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Met Office

Laboratory measurements and modelling of the scattering properties of hollow and solid ice crystals

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Why Ice Clouds?

- IPCC concluded that clouds are the biggest uncertainty in predicting climate change (2013)
- Ice clouds have a large range of crystal shapes and sizes
- Global coverage of ~30%

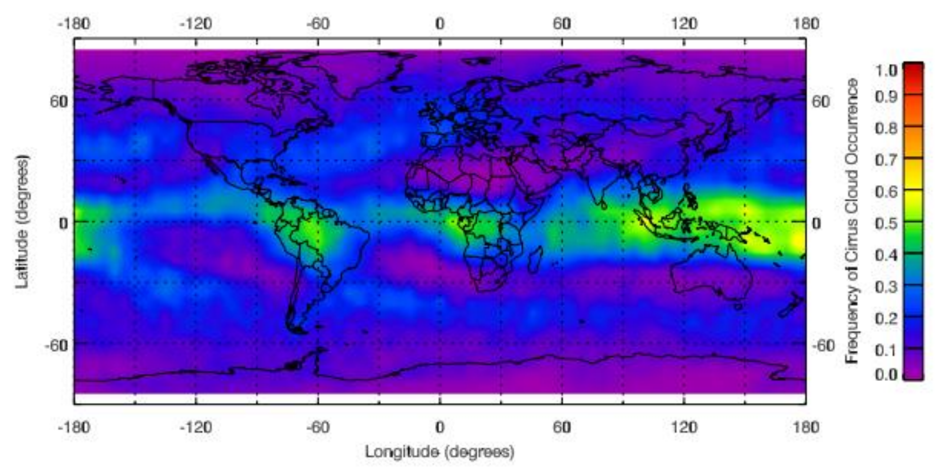
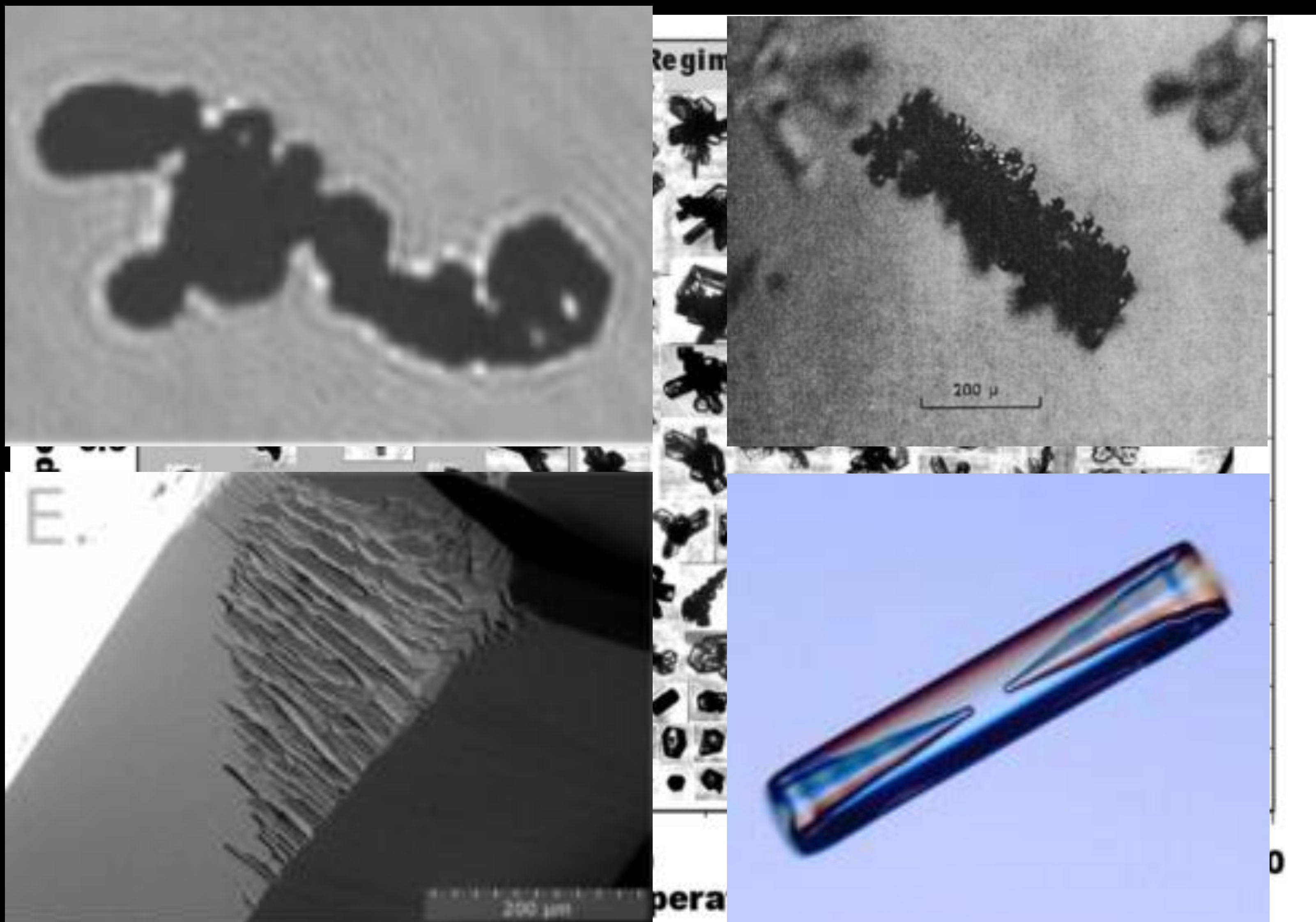


Image from: Sassen et al. 2008, J. Geophys. Res. 113 doi:10.1029/2008JD009972,

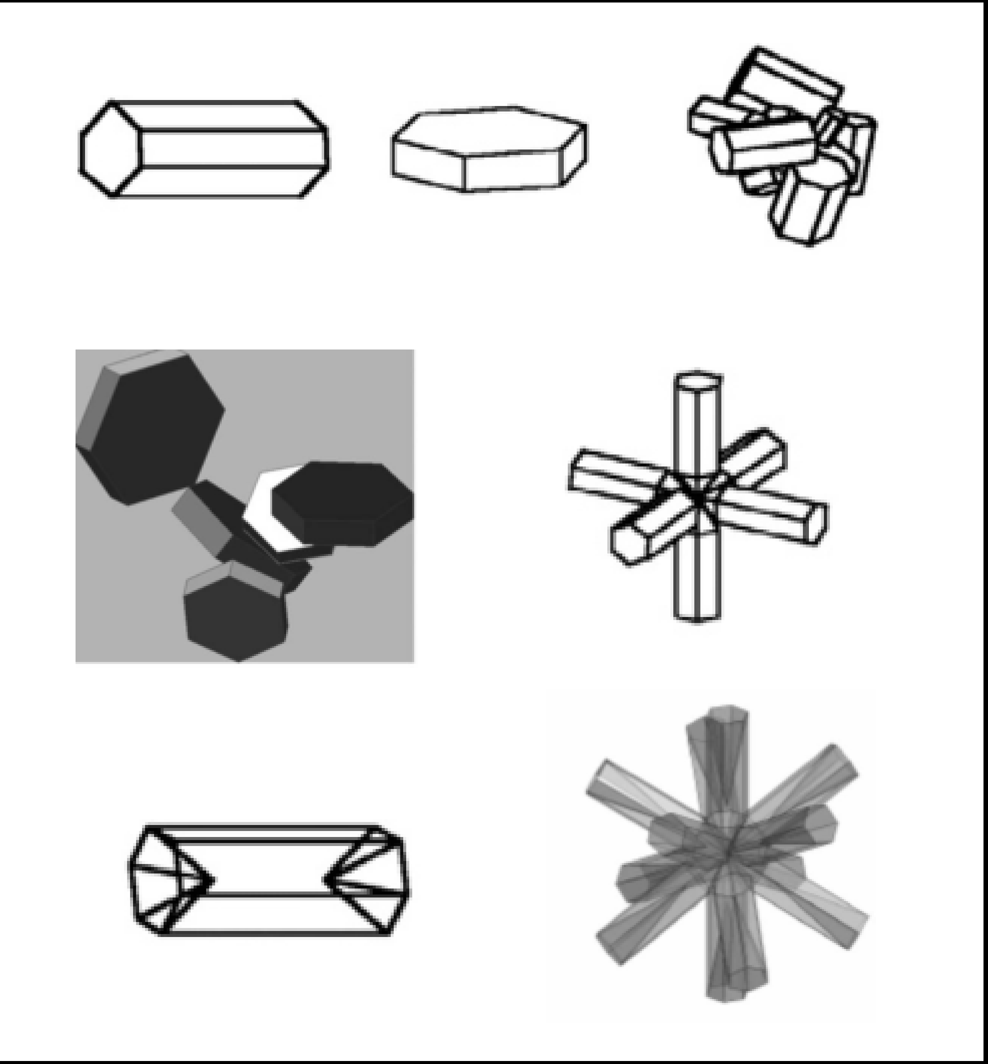
Ice Crystal Habits



Images from: Connoly et al, 2005, QJRMS, doi: 10.1256/qj.03.217, Ono et al 1927, Pfalzgraff et al, 2010 , ACP, doi: 10.5194/acp-10-2927-2010
and http://www.its.caltech.edu/~atomic/snowcrystals/class/class.htm Image from Bailey and Hallet, 2009, J. Atmos. Sci. 66 doi: 10.1175/2009JAS2883.1

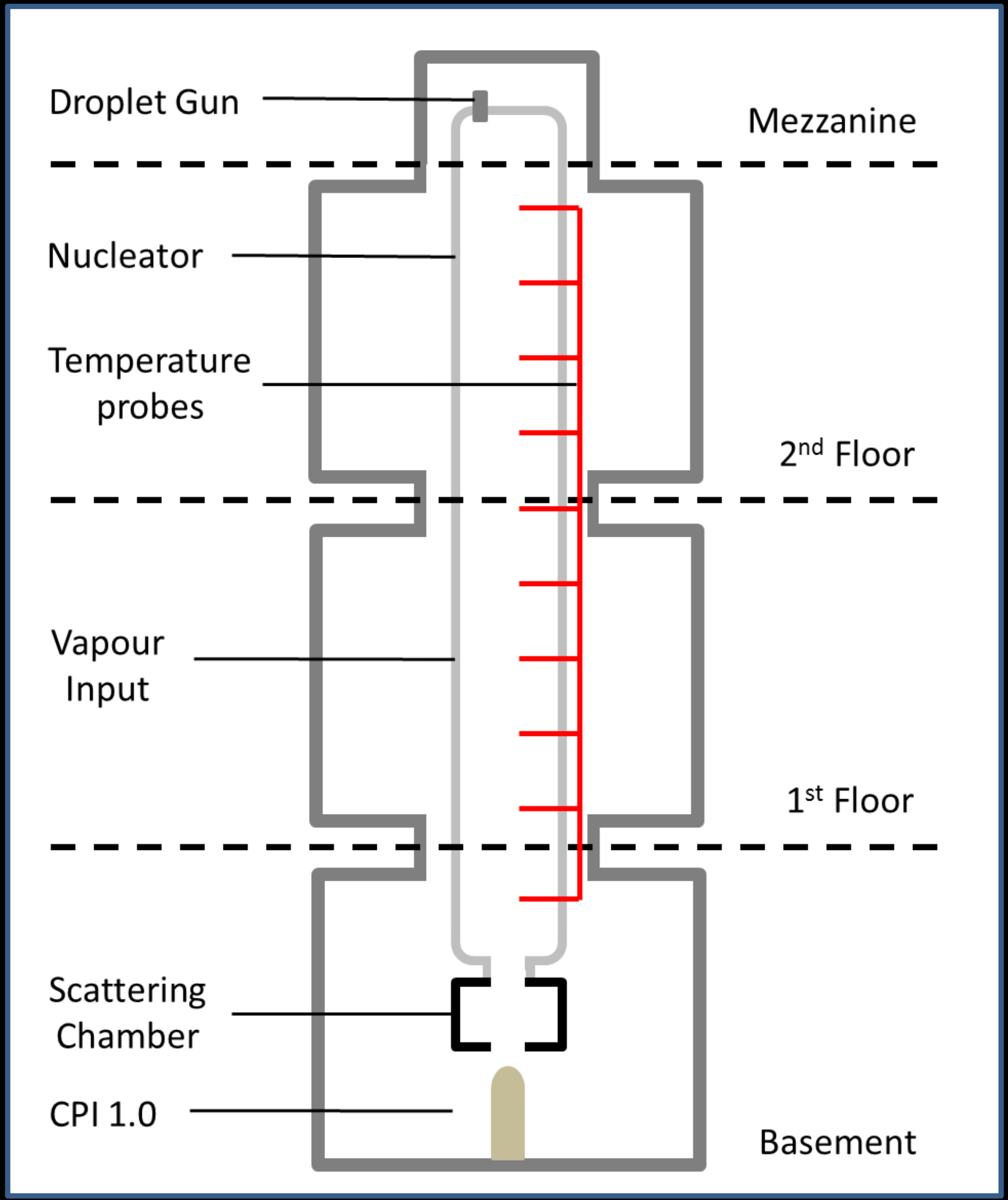
Ice Particles In Scattering Models

- Real ice particles represented by simplified models
- Habit mixture models are commonly used, including hollow particles
- Featureless phase functions are sought

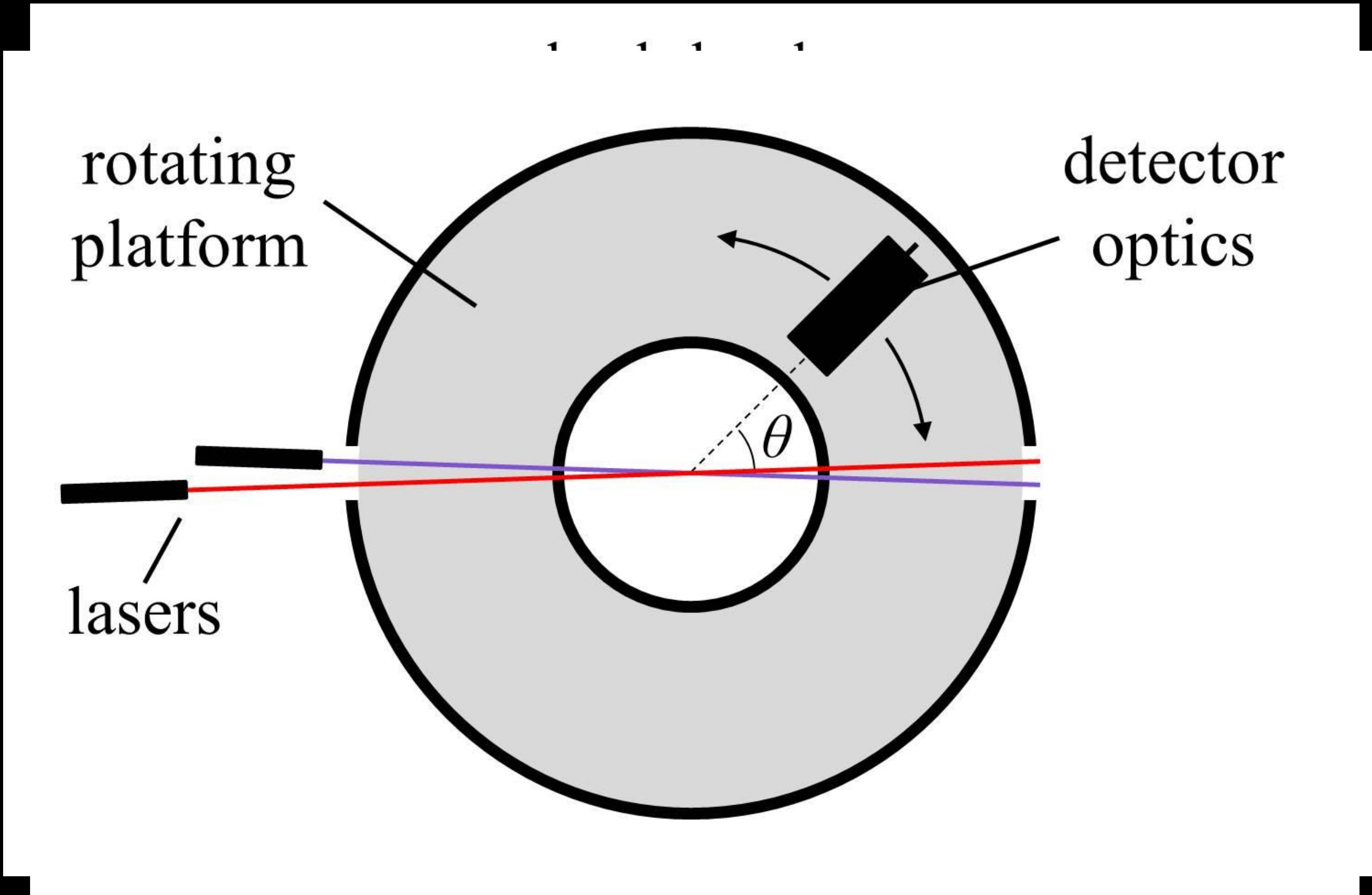


Particle geometries from the Baum et al. 2011 mixture model. Hollow bullet rosette from Yang et al, 2008, JAMC doi:10.1175/2008JAMC1905.1

The Manchester Ice Cloud Chamber



Scattering Chamber

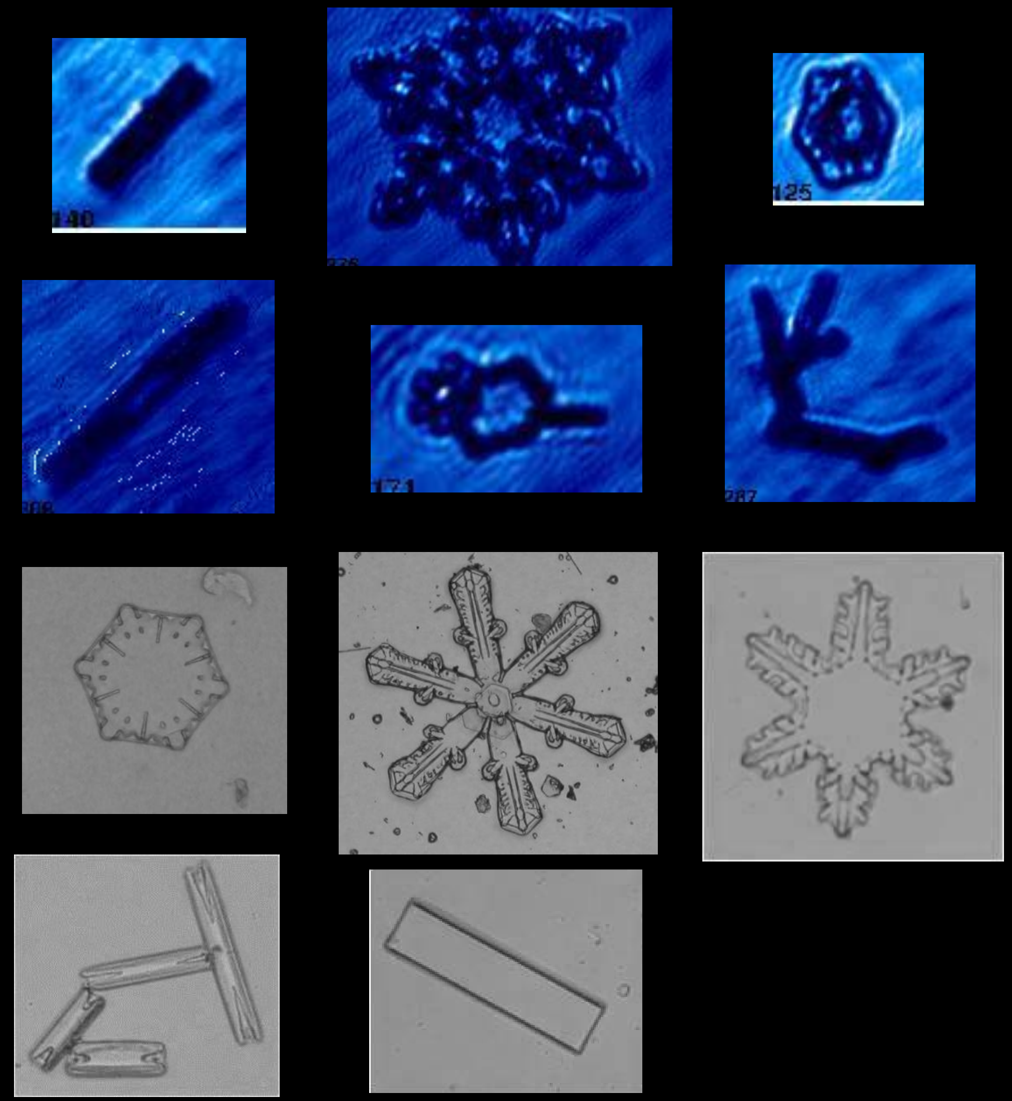


What we measure

- We are measuring the intensity of the scattered light from an *ensemble* of particles
- We measure between 0^{o} and 150^{o}
- To get the *phase function*, we need to know the full 0^{o}-180^{o} range
- We use suitable modelled data to ‘fill in the gap’ – data is then normalised to get P_{11}
- The normalised data is used to find the *asymmetry parameter, g*

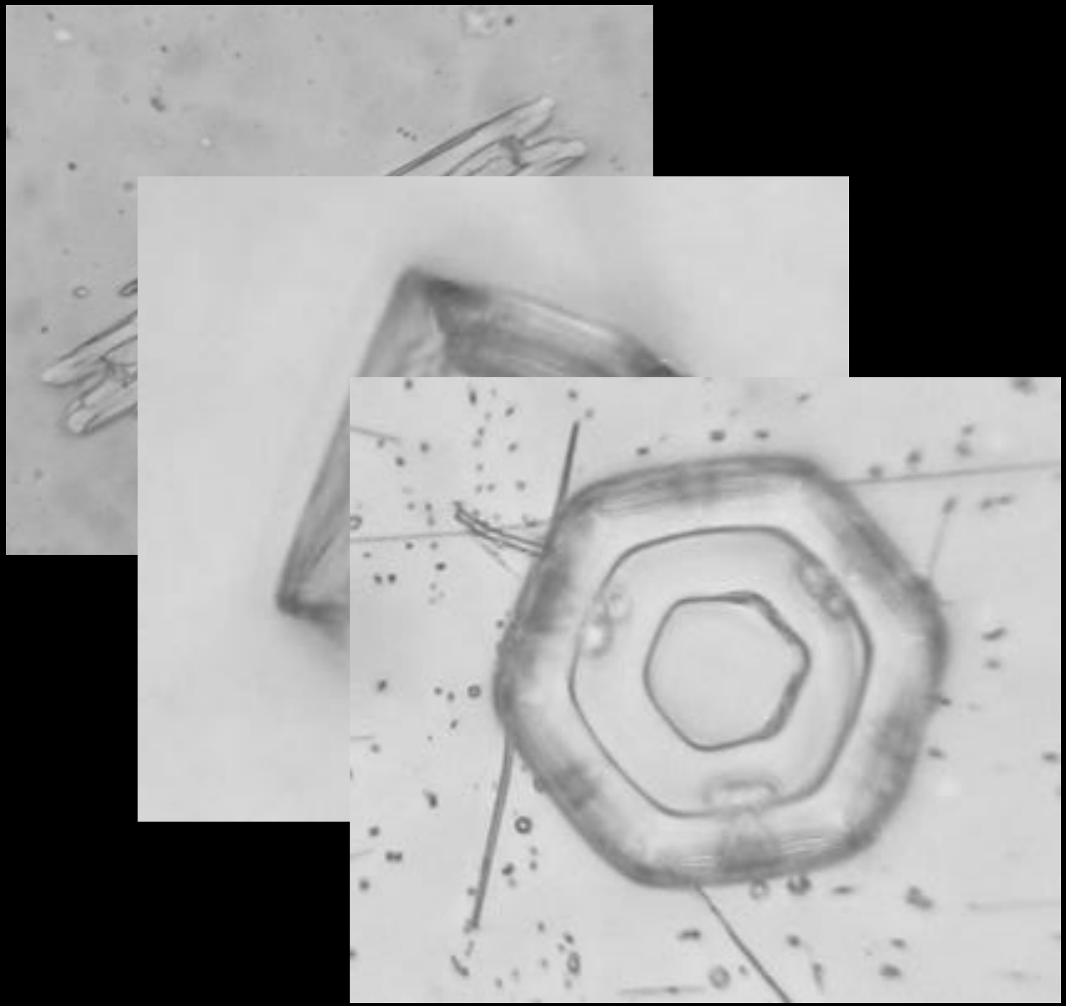
Cloud monitoring

- The Cloud is monitored using a Cloud Particle Imager (CPI)
- Formvar replicas are also taken throughout the course of the experiment , giving additional insight into internal structure



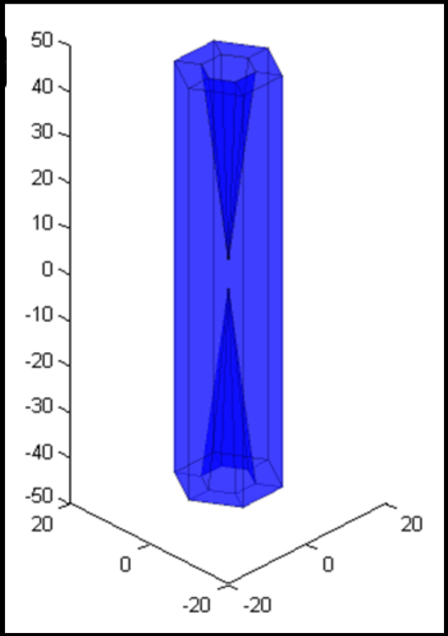
Findings from the Formvar Replicas

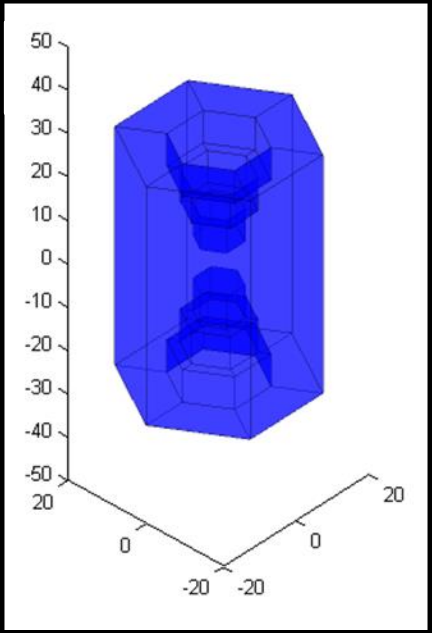
- Different internal structures found at -7°C and -30°C
- ‘warm’ structure similar to current particle models
- ‘cold’ structure more complex

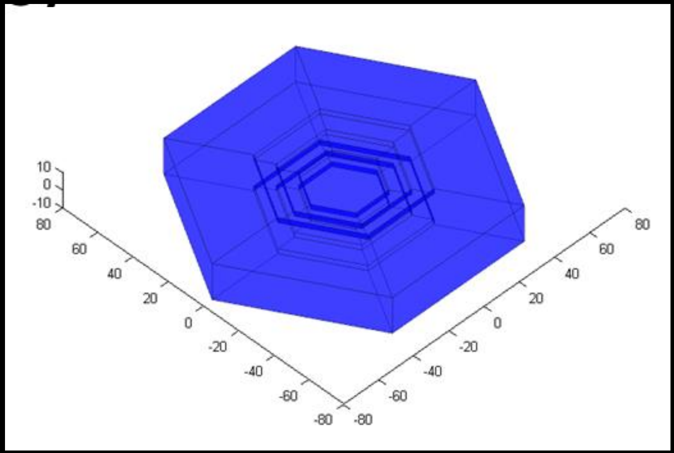


Particle models

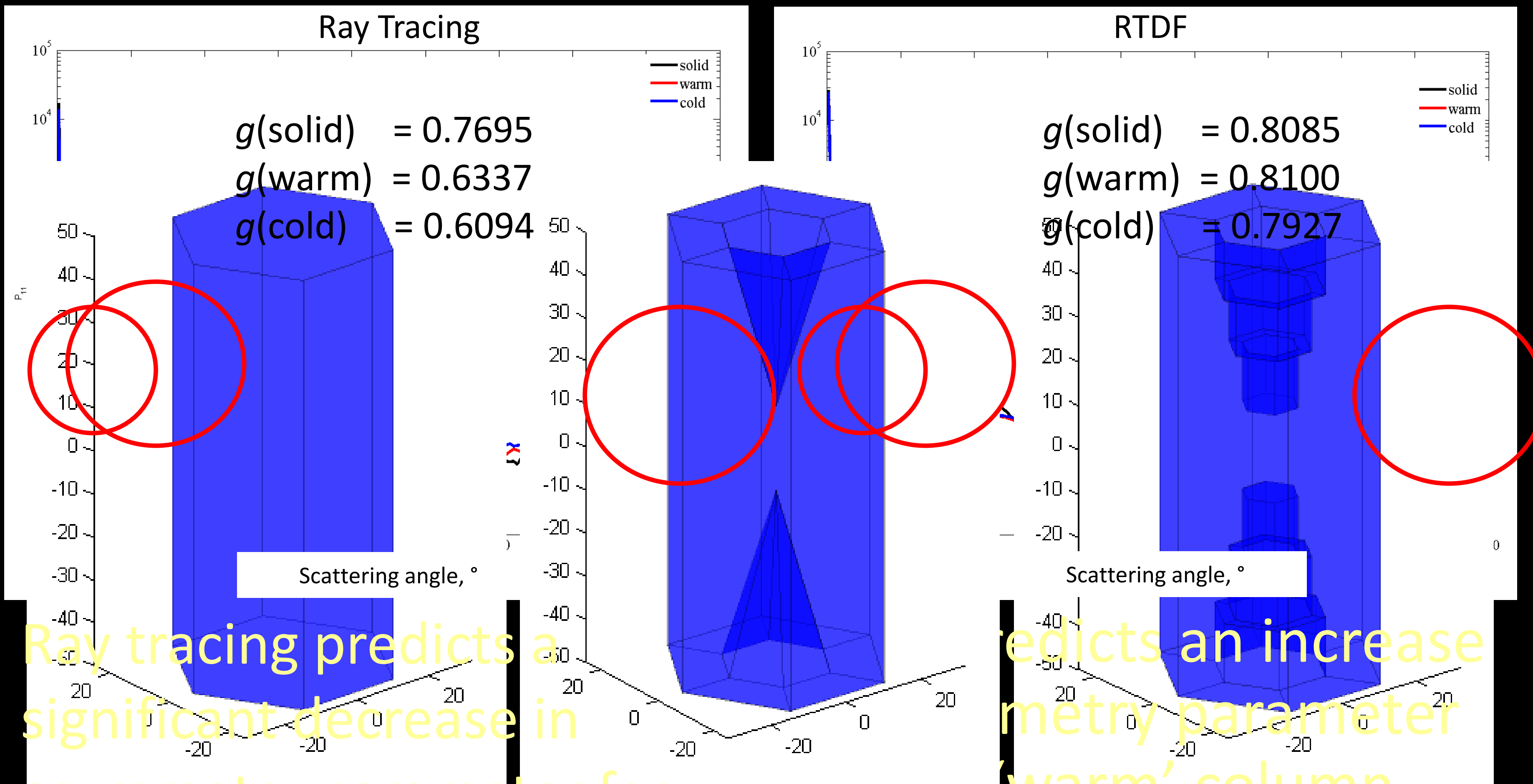
- ‘Warm’ column cavity represented by hexagonal based pyramid
- ‘cold’ column cavity represented by a series of hexagonal stepped intrusions
- Hollow plates also represented using the ‘cold’ coumn intrusion







Theoretical results



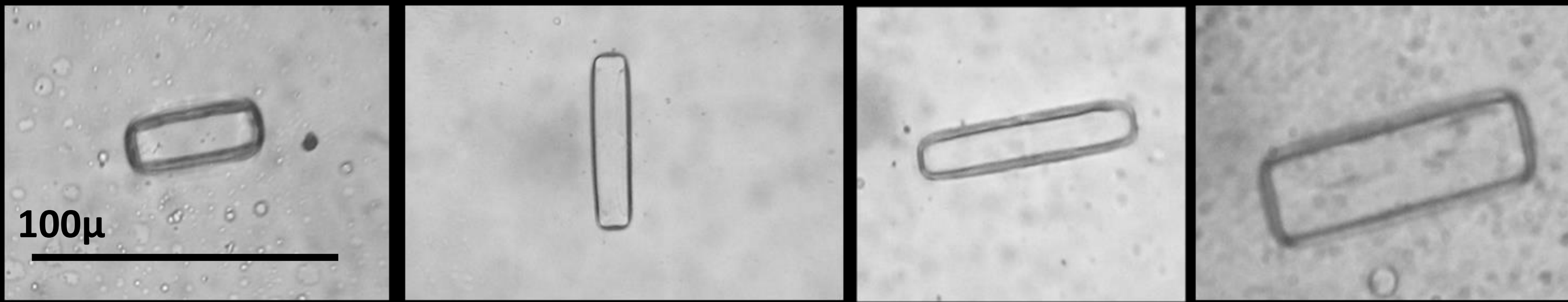
Ray tracing predicts a significant decrease in asymmetry parameter for both hollow crystals

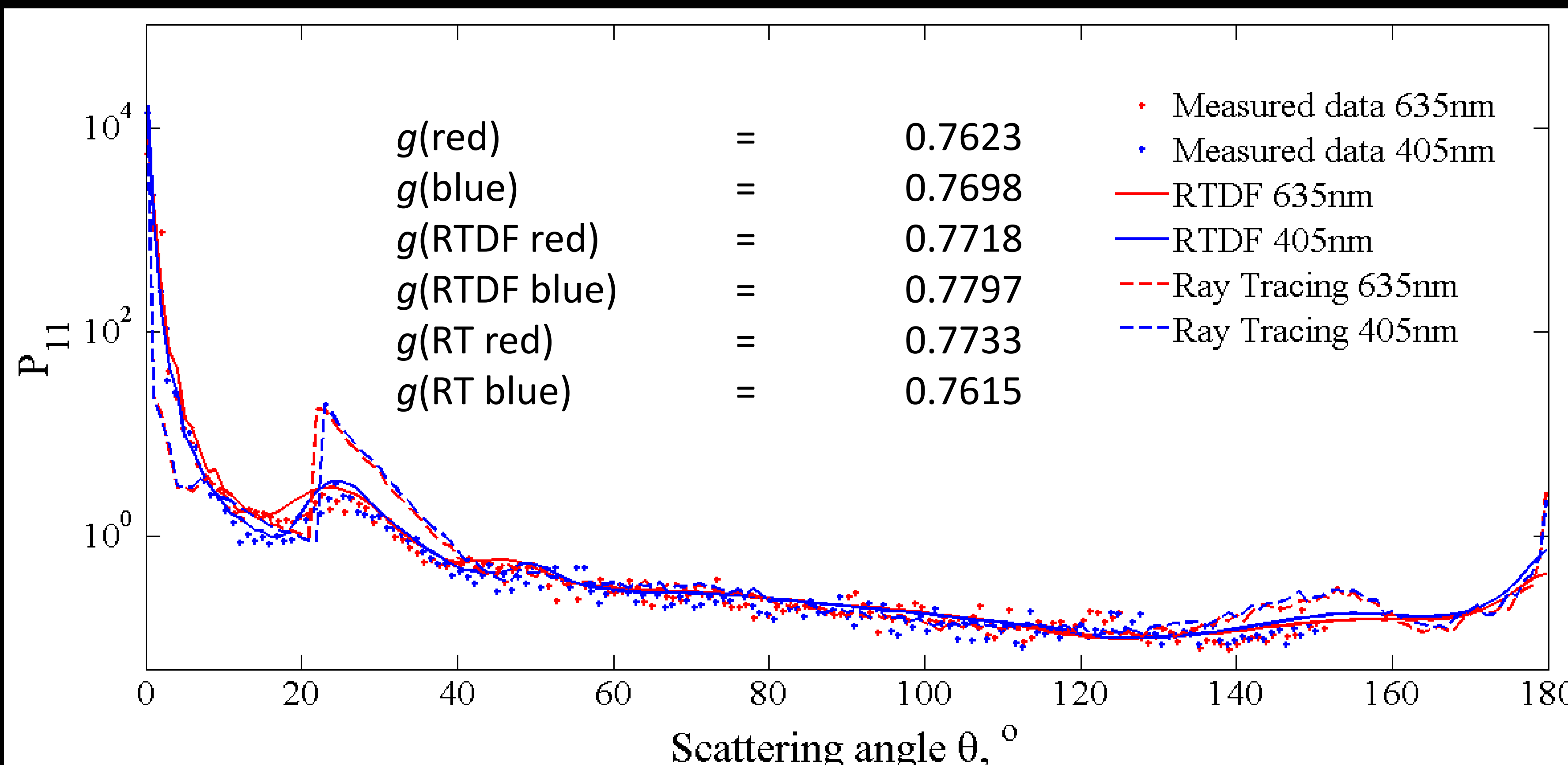
…edicts an increase …metry parameter for the 'warm' column, but a decrease for the 'cold' column

'Solid' 'Warm' 'Cold'

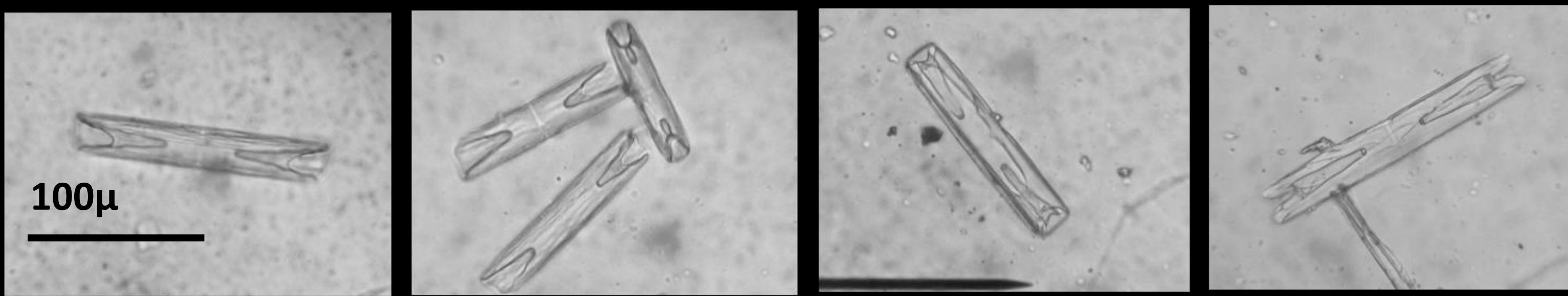
Acknowledgements: with thanks to Evelyn Hesse for RTDF calculations

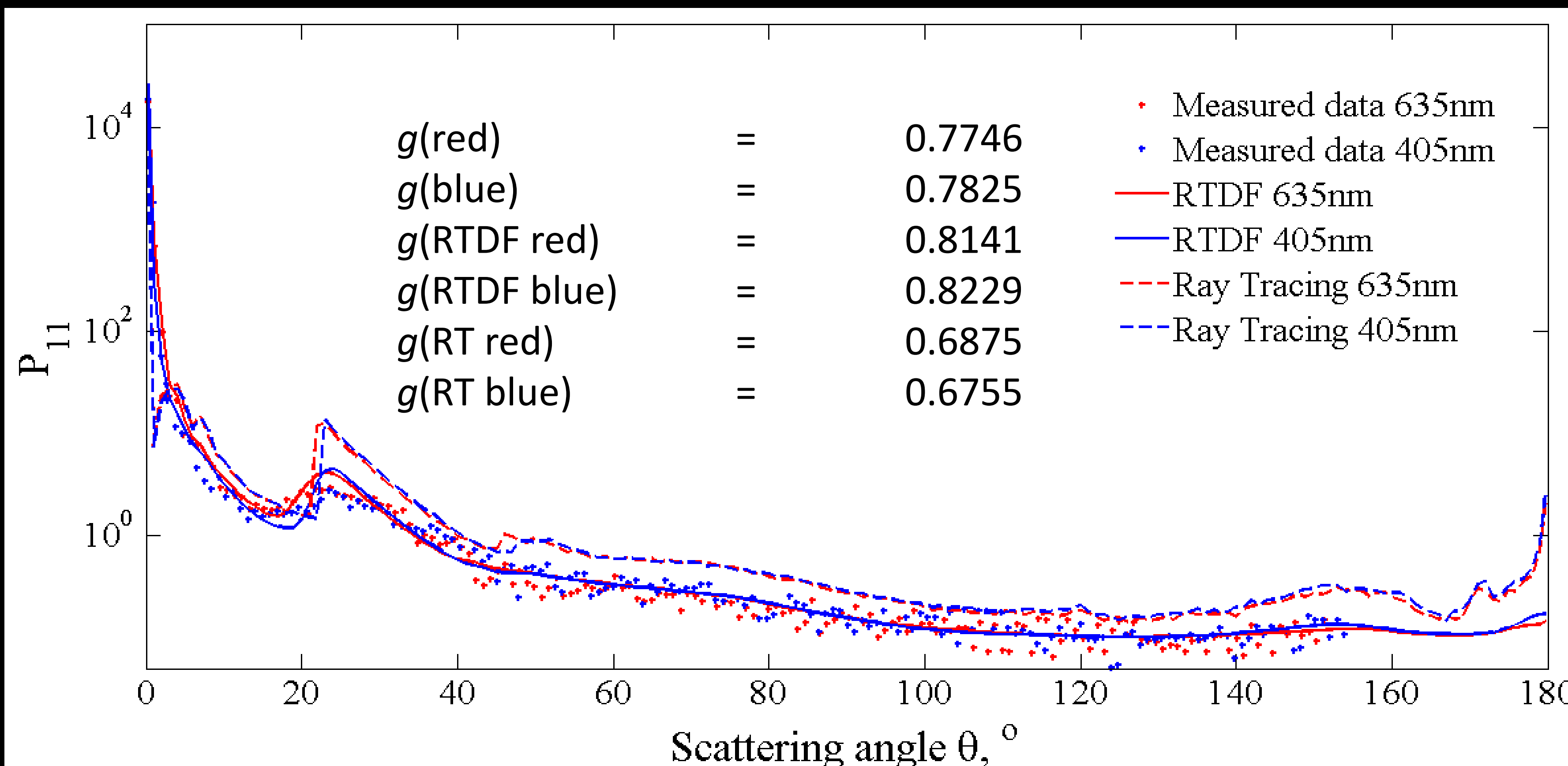
Measured results -7ºC solid columns



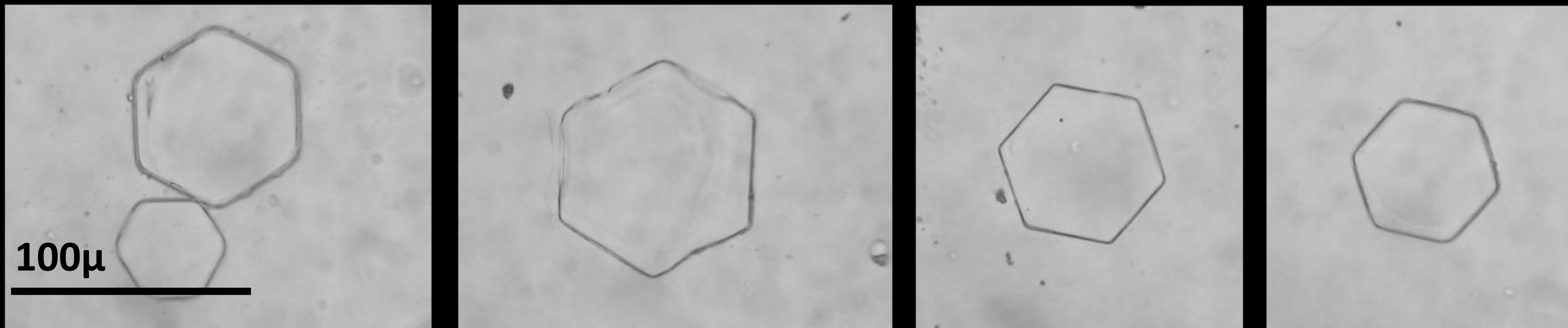


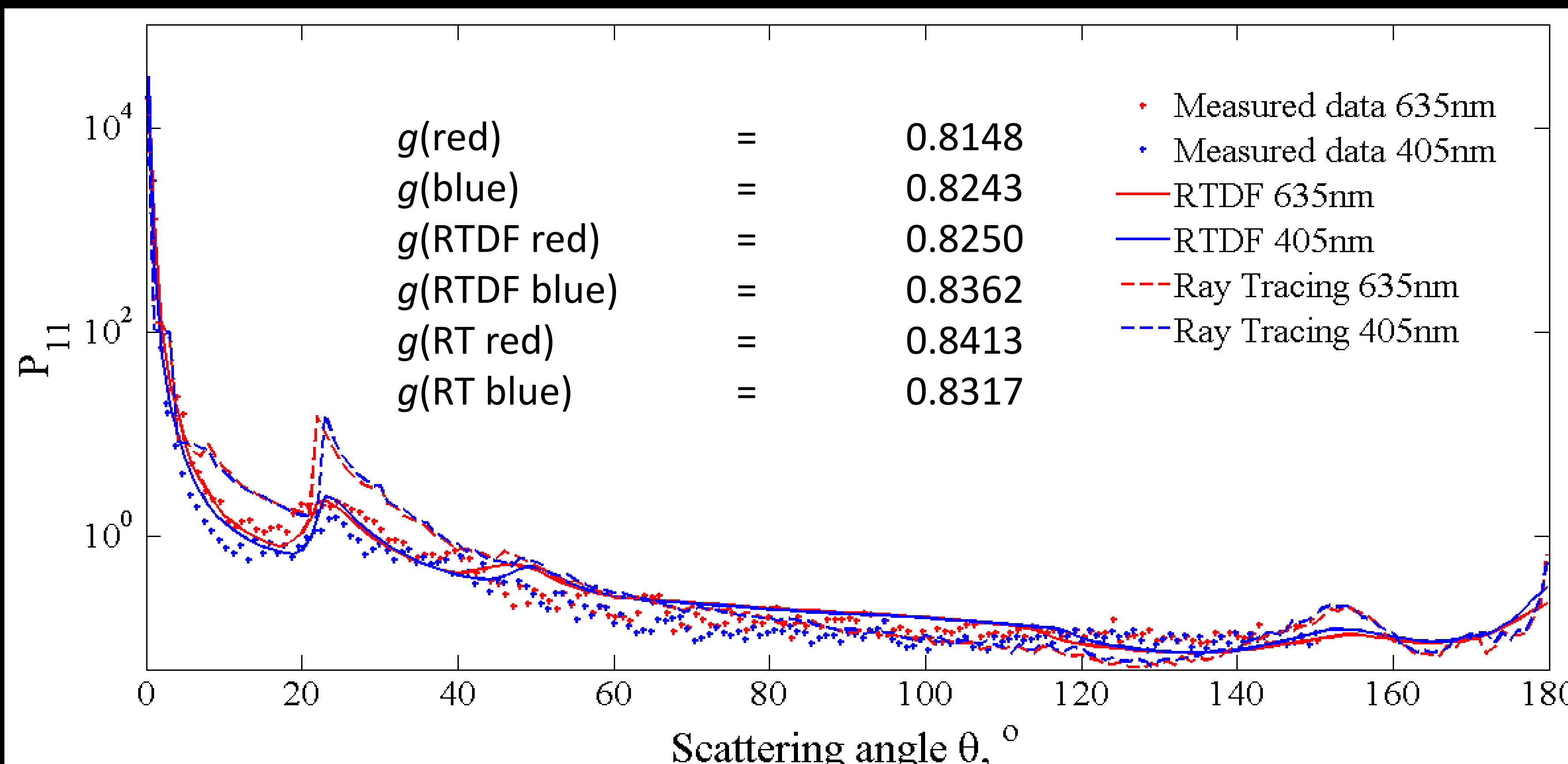
Measured results -7ºC hollow columns



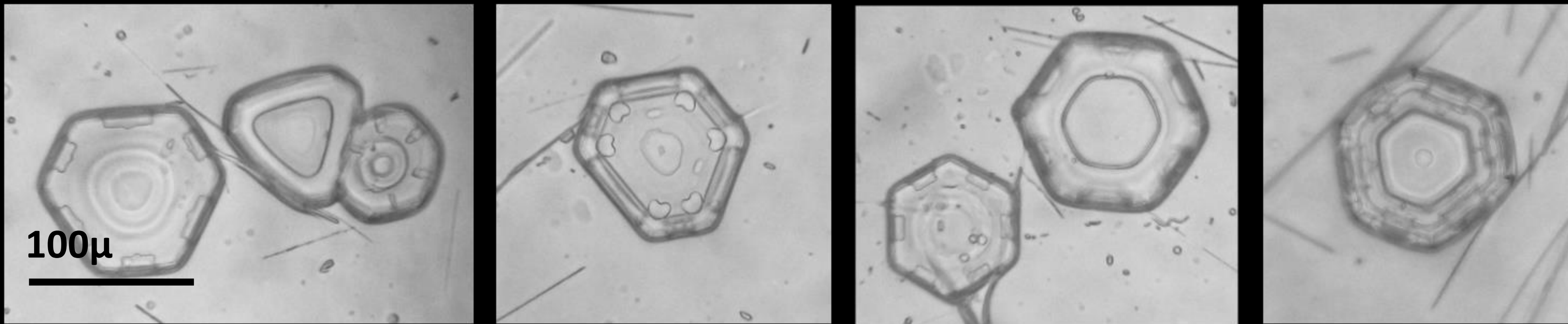


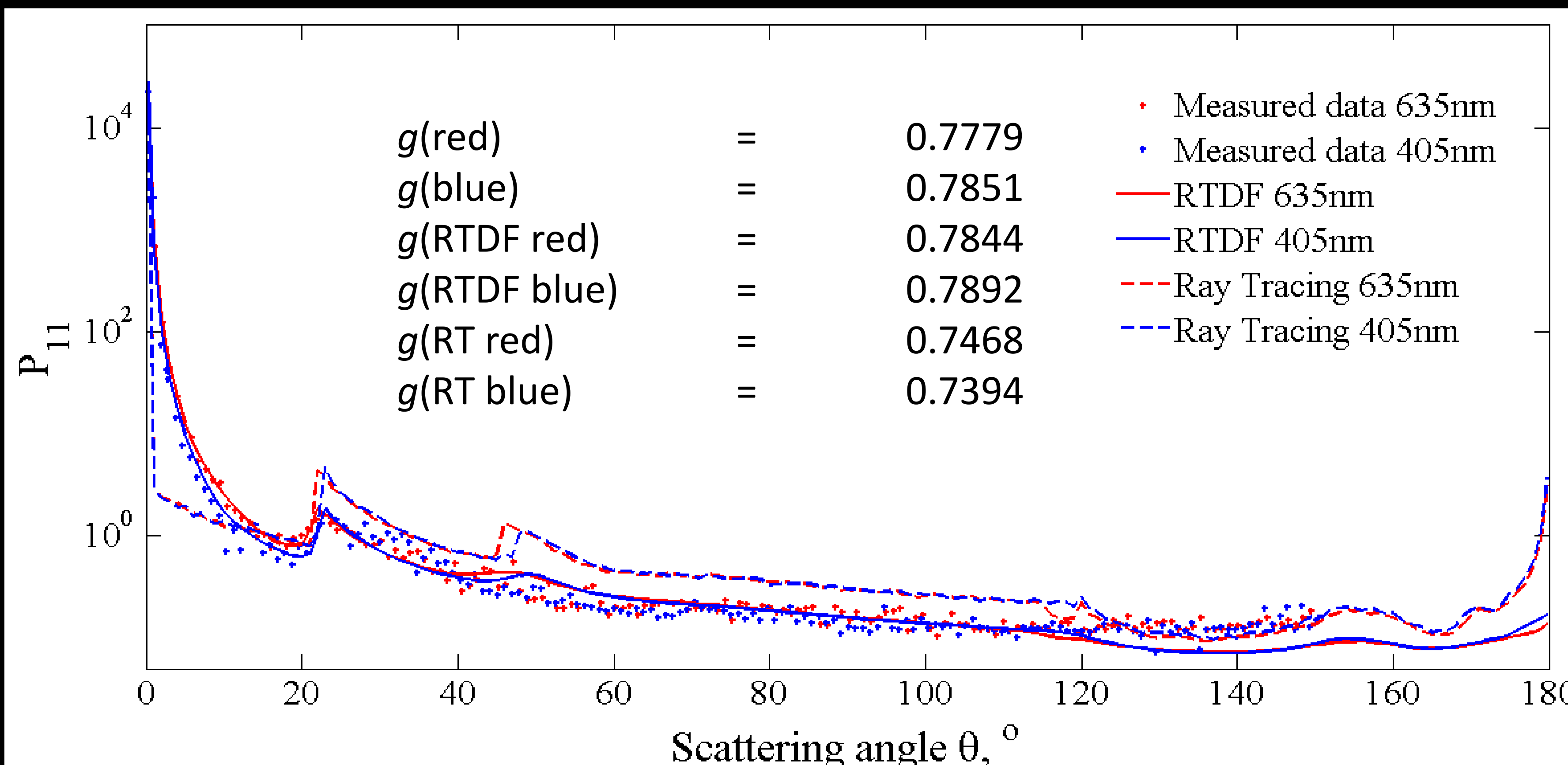
Measured Results -15^{o}C solid plates



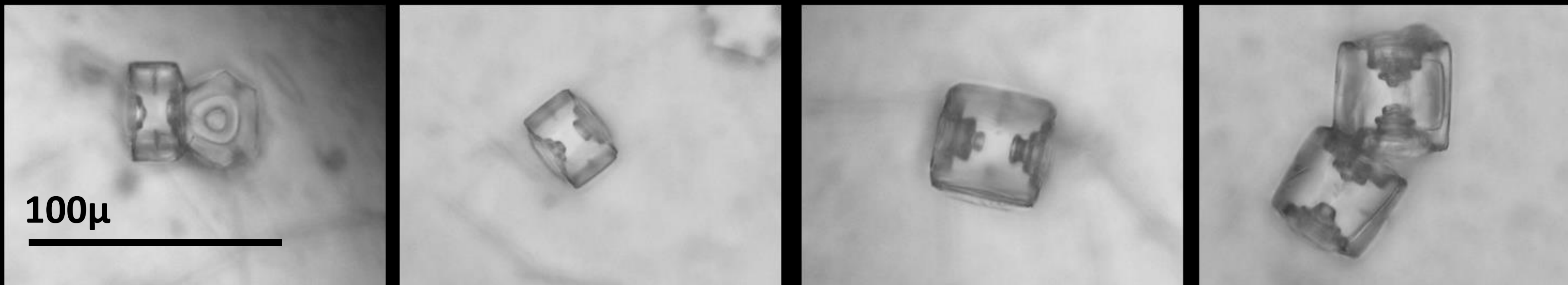


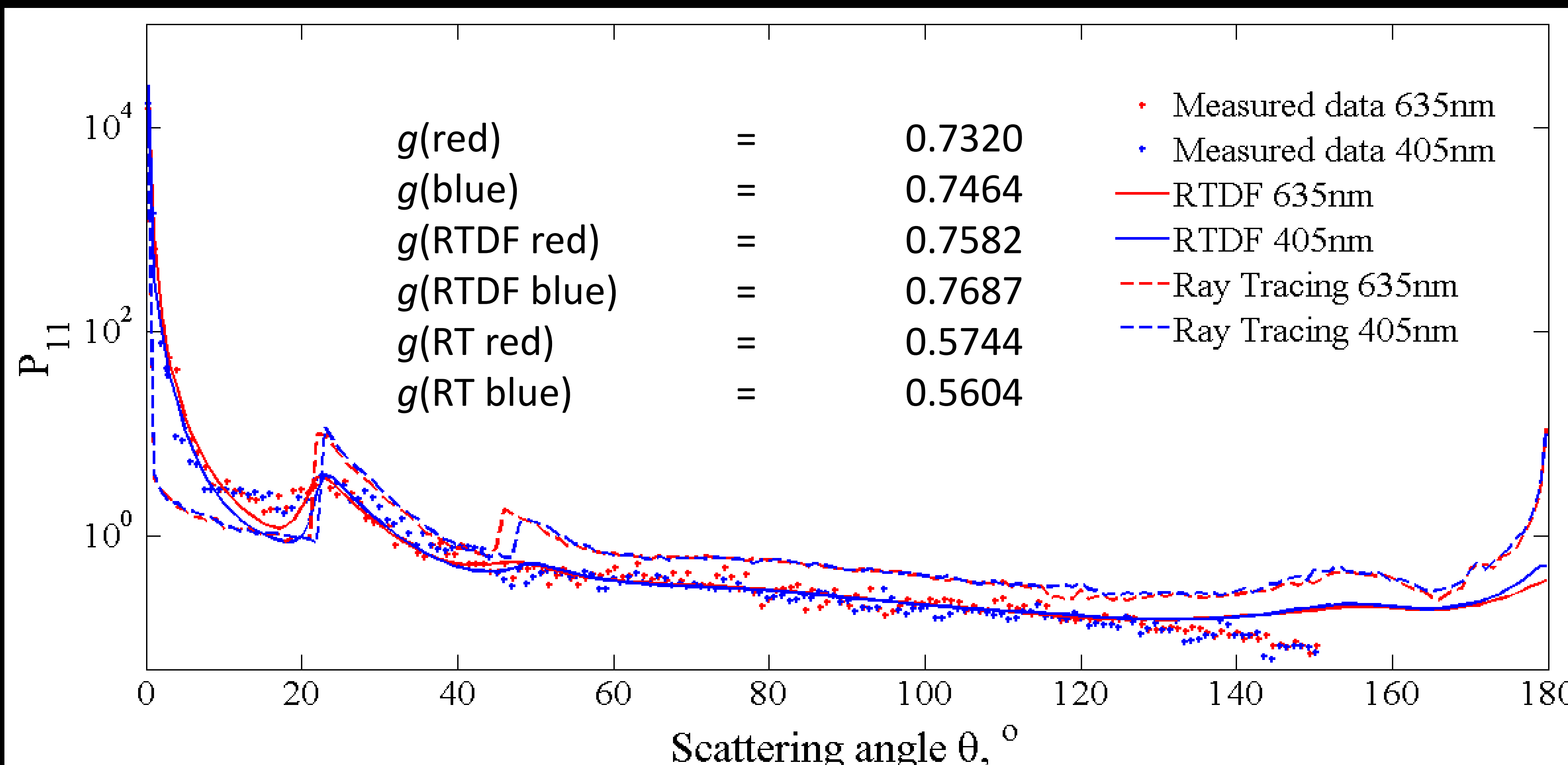
Measured Results -15°C hollow plates





Measured Results -30ºC hollow columns/plates





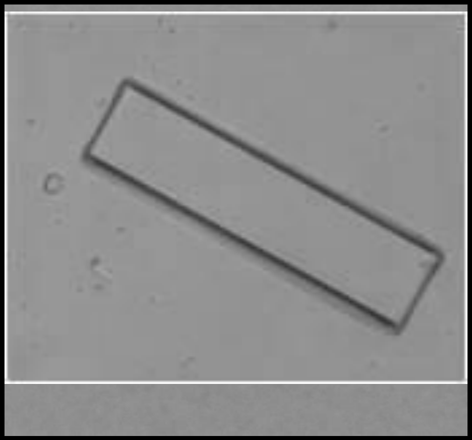
What can we conclude from this?

- Both RT and RTDF predict accurate asymmetry parameters for solid particles – however, differences are seen in the phase functions
- RT deviates largely from measured results for hollow particles (both ‘warm’ and ‘cold’ geometries)
- RTDF fits closely to measured results for both solid and hollow columns
- This suggests a decrease in asymmetry parameter for hollow particles with the ‘cold’ cavity

Difficulties

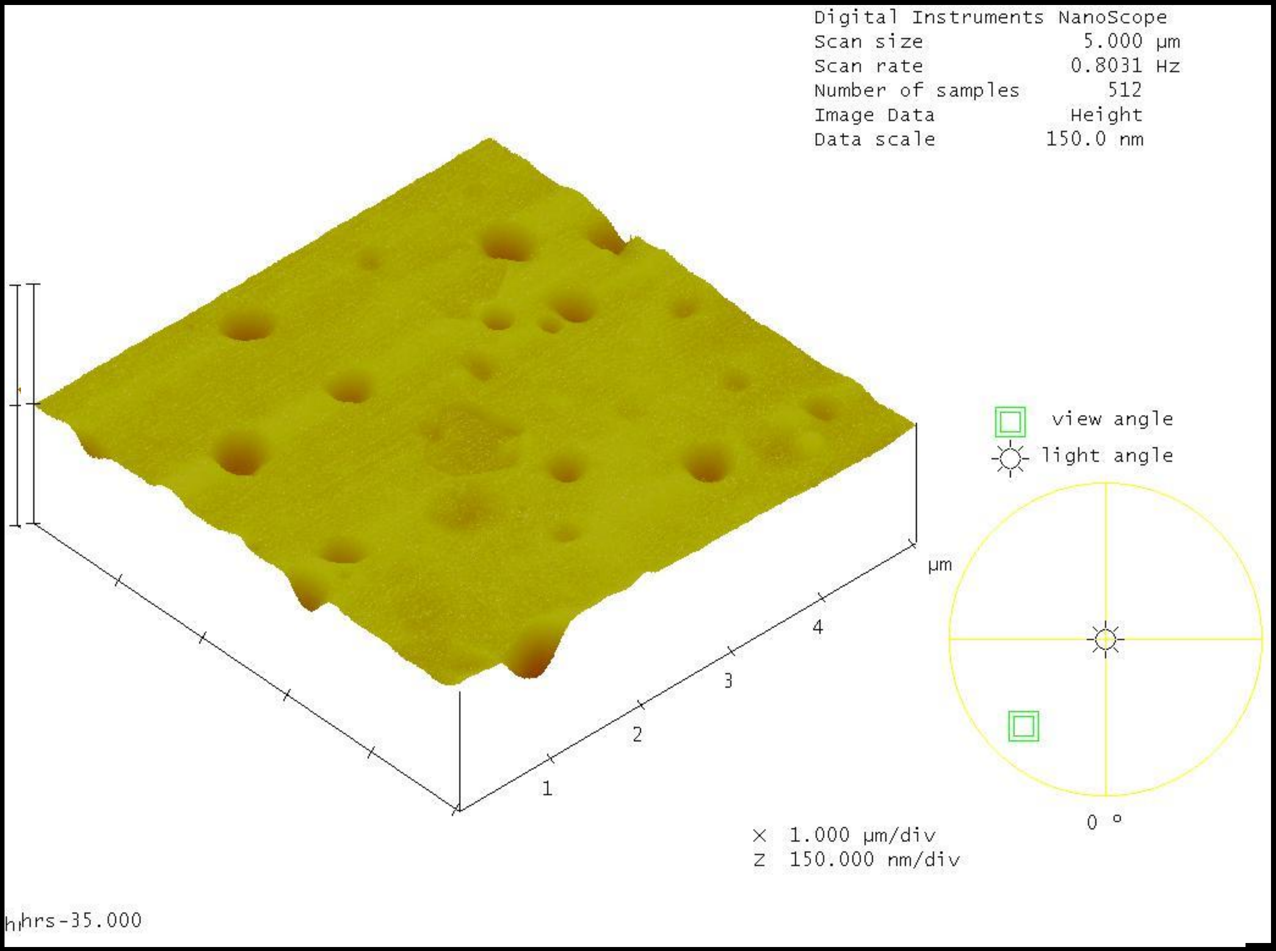
- Due to the inhomogeneous cloud chamber environment, relative humidity (and supersaturation) is difficult to measure
- Impossible to separate the effects of hollowness and roughness – both linked with supersaturation
- Currently unable to measure roughness
- A comparison of RT and RTDF highlights the limitations of geometric optics for hollow particles

Difficulties - Roughness



Holes on the surface may be artefacts – from the collection technique

Surface appears amorphous suggesting a slide



Looking forward

- Work is still on-going
- Current set up has been modified to measure P_{12}
- Need to test models ability to adequately treat cavities *and* polarization