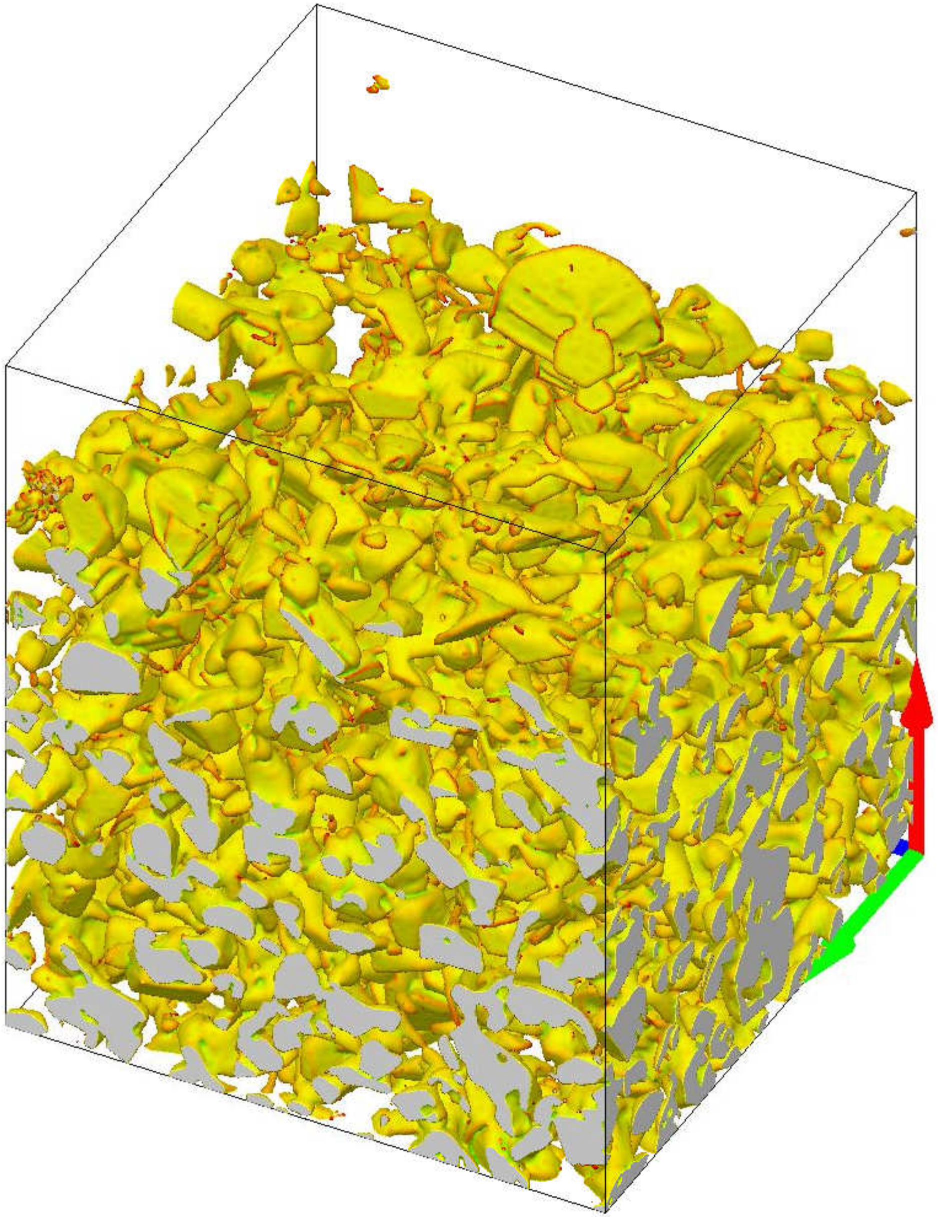
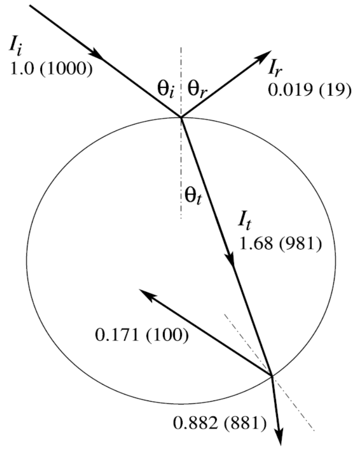
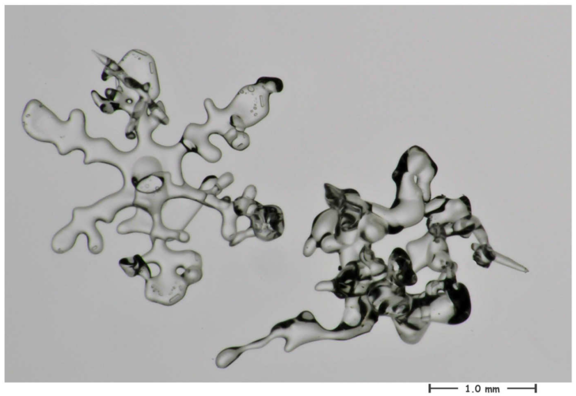
Study of the reflectance of snow based on measurements and modeling

8/7/2015, Frédéric Flin





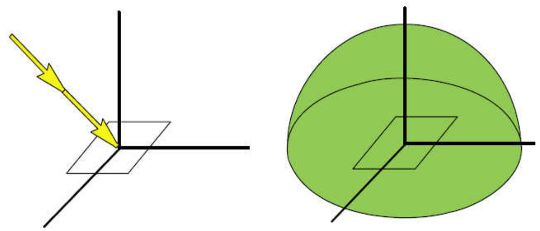


Alexander Regenscheit M2R 2014

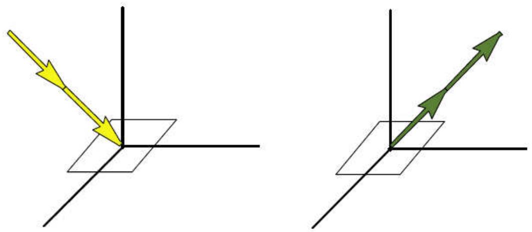
Supervised by
Marie Dumont and Frédéric Flin

Definitions

- Albedo:
  - Ratio between reflected radiation into the whole hemisphere over the incident irradiance



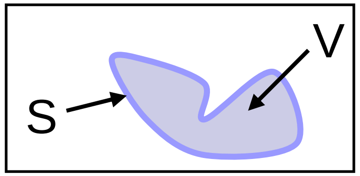
- Bidirectional reflection density function (BRDF):
  - Ratio of reflected radiance in an infinitesimal solid angle direction over the incident irradiance of a collimated beam



- Specific Surface Area (SSA):
  - Ratio between surface (interface ice/air) and volume of ice

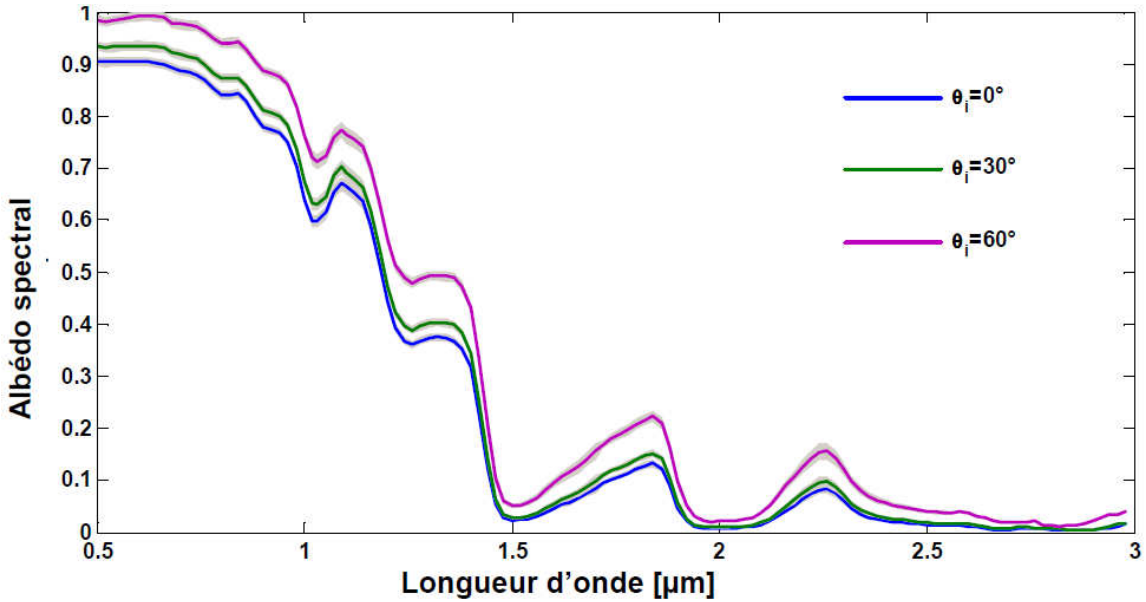
  → Measure for grain size

$$SSA = \frac{S}{V \cdot \rho_{glace}}$$

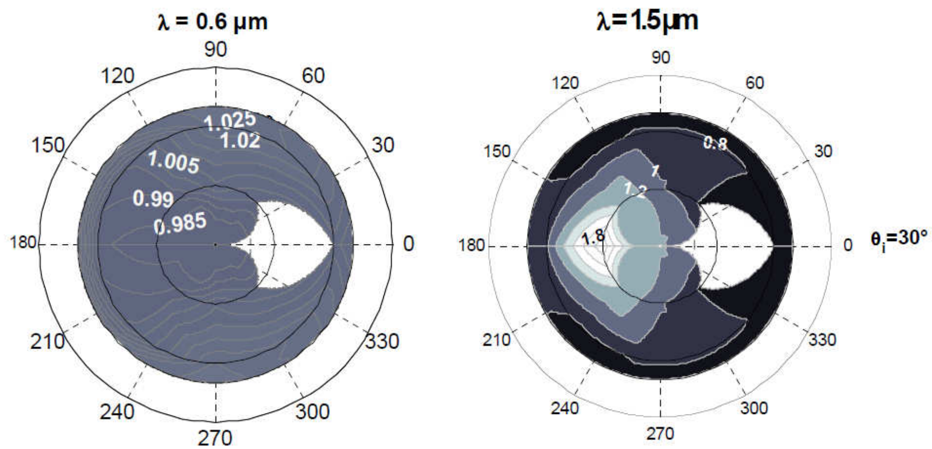


Optical properties of snow

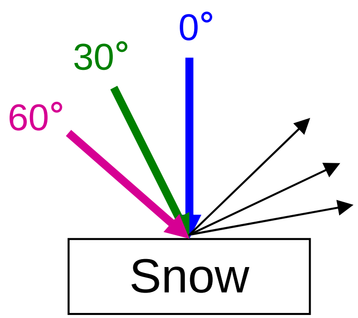
Albedo



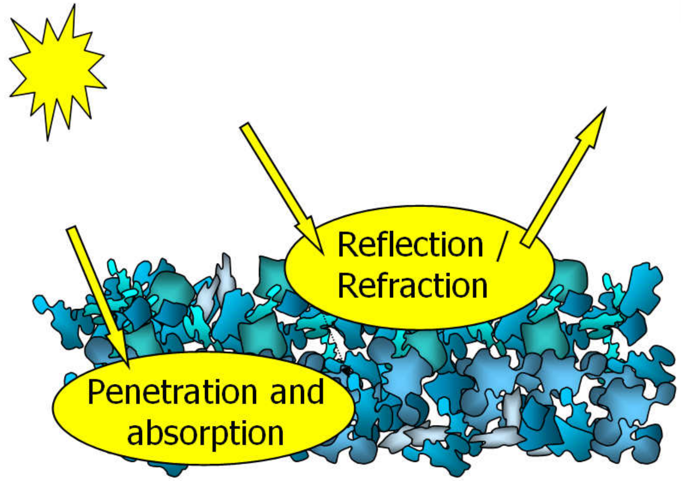
BRDF



- dominant multiscattering λ < 1 µm
- strong forward scattering for λ > 1 µm (absorption)

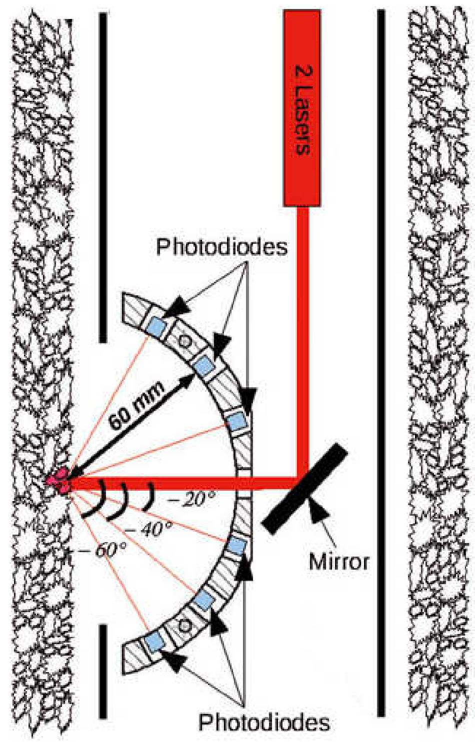


Motivation



- Application of optical properties of snow :
  - Modeling of the snowpack (energy balance) (Brun et al., 1989)
  - Remote sensing of reflectance (Dumont, 2010)
  - In situ measurements of SSA (DUFISSS, POSSSUM) (Arnaud, 2011)

- Albedo and BRDF depending on the microstructure of snow (Haussener et al. 2012; Picard et al., 2009; Kaempfer et al., 2007)



Motivation

For a better understanding of the relation between microstructure and optical properties:

- BRDF measurements of two different snow types were done 2012/13 (IPAG) together with taking tomography images of this snow (3SR)

Goal of the internship

- Comparison of these measurements with the results of different models
- Comparison of different models with each other
- Evaluating the range of correctness of the models
- Impact of grain shape on BRDF

Content

- Measurements
- Models
- Results
- Conclusion

Measurements

Sampling for BRDF measurements at IPAG

Sampling for tomography at 3SR Lab

+Grain photographs

+Density measurements

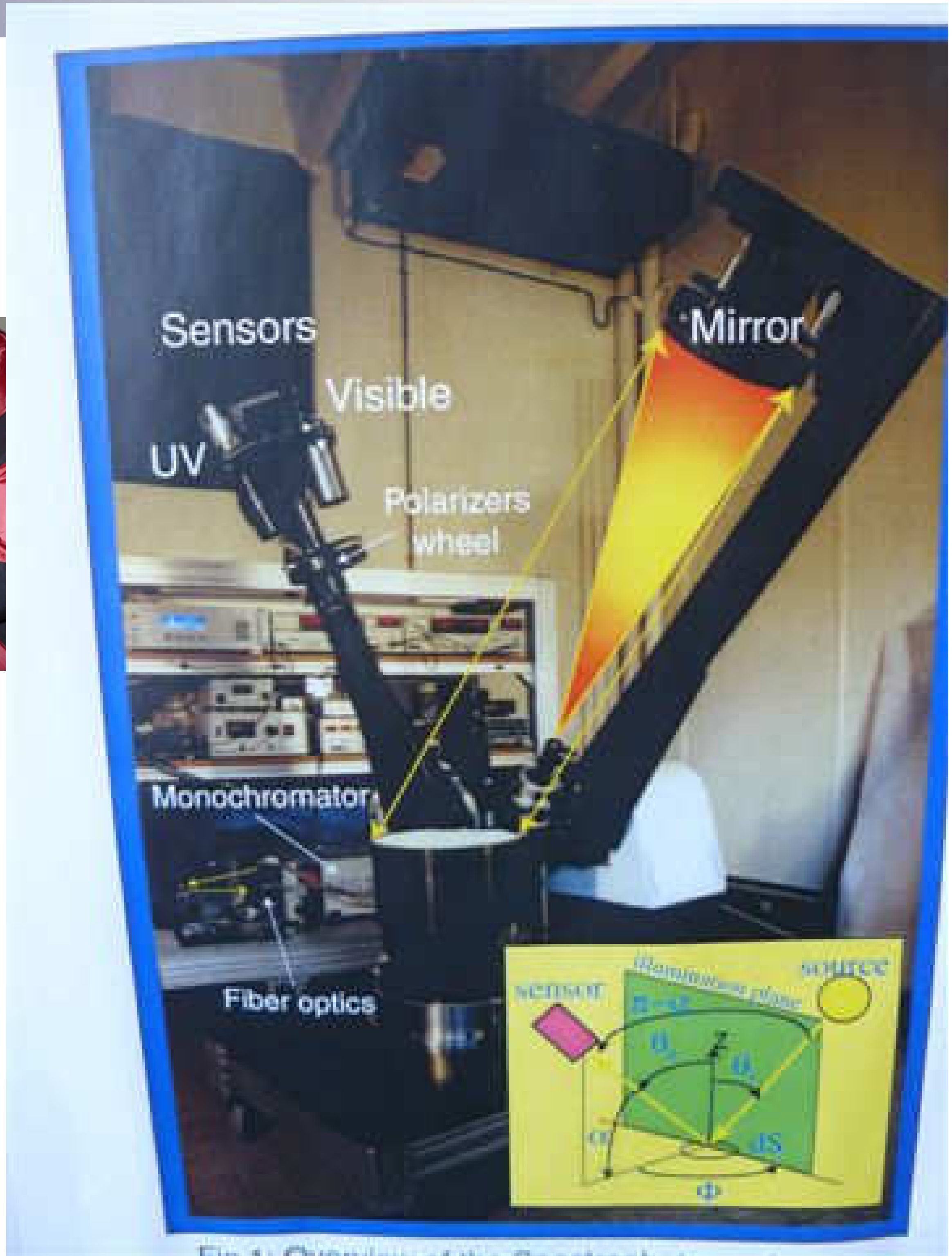
+SSA measurements

Before and after BRDF measurements

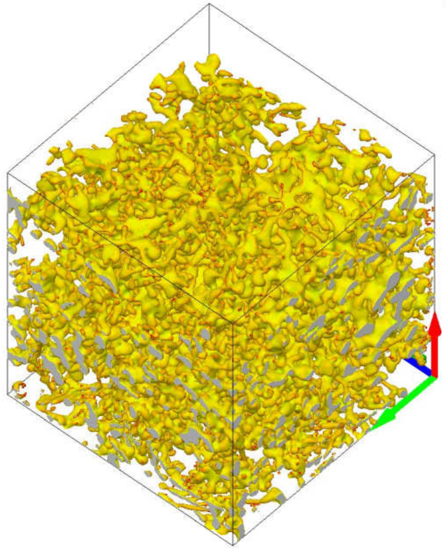
Measurements

Sampling for BRDF measurements at IPAG

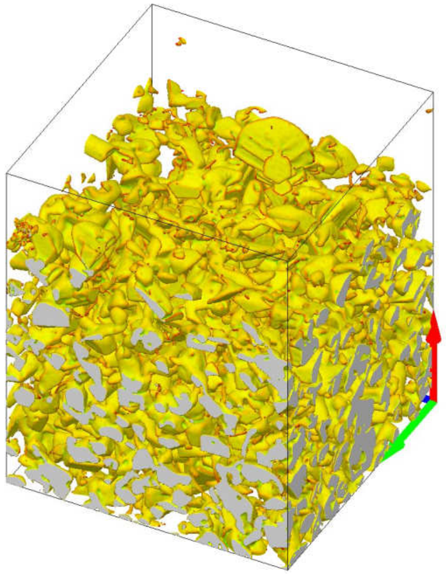
Sampling for tomography at 3SR Lab

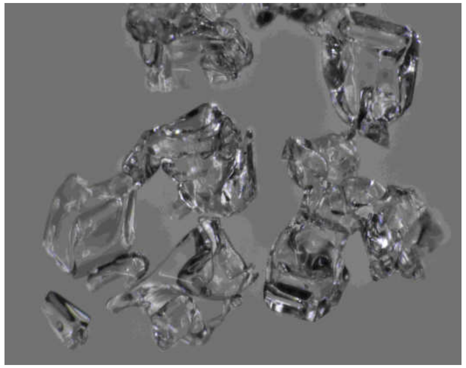


Measurements



- March 2012 – recent snow
  - Naturally deposited snow
  - Three tomography images (3SRLab)
  - 5 reflectance measurement configurations (IPAG)





- March 2013 – faceted snow
  - 17 days under temperature gradient
  - Sieved snow
  - Two tomography images
  - 9 reflectance measurement configurations

Models:

Microstructural properties → optical properties

- DISORT: (Stamnes, 1988)
  - Exact solution of the radiative transfer equation
  - Mie-scattering (spheres)
- Photon tracking model PBRT: (Malgat, 2012)
  - Optical law based probability model
  - Calculates reflectance from digital images
- Analytical model: (Kokhanovsky, 2012)
  - Approximation of the radiative transfer equation,
  - Based on reflection function for snow grains,
  - Valid for weakly absorbing media
  - Two free parameters:
    - M as a measure for the impurites
    - $L = b^2 d$ (b = shape factor; d = mean diameter of grains)

→ To compare measurements with the models the SSA has to be equivalent

Results

- Albedo:
  - DISORT vs PBRT for image of spheres
  - DISORT vs PBRT for tomography images of snow
  - DISORT and PBRT vs measurements
- BRDF:
  - Measurements vs analytical model
  - Measurements of different snow grains

Albedo – DISORT vs PBRT - spheres

Numerical samples:

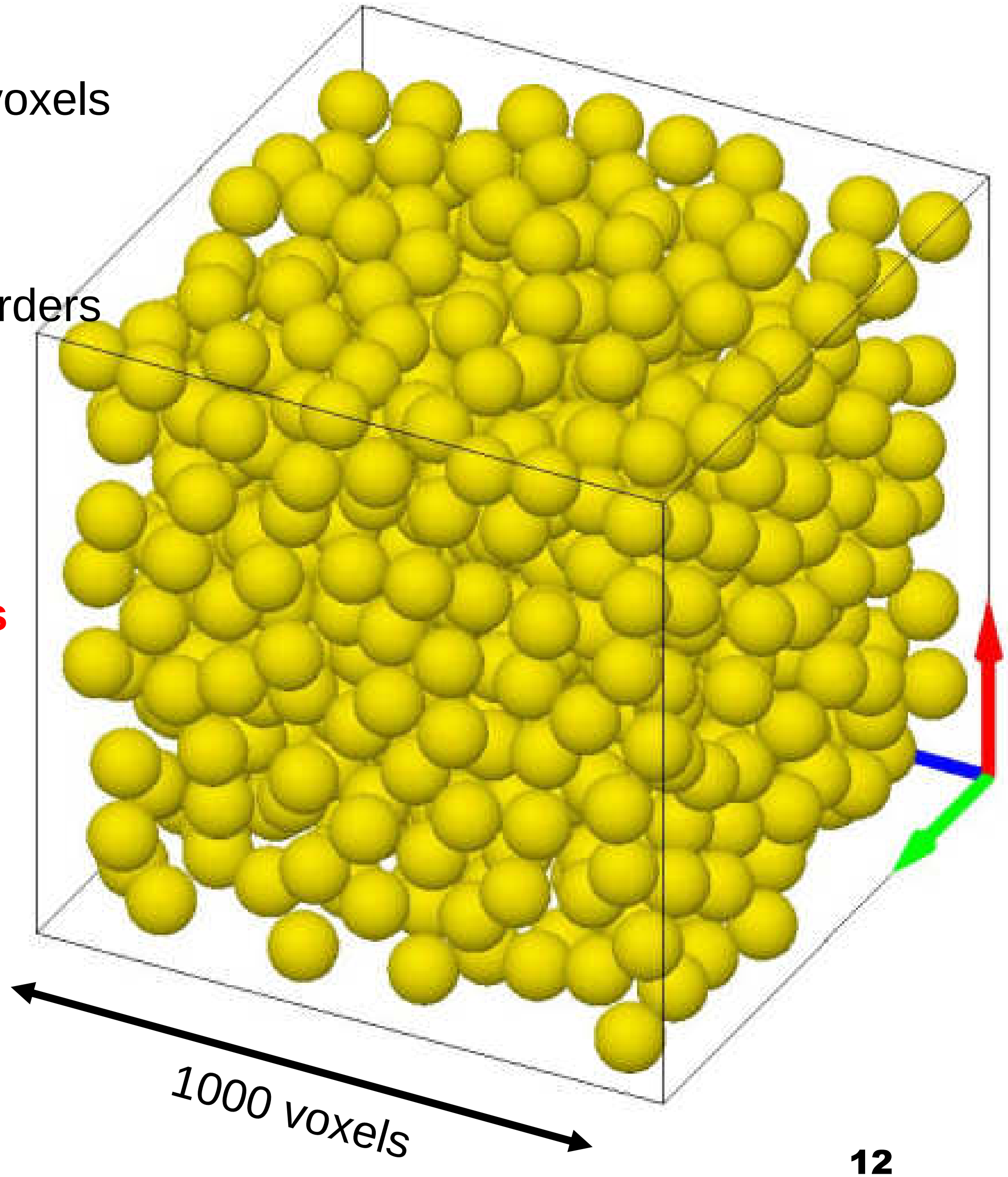
-600 non-overlaping spheres of r = 50 voxels

-Scaling on r

→ density = 288 kg/m^3

→ SSA = 32.72 m^2/kg

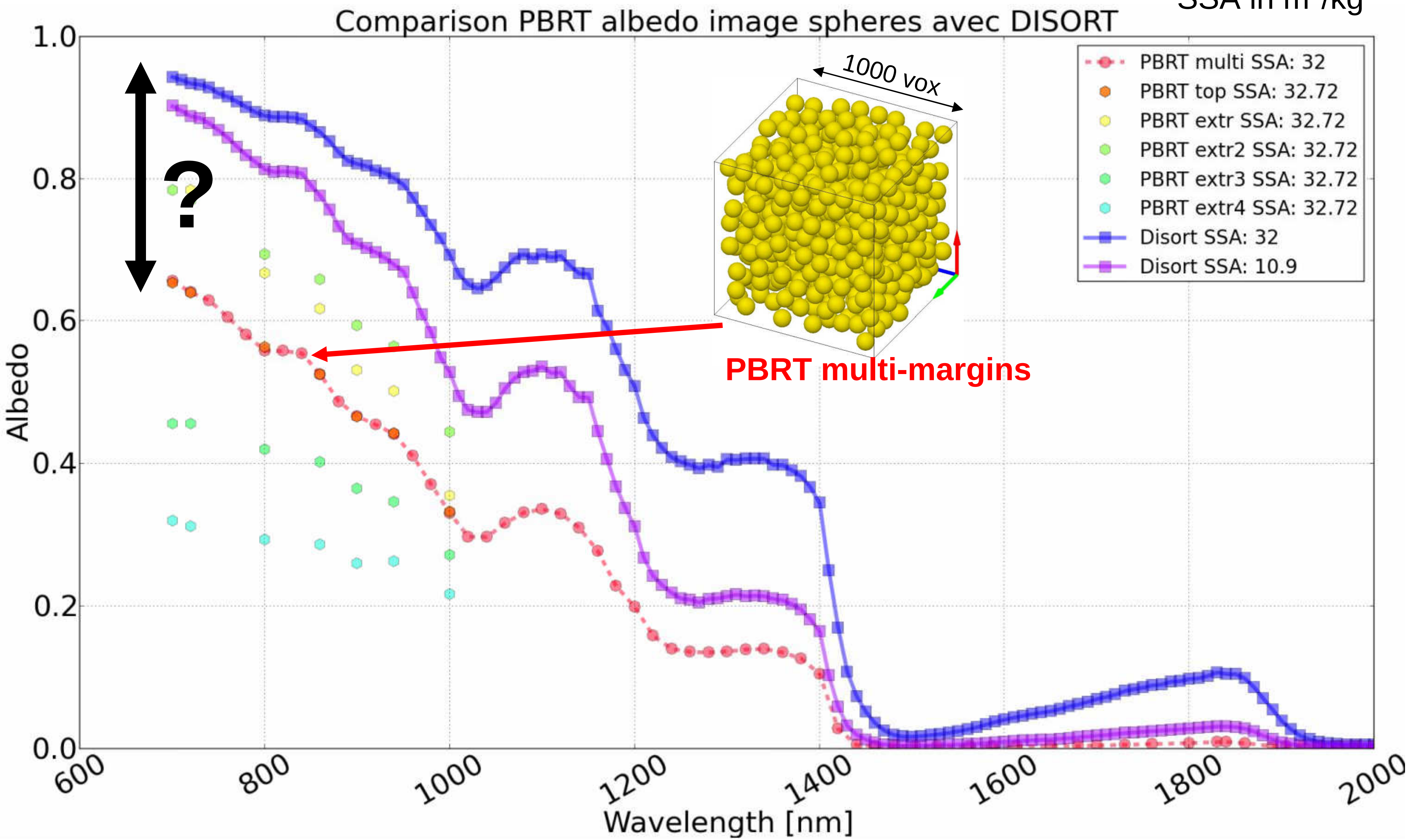
-spheres do not intersect the image borders



PBRT multi-margins

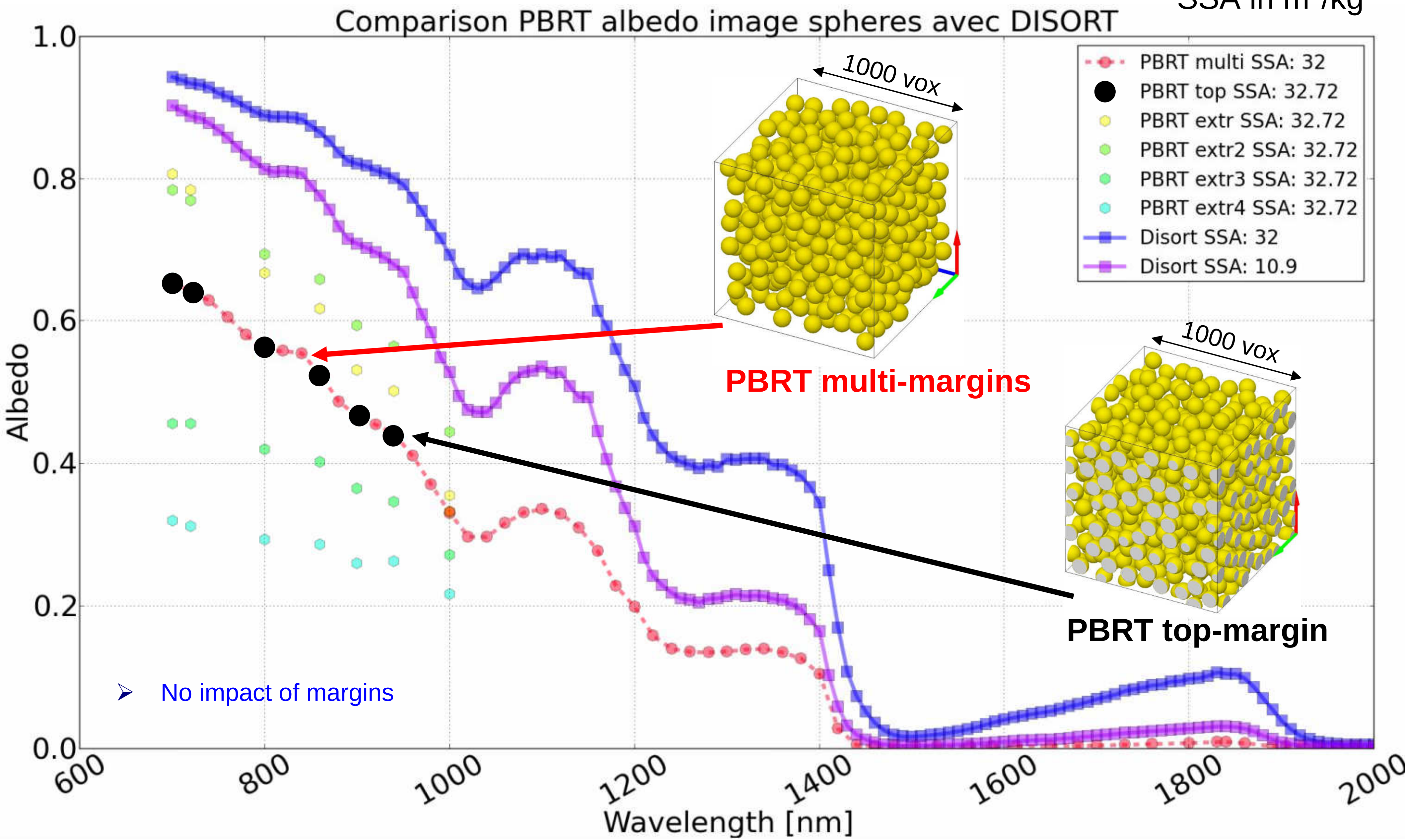
Albedo – DISORT vs PBRT - spheres

SSA in m²/kg



Albedo – DISORT vs PBRT - spheres

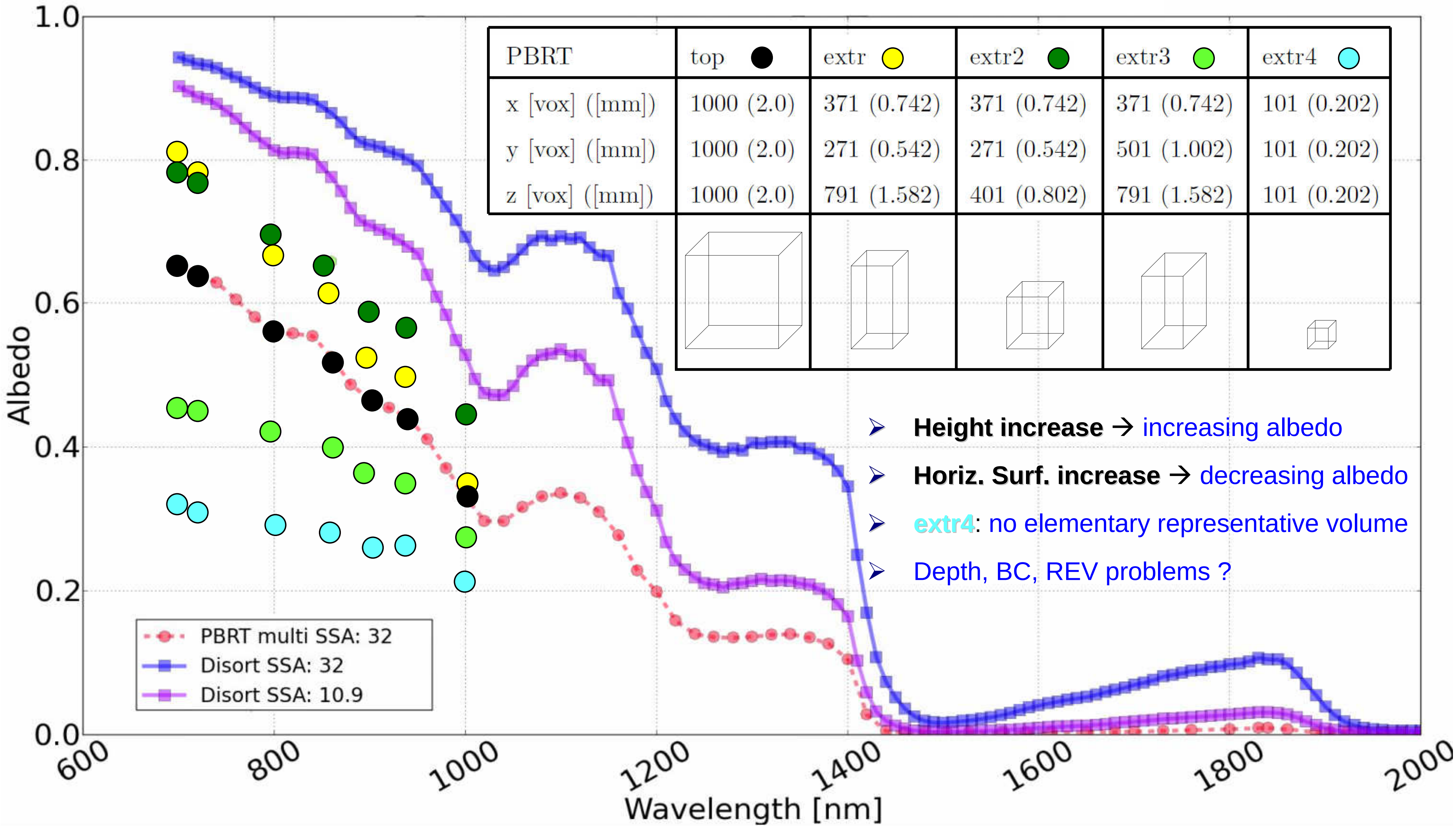
SSA in m²/kg



- No impact of margins

Albedo – DISORT vs PBRT - spheres

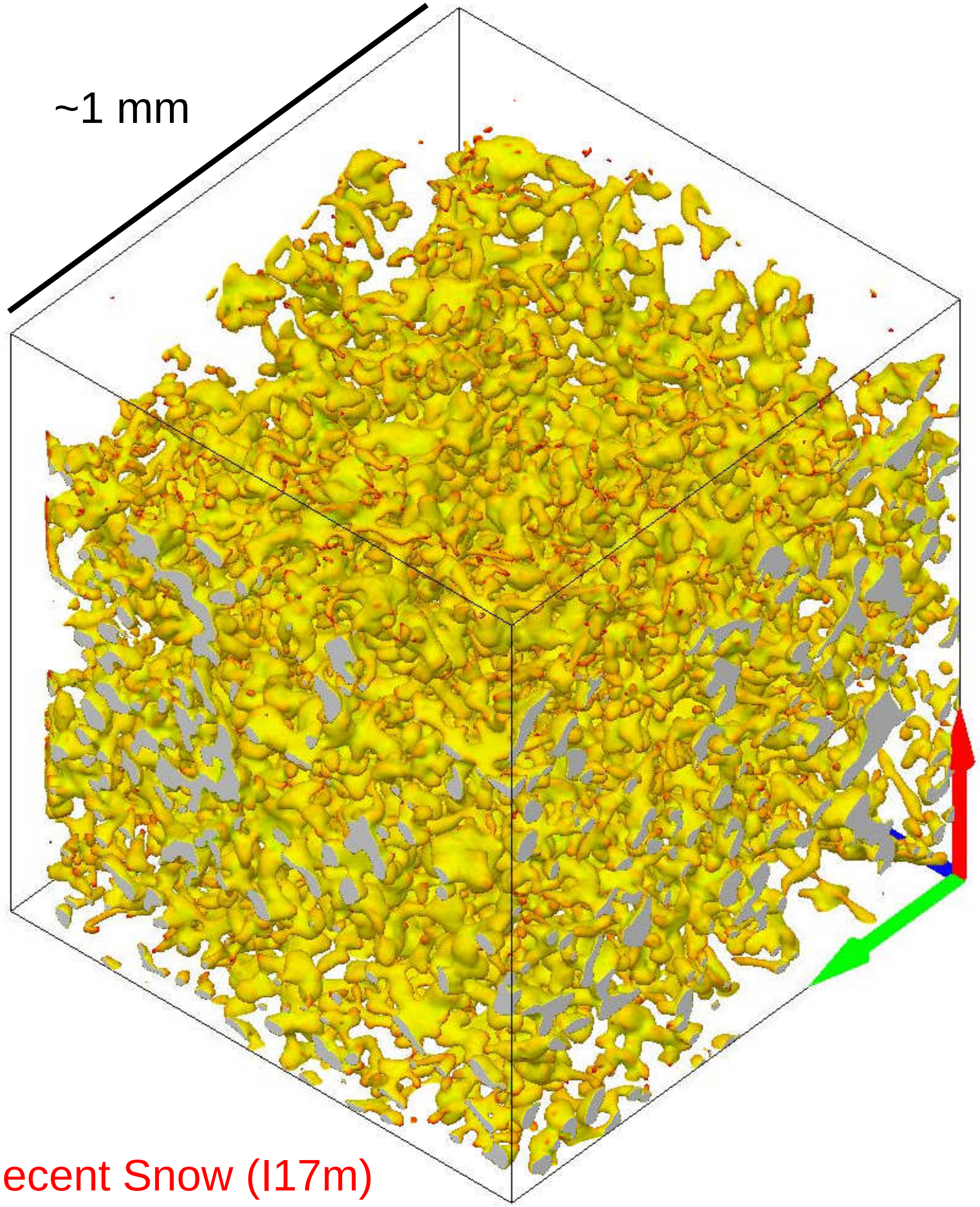
SSA in m²/kg



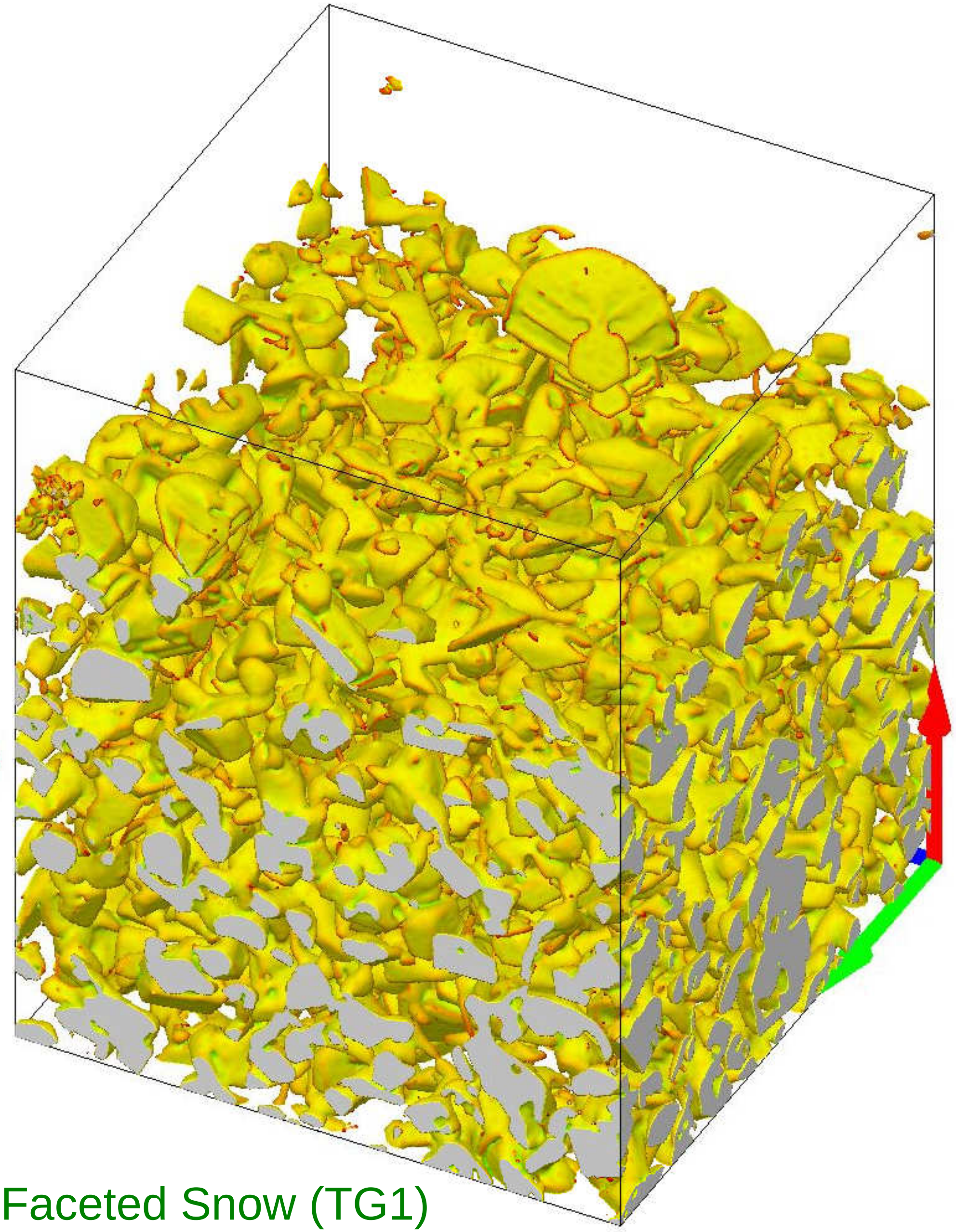
PBRT	top ●	extr ●	extr2 ●	extr3 ●	extr4 ●
x [vox] ([mm])	1000 (2.0)	371 (0.742)	371 (0.742)	371 (0.742)	101 (0.202)
y [vox] ([mm])	1000 (2.0)	271 (0.542)	271 (0.542)	501 (1.002)	101 (0.202)
z [vox] ([mm])	1000 (2.0)	791 (1.582)	401 (0.802)	791 (1.582)	101 (0.202)

- **Height increase** → increasing albedo
- **Horiz. Surf. increase** → decreasing albedo
- **extr4**: no elementary representative volume
- Depth, BC, REV problems ?

Albedo – DISORT vs PBRT - snow

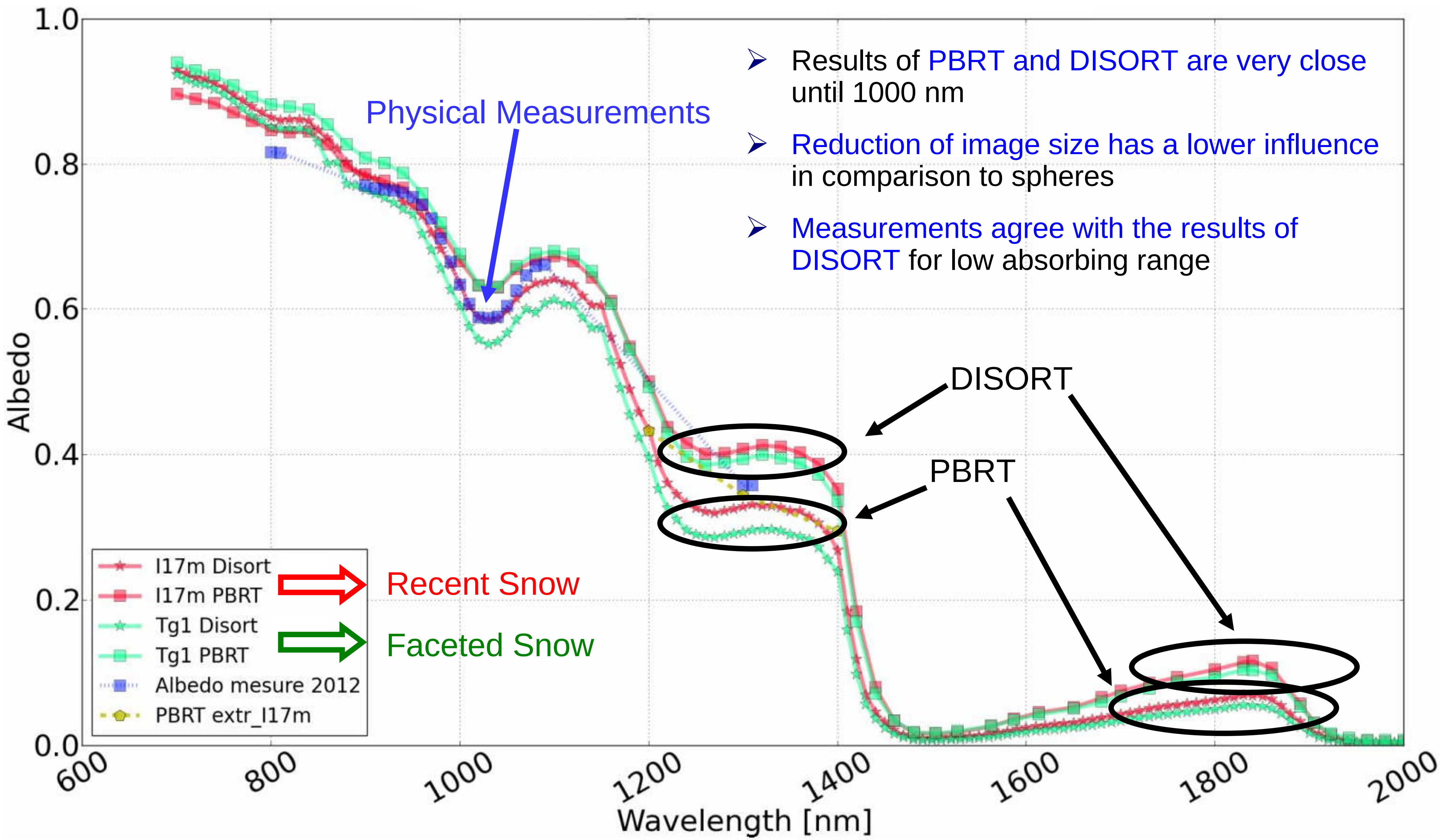


Recent Snow (I17m)



Faceted Snow (TG1)

Albedo – DISORT vs PBRT - snow



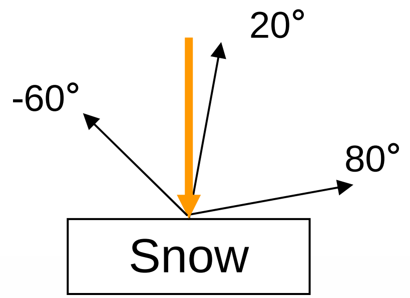
Albedo – DISORT vs PBRT

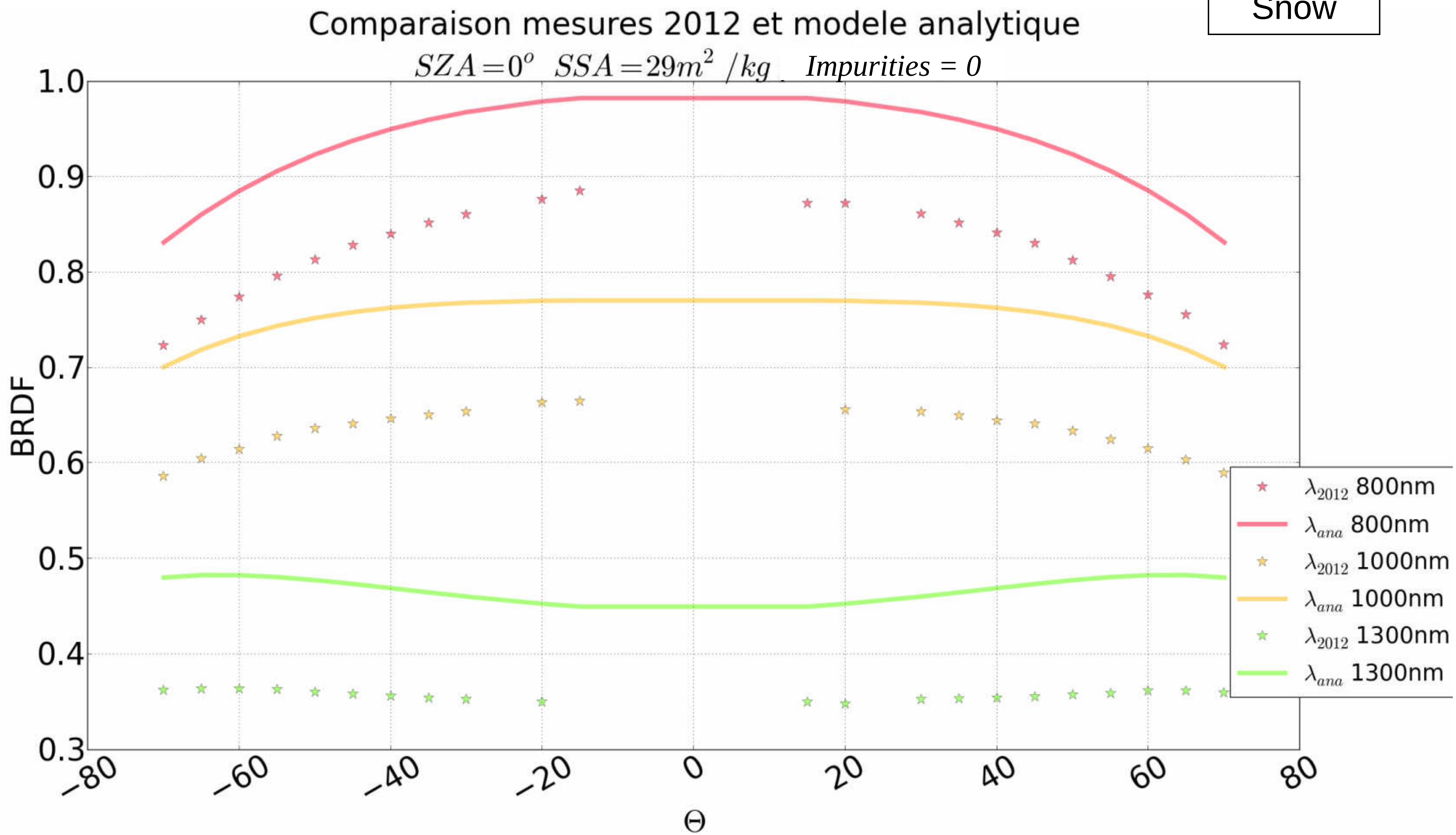
- Results depending strongly on image size
- Tomography images deliver PBRT results closer to DISORT than spheres
- Size effect is stronger for the spheres than for the tomography images
- Measurements confirm DISORT in weak absorbing range

BRDF – Analytical Model vs Measurements

- Influence of impurities (M) was neglected ($\lambda \geq 800$ nm)
- $L = b^2 d$:
  - $d = 6 / (SSA^*\rho)$
  - $b = 3.6$ shape factor for spheres

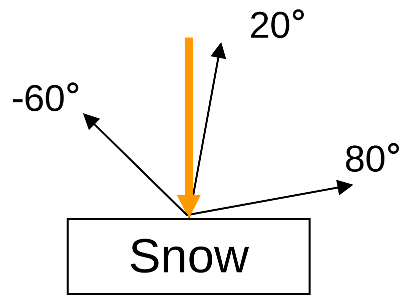
BRDF – Analytical Model vs Measurements

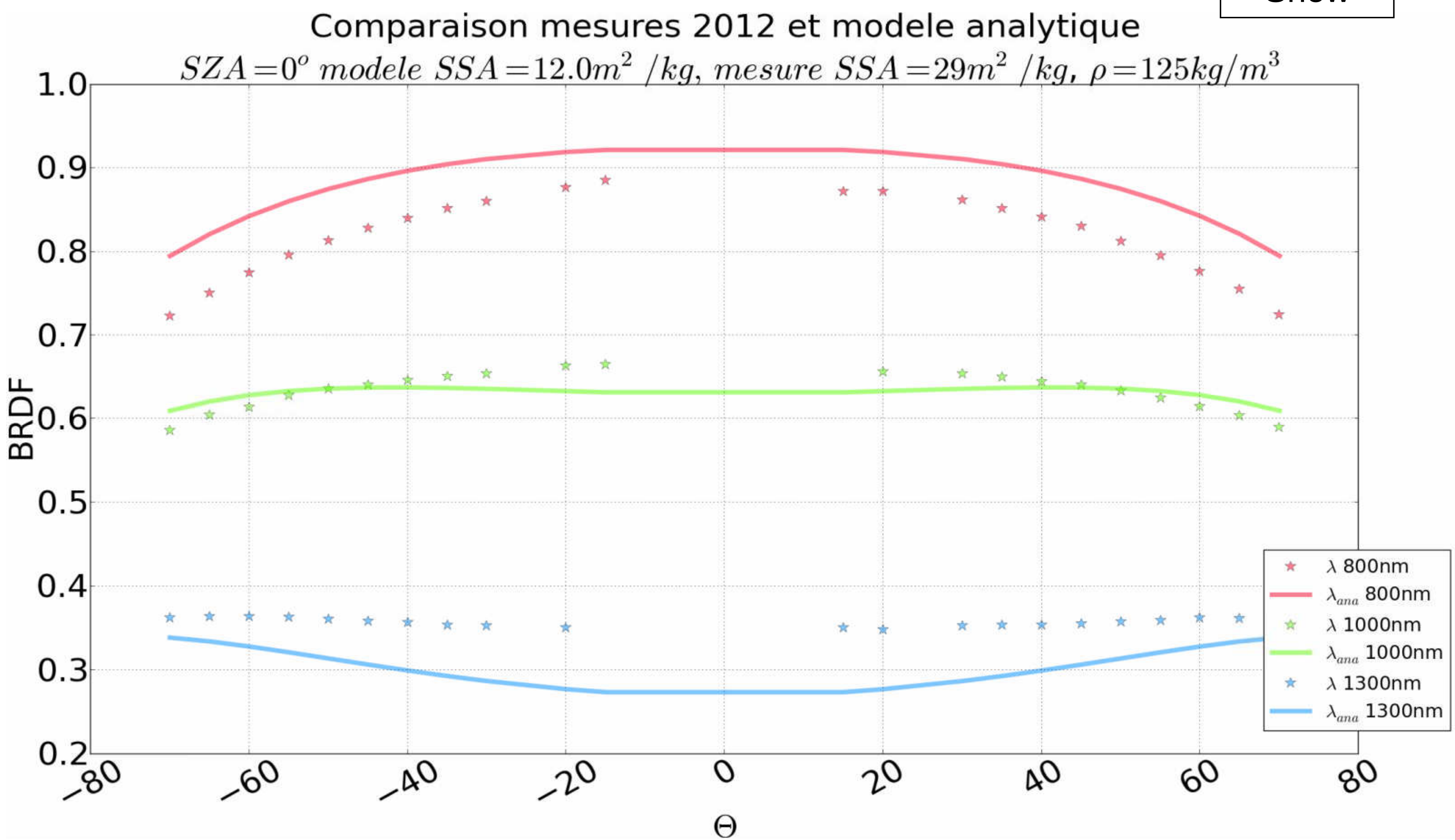




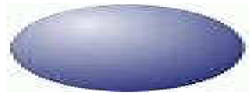
BRDF – Analytical Model vs Measurements

Adjusted using SSA





BRDF – Analytical Model vs Measurements

- Influence of impurities (M) was neglected ($\lambda \geq 800$ nm)
- $L = b^2 d$:
  - $d = 6 / (SSA*\rho)$
  - $b = 3.6$ shape factor for spheres 
  - $b = 5.6$ shape factor for non-spherical grains 

BRDF – Analytical Model vs Measurements

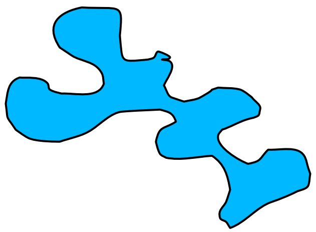
- Strong deviation between model and measurements for spherical shape
- Adaption of the model by varying the shape factor reduces the deviation between model and measurements
- Shape factor for non-spherical grains is in agreement with the real grain shape for recent snow
- Model is more isotropic for 800 nm and 1000 nm, however less isotropic for 1300 nm than the measurements

BRDF – Impact of grain shape

- To investigate the impact of the grain shape the measurements of two different types of snow are compared:

- Recent snow 2012

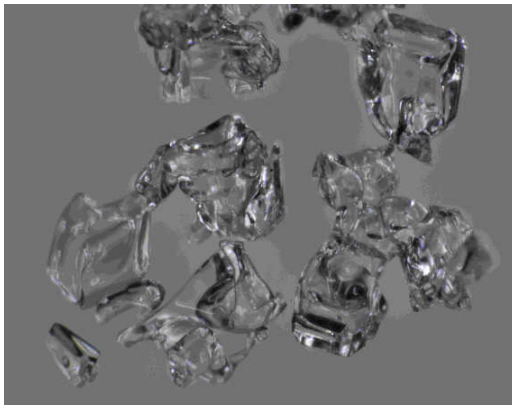
  → rounded shape

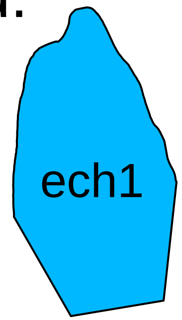


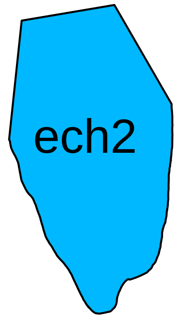
- Faceted snow 2013

  → rounded shape on the top (ech1)

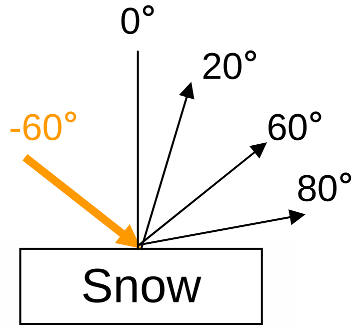
  → faceted shape on the top (ech2)





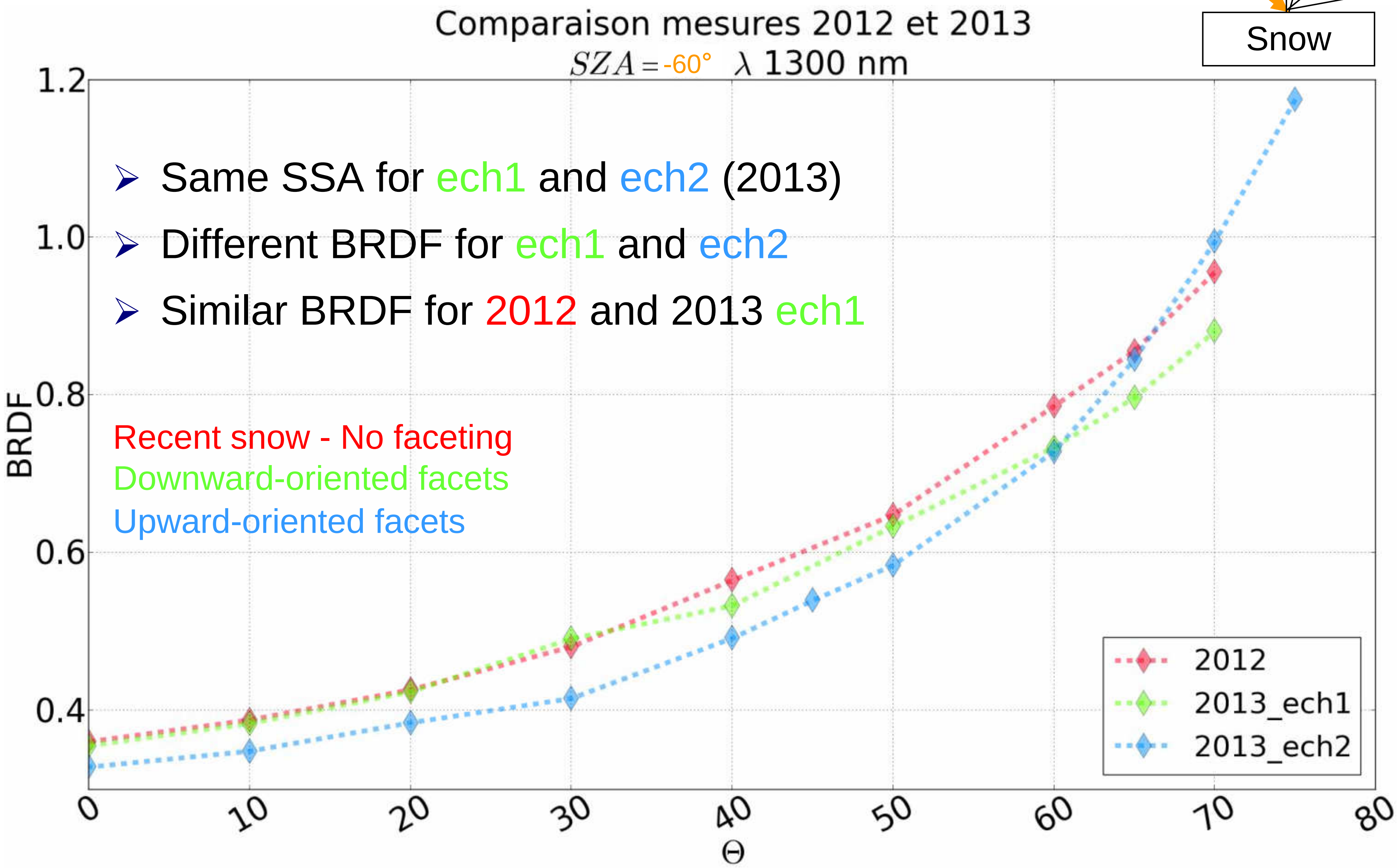


BRDF – Impact of grain shape



- Same SSA for ech1 and ech2 (2013)
- Different BRDF for ech1 and ech2
- Similar BRDF for 2012 and 2013 ech1

Recent snow - No faceting
Downward-oriented facets
Upward-oriented facets



BRDF – Impact of grain shape

- For the same SSA but different grain shape different BRDF values were measured
- In the case of similar grain shape but different SSA values similar BRDF values were measured
- Very strong diffusion in forward direction was observed for the sample with facetted grains on the top compared to the results for rounded grains

Conclusion and outlook

DISORT:

- Confirmation of DISORT albedo modeling for low absorbing range (900 – 1100 nm) with measurements

PBRT:

- PBRT could not be validated → strong size dependence
- Outlook:
  → Investigation of surface size and depth impact
  → Find a representative elementary volume
  → Influence of the amount of photons
  → Testing the influence of impurities

Conclusion and outlook

Analytical model:

- Could not describe the measurements
- Adjusting the shape factor led to a better result
- Very high anisotropy of the model for the wavelength 1300 nm compared to the measurements (out of validity range)

Conclusion and outlook

Impact of grain shape on BRDF:

- The impact of the shape on the BRDF was found to be strong
- For the faceted snow on top a very strong forward diffusion, compared to recent snow and faceted grains oriented to the bottom, was observed.

  → could be a key to characterize the degree of metamorphism for faceted snow

Bibliography

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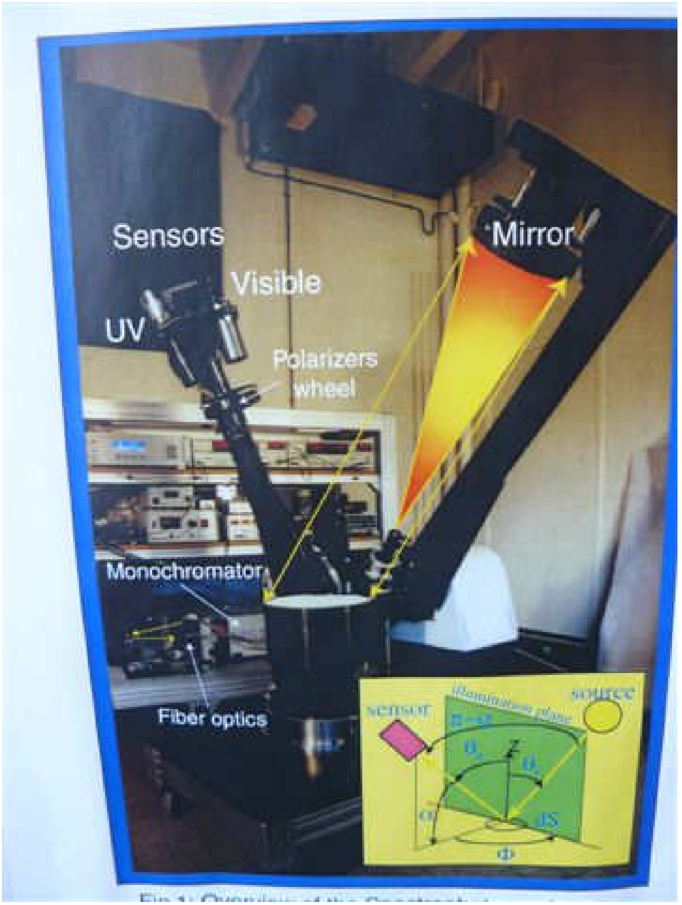
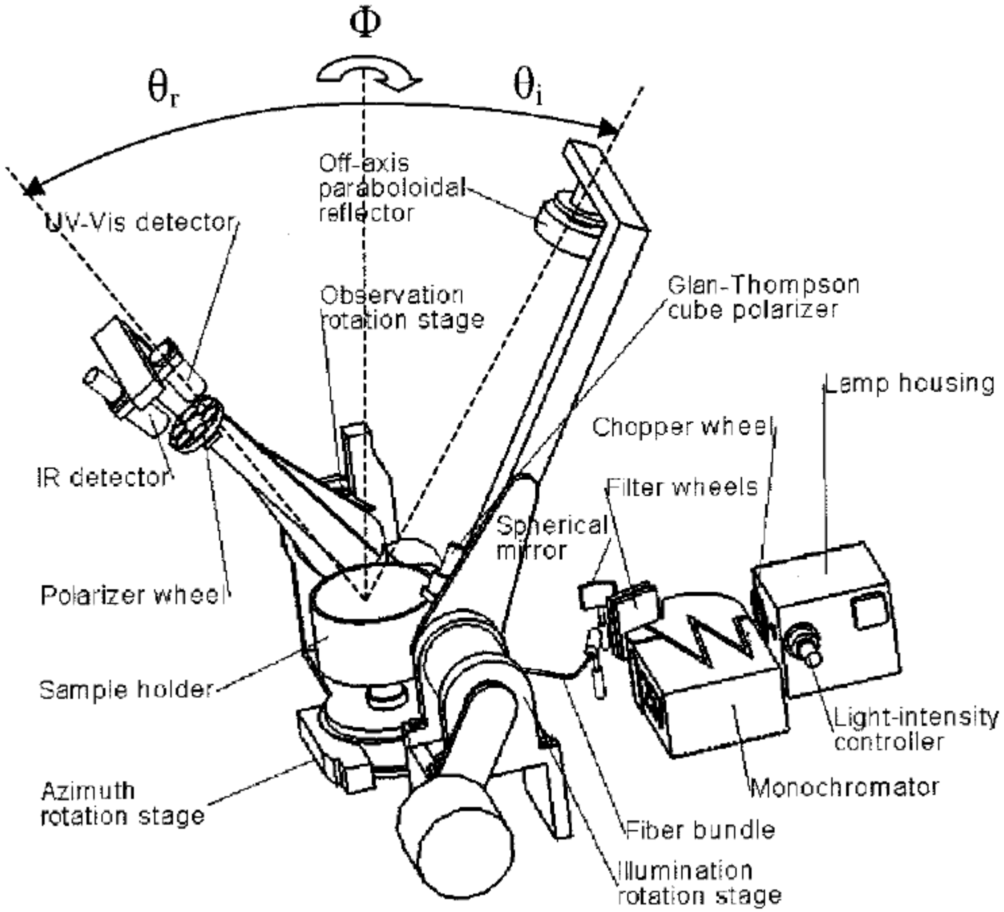
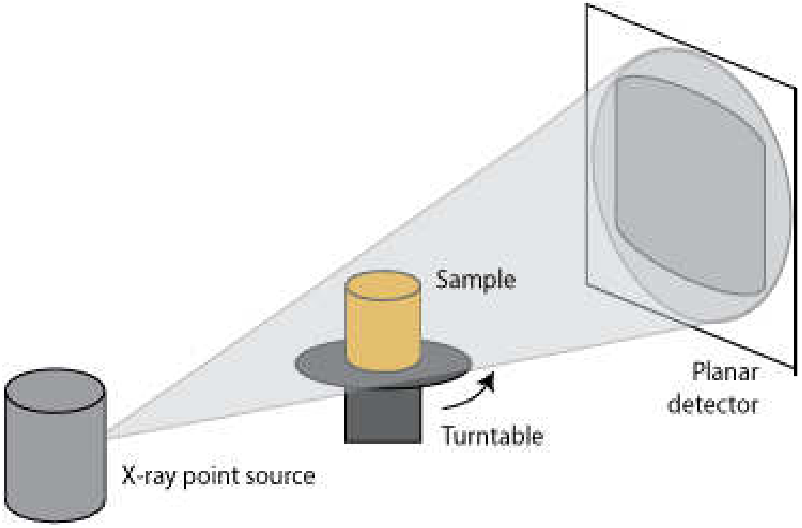
- Kaempfer, T., Hopkins, M., and Perovich, D. : A three-dimensional microstructure-based photon-tracking model of radiative transfer in snow, Journal of Geophysical Research : Atmospheres (1984–2012), 112, 2007.
- Picard, G., Brucker, L., Fily, M., Gallée, H., and Krinner, G. : Modeling time series of microwave brightness temperature in Antarctica, J. Glaciol., 55, 537 – 551, 2009.
- Haussener, S., Gergely, M., Schneebeli, M., and Steinfeld, A. :Determination of the macroscopic optical properties of snow based on exact morphology and direct pore-level heat transfer modeling, Journal of Geophysical Research : Earth Surface (2003–2012), 117, 2012.

Spectrometer



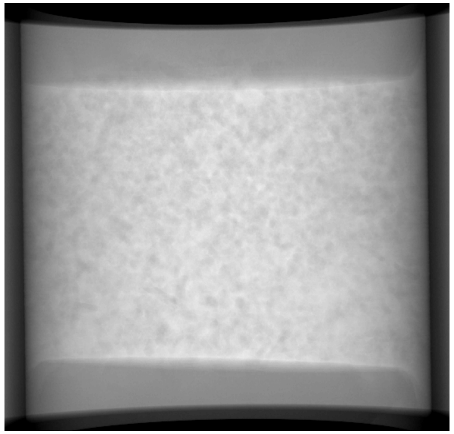


Obtention of 3D images by X-ray tomography



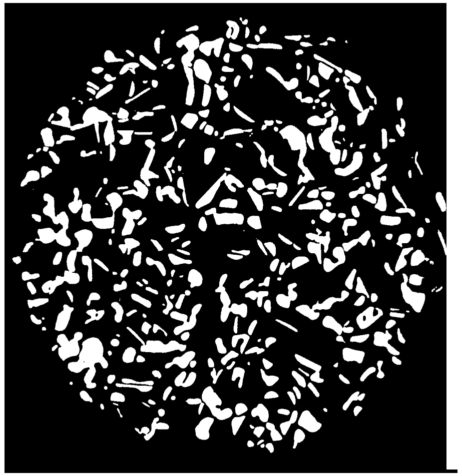
Principle of X-ray tomography

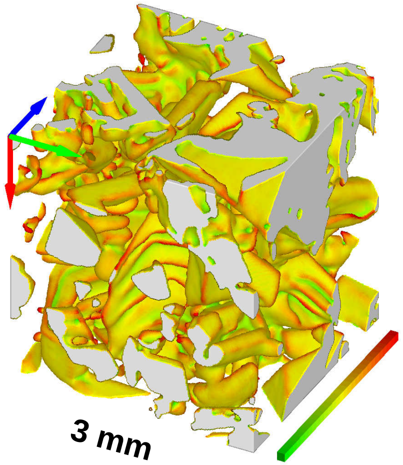
Tomography



Several radiographies of the sample at different angular positions

Thresholding and image processing





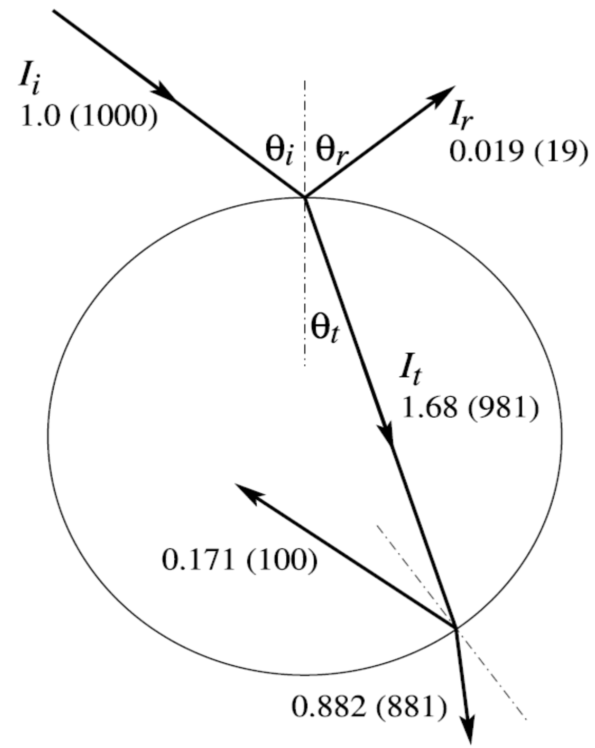
3D binary image of the sample
→ Resolution between 7 and 9 µm

DISORT

- Exact solution of radiative transfer equation, continuous medium
- Inputs are single scattering properties
    - Log normal distribution:
        - Logarithm of radius of spheres is normally distributed
    - Mie scattering:
        - elastic scattering of el. magnetic waves by spheres
        - size of particles in range of wavelength

Photon tracking model PBRT

- Adapted to tomography images by R. Malgat and D. Coeurjolly (LIRIS,DigitalSnow Project)
- Interaction between ray and snow grains are governed by Snell's and Fresnel's law as well as the absorption law of Bouguer – Lambert
- Probability of reflected or transmitted photon deduced from ratio of Fresnel's law of reflected and incident radiance and a Monte-Carlo based calculation of a random number between 0 and 1
- Number > I_r/I_i → reflection
- Number < I_r/I_i → transmission



Analytical Model

- Based on single scattering phase function
- Takes into account directional signatures
- Valid for weakly absorbing range (ice <1,24 µm)