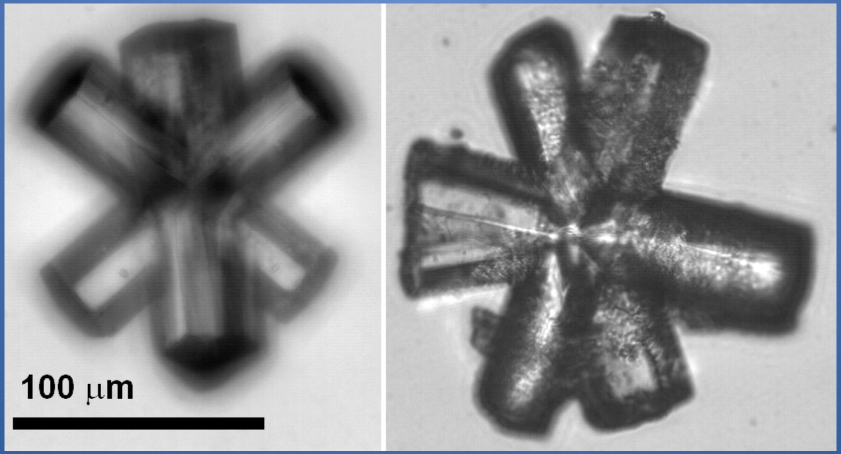
Ice particle surface roughness

Why do we care?

How often does it occur?

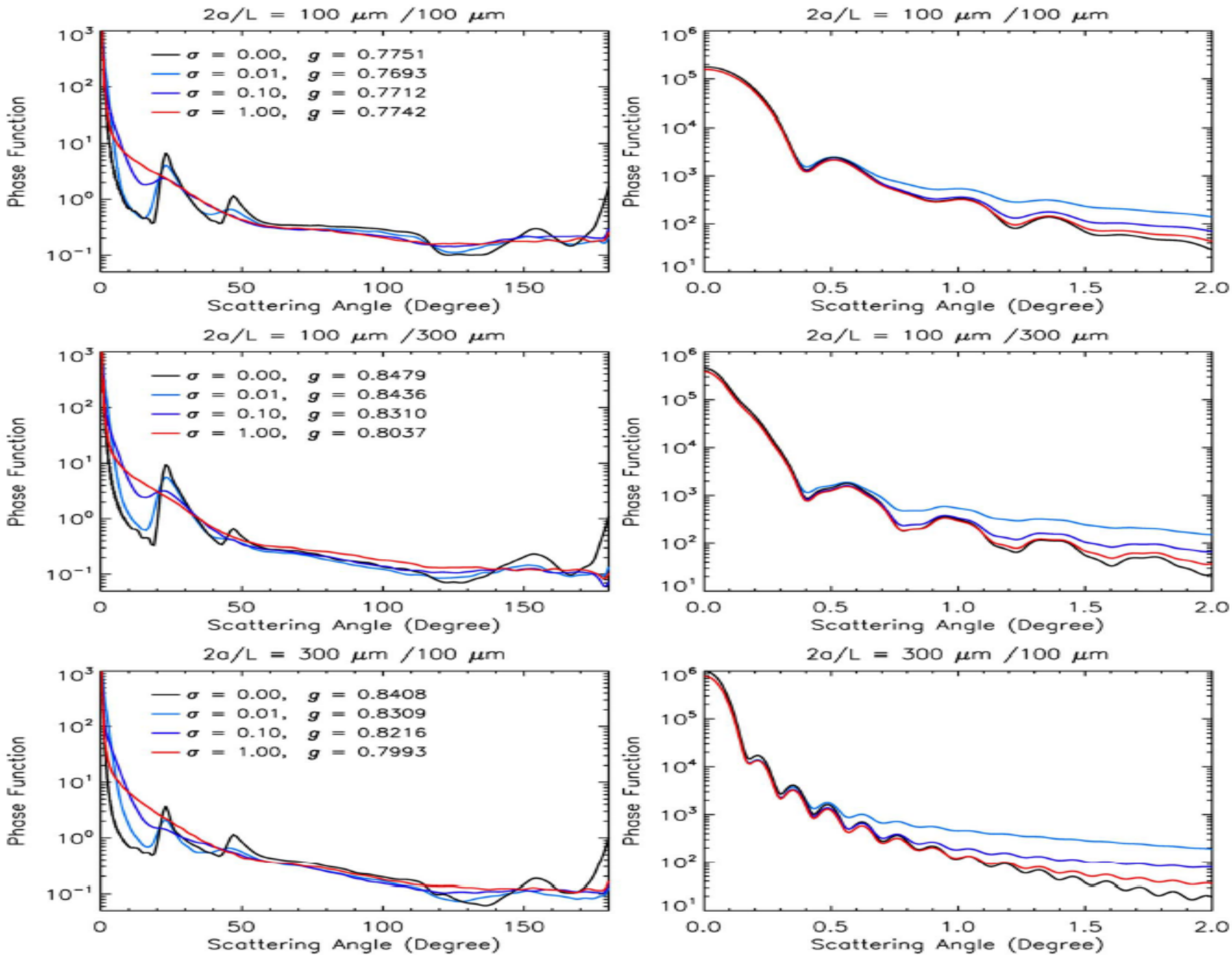
Carl Schmitt, Martin Schnaiter, Andrew Heymsfield
CMMAP summer 2013 team meeting



Outline

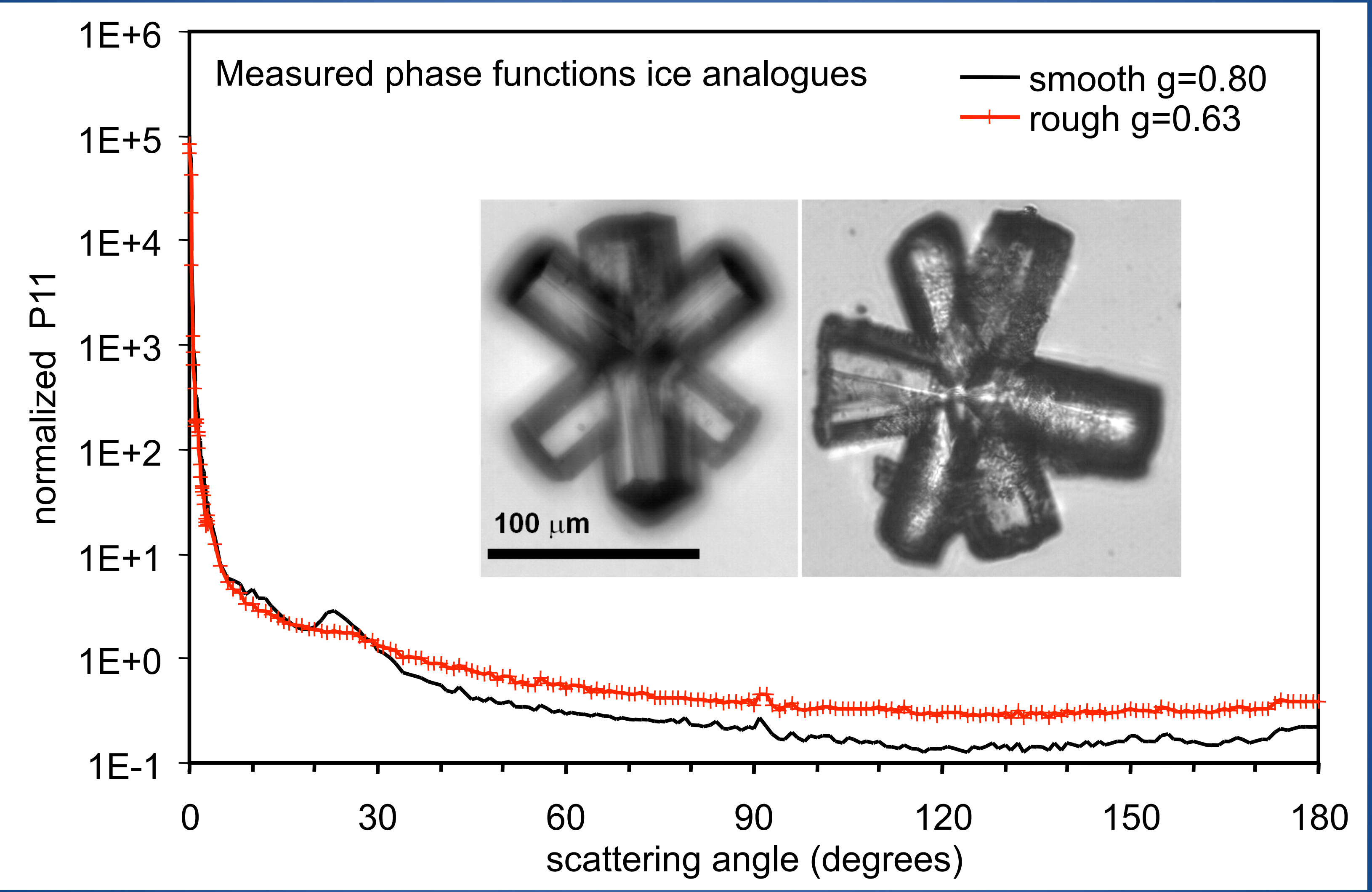
- Why is ice crystal surface roughness important?
- How can we determine the existence of surface roughness? (case study)
- What situations lead to surface roughness?
- Bonus material (if I have time): From aircraft microphysical data, how can we separate “cloud ice” from “snow” for modeling purposes?

Why is ice crystal surface roughness important?



2a/L = 100 μm /100 μm
σ = 0.00, g = 0.7751
σ = 0.01, g = 0.7693
σ = 0.10, g = 0.7712
σ = 1.00, g = 0.7742
Phase Function
Scattering Angle (Degree)
2a/L = 100 μm /100 μm
Phase Function
Scattering Angle (Degree)
2a/L = 100 μm /300 μm
σ = 0.00, g = 0.8479
σ = 0.01, g = 0.8436
σ = 0.10, g = 0.8310
σ = 1.00, g = 0.8037
Phase Function
Scattering Angle (Degree)
2a/L = 100 μm /300 μm
Phase Function
Scattering Angle (Degree)
2a/L = 300 μm /100 μm
σ = 0.00, g = 0.8408
σ = 0.01, g = 0.8309
σ = 0.10, g = 0.8216
σ = 1.00, g = 0.7993
Phase Function
Scattering Angle (Degree)
2a/L = 300 μm /100 μm
Phase Function
Scattering Angle (Degree)

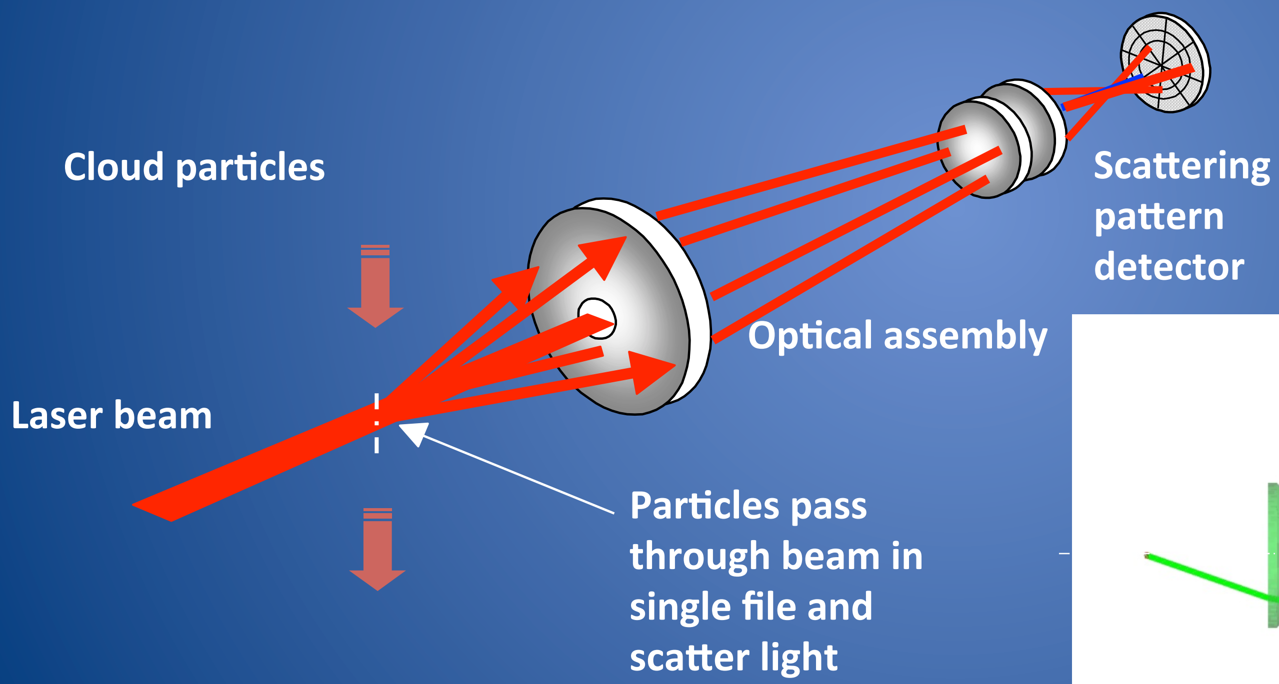
Surface Roughness – Direct measurements of Scattering Function

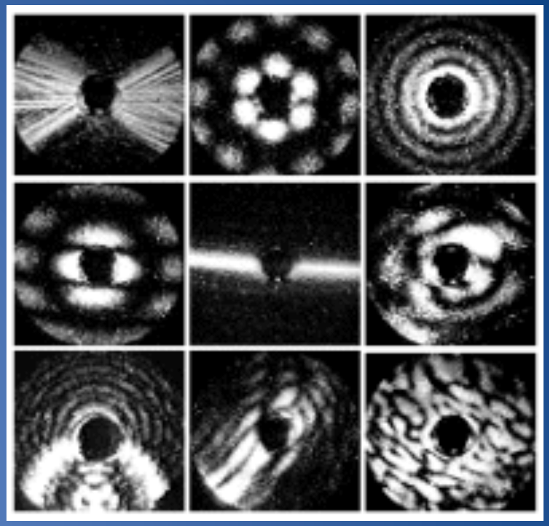


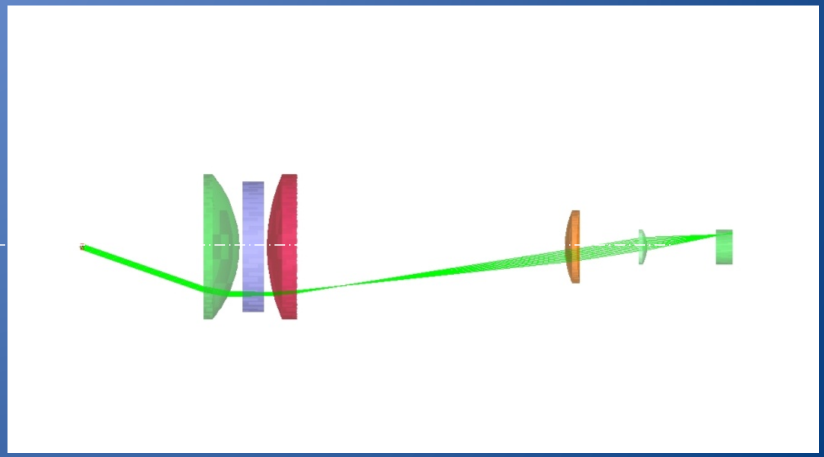
How can we tell that ice crystal surfaces are rough?

Small Ice Detector (SID3)
Principle of operation

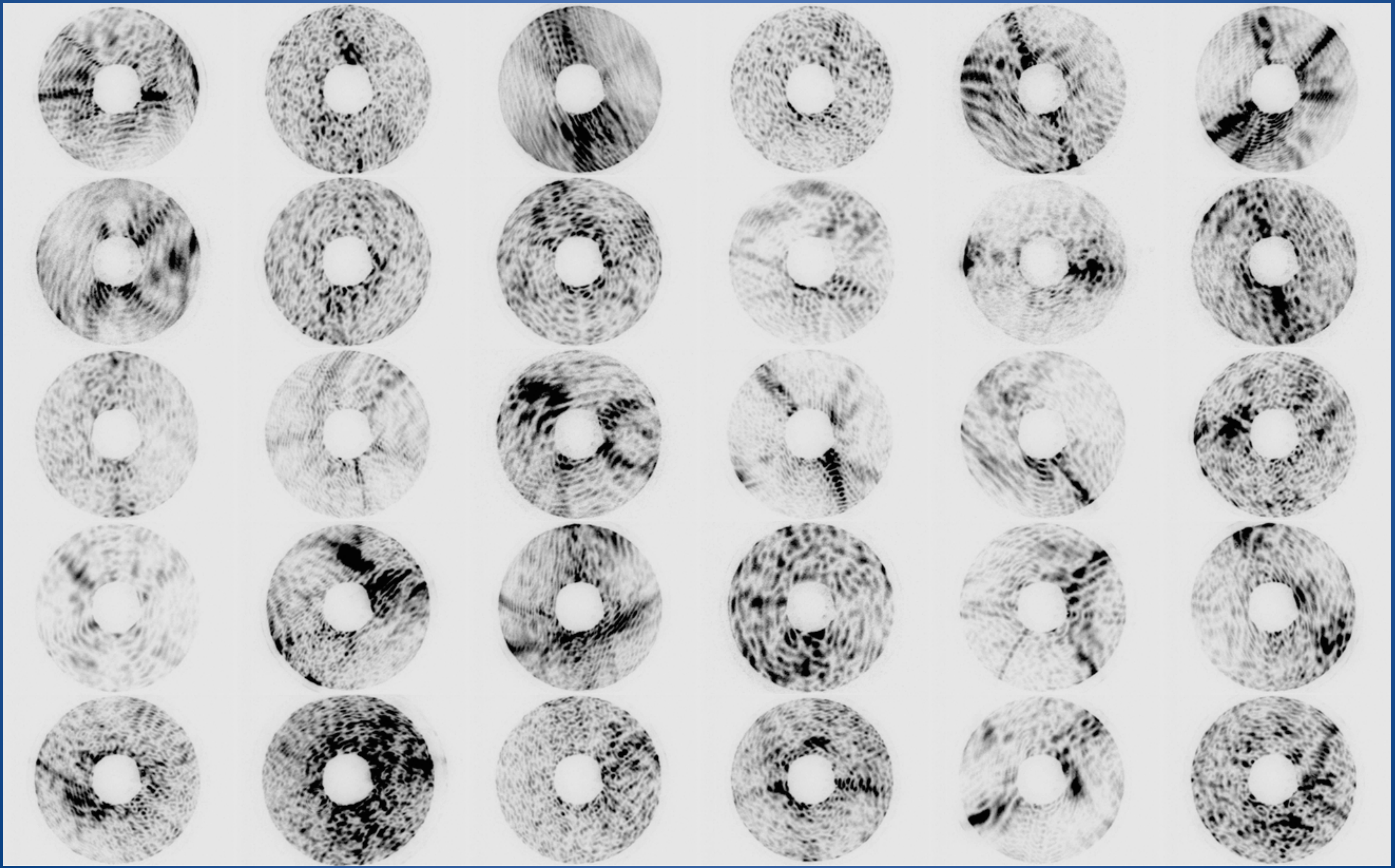
Records spatial pattern of light scattered in forward direction by individual particles passing through a laser beam





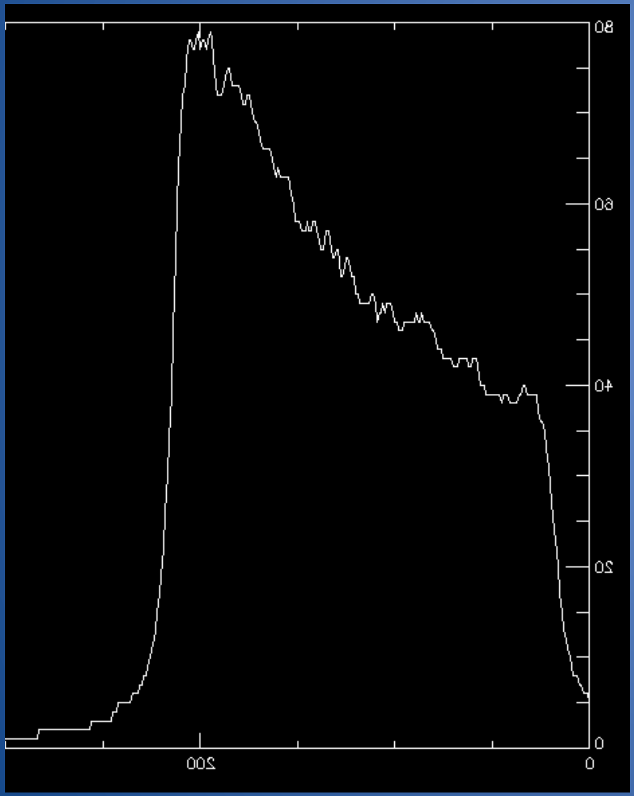


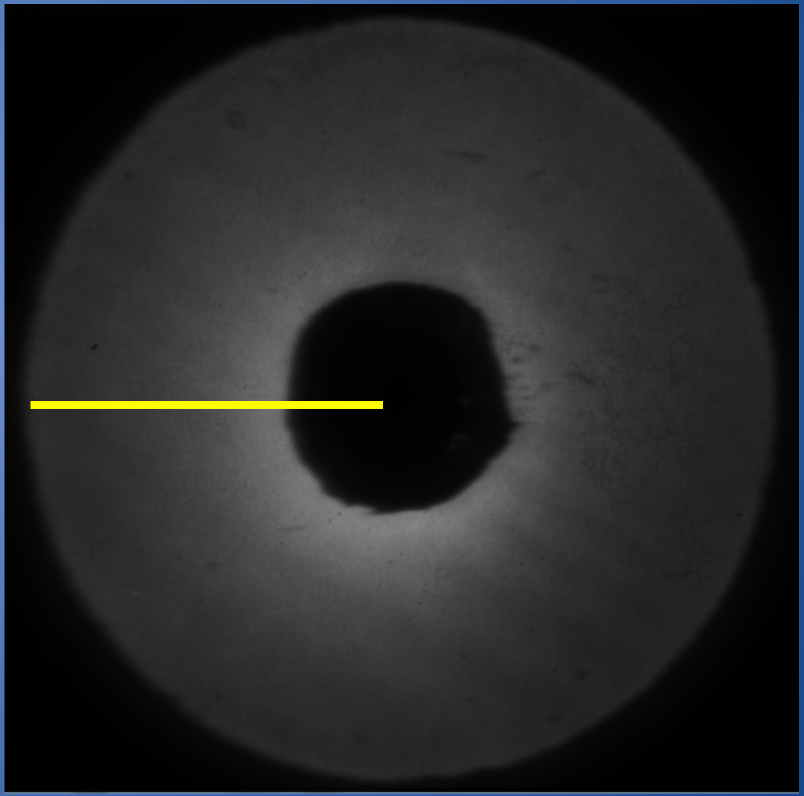
SID3 scattering patterns from aircraft measurements are frequently speckled which indicates rough surfaces



SID3 measures forward scattering from 8-25 degrees, and can be used to look at the phase function in that angle range.

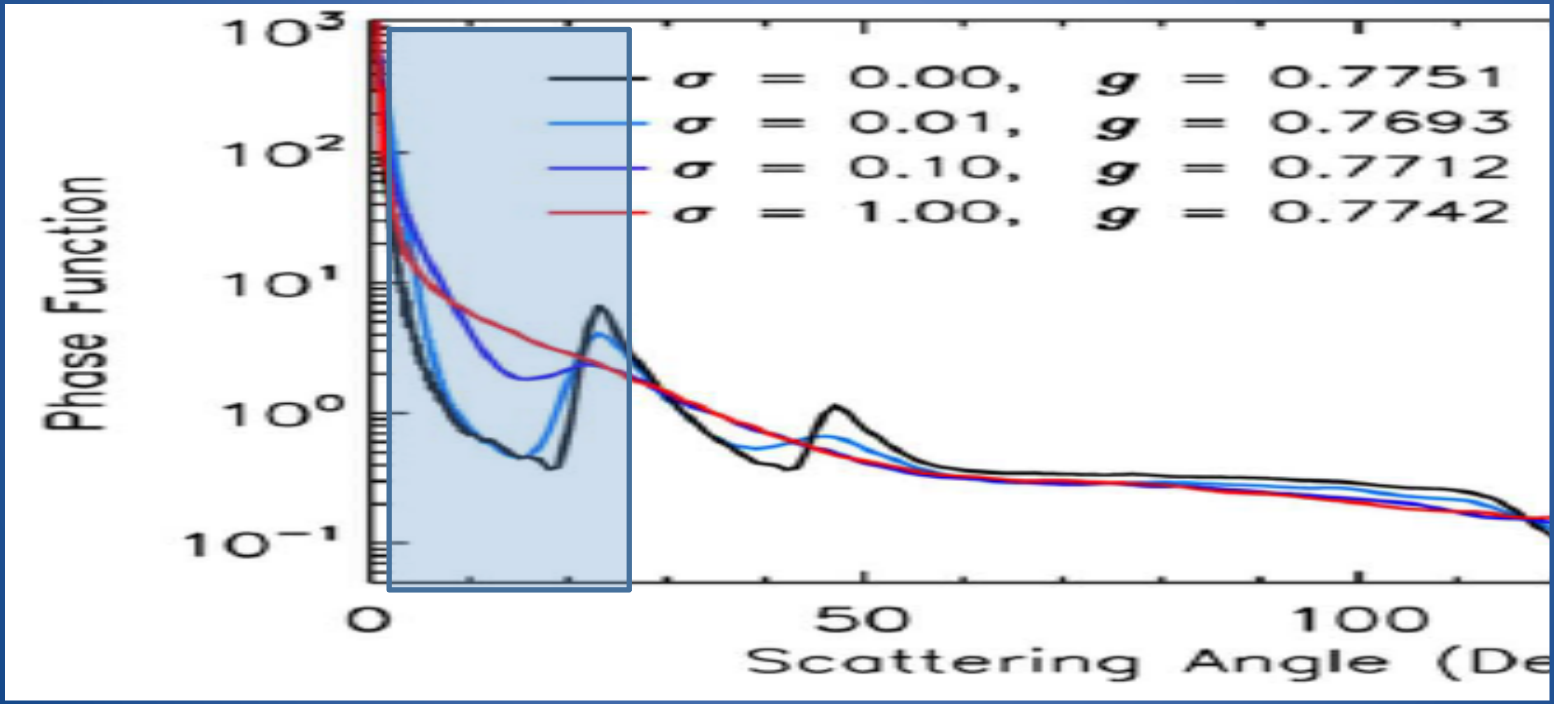
In this case, several thousand images from the 21-April-2011 MACPEX flight are averaged. The plot on the left shows the values along the yellow line through the averaged image on the right. This represents the averaged phase function for that angular range.





Phase function below is from Yang et al (2008). Shows ray tracing calculations for crystals with smooth and varying degrees of roughness on the surfaces. The SID3 measurements capture the forward part of the phase function (highlighted area). Note the different slopes in the 5-20 degree region.

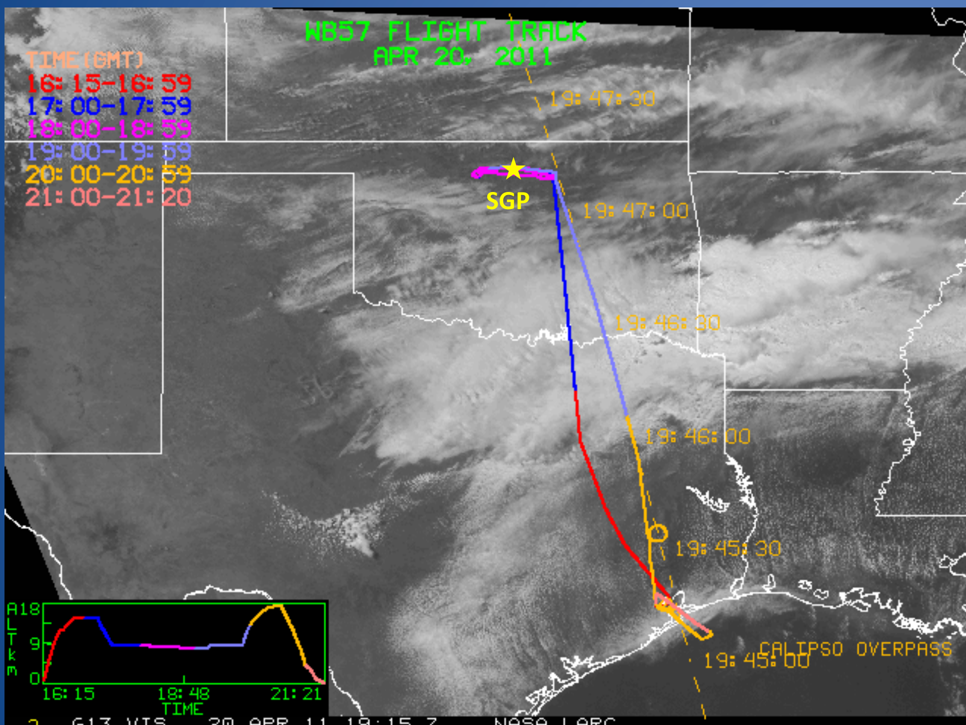
Short Column shape: L/2a = 100um / 100um

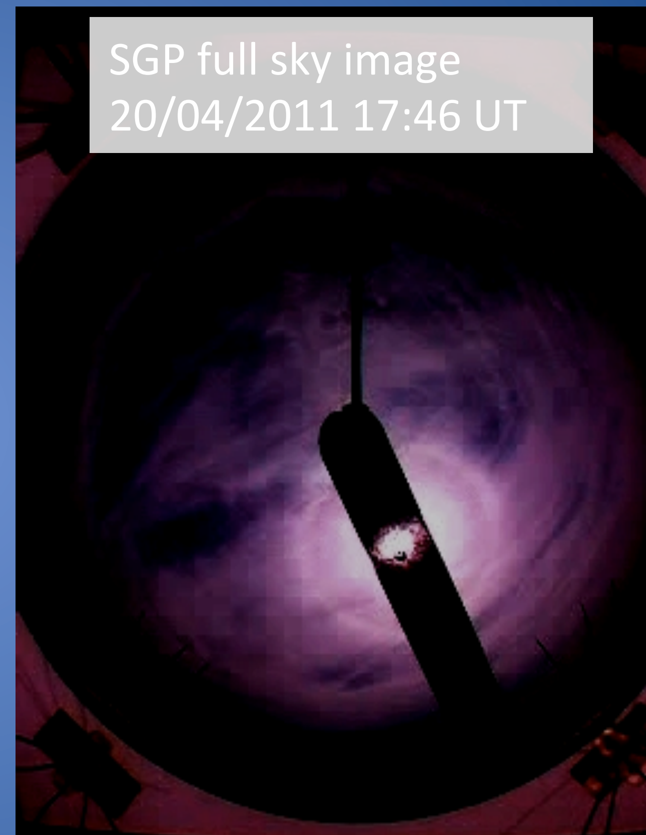


Case study from MACPEX

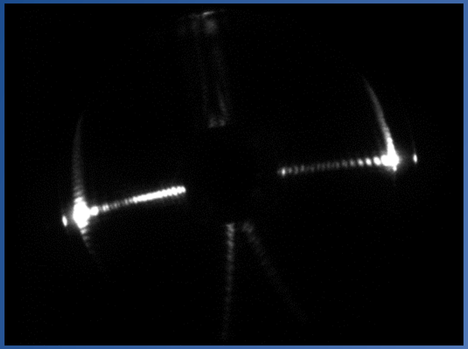
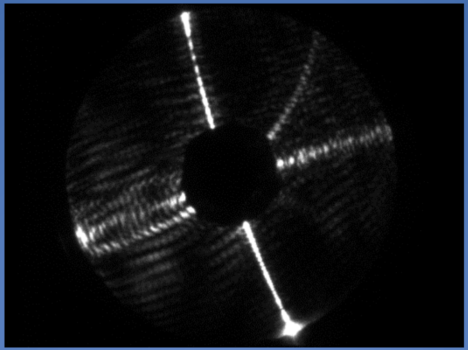
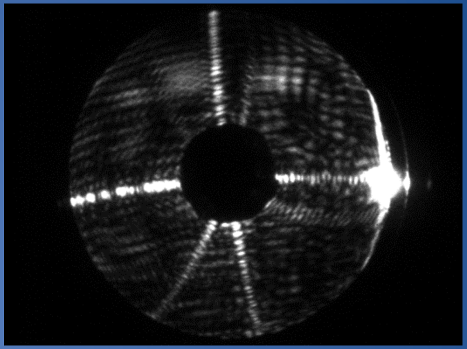
- Halos were observed at the DOE ARM SGP site.
- Halos imply smooth surface crystals.
- Lets look at SID3 data from the time period when the NASA WB-57 was at the SGP site compared to other "non-halo" locations.

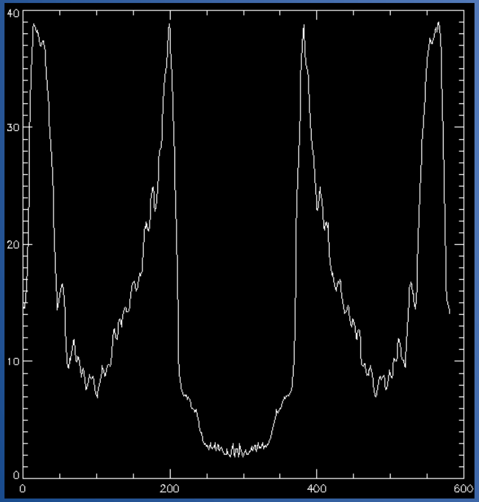
22° halo over the SGP ARM site

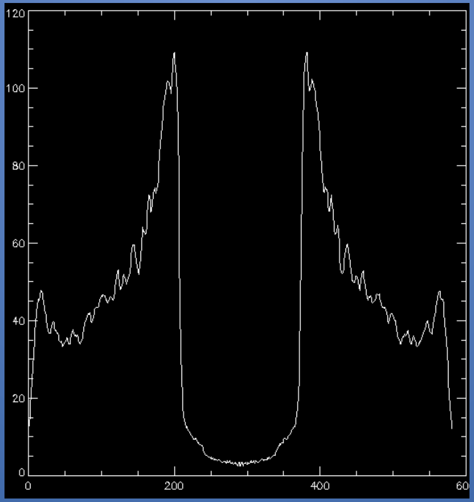


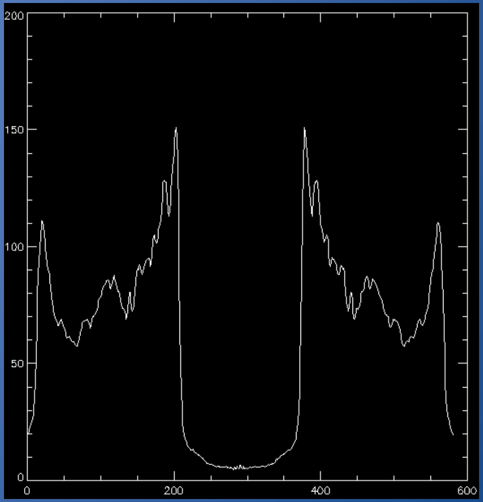


SID3 Halos observed during April 20 flight near SGP site. Pilot and local ground personnel commented on halos.

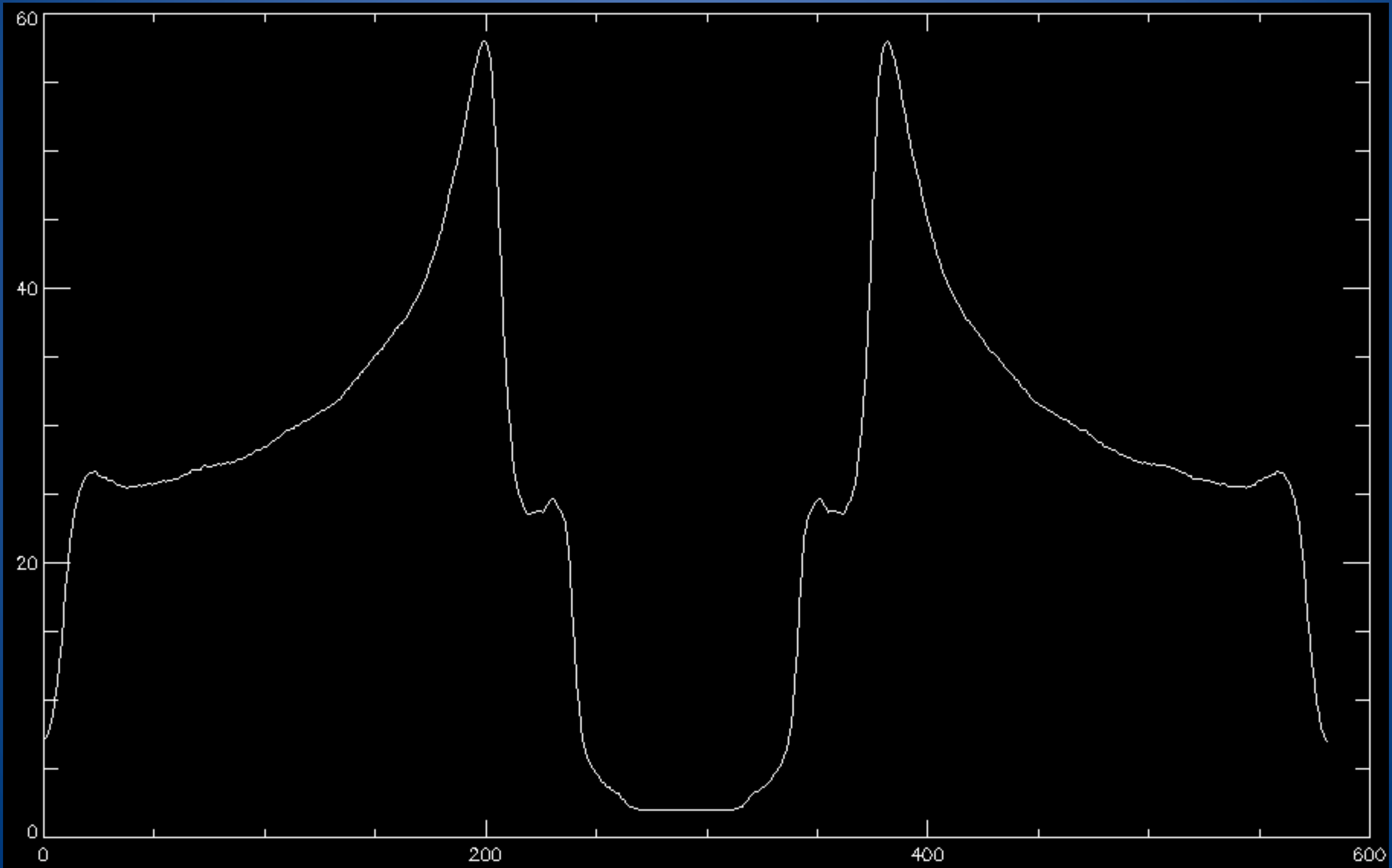






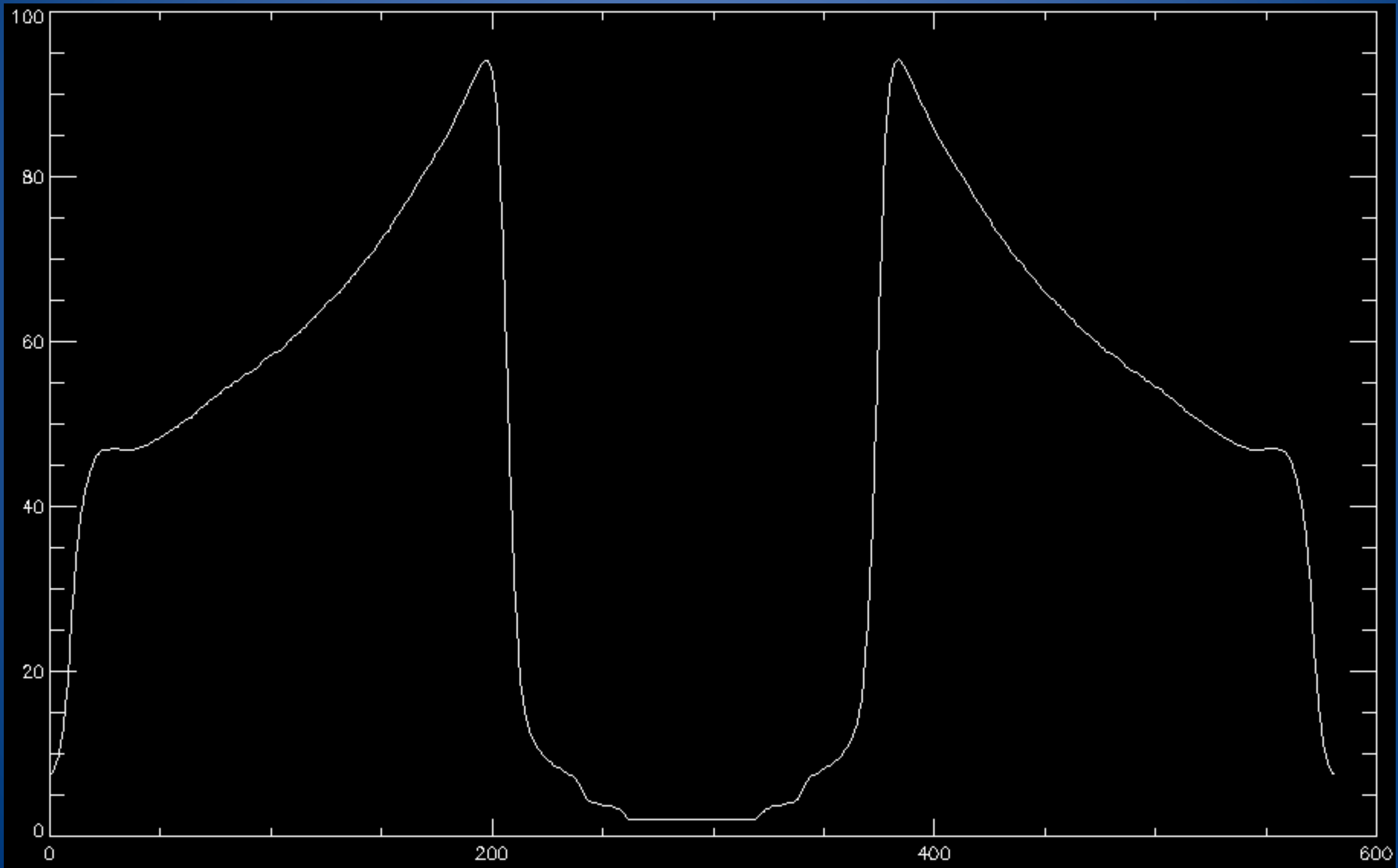


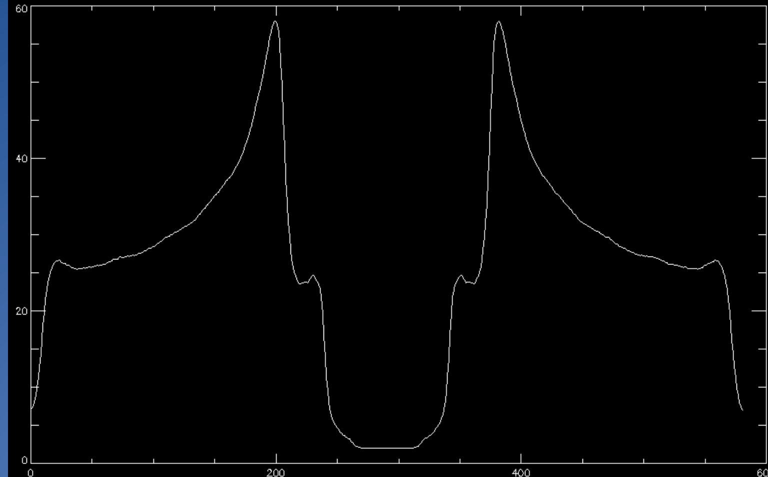


2000 SID3 scattering patterns from MACPEX April 20 averaged around the time the Halos were observed.



SID3 measurement for April 21 when no halos were noted





0
20
40
60
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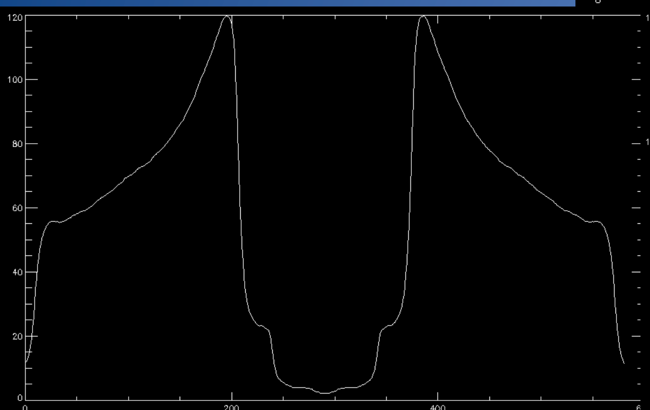

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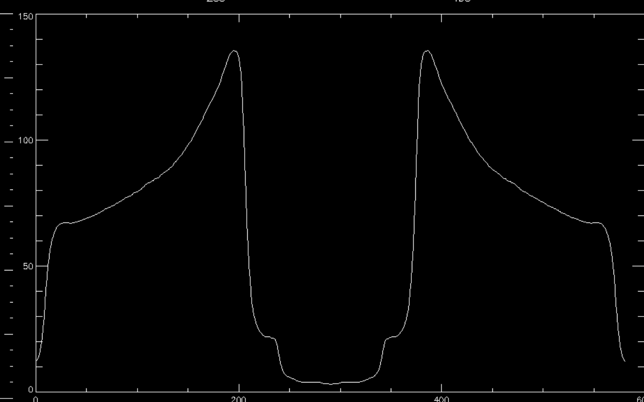

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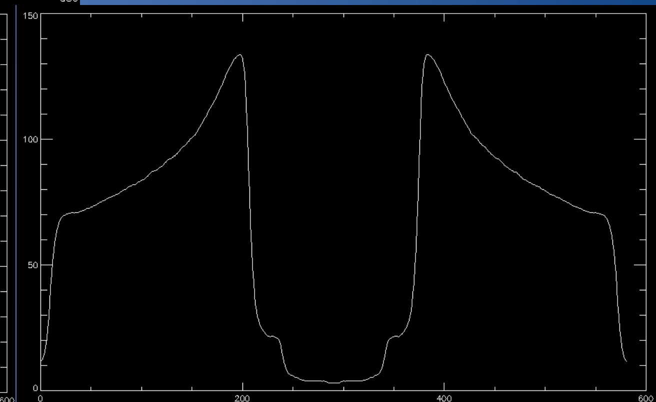

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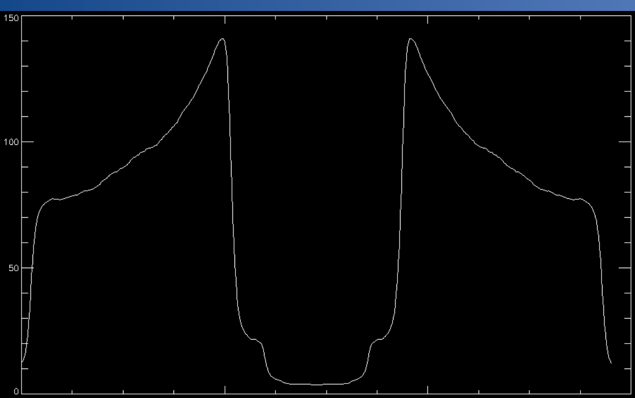

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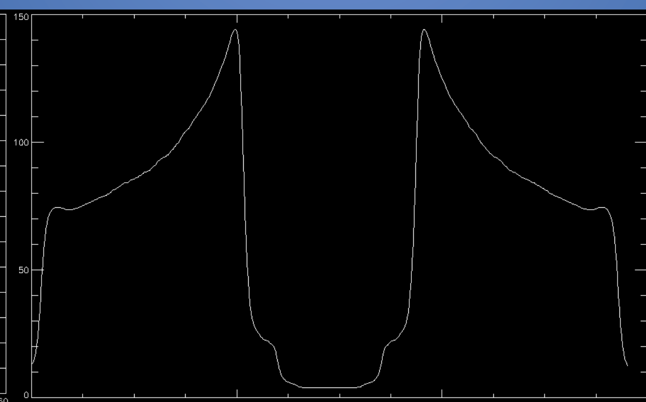

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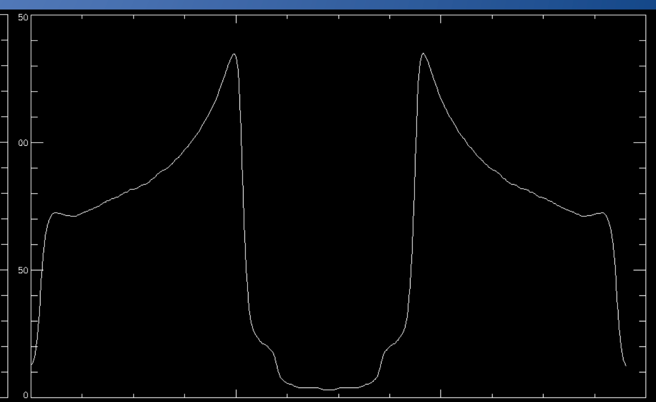

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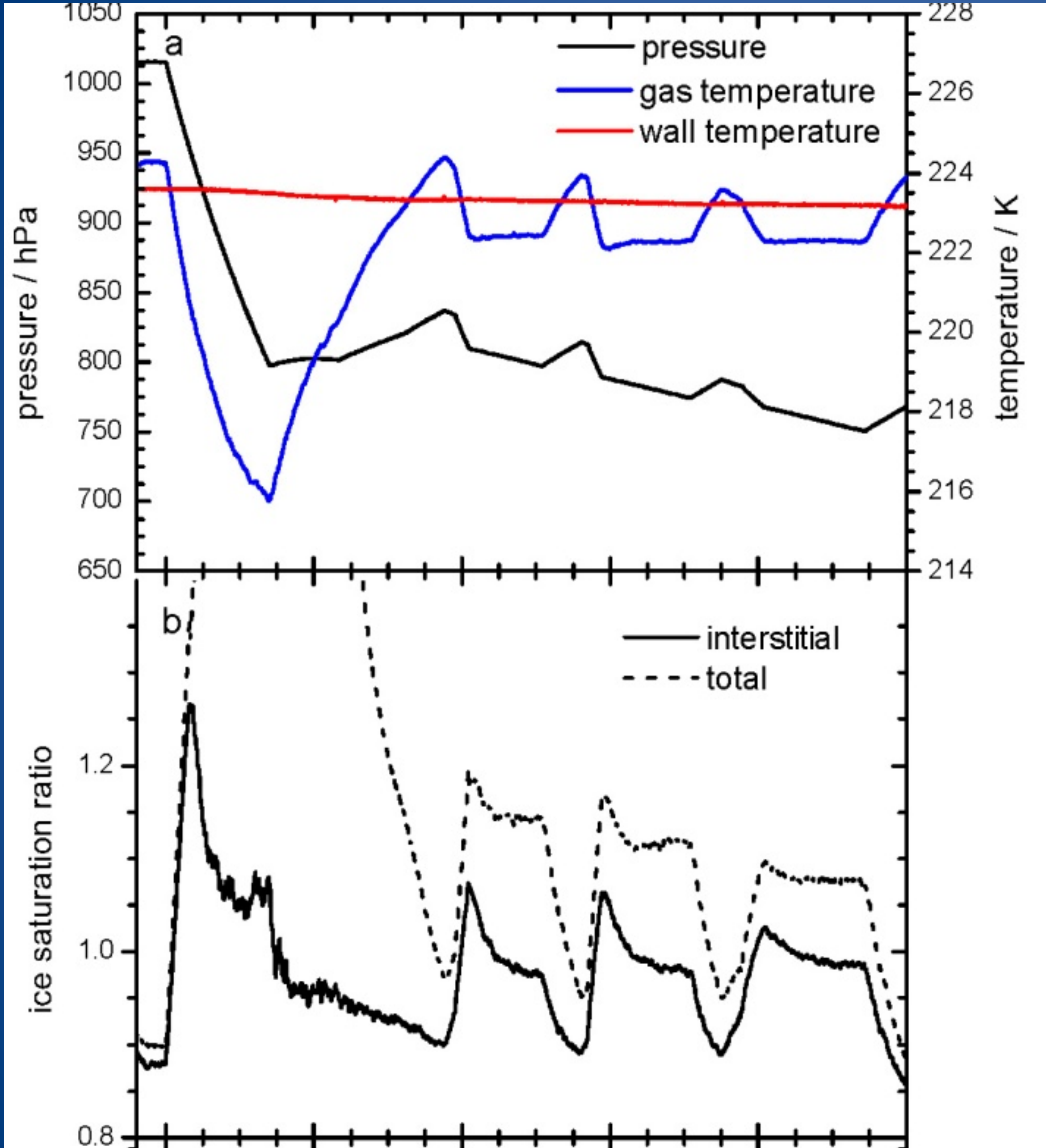
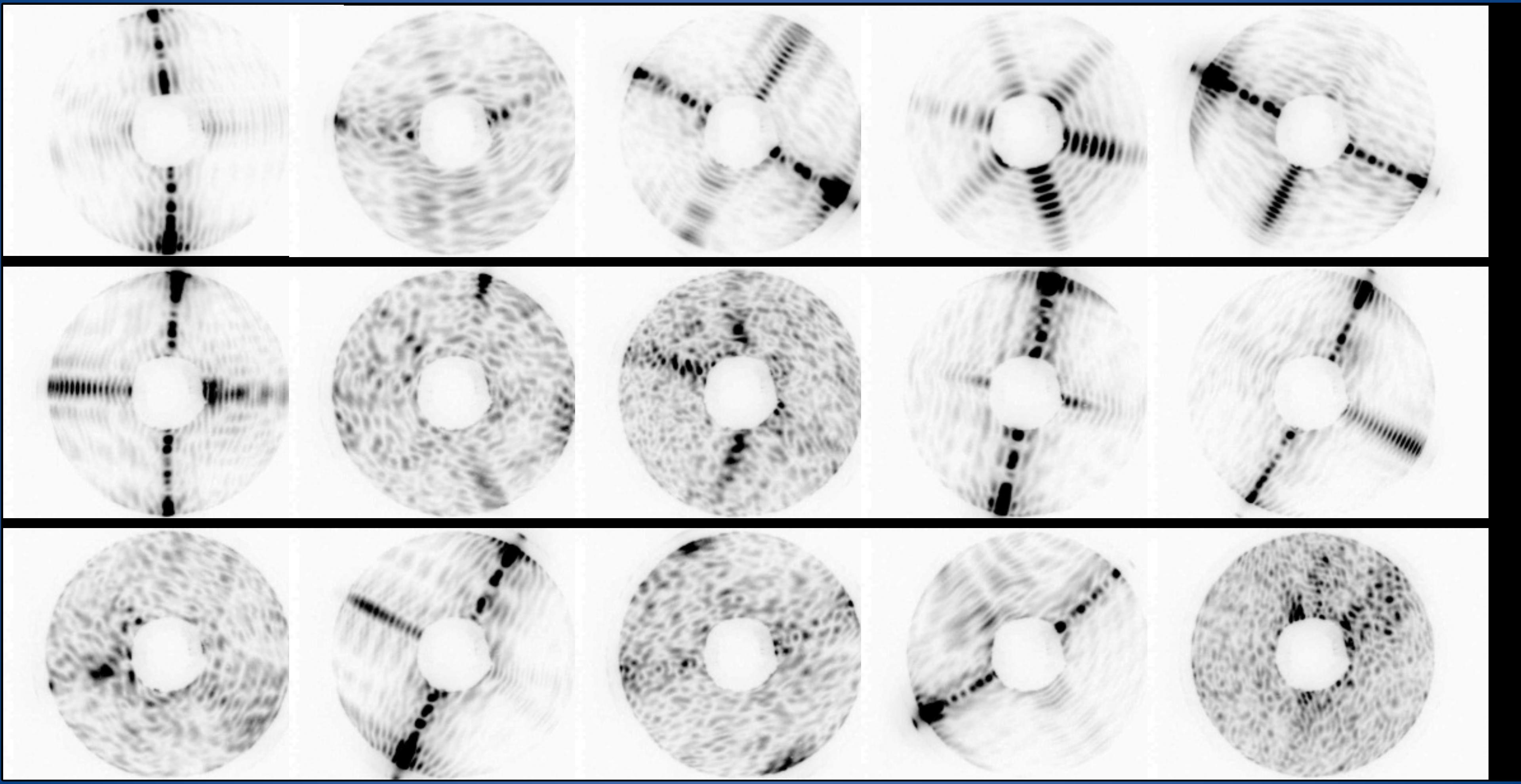
Laboratory studies (AIDA) can help us understand what causes roughness.



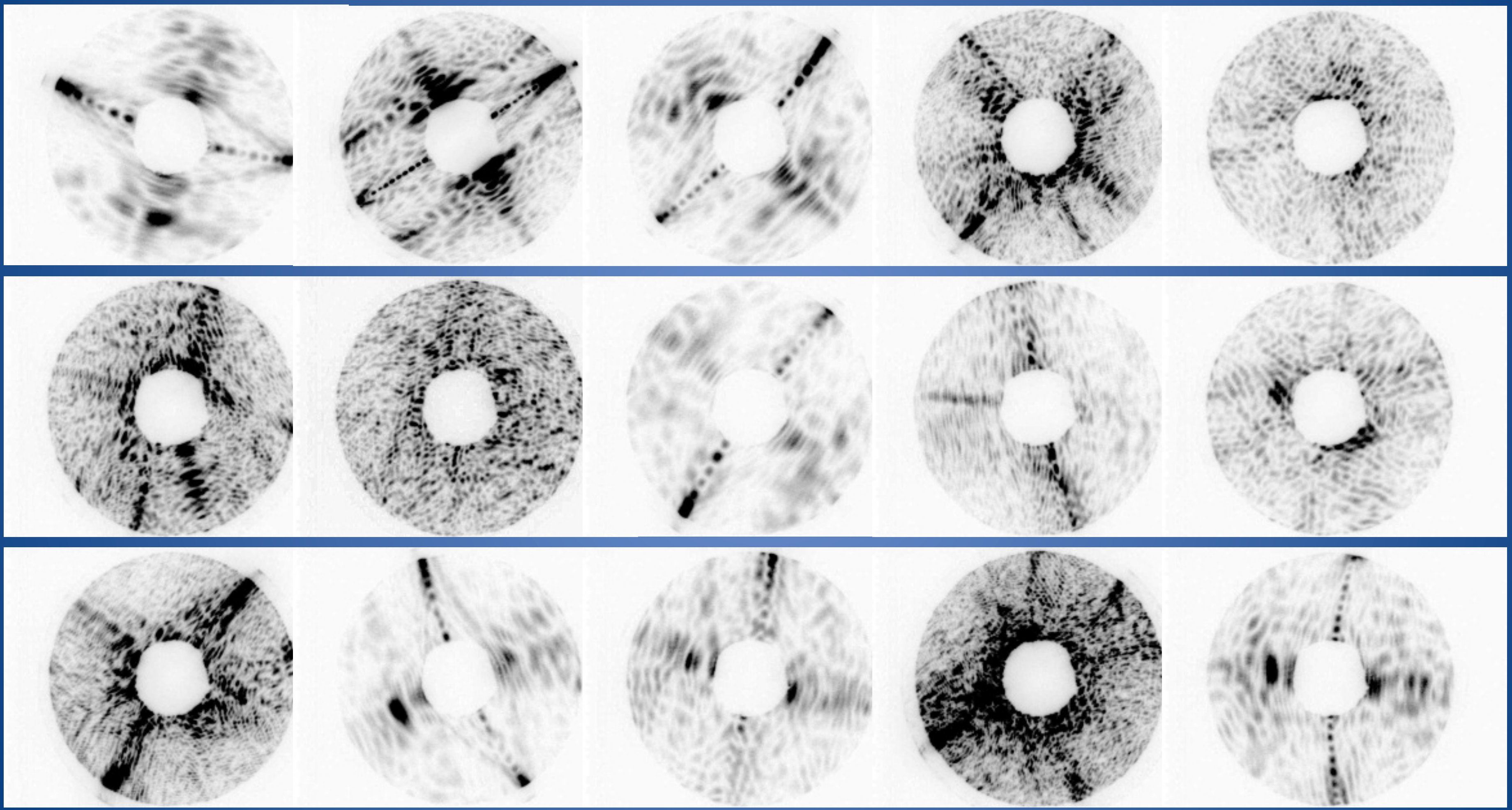
Experiments in AIDA to determine what conditions lead to surface roughness and hollowness:

1. Soot particles are used as nuclei to generate ice clouds.
2. After an initial growth phase, the particles are allowed to sublimate.
3. After sublimation, the particles are generally 50% smooth surfaced solid columns.
4. Particles are then re-grown at different supersaturation levels.

SID3 scattering patterns from AIDA cloud chamber experiments with growth at low supersaturations.



From AIDA: with growth at high supersaturations.



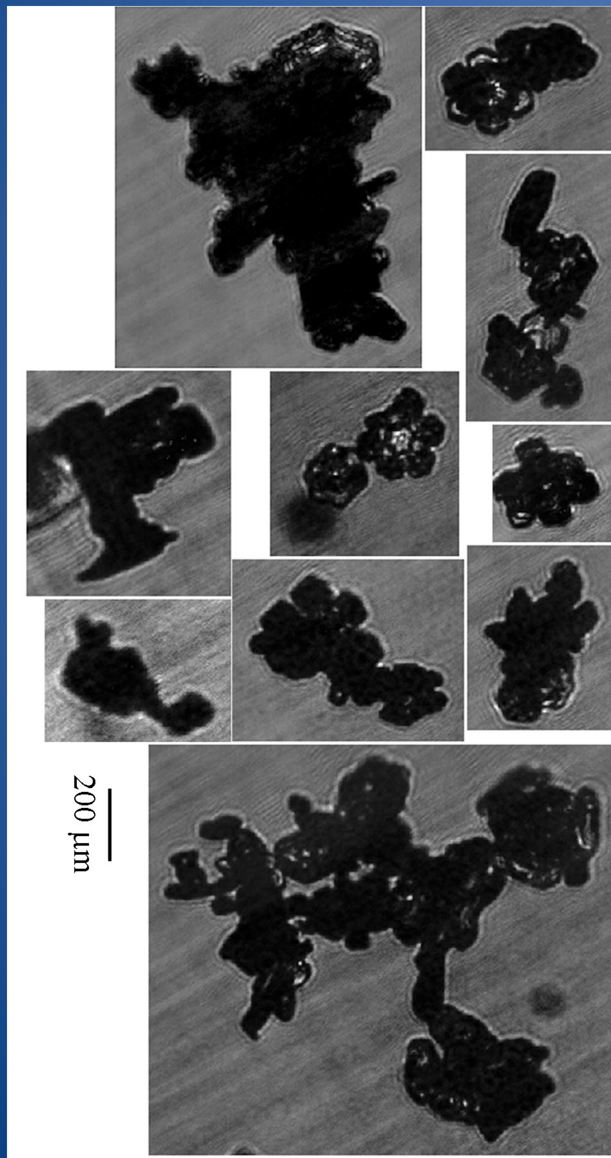
Estimates of roughness and hollowness based on super-saturation during regrowth

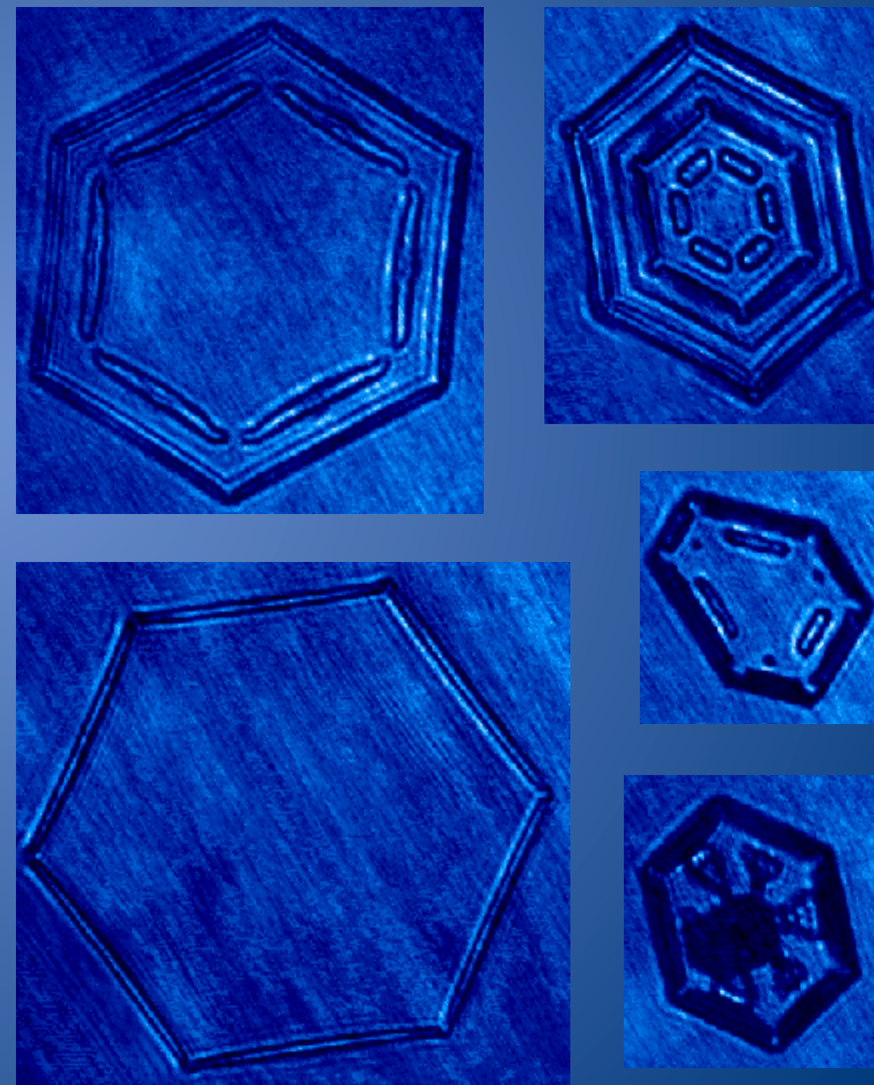
Supersaturation during re-growth period	Roughness	Column and bullet rosette Hollowness
5%	20%	<5%
35%	85%	100%

Growth of ice crystals under high super-saturation conditions leads to surface roughness. Low super-saturations values result in smooth surfaced crystals.

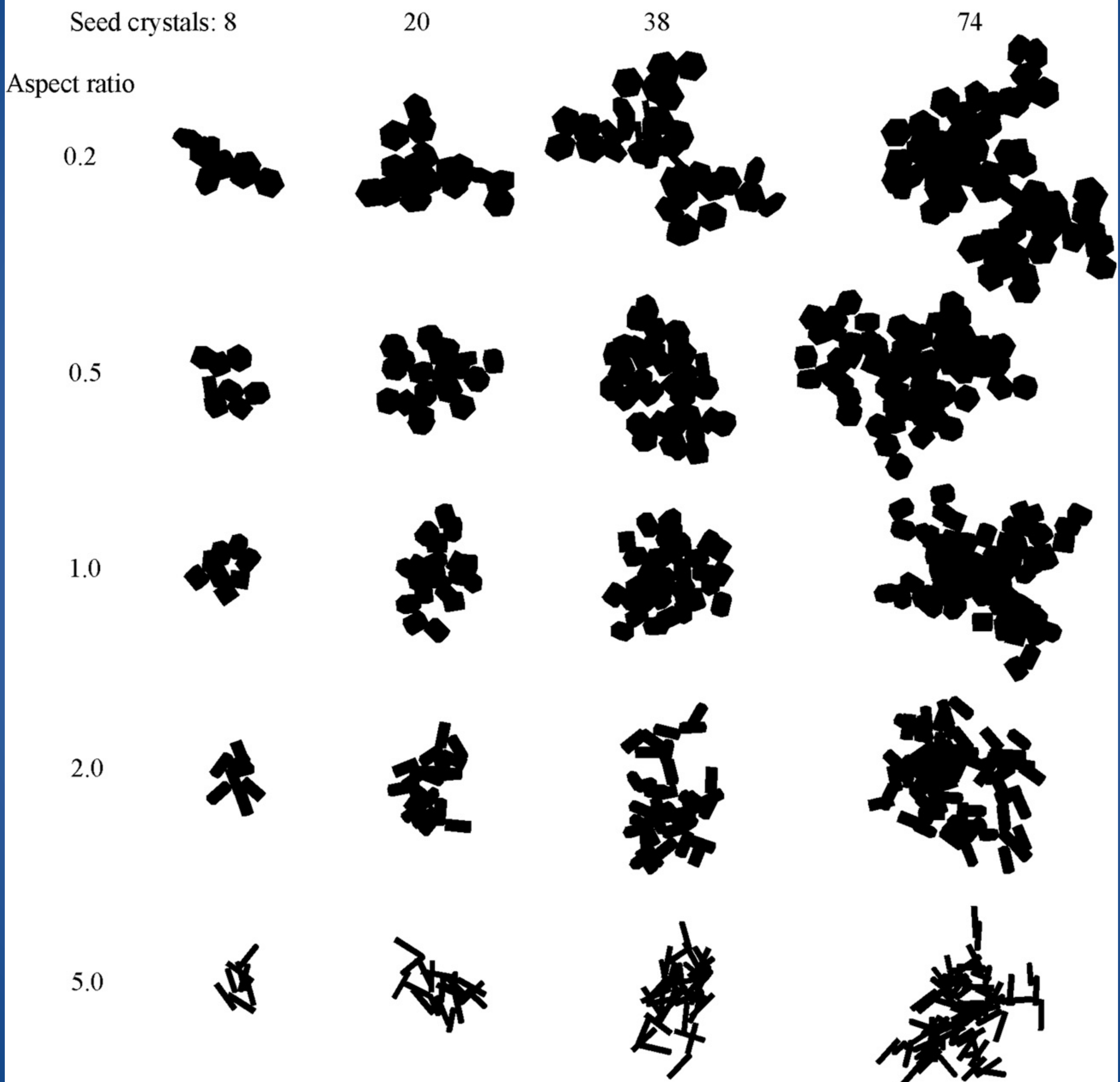
Bonus material: The separation of "cloud ice" and "snow"

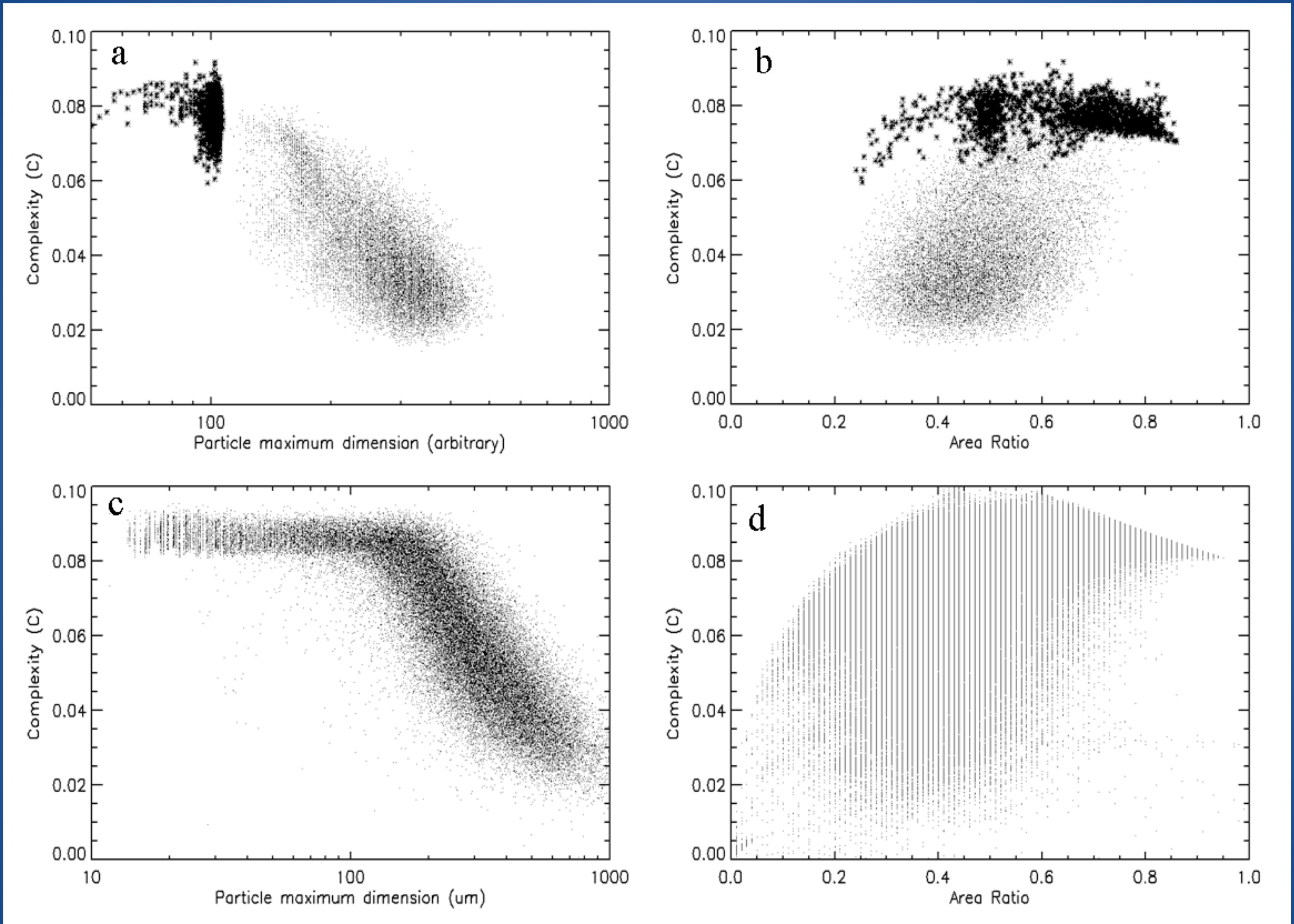
Observational justification and quantification of the separation of cloud ice and snow





Simulated ice crystal aggregates.

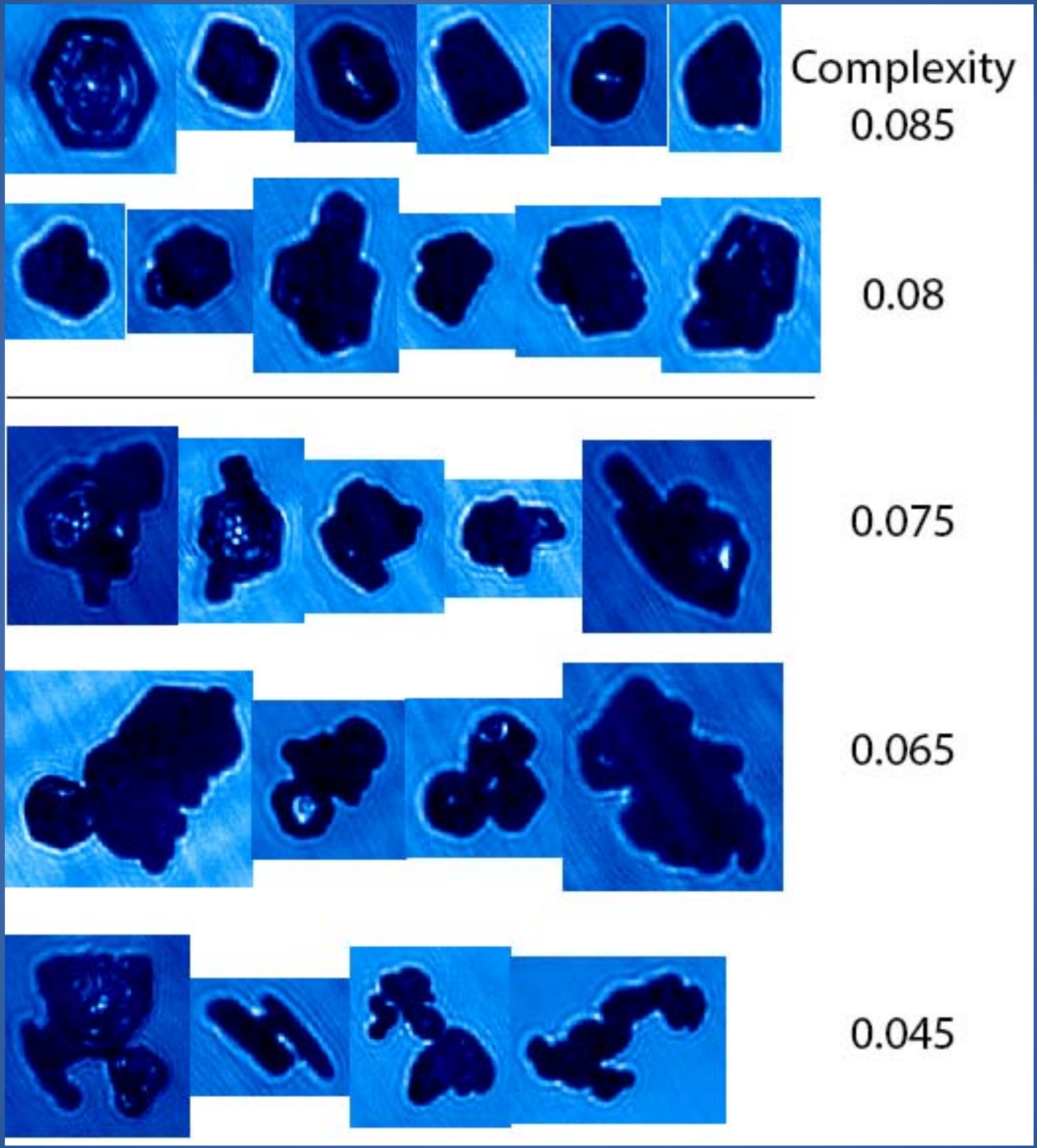


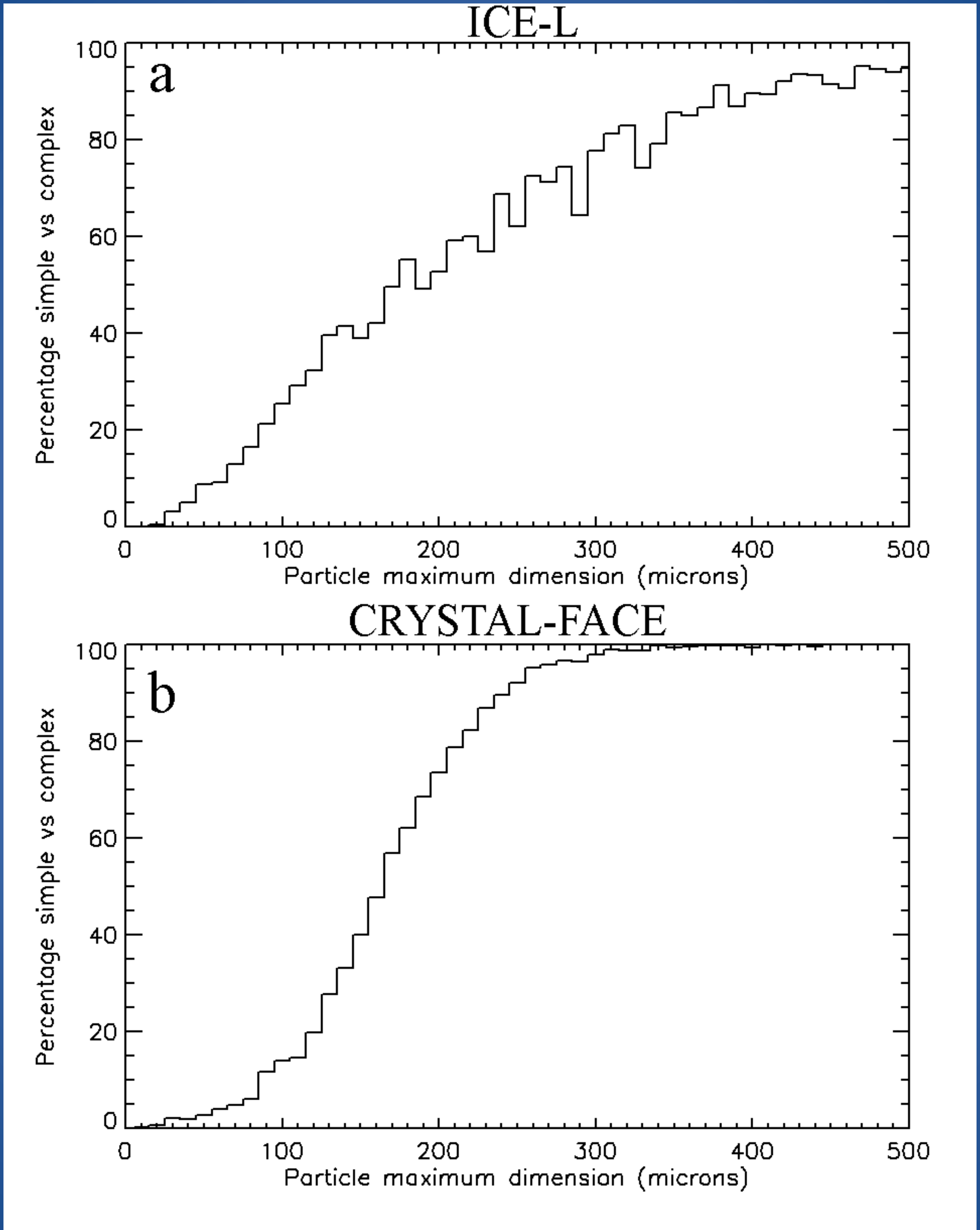


a
b
c
d
Complexity (C)
Particle maximum dimension (arbitrary)
Area Ratio
Particle maximum dimension (um)
0.00
0.02
0.04
0.06
0.08
0.10
10
100
1000
0.0
0.2
0.4
0.6
0.8
1.0

Complexity

$C = A/\sqrt{}ar\ P\uparrow 2$


Complexity
0.085
0.08
0.075
0.065
0.045


ICE-L
a
Percentage simple vs complex
Particle maximum dimension (microns)
0
20
40
60
80
100
0
100
200
300
400
500
CRYSTAL-FACE
b
Percentage simple vs complex
Particle maximum dimension (microns)
0
20
40
60
80
100
0
100
200
300
400
500

Questions?