The effect of ice bouncing and shattering on the performance of airborne cloud microphysical instrumentation

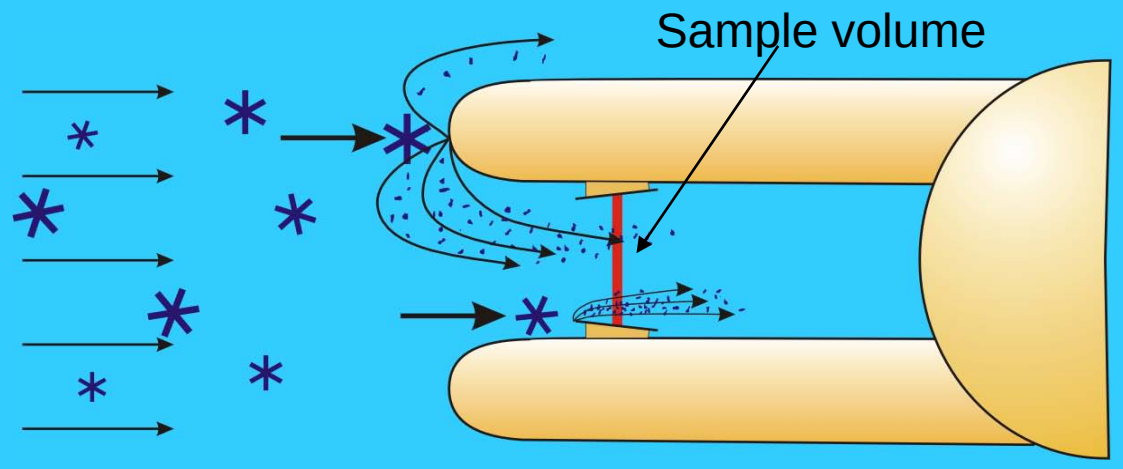
Alexei Korolev
Cloud Physics and Severe Weather Section
Environment Canada

Objectives

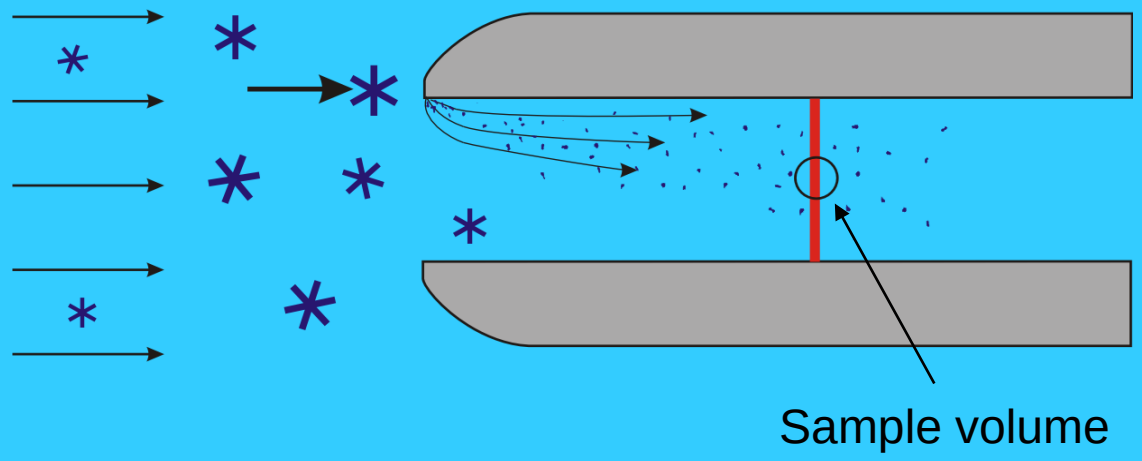
Demonstrate some results from the AIIE flight campaign quantifying the effect of shattering on in-situ ice particle measurements

Warn the ISDAC community to use the in-situ cloud microphysical data with cautious

Open path inlets (arms): OAP-2DC, OAP-2DP, HVPS, CIP, CDP



Inlet tubes: FSSP, CPI, CAS, SID



Cox Wind Tunnel

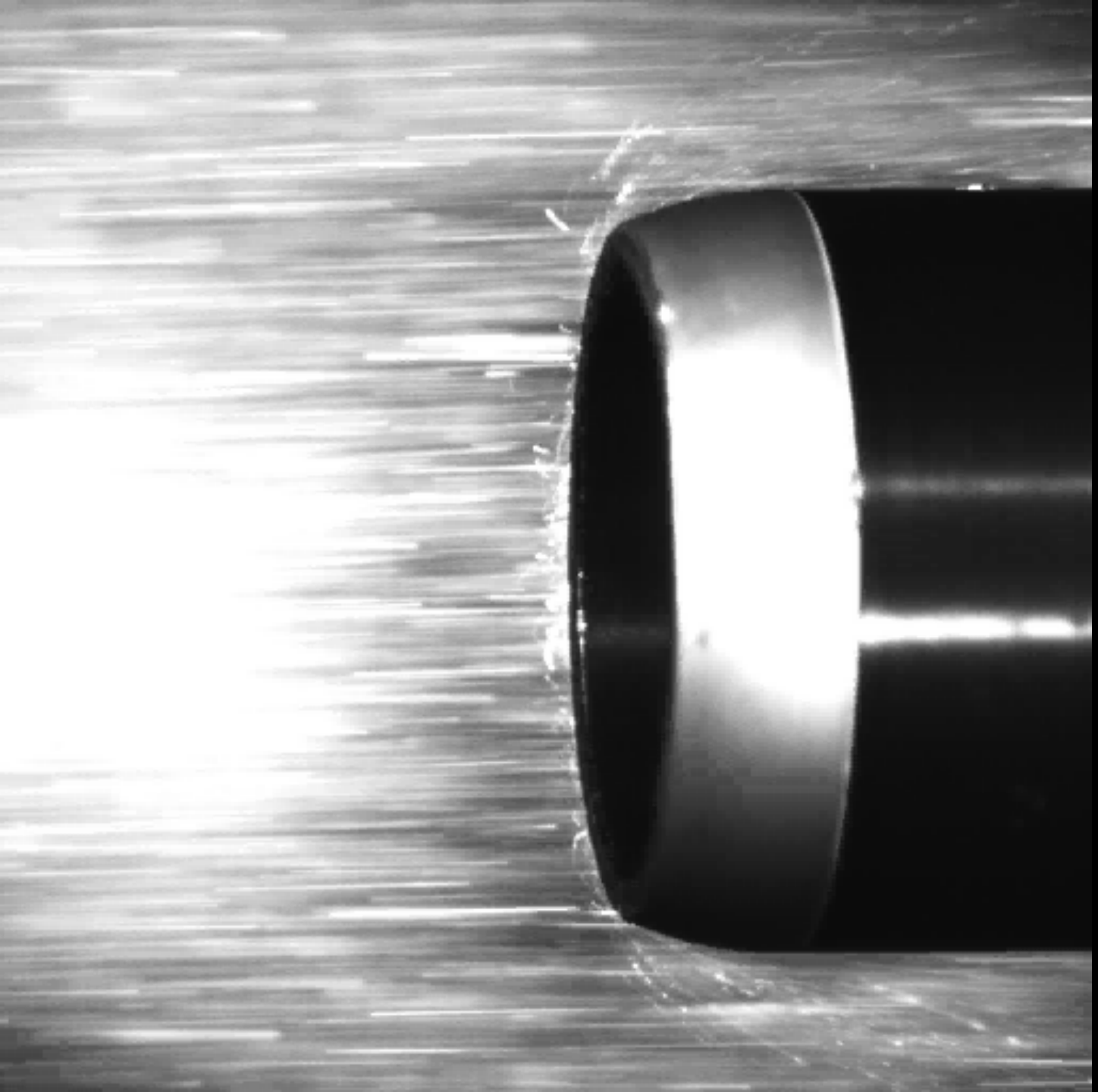
NASA High Speed Video

OAP-2DC arm
D ~ 2.5cm
TAS ~ 80m/s

Cox Wind Tunnel

NASA High Speed Video

CIP arm tip
TAS ~ 80m/s



Cox Wind Tunnel

NASA High Speed Video

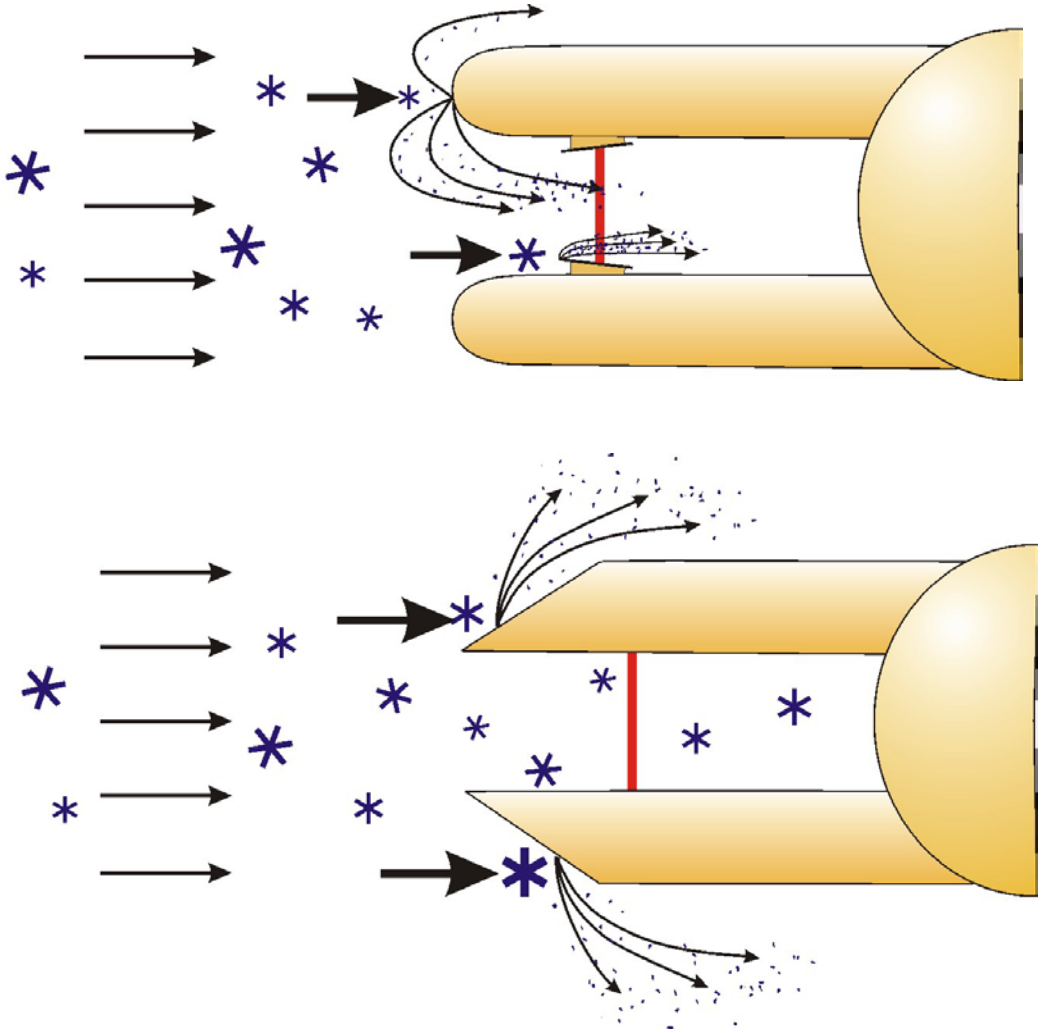
FSSP inlet
D ~ 5cm
TAS ~ 80m/s

Strategy for the ice shattering study

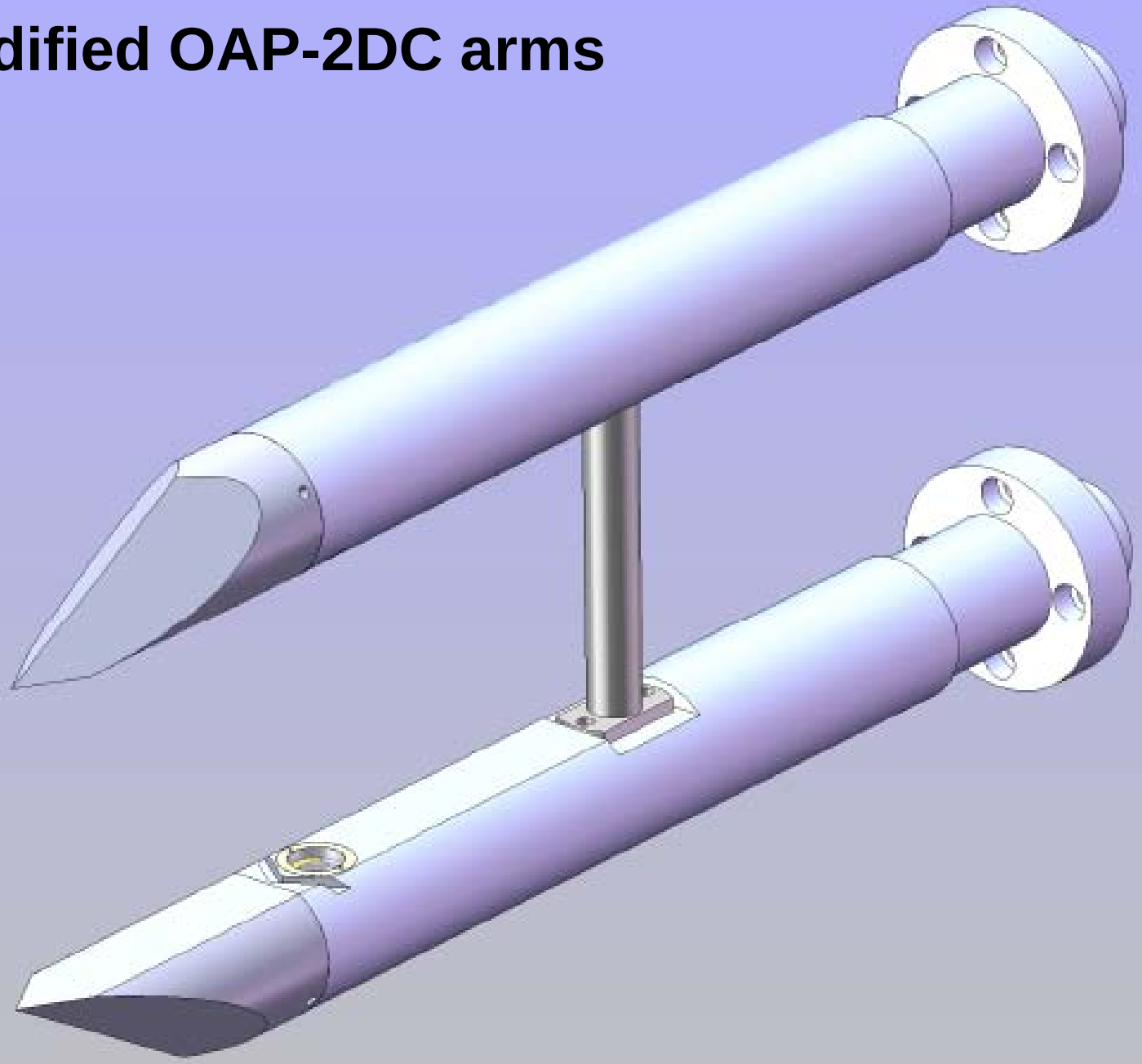
1. Redesign inlets to mitigate shattering

2. Fly probes in pairs “standard & modified” to estimate the effect of shattering on the conventional inlets

Concept of the probes' inlets and arms redesign



Modified OAP-2DC arms



30 April 2008, NRC Convair 580, ISDAC, Fairbanks

Airborne Icing Instrumentation Evaluation Project (AIIE)

March-April 2009, Southern Ontario

objectives:

1. Evaluation of ice shattering efficiency of PMS OAP-2DC

2. Evaluation of ice shattering efficiency of DMT CIP

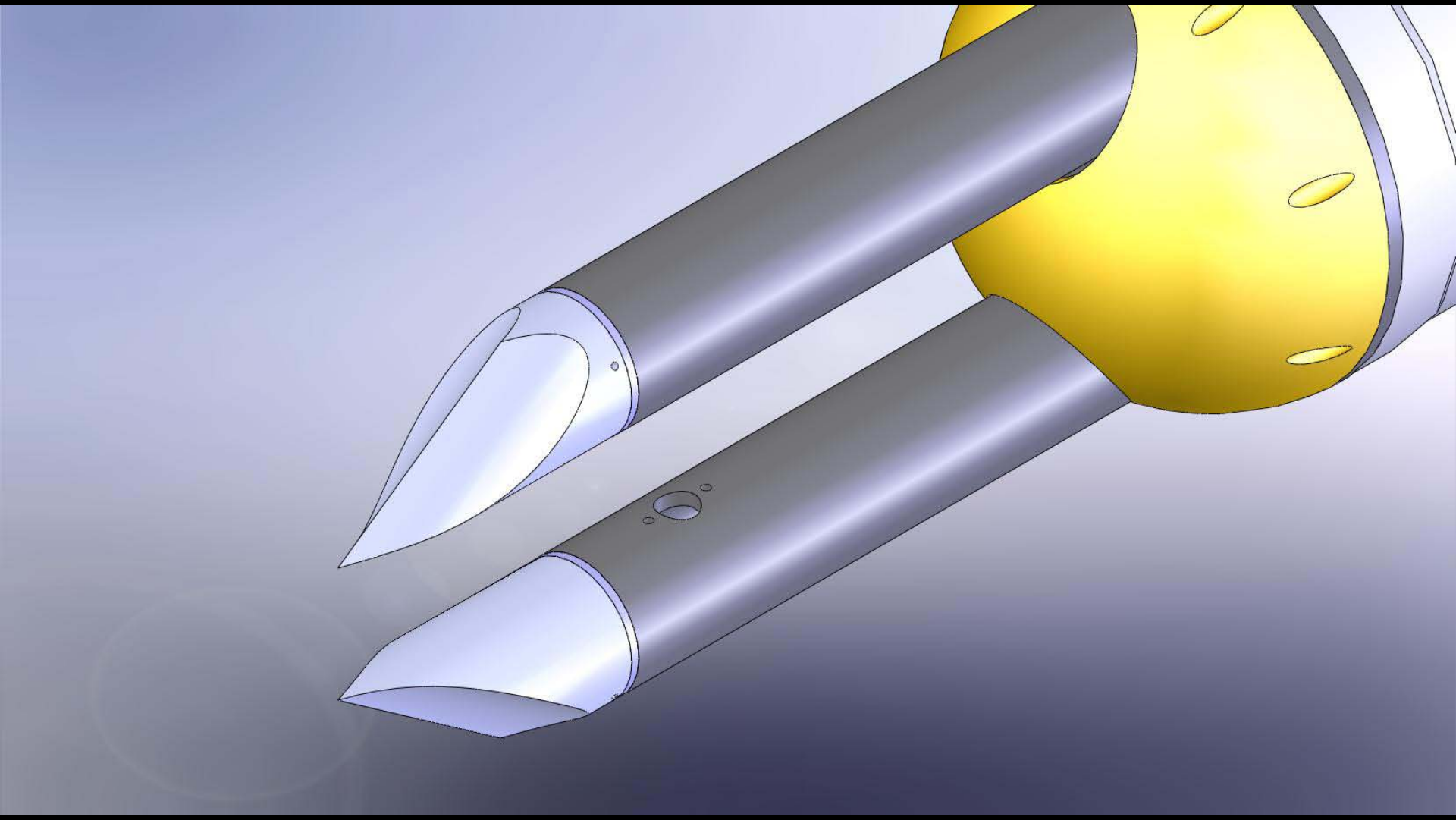
3. Evaluation of ice shattering efficiency of PMS FSSP

4. Evaluation of the performance of redesigned Nevzorov sensors

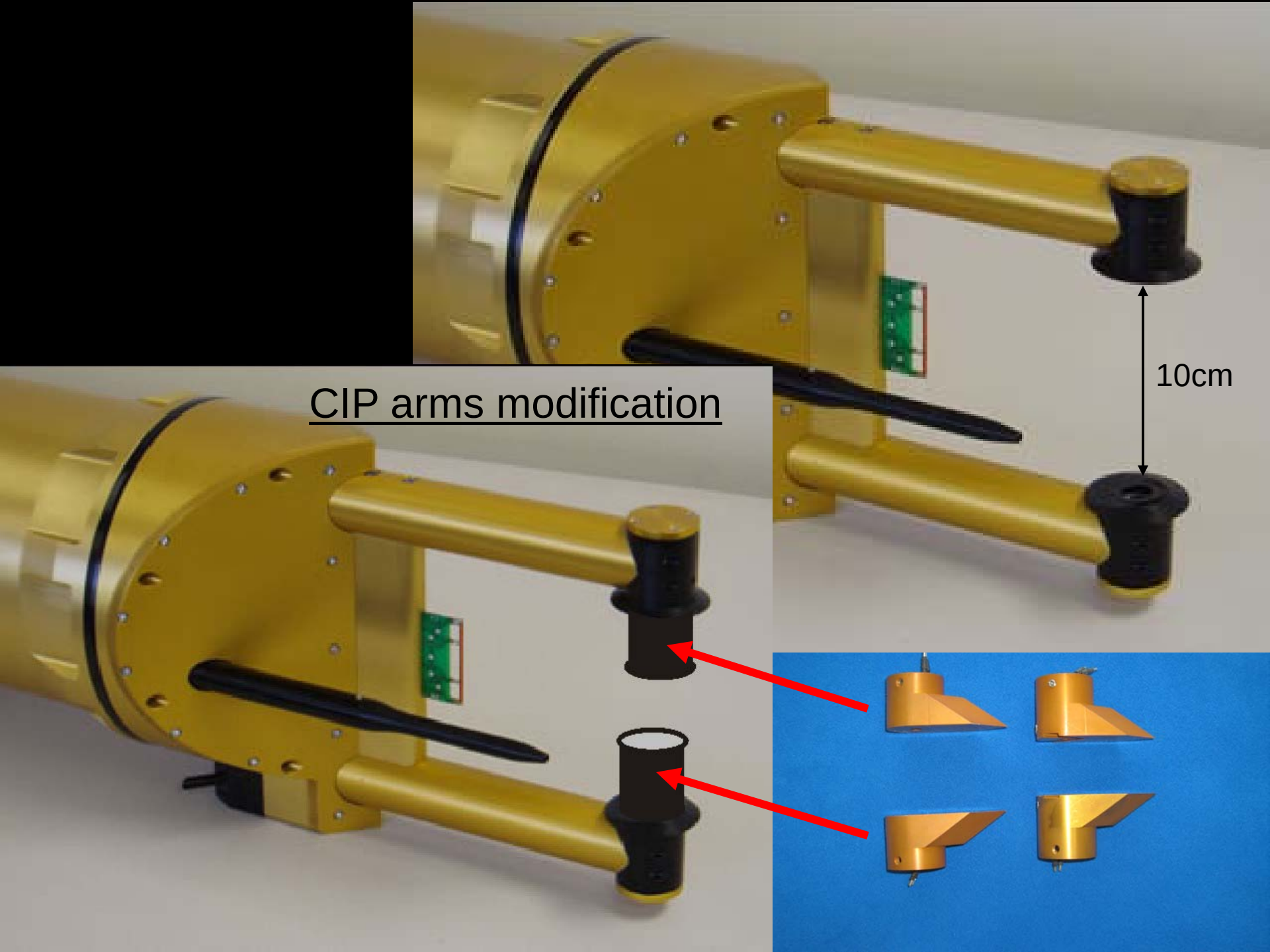
Set of the redesigned OAP-2DC arms

Trapezoid
H-carved
Flat
P-carved

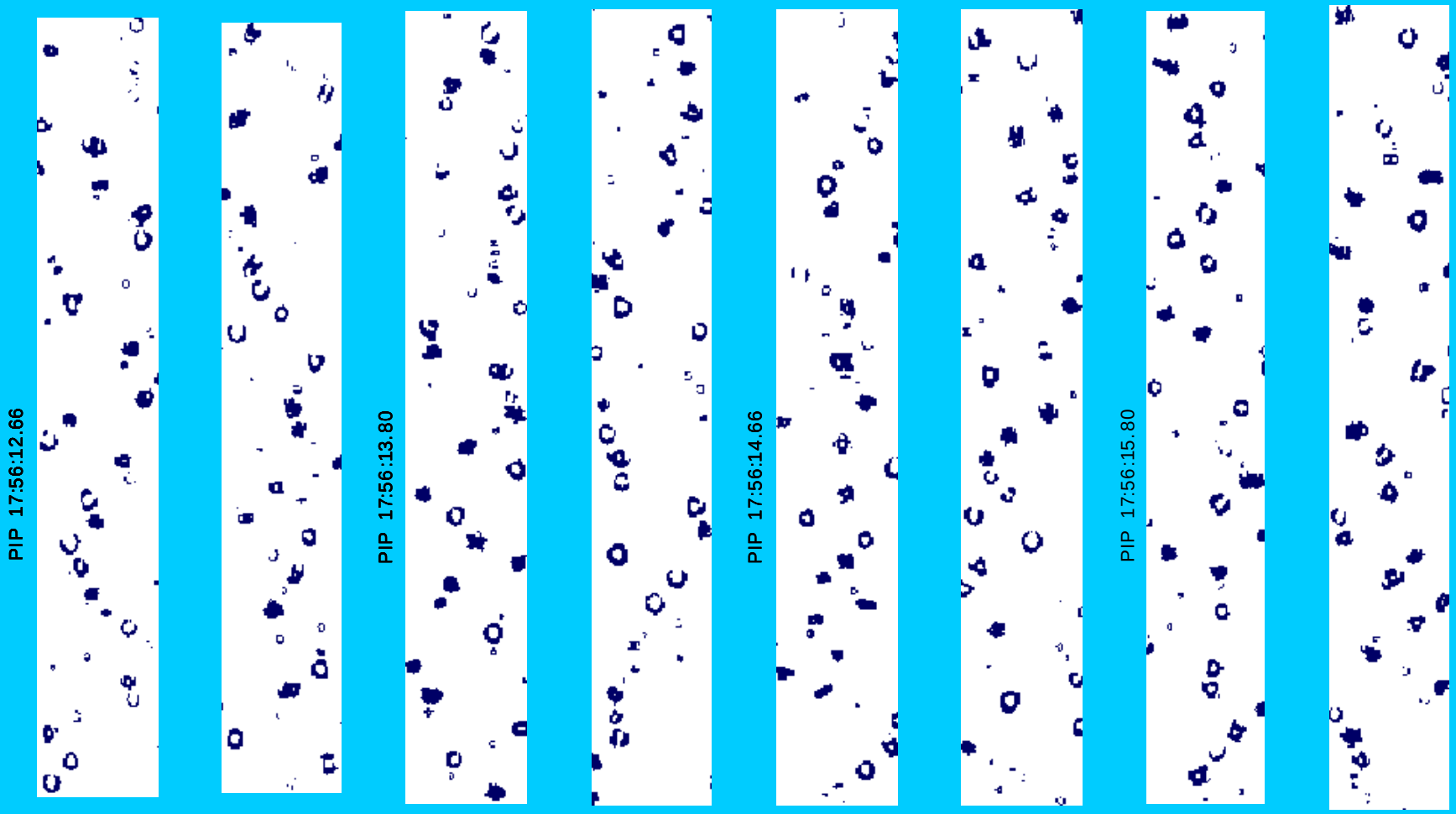
FSSP modification: (1) remove inlet tube; (2) replace arm tips



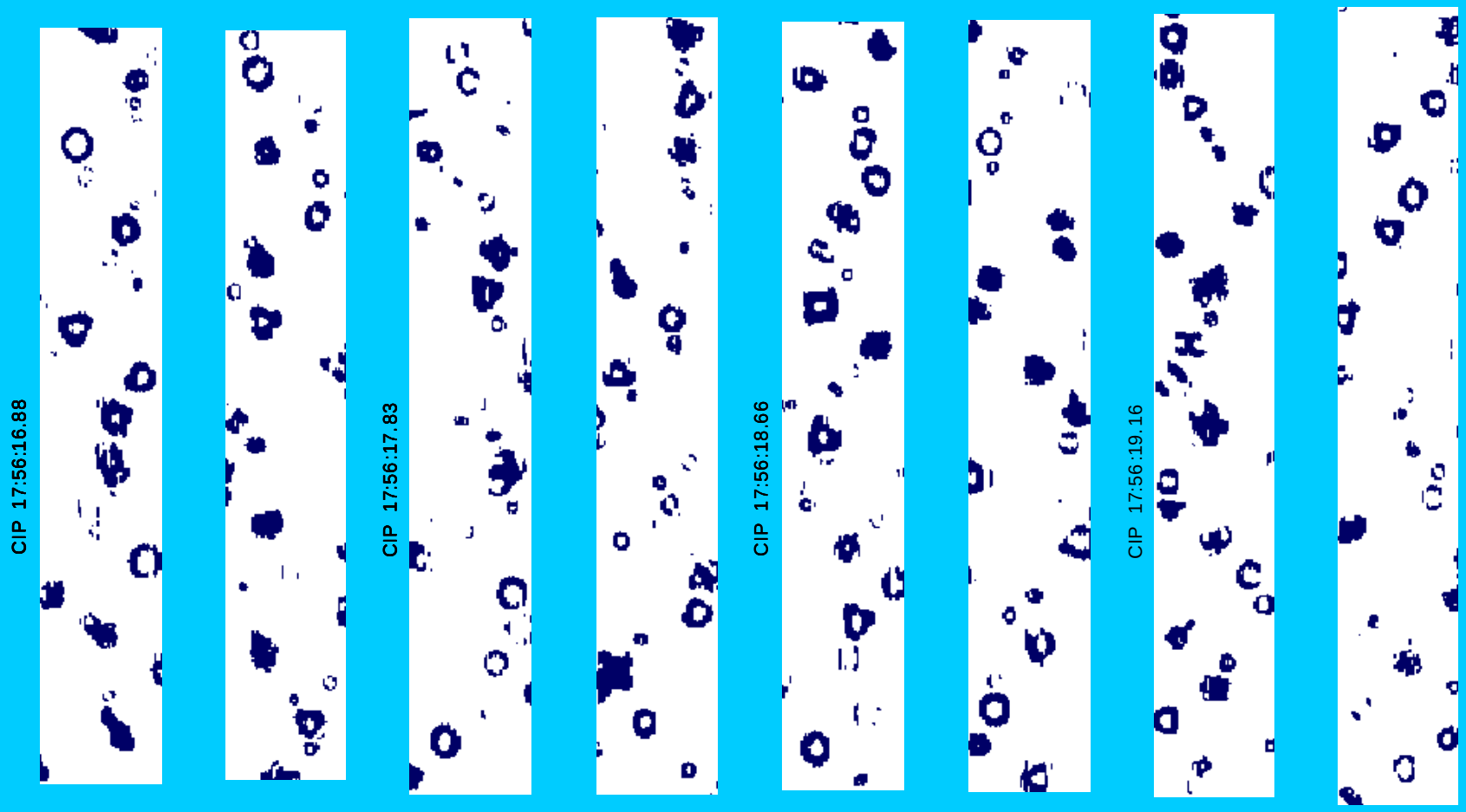
CIP arms modification



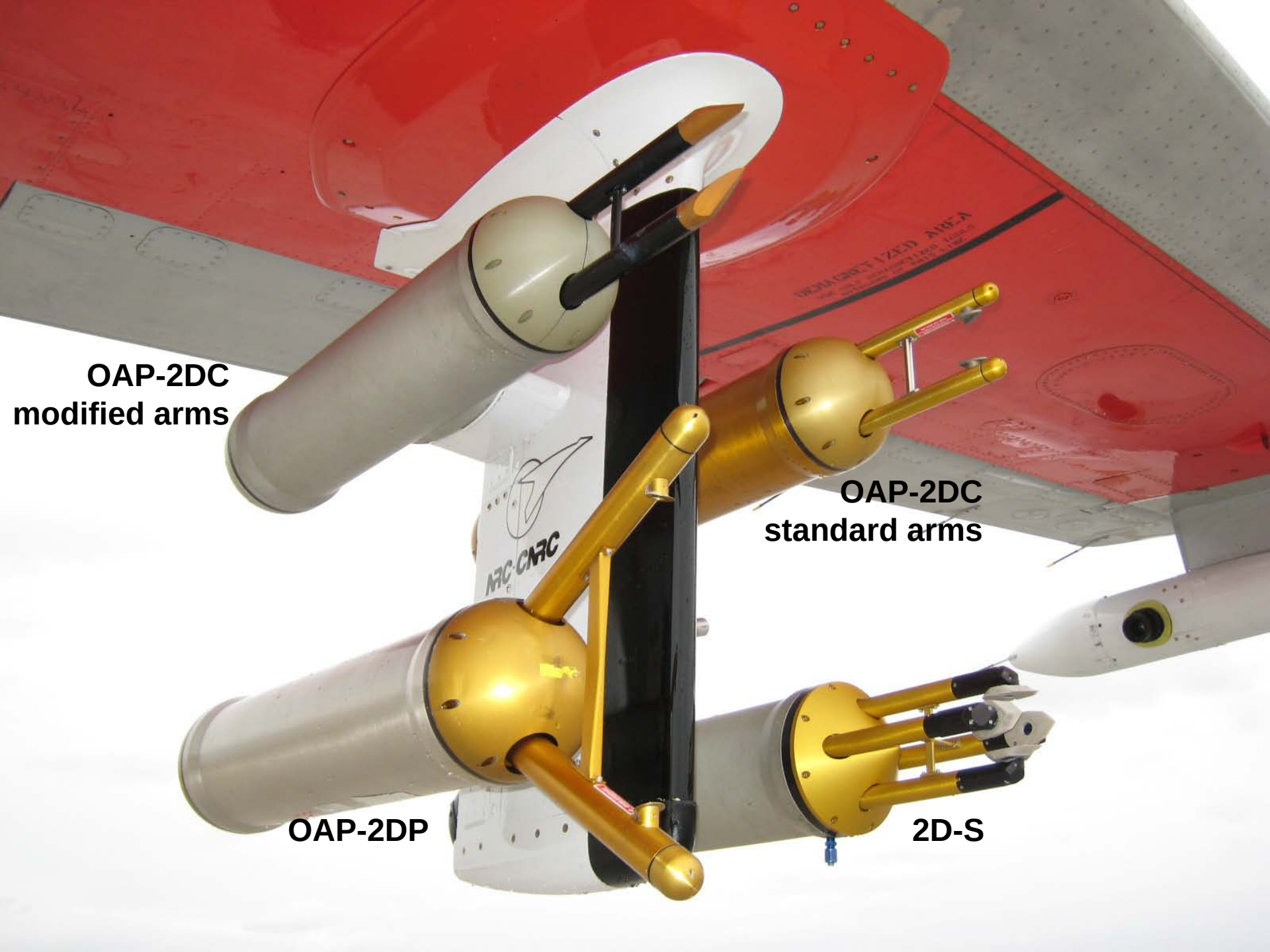
CIP, pixel resolution 25μm



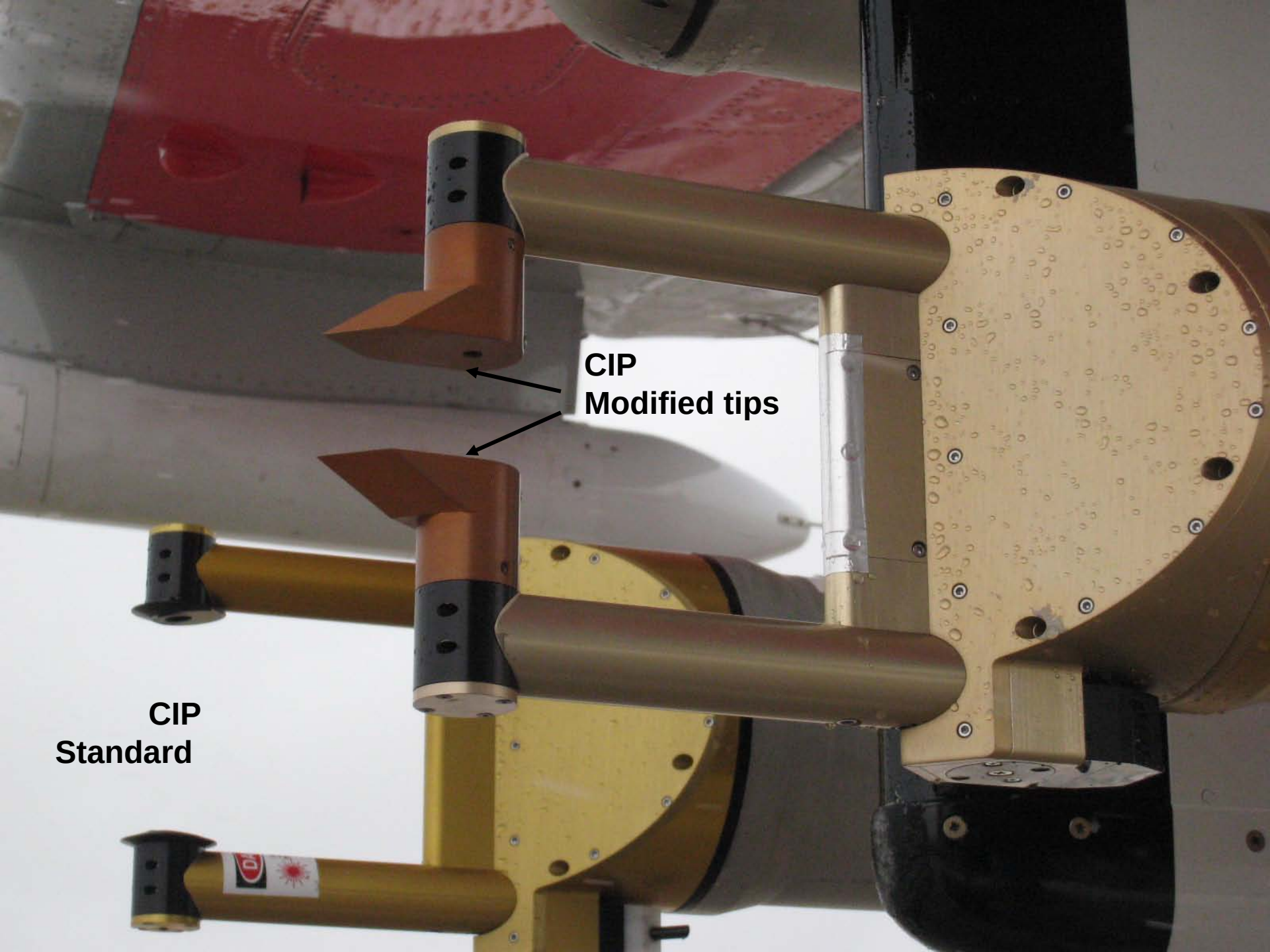
CIP, pixel resolution 15μm



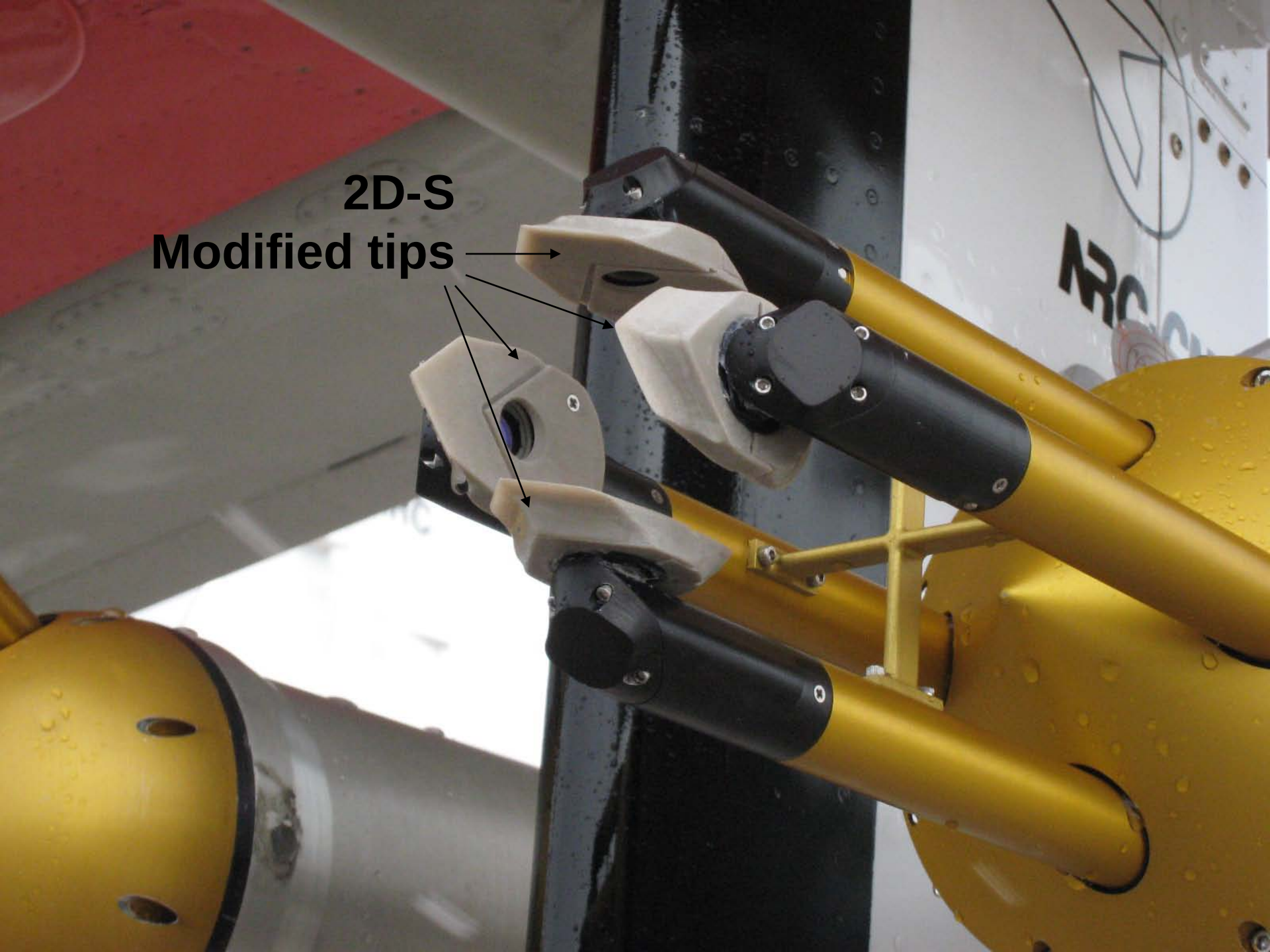
NRC Convair 580


OAP-2DC
modified arms
OAP-2DC
standard arms
OAP-2DP
2D-S
NRC·CNRC

FSSP
Modified
FSSP
Standard

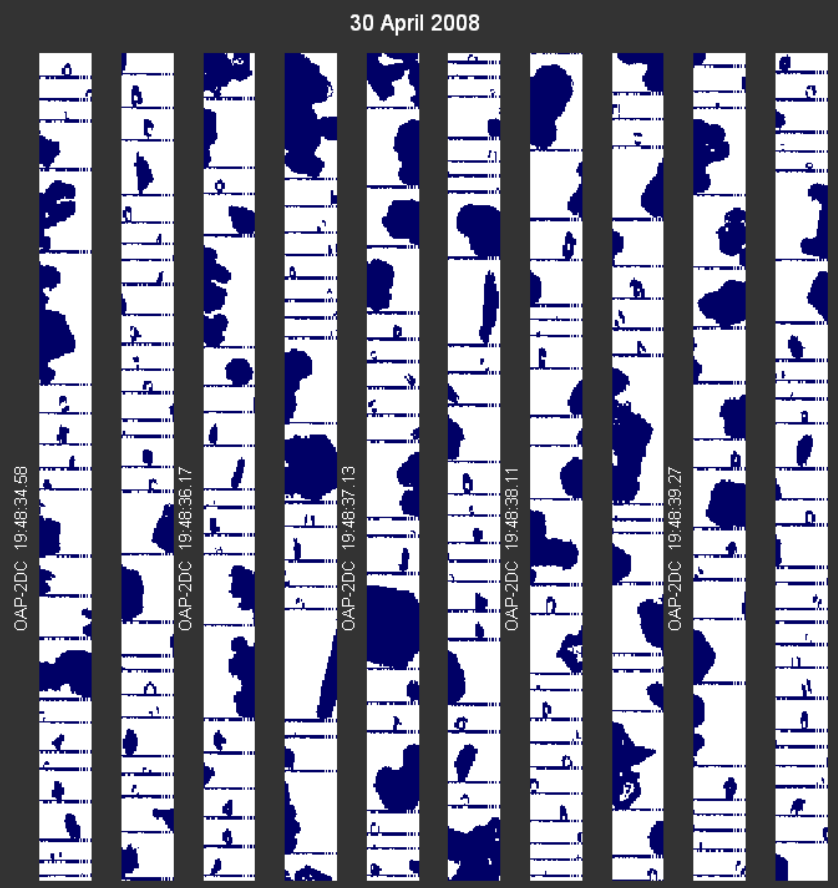

CIP
Modified tips
CIP
Standard

NRC·CNRC
NRC·CNRC

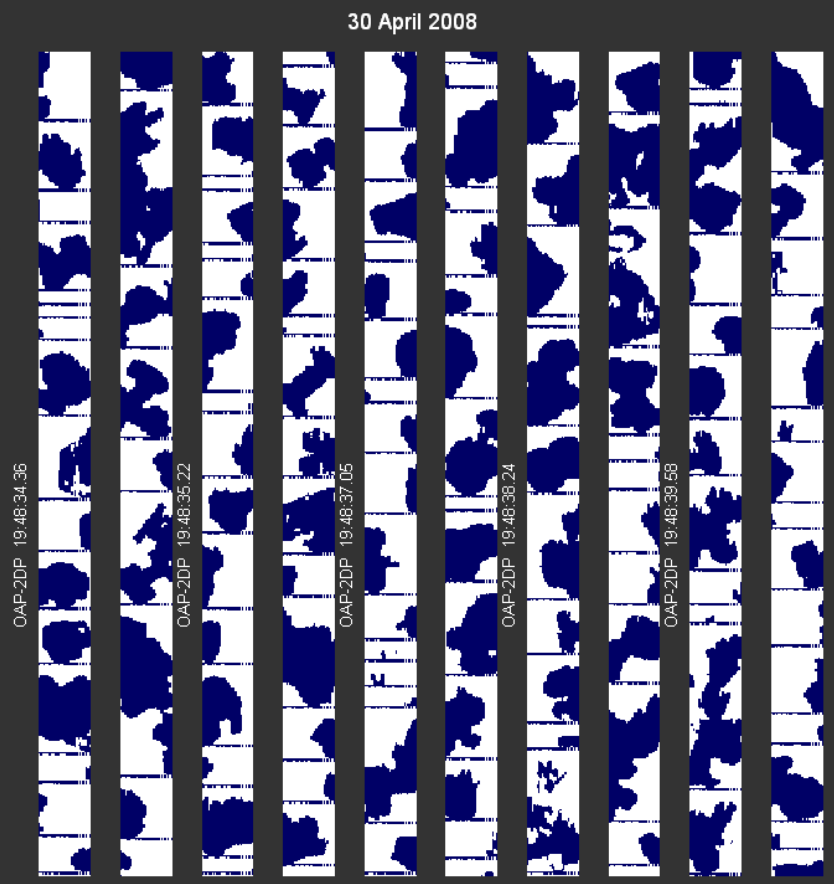

2D-S
Modified tips

RESULTS

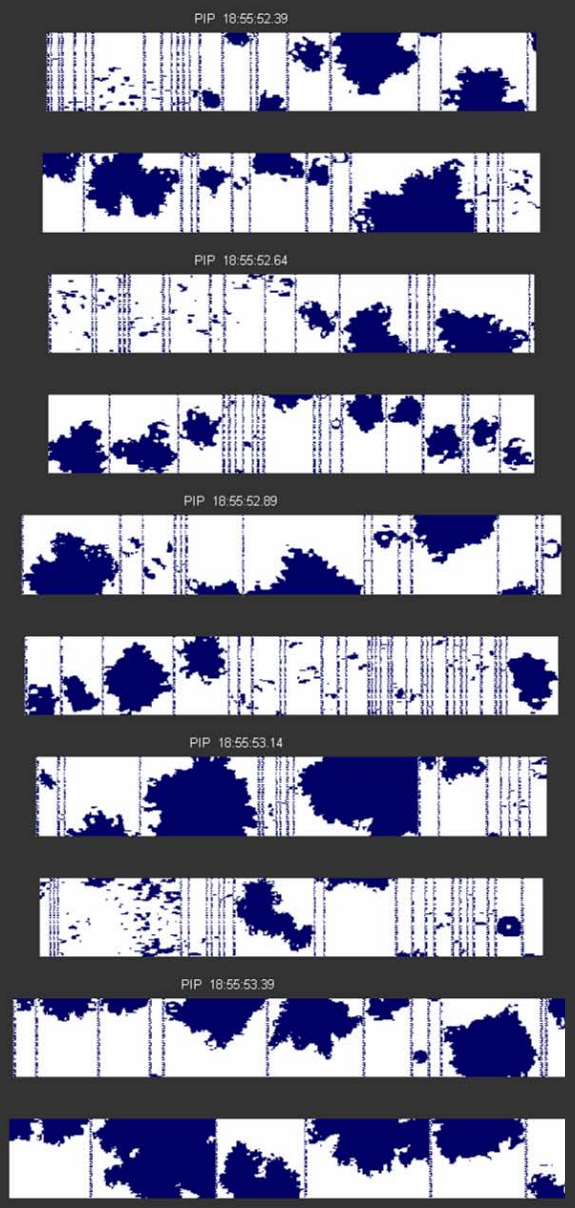
Standard OAP-2DC arms



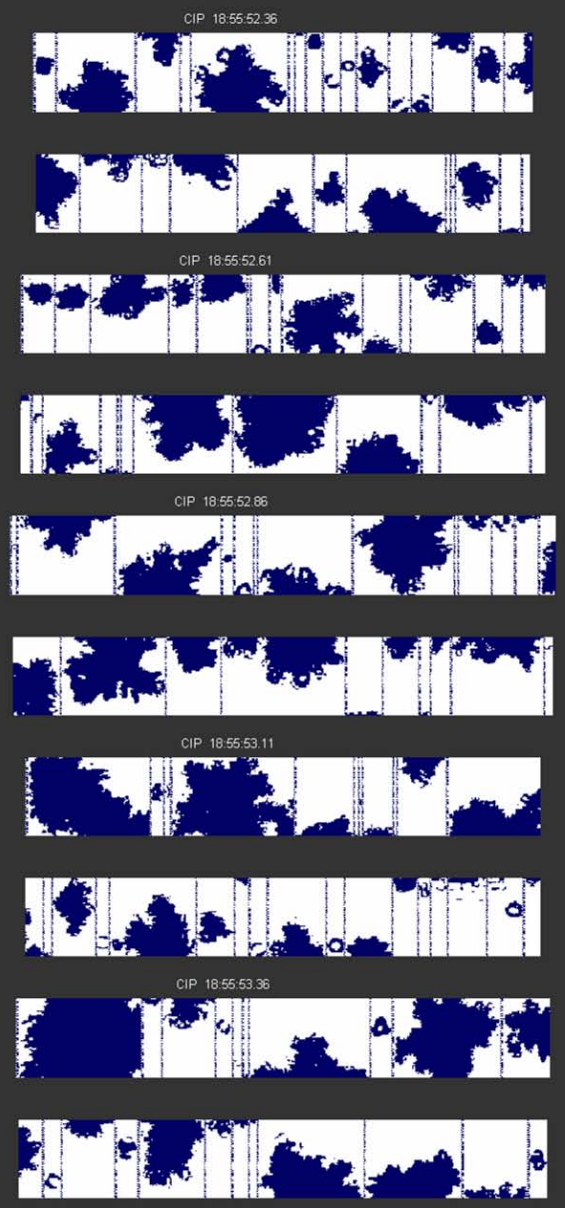
Modified OAP-2DC arms

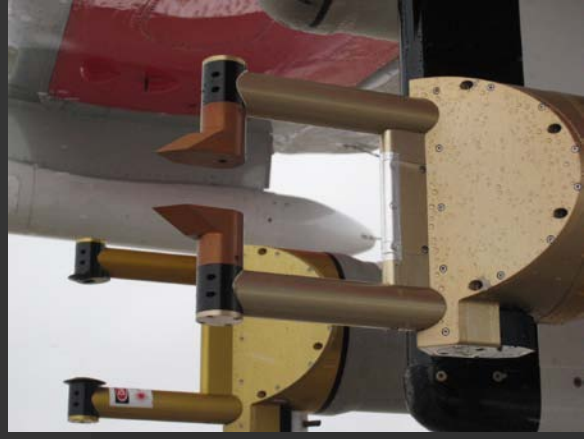


Standard CIP arms



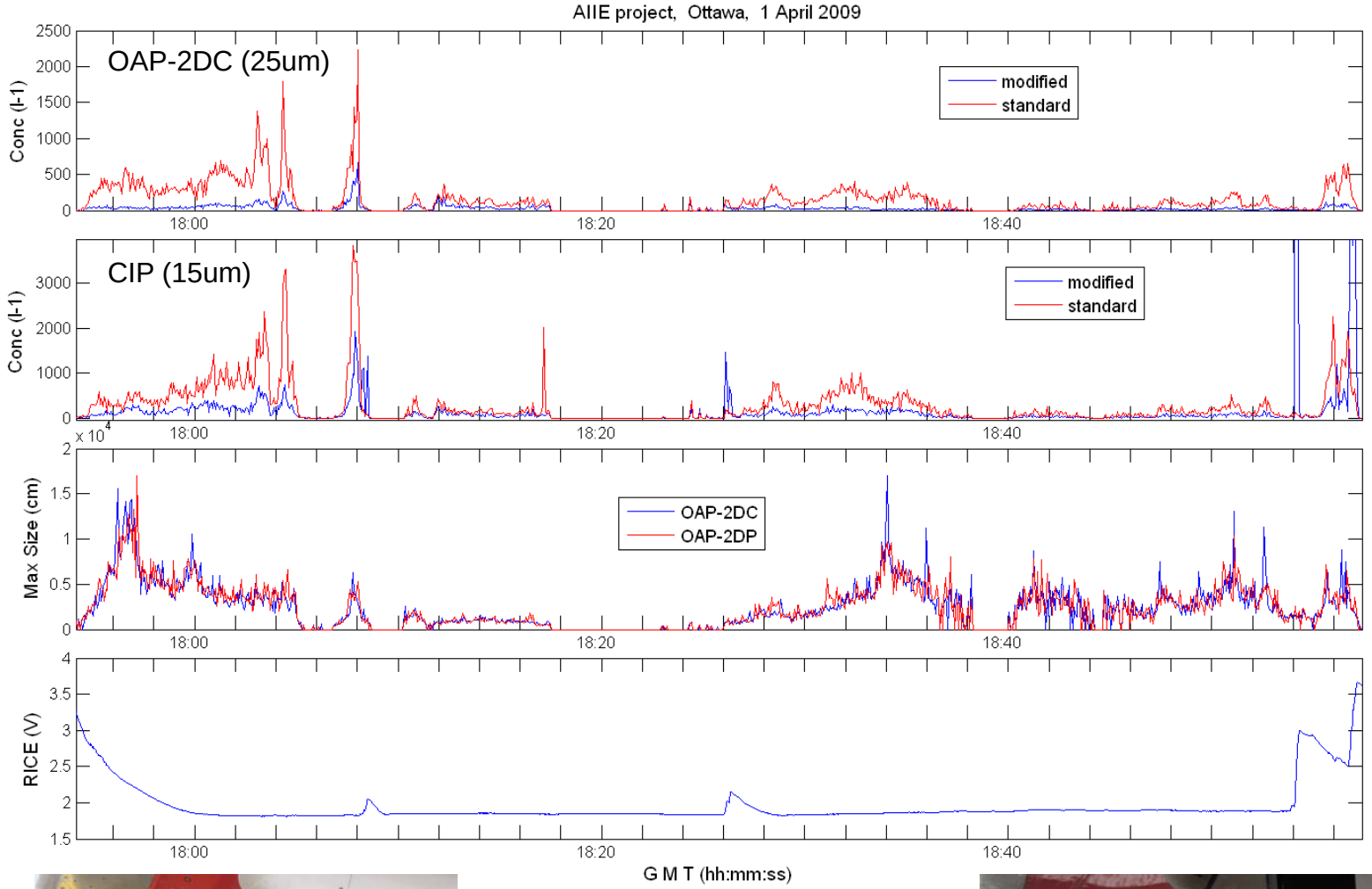
Modified CIP arms

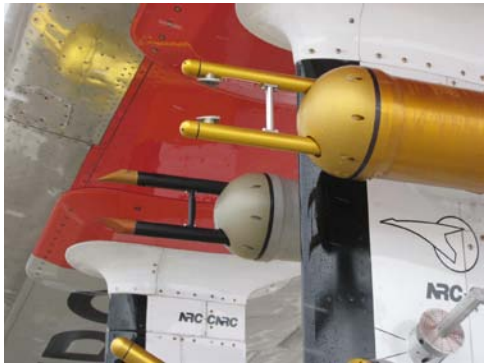




1 April 2009

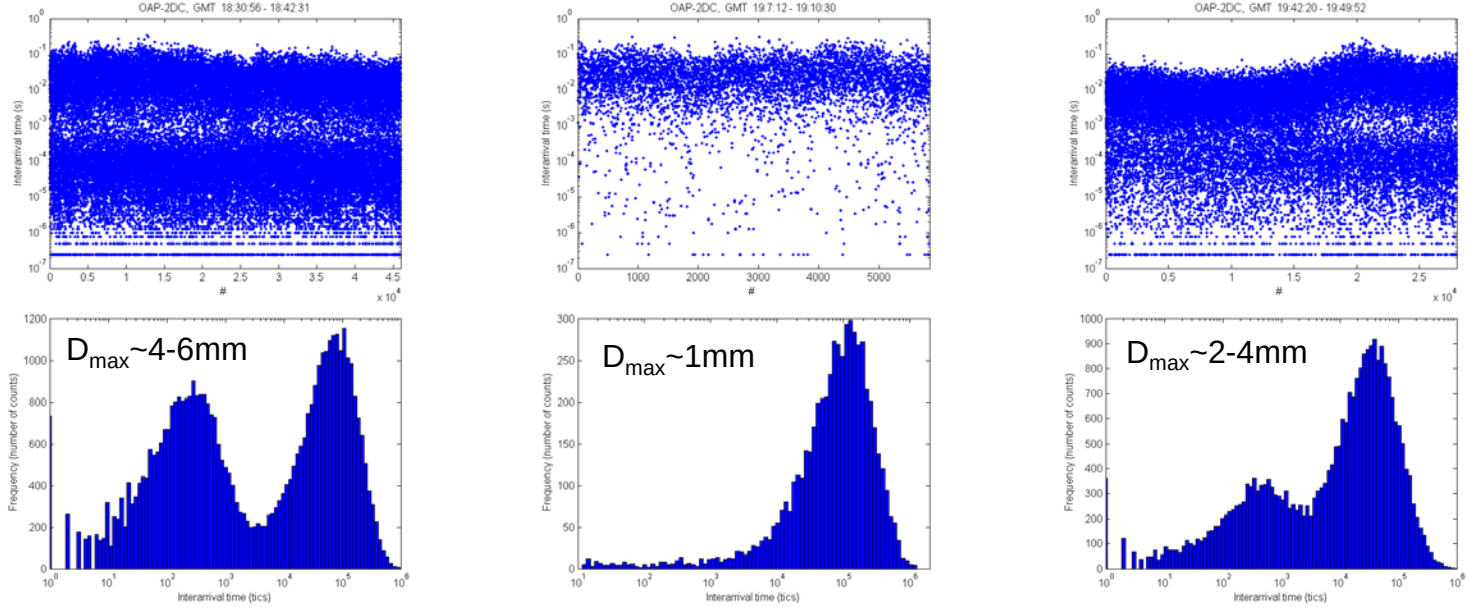
OAP-2DC and CIP response in ice clouds



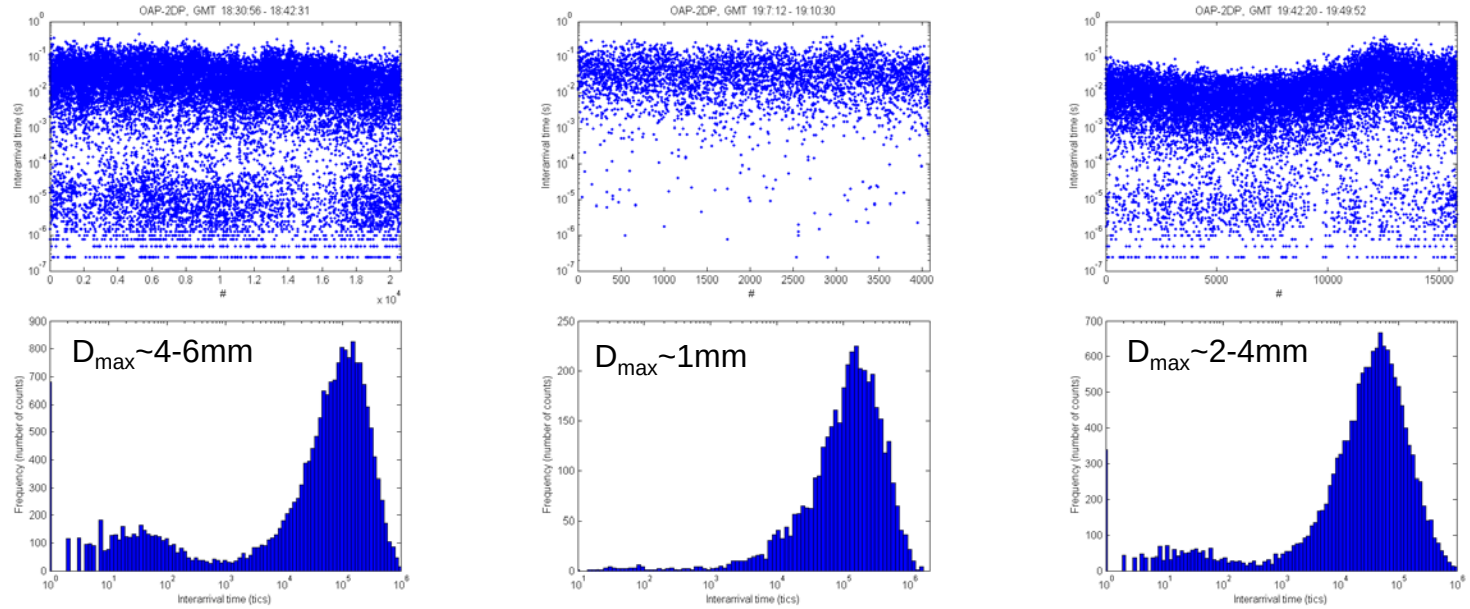


Statistics of OAP-2DC interarrival time

Standard arms

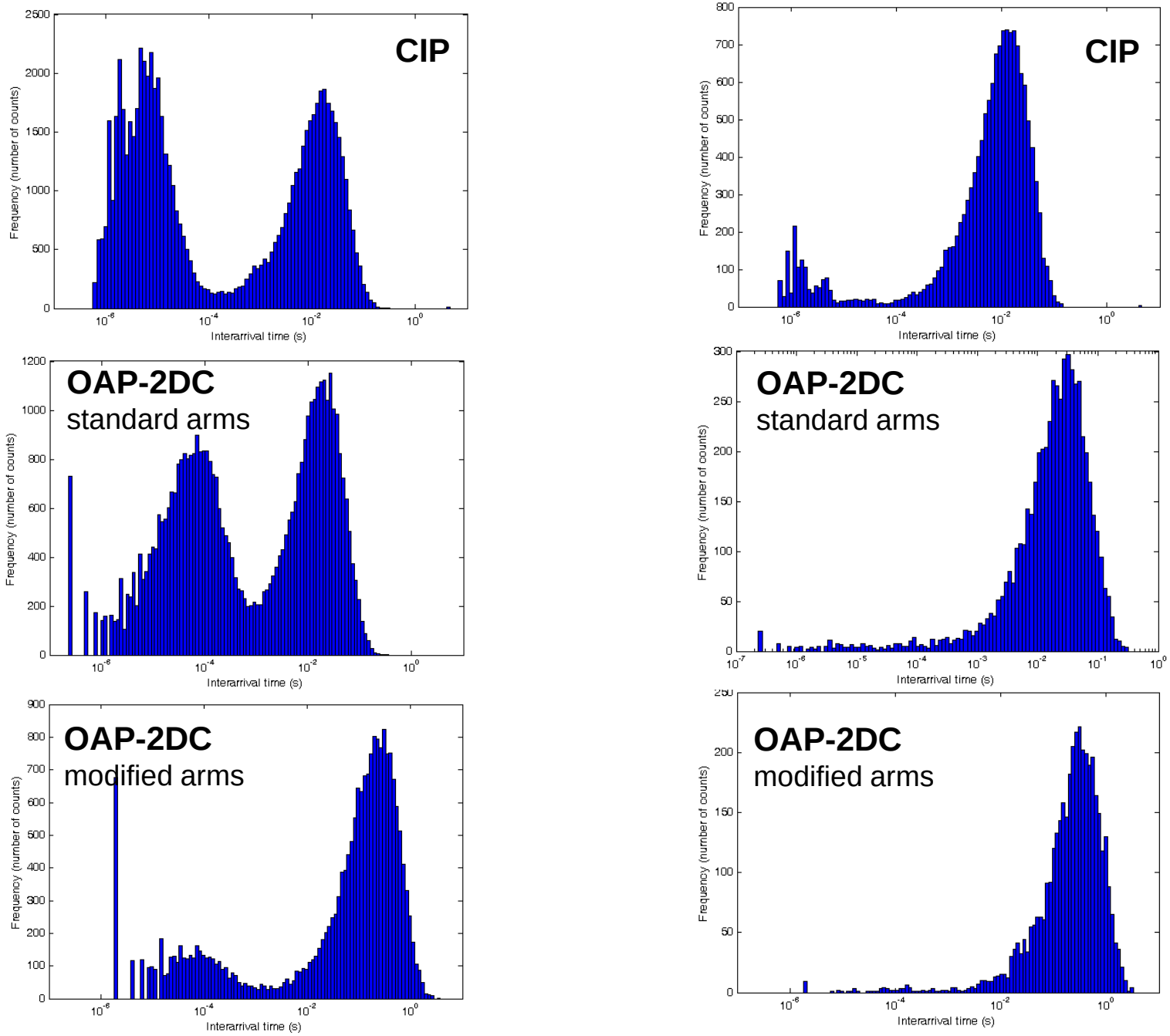


Modified arms

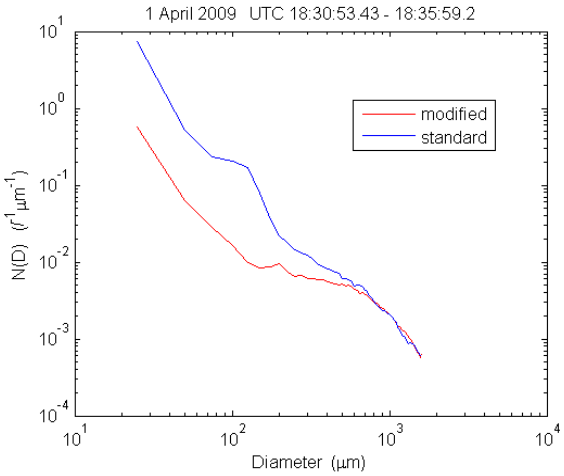


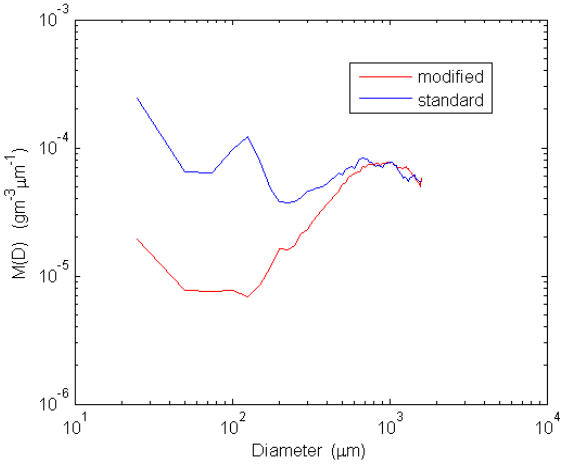
Large particles: D_{max}~4-6mm

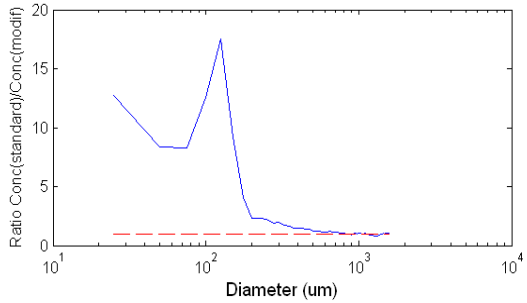
Small articles: D_{max}~1mm



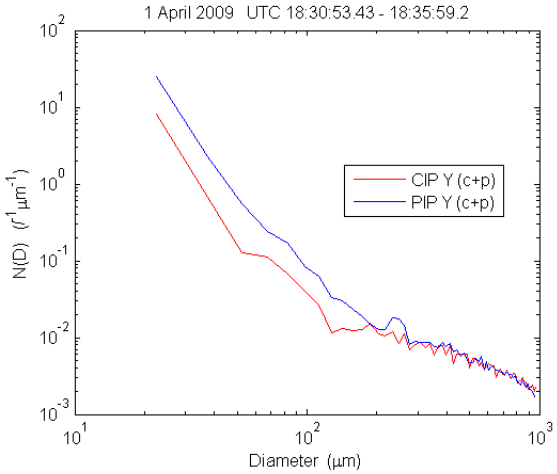
OAP-2DC

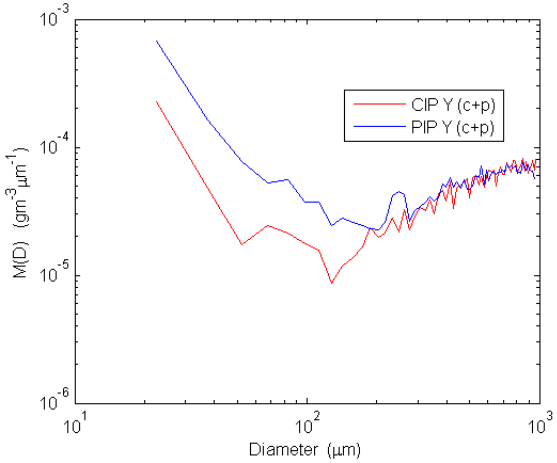

1 April 2009 UTC 18:30:53.43 - 18:35:59.2
modified
standard
N(D) (l^{-1}µm^{-1})
Diameter (µm)

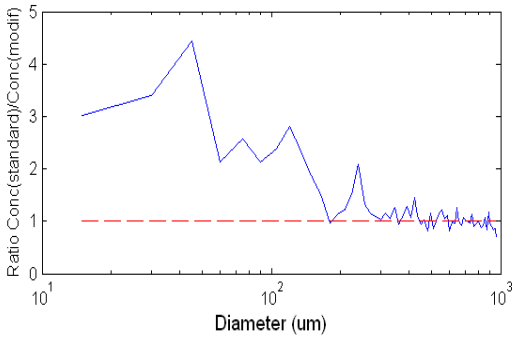

modified
standard
M(D) (gm^{-3}µm^{-1})
Diameter (µm)

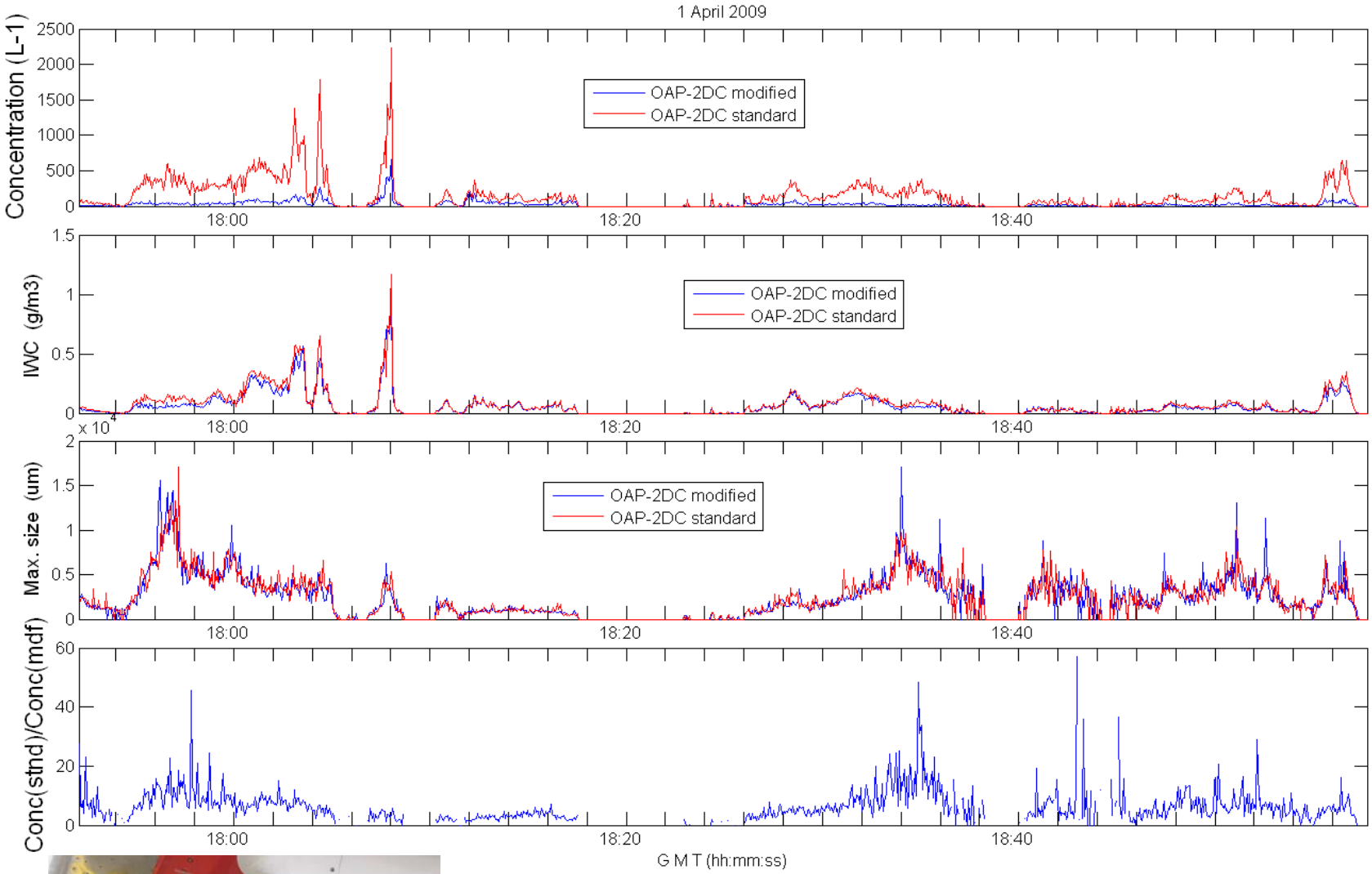

Ratio Conc(standard)/Conc(modif)
Diameter (um)

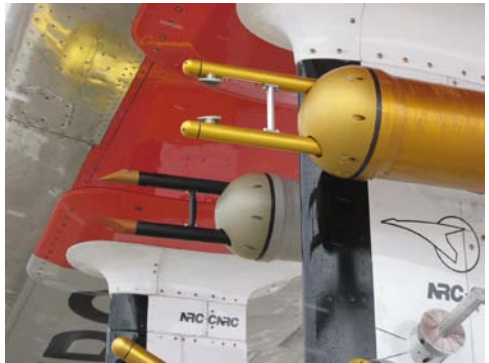
CIP

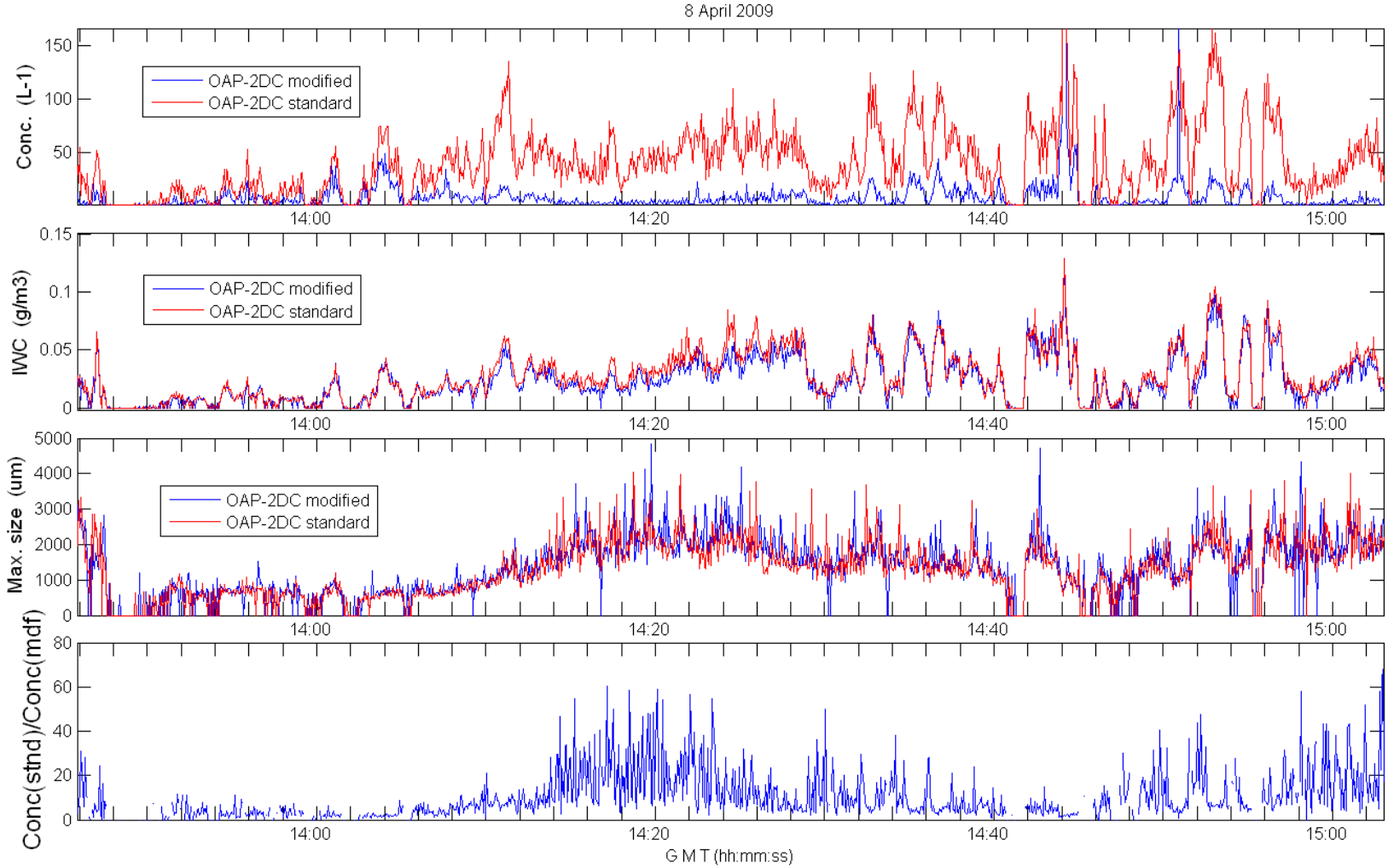

1 April 2009 UTC 18:30:53.43 - 18:35:59.2
CIP Y (c+p)
PIP Y (c+p)
N(D) (l^{-1}µm^{-1})
Diameter (µm)

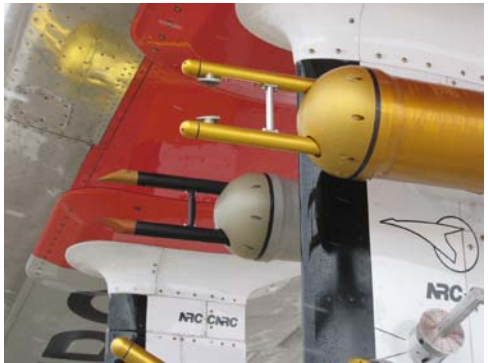

CIP Y (c+p)
PIP Y (c+p)
M(D) (gm^{-3}µm^{-1})
Diameter (µm)


Ratio Conc(standard)/Conc(modif)
Diameter (um)


1 April 2009
Concentration (L-1)
OAP-2DC modified
OAP-2DC standard
IWC (g/m3)
x 10^4
Max. size (um)
Conc(stnd)/Conc(mdf)
18:00
18:20
18:40
G M T (hh:mm:ss)

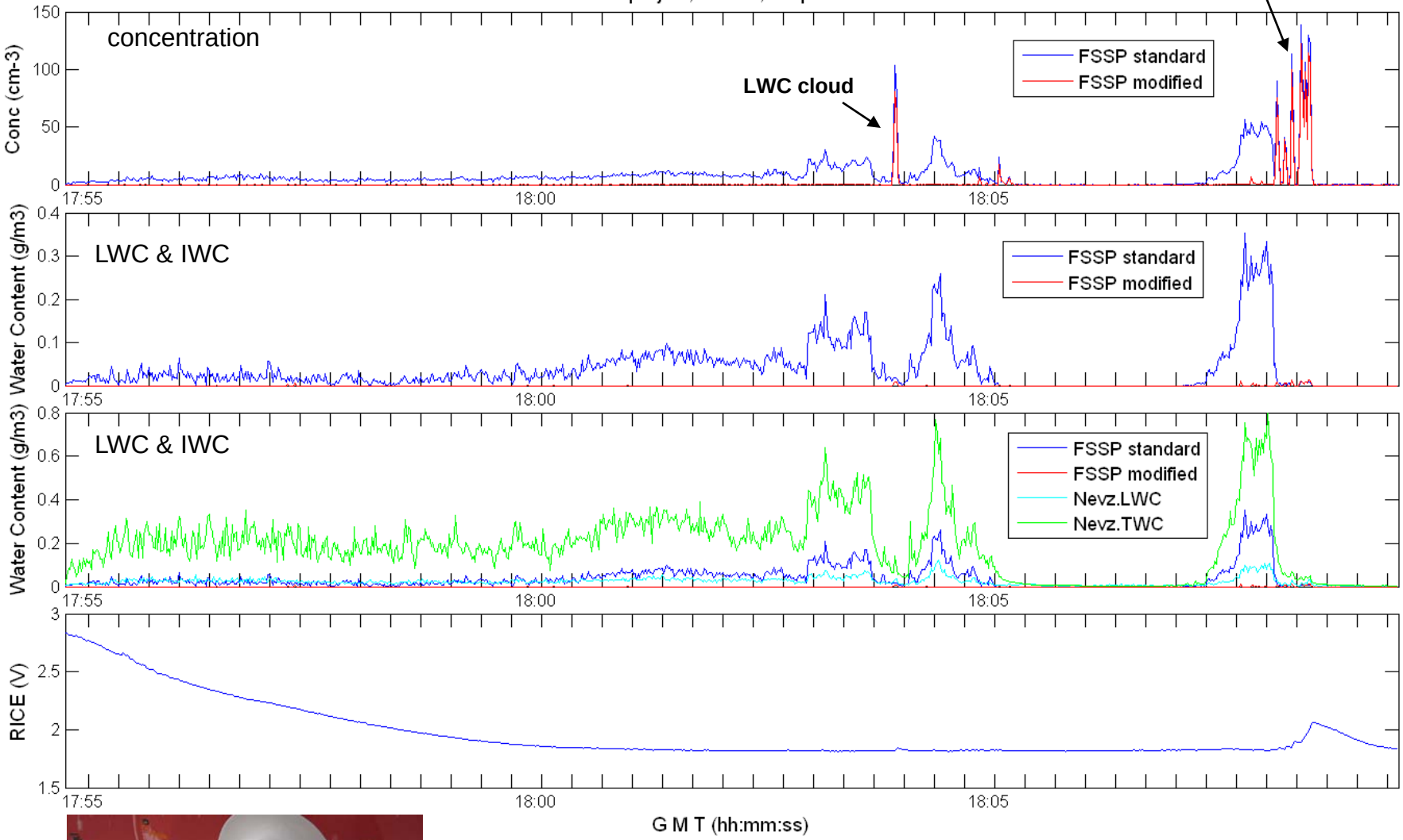

NRC CNRC
NRC


8 April 2009
Conc. (L-1)
OAP-2DC modified
OAP-2DC standard
IWC (g/m3)
Max. size (um)
Conc(stnd)/Conc(mdf)
14:00
14:20
14:40
15:00
G M T (hh:mm:ss)

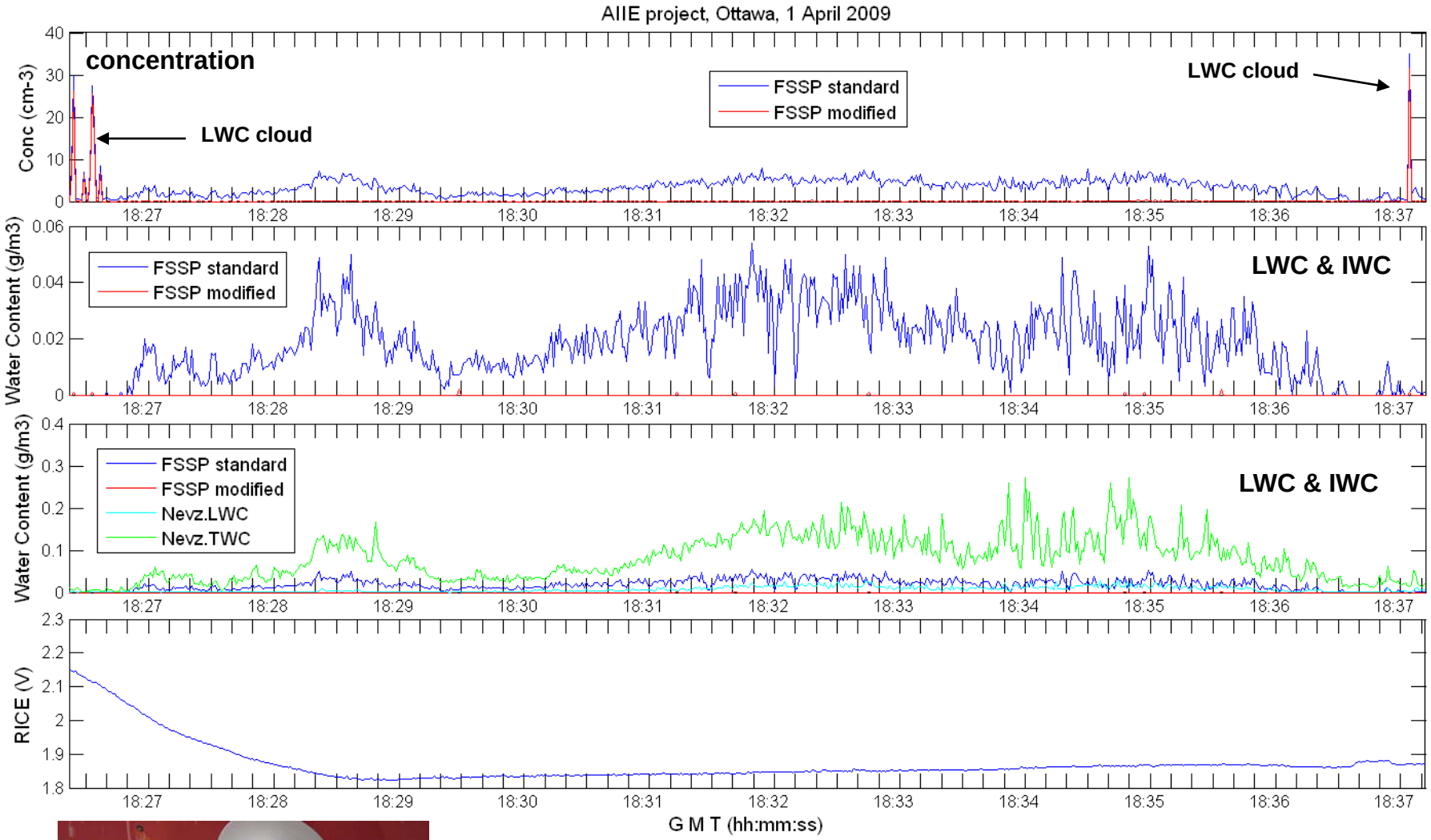

NRC
NRC CNRC

FSSP response in ice clouds

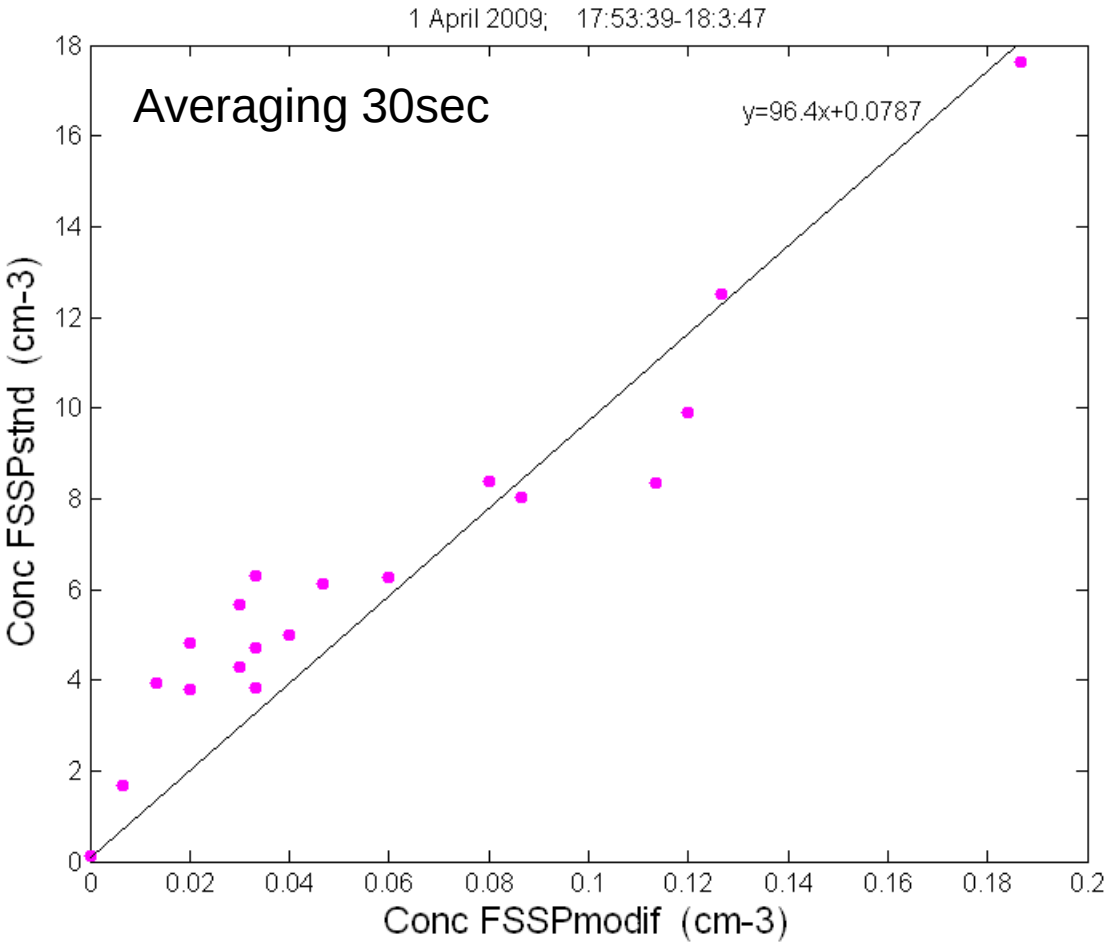
AIIE project, Ottawa, 1 April 2009



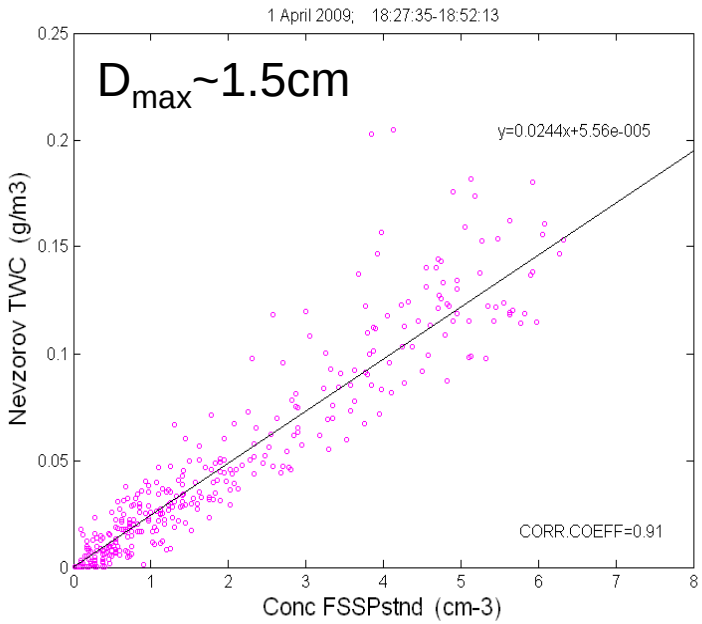
FSSP response in ice clouds

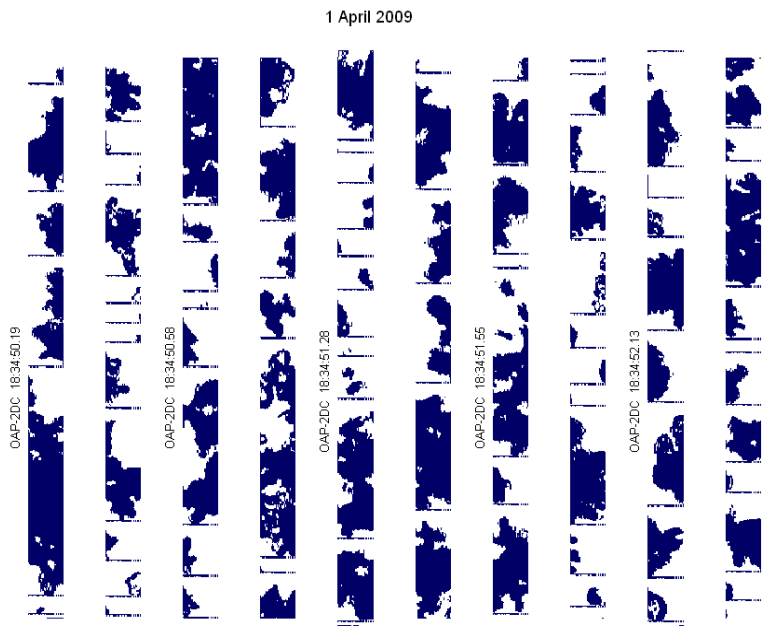


FSSP response in ice clouds

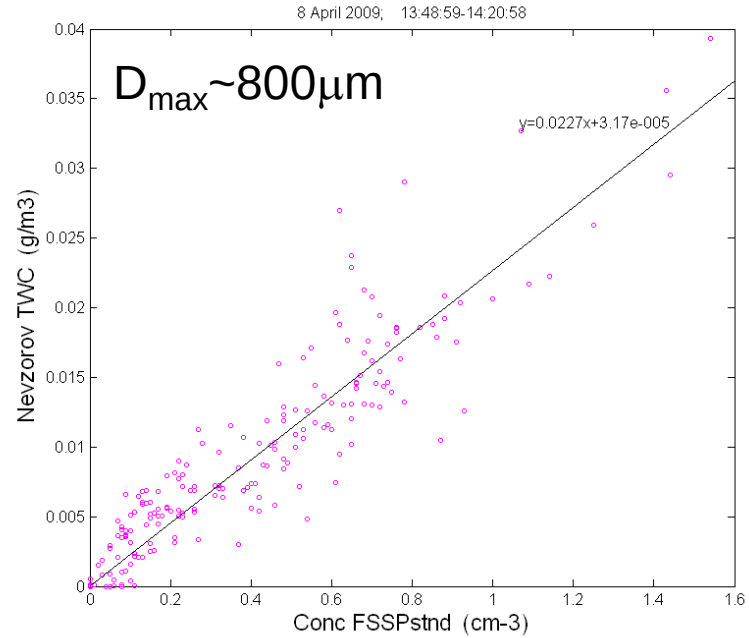


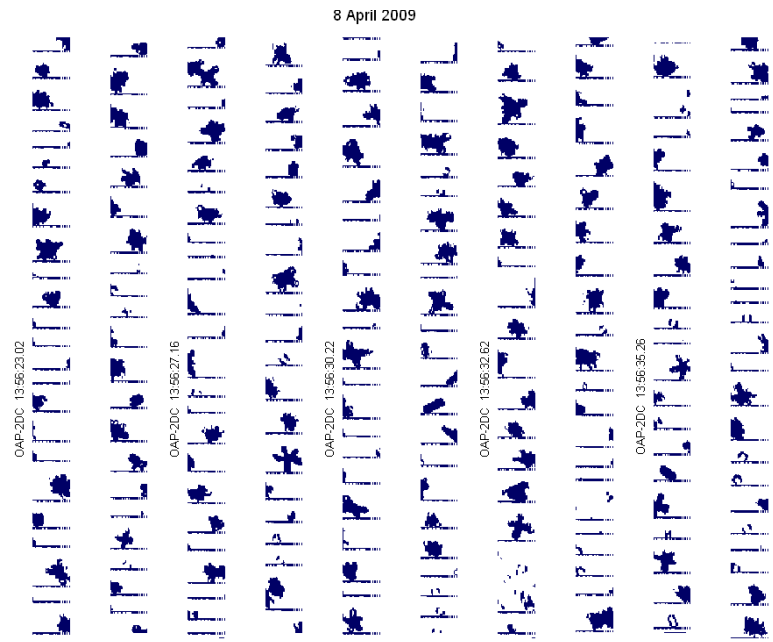
Case 1

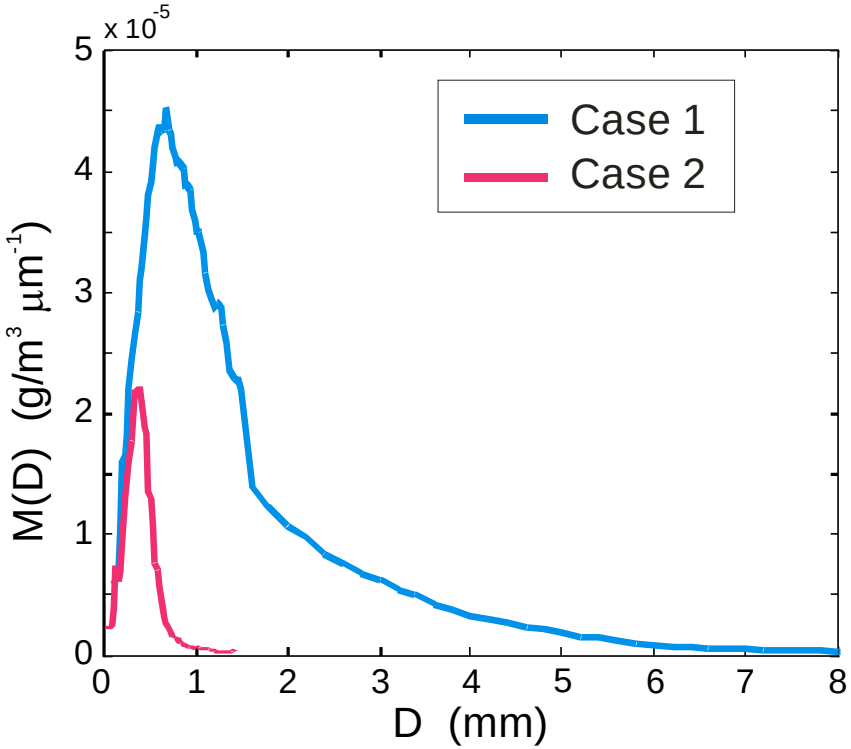

1 April 2009; 18:27:35-18:52:13
D_{max}~1.5cm
y=0.0244x+5.56e-005
CORR.COEFF=0.91
Nevzorov TWC (g/m3)
Conc FSSPstnd (cm-3)


1 April 2009
OAP-2DC 18:34:50.19
OAP-2DC 18:34:50.58
OAP-2DC 18:34:51.28
OAP-2DC 18:34:51.55
OAP-2DC 18:34:52.13

Case 2

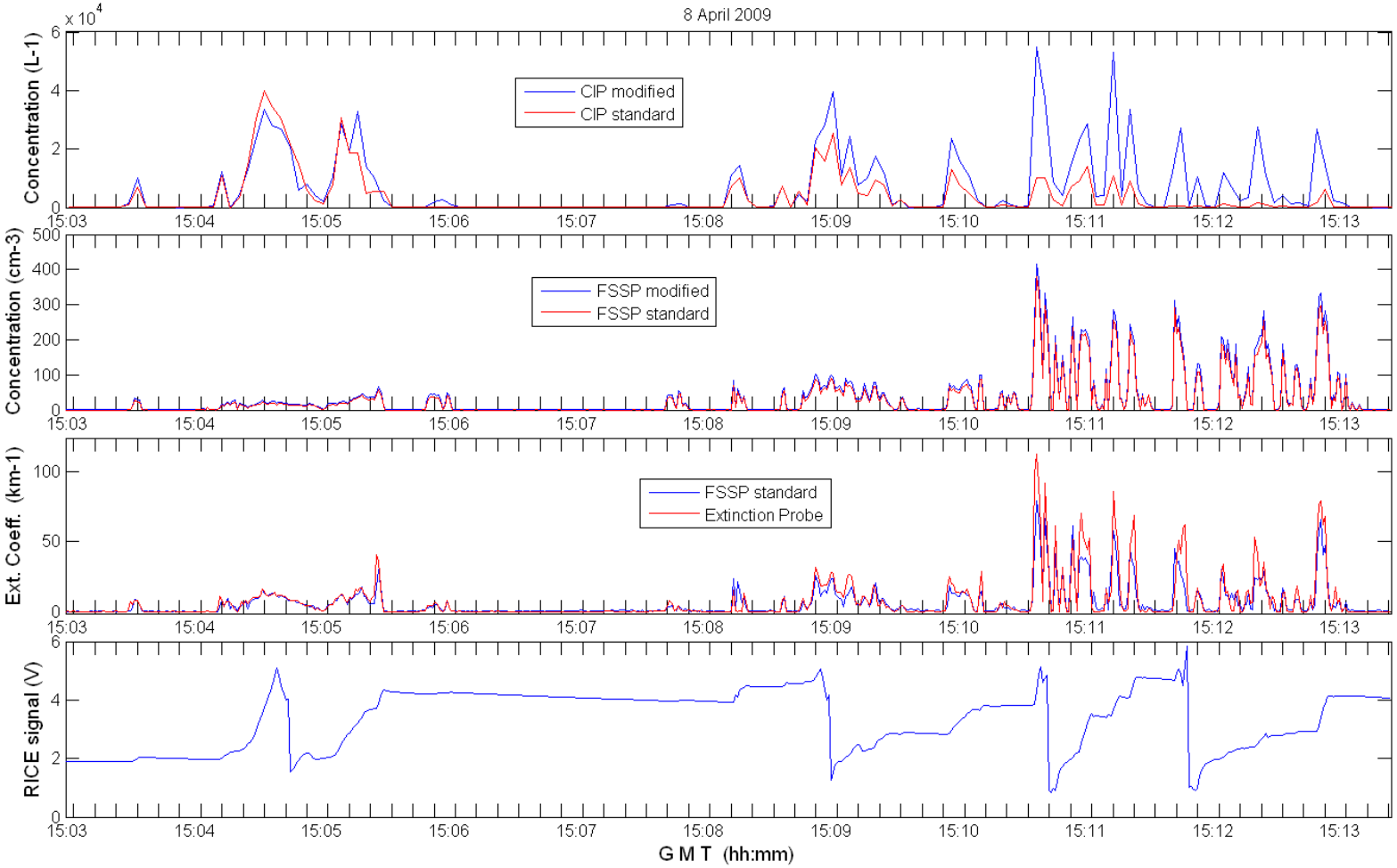

8 April 2009; 13:48:59-14:20:58
D_{max}~800μm
y=0.0227x+3.17e-005
Nevzorov TWC (g/m3)
Conc FSSPstnd (cm-3)


8 April 2009
OAP-2DC 13:56:23.02
OAP-2DC 13:56:27.16
OAP-2DC 13:56:30.22
OAP-2DC 13:56:32.62
OAP-2DC 13:56:35.26



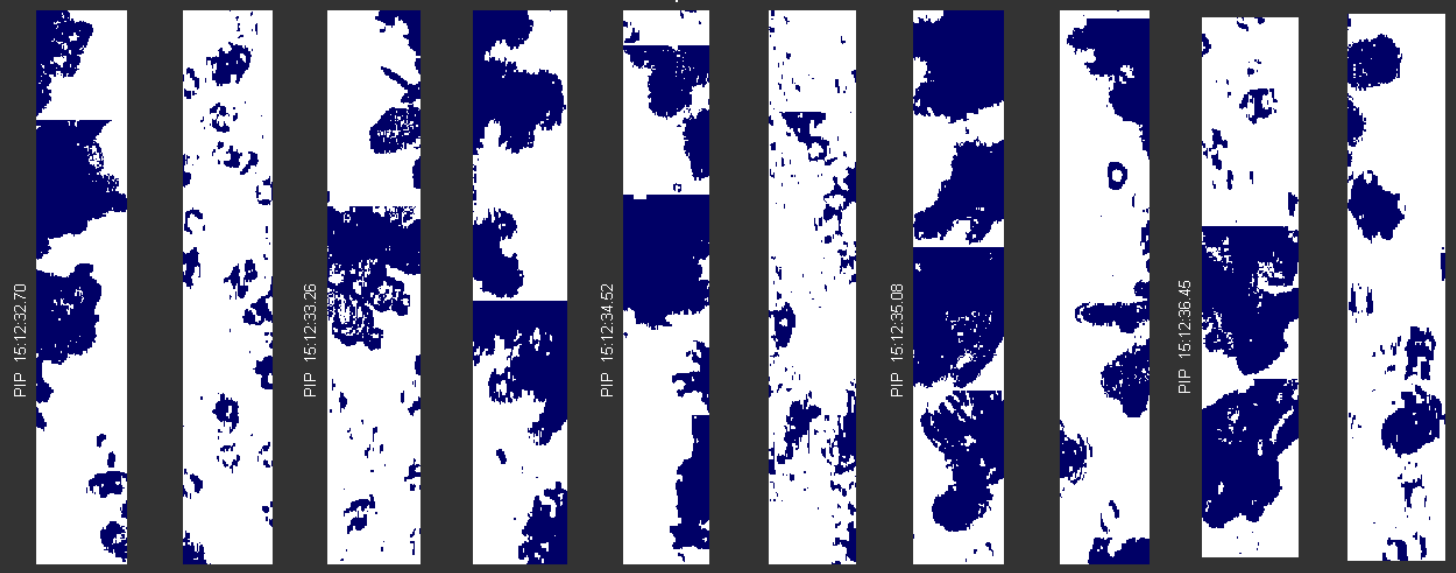
The shattering efficiency of the standard FSSP inlet tube is linearly related to ice mass, and to a first approximations does not depend on particle size and their habits

Performance of CIP in optically dense clouds



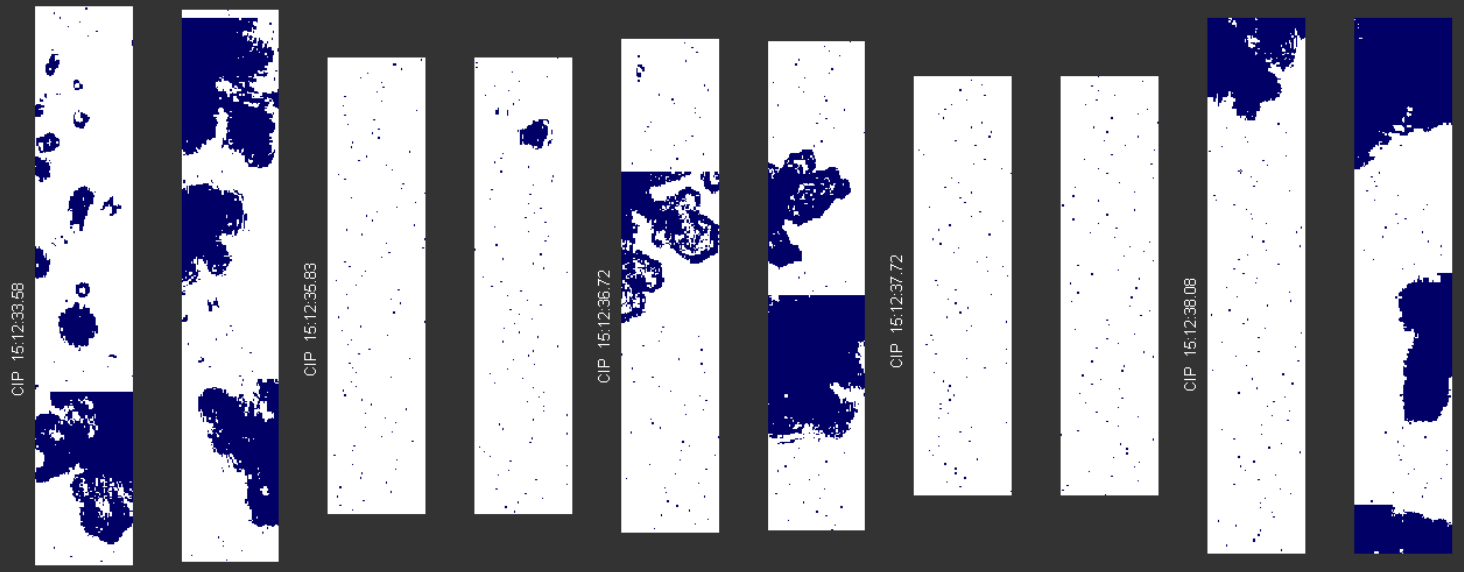
CIP (standard) Sample Volume Length =10cm

8 April 2009

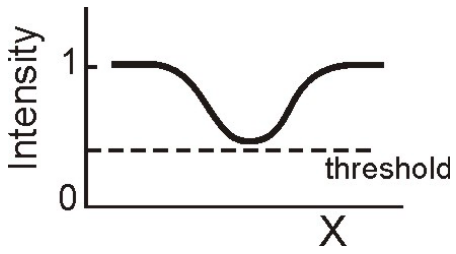


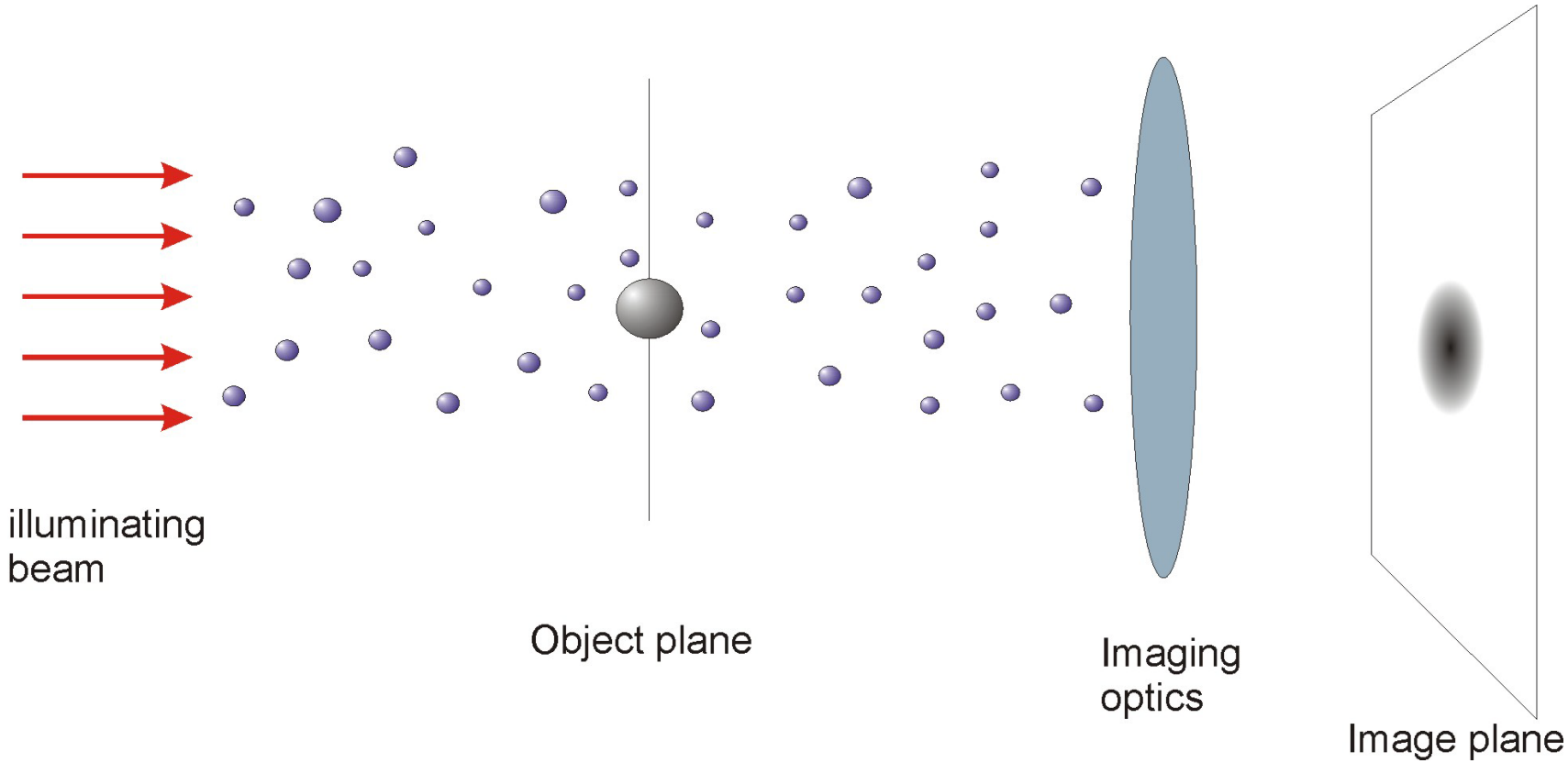
CIP (modified) Sample Volume Length =4cm

8 April 2009



Concept of the CIP limiting imaging performance in optically dense clouds





Conclusions

1. Ice particle shattering may result in the overestimation of the measured concentration ten fold or more.

2. For some instruments (e.g. OAP-2DC) existing algorithms are incapable of filtering out all shattering events.

3. Modification of probes inlets seems to be the only solution to minimize the effect of shattering.

AIIE project group photo

Acknowledgements:

Sara Lance (NOAA)

Dave Rogers (NCAR)

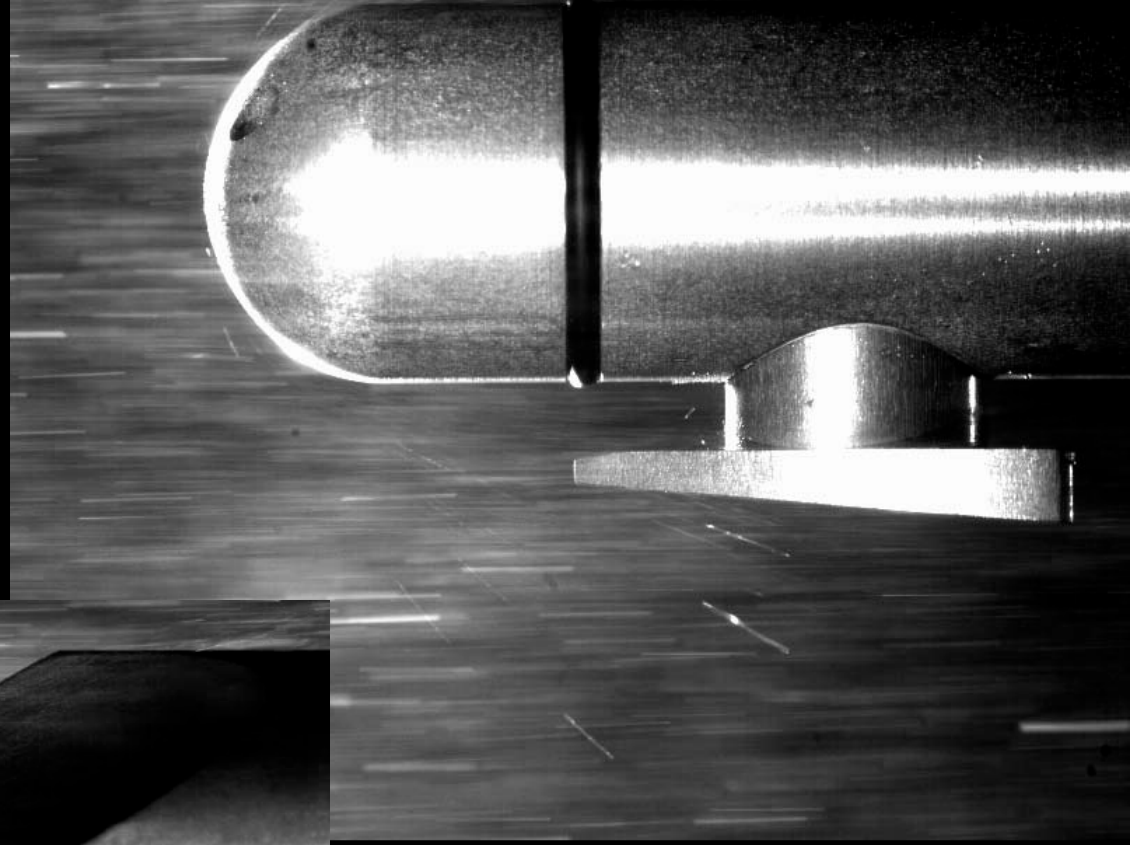
Ed Emery (NASA)

DMT Inc.

COX wind tunnel tests

EC & NASA

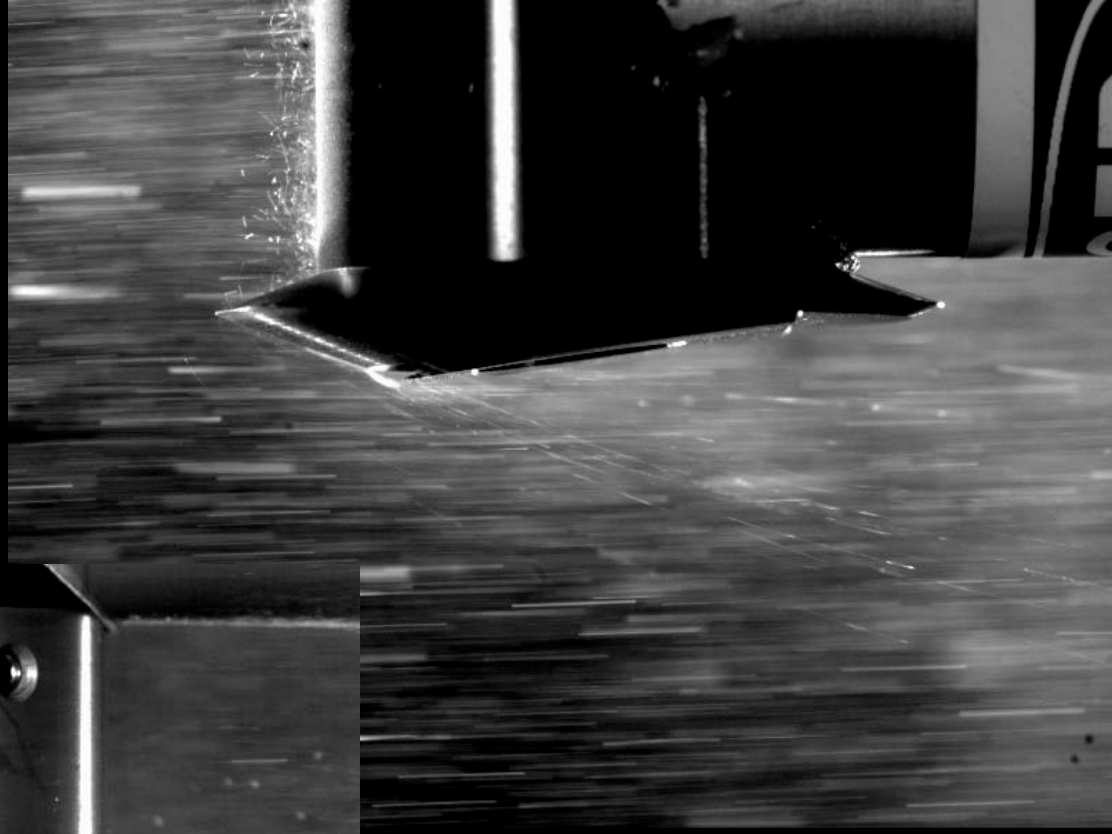
16-26 September 2009

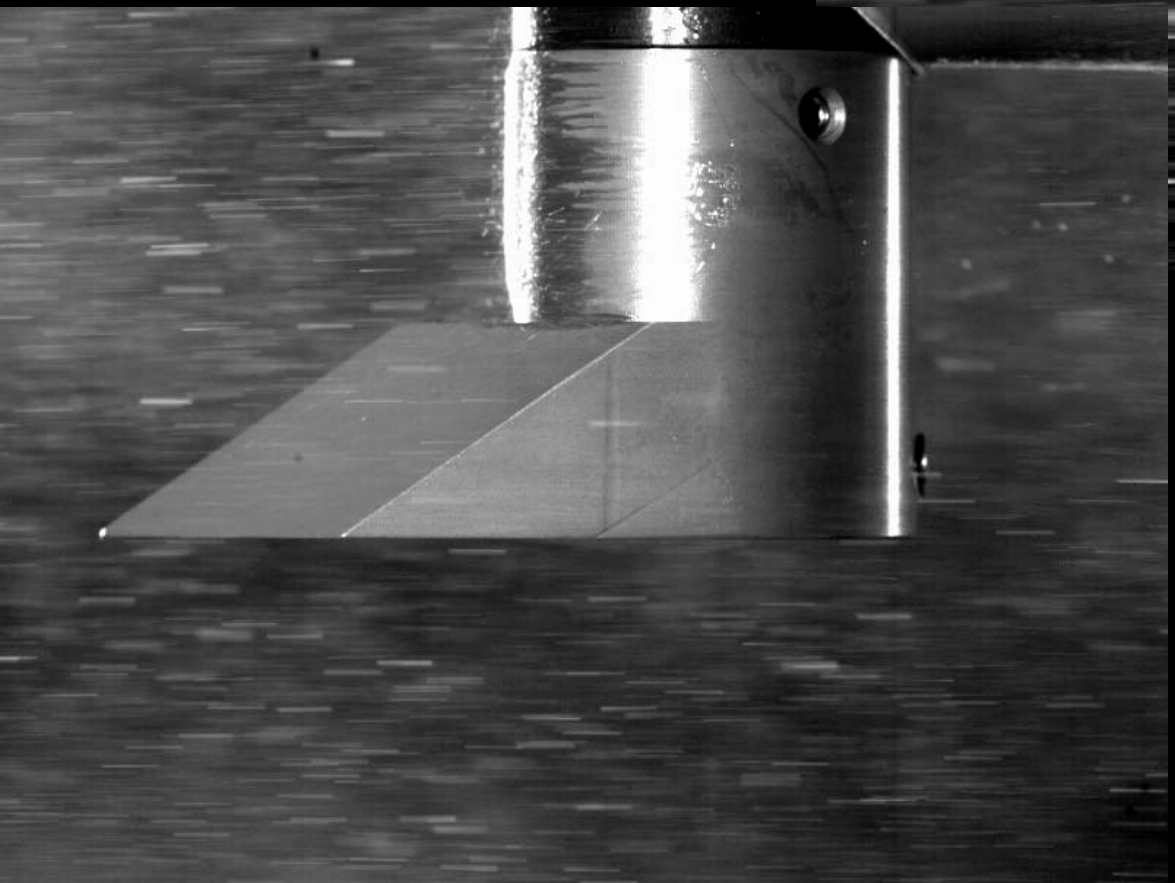


COX wind tunnel tests

EC & NASA

16-26 September 2009





CPI images of shattered particles

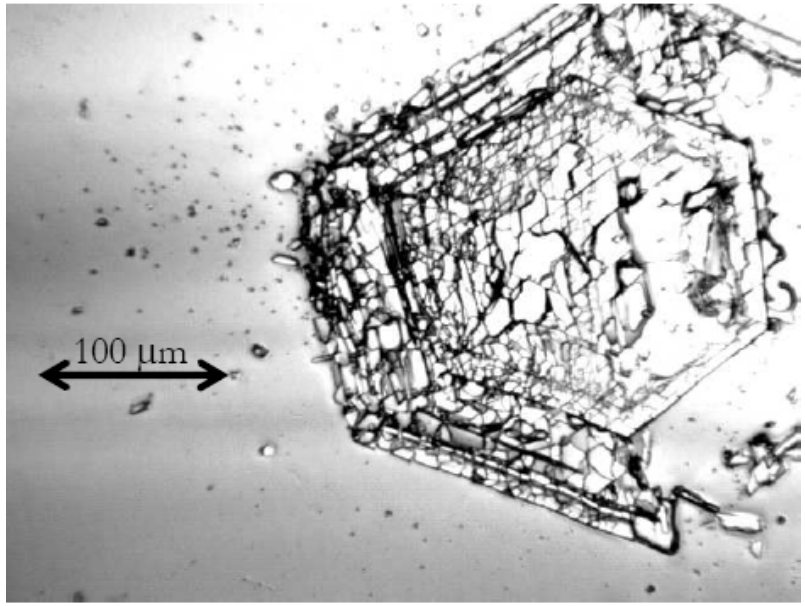
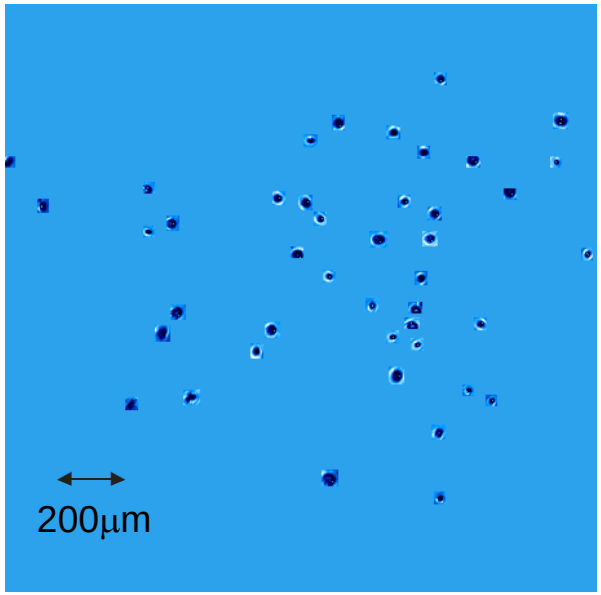
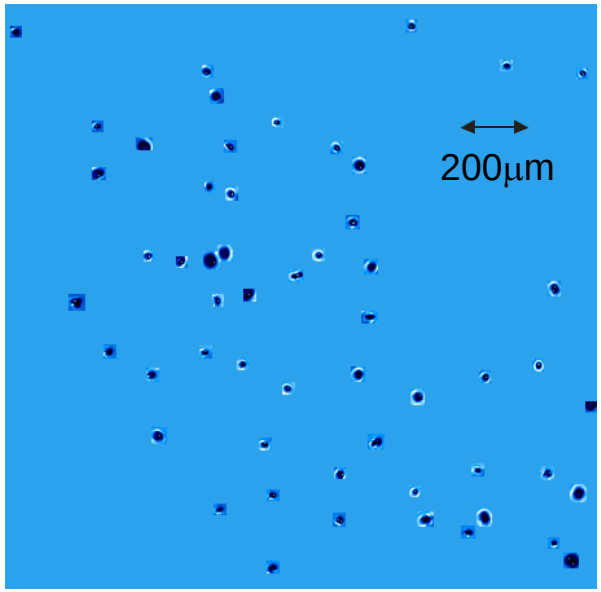


Figure 1: 300 x 400 µm still images showing broken ice crystals collected in formvar solution by continuous replicator from continental clouds in Oklahoma in the size range from 5 µm to 320 µm, showing multiple fractures. Note ice fractures are parallel to crystal axis in many areas and the fracture density is not homogeneous

Vidaurre and Hallett, 2009





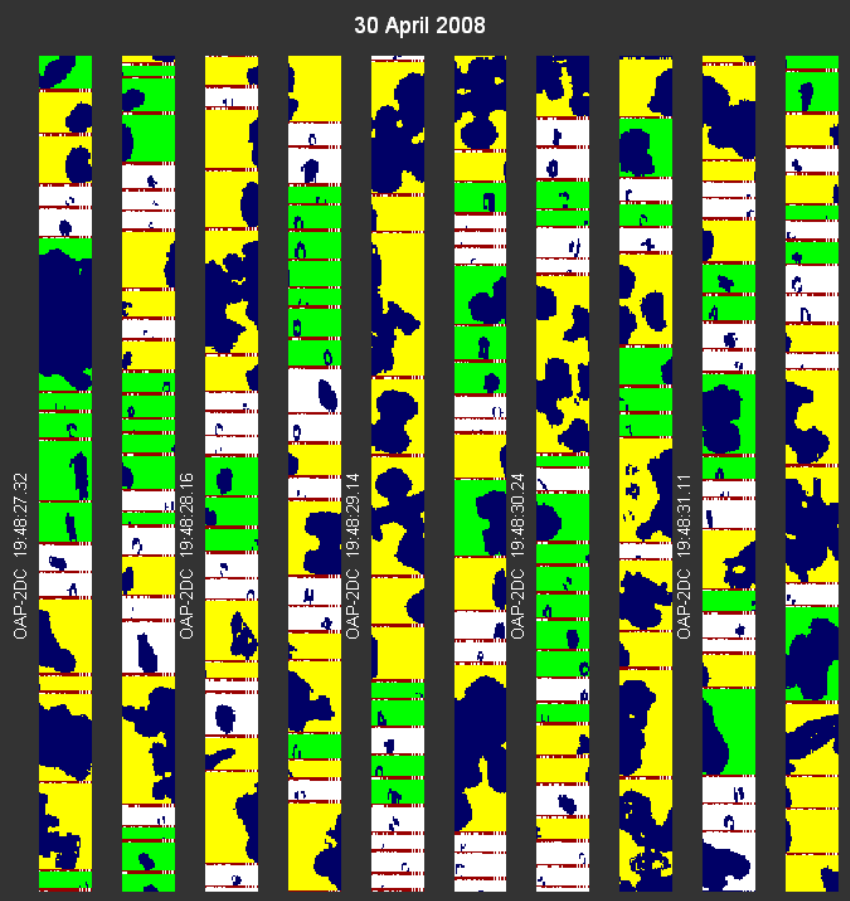
Summary of our knowledge about ice shattering at characteristic speed ~100m/s

travel distance across the airflow:	**few cm**
number of fragments:	**$2\text{-}10^3$**
min size of fragments:	**~ 10μm**
size of a cluster of shattered particles:	**<5cm**

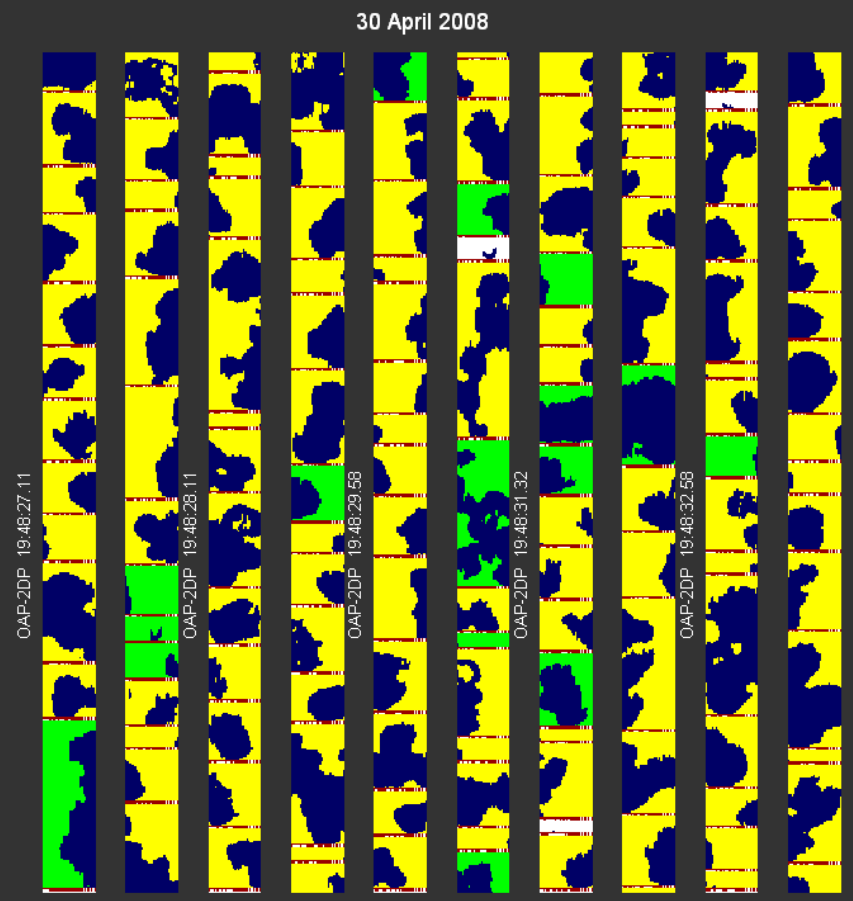
Rejected and accepted OAP-2DC images

τ_{rej}=1000 tics ⇔ ΔX=2.5cm

Standard OAD-2DC arms



Modified OAD-2DC arms

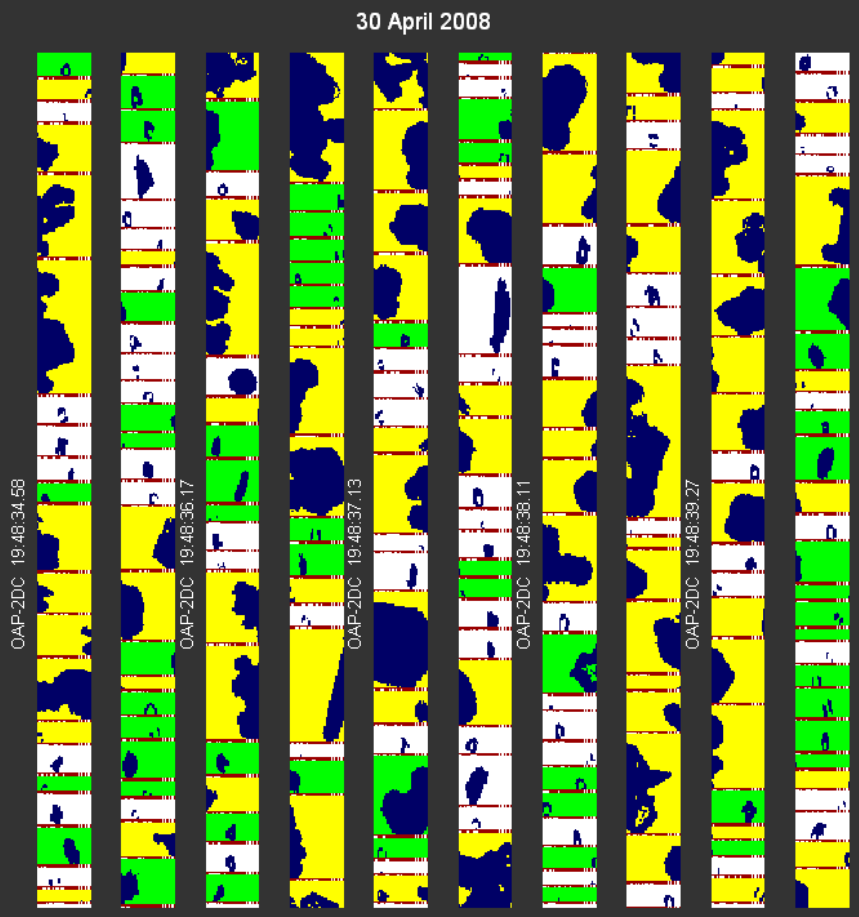


interarrival time | aspect ratio | partial images | complete images

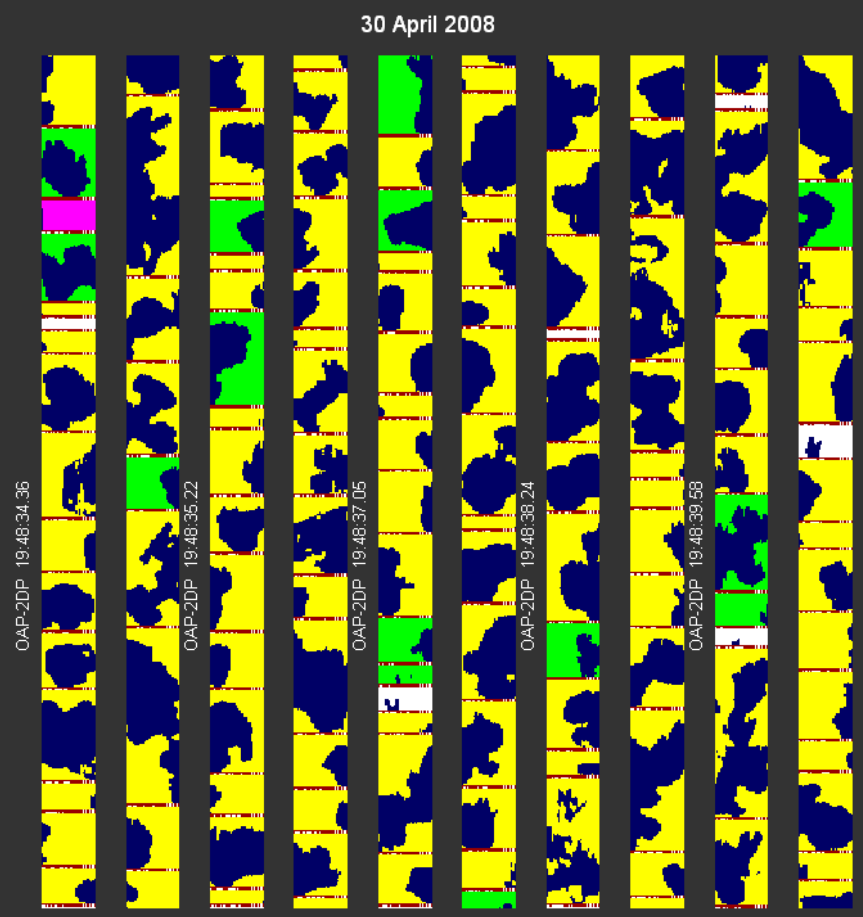
Rejected and accepted OAP-2DC images

τ_{rej}=1000 tics ⇔ ΔX=2.5cm

Standard OAD-2DC arms

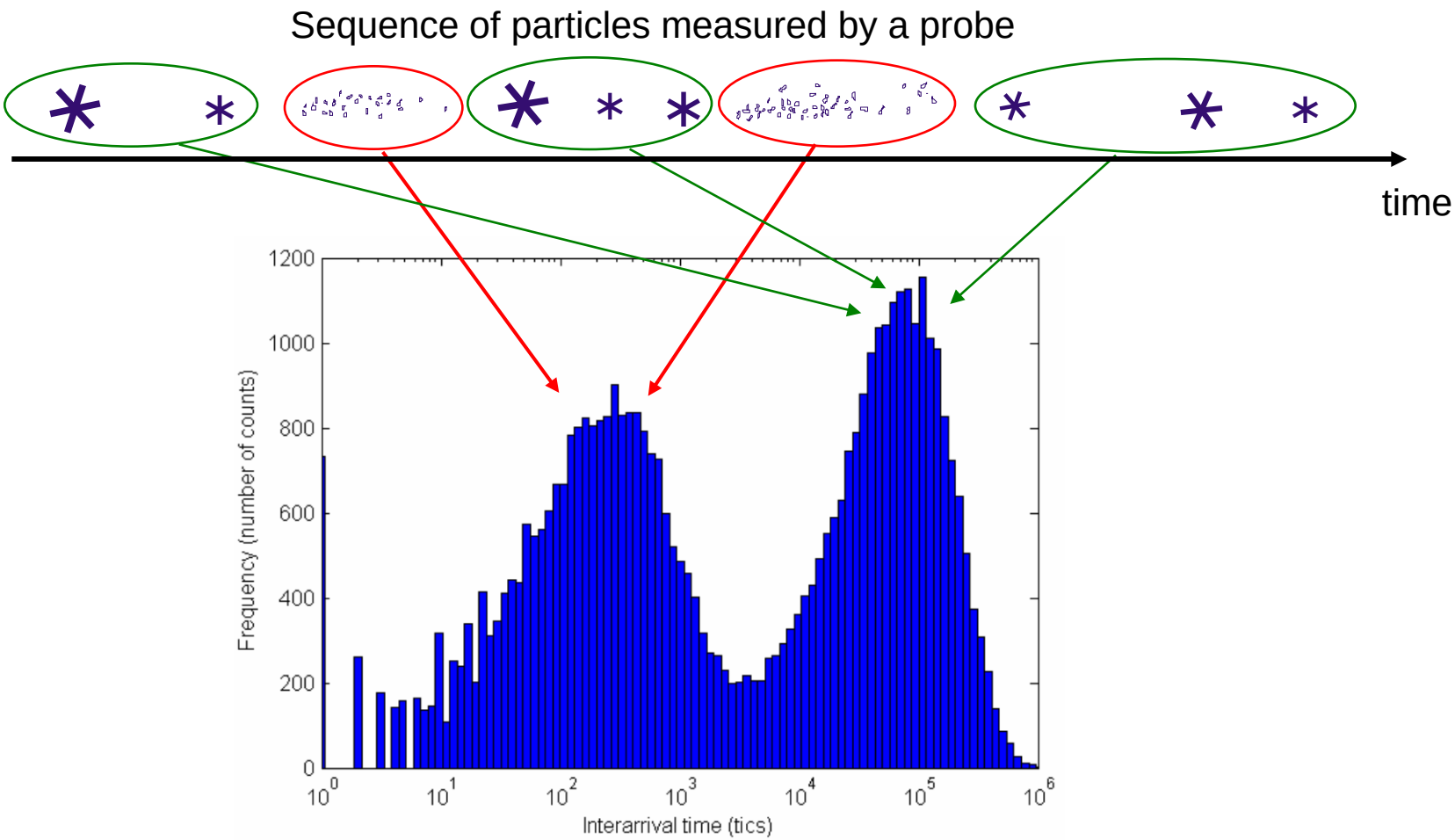
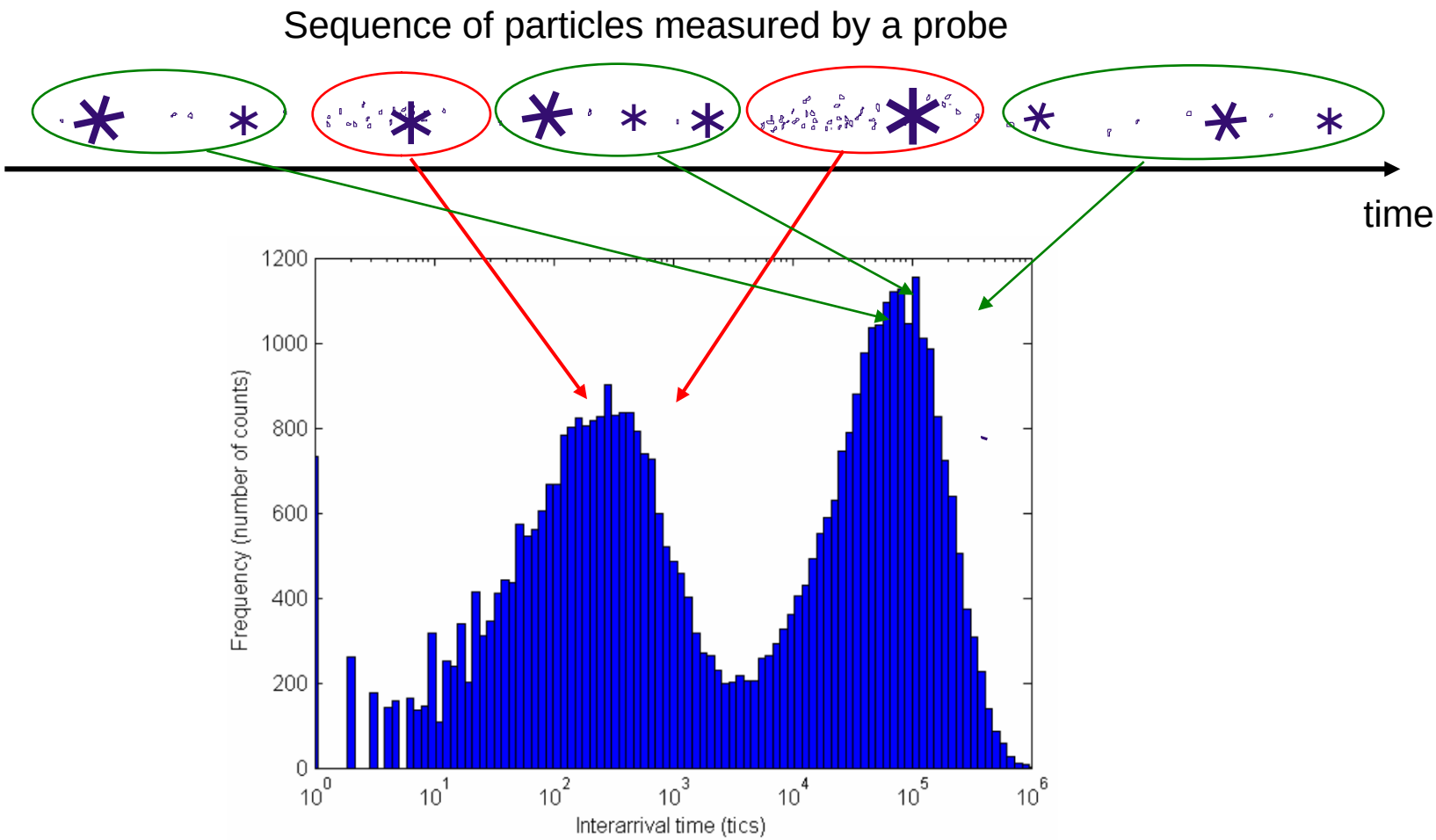


Modified OAD-2DC arms



interarrival time | aspect ratio | partial images | complete images

Idealized concept of filtering out shattering events based on interarrival time



ACTUAL
filtering of shattering events based on interarrival time