Results from ice nucleation experiments at AIDA obtained with the HOLographic Instrument for Microscopic Objects (HOLIMO)

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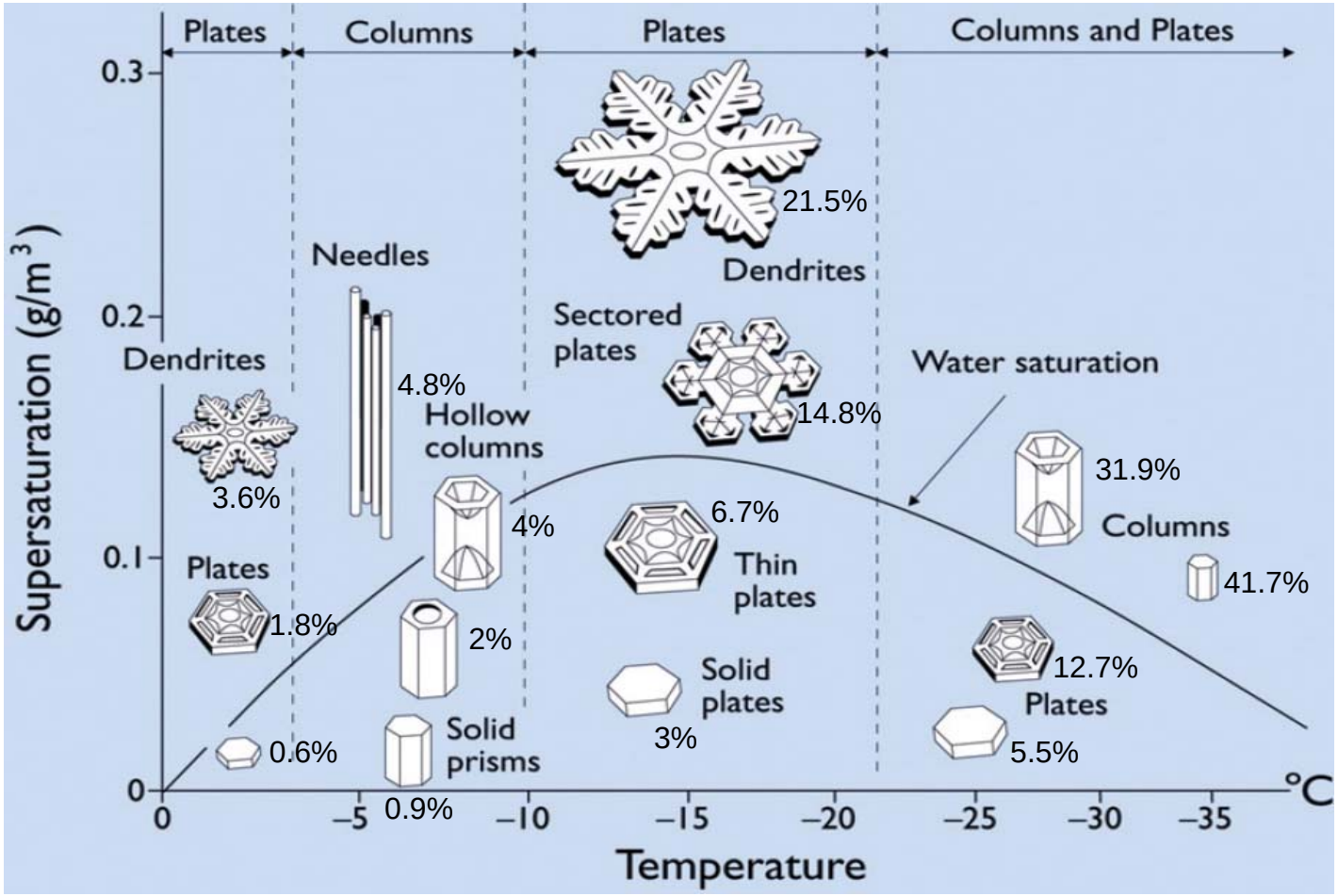
Outline

- Introduction
  - Motivation
  - Applications of holography
- Holographic instrument HOLIMO
  - Description and characterization
  - Image reconstruction and segmentation
- Results
  - AIDA campaign
- Outlook

Ice crystal habit diagram for crystal growth



Libbrecht, 2005: adapted Furakawa diagram

Depth of field

Analogy for holography

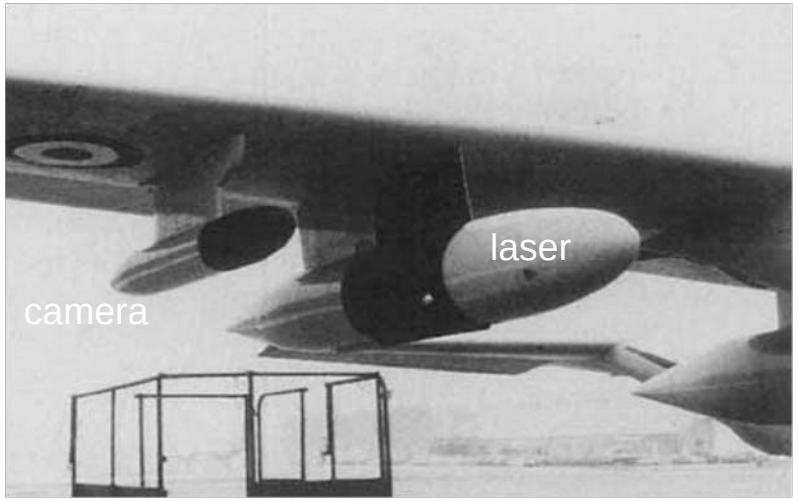
Analogy for optical microscopy

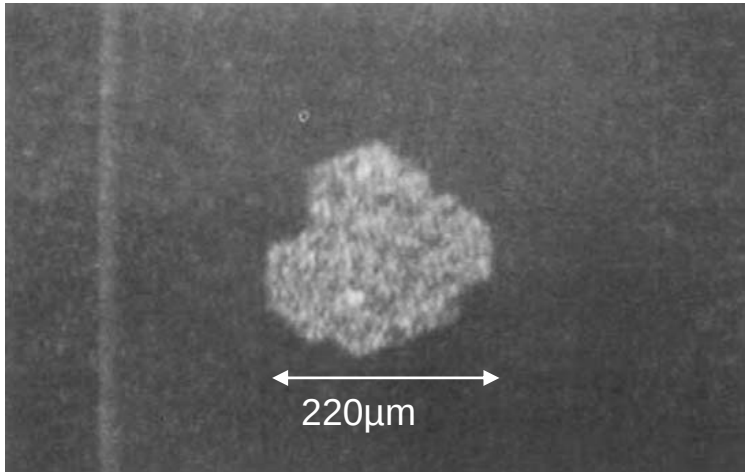
bigger observing volume with holographic probes than with optical microscopes

→ positioning and sizing in space

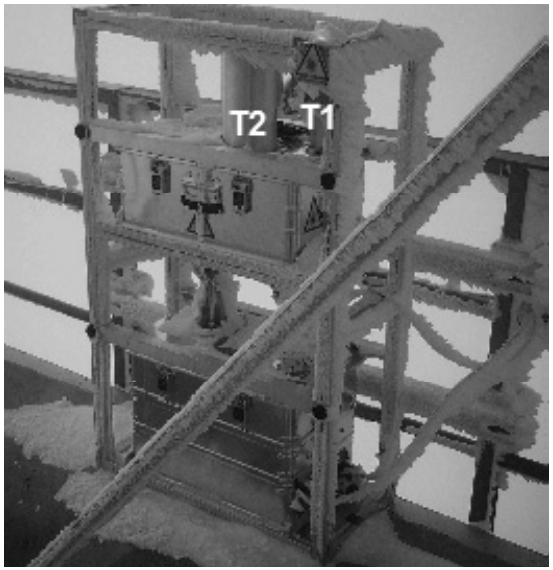
Holography in Atmospheric Science

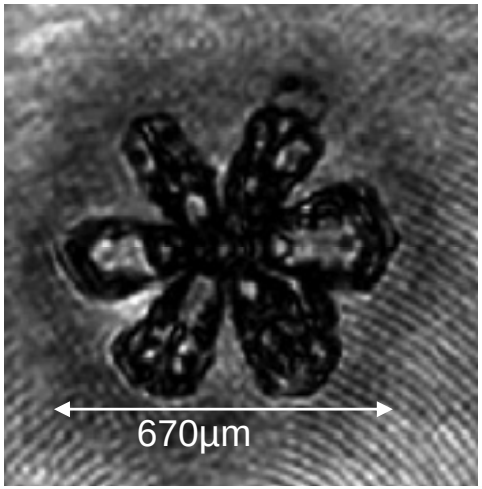
Airborne cloud physics measurements (Brown, 1989)



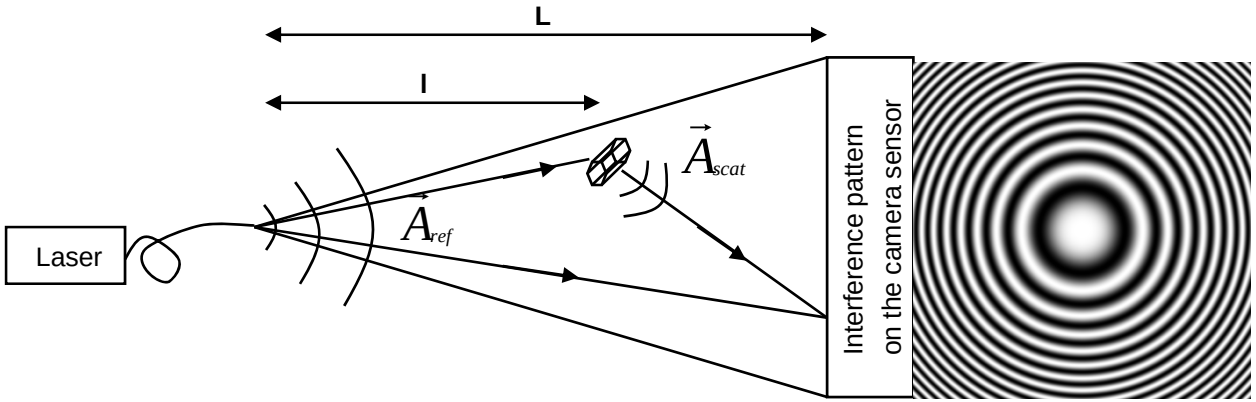


Atmospheric ice particles (Raupach et al., 2006)

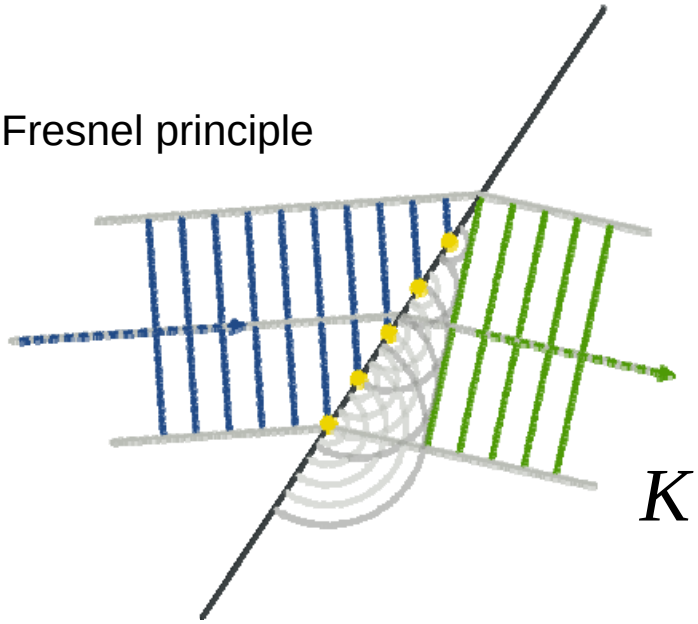




Setup and reconstruction method of HOLIMO



Huygens-Fresnel principle

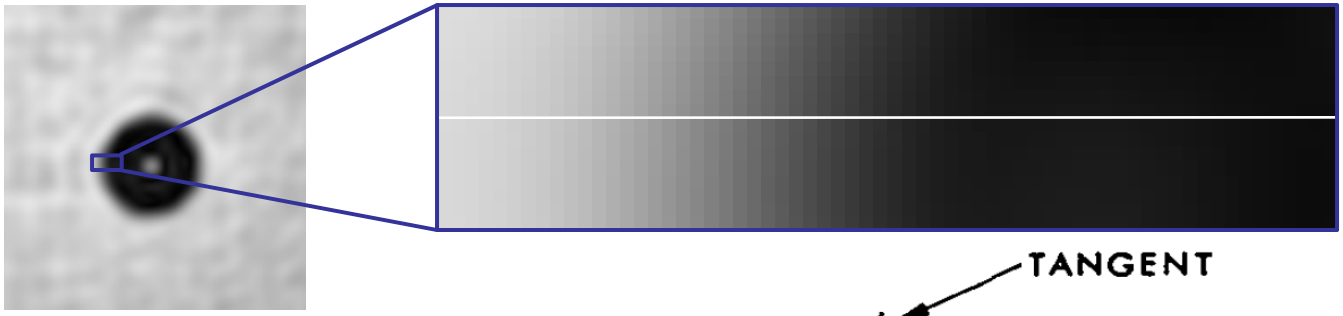


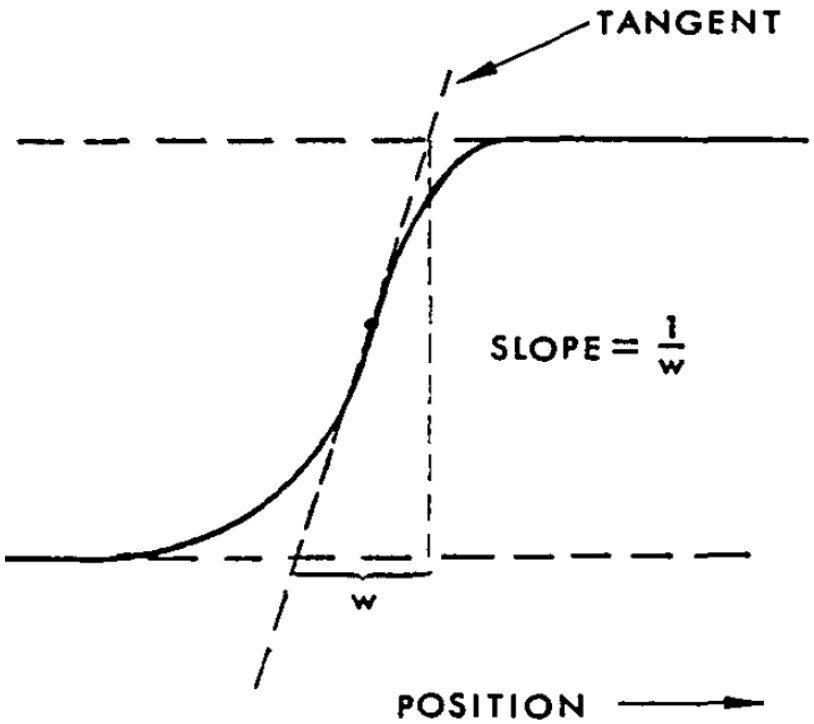
Kirchhoff-Helmholtz transformation only at far field distances

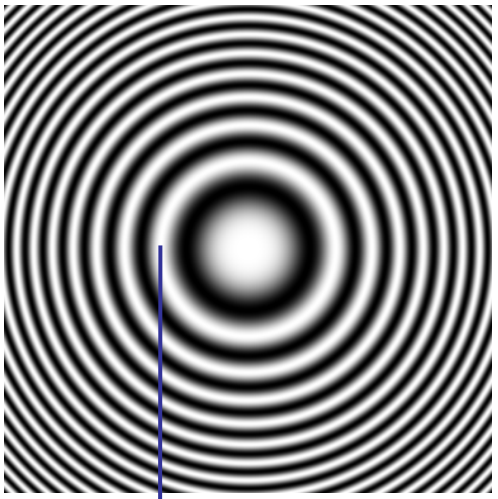
$$K(\vec{r}) = \int_A d^2\vec{\xi}\,\underbrace{\tilde{\vec{I}}(\vec{\xi})}_{\text{Image intensity}} \cdot \underbrace{e^{\frac{2\cdot\pi\cdot i\cdot\vec{\xi}\cdot\vec{r}}{\lambda\cdot\xi}}}_{\text{System response}}$$

Resolution considerations

- Robinson, 1970: Calculation of edge smear in far-field holography
  - w/d = 1/(2m), w=relative edge width, d=object size, m=amount of side lobes

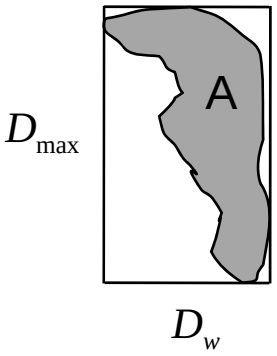






Classification scheme

- Aspect ratio $\alpha = \frac{D_w}{D_{\max}}$
- Roundness $\beta = \frac{4 \cdot A}{\pi \cdot D_{\max}^{\ 2}}$
- Equivalent sphere diameter $d_{sphere\_equiv} = 2 \cdot \sqrt{A/\pi}$



$\alpha \approx 0.72$

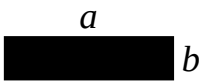
$\beta \approx 0.83$

$\alpha \approx 0.72$

$\beta \approx 0.44$

$\alpha = 1$

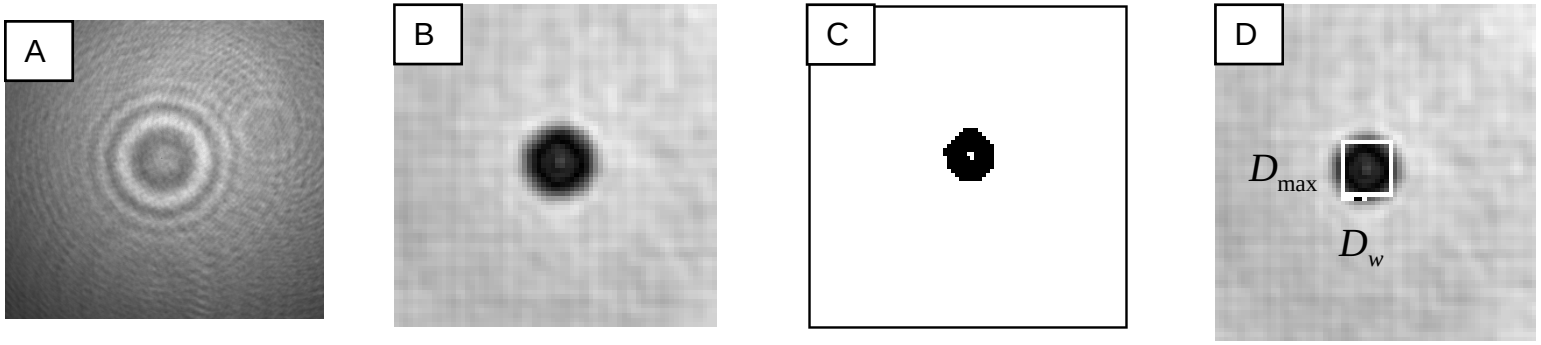
$\beta \approx 0.67$



$\alpha = \frac{2ab}{a^2 + b^2}$

$\beta = \frac{4ab}{\pi(a^2 + b^2)}$

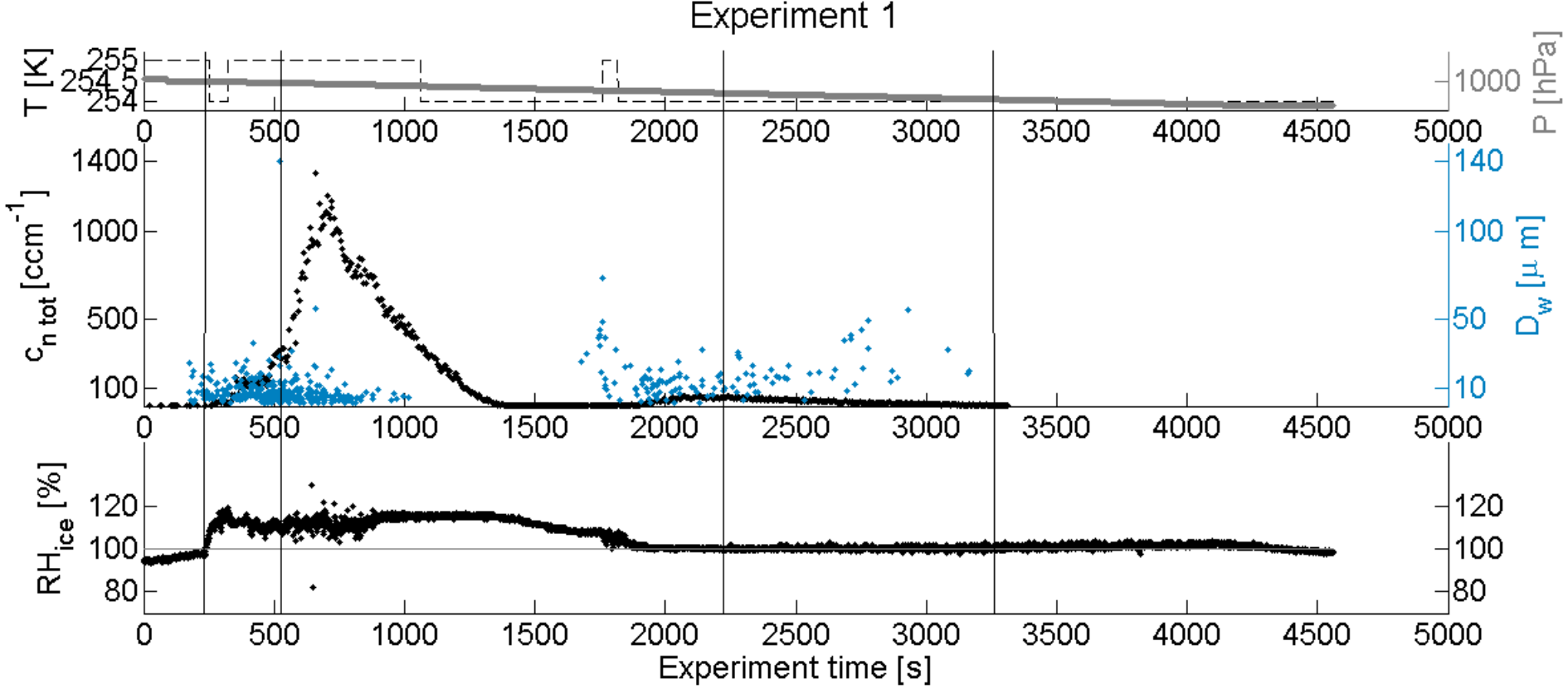
Example of reconstruction and segmentation

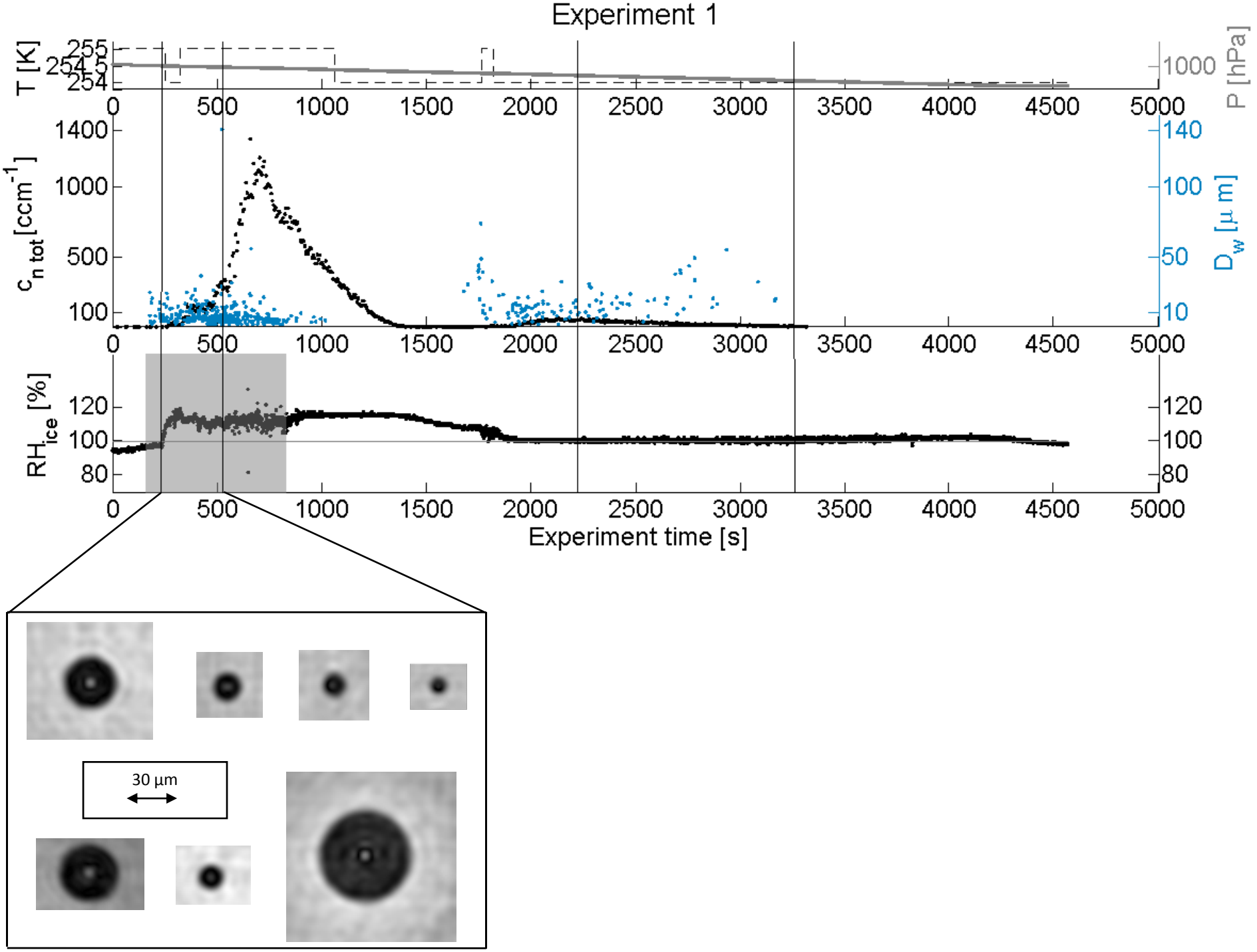


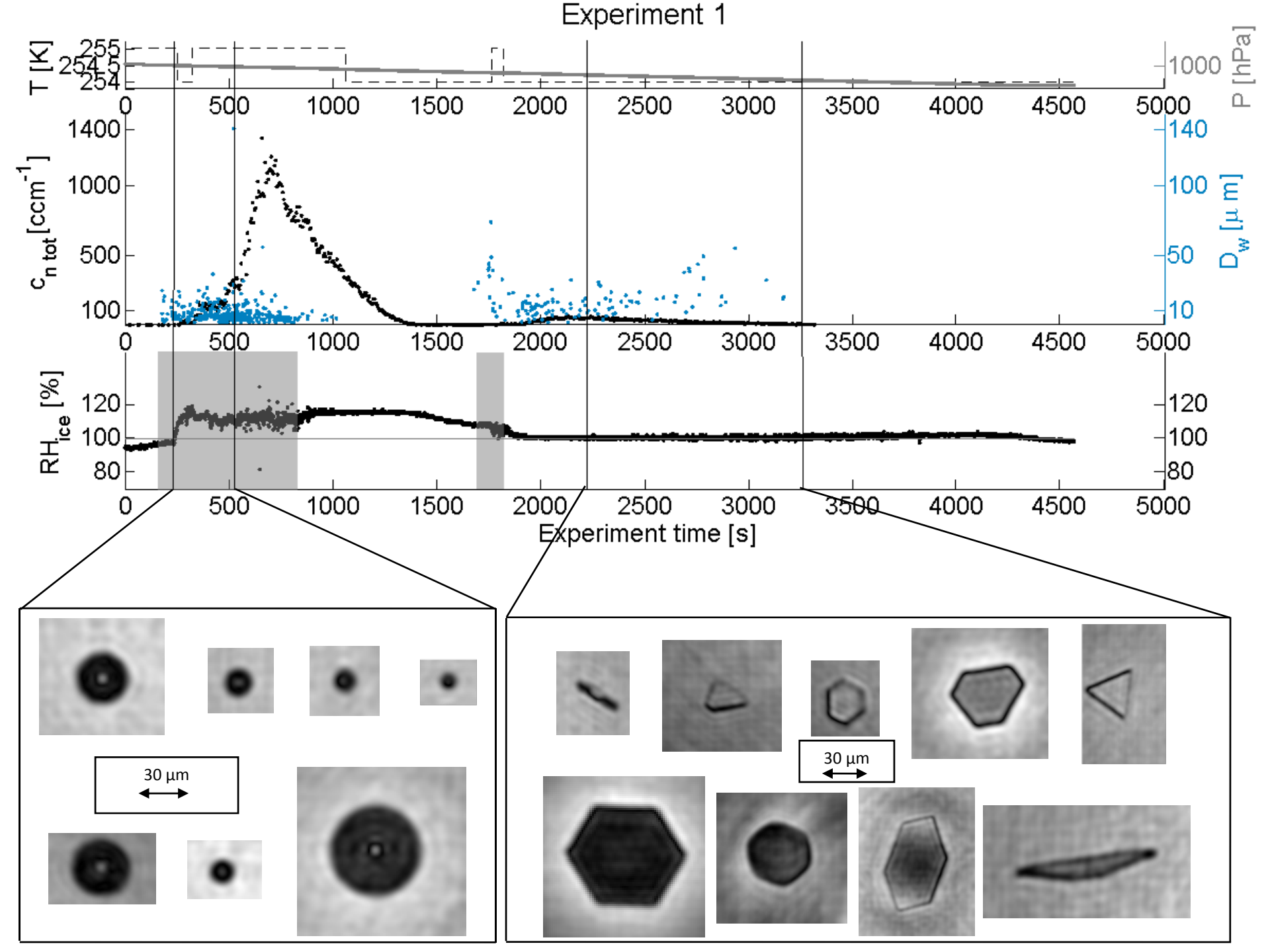
$$\alpha = \frac{D_w}{D_{\max}} = 1, \beta = \frac{4 \cdot A}{\pi \cdot D_{\max}{}^2} \approx 1: \qquad \text{Droplike (cirular)}$$

Results of the AIDA campaign IN11

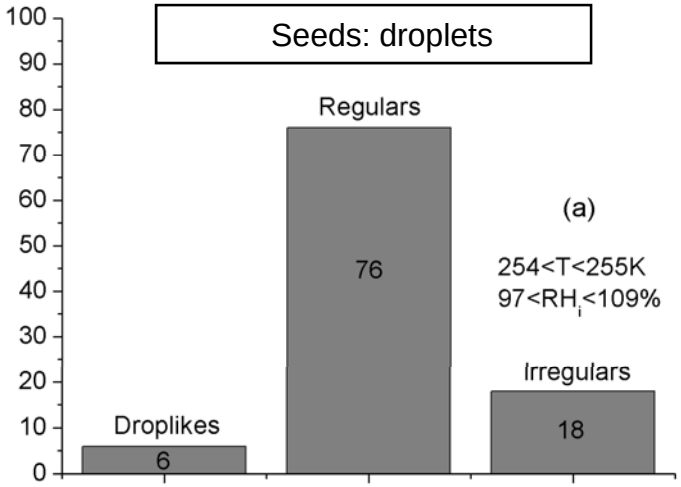
day		aerosol	AIDA wall T (°C)	remarks
12/11	(Mo)	Ice seeds	-18	Mixed phase clouds
14/11	(Mi)	SA, ice seeds	-21	Mixed phase clouds
15/11	(Do)	SA	-43	SuccAcid coated
19/11	(Mo)	GFG soot	-45	uncoated
21/11	(Mi)	GFG soot	-45	SuccAcc coated

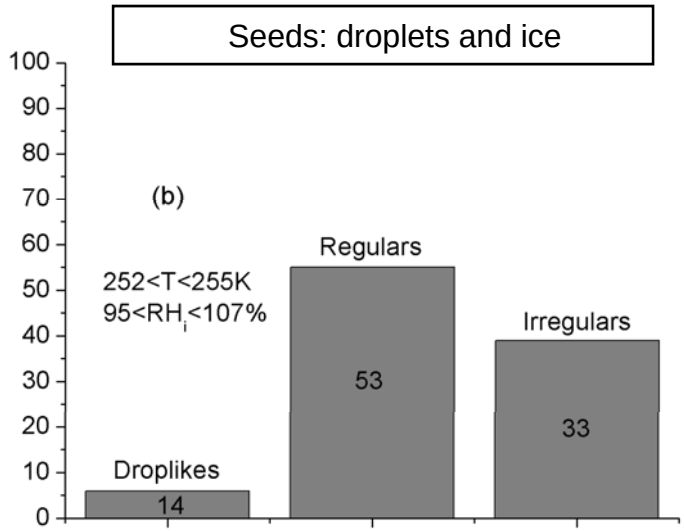

Experiment 1
T [K]
255
254.5
254
1000
P [hPa]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
1400
1000
500
100
$c_{n\ tot}$ [ccm^{-1}]
140
100
50
10
D_w [μ m]
RH_{ice} [%]
120
100
80
Experiment time [s]

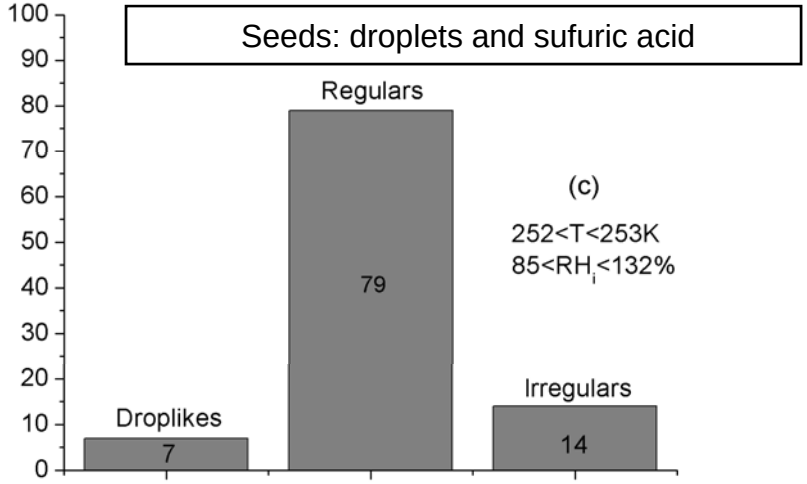

Experiment 1
T [K]
P [hPa]
$c_{n\,tot}$ [ccm^{-1}]
D_w [µ m]
RH_{ice} [%]
Experiment time [s]
30 µm

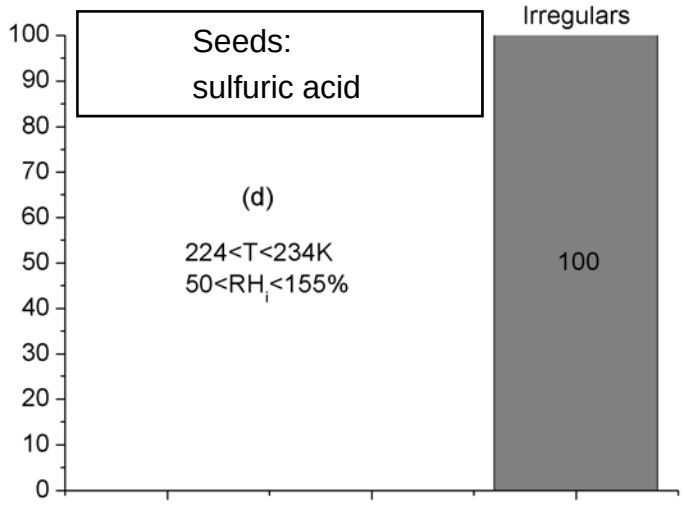

Experiment 1
T [K]
255
254.5
254
P [hPa]
1000
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
$c_{n\ tot}$ [ccm^{-1}]
1400
1000
500
100
D_w [µ m]
140
100
50
10
RH_{ice} [%]
120
100
80
Experiment time [s]
30 µm
30 µm

Frequency of occurrence of hydrometeors with sizes smaller than 60µm obtained from 4 different experiments









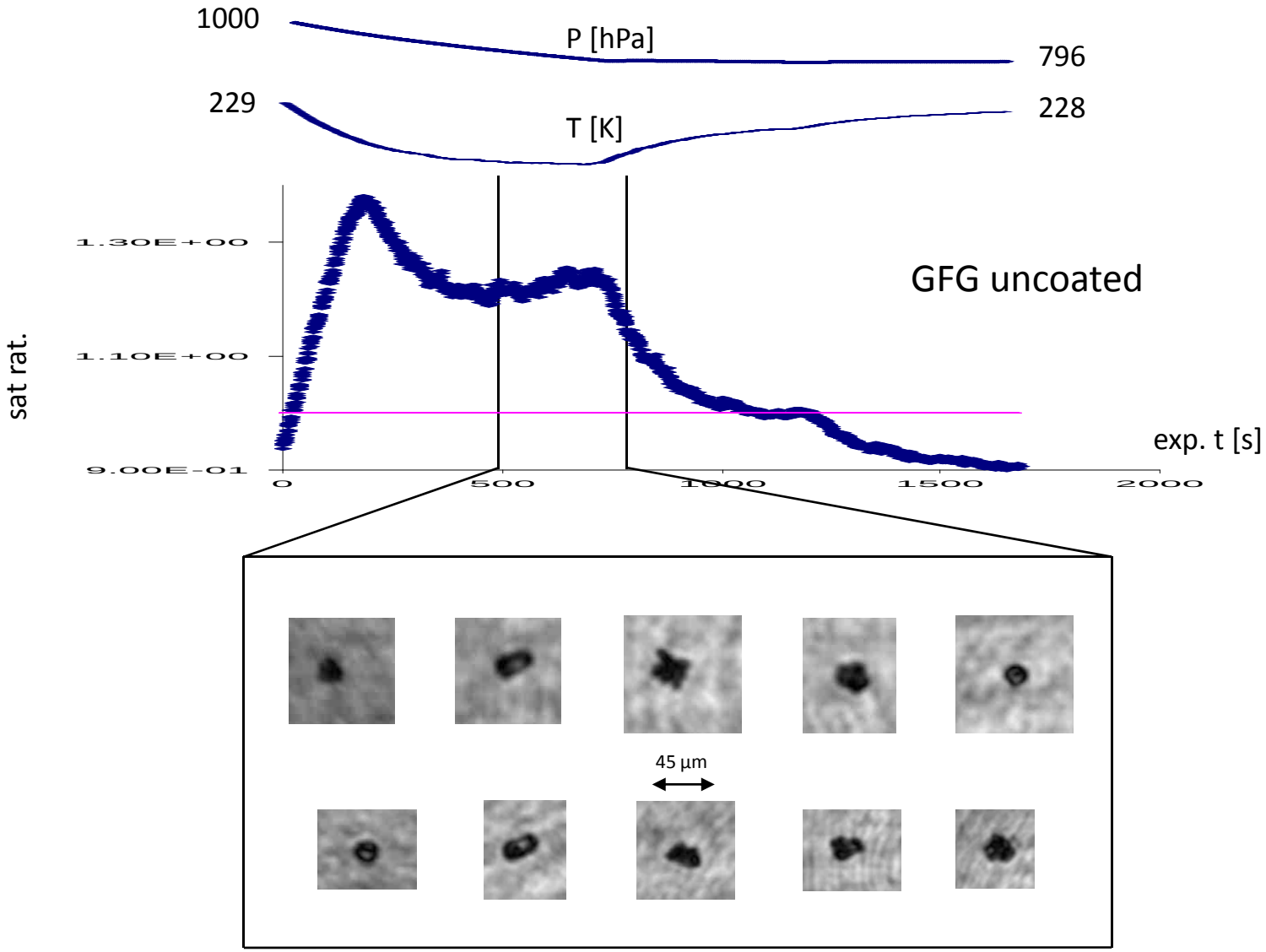
Conclusion and outlook

- Successful feasibility study for the holographic instrument at AIDA
  - Investigation of ice nucleation ability of inorganic aerosols
  - Evaluation of ice nucleation ability of coated and uncoated soot particles in progress
- Improvement of the holographic instrument for further campaigns

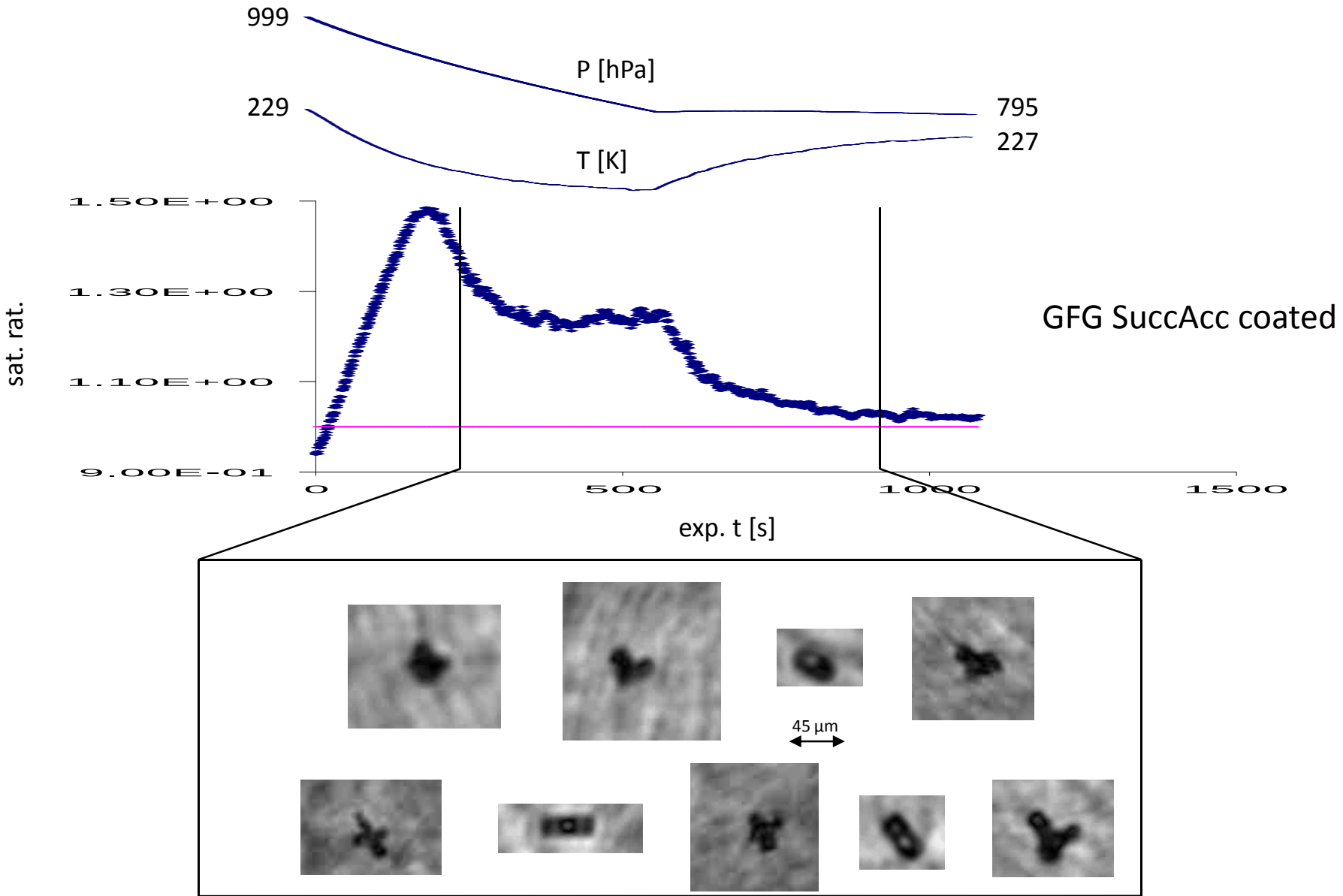
PRELIMINARY RESULTS

- Week 2
- Soot aerosols (coated/uncoated)
- Experiments 14 and 18

Experiment 14



Experiment 18

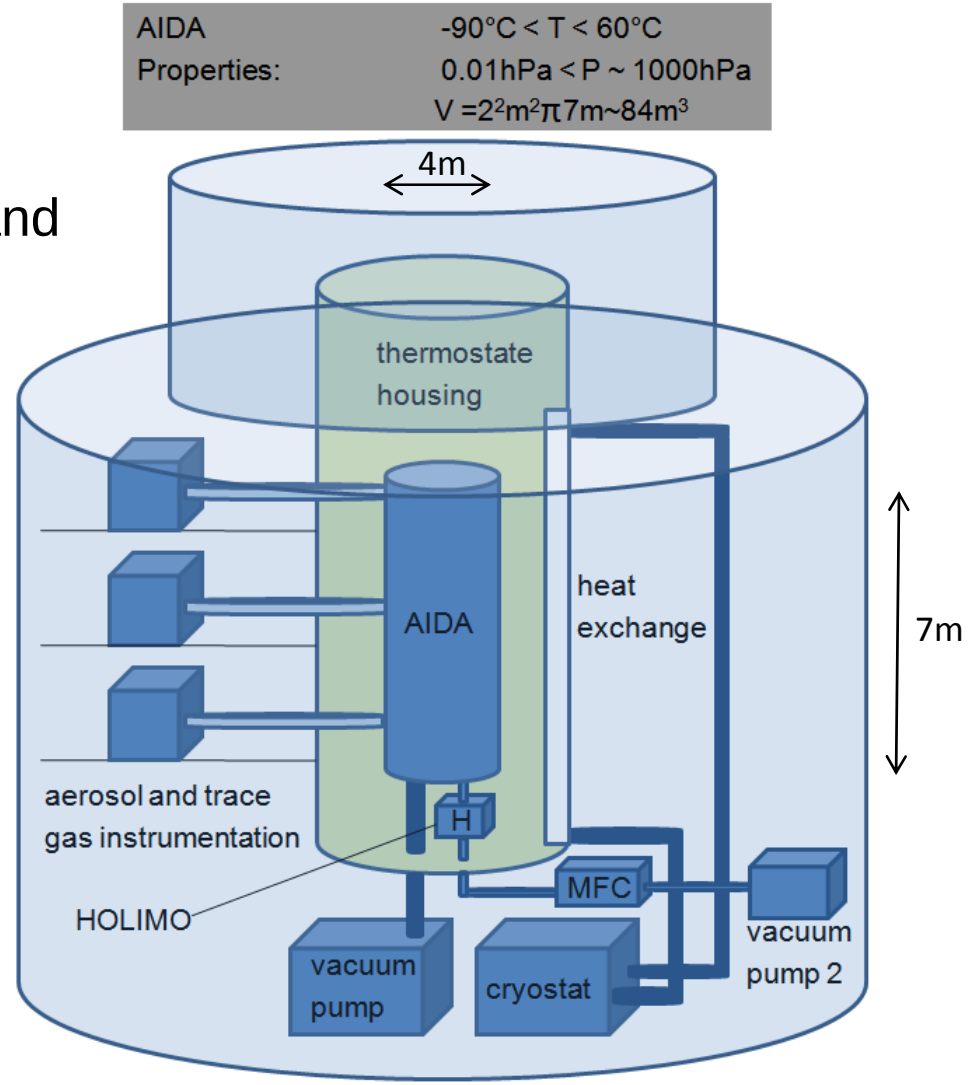


Appendix

Results of the AIDA campaign

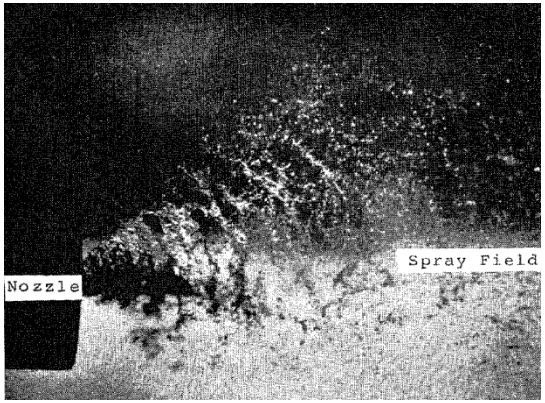
-- Ice particle habit evolution in mixed phase clouds

Supersaturation via temperature and adiabatic expansion



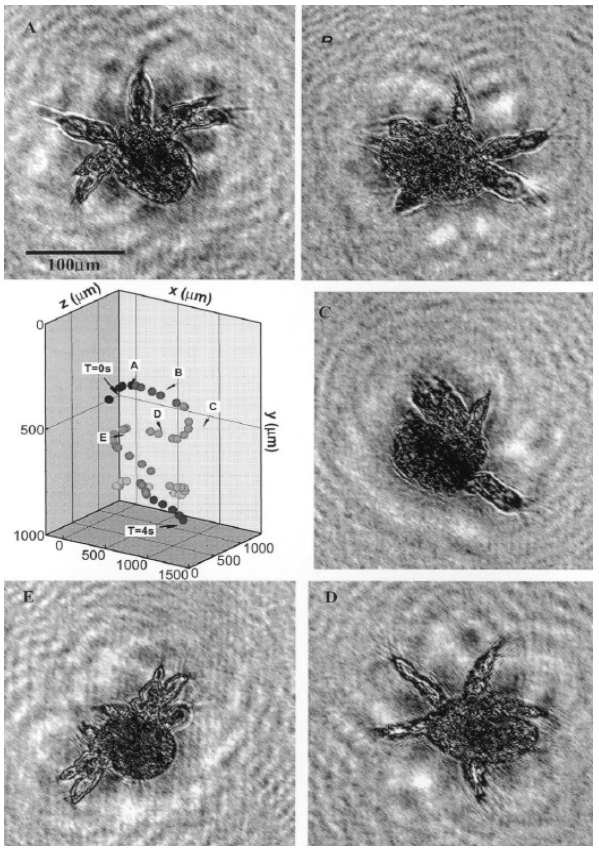
Applications of holography

Holography of nozzles, jets and sprays



(Trolinger et al., 1975)

3D particle distributions and motions
- free swimming copepod (crayfish) nauplius

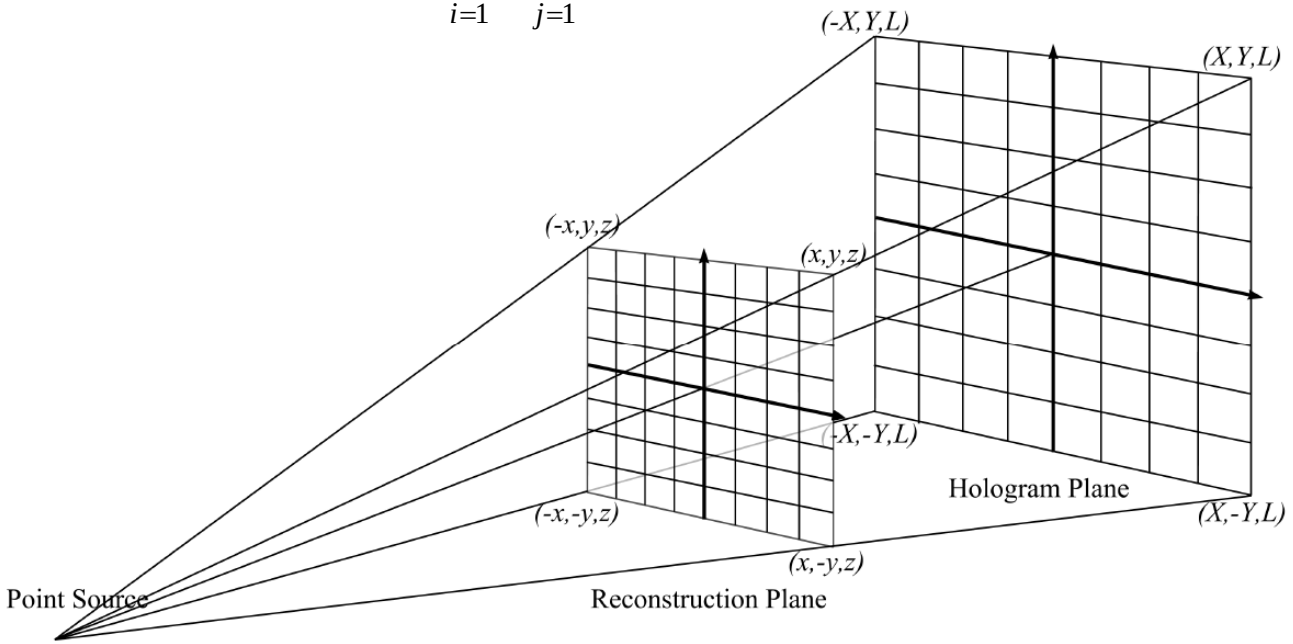


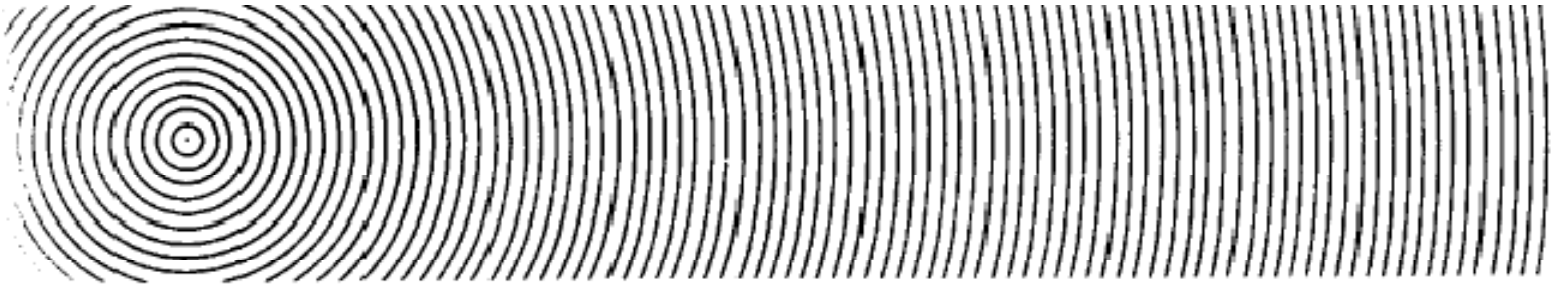
(Sheng et al., 2006)

Kirchhoff-Helmholtz transformation

Finite pixel amount of Camera leads to discretized KH transformation

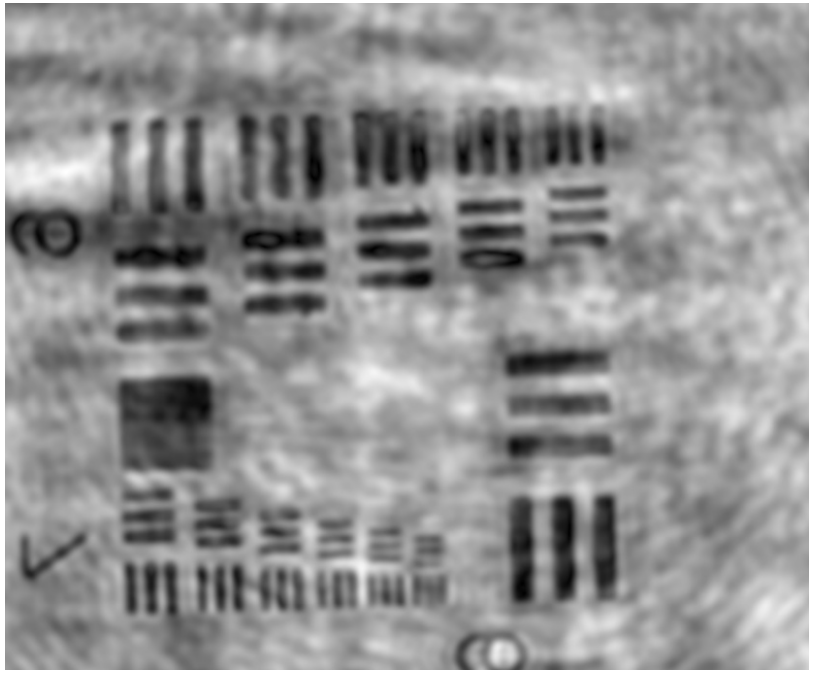
$$KH(x,y;l)=\sum_{i=1}^{n}\sum_{j=1}^{n}\tilde{I}(i,j;L)\,e^{\frac{2\cdot\pi\cdot i}{\lambda}\frac{x\cdot X+y\cdot Y+l\cdot L}{\sqrt{X\cdot X+Y\cdot Y+L\cdot L}}}$$





Spherical **Paraboloidal** **Planar**

Resolution considerations with the USAF 1951 target



Smallest line: 4.4 µm