	Grand
Coût	0 E/jour ou 8000 E/8h
Particularités	Faisceau parallèle, flux intense, Contraste de diff., DCT..

1.3. Instruments – ESRF : nano-, micro-tomographie et DCT

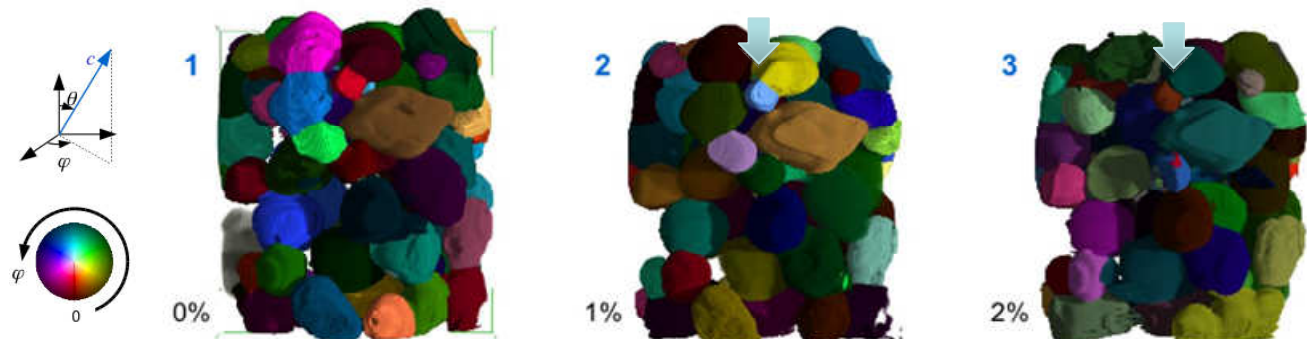
DCT : Technique de caractérisation microstructurale des polycristaux



Ludwig et al., J. Appl. Cryst. 2008, 41, 302.

- ➔ connaître
- le squelette 3D de la phase glace de la neige
 - l'orientation cristallographique de chaque grain de glace

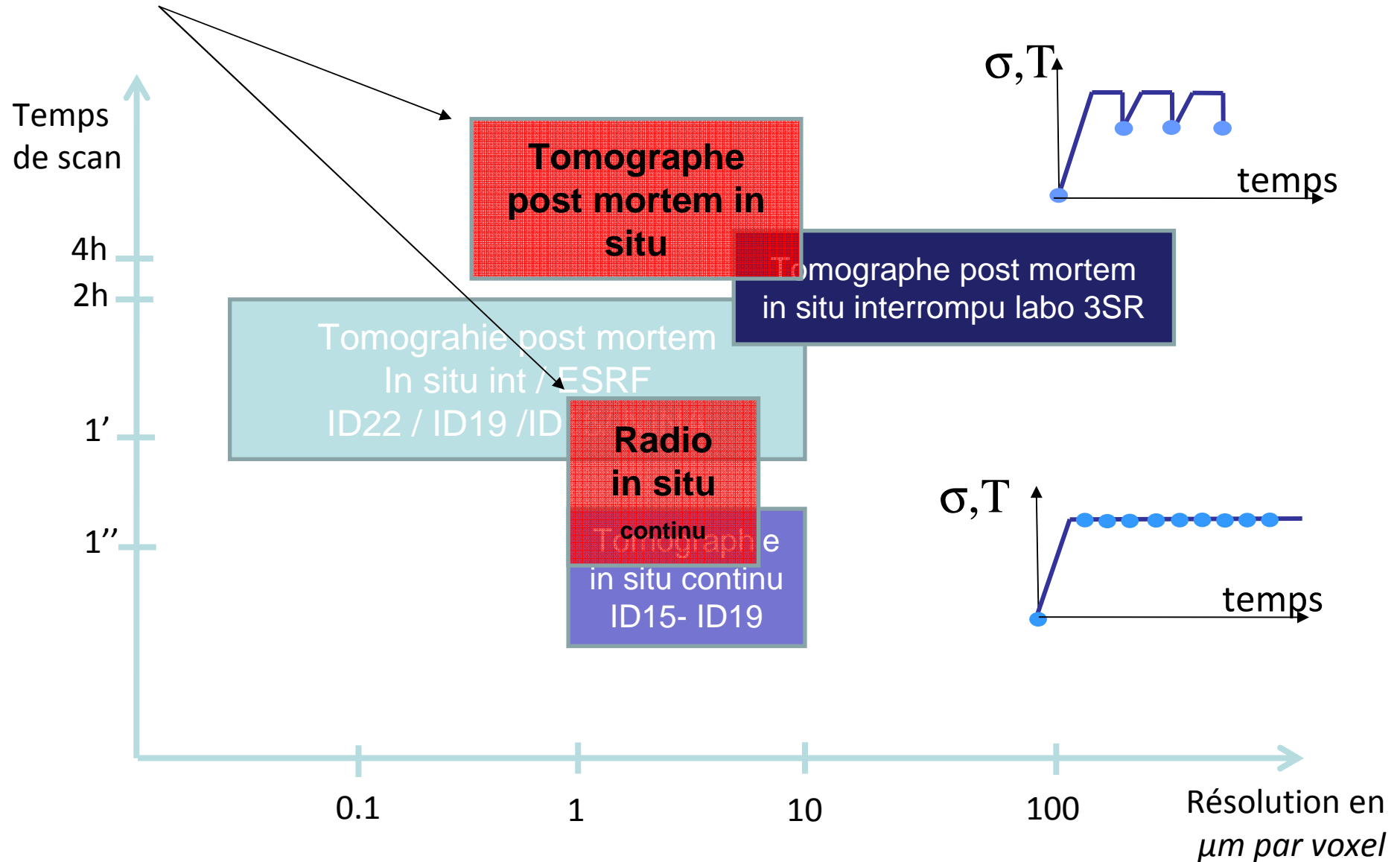
**Compression in situ
d'échantillons de neige**
cylindre: $h=1\text{cm}$ et $\phi=1\text{cm}$



Rolland du Roscoat et al., ADV. ENG. MATER, 2011.

1. Conclusions – Tomographie sur le bassin grenoblois

Tomographe de laboratoire « EASYTOM XL Nano » sur Grenoble



2.1. CEN – CellStat: for the observation of static samples



1. Sampling



2. Impregnation



3. Freezing

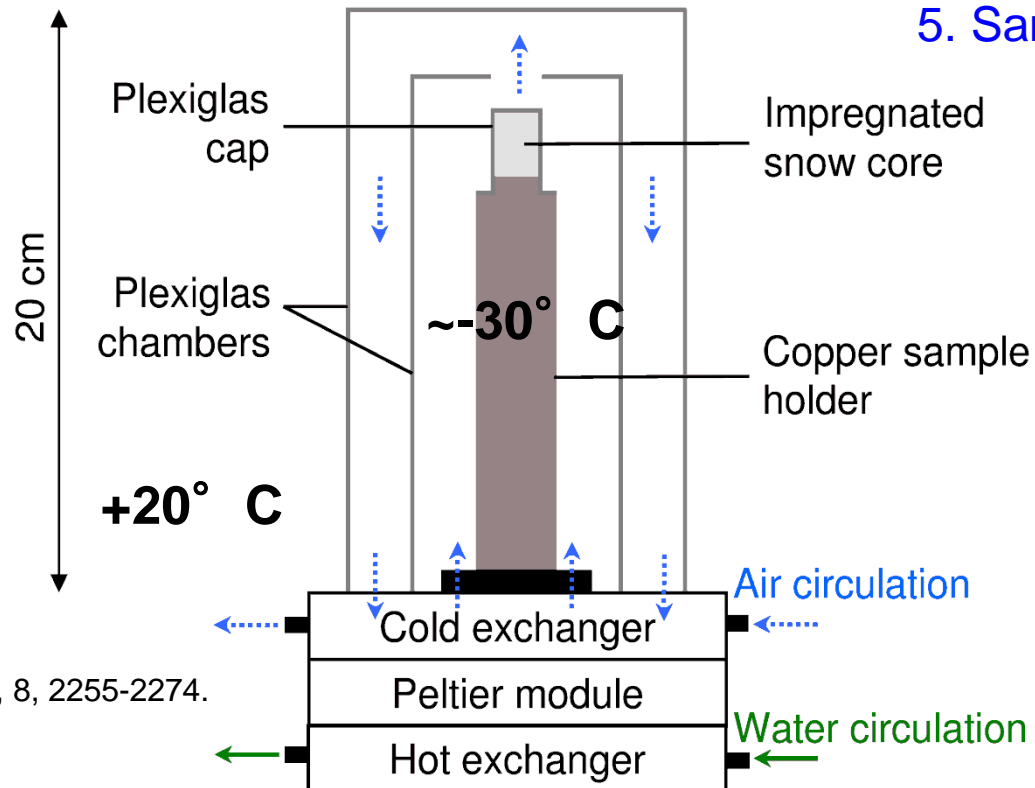
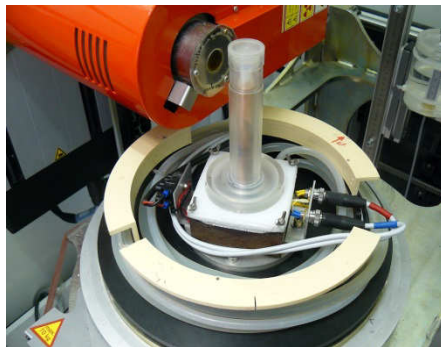


4. Machining



5. Sample holder

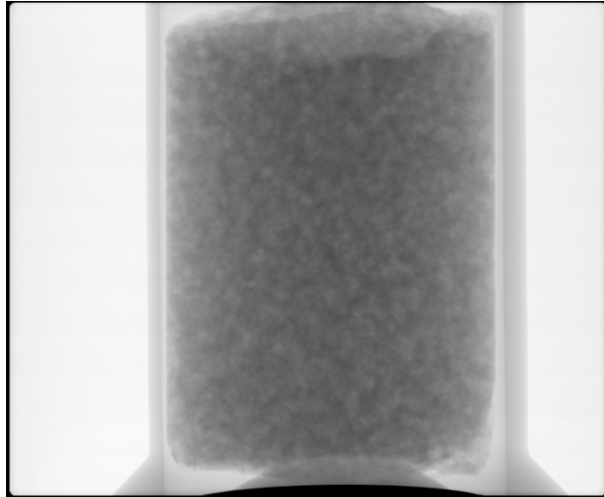
Cryogenic cell



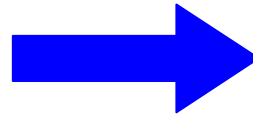
Calonne et al., 2014, The Cryosphere, 8, 2255-2274.

2.1. CEN – Obtention of 3D binary images

Obtention of 1200 radiographies



Reconstruction
(Softwear DigiXCT)



chloronaphtalene

ice

residual air bubble

Reconstructed cross-section

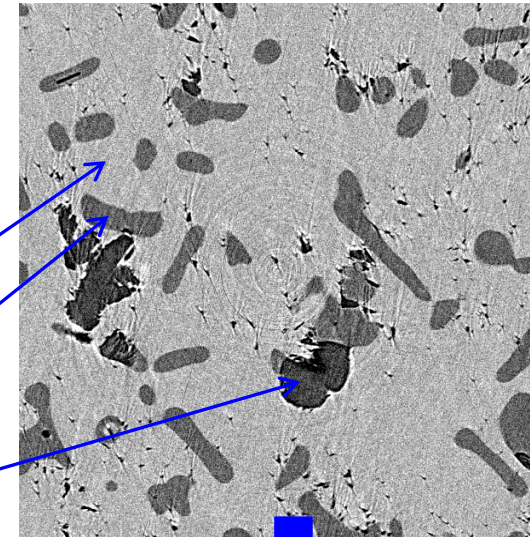
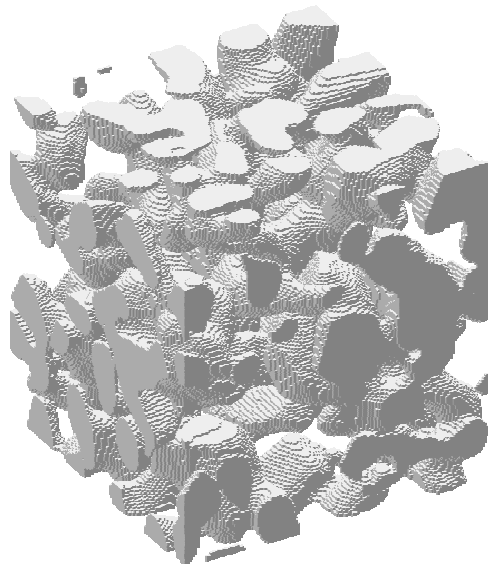
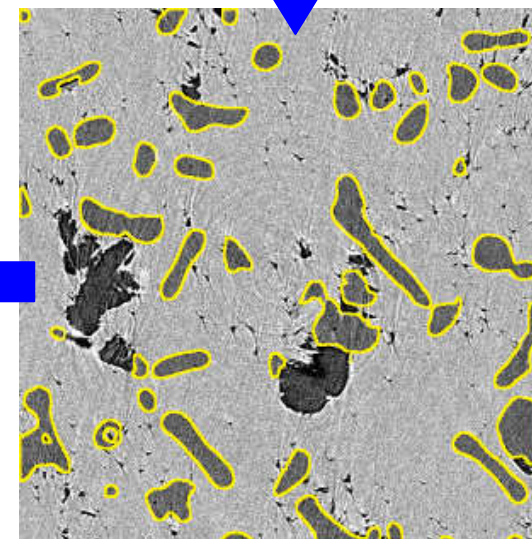
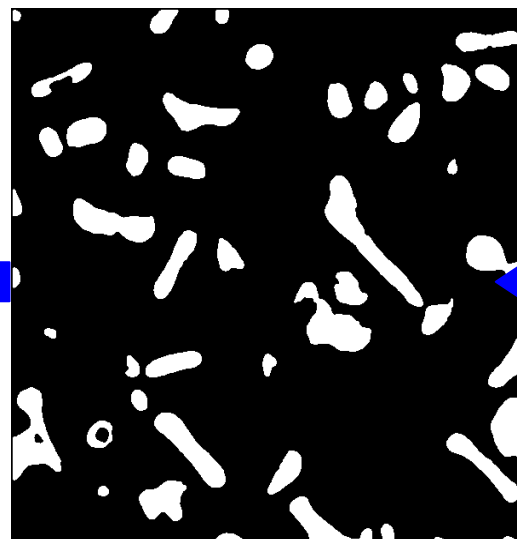


Image processing



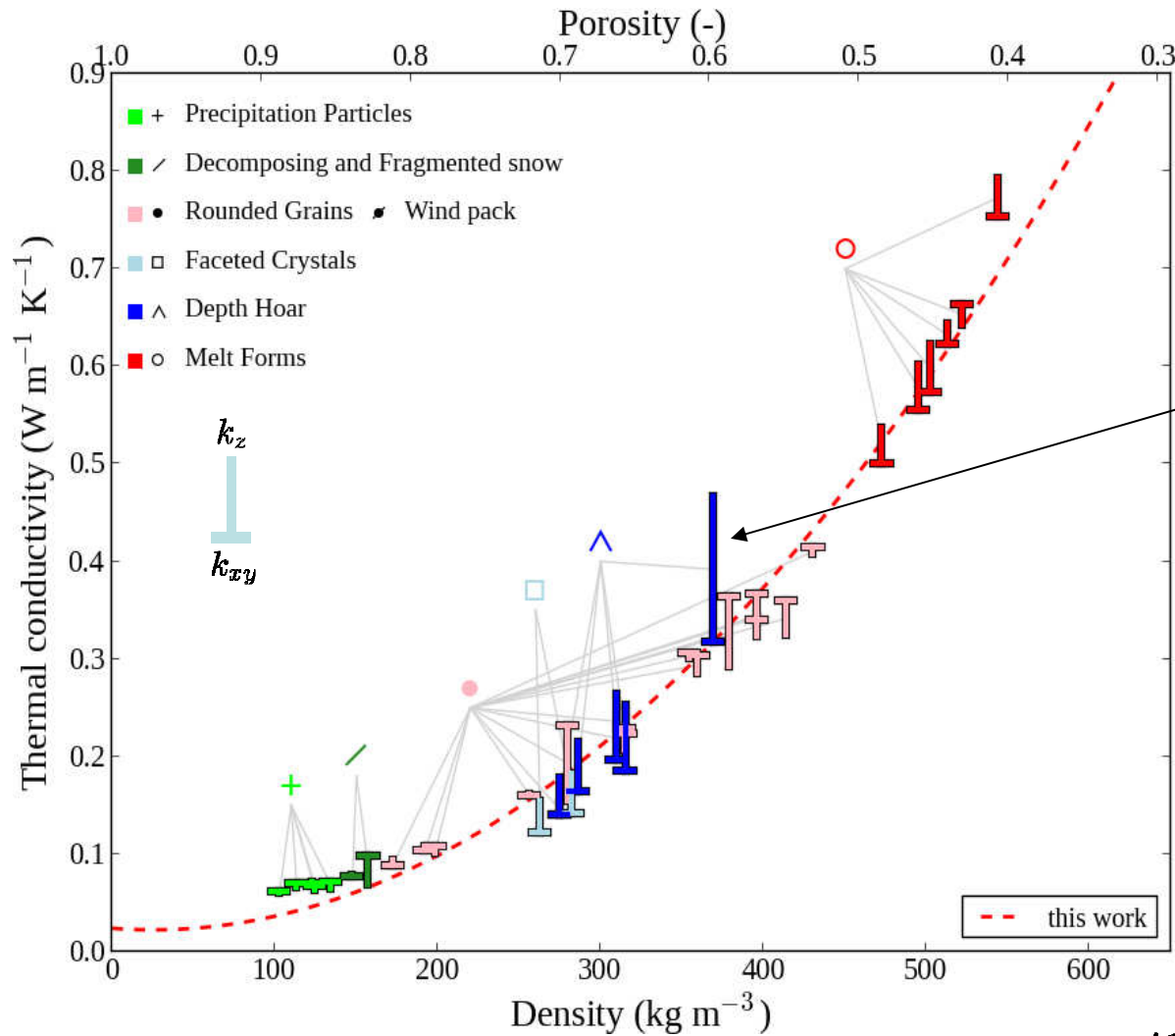
3D images



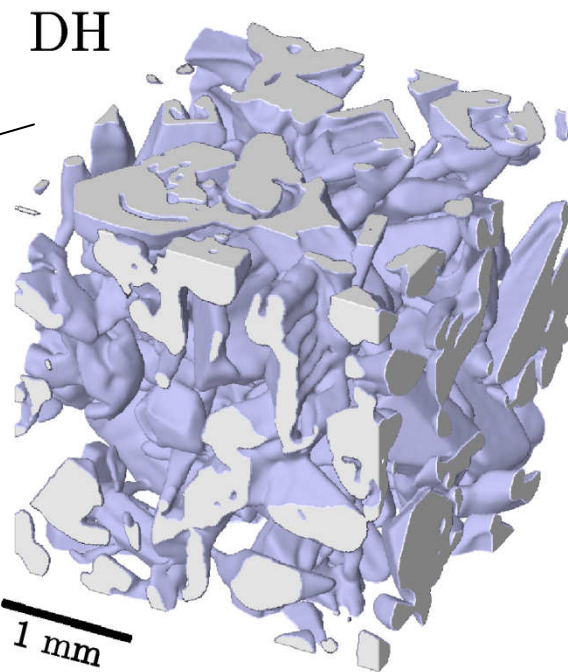
Binary cross-section

Thresholded cross-section

2.1. CEN – A typical application : Effective thermal conductivity



Calonne et al., GRL, 2011.



$$\kappa_i = 2.107 \text{ W m}^{-1} \text{ K}^{-1}$$

$$\kappa_a = 0.024 \text{ W m}^{-1} \text{ K}^{-1}$$

2.1. CEN – CellDyM: Dynamic Monitoring of snow

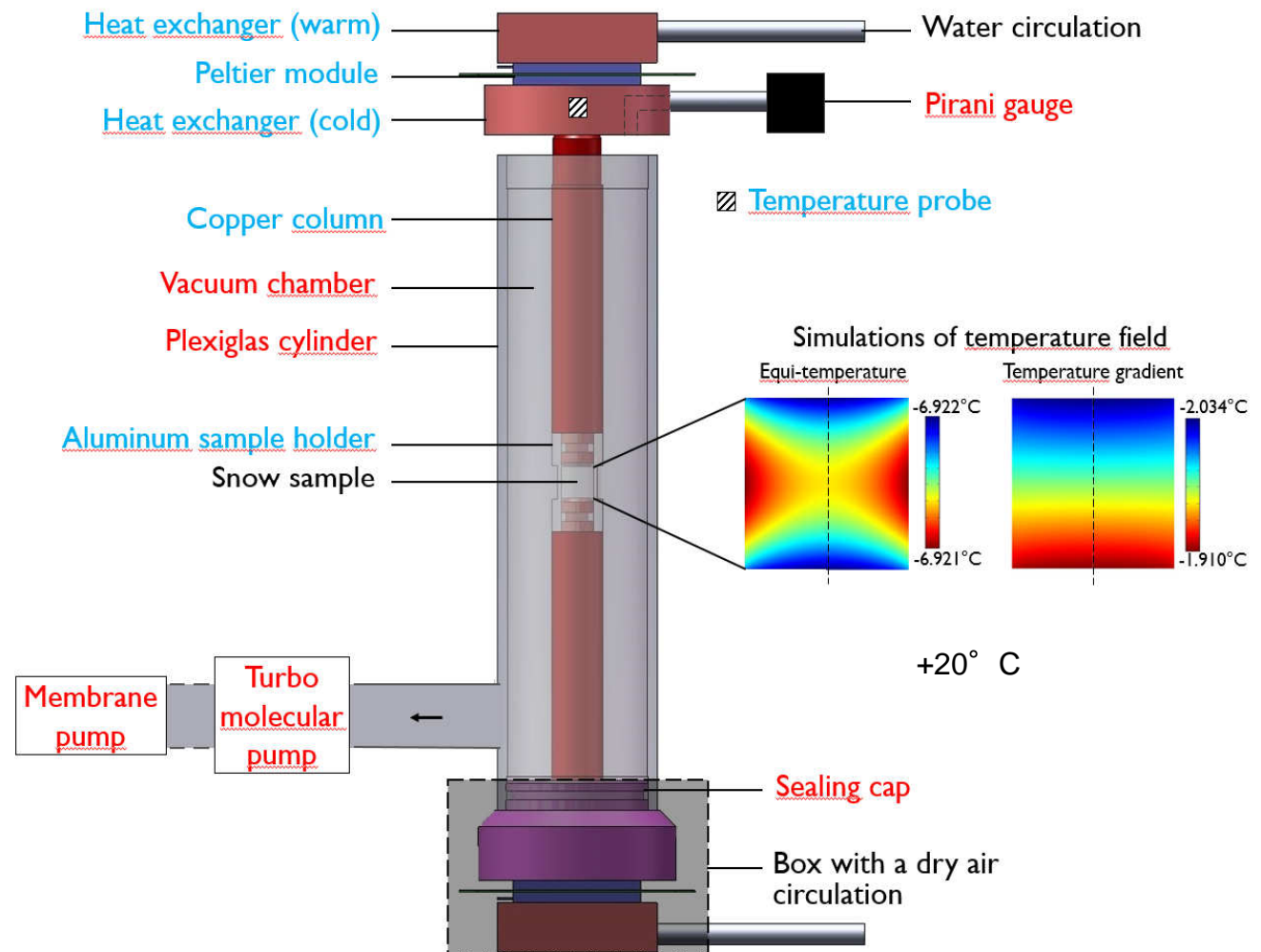
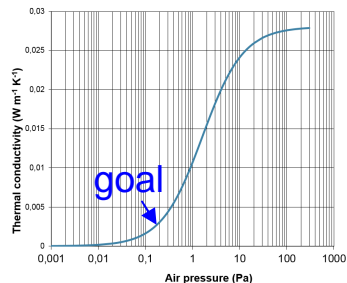
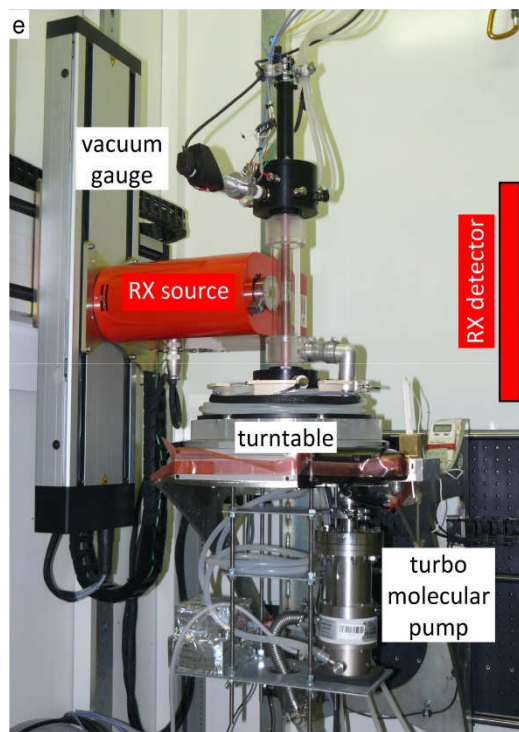
Insulation from the outside → vacuum system

Pressure of about 0.1 Pa, leading to a thermal conductivity of air $\sim 0.0015 \text{ Wm}^{-1}\text{K}^{-1}$ (reduced by 28 compared to that at atmospheric pressure).

Cold production and conduction → 2 Peltier modules

Precision of Pt100 about $\pm 0.03^\circ \text{C}$ (between 0 and -10°C)
 Regulation of Peltier modules about $\pm 0.01^\circ \text{C}$

Calonne et al., GRL, in press.



2.1. CEN – CellDyM: Dynamic Monitoring of snow

1. Sampling



2. Storage



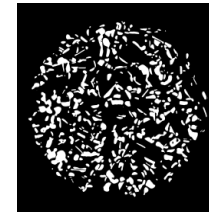
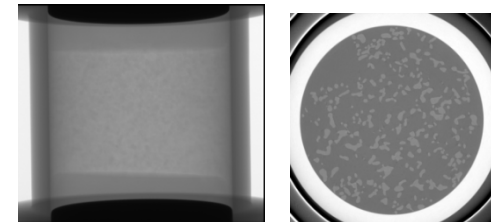
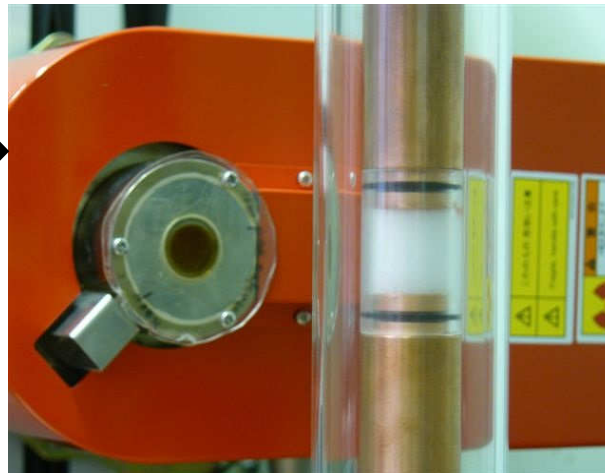
3. Set up of the cryogenic cell



4. Setup of the snow sample

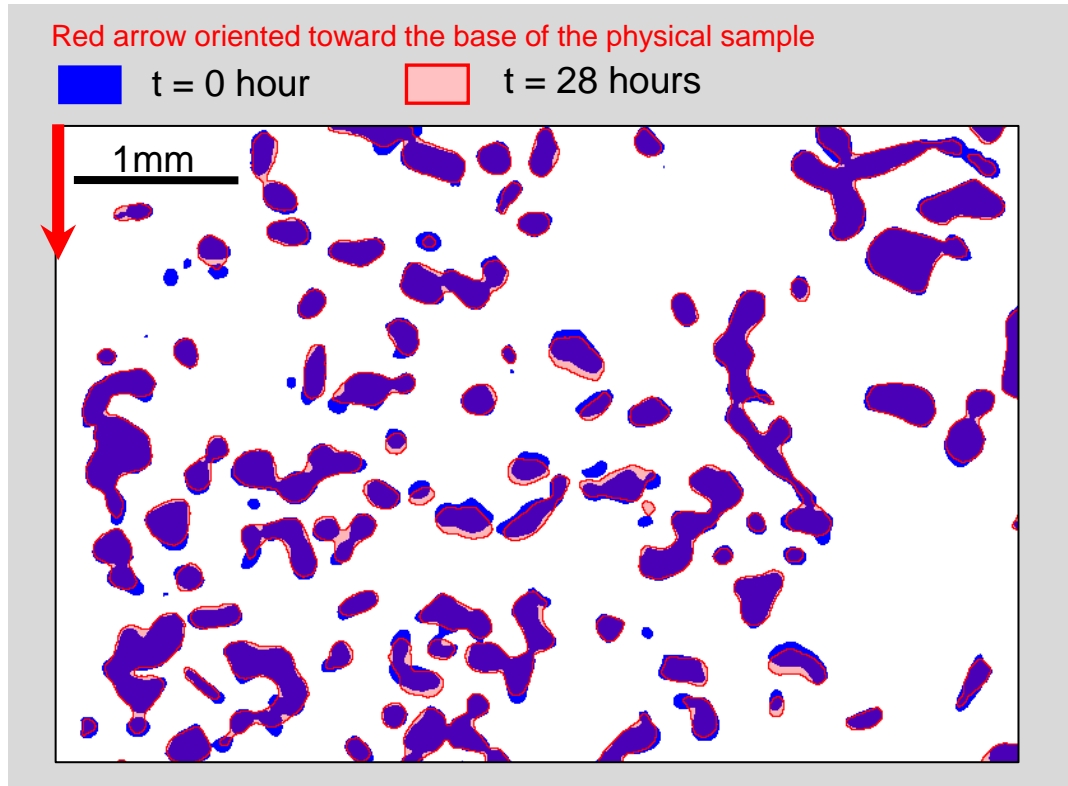


5. Tomography



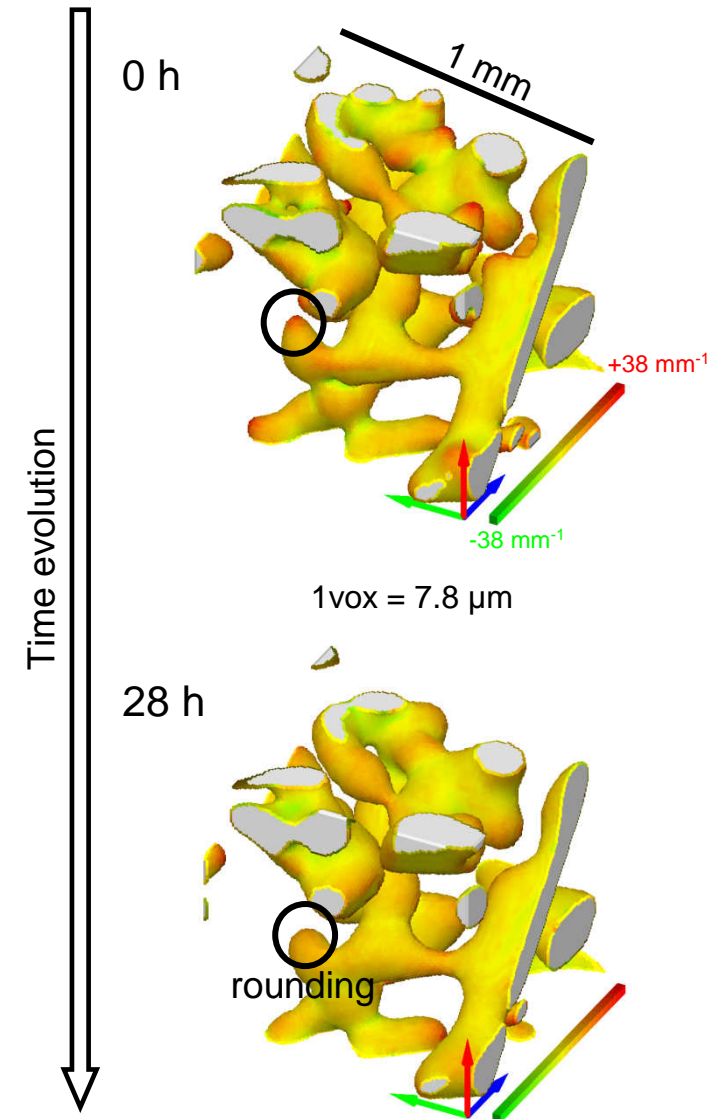
2.1. CEN – CellDyM: Dynamic Monitoring of snow

Equi-temperature metamorphism at -7°C



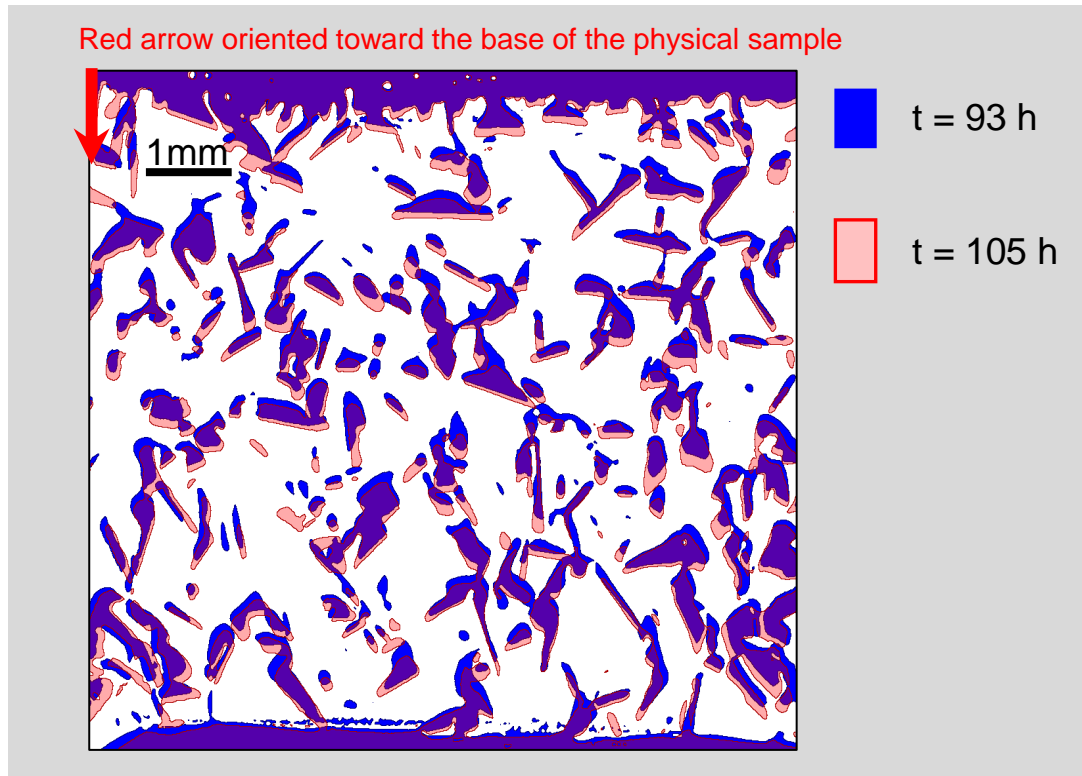
Typical features of the evolution under curvature effects:

- Slow evolution
- Settlement
- Grain rounding
- Growth/decay of bonds



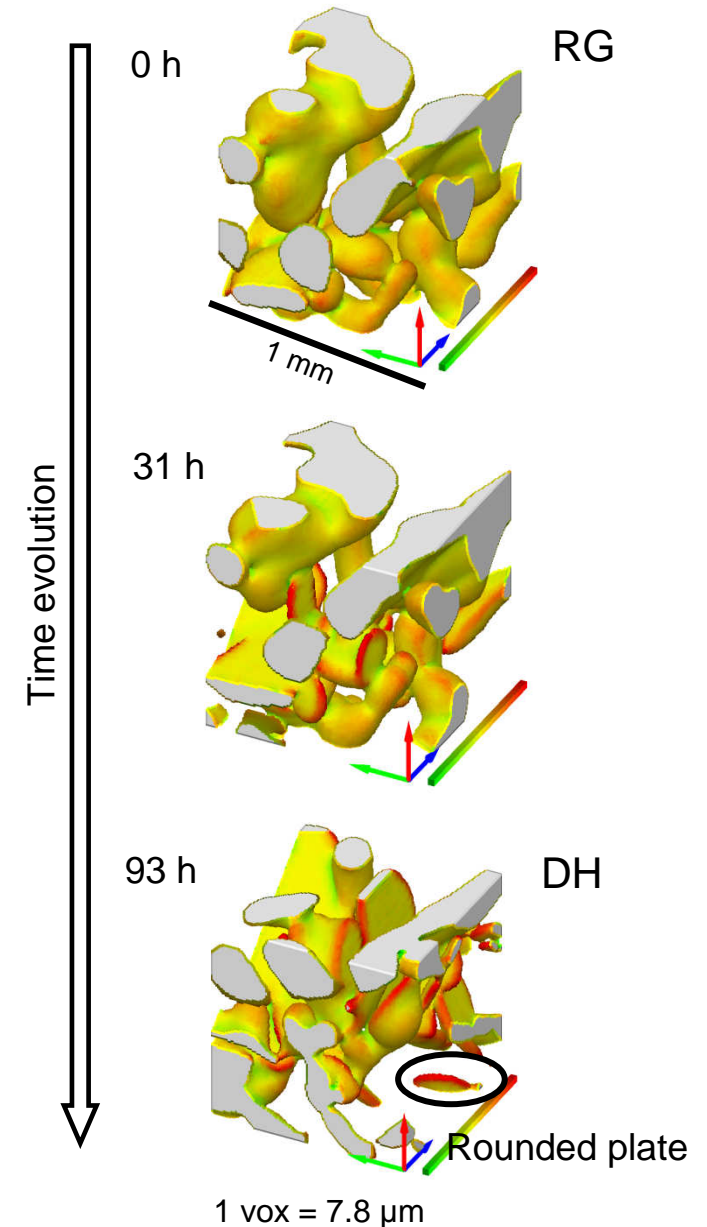
2.1. CEN – CellDyM: Dynamic Monitoring of snow

Temperature gradient metamorphism of 18° C/m at -2° C



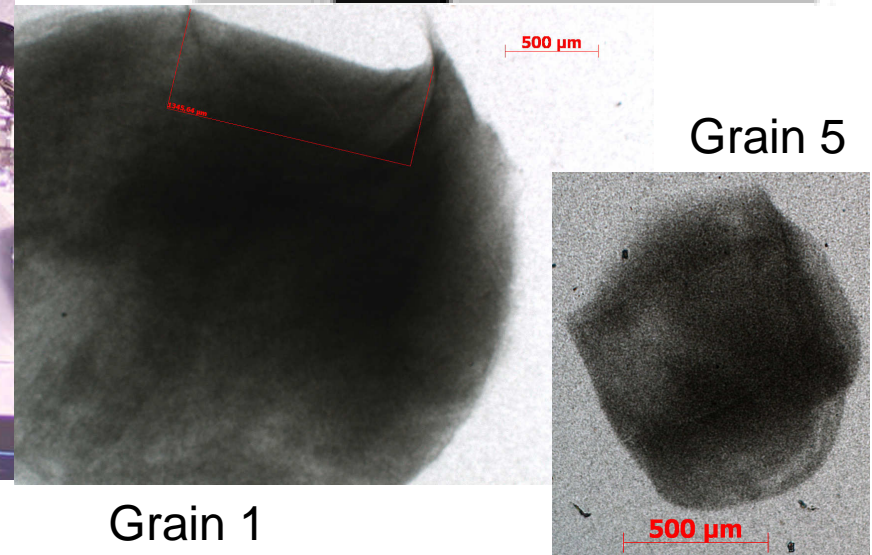
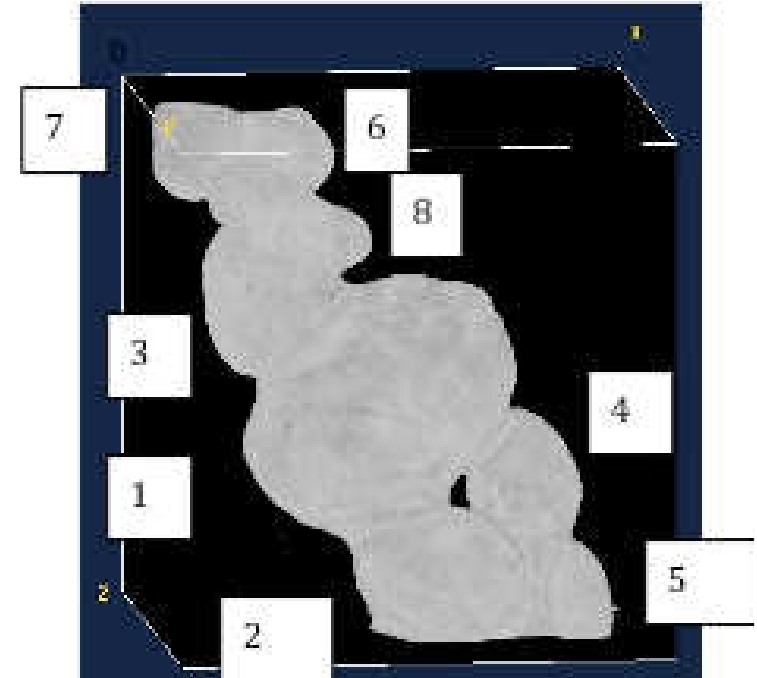
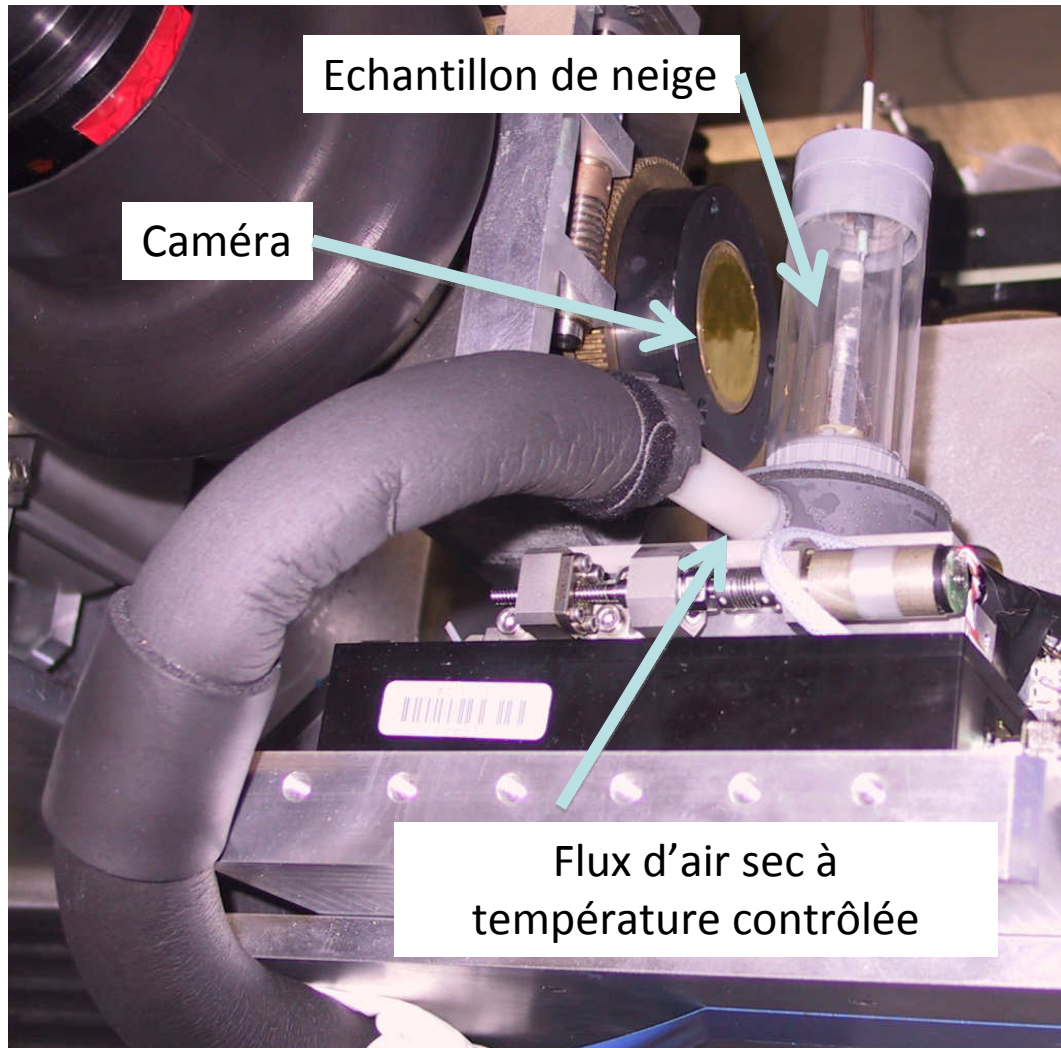
Typical features of the evolution under temperature gradient effects:

- Deposition/sublimation at the base/top of grains
- Fast evolution from RG to DH
- General growth of the ice structures
- at -2° C : formation of rounded plates



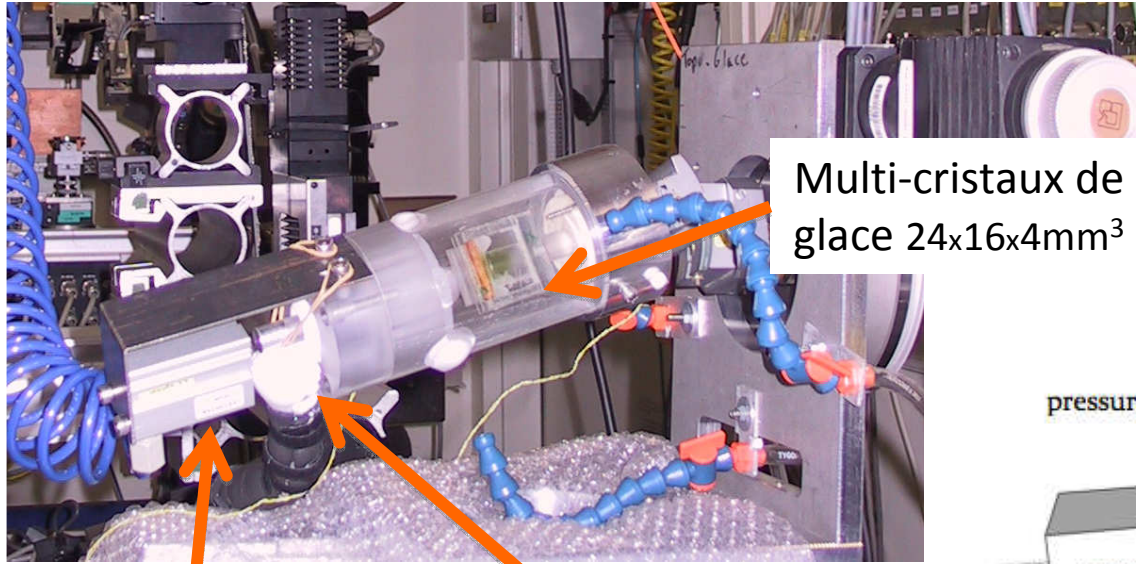
2.2. LGGE – Cellule DCT

Cellule à double parois et deux capteurs de température (haut et bas de l'échantillon)



2.2. LGGE – Cellule Diffraction Topographie

Cellule à double parois et deux capteurs de température (haut et bas de l'échantillon)

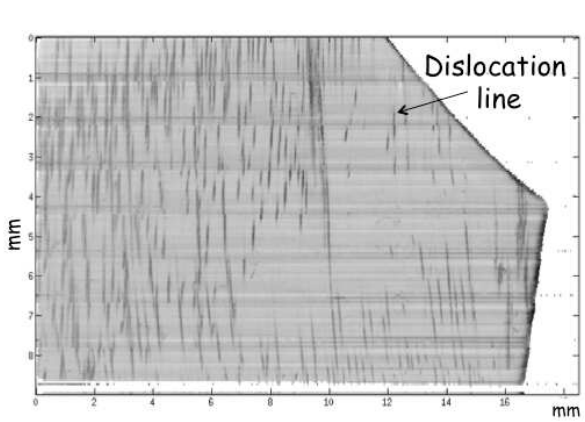
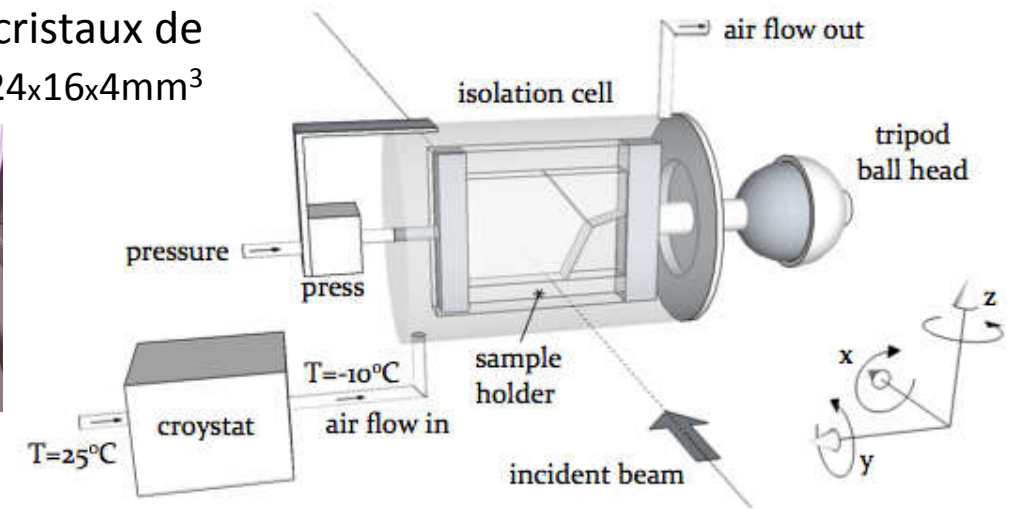


Multi-cristaux de glace 24x16x4mm³

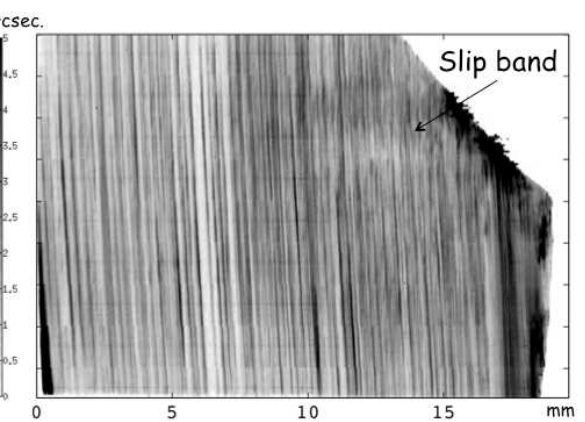
Application de la contrainte

Flux d'air sec à température contrôlée

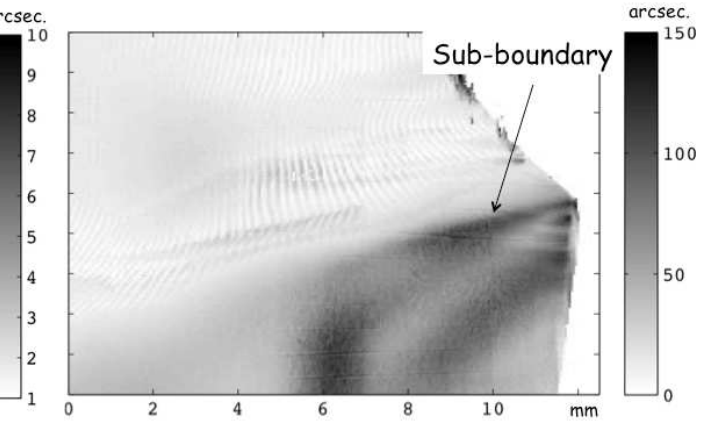
Kluender, Ph D Thesis, 2011



Initial stage



$\sigma_1 = 0.85$ MPa during 15 minutes



$\sigma_2 = \sigma_1 + 1.1$ MPa during 70 minutes
subgrain creation begins from the triple junction

	3SR	SIMaP	ESRF
Résolution	+	++	+++
Vitesse acq.	++	+	+++
DCT	-	-	+
Disponibilité	+	+	-
Ch. Froide	-	-	-
Espace cabine	++	+	+++
Coût	500 E/jour	500 E/jour	0 ou 8000 E/8h
CellStat (CEN)	Opérationnelle	Facilement adaptable	Facilement adaptable
CellDyM (CEN)	Opérationnelle	Adaptable	Adaptable
Cellule DCT (LGGE)	Adaptable	Adaptable	Opérationnelle
Cellule Diffraction topo (LGGE)	Opérationnelle
Autres ???			