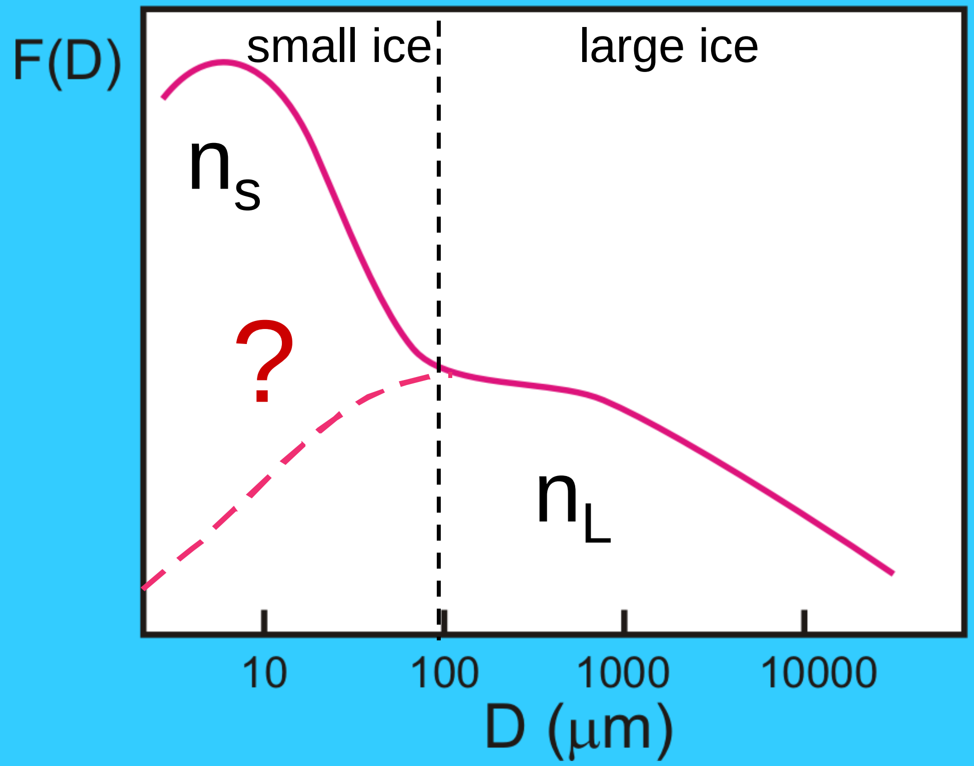
Discussion
on small ice particle measurements

Observations suggest that small ice particles are common in ice clouds



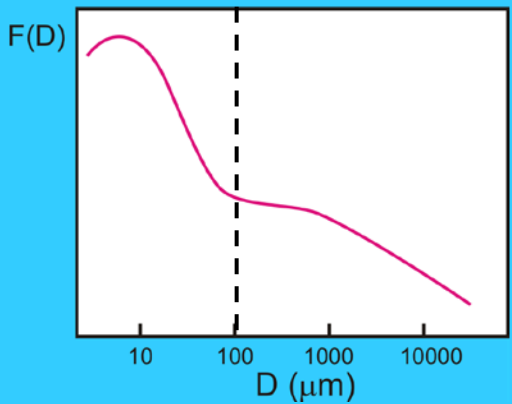
$n_s / n_L \sim 10^2 – 10^3$

Controversial facts:

1. Observation of small ice particles in sublimating zones (RHi<100%)

2. Observation of small ice particles in supersaturated clouds (RHi>100%)

Existence of a source of small ice particles



Ice multiplication

? **natural**

artificial ?

Independent of temperature
-40<T<0C

Shuttering during sampling

i) measurement methods and challenges.

ii) hypotheses for the production and maintenance of small ice particles.

i) measurement methods and challenges

1. Problems of the existing techniques for ice measurements

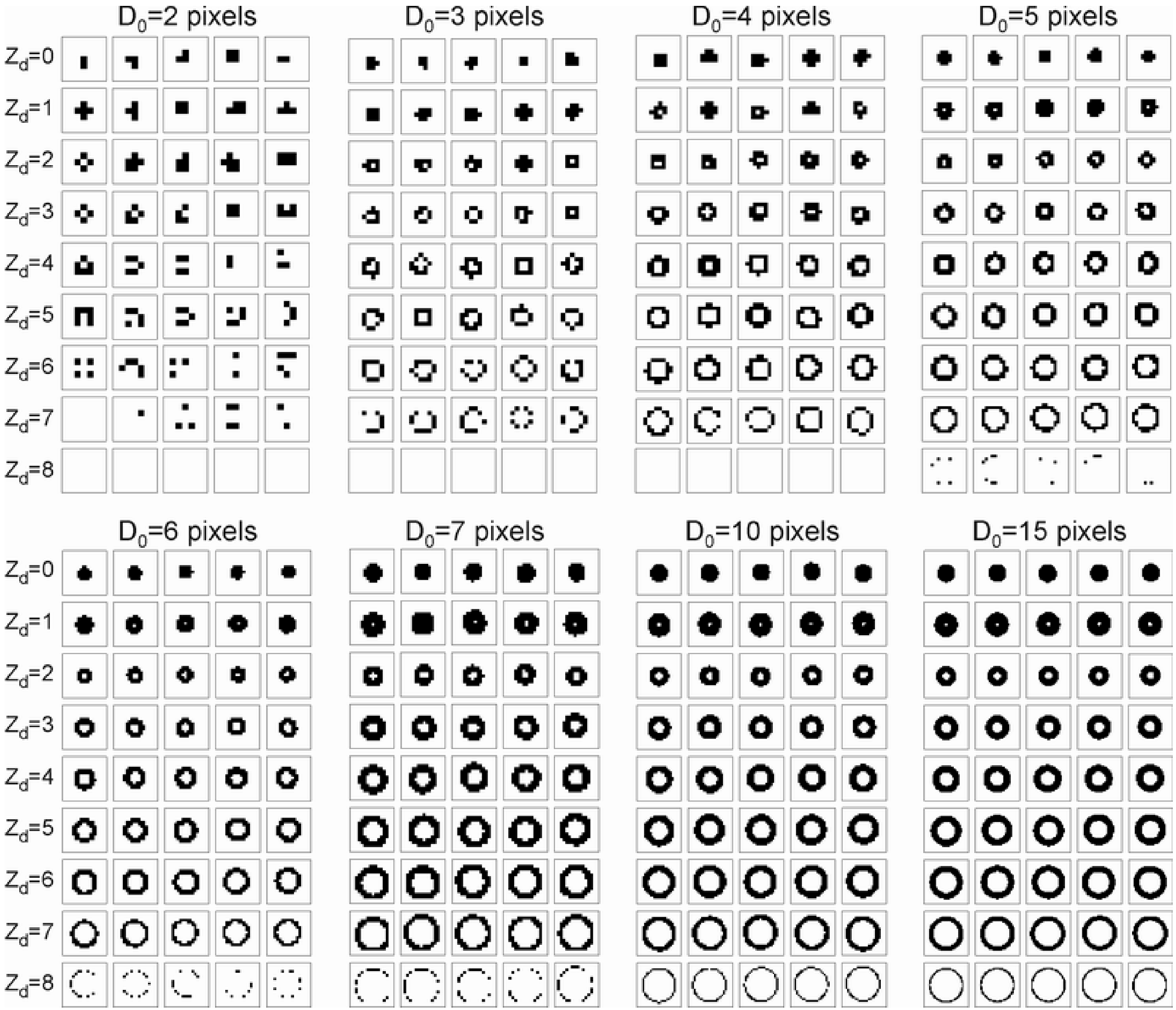
   a) sizing and depth-of-field in imaging probes

   b) coherent vs non-coherent light

   c) imaging versus scattering

   d) re-shape and redesign inlets

Formation of images for coherent illumination (Fresnel diffraction)



Depth-of-Field in imaging probes

$$DoF \propto D^2$$

$$n \propto \frac{1}{SampleVolume} \propto \frac{1}{DoF} \propto \frac{1}{D^2}$$

$$\Delta n \propto \frac{\Delta D}{D^3}$$

OAP-2DC

D	25µm	50µm	75µm	100µm	125µm	150µm	175µm	200µm
DoF(mm)	1.5	6.0	13.5	24	38	54	74	96

i) measurement methods and challenges

1. Problems of the existing techniques for ice measurements

   a) sizing and depth-of-field in imaging probes

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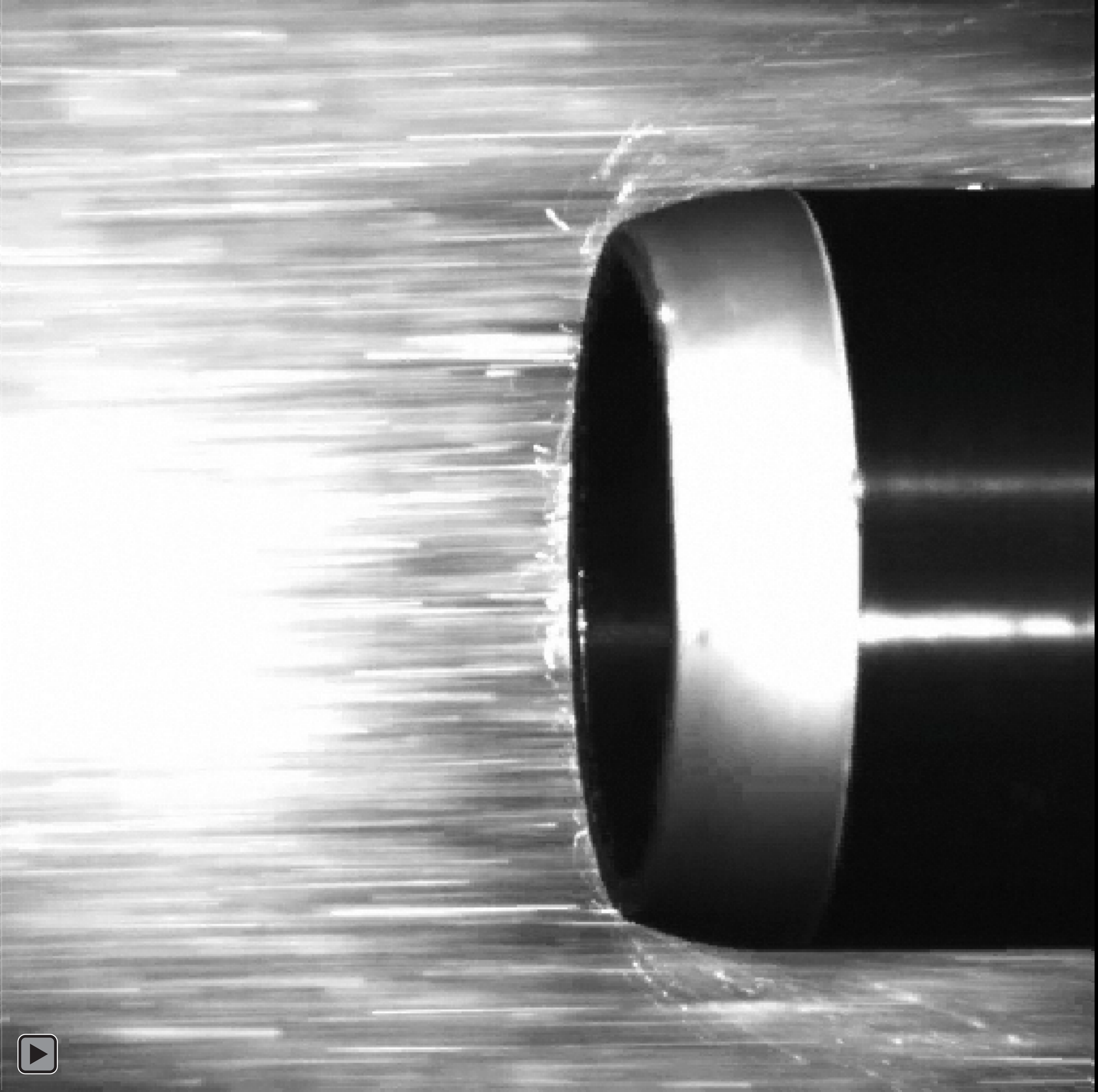
   d) re-shape and redesign inlets



Cox Wind Tunnel

NASA High Speed Video

FSSP inlet
D ~ 5cm
TAS ~ 70m/s

Solutions for existing imaging probes:

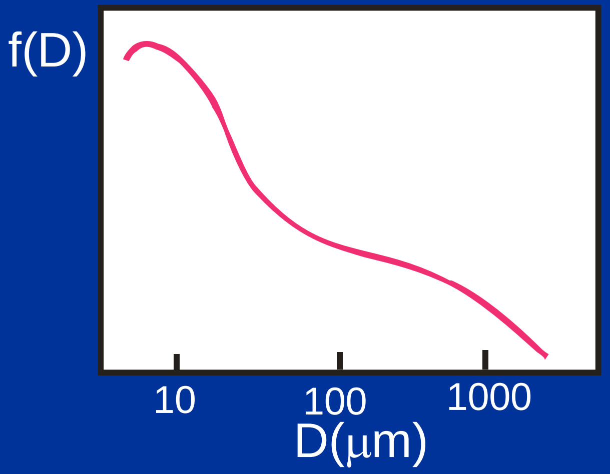
1. Improve size retrieval algorithms (e.g. use several grey levels)
2. Laboratory calibrations (e.g. spinning disc technique)
3. Wind tunnel calibrations
4. Redesign of probe inlets seems to be the only solution for the shattering problem.

i) **measurement methods and challenges**

2. **new in-situ techniques (“non-intrusive”)**

3. **slow moving platforms**

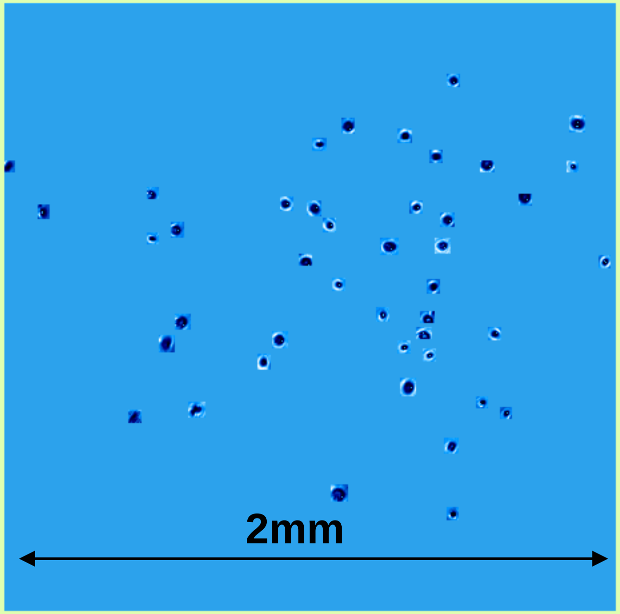
ii) hypotheses for the production and maintenance of small ice particles



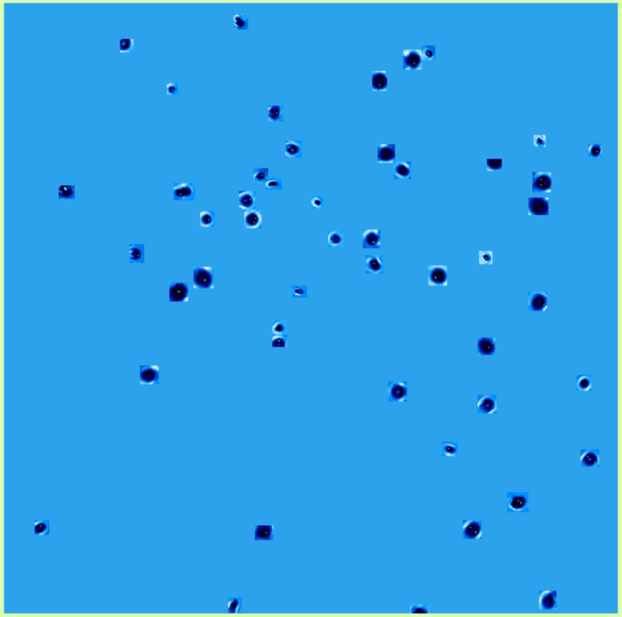
How to explain the universality of the ice particle size distributions in both supersaturated and undersaturated environments?

3-Feb-2000

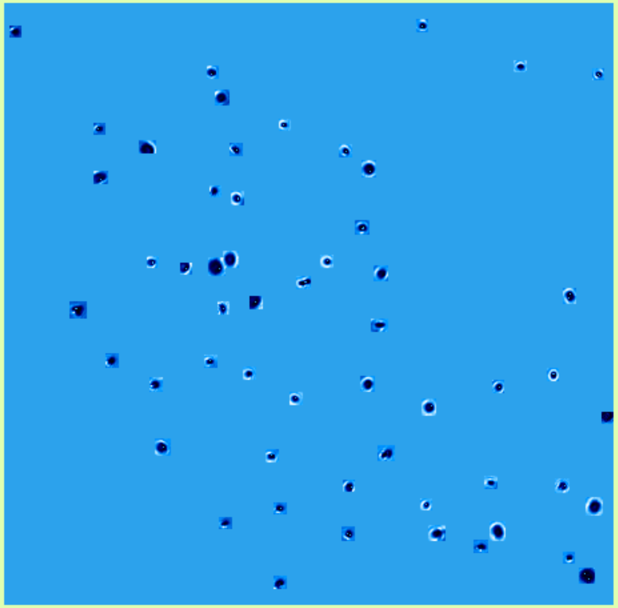
$V = 2 \times 2 \times 0.1mm = 0.0004cm^{-3}$; $N \sim 10^{5}cm^{-3}$



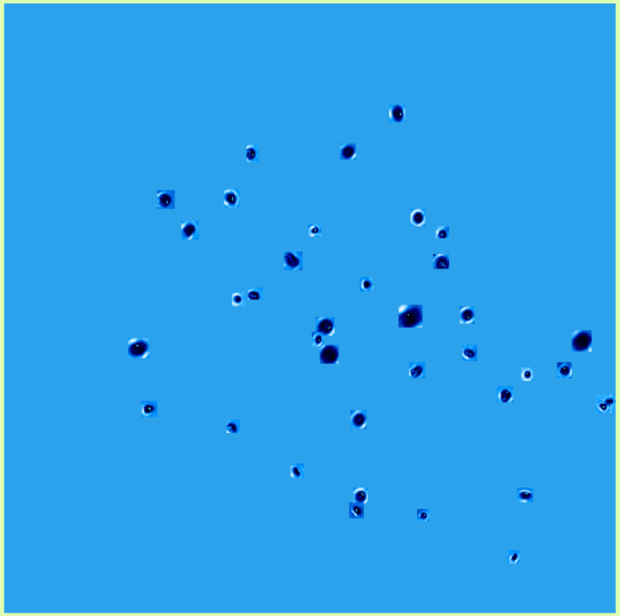
21:00:51.86   43 particles



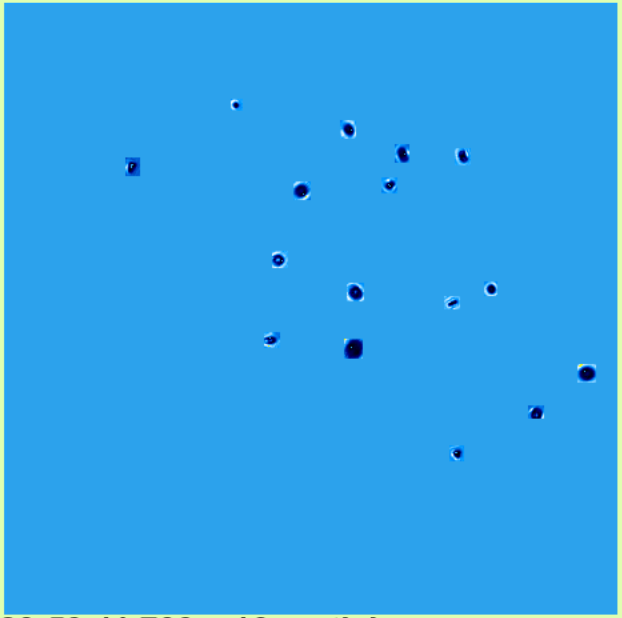
21:00:27.212   50 particles



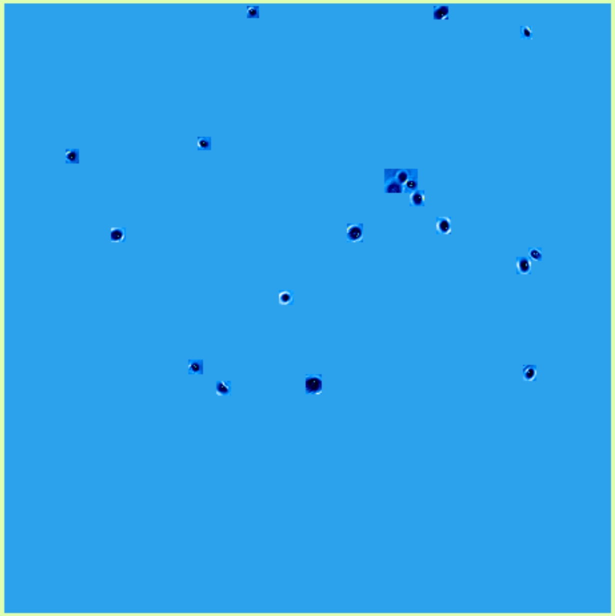
20:58:53.692   55 particles



20:59:30.943   36 particles



20:59:11.709   16 particles



20:58:54.903   19 particles

Vidaurre and Hallett, 2006

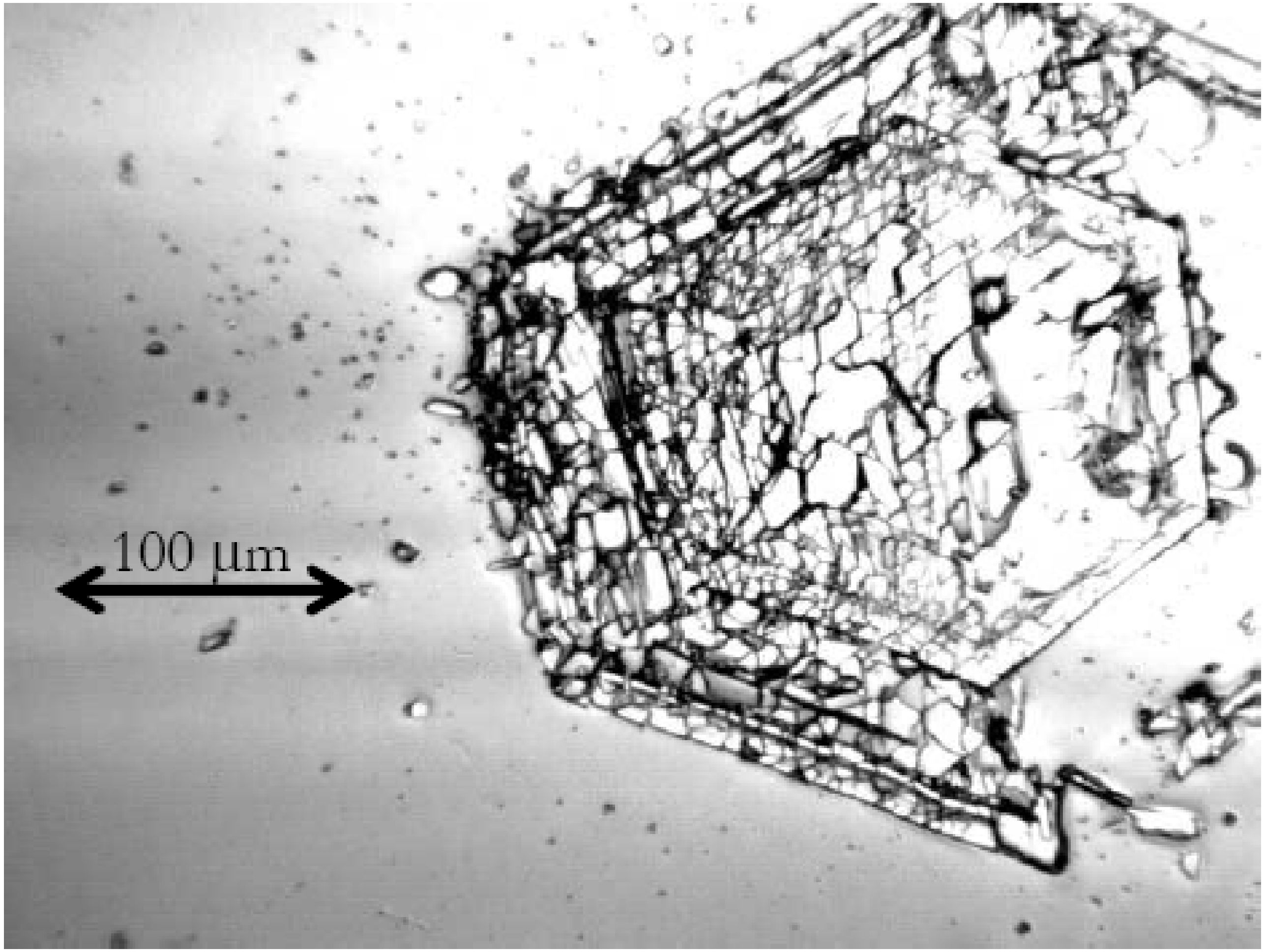
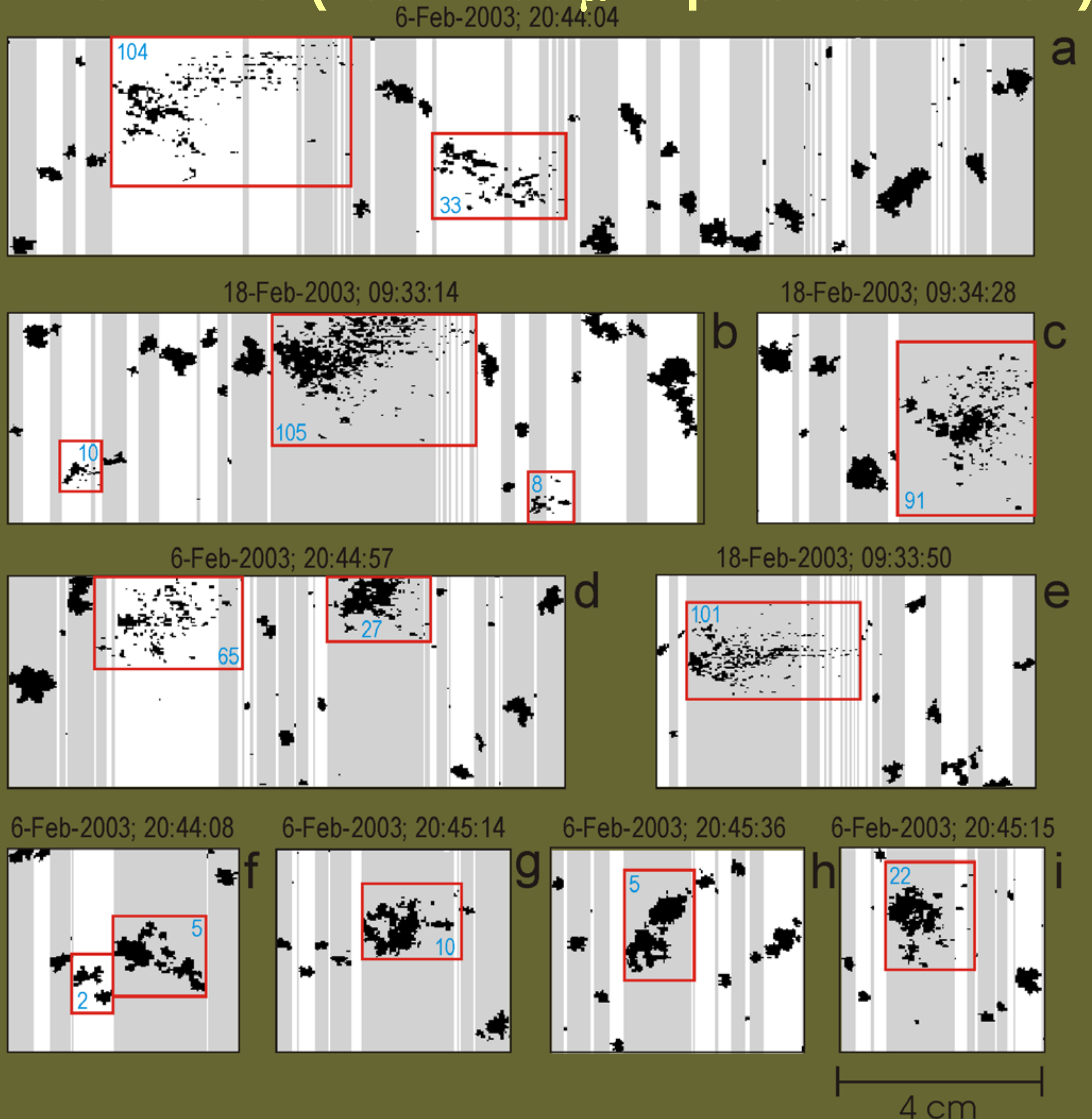


Figure 1: 300 x 400 µm still images showing broken ice crystals collected in formvar solution by continuous replicator from continental clouds in Oklahoma in the size range from 5 µm to 320 µm, showing multiple fractures. Note ice fractures are parallel to crystal axis in many areas and the fracture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

SPEC HVPS (200 x 400 μm pixel resolution)



Conclusion #1

After bouncing at 100m/s ice particles may travel a few centimeters across the air streamlines.

Conclusion #2

Ice particles shattered at ~100m/s may form a cascade of fragments with sizes down to 10-20μm or even smaller.

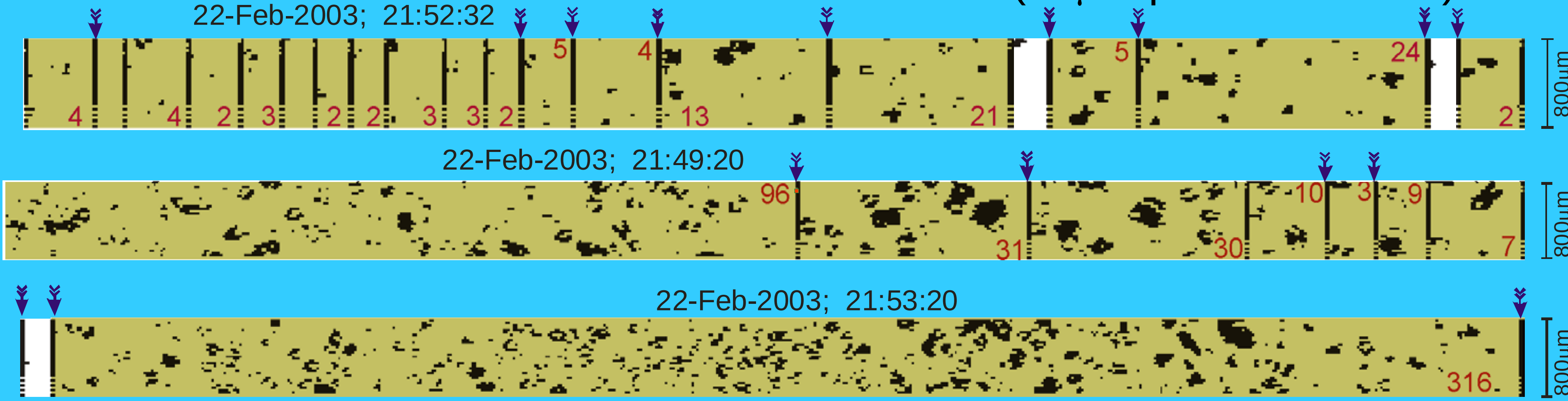
Conclusion #3

The number of fragments resulting from a shattering event depends on the kinetic energy of the ice particle (TAS and mass), its habit, and it may reach few thousands per particle.

Conclusion #4

After shattering, ice particles form clusters of debris elongated in the flight direction. The dimension of the cluster depends on the particle size and may reach 4-5cm along the flight direction .

OAP-2DC (25μm pixel resolution)



Korolev and Isaac (2005)

Vidaurre and Hallett, 2006

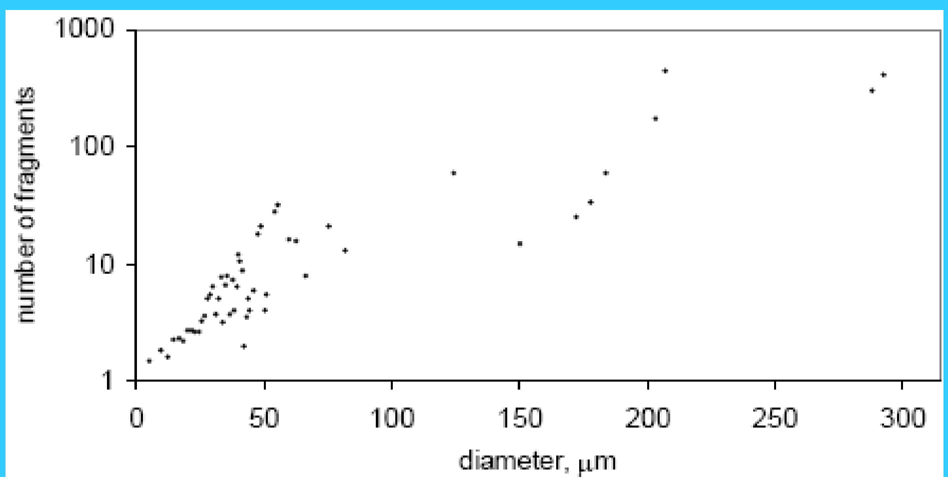
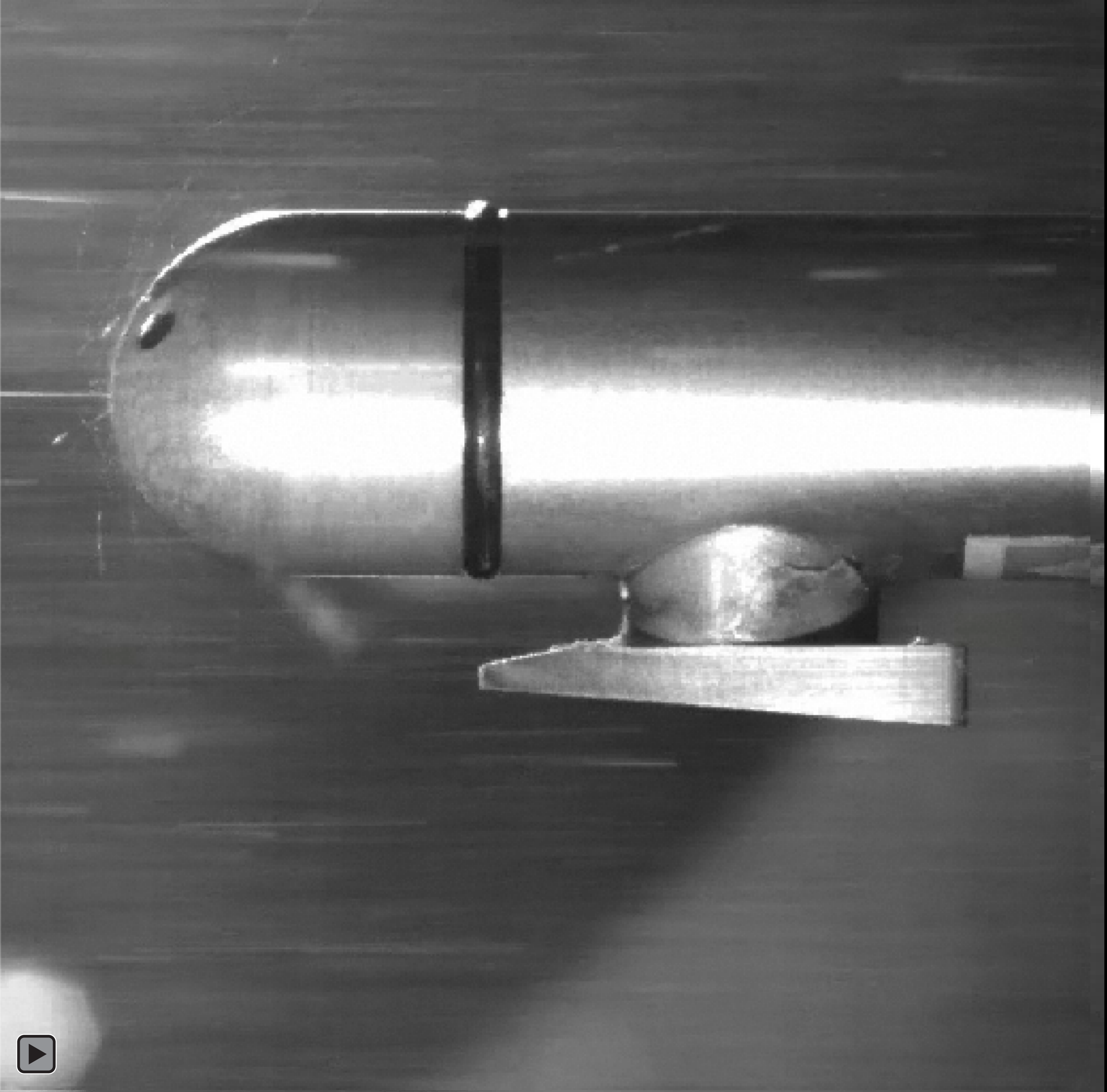
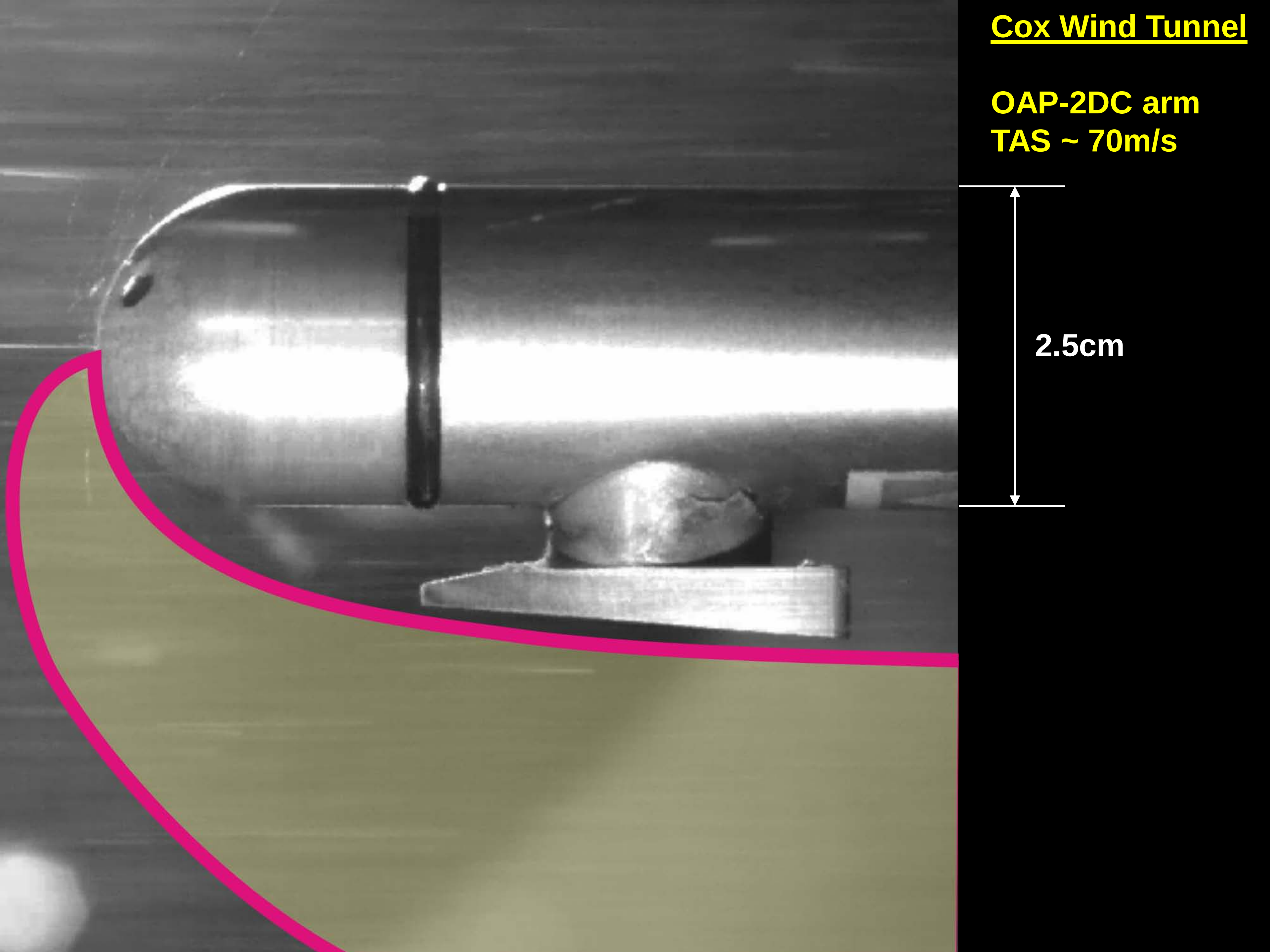


Figure 3: Average number of fragments vs. size for ice particles a) collected in formvar solution by continuous replicator from continental clouds in Oklahoma in the size range from 5 μm to 320 μm; with an average speed of 130 m/s flying on the UND Citation aircraft, and b) video-recorded following impact on the



Cox Wind Tunnel

OAP-2DC arm
D ~ 2.5cm
TAS ~ 70m/s


Cox Wind Tunnel
OAP-2DC arm
TAS ~ 70m/s
2.5cm

Solutions for existing imaging probes:

Particle sizing and sample volume:

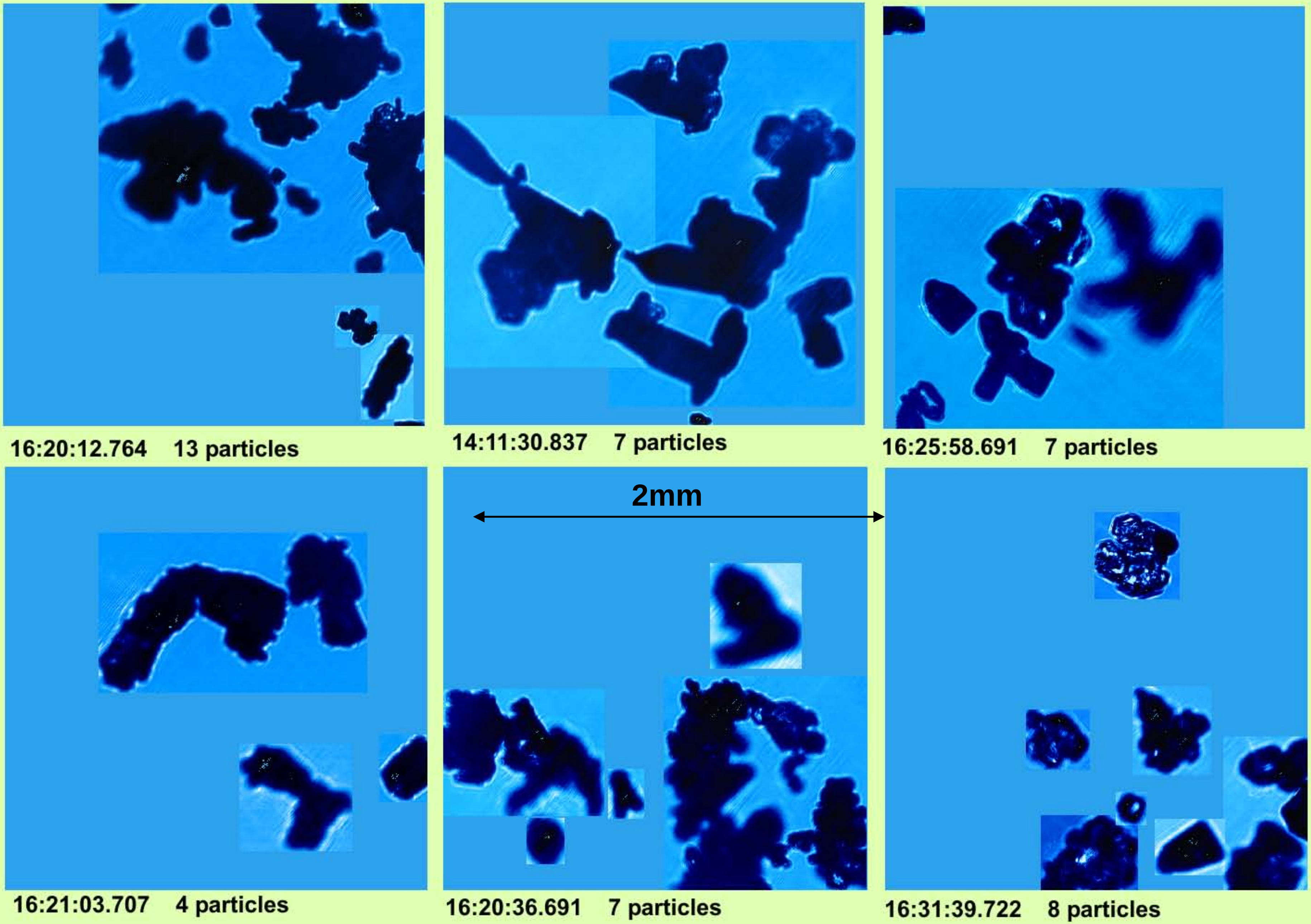
1. Improve size retrieval algorithms (e.g. several grey levels)
2. Laboratory calibrations (e.g. spinning disc technique)
3. Wind tunnel calibrations

Source of light:

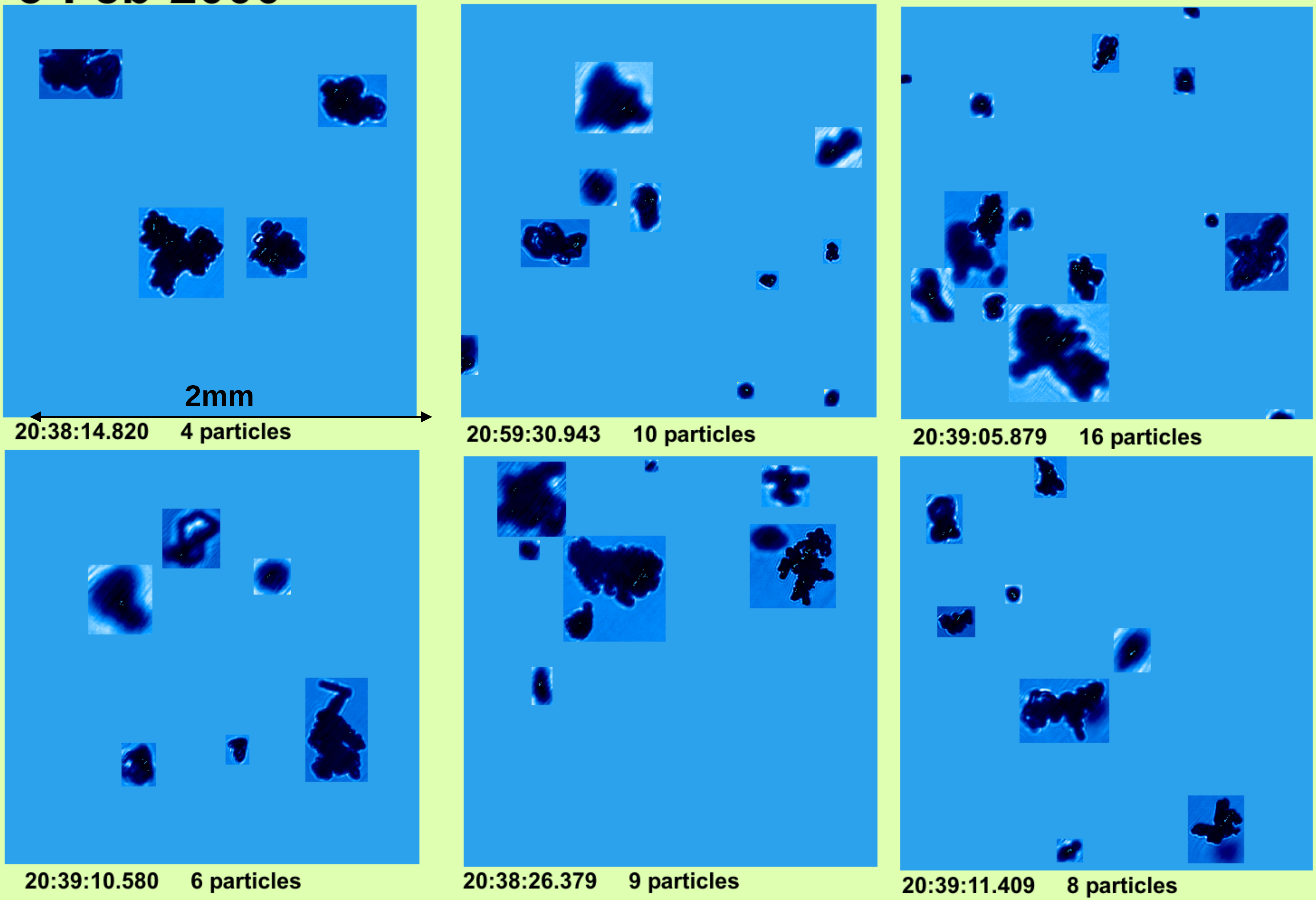
Coherent vs non-coherent

Shattering:

1. Existing algorithms have principal limitations in identifying shattering events.
2. Redesign of probes’ inlets seems to be the only solution for the shattering problem.


16:20:12.764 13 particles
14:11:30.837 7 particles
16:25:58.691 7 particles
2mm
16:21:03.707 4 particles
16:20:36.691 7 particles
16:31:39.722 8 particles

3-Feb-2000


2mm
20:38:14.820 4 particles
20:59:30.943 10 particles
20:39:05.879 16 particles
20:39:10.580 6 particles
20:38:26.379 9 particles
20:39:11.409 8 particles

Something is wrong