In-situ Observations of Ice Crystal Habits, Their Crystal Complexity and Light Scattering Properties During ACRIDICON-CHUVA

ACRIDICON-CHUVA Workshop, Ilhabela

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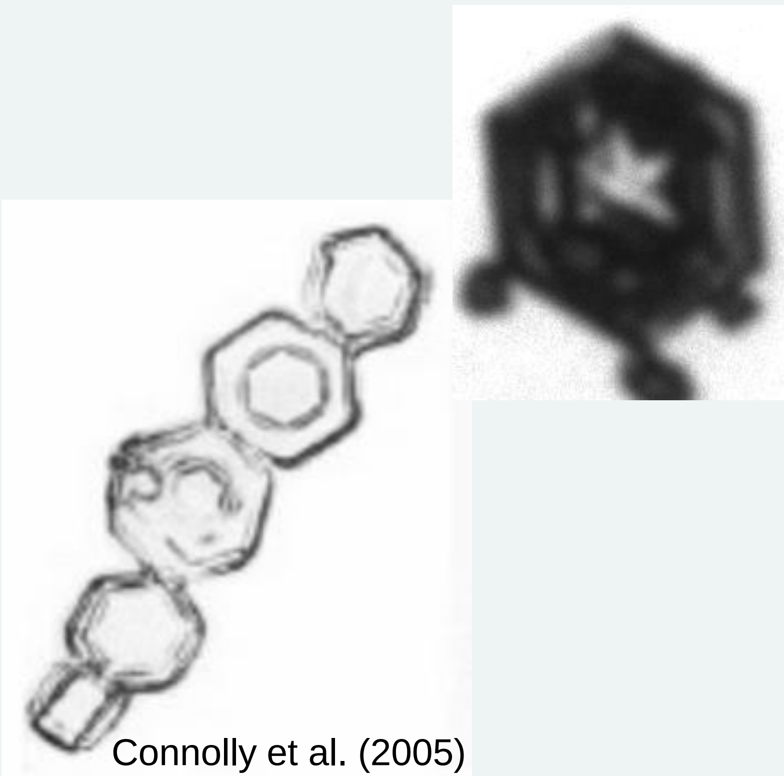
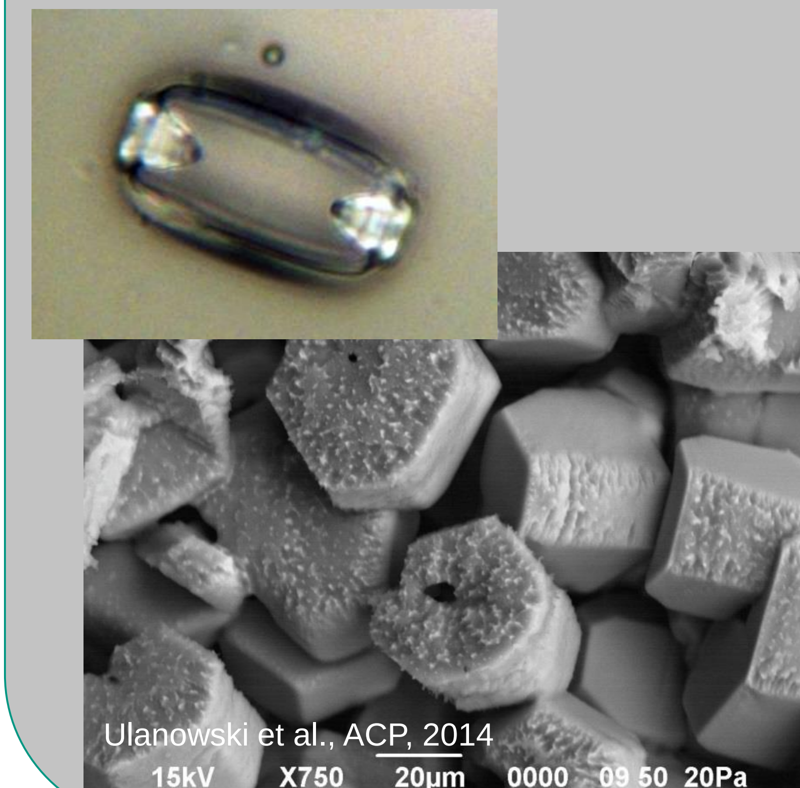
Ice crystal complexity

Large-scale complexity



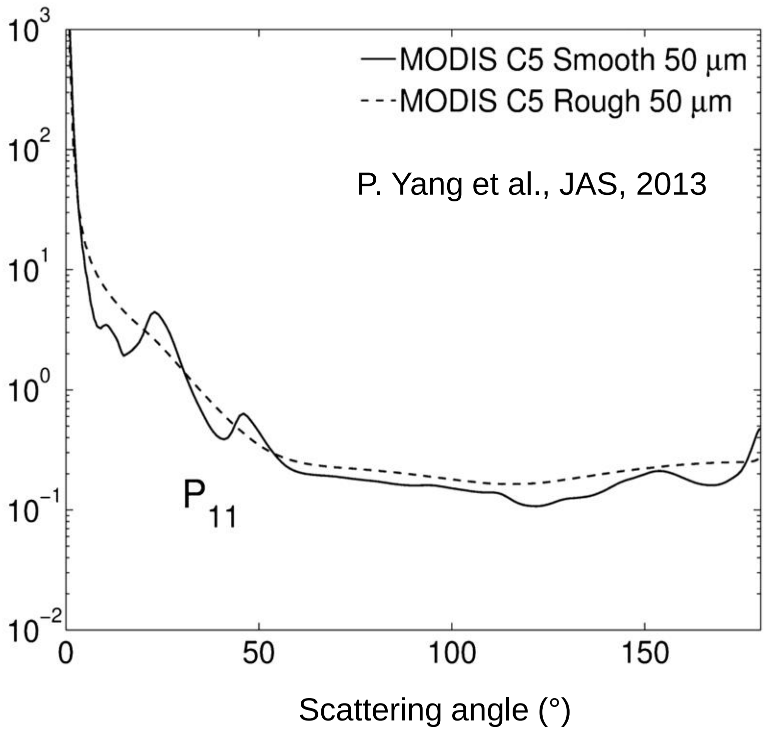
Connolly et al. (2005)

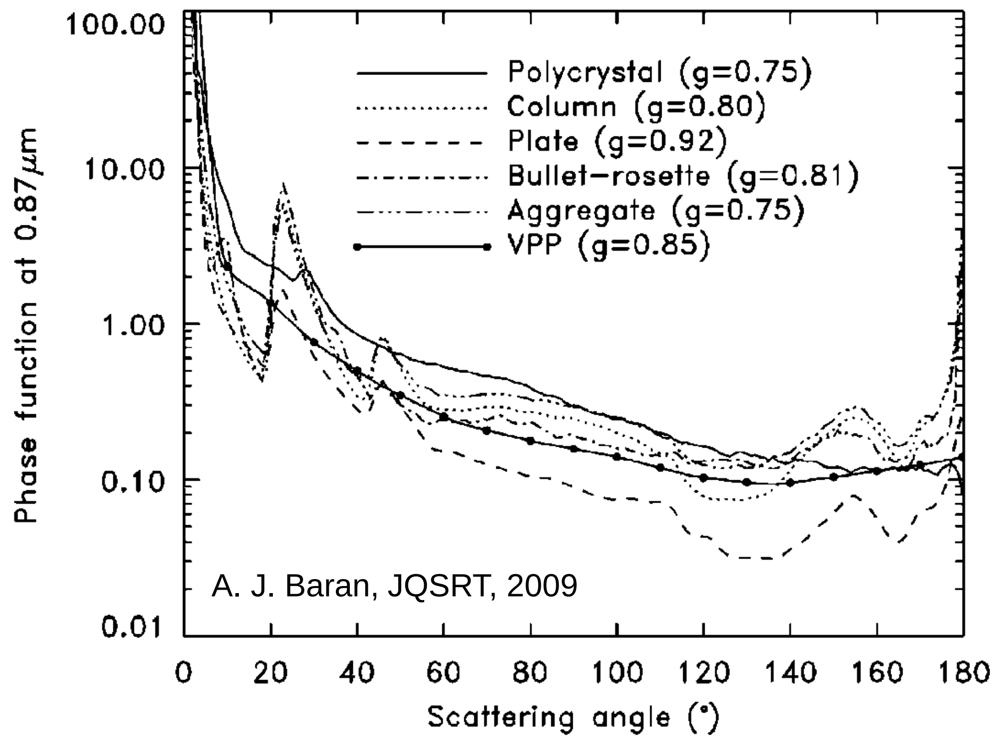
Small-scale complexity



Ulanowski et al., ACP, 2014

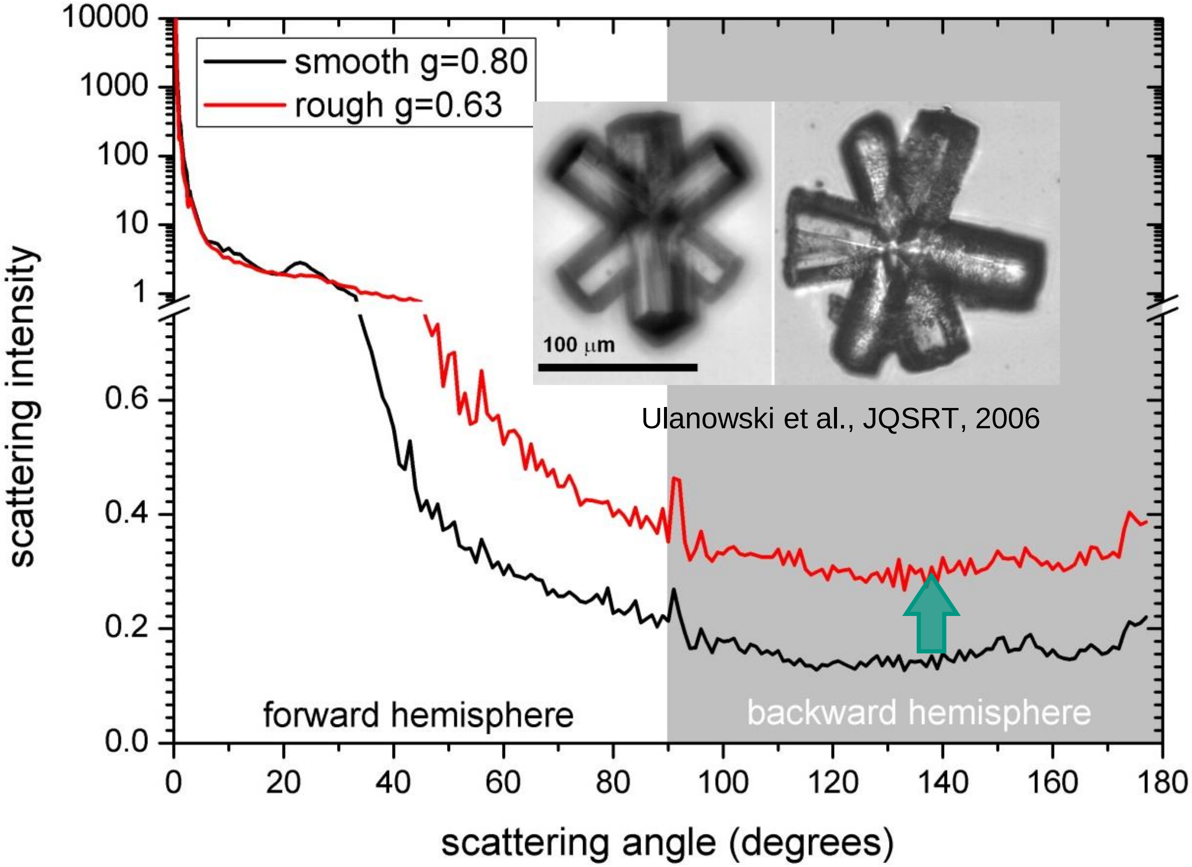
Complex particles – similar light scattering





- Scattering phase function of ice particles depend on their shape and complexity (aggregation, polycrystals, surface roughness, hollowness, etc.)
- Polycrystal and roughened ice particles show a **featurless scattering function**

Ice Crystal Complexity Increases Back Reflection



- Lab and modeling studies show that roughness reduces the asymmetry parameter

  2 times higher back reflection

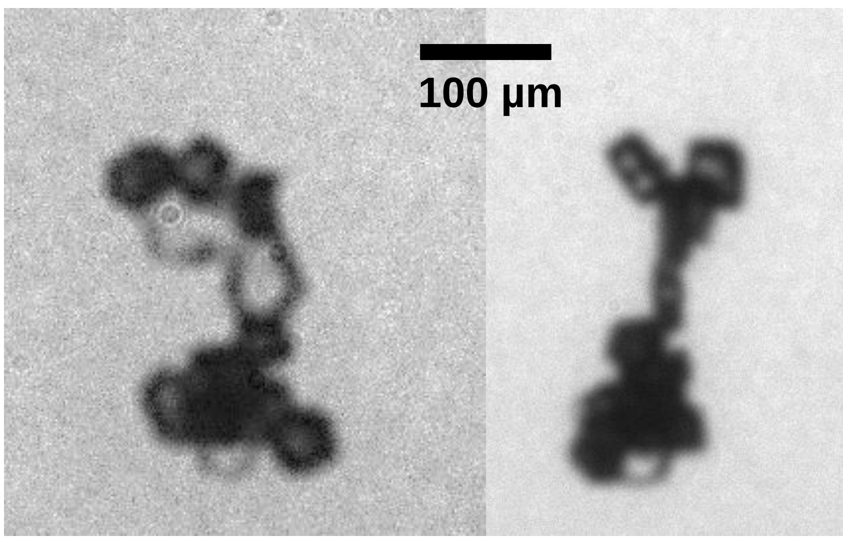
PHIPS / SID-3 Package on-board HALO

HALO (**H**igh **A**ltitude and **Lo**ng Range Research Aircraft)

PHIPS/SID-3 Instrument Package

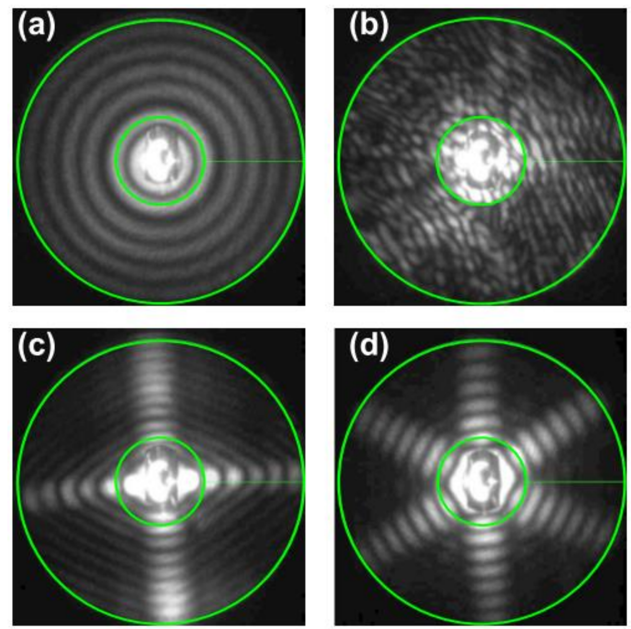
PHIPS-HALO

- Polar light scattering function (1° to 170°) of single ice particles
- Simultaneous stereoscopic (3D) imaging of the same particle
- **Large-scale complexity** (50 µm – 1 mm)



SID-3

- Spatial light scattering (diffraction) pattern in forward direction (6° to 25°)
- Shape information especially for small particles (5 - 50 µm)
- **Small-scale complexity**



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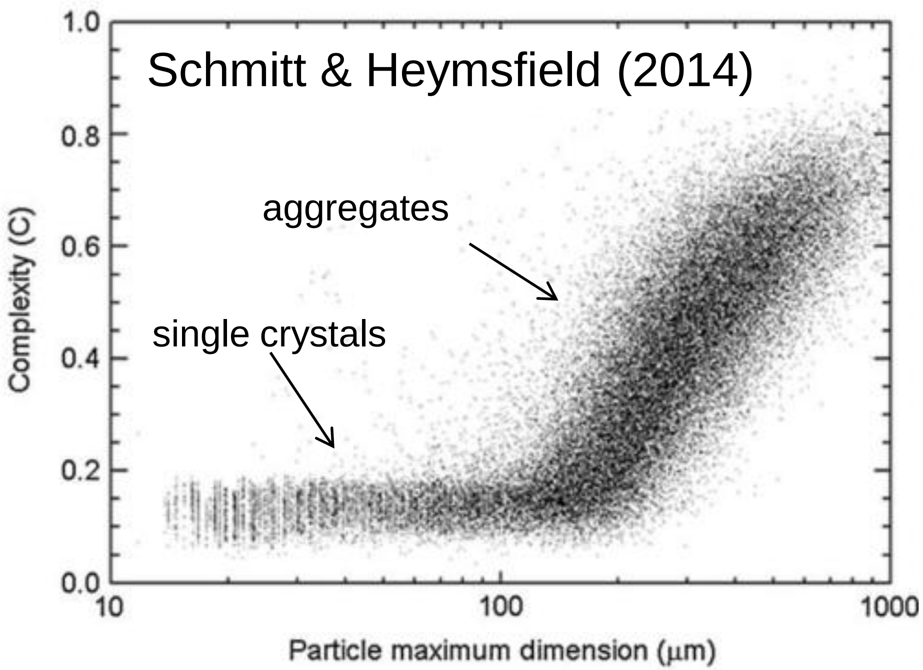
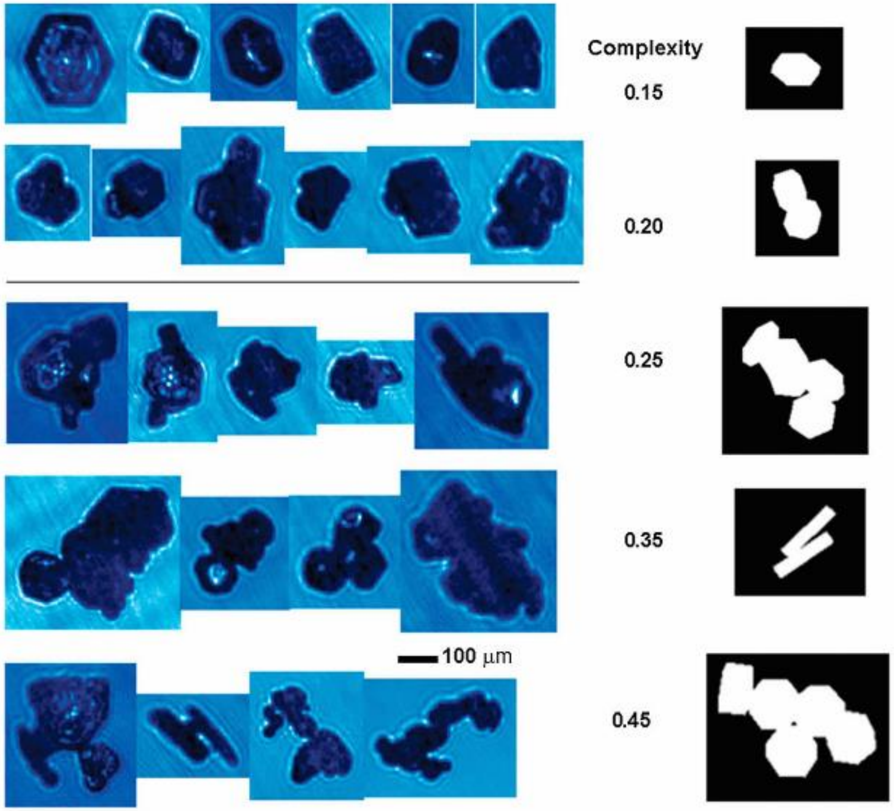
Large-Scale Complexity

$$C' = \frac{A}{\sqrt{ar}P^2}$$

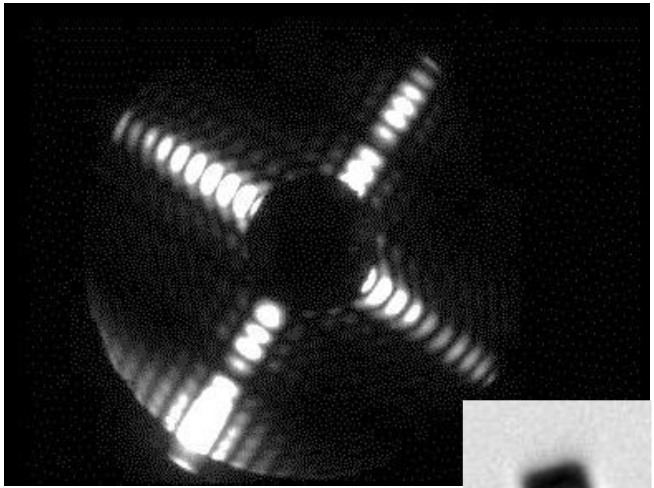


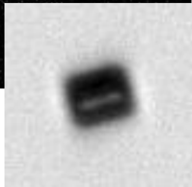


Small-scale Ice Crystal Complexity

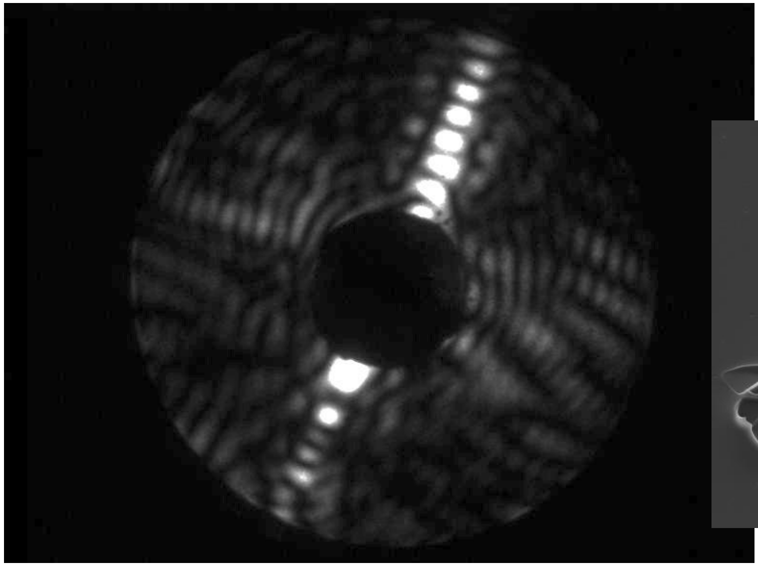
Crystal complexity leads to spatially randomized light scattering. The shape distinct diffraction features will disappear.

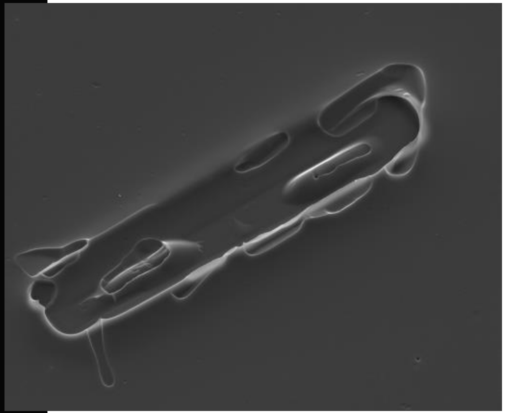
Pristine column





Roughened or distorted column





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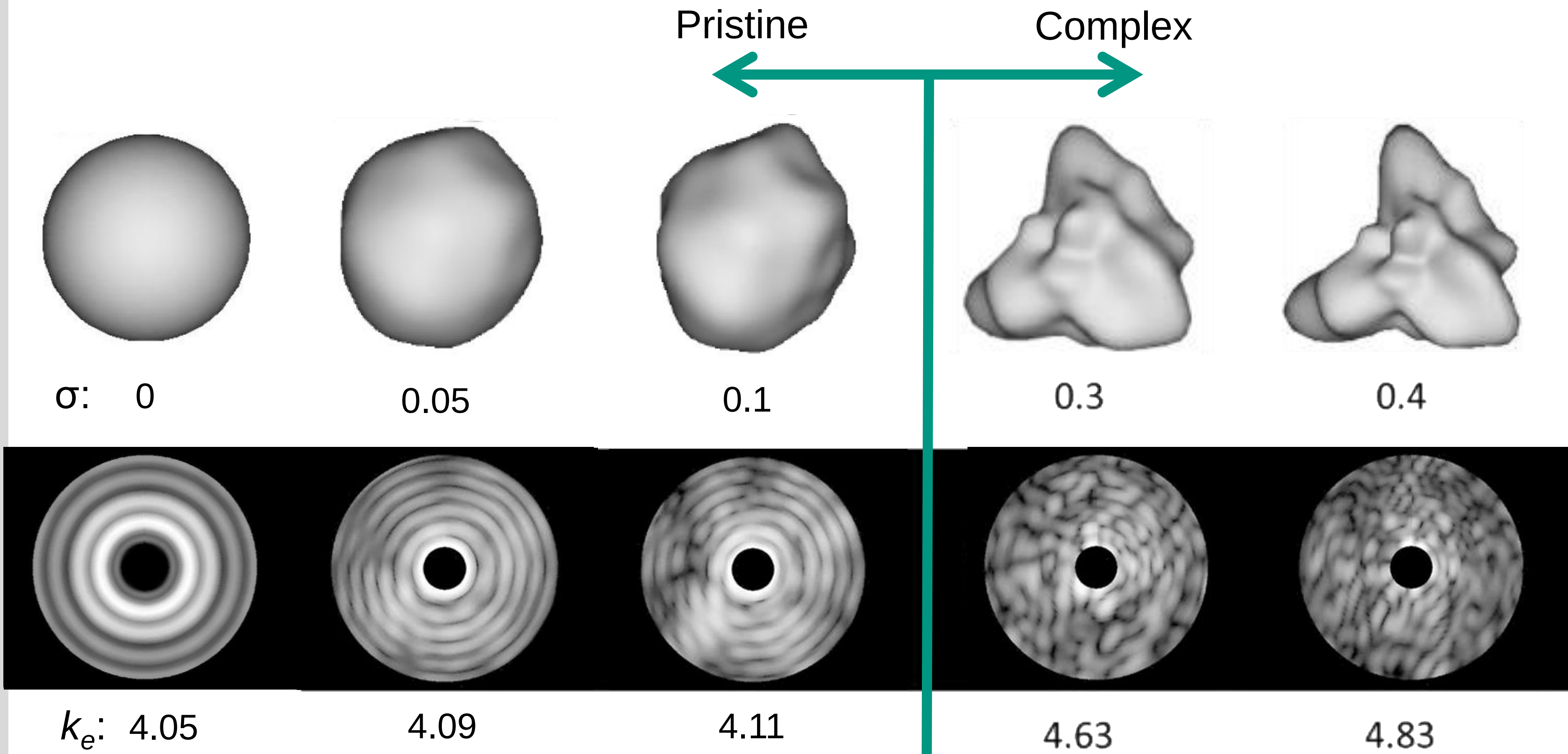
Quantification of Small-scale Complexity through k_e



Schnaiter et al., *ACPD*, 2015

$\boxed{\sigma \sim k_e}$

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Ice Crystal Habits

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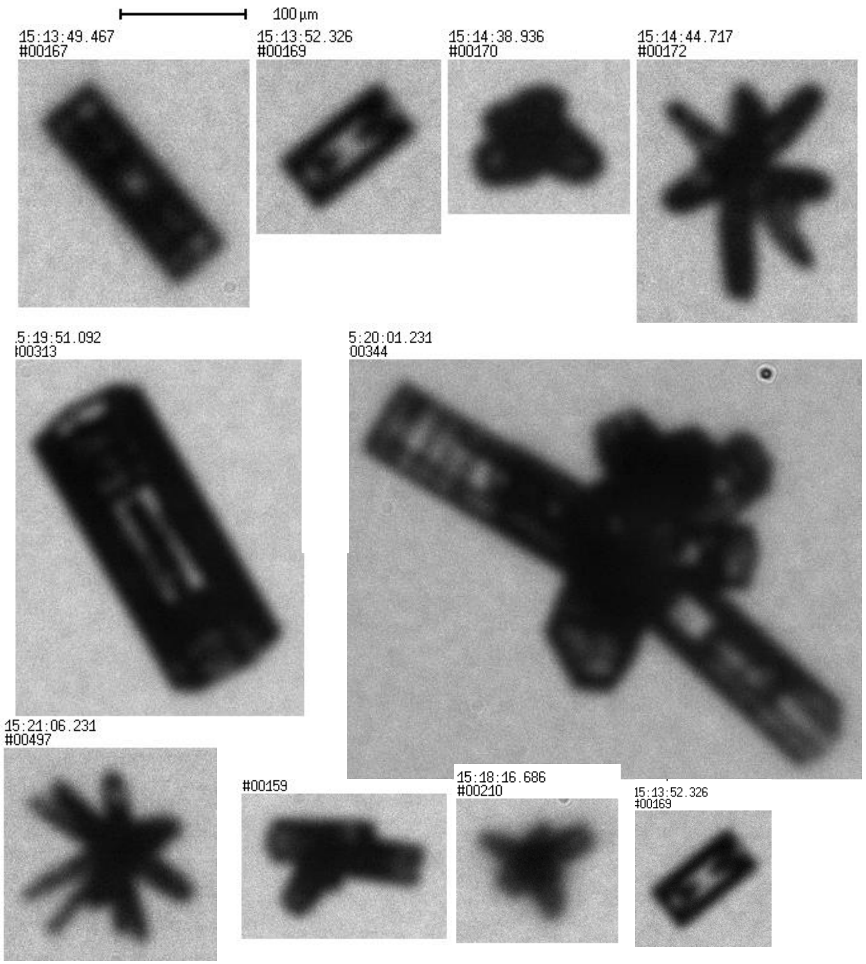
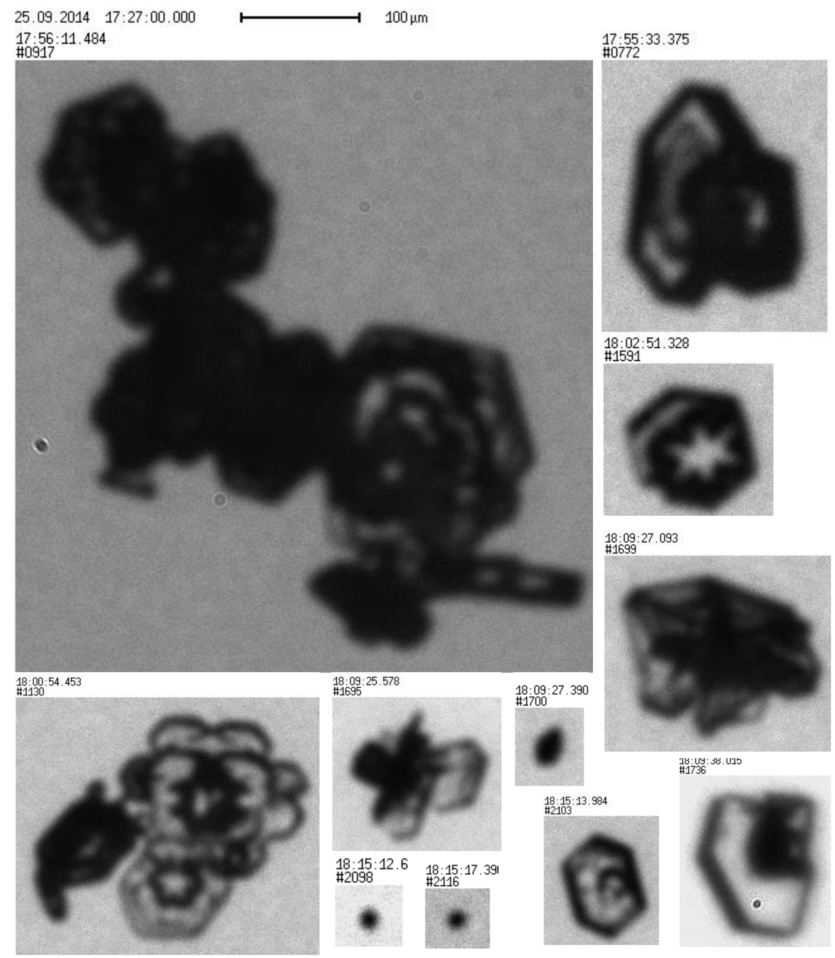
Particle Habit Classification: in-situ vs outflow

In-situ cirrus



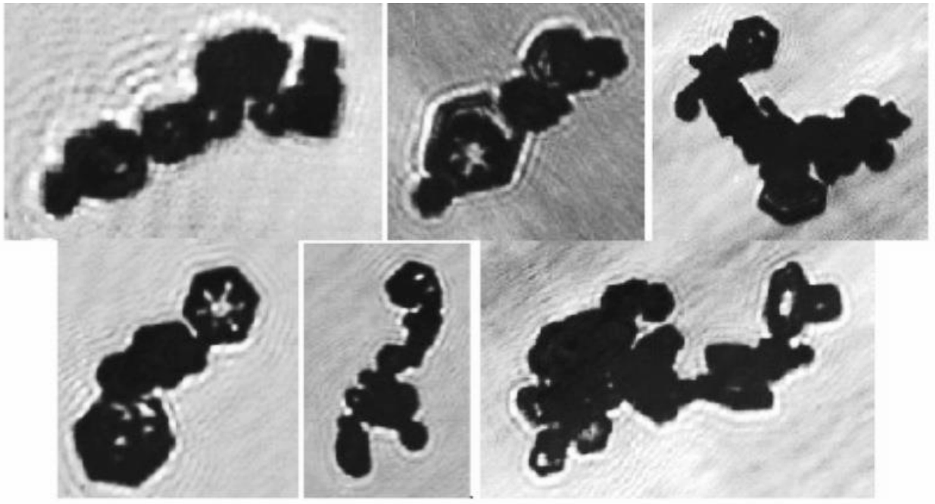
Outflow cirrus

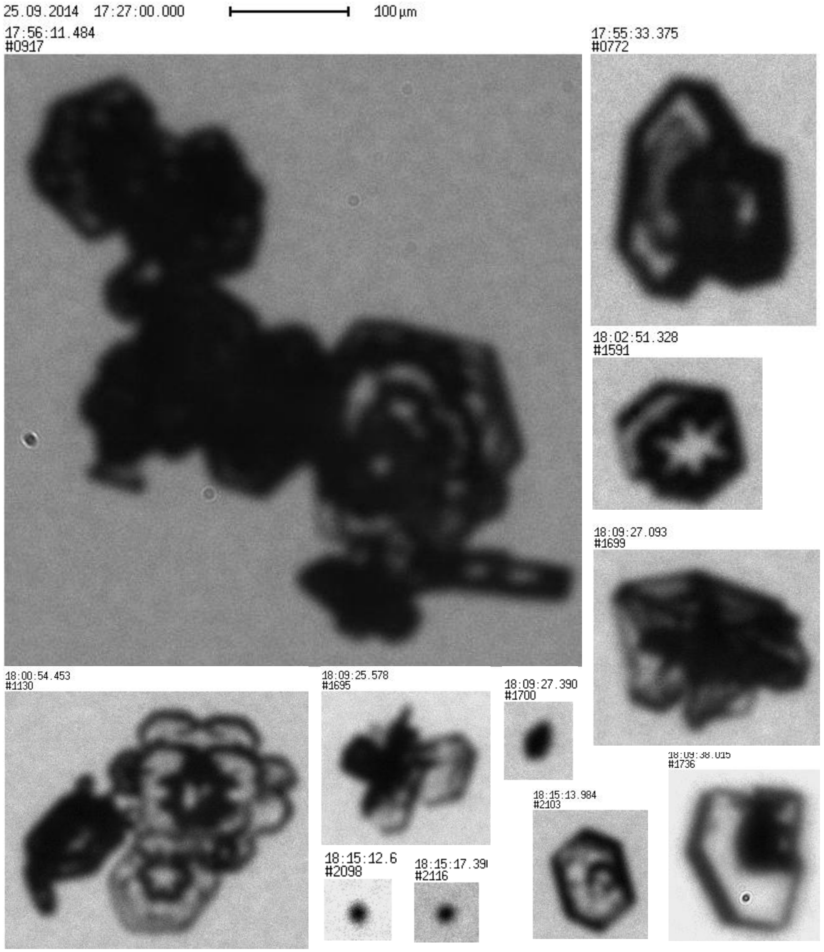


Particle Habit Classification: in-situ vs outflow

Outflow cirrus

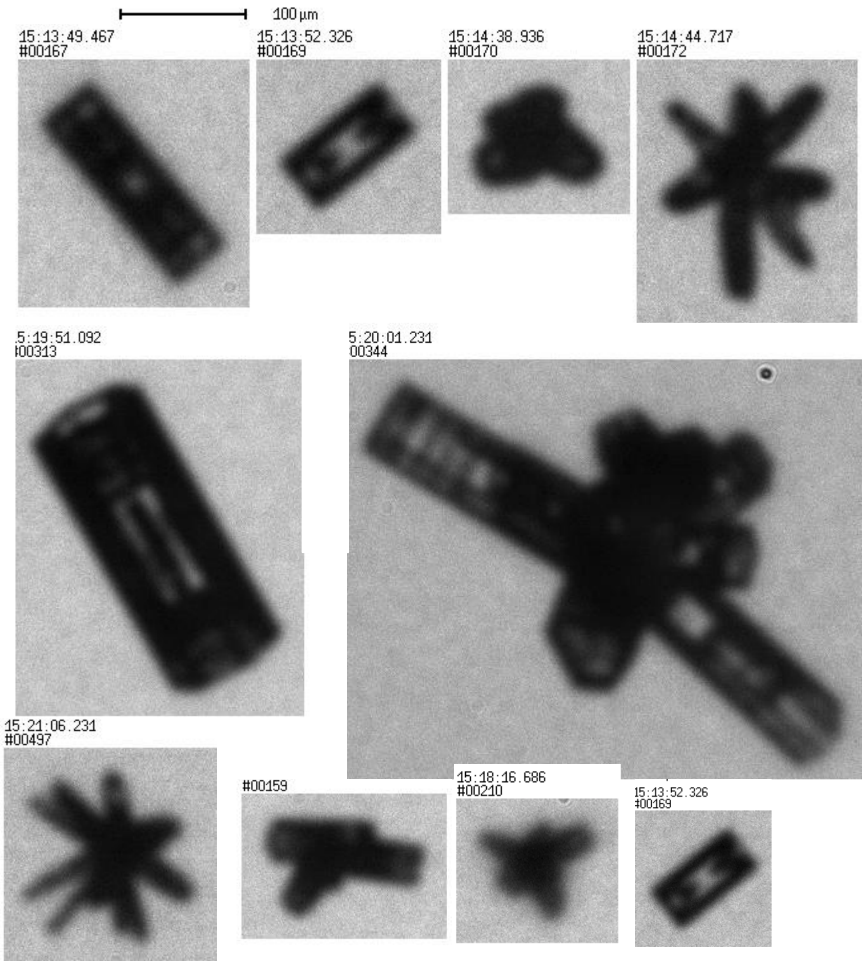
Connolly et al. (2015)



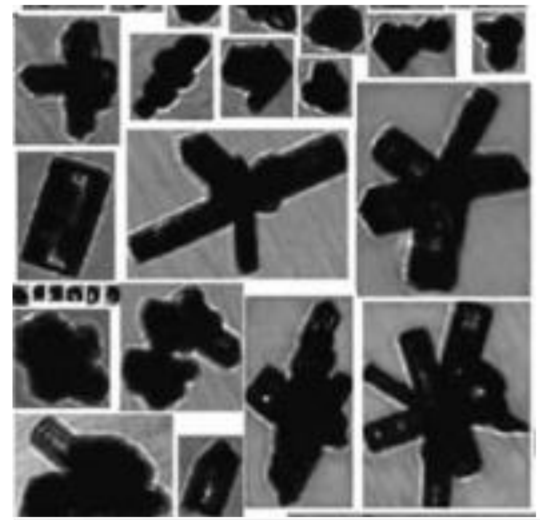


Particle Habit Classification: in-situ vs outflow

In-situ cirrus



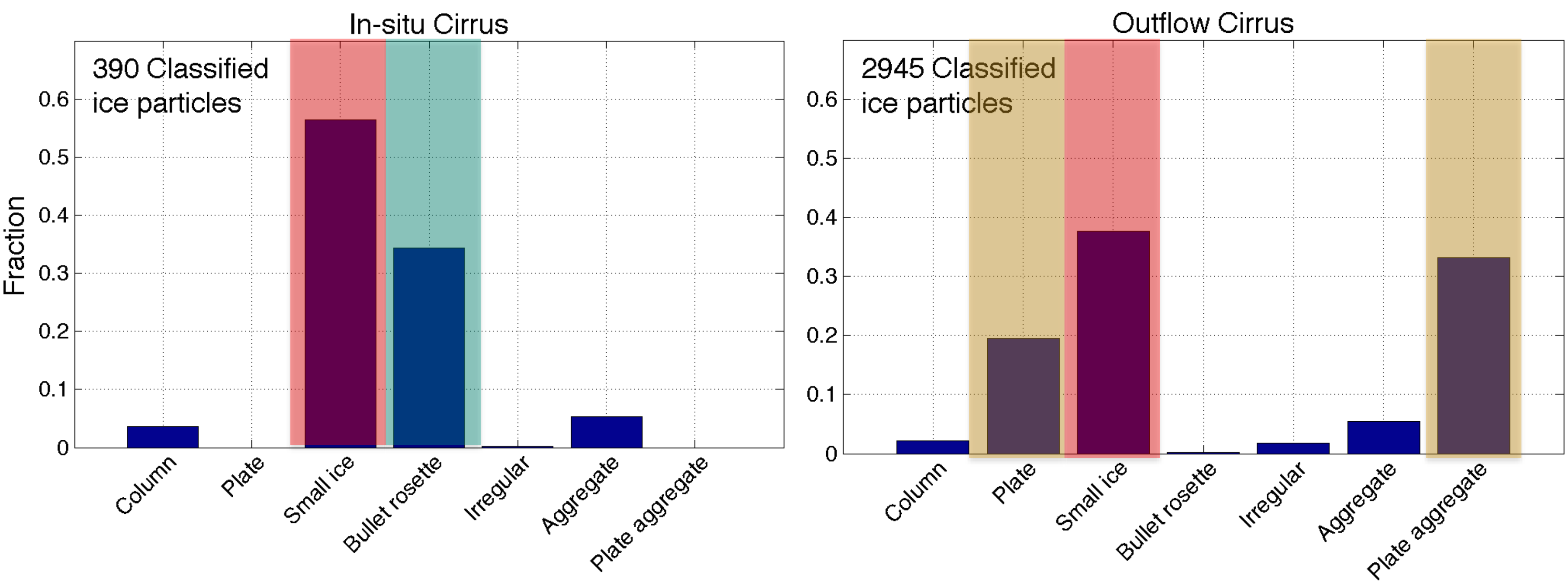
Lawson et al. (2006)



Connolly et al. (2005)

Particle Habit Classification: in-situ vs outflow

- Ice particles imaged with PHIPS-HALO instrument were classified to **plates**, **columns**, **bullet rosettes**, **small** ice particles and (plate) **aggregates**



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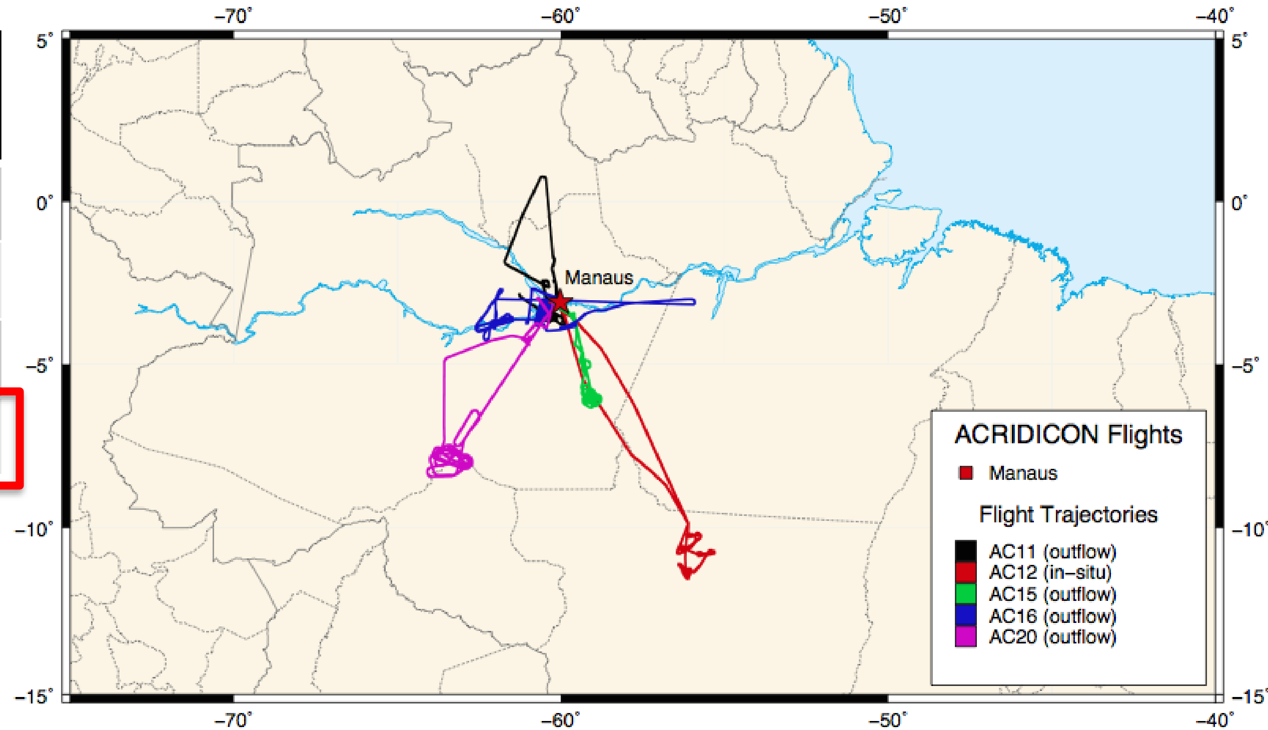
Large-scale complexity

Flight Overview

Outflow flights

Flight	Aerosol concentration
AC11	490 cm^{-3}
AC15	1100 cm^{-3}
AC16	2000 cm^{-3}
AC20	2000 cm^{-3}

In-situ cirrus
AC12



- Outflow anvils were probed at different altitudes and some anvils with different distances to the core

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Outflow Southwest of Manaus

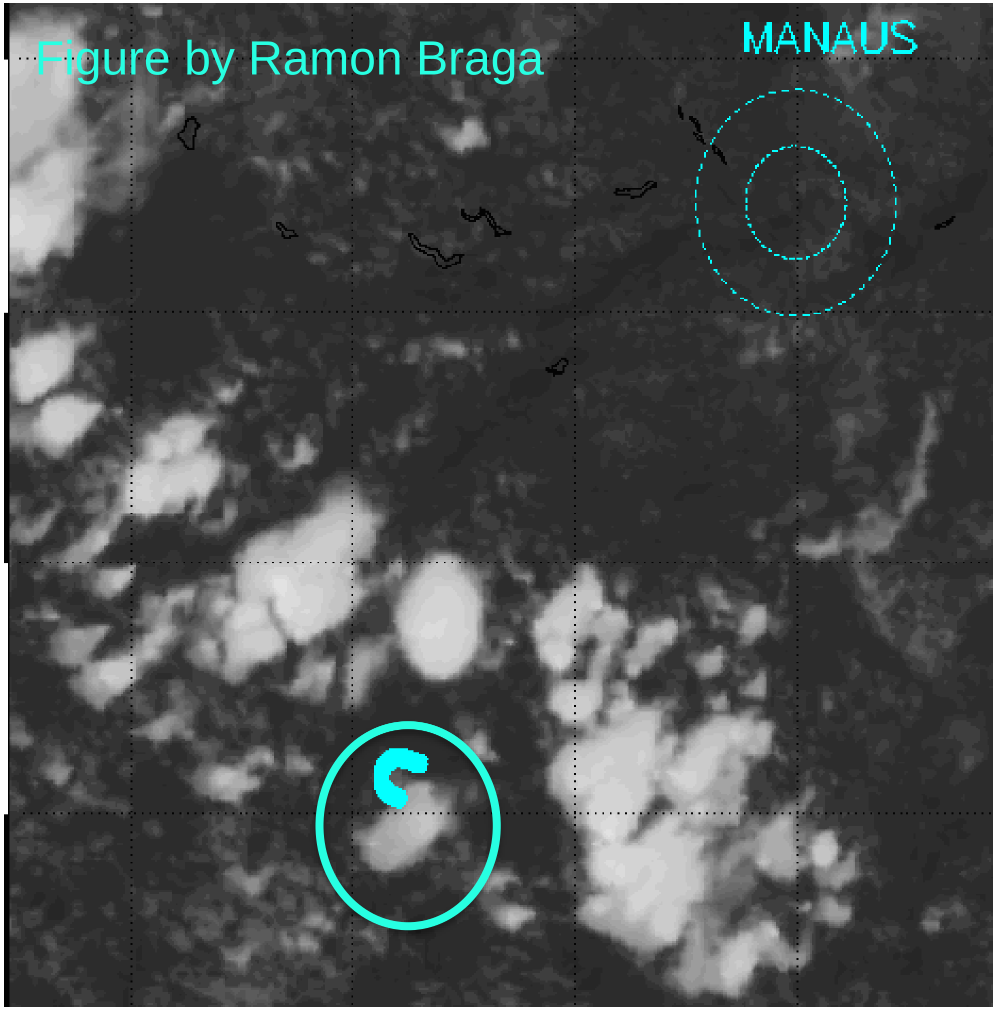

Photo by courtesy of Manfred Wendisch

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Outflow Southwest of Manaus

216 K

200 µm

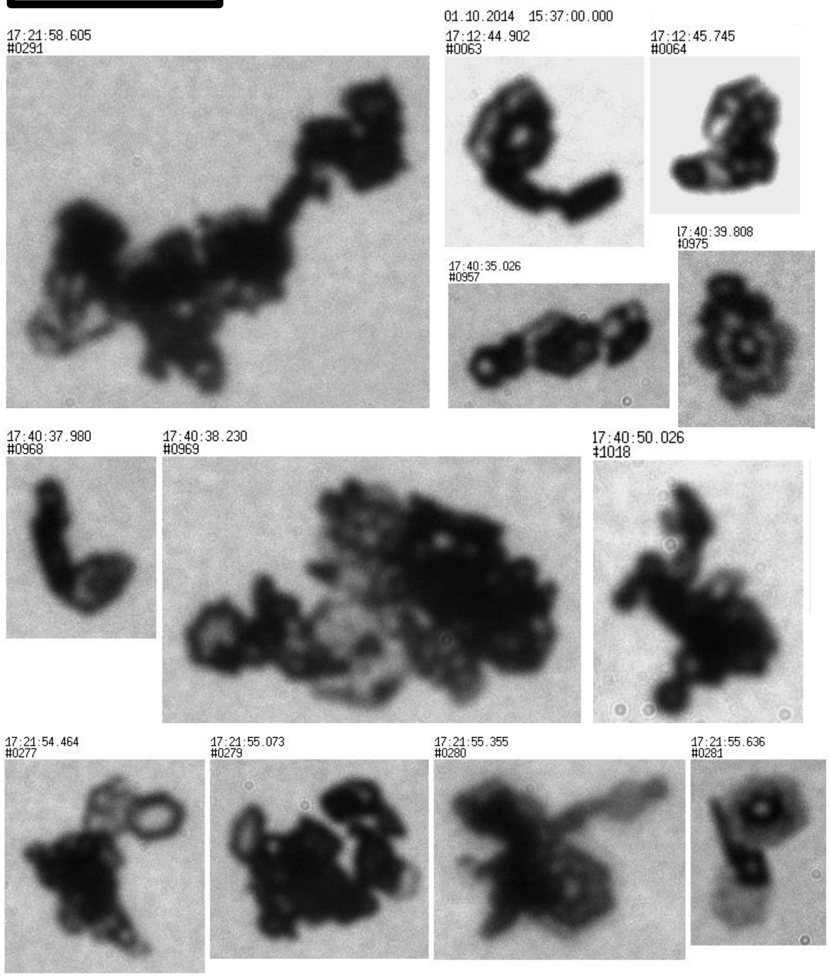

Photo by courtesy of Manfred Wendisch

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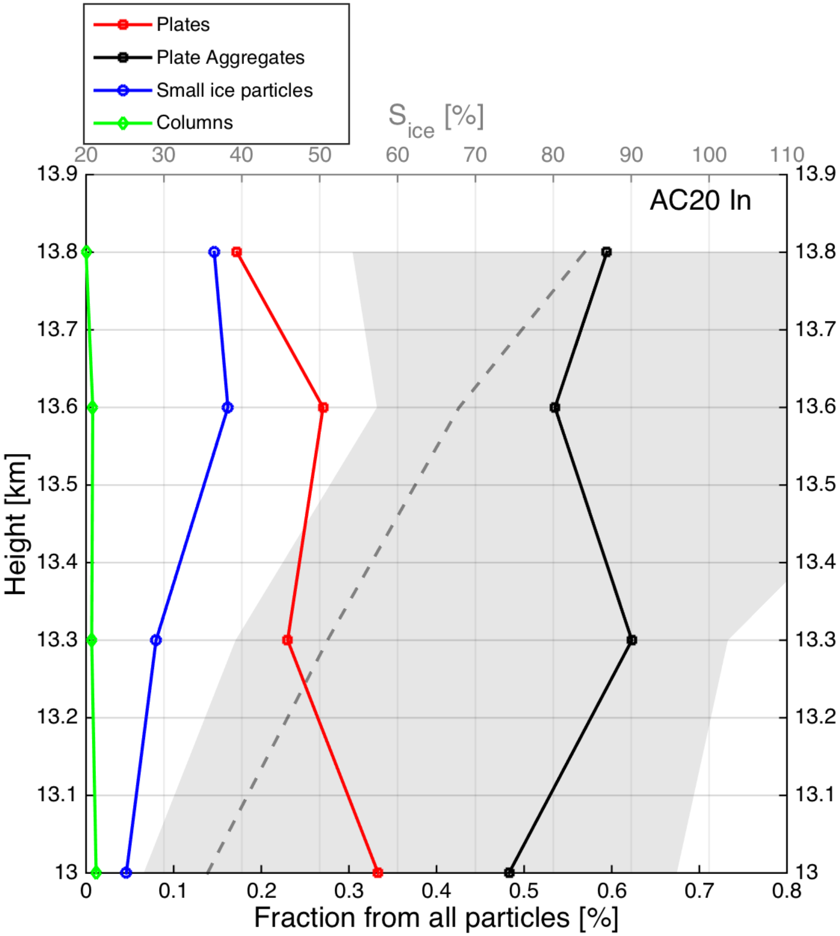
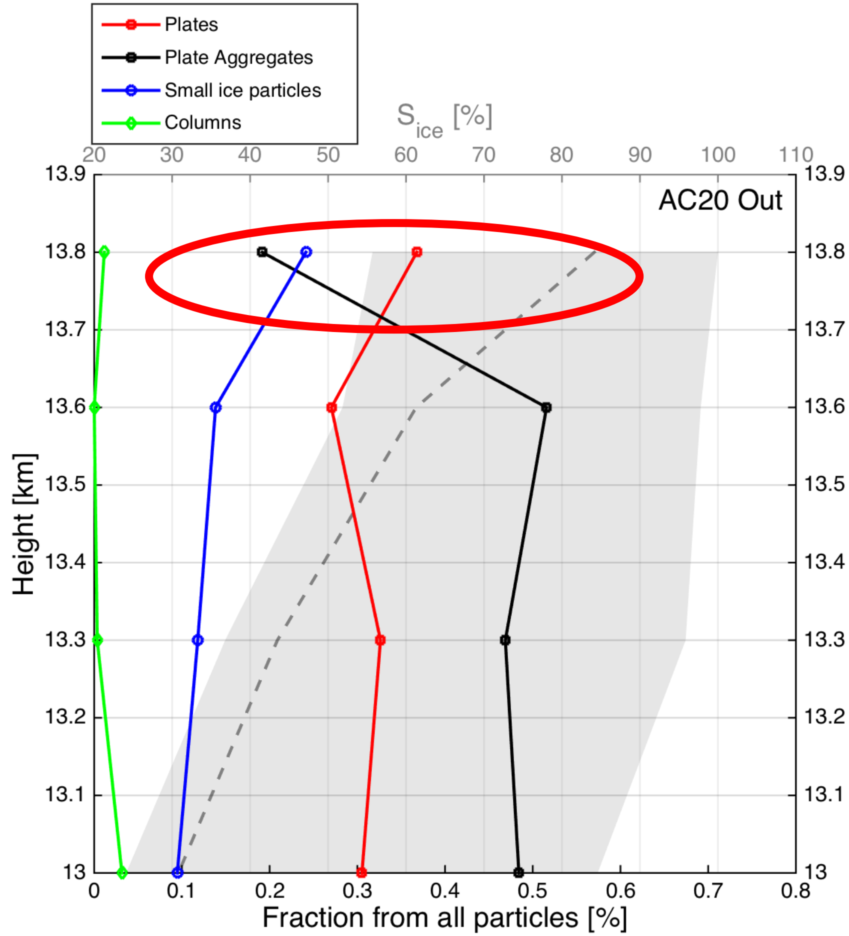
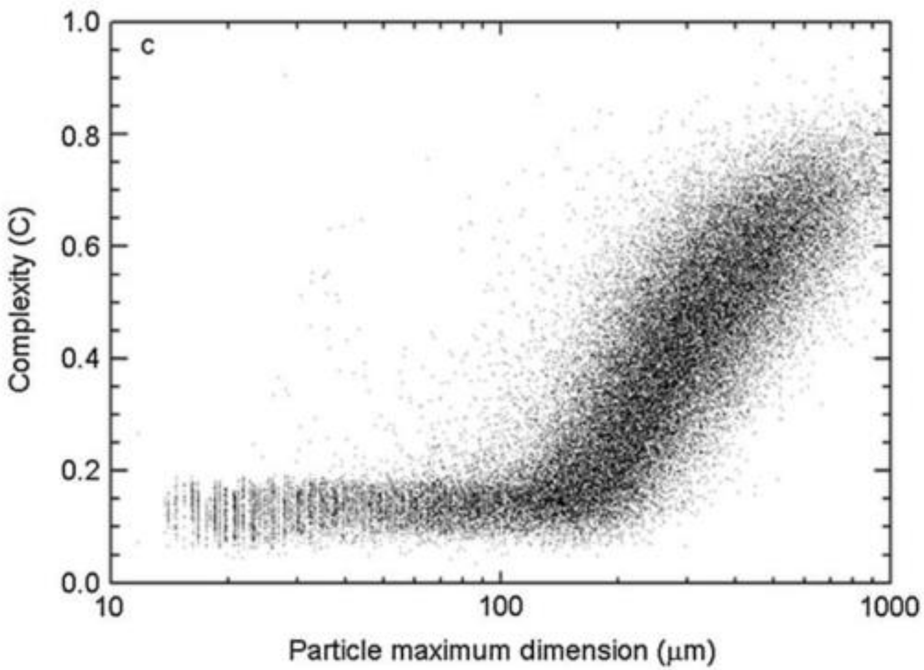




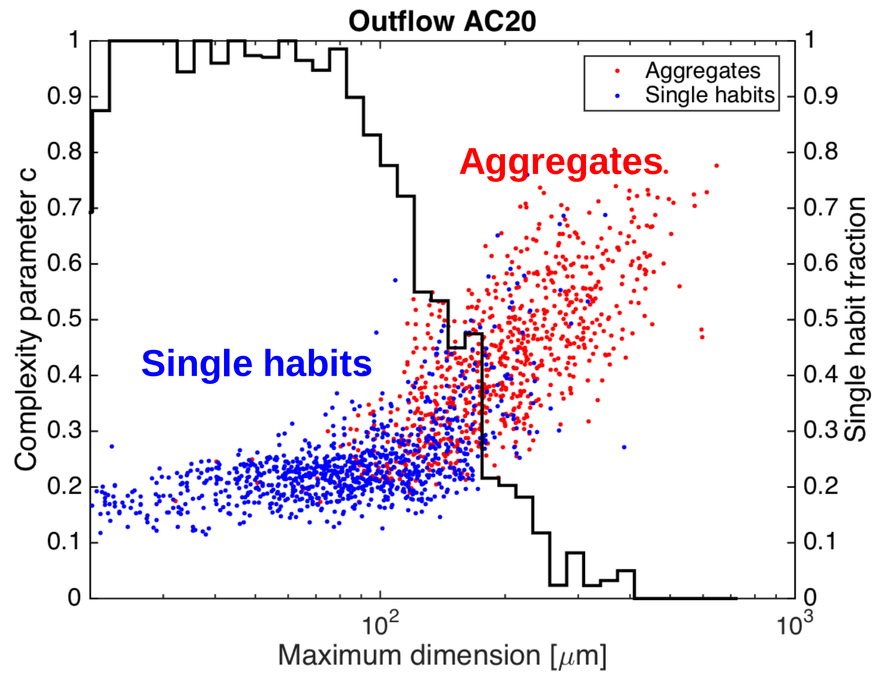
- Outflow well mixed up to the upper edge

Dimensions of the Complex Particles

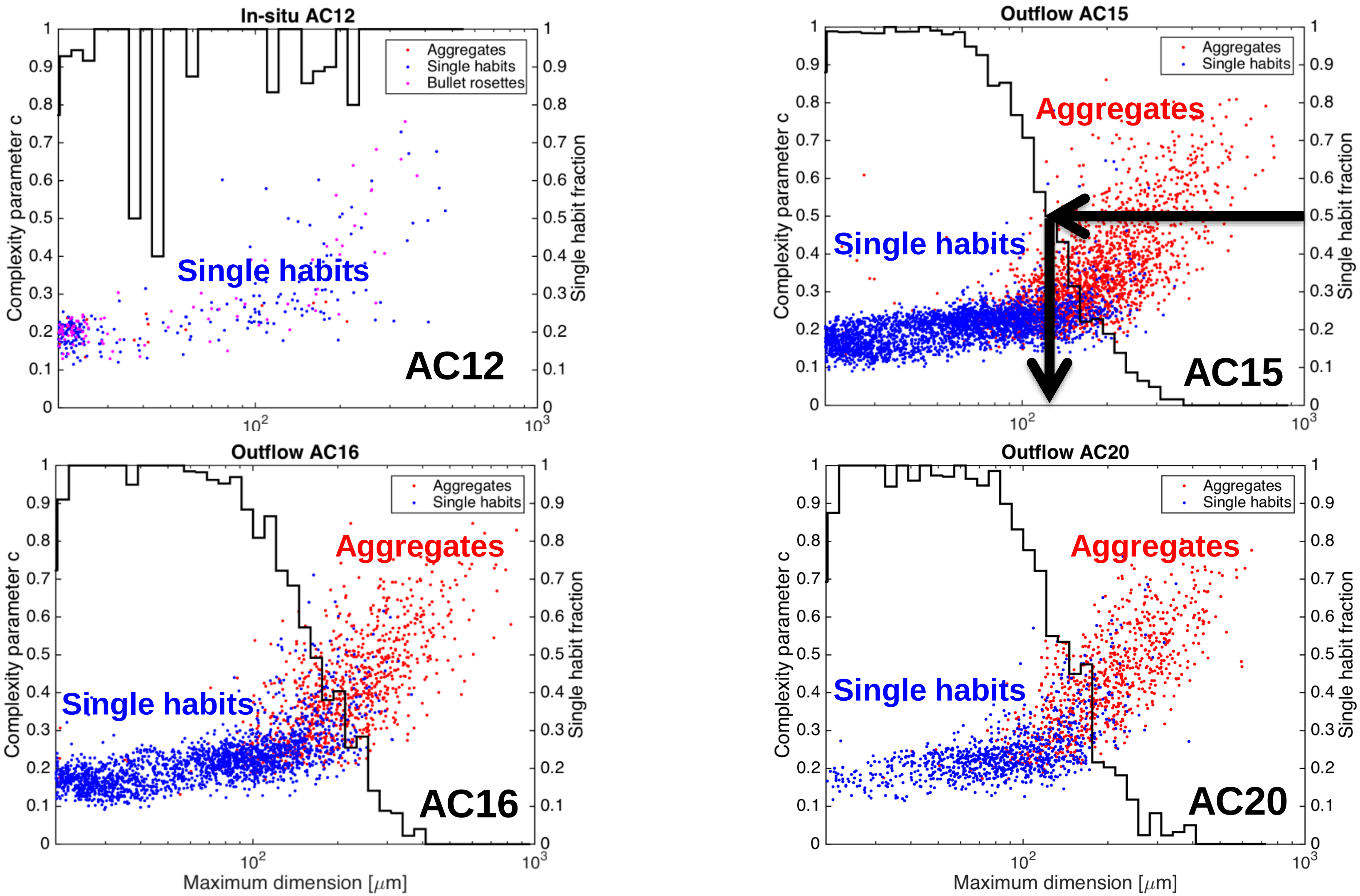
CRYSTAL-FACE



AC20



Dimensions of the Complex Particles



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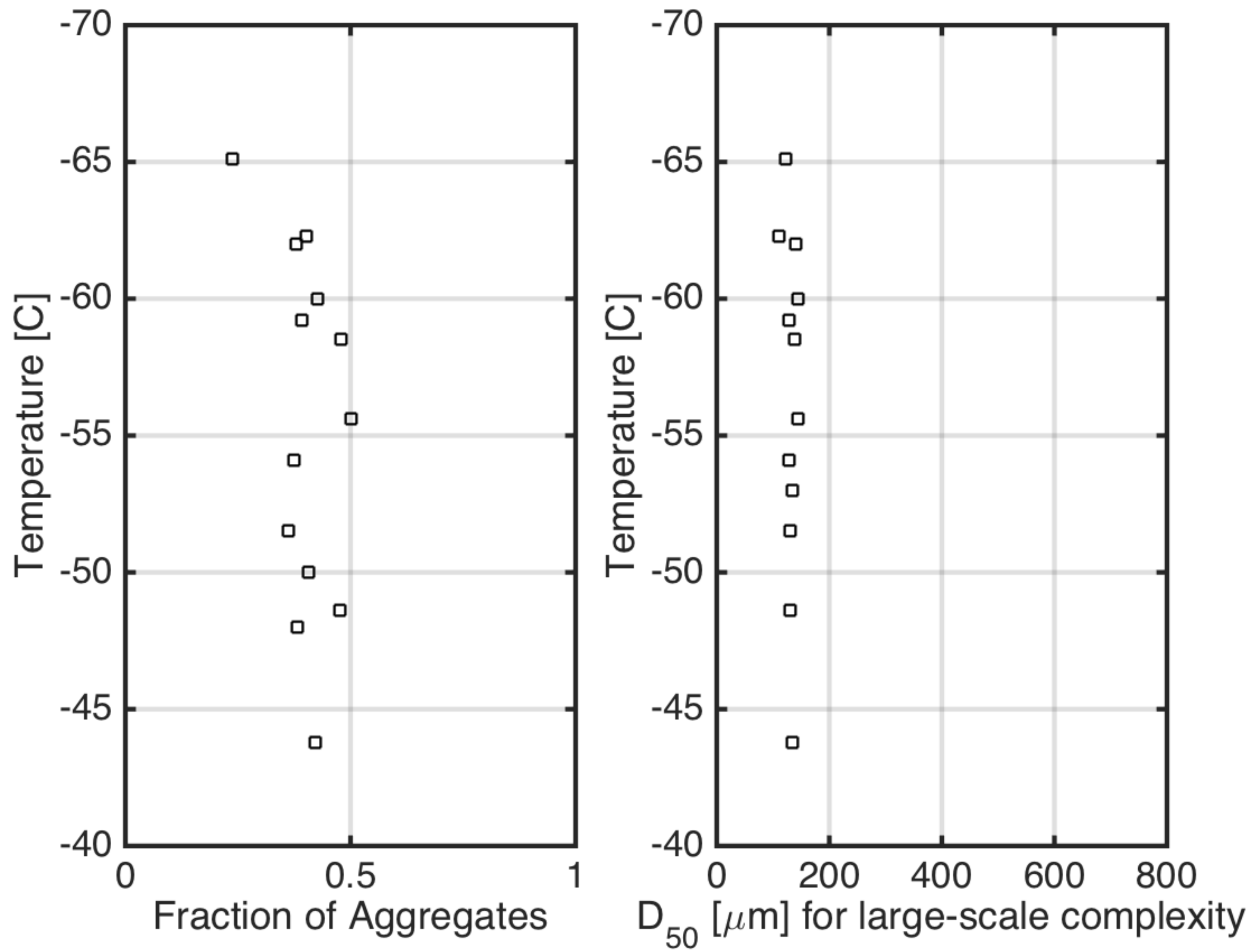
Dimensions of the Complex Particles



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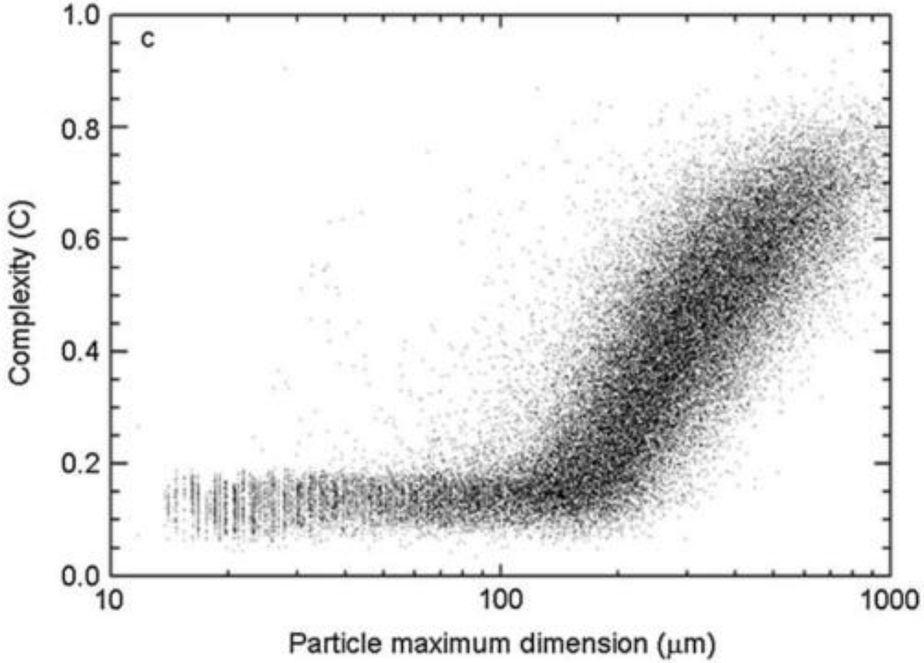
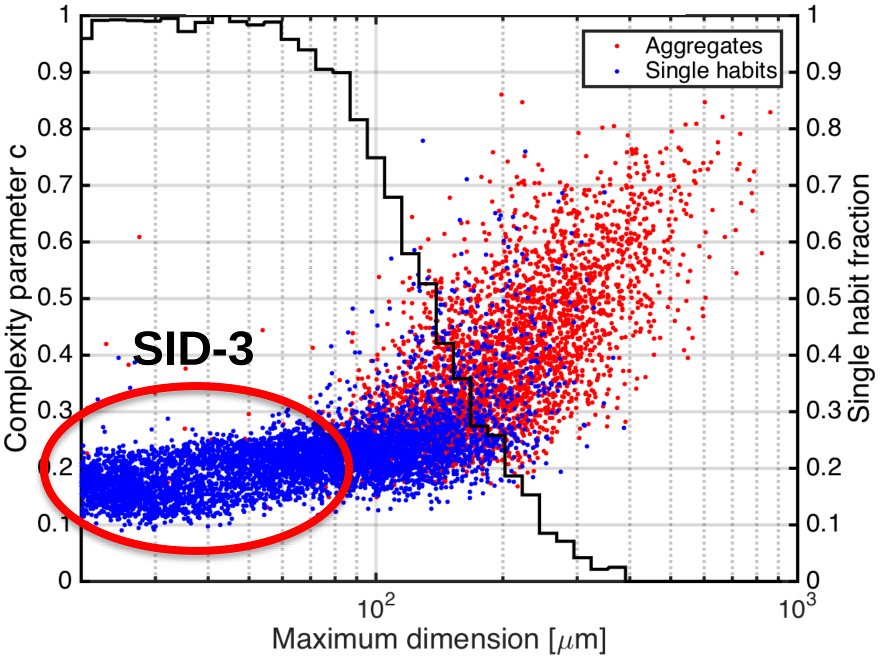
Large-Scale Complexity

CRYSTAL-FACE



ACRIDICON-CHUVA



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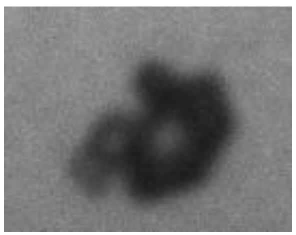
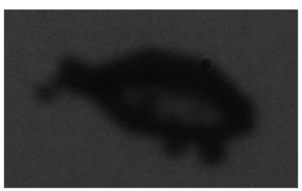
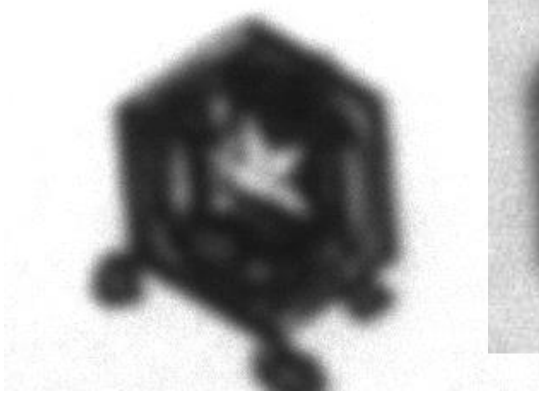
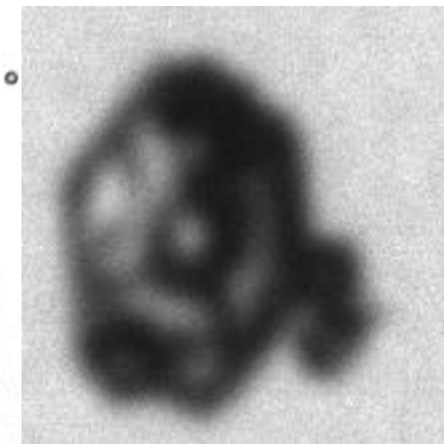
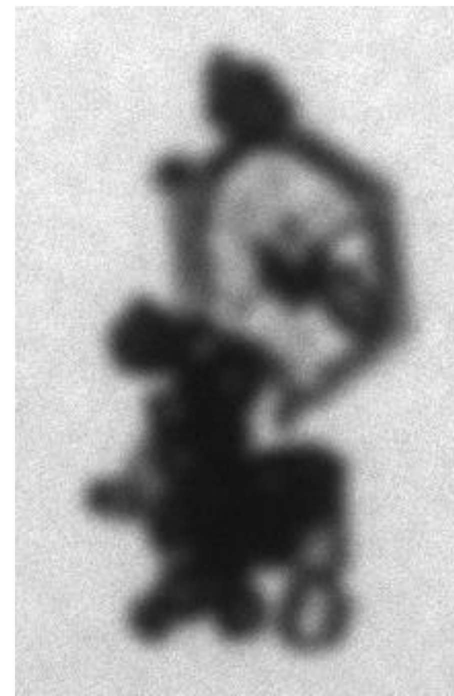
The Liquid Origin of Outflow Ice Particles

- Plates formed at temperatures above -40°C
- Riming observed

AC20 rimed plates

Small-scale complexity

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Flight Overview

Outflow flights

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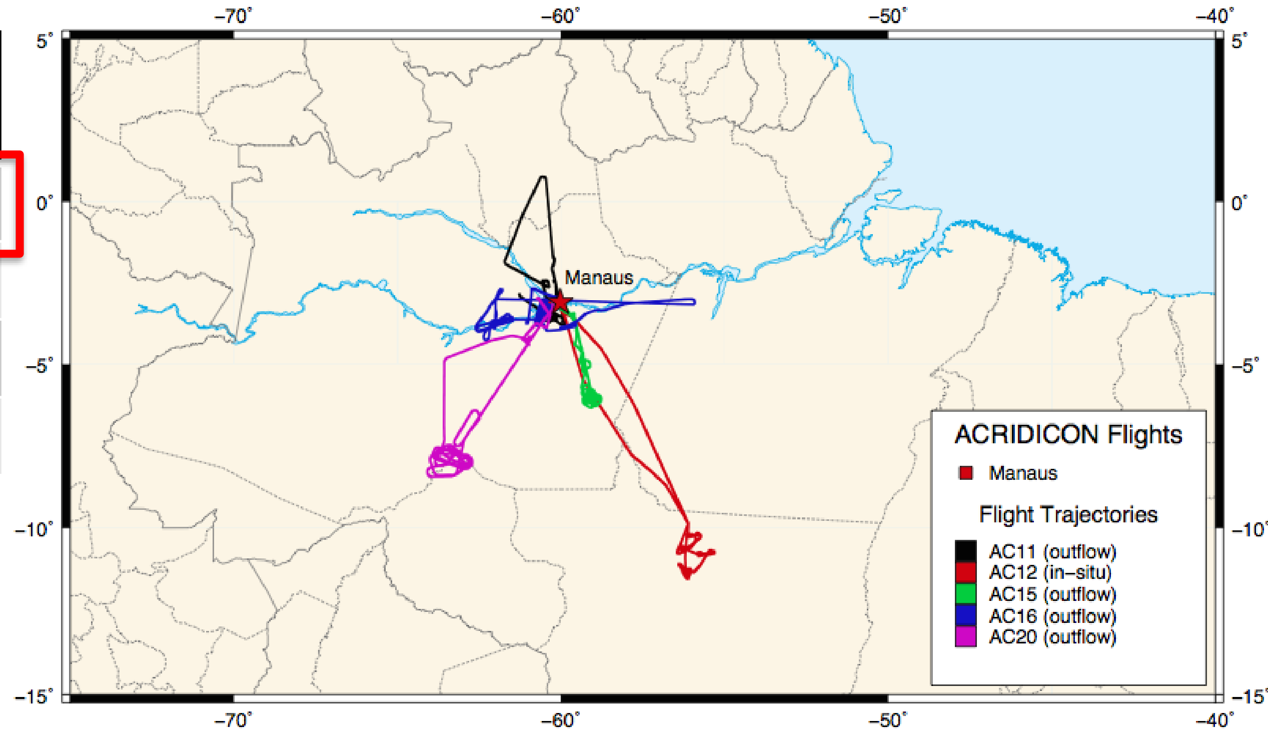
In-situ cirrus
AC12



- Outflow anvils were probed at different altitudes and some anvils with different distances to the core

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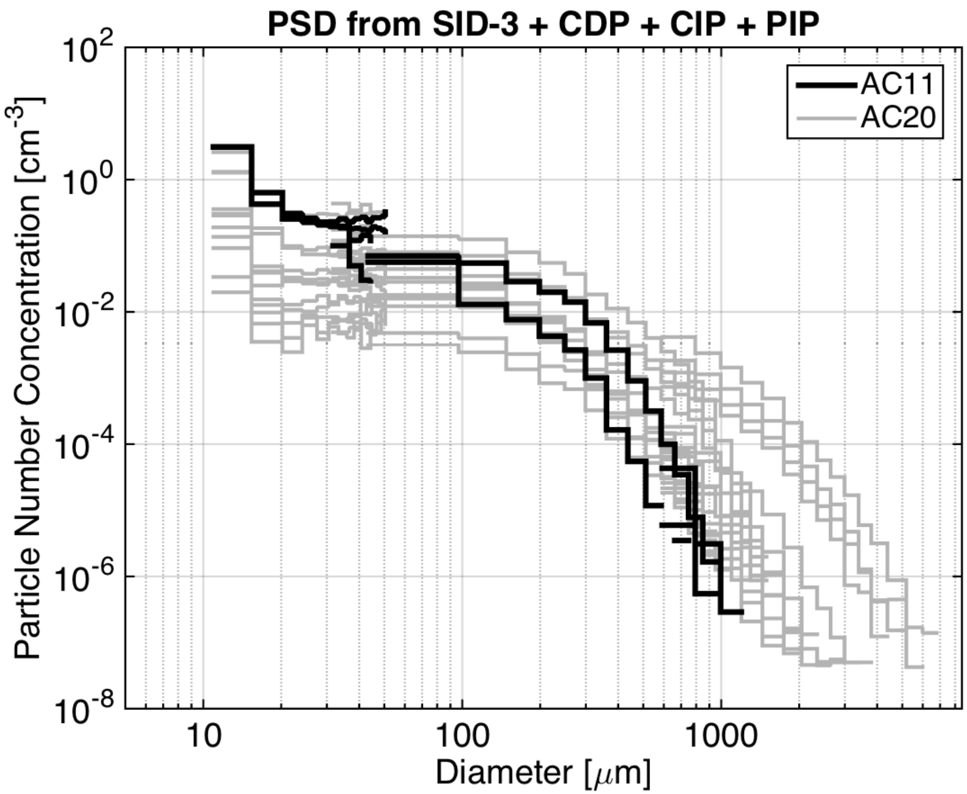
Outflow Southwest of Manaus



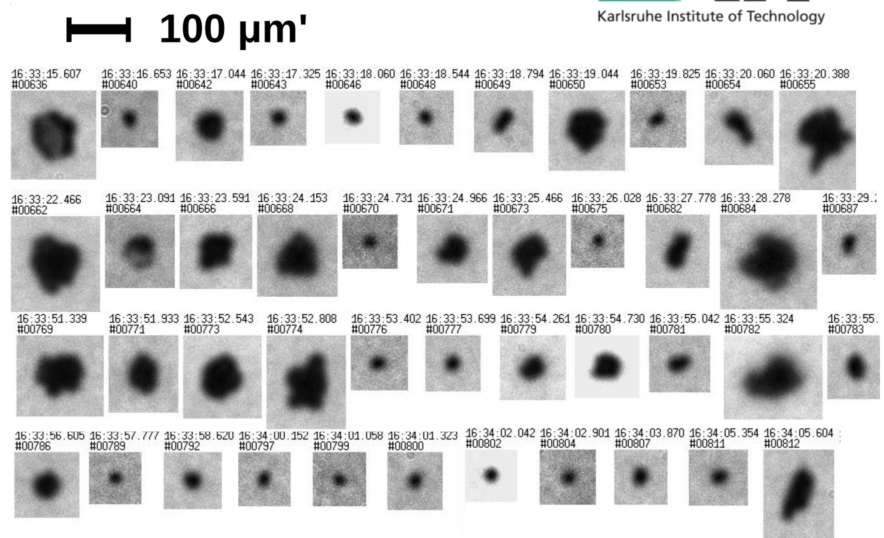


Photo by courtesy of Hans Schlager

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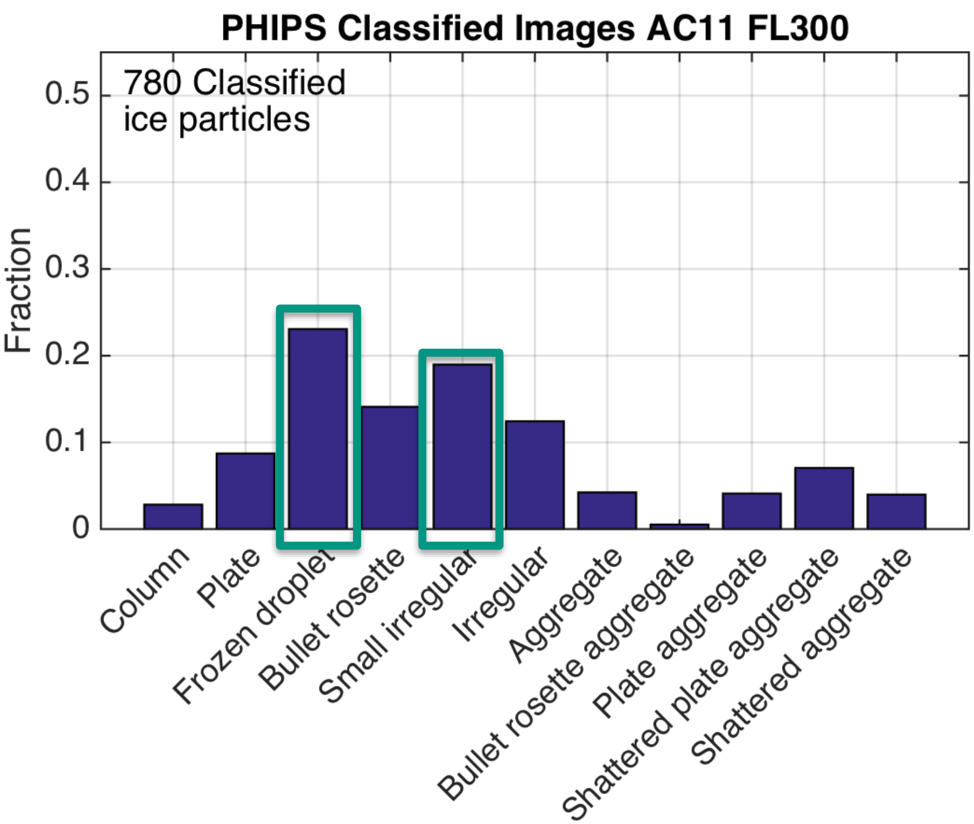
Outflow North of Manaus

220 K



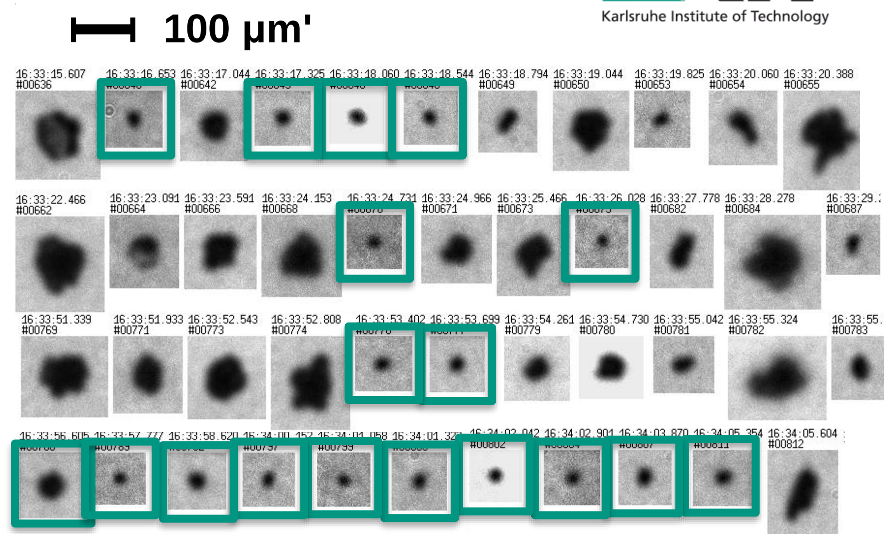
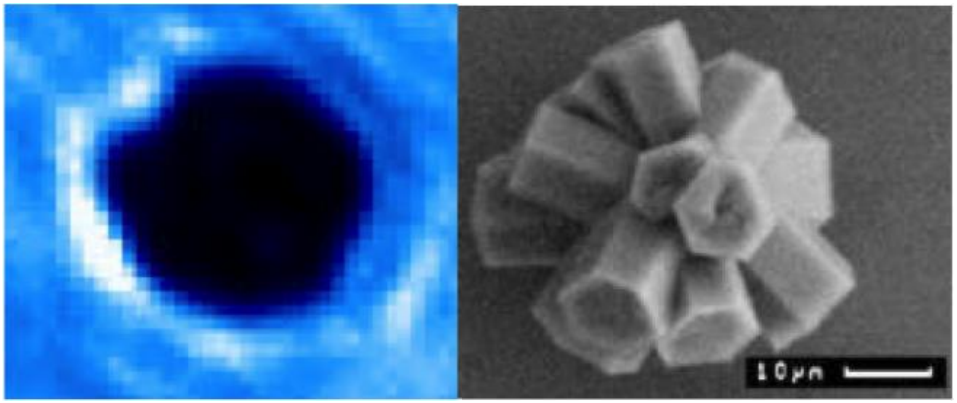
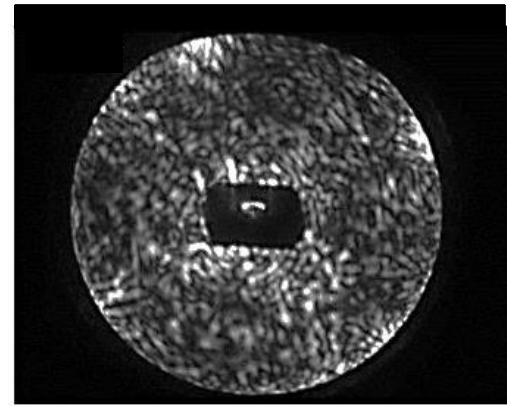


Photo by courtesy of Hans Schlager

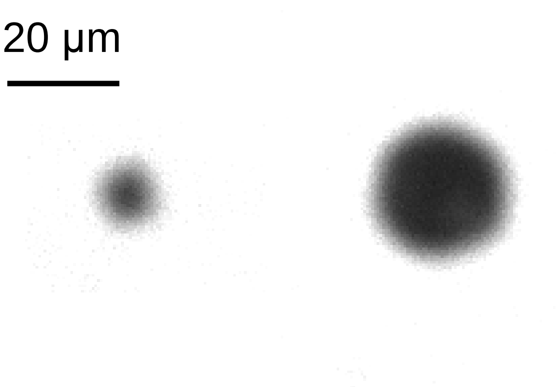
Outflow North of Manaus

Z. Ulanowski, ICCP, 2004

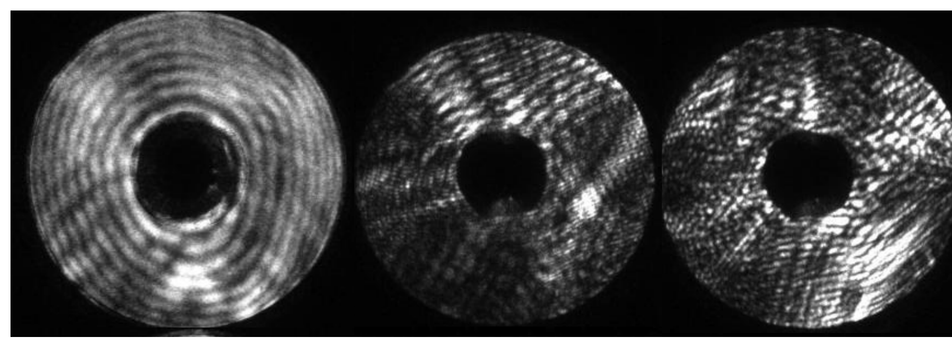




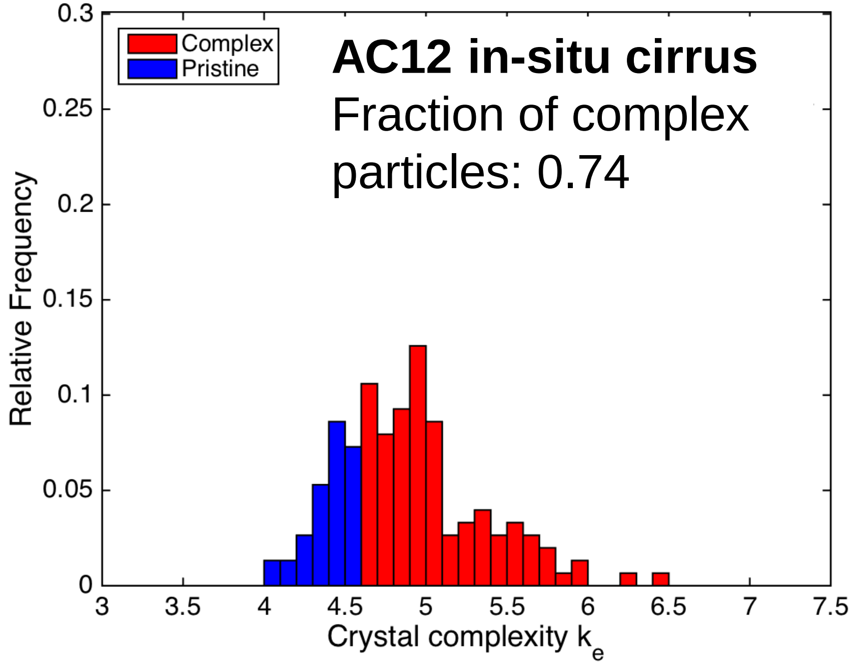
PHIPS Images of Frozen Droplets

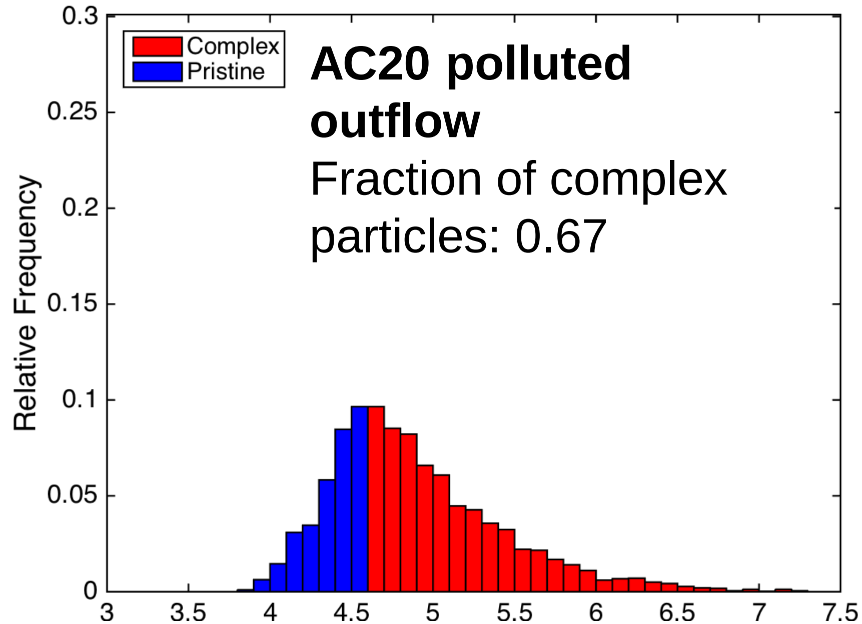


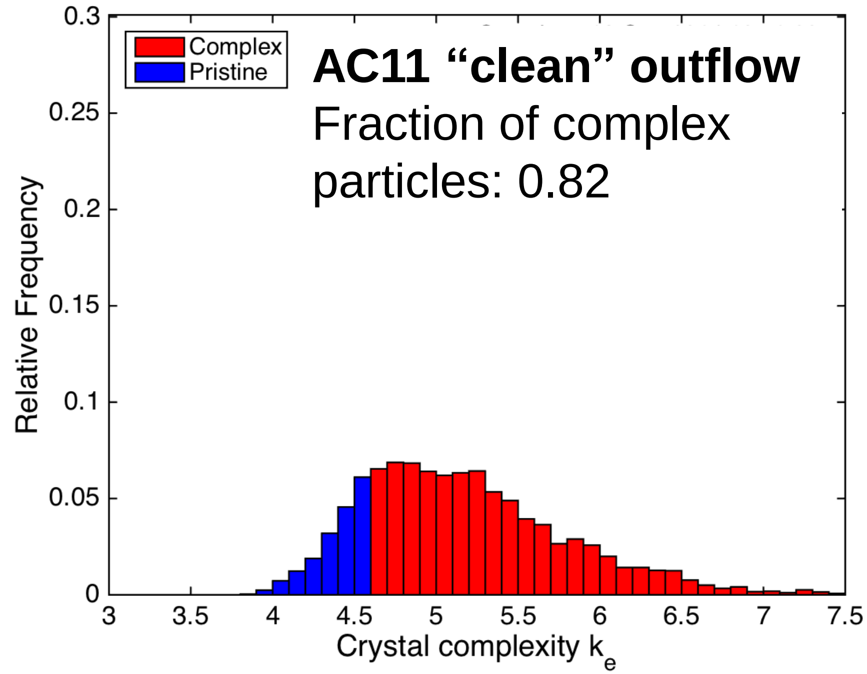
SID3 Diffraction Patterns



Ice Crystal Complexity







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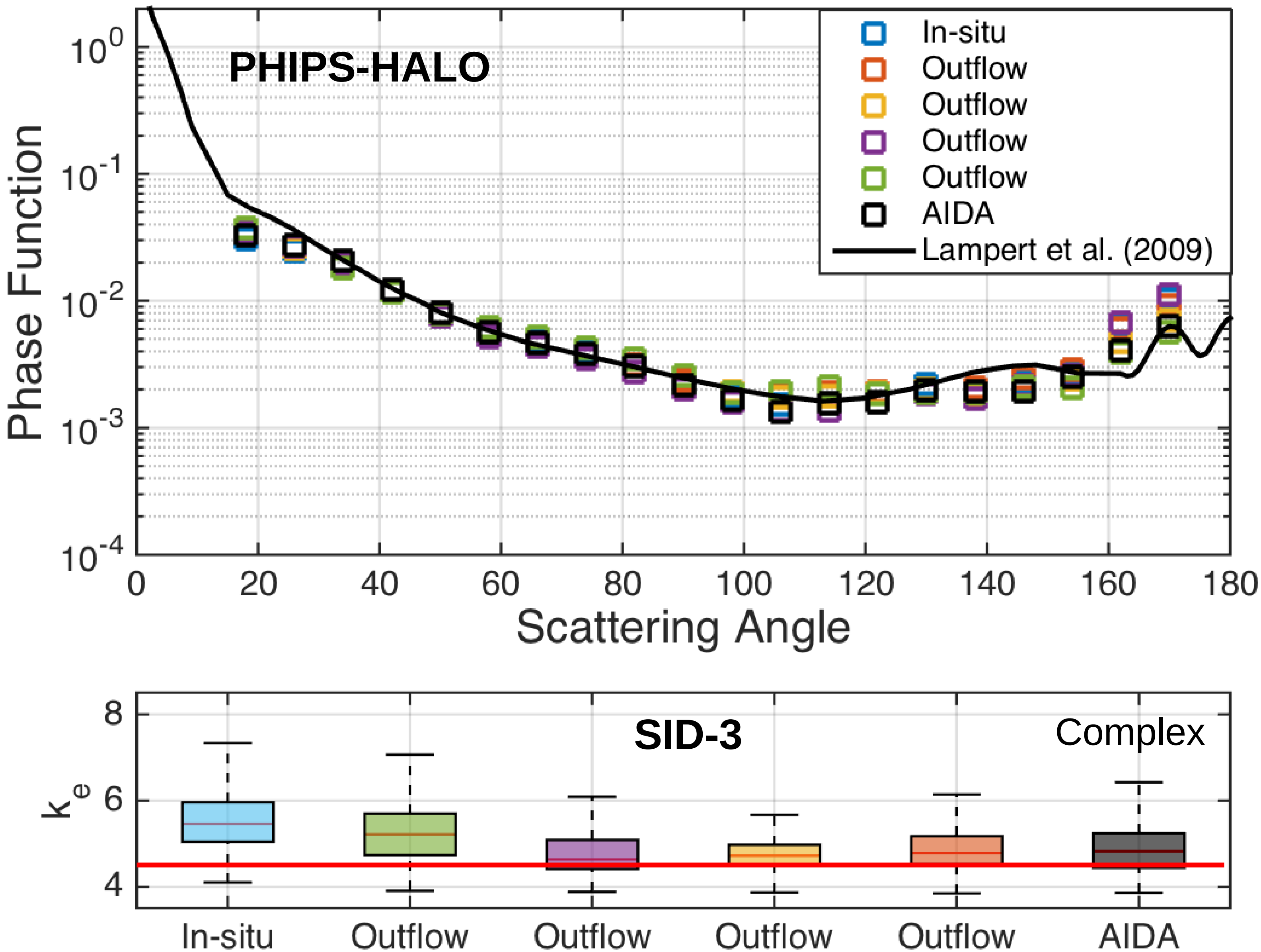
PHIPS-HALO
Phase Function
Scattering Angle
In-situ
Outflow
Outflow
Outflow
Outflow
AIDA
Lampert et al. (2009)
SID-3
Complex
k_e
In-situ
Outflow
Outflow
Outflow
Outflow
AIDA

Take-Home Message

- Verified a method to study large-scale complexity from PHIPS-HALO images
- Outflows well mixed
- High degree of crystal complexity is observed in all sizes, shapes and formation pathways
  - This leads to uniform angular light scattering behaviour

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