

# Autocorrelation and the rose diagram for analyzing structure and anisotropy in polymer foams

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# The project

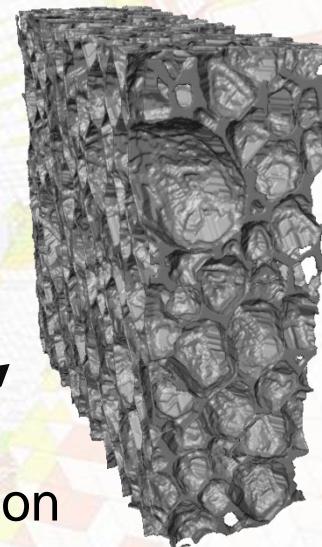
Action de Recherche Concertée (ARC)

*From imaging to geometrical modelling of complex micro-structured materials:  
Bridging computational engineering and material science*

**Application:** ElectroMagnetic Interference (EMI) shielding



Reflected EM  
radiation



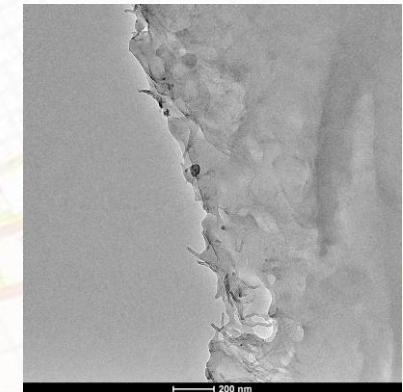
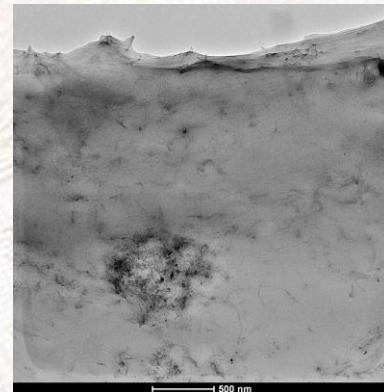
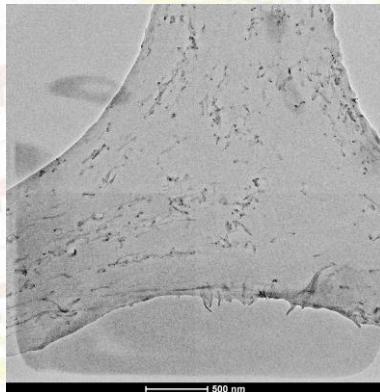
Incident EM radiation



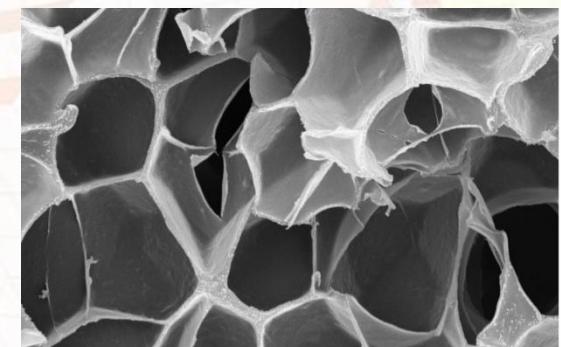
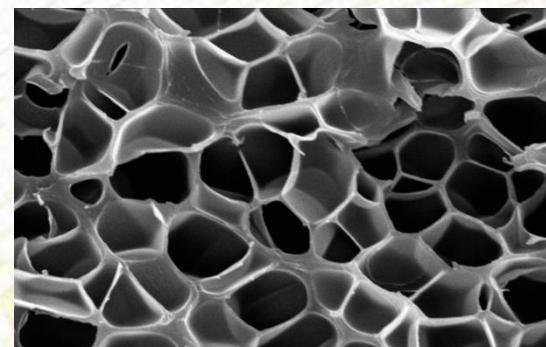
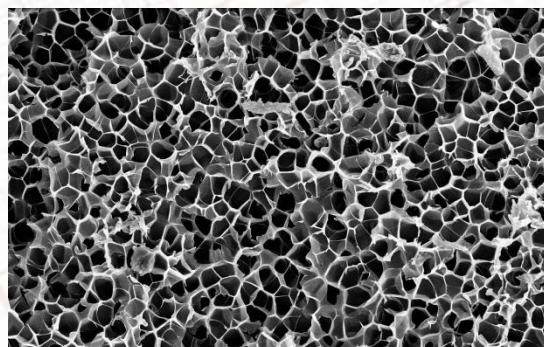
Residual output  
EM radiation

# Microstructure characterisation

- Transmission Electron Microscopy (TEM)

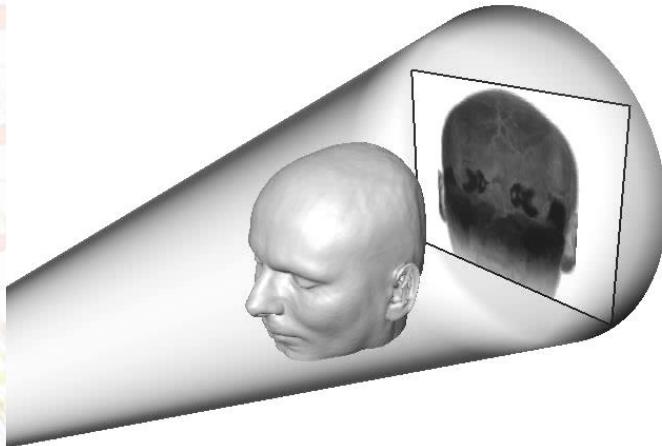


- Scanning Electron Microscopy (SEM)

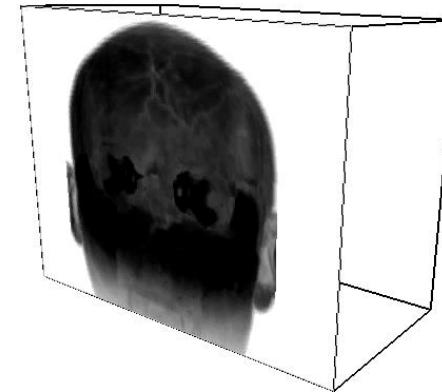


- X-ray Microtomography

# X-Ray microtomography



Acquisition



Reconstruction

- Two main things to think about:
  - Contrast
  - Resolution

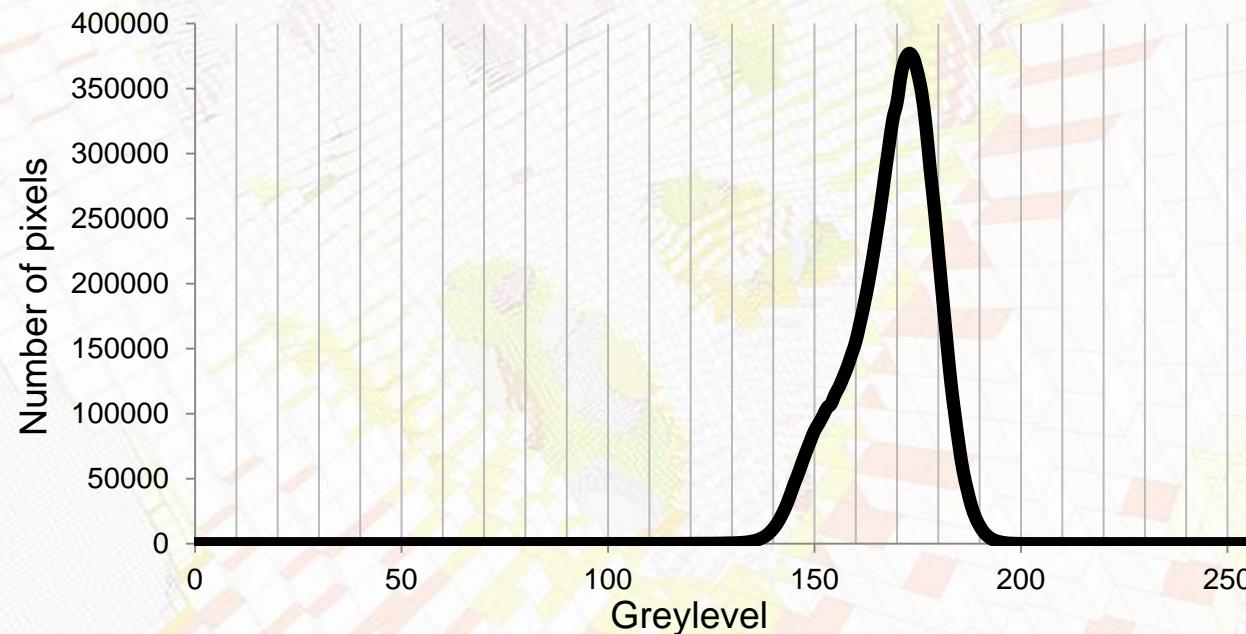


# Microtomograms

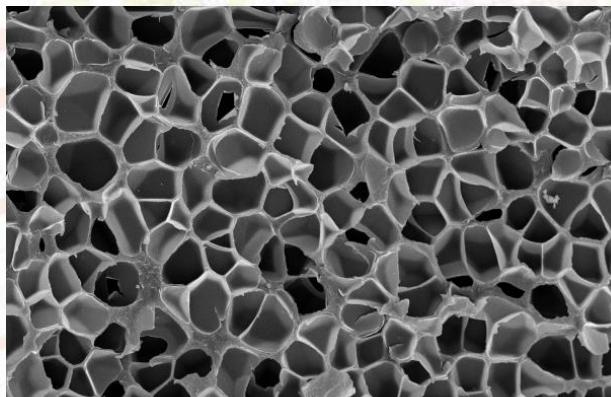
0.5 mm

# Acquisition parameters

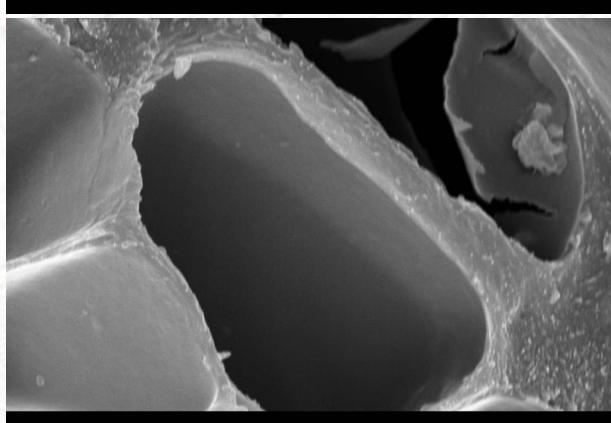
- Parameters
  - 25 kV – 250 mA
  - Exposure time per projection : 4.1 s
  - 3600 projections
- Projection histogram



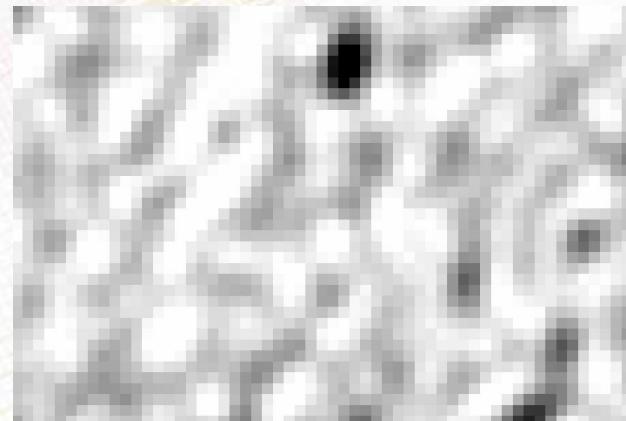
# XRCT vs. SEM



7072 19KV X300 100µm WD37

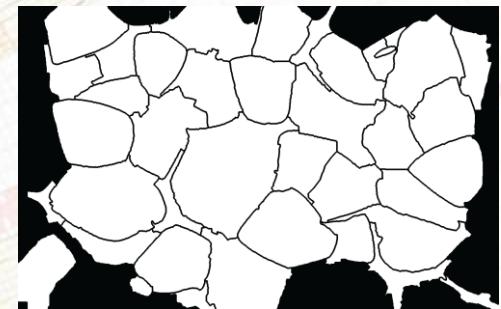
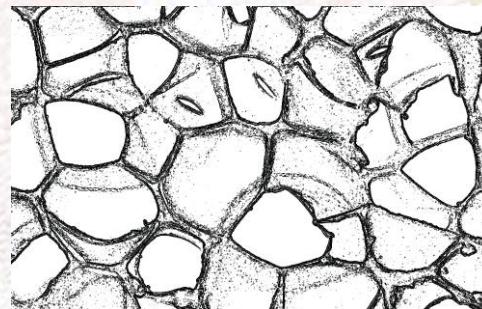
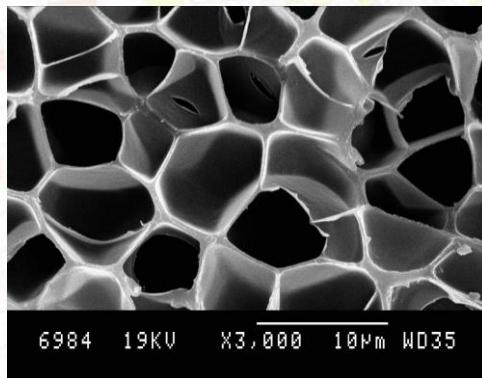


7073 19KV X3,000 10µm WD37

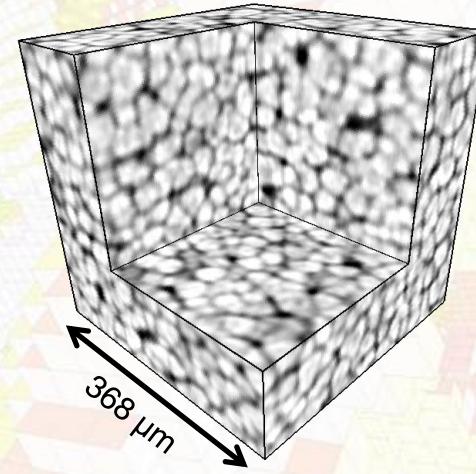
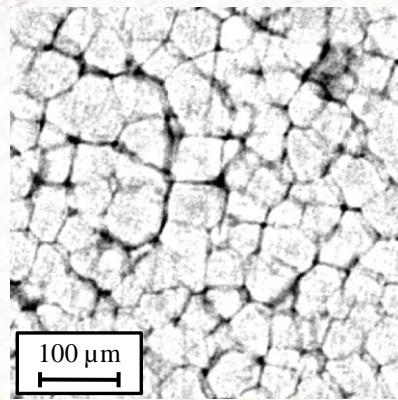


# Options

- Just use SEM



- Make better tomograms



- Make do
- Make better samples

# Autocorrelation

$$R(\tau) = \frac{E[(X_t - \mu)(X_{t+\tau} - \mu)]}{\sigma^2}$$

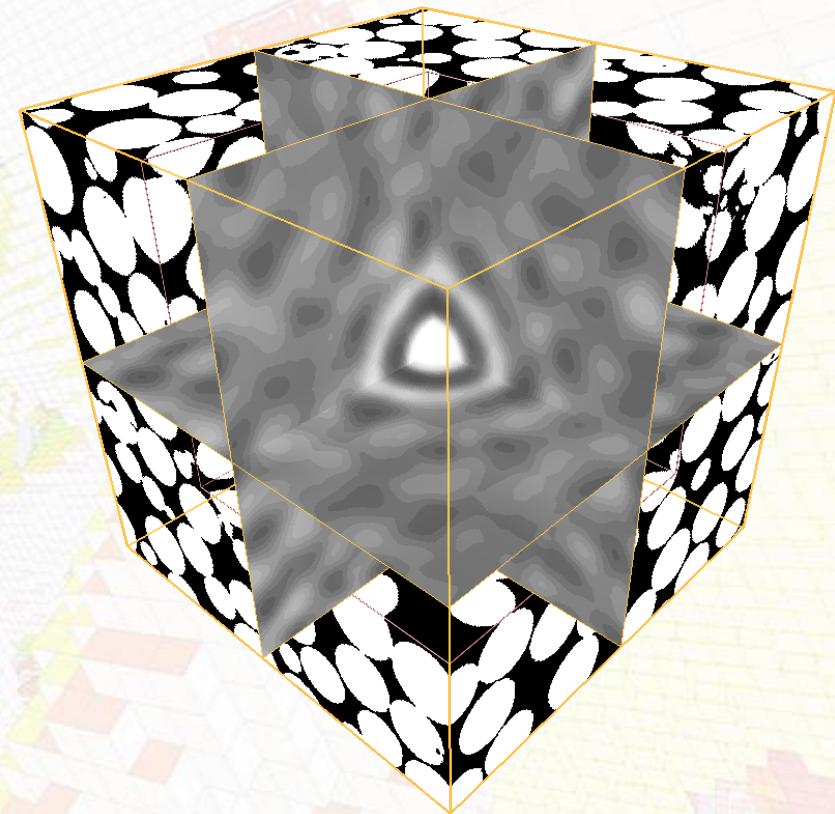
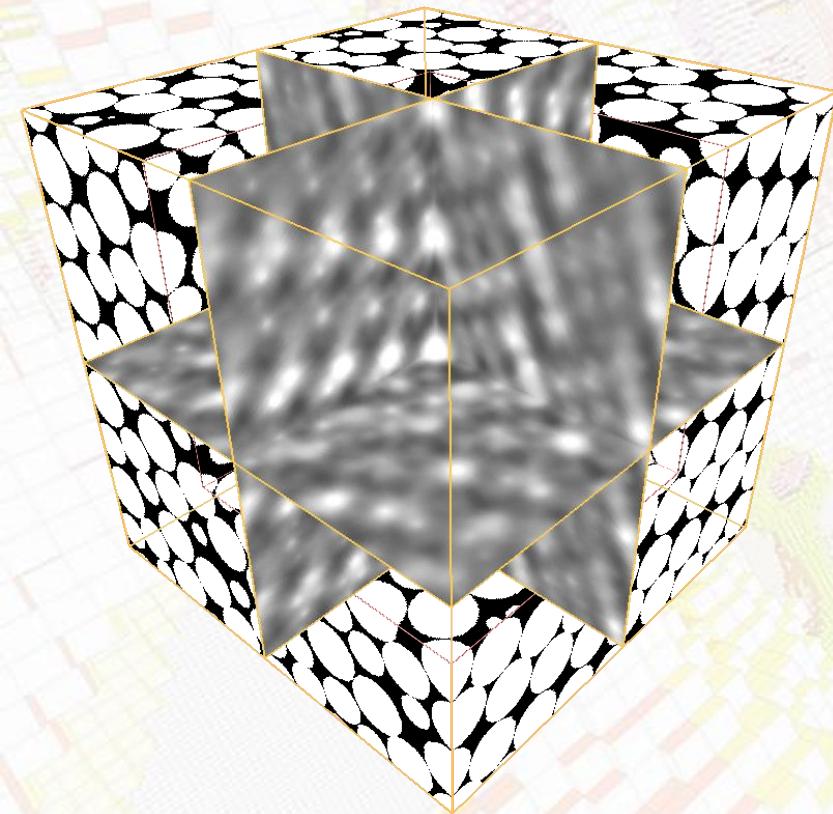
$$R(\tau_x, \tau_y, \tau_z)$$

- Statistical approach
- Global measurement
- Greyscale tomogram considered a 3D signal
- Identification of « pattern frequencies » in noisy signals
- Efficient global anisotropy measurement<sup>1</sup>

[1] F. Wehrli, B. Vasilic, P. Saha, and M. Wald. Performance comparison of the spatial autocorrelation function and the mean intercept-length in the determination of trabecular bone anisotropy in the in vivo environment. Proceedings of the 14th Annual Meeting of ISMRM, 2006.

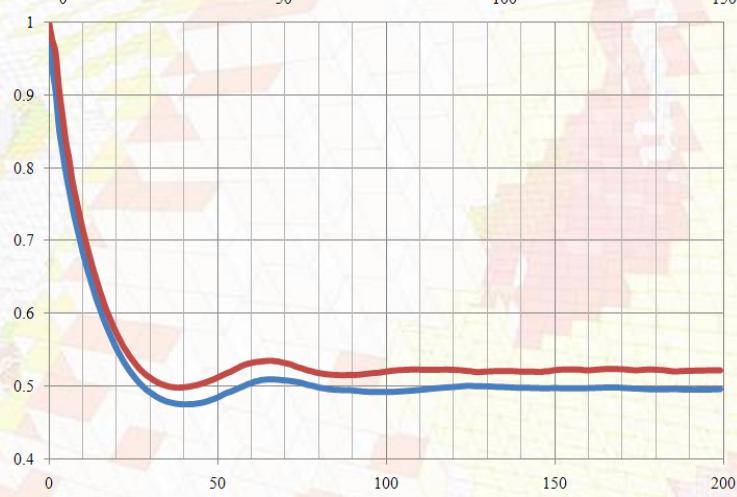
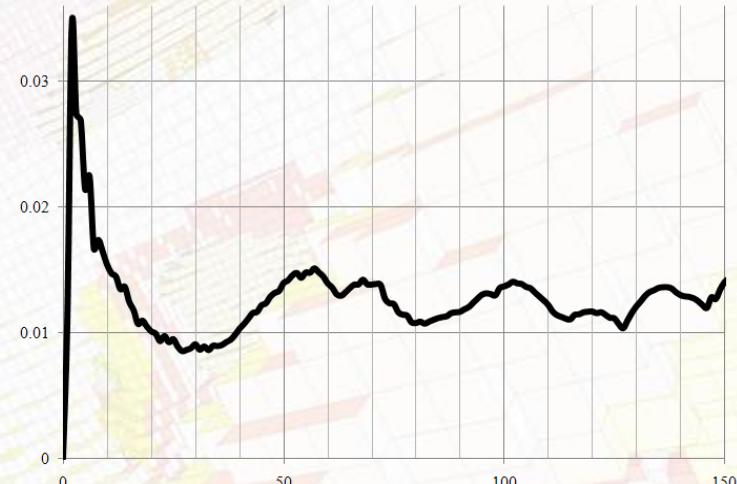
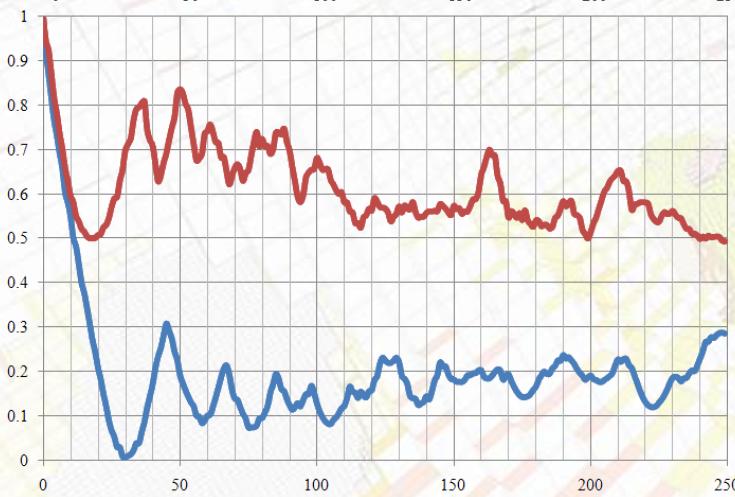
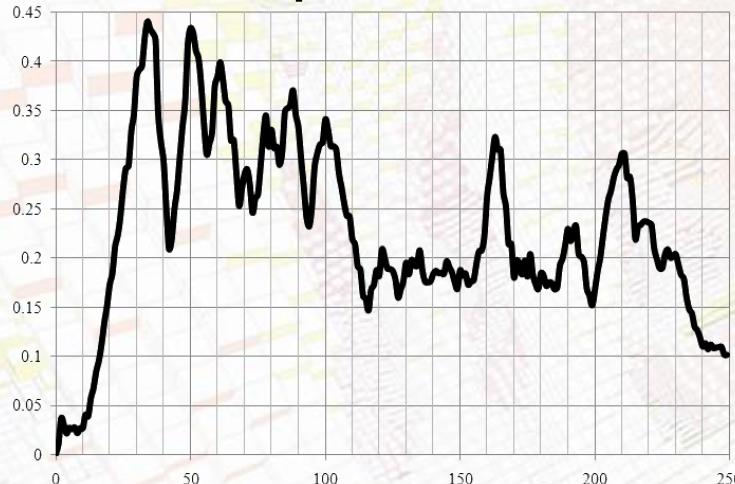
# Characteristic length

- Average autocorrelation =  $f(\text{translation distance})$
- Examples

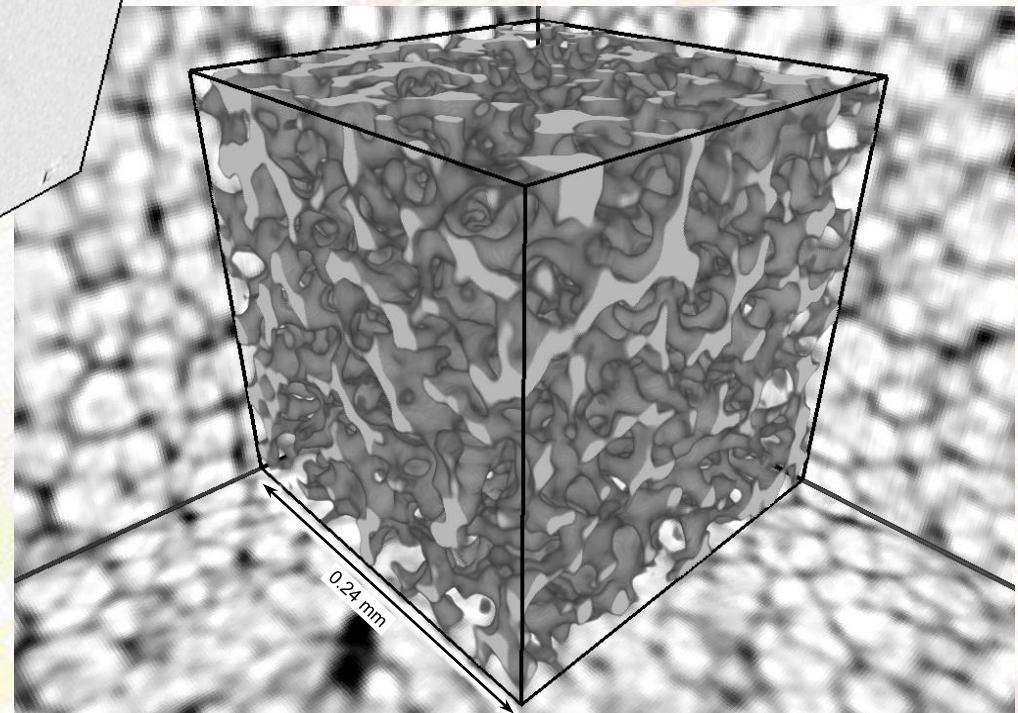
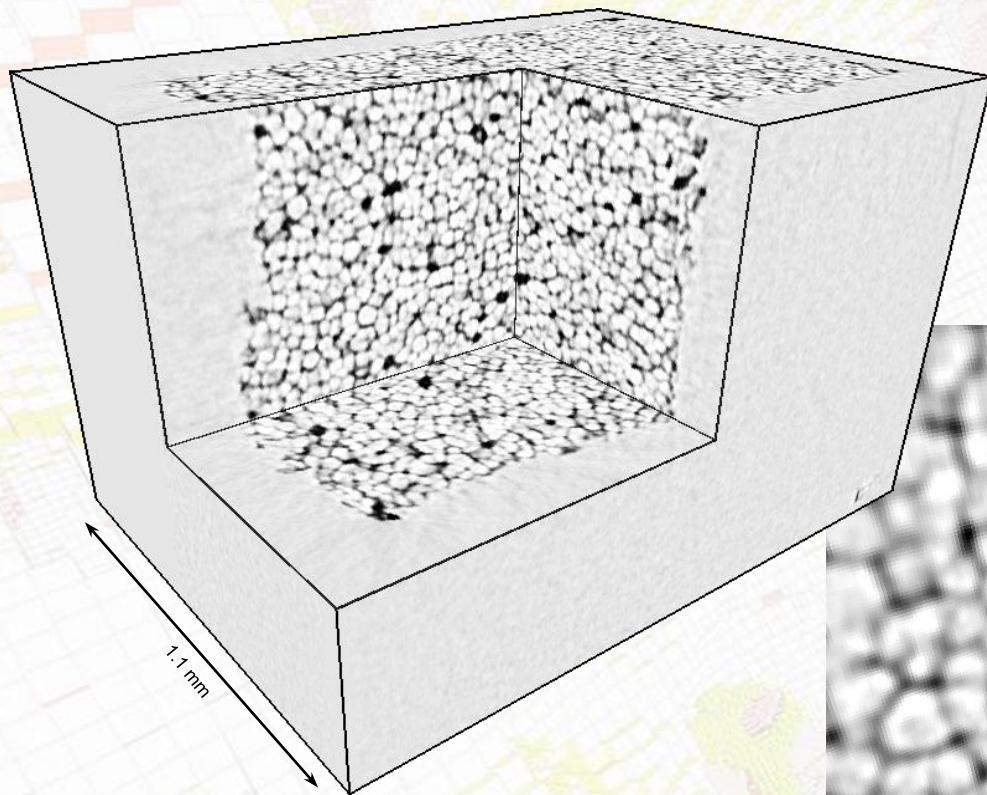


# Characteristic length

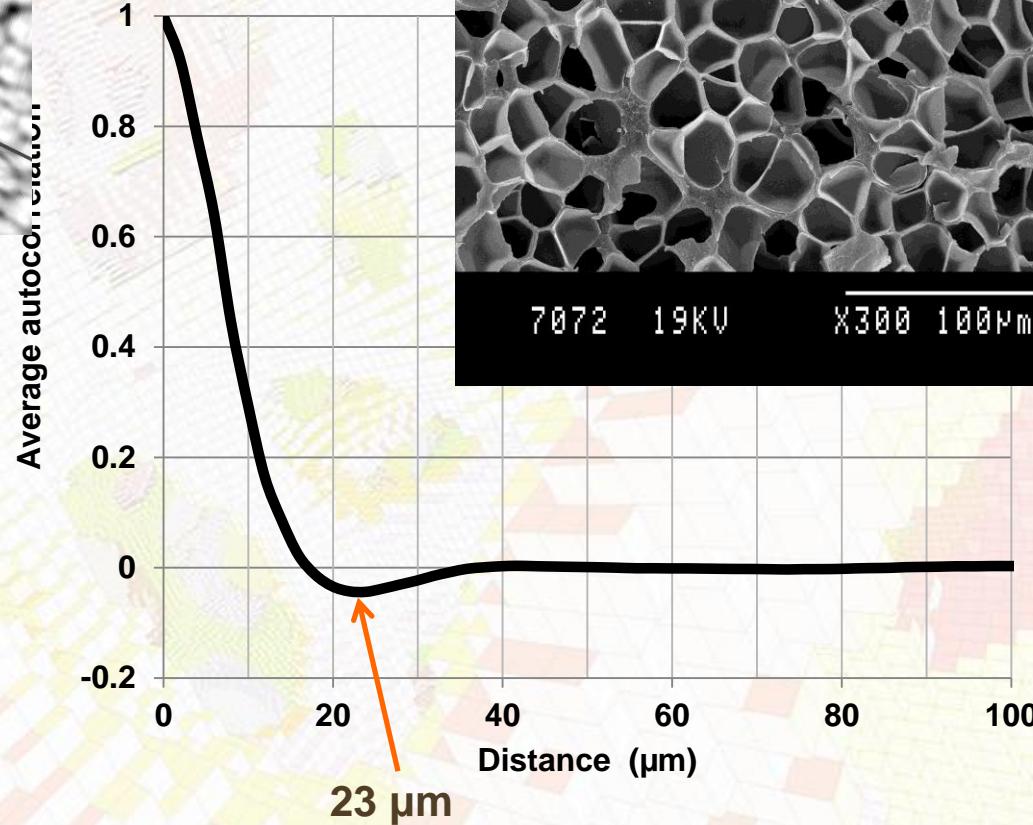
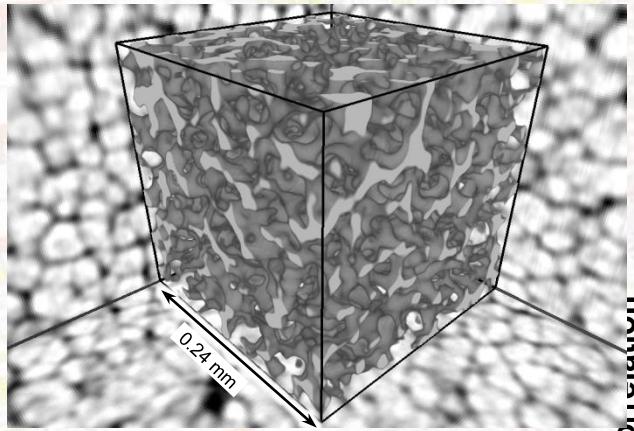
## ■ Exemples



# Characteristic length in polymer foams



# Characteristic length in polymer foams



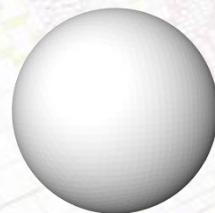
# The rose diagram

$$R(\tau_x, \tau_y, \tau_z)$$

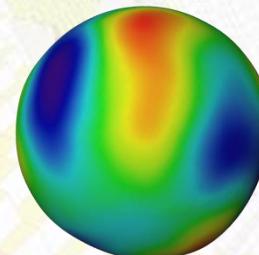
$$r = \sqrt{\tau_x^2 + \tau_y^2 + \tau_z^2}$$

- View autocorrelation in all directions

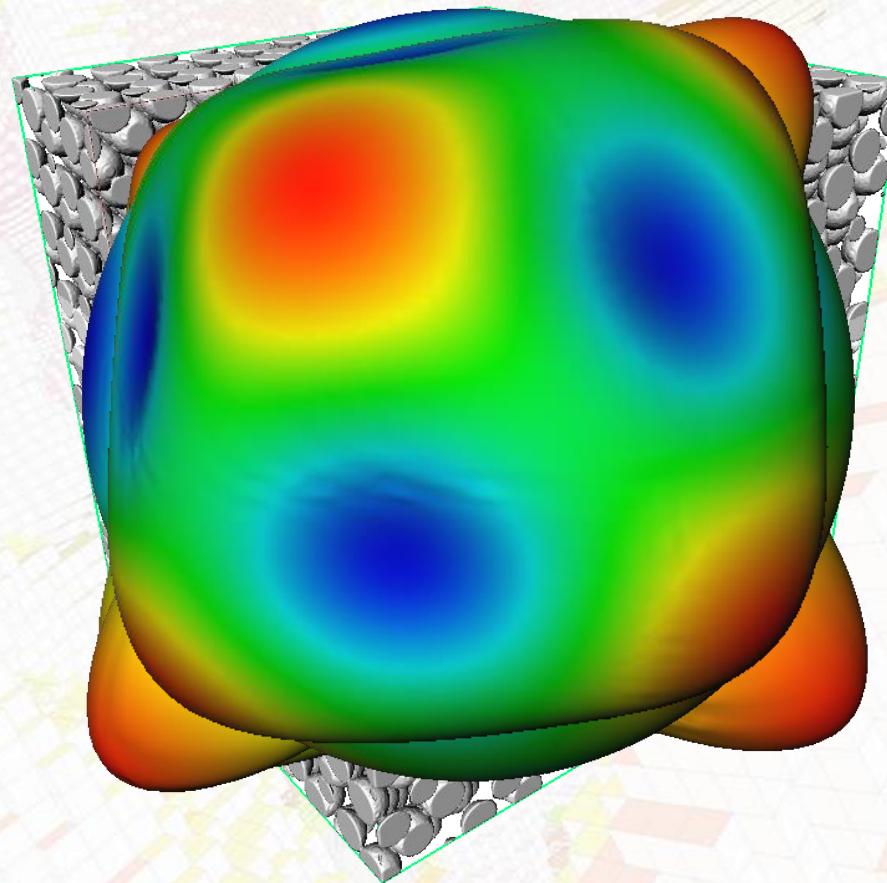
- Meshed sphere



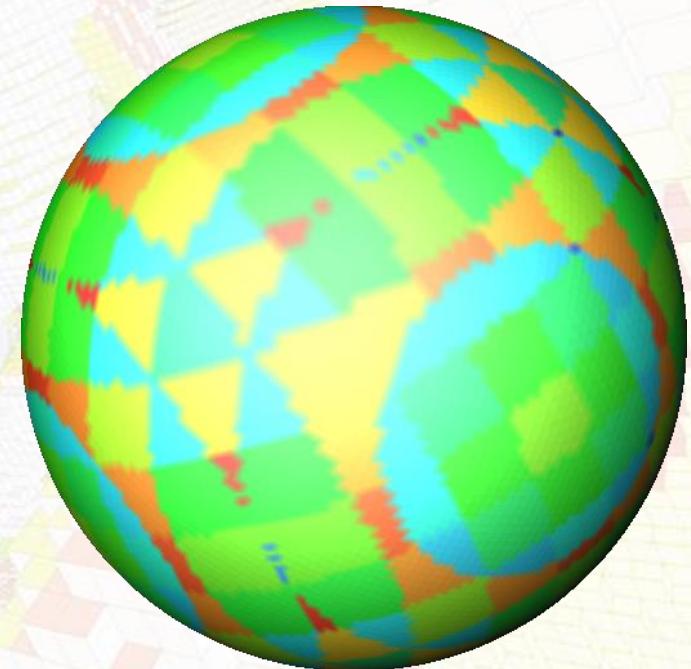
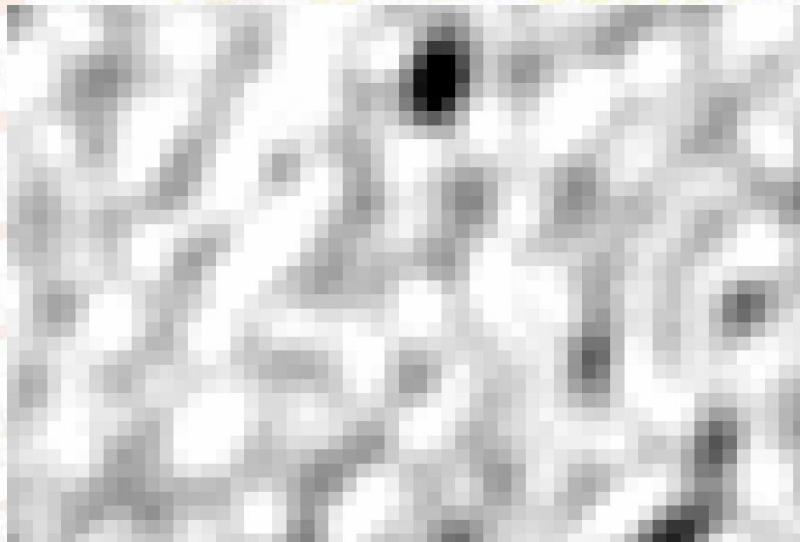
- Map autocorrelation at each vertex



# Rose diagram



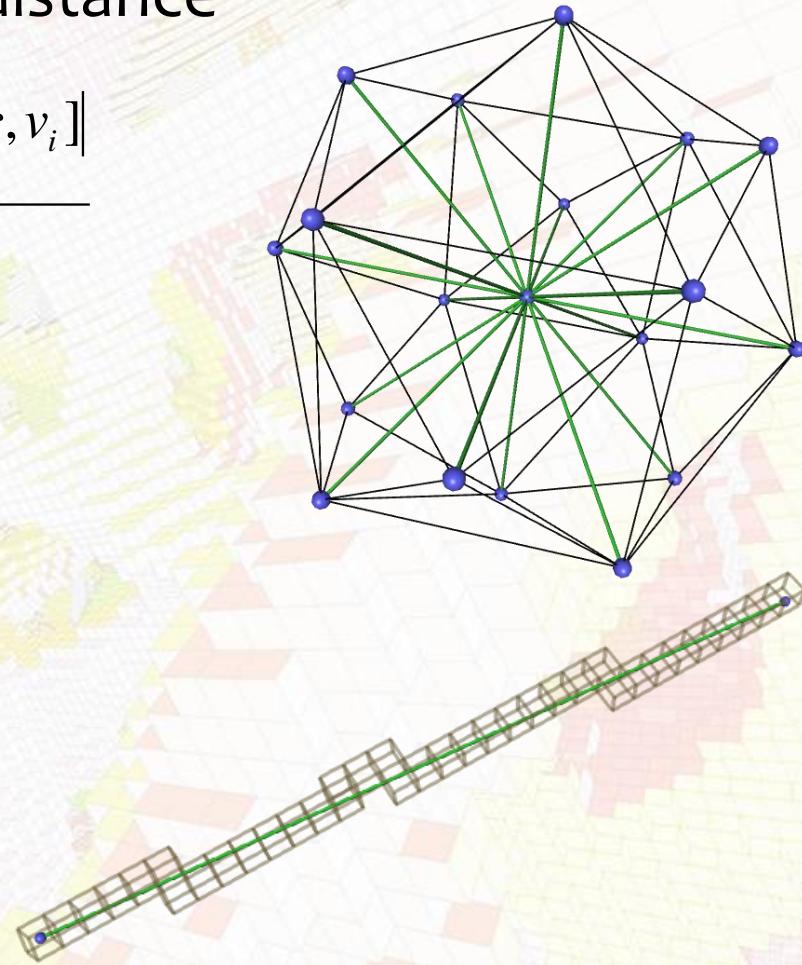
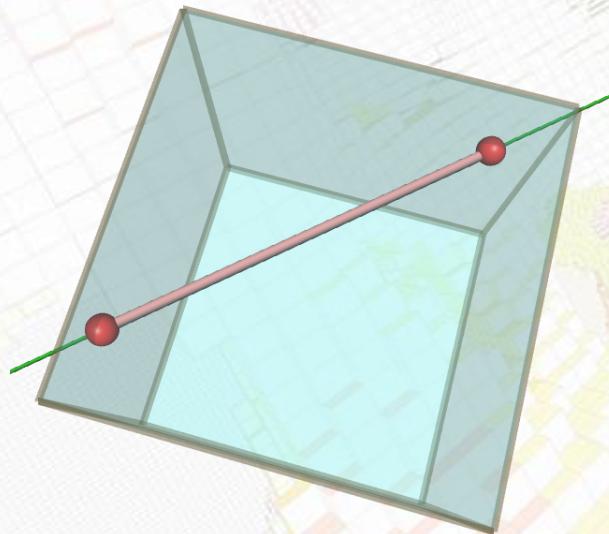
# At what distance ?



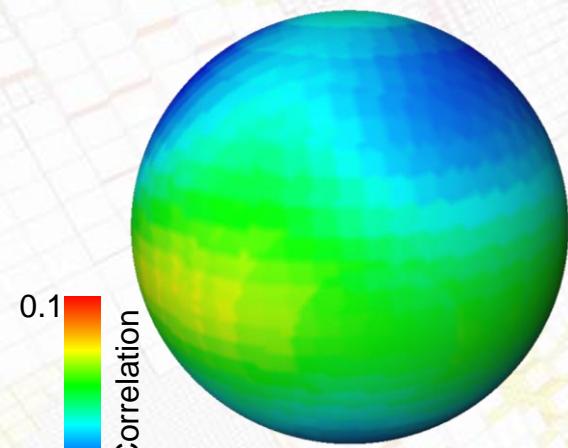
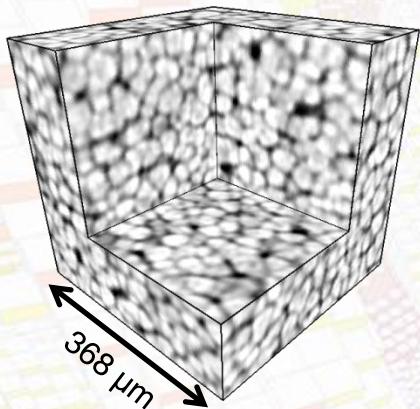
# Better view of anisotropy

- Integration over a certain distance

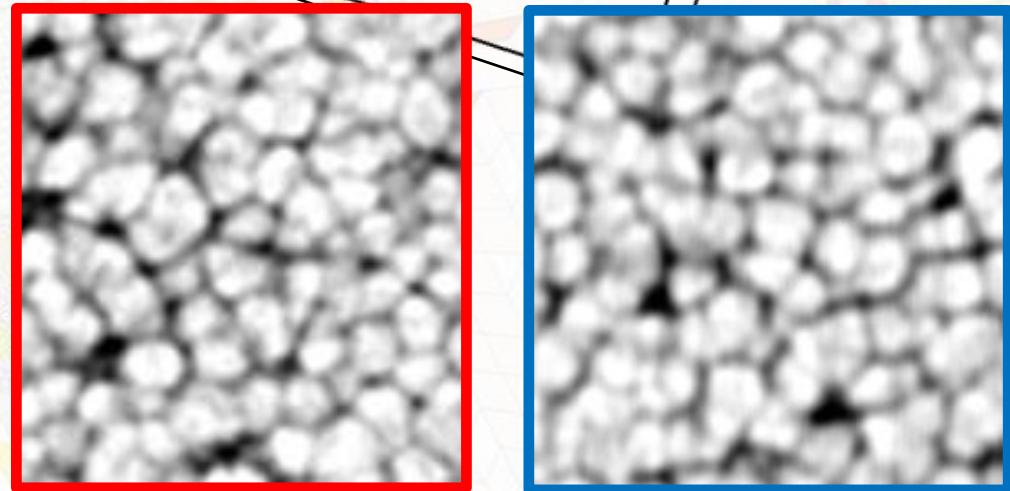
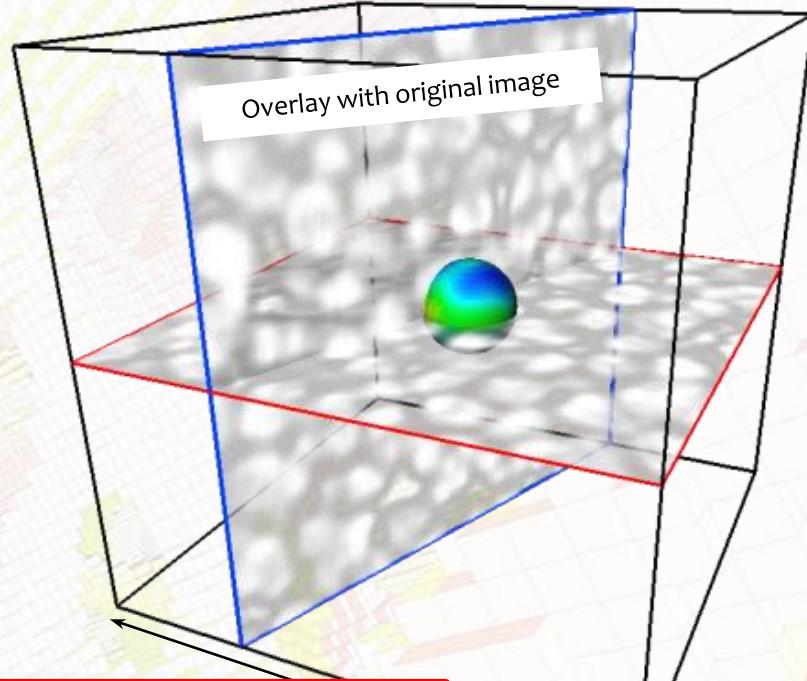
$$R_m(v_i) = R_m(c, v_i) = \frac{\sum_{p \cap [c, v_i] \neq \emptyset} R(p) * |p \cap [c, v_i]|}{|[c, v_i]|}$$



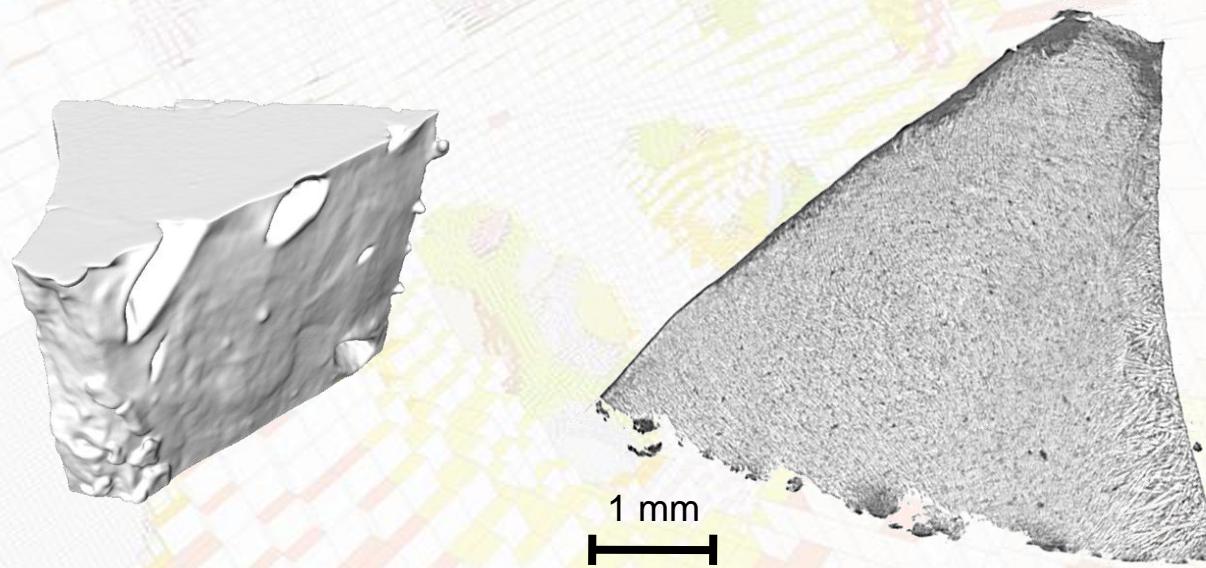
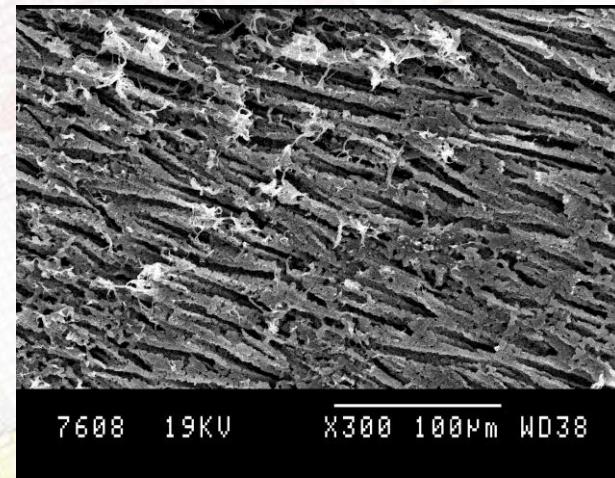
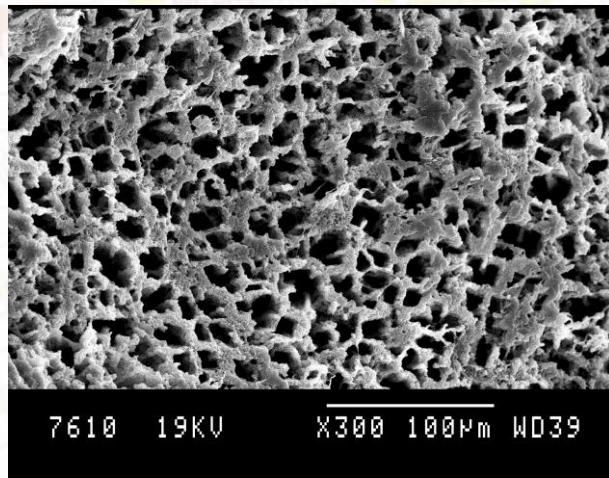
# Results



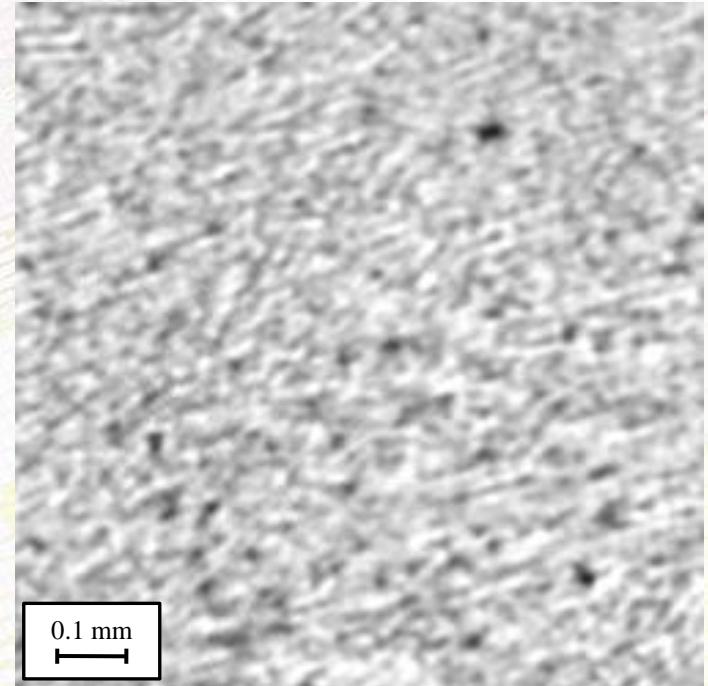
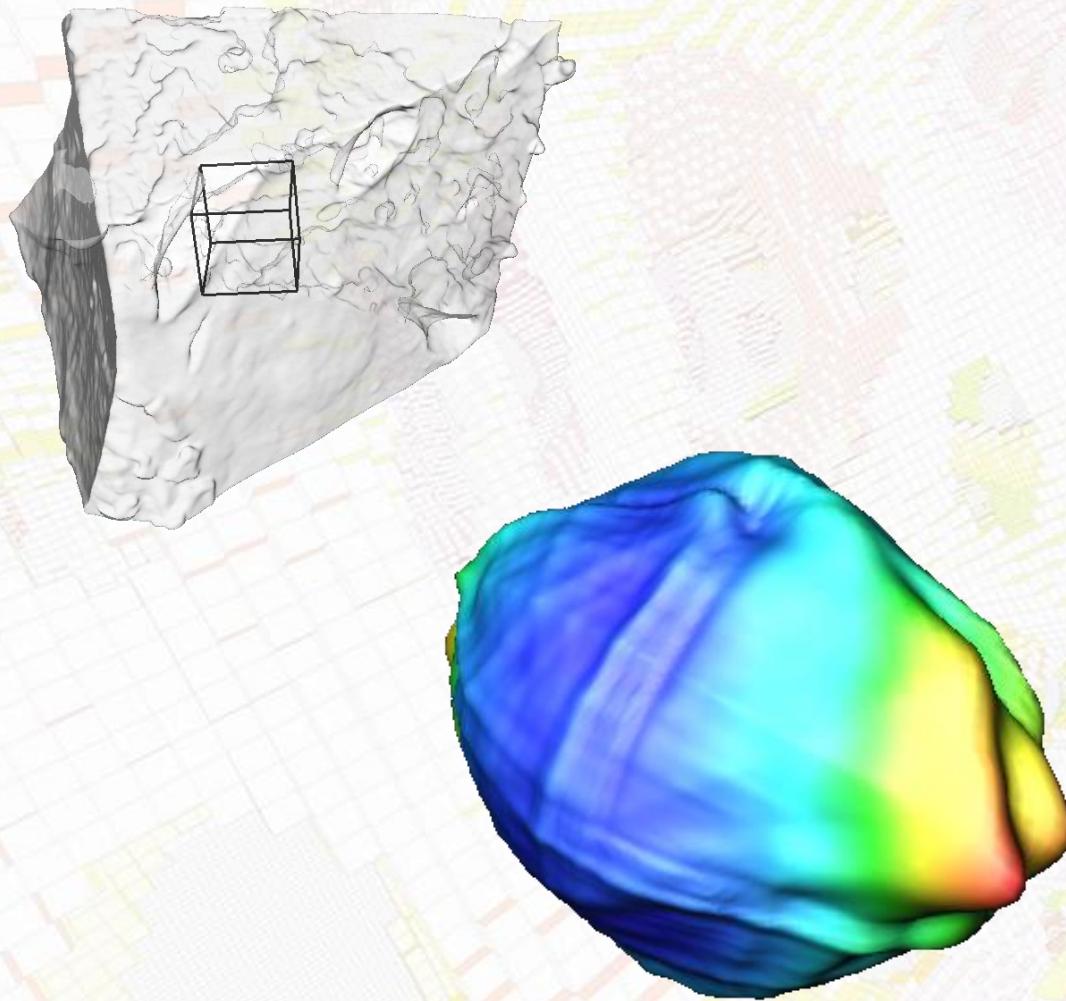
Autocorrelation in all directions



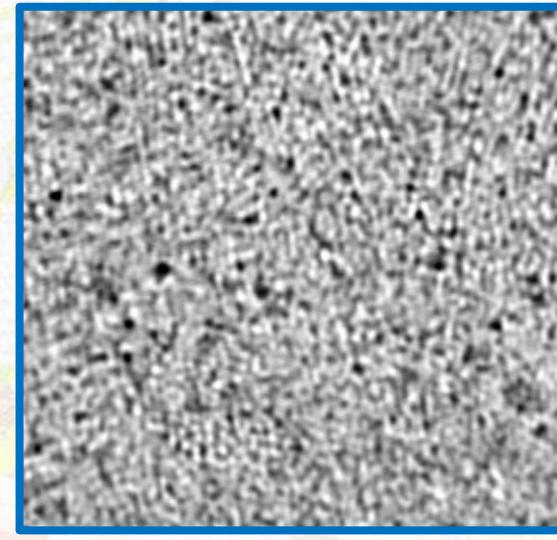
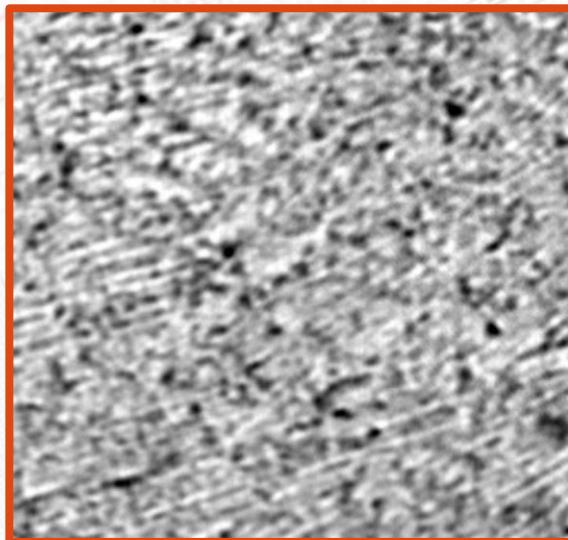
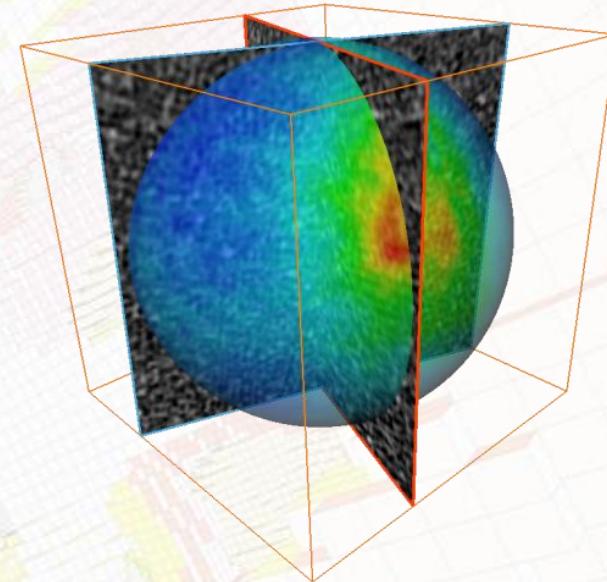
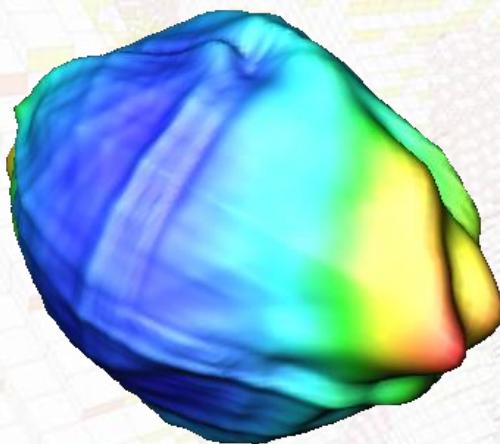
# Anisotropic foams



# Anisotropic foams



# Anisotropic foams



# Conclusions & perspectives

- Autocorrelation
  - Efficient for low resolution or noisy data
  - No segmentation necessary
  - Subvoxel accuracy of characteristic length
- Rose diagram
  - Provides global preferential orientation of features
  - Insensitive to random noise (*very sensitive to directional noise !*)
- Directional characteristic lengths
  - Decompose average autocorrelation plots into directional cones

## Acknowledgments

- The Belgian French-speaking Community for a post-doctorate
- The Fonds National de Recherche Scientifique for tomographic equipment
- Nicolas Combaret (VSG) for the integration of the autocorrelation module