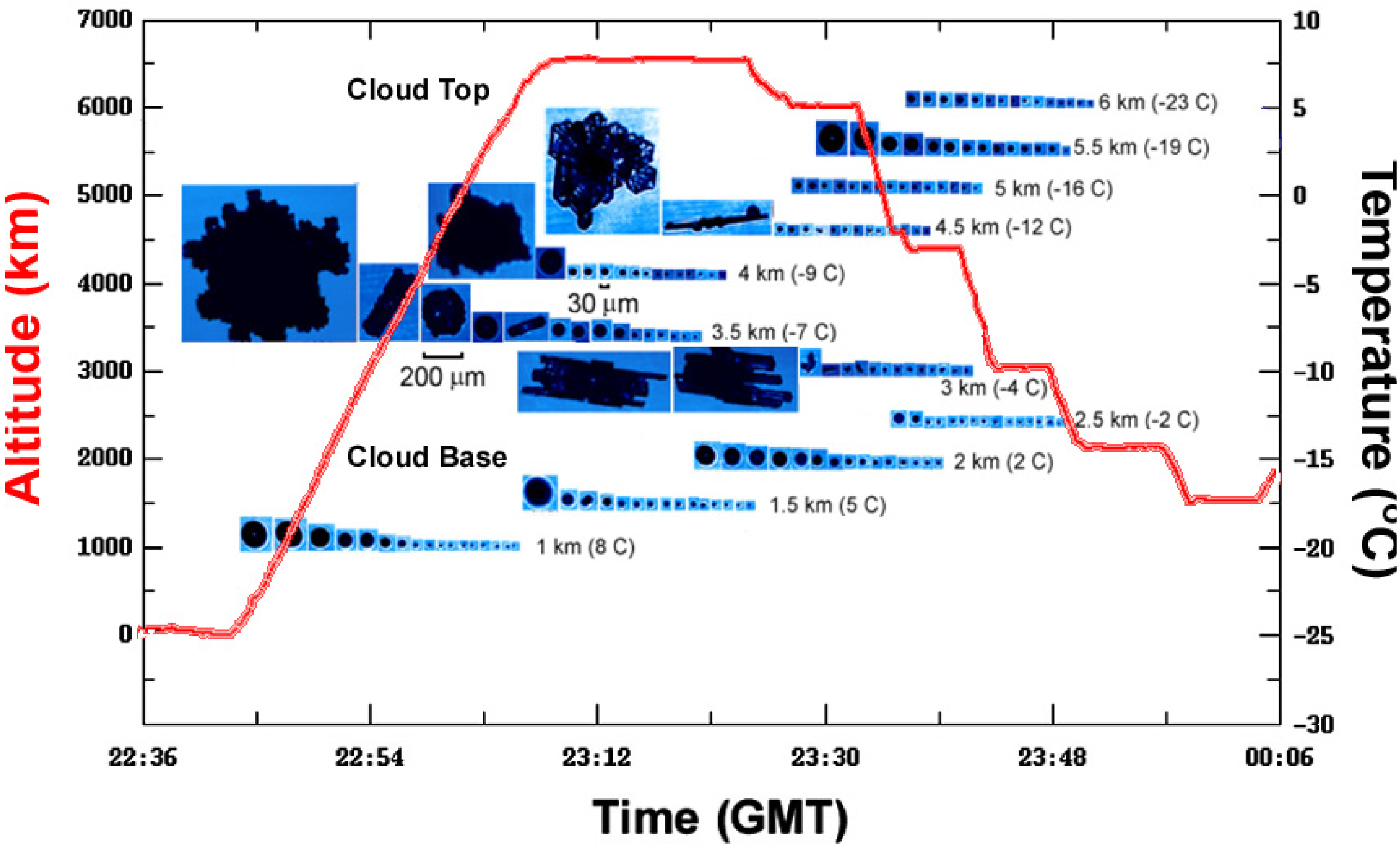
Microphysical Properties of Arctic Clouds and Analysis of Airborne Instrumentation



Paul Lawson

ARM Science Team Meeting – Monterey

29 March 2007

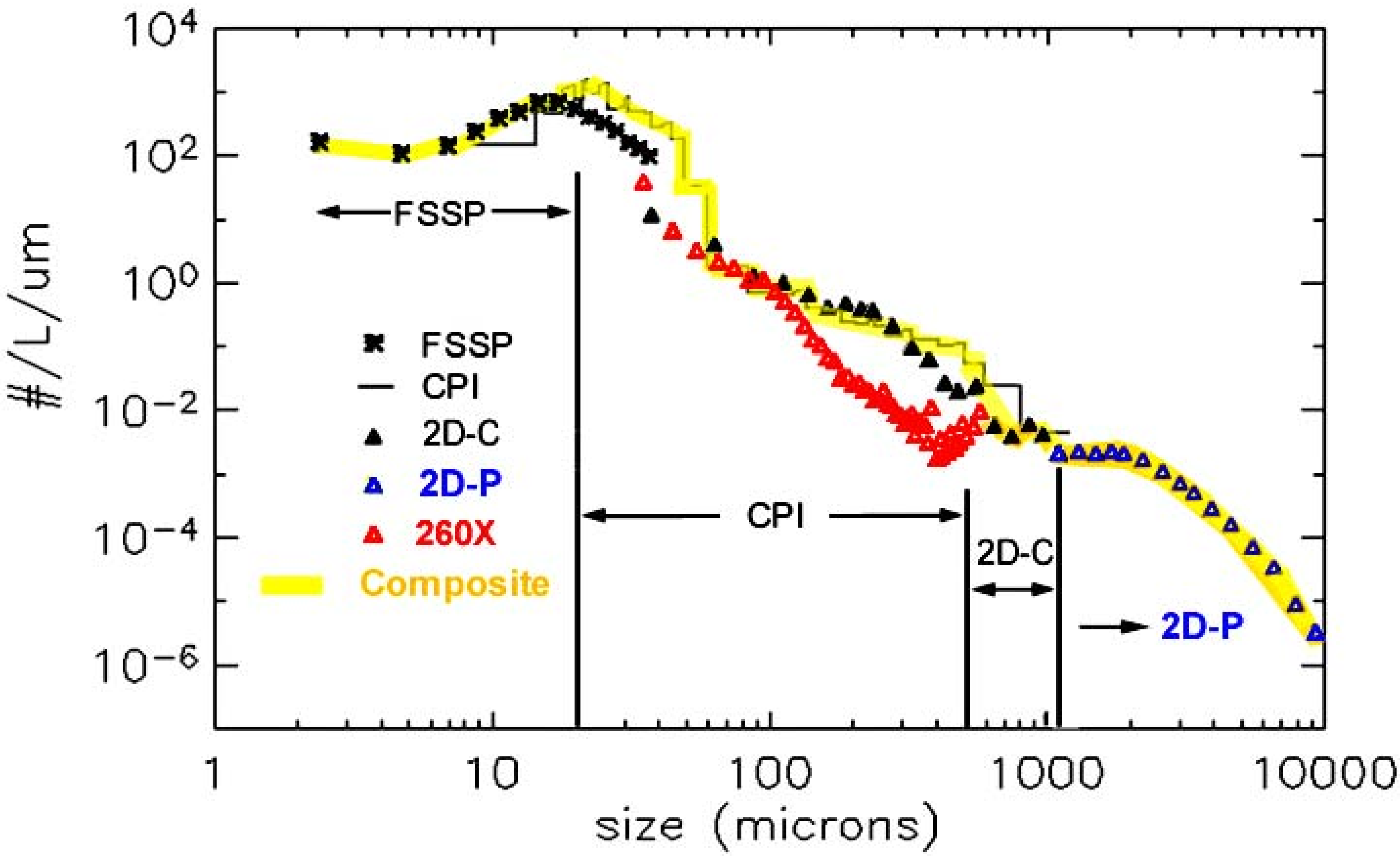
OUTLINE

- Revisiting C-130 Microphysical Observations from SHEBA-FIRE.ACE

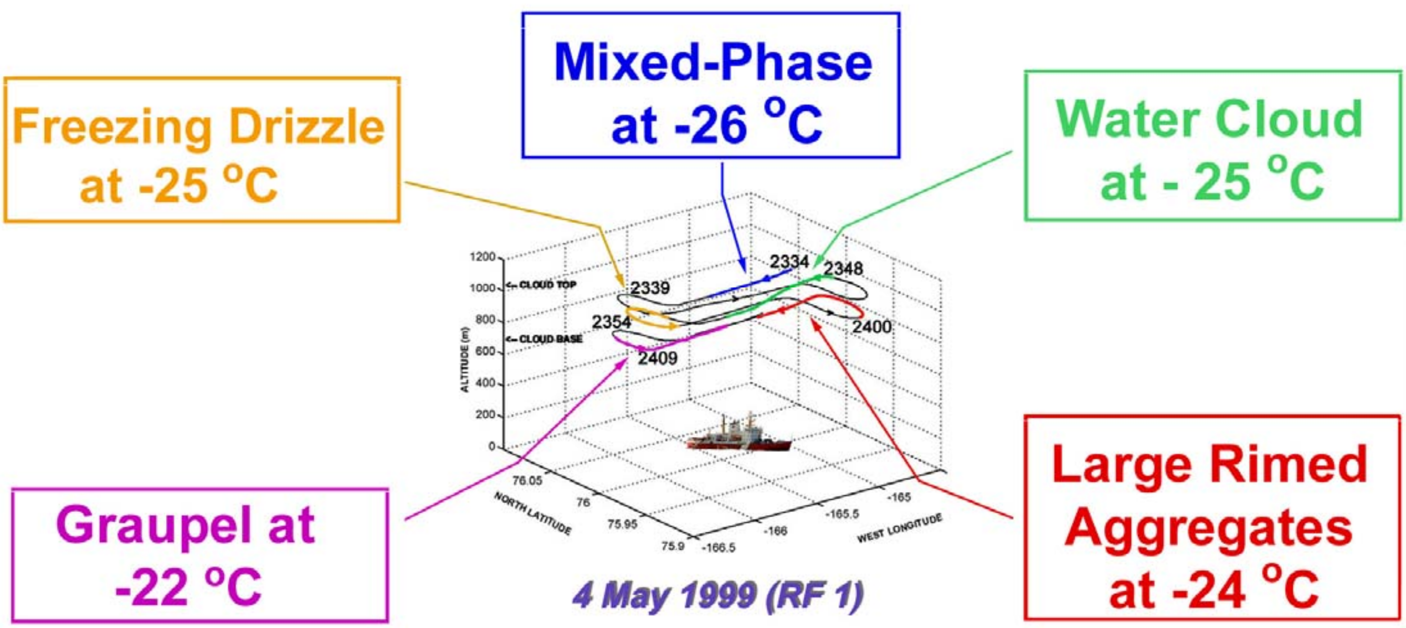
- Capability of Current Particle Probes

- Some New Airborne Microphysics & Radiation Measurement Instrumentation

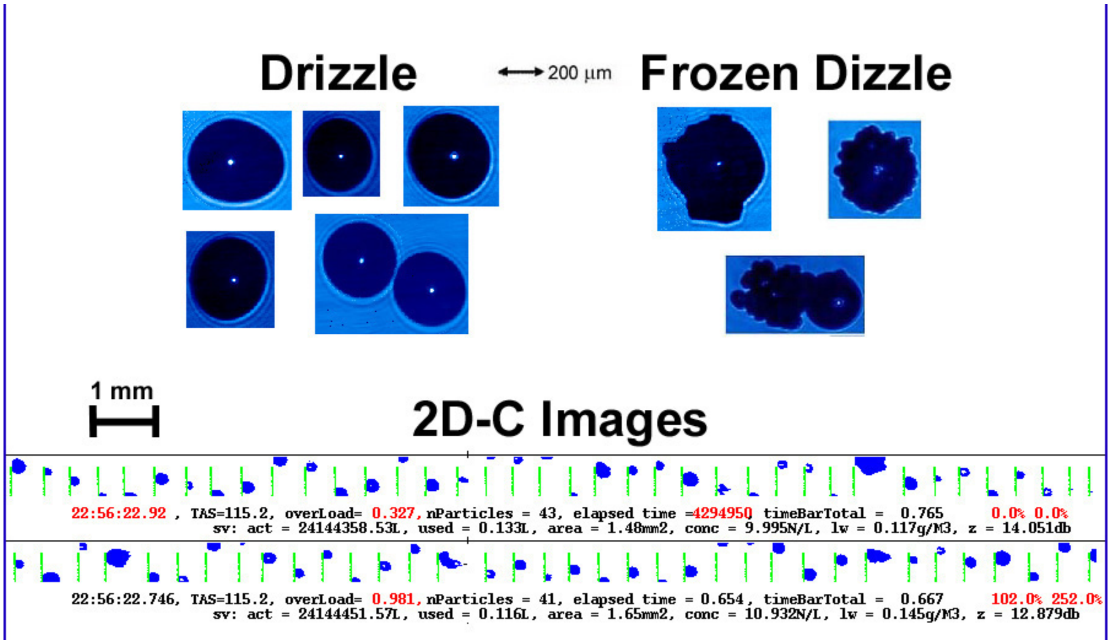
Example of Composite Particle Size Distribution (PSD) using FSSP, CPI, 2D-C and 2D-P. All previous publications used only FSSP, CPI and 260X Probe, which (as shown in red) is significantly different than the CPI and 2D-C PSD.

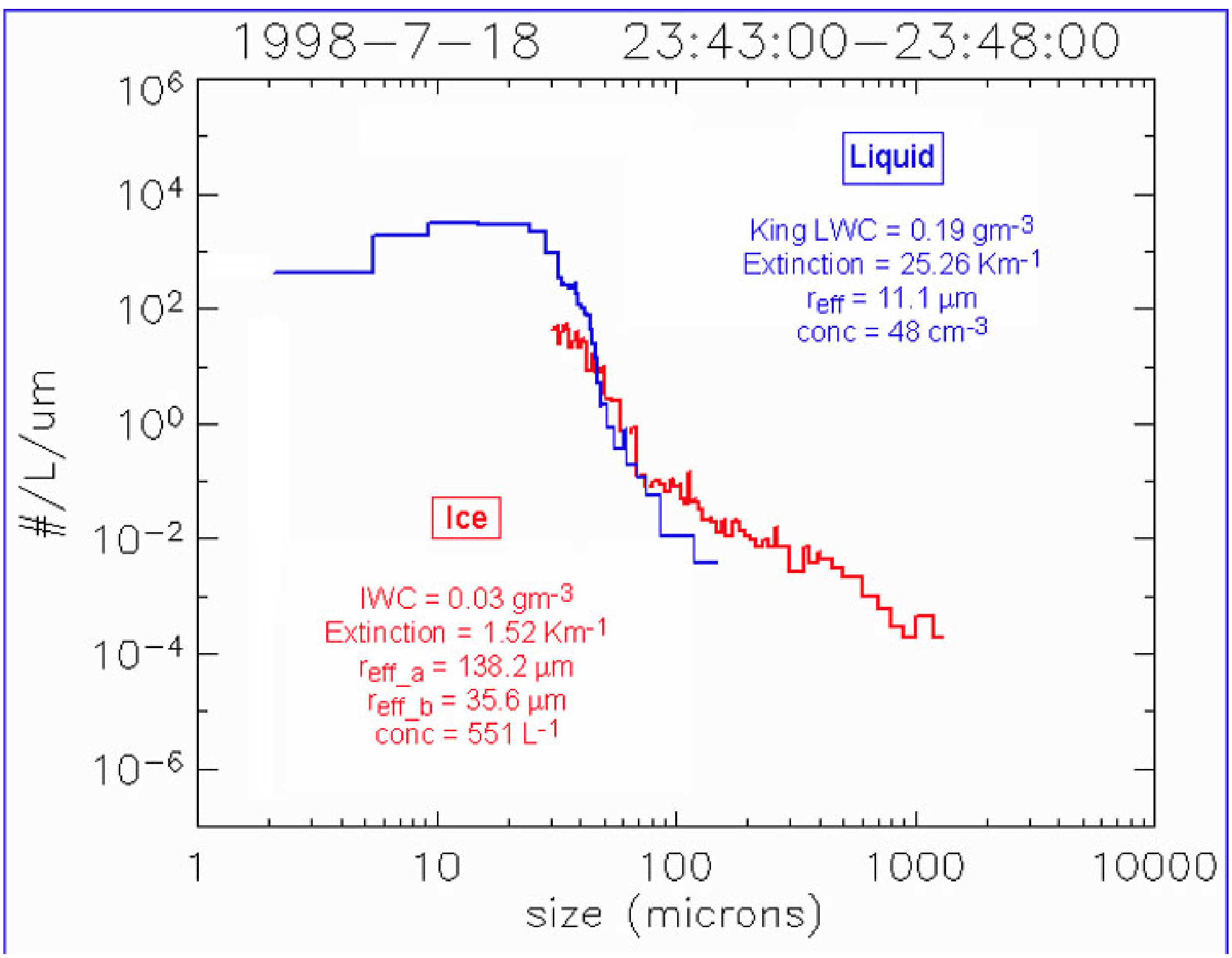


Mixed-Phase Arctic Clouds Often Display Extremely Inhomogeneous Microphysics

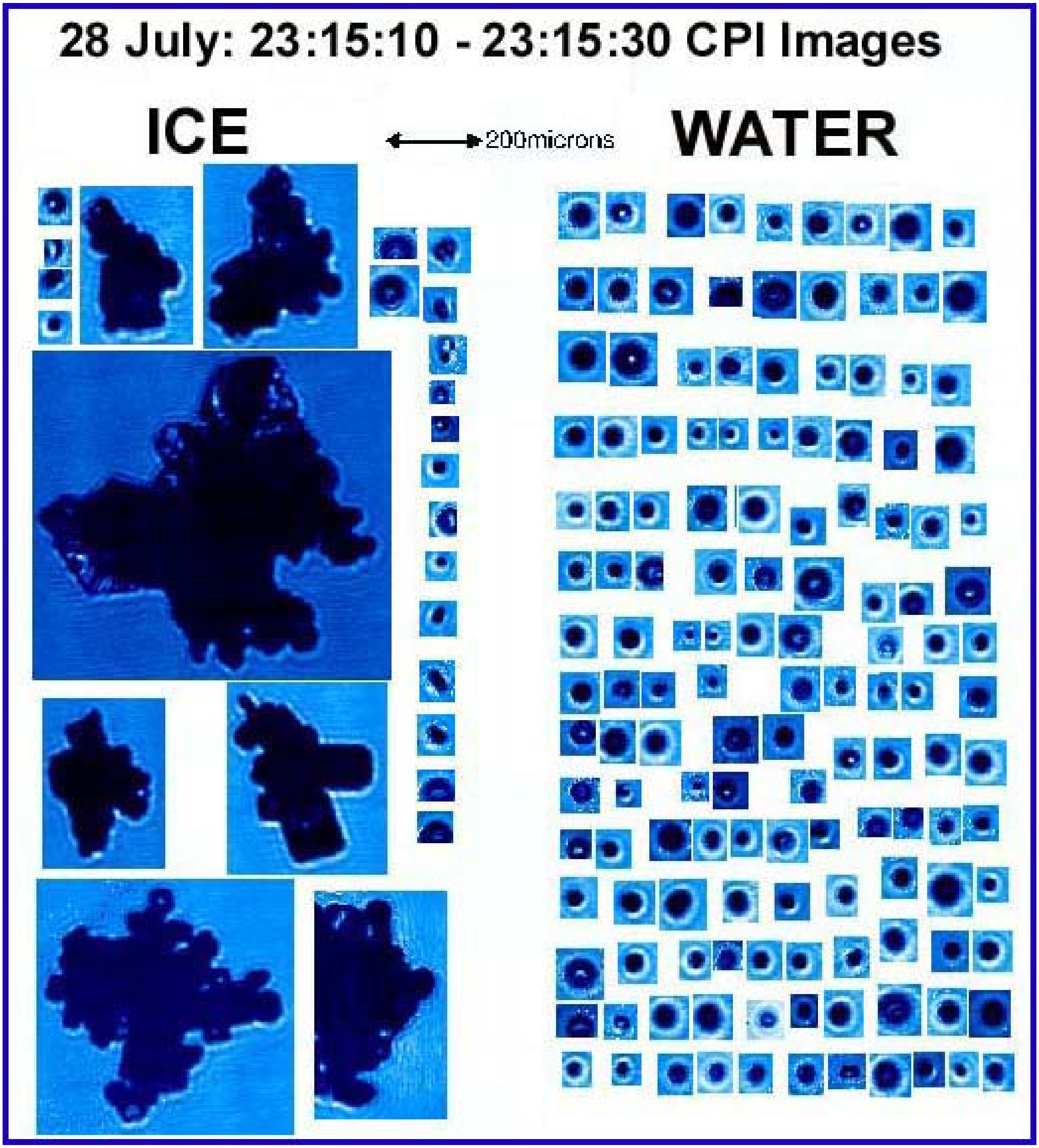


Example of Images of Freezing Drizzle Observed by CPI and 2D-C and Composite PSD's for Water and Ice

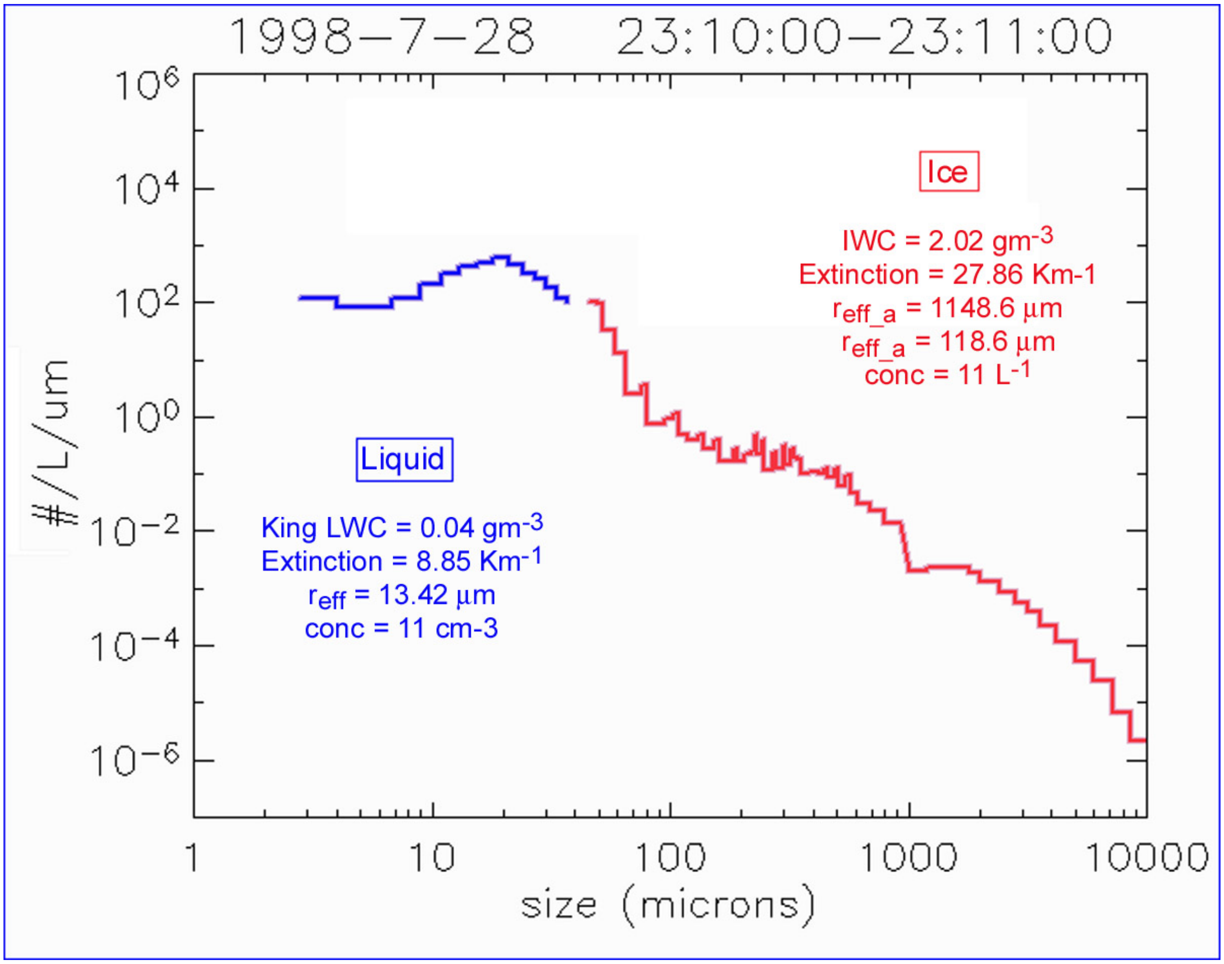


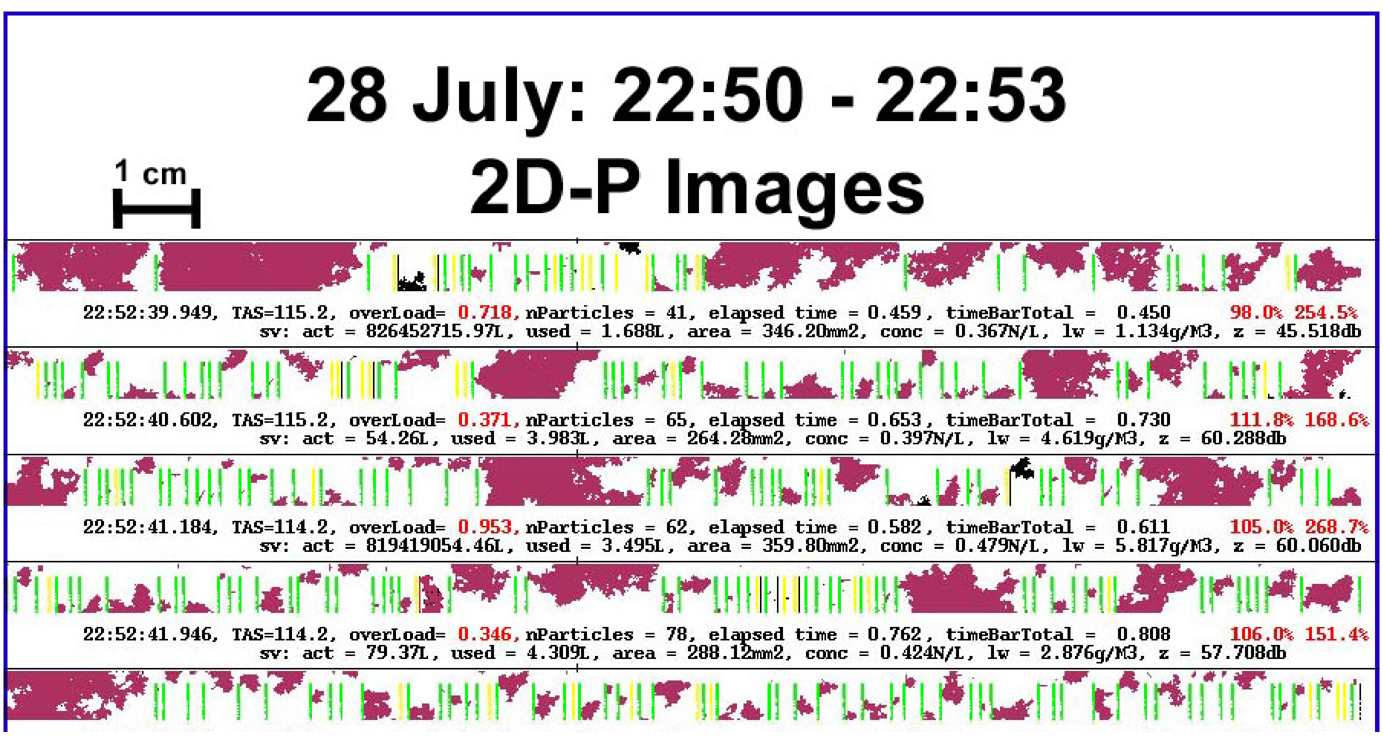


Supercooled Liquid Cloud Water at –37° C



Large (1 to 3 cm) Snow, 5 mm Graupel and High (2 g m^{-3}) IWC Observed in Arctic Clouds





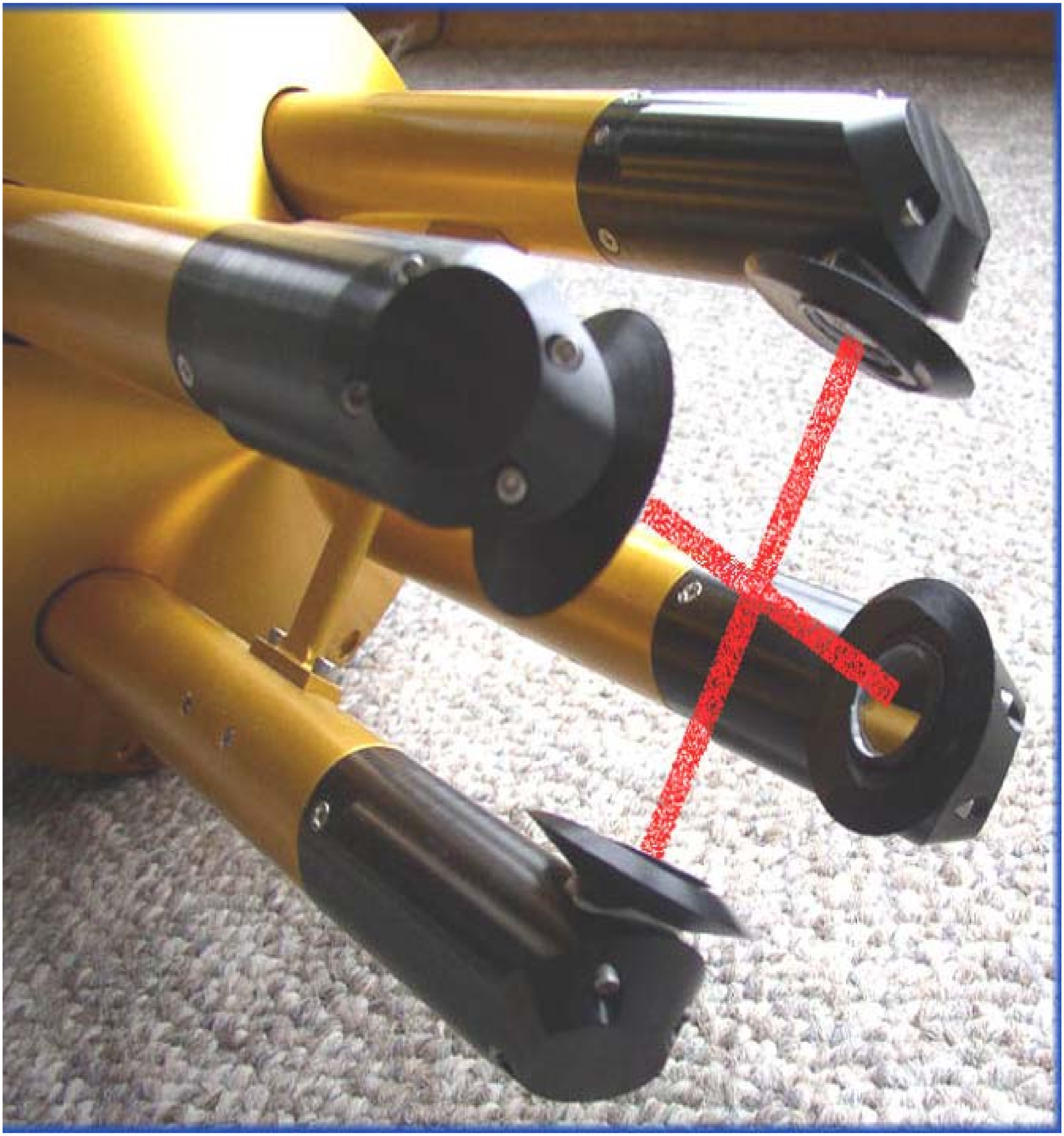
Cloud Particle Probes

1. **Optical Array Probes:**
   e.g. 2D-C, 2D-P, CIP, PIP, 2D-S, HVPS

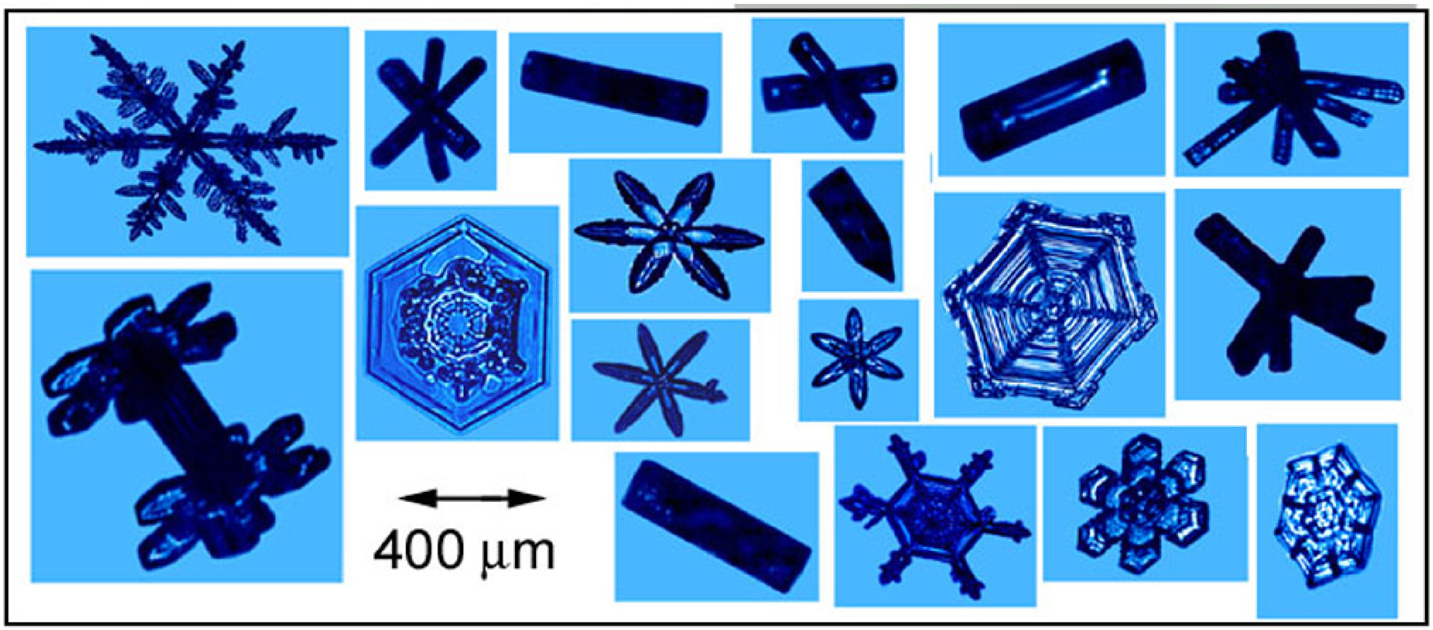
2. **Scattering Probes:**
   e.g. FSSP, CAS, CDP

3. **Cloud Particle Imagery**
   e.g., CPI, VIPS, Replicator

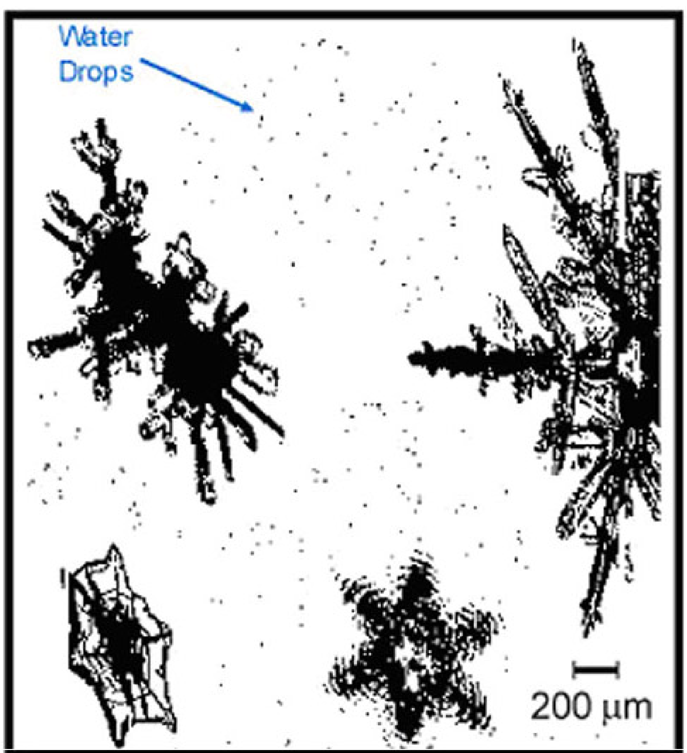
2D-S Probe has independent, custom, dual 128-photodiode arrays running at 17 MHz. Particles from 10 μm to 1.28 mm are imaged. (Lawson et al. 2006 Dec *JTech*)



CPI Images



2D-S Images



Stereo Pairs

Some Advantages of the 2D-S (Stereo) Probe

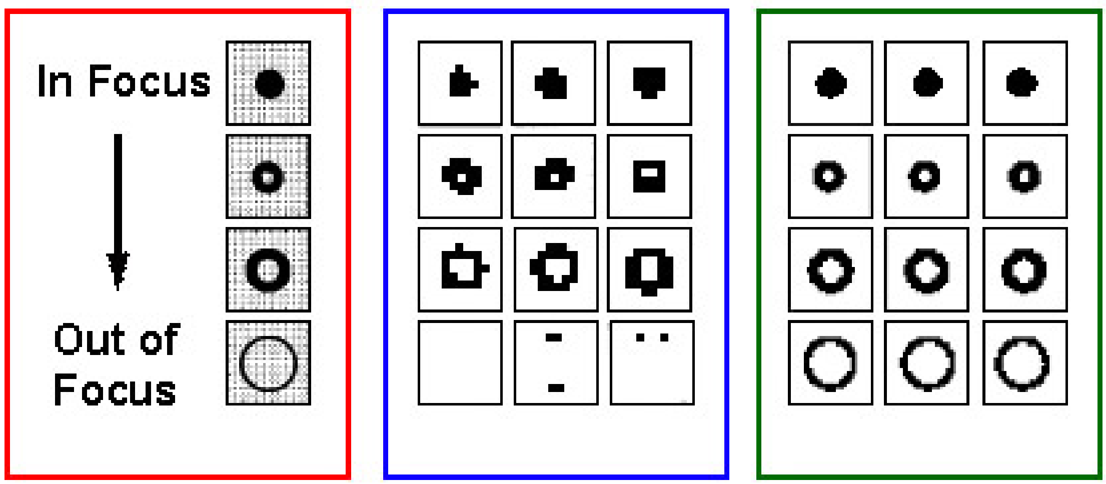
- **Dual 128 Photodiode arrays both image 10 μm and larger particles at 170 m s^{-1}. In comparison, RICO data collected in drizzle shows that the 2D-C probe does not image ANY particles < 100 μm at 100 m s^{-1}, and NAMMA data collected in warm Cu suggests that CAPS sees (virtually) no particles < 75 μm at 190 m s^{-1}. However, when these probes sample larger particles, fictitious PSD's are created that appear very realistic.**

- **2D-S with its10 μm slices and high data transfer rate enable 2D-S to measure particle spacing, accurately identify splashed drops and shattered ice particles.**

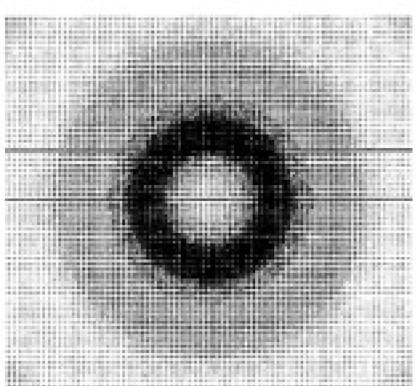
- **2D-S with its two identical probes in one canister provides redundancy, comparison and stereo particles in the beam overlap region.**

Effects of Diffraction on 100 μm Spherical Particle (Korolev et al. 1998)

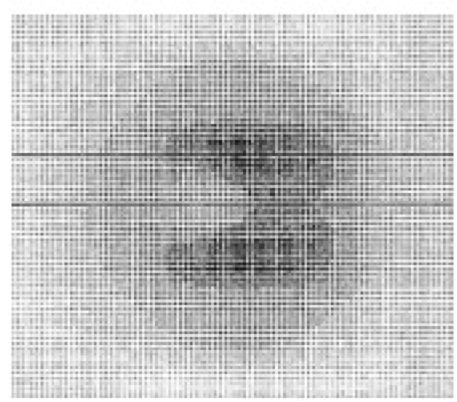
Theoretical Diffraction Patterns	2D-C & CAPS 25 μm Pixels	2D-S 10 μm Pixels



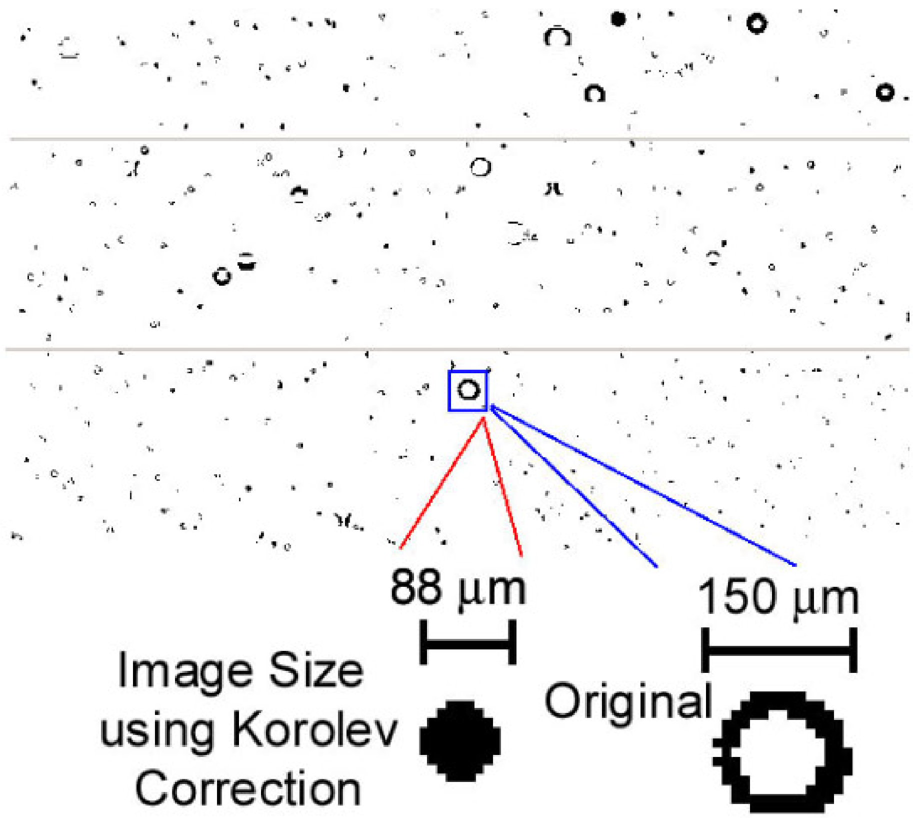
Effects of Airspeed (Jensen and Granek 2002)

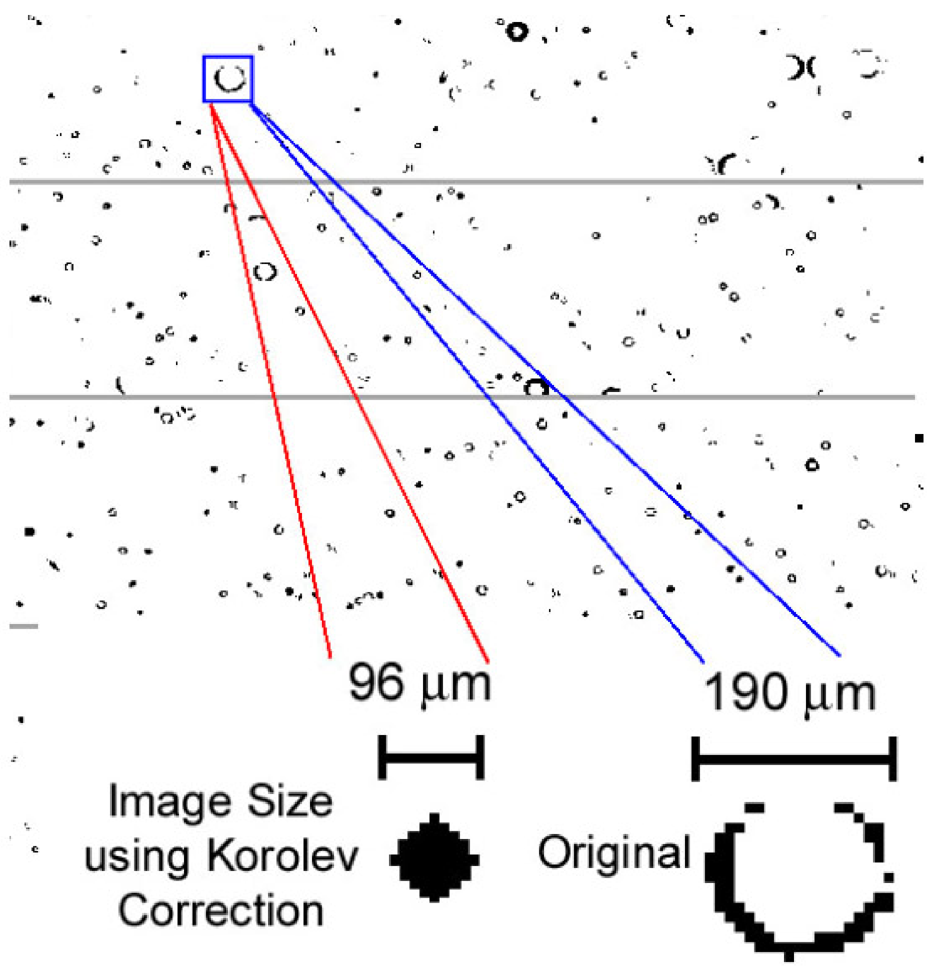


Zero m s^{-1}



80 m s^{-1}


88 μm
150 μm
Image Size
using Korolev
Correction
Original


96 μm
190 μm
Image Size
using Korolev
Correction
Original

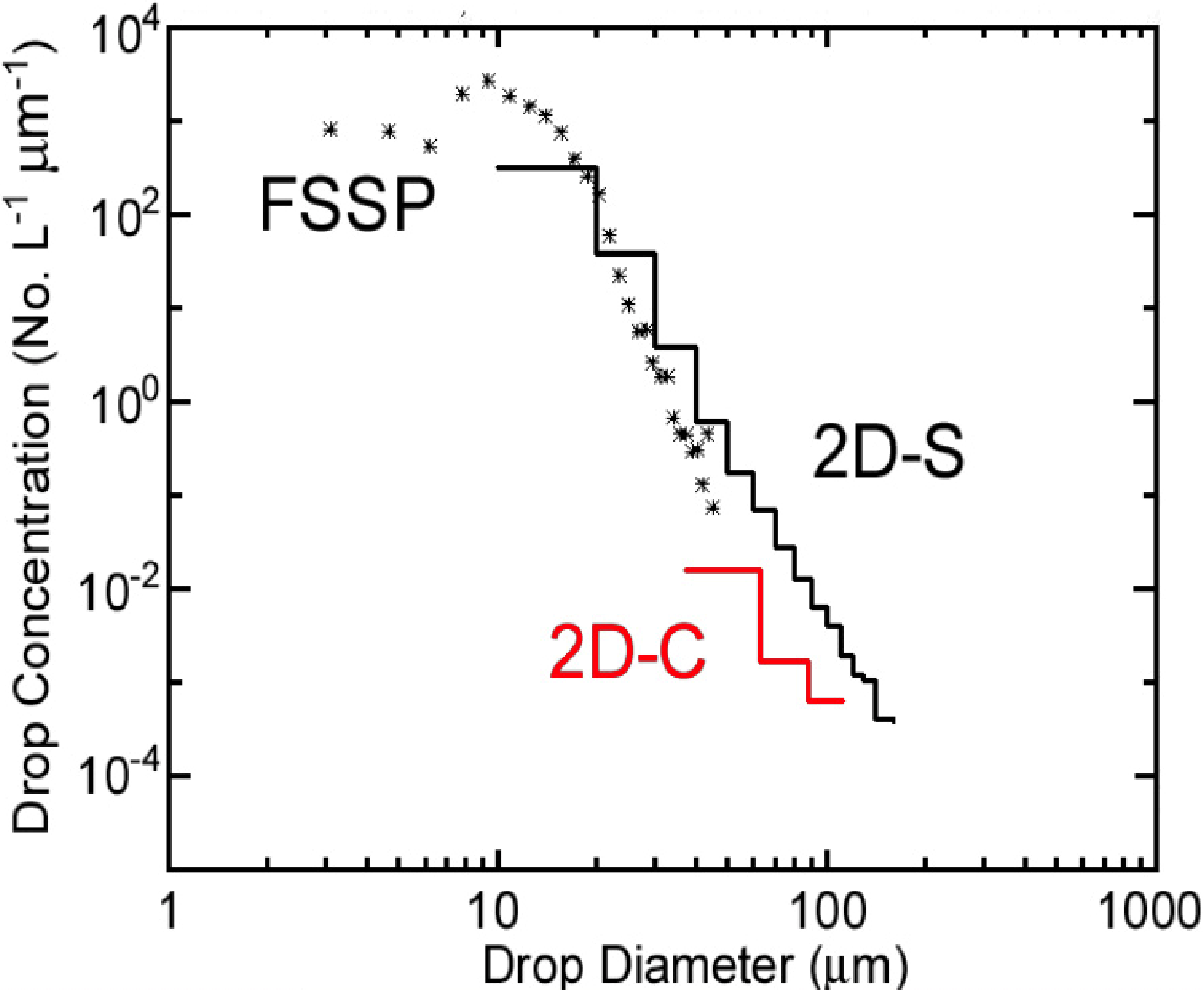
Comparison of 2D-S and 2D-C in RICO Cumulus with Maximum Drizzle Drop Size = 120 μm

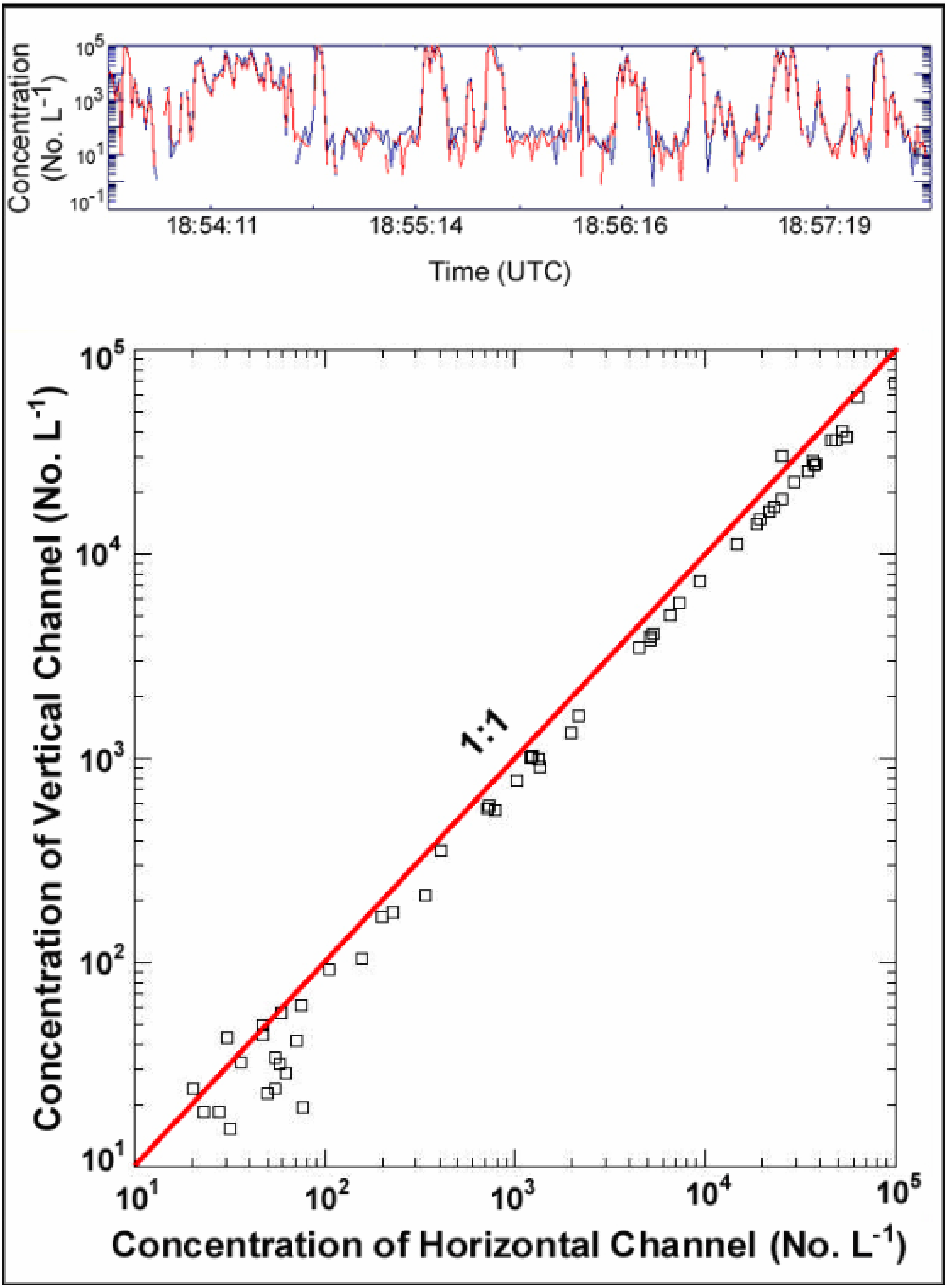
<table>
<tr><th>2D-S Size (μm)</th><th>H-Channel 2D-S Counts</th><th>2D-C Size (μm)</th><th>Expected 2D-C Counts</th><th>Actual 2D-C Counts</th></tr>
<tr><td>10</td><td>30876</td><td></td><td></td><td></td></tr>
<tr><td>20</td><td>18564</td><td rowspan="3">25</td><td rowspan="3">16585</td><td rowspan="3">0</td></tr>
<tr><td>30</td><td>4508</td></tr>
<tr><td>40</td><td>895</td></tr>
<tr><td>50</td><td>326</td><td rowspan="2">50</td><td rowspan="2">622</td><td rowspan="2">0</td></tr>
<tr><td>60</td><td>222</td></tr>
<tr><td>70</td><td>74</td><td rowspan="3">75</td><td rowspan="3">97</td><td rowspan="3">0</td></tr>
<tr><td>80</td><td>48</td></tr>
<tr><td>90</td><td>19</td></tr>
<tr><td>100</td><td>9</td><td rowspan="2">100</td><td rowspan="2">13</td><td rowspan="2">0</td></tr>
<tr><td>110</td><td>2</td></tr>
<tr><td>120</td><td>1</td><td rowspan="3">125</td><td rowspan="3">0.8</td><td rowspan="3">0</td></tr>
<tr><td>130</td><td>0</td></tr>
<tr><td></td><td></td></tr>
</table>

Comparison of 2D-S and 2D-C in RICO Cumulus with Maximum Drizzle Drop Size = 150 μm

<table>
<tr><th>2D-S Size (μm)</th><th>H-Channel 2D-S Counts</th><th>2D-C Size (μm)</th><th>Expected 2D-C Counts</th><th>Actual 2D-C Counts</th></tr>
<tr><td>10</td><td>181273</td><td></td><td></td><td></td></tr>
<tr><td>20</td><td>95271</td><td rowspan="3">25</td><td rowspan="3">89357</td><td rowspan="3">0</td></tr>
<tr><td>30</td><td>27989</td></tr>
<tr><td>40</td><td>6075</td></tr>
<tr><td>50</td><td>1992</td><td rowspan="2">50</td><td rowspan="2">3969</td><td rowspan="2">30</td></tr>
<tr><td>60</td><td>1166</td></tr>
<tr><td>70</td><td>469</td><td rowspan="3">75</td><td rowspan="3">595</td><td rowspan="3">9</td></tr>
<tr><td>80</td><td>326</td></tr>
<tr><td>90</td><td>106</td></tr>
<tr><td>100</td><td>60</td><td rowspan="2">100</td><td rowspan="2">82</td><td rowspan="2">7</td></tr>
<tr><td>110</td><td>19</td></tr>
<tr><td>120</td><td>8</td><td rowspan="3">125</td><td rowspan="3">8</td><td rowspan="3">0</td></tr>
<tr><td>130</td><td>3</td></tr>
<tr><td>140</td><td>0</td></tr>
<tr><td>150</td><td>1</td><td rowspan="2">150</td><td rowspan="2">0.5</td><td rowspan="2">0</td></tr>
<tr><td>160</td><td>0</td></tr>
</table>

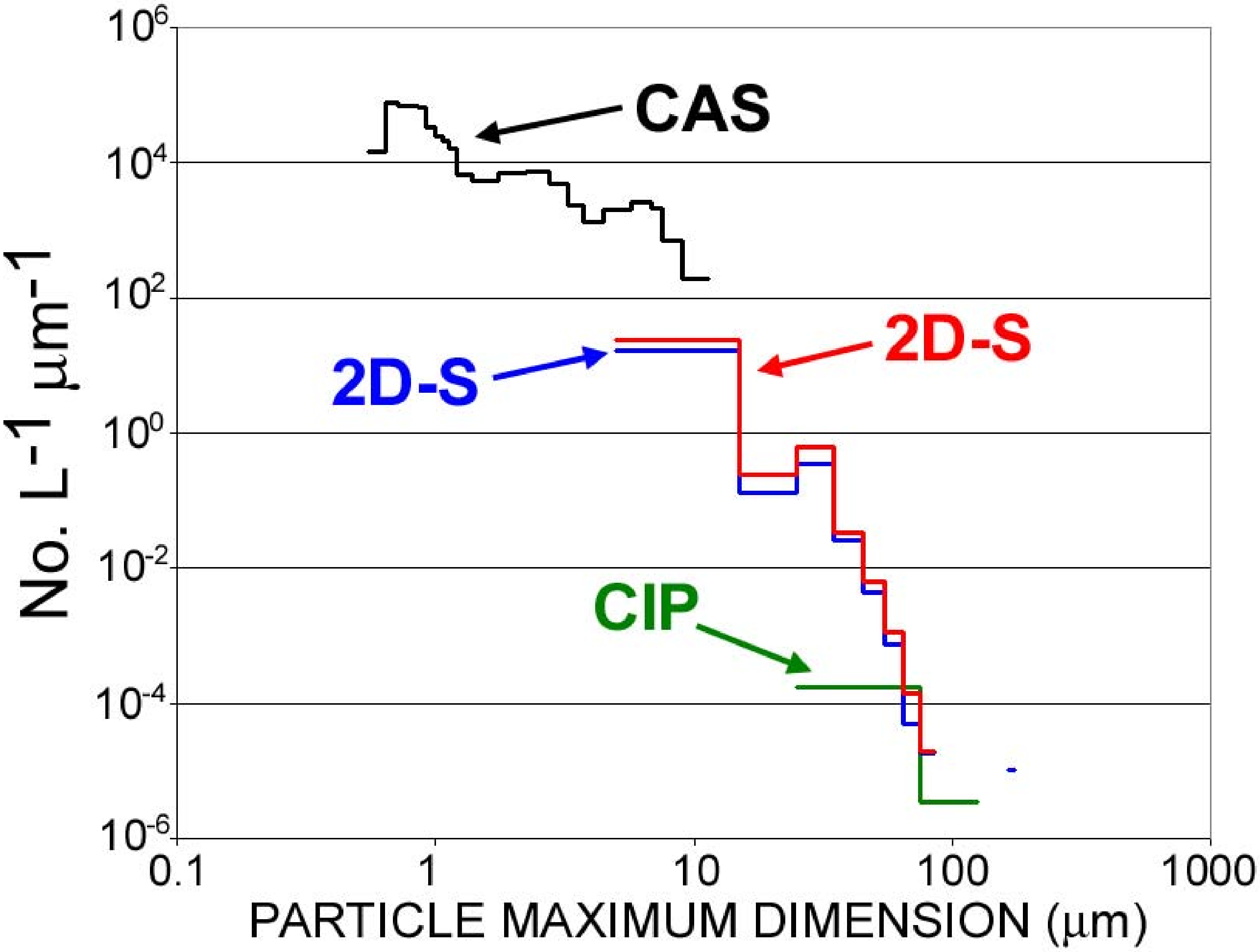
- **In RICO Drizzle with Max Drop Diameters < 120 μm the NCAR C-130 2D-C Recorded NO Images.**
- **In Drizzle with Max Drop Diameters < 150 μm the 2D-C Recorded the DSD Shown Below.**

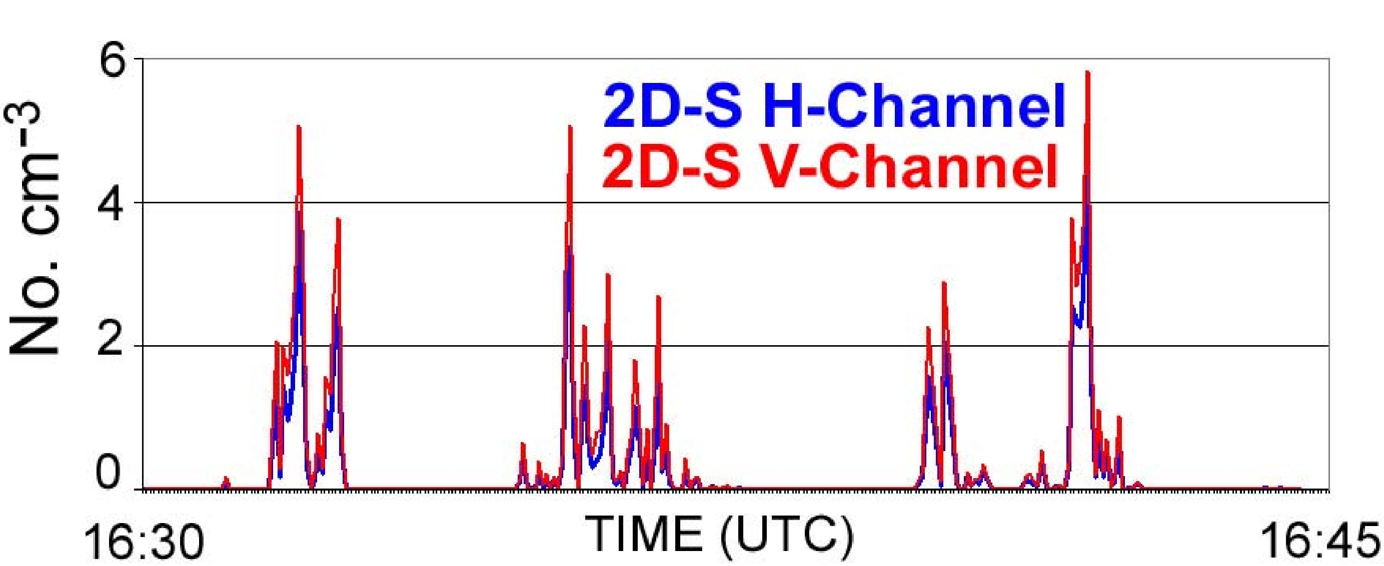




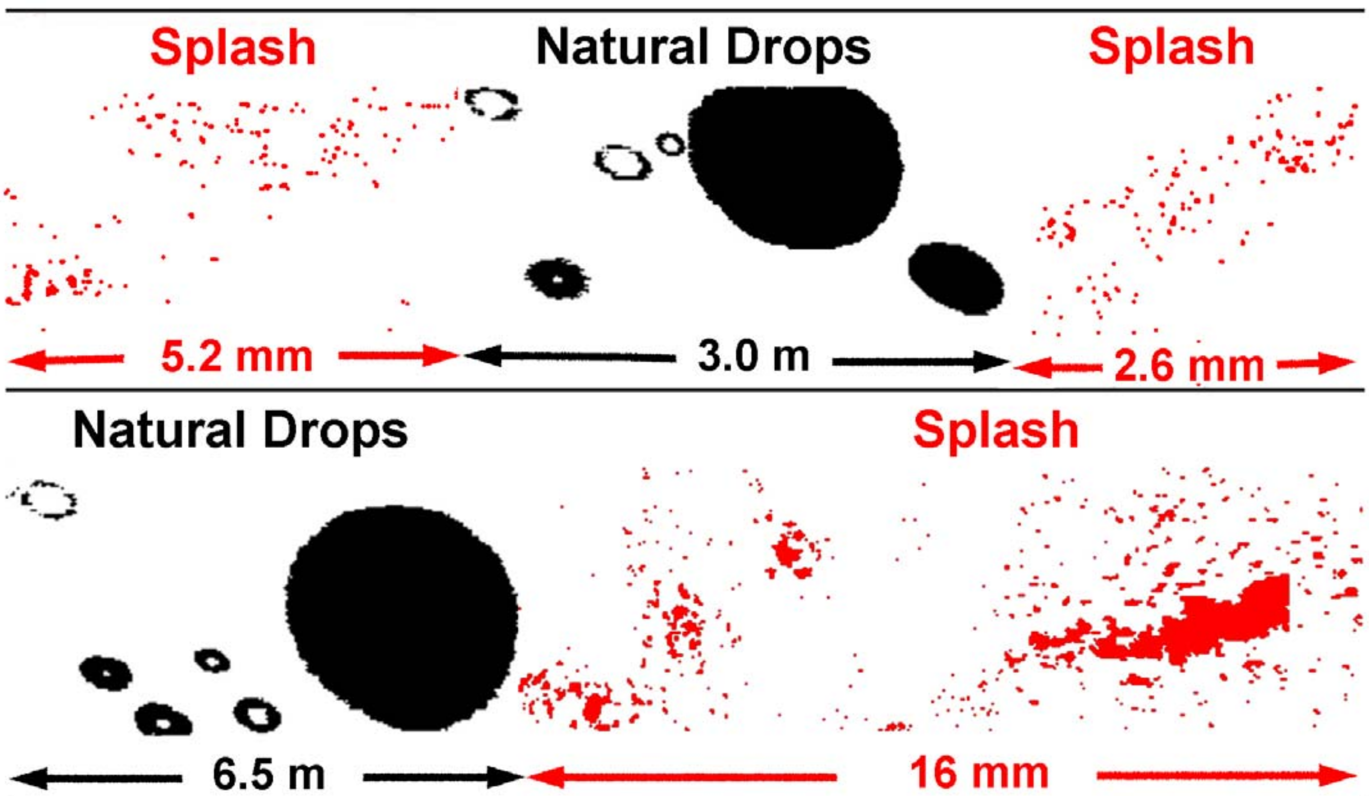
Concentration (No. L-1)
18:54:11
18:55:14
18:56:16
18:57:19
Time (UTC)
1:1
Concentration of Vertical Channel (No. L-1)
Concentration of Horizontal Channel (No. L-1)

Comparison of CAPS (CAS + CIP) and 2D-S in 15 min of Drizzle with Maximum Drop Diameter of 75 μm. CIP saw 160 drops while 2D-S saw 8,093 Drops





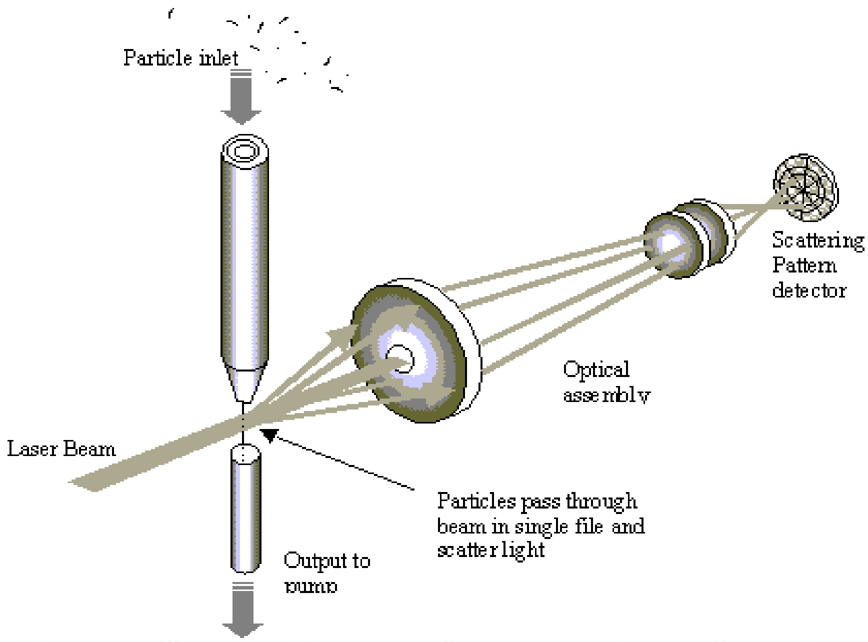
2D-S probe records contiguous 10 μm slices in the atmosphere, which reveals actual spacing of particles. Analysis of particle spacing is a good method to determine splashed water drops and shattered ice particles (e..g. Splash drops shown below)

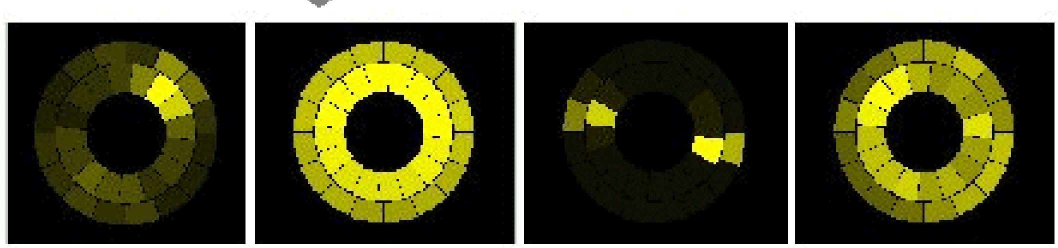


Some Evolving Airborne Microphysics Technologies

- Small Ice Detector (SID, SID2, SID2H & SID3)
- Cloud Extinctiometer
- Next Generation HVPS
- 3V-CPI
- Micro-CPI
- In Situ Cloud Lidar

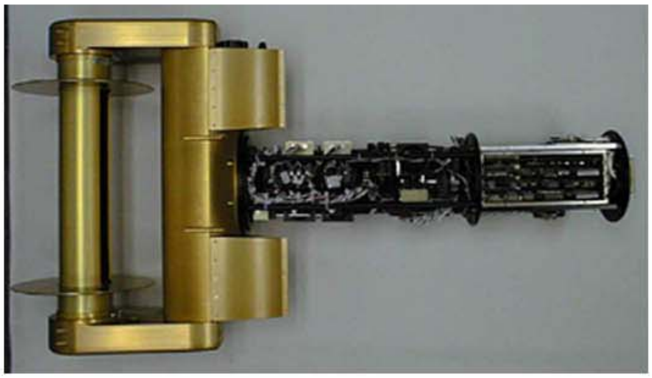
SID2 – Distinguishes between spherical and non-spherical particles 1 μm and larger. Scattering pattern provides information on particle shape... SID2H – uses CCD array. SID3 – Being designed for aerosols. Paul Kaye at British Met Office

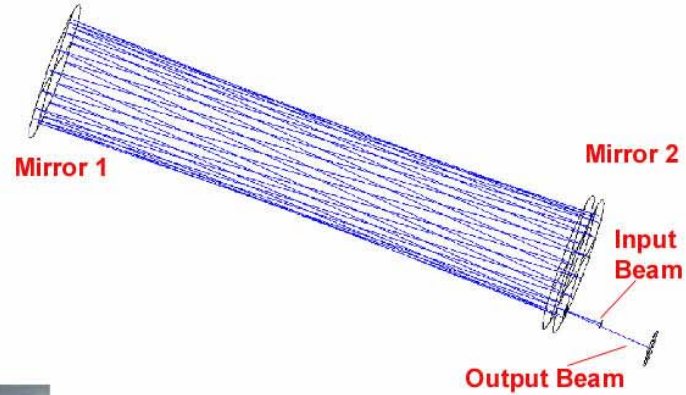


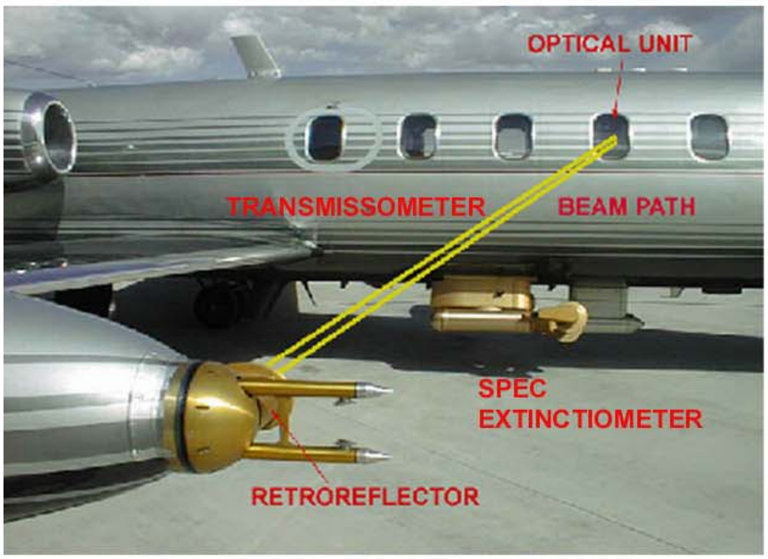


Flake particle | Water droplet | Fibre | Irregular cubic particle

Figure 6: False colour images of the scattering received by a custom detector array chip for various particle types. Data of this form are passed to the host processor for analysis and particle classification.





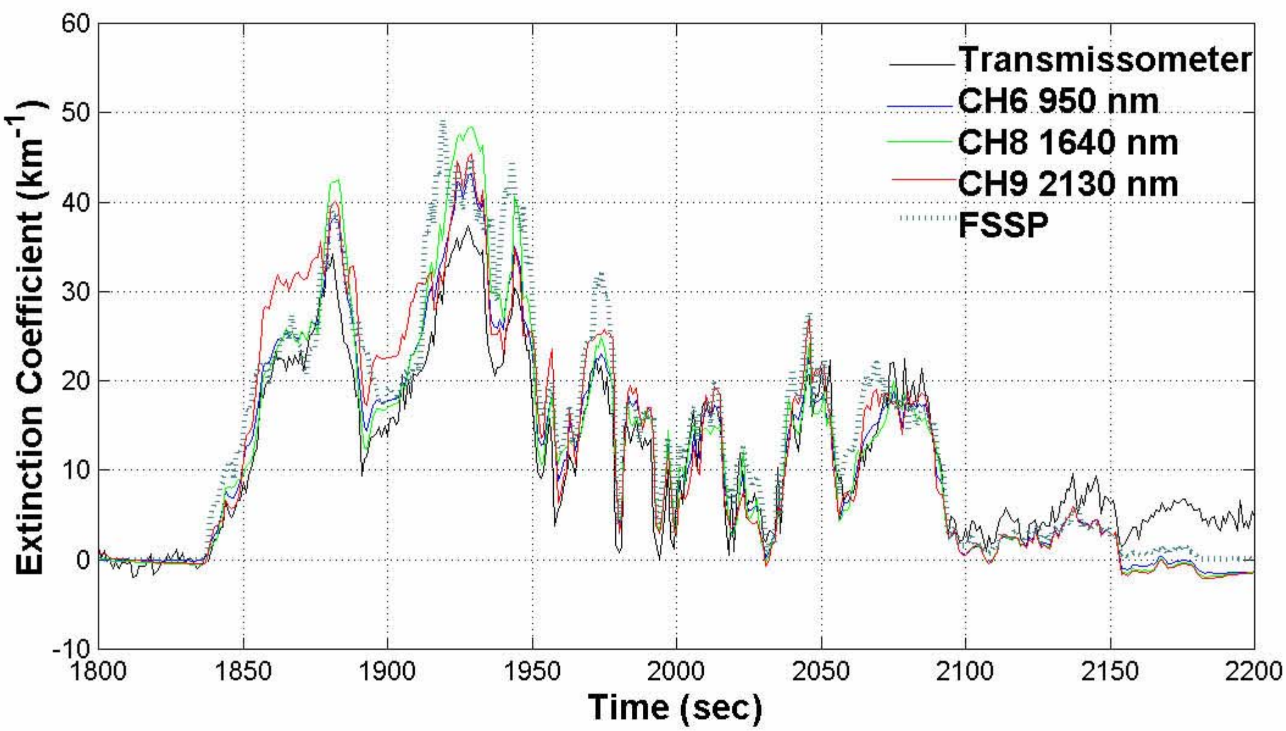


SPEC Extinctiometer

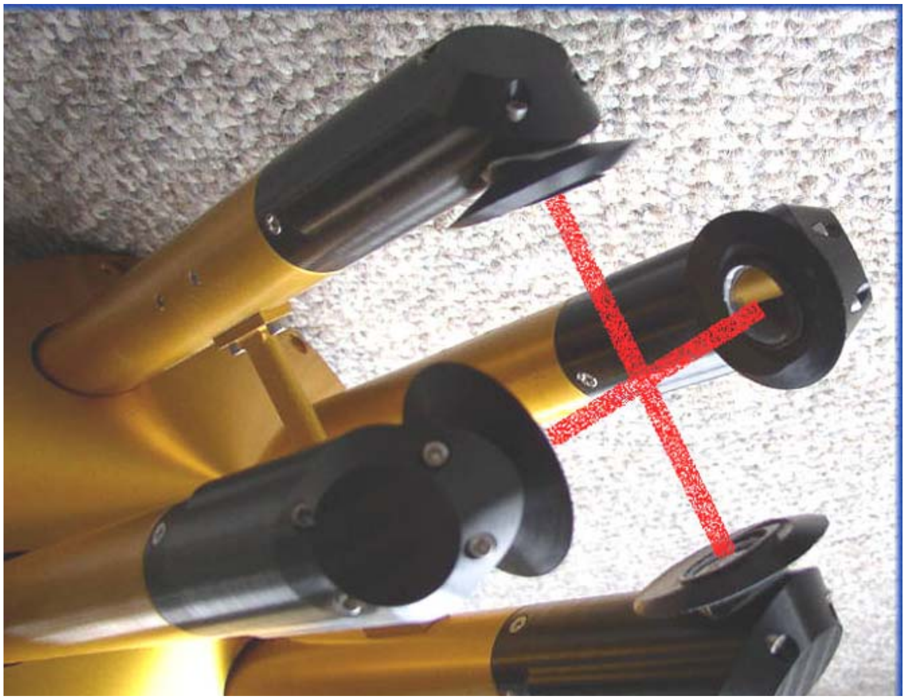
. Measures extinction coefficient simultaneously at 3 of 9 possible wavelengths:
Detector 1(450,550,650,750,850, or 950 nm)
Detector 2(1375 or 1640 nm)
Detector 3(2130 nm)

. 8 meter effective optical path in 0.3 meter, 26 pass Herriott cell

. Installs in PMS style canister

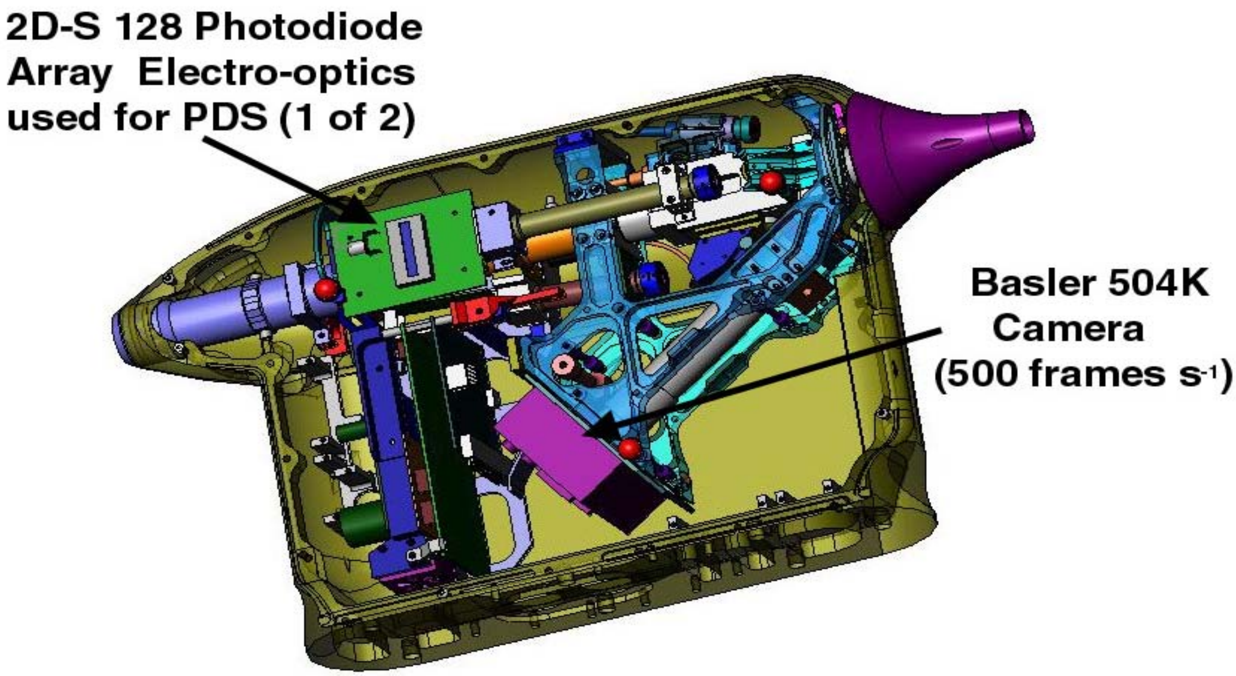


Extinction measured in a wave cloud over Colorado on 26 April 2000.

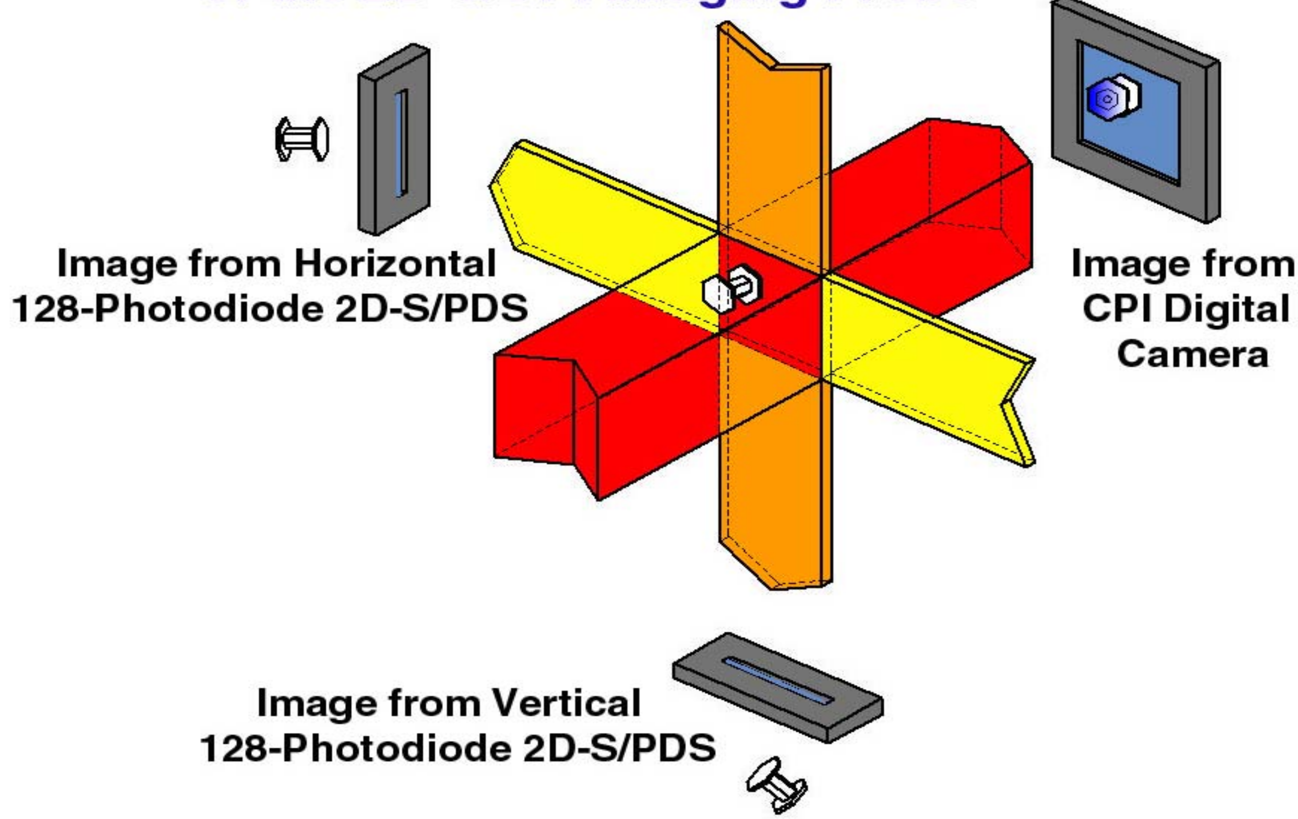


Next Generation HVPS with 100 μm pixels images particles to 1.3 cm and retrofits into existing housing – Or more engineering required to design dual-beam version with 150 μm resolution that images particles out to 2 cm.

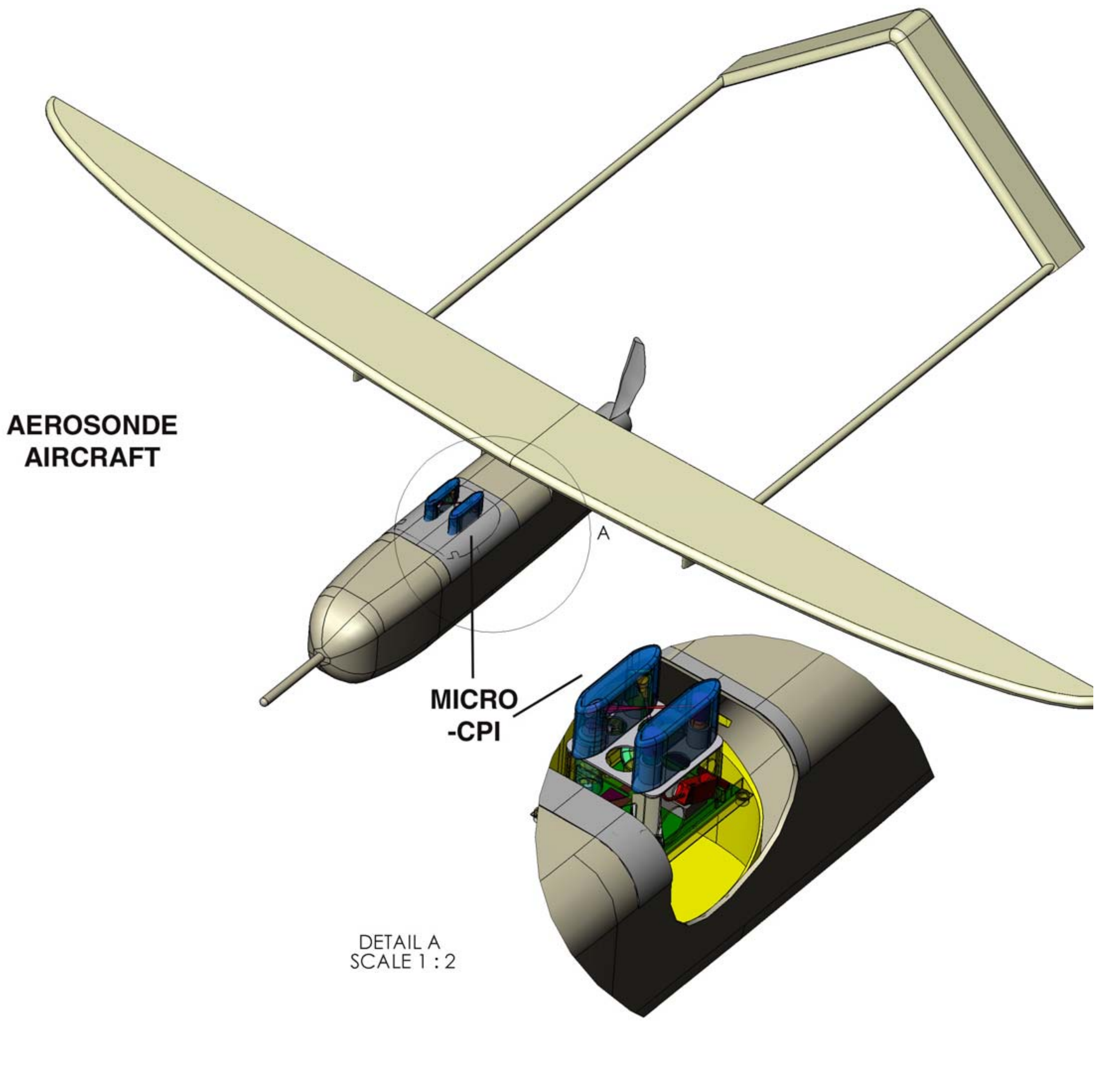
3V-CPI Combines 2D-S and (500 fps) CPI in one instrument. Being built for HIAPER GV



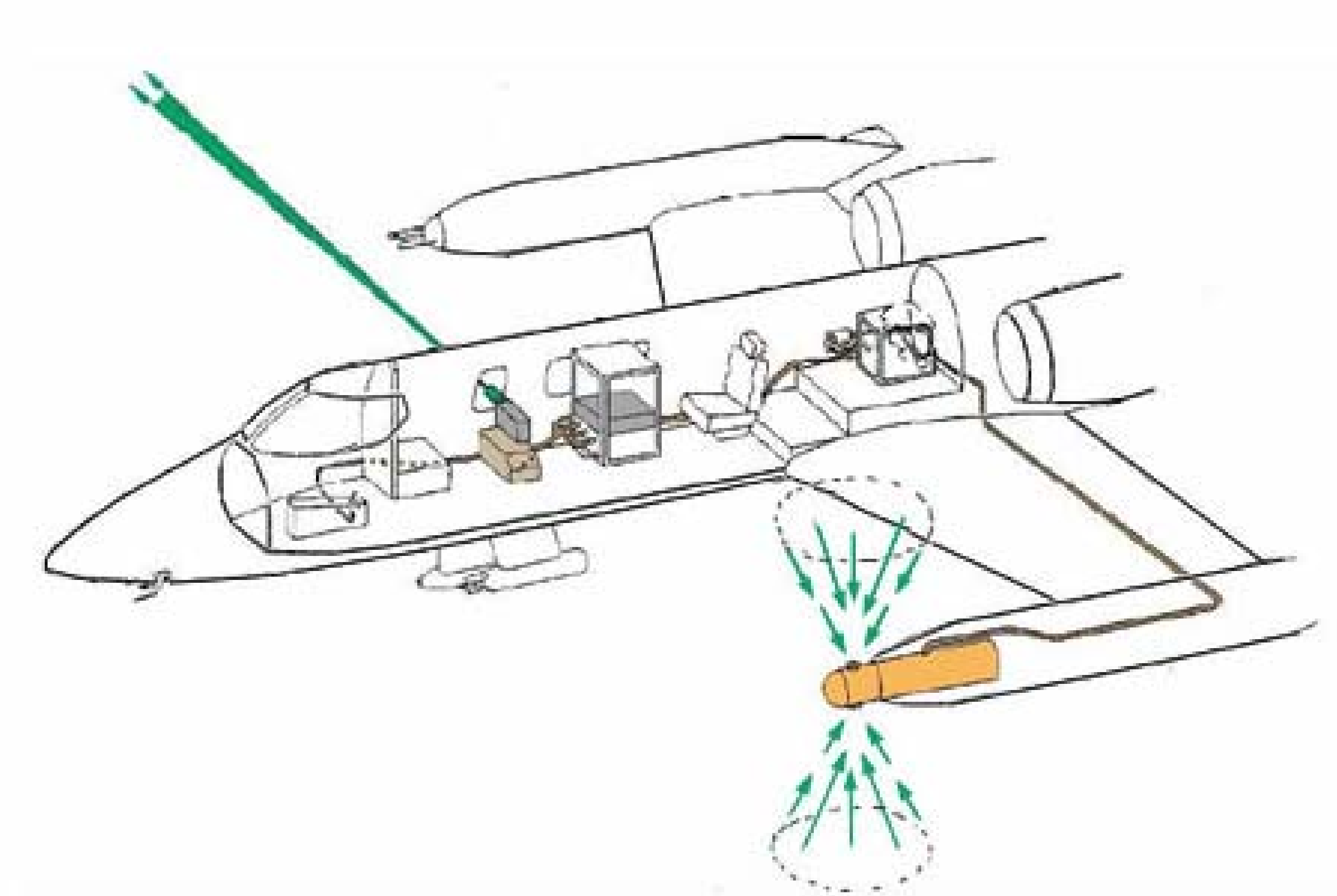
Schematic Showing Electro-Optics of the 2D-S/CPI Imaging Probe



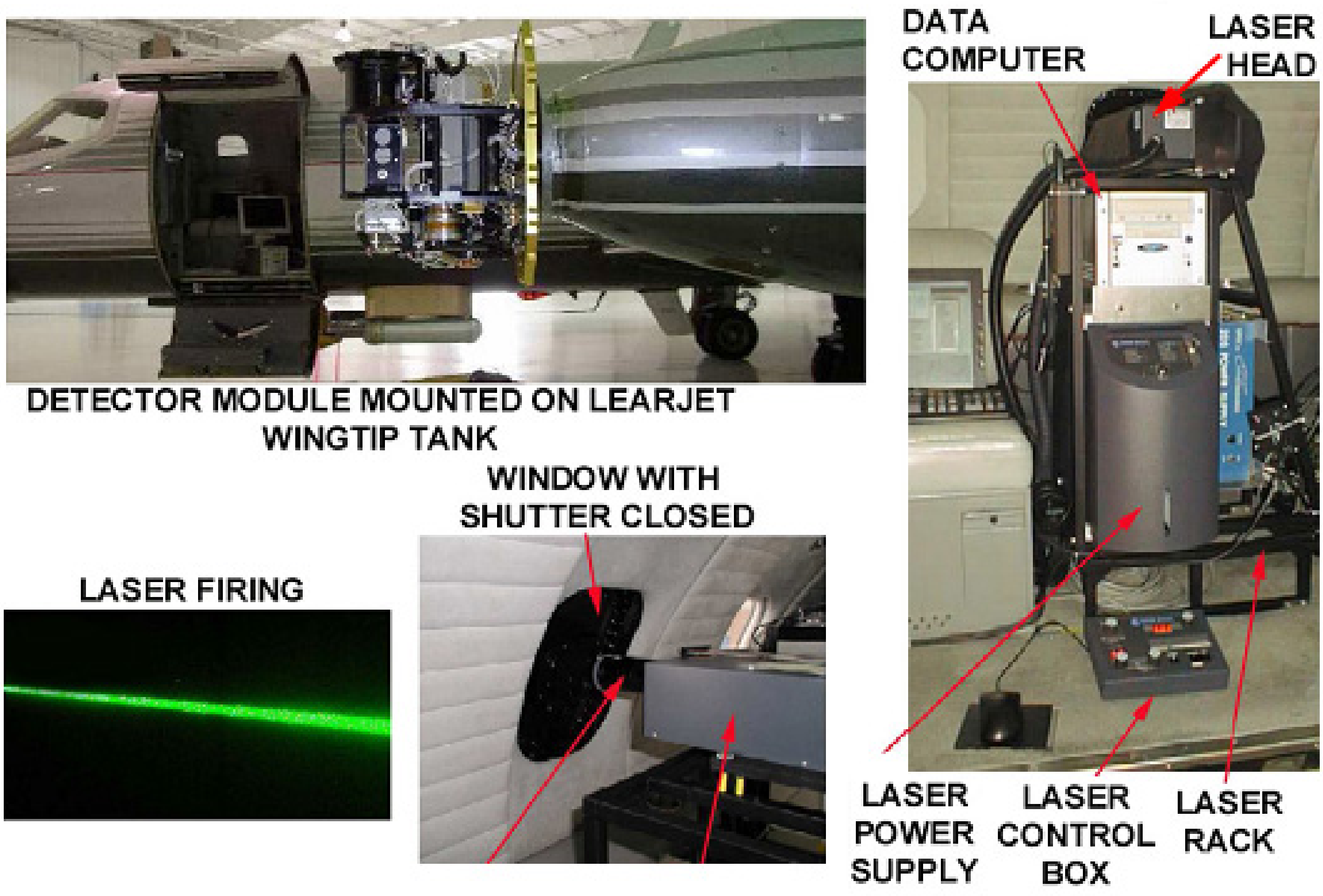
Micro-CPI combines forward scattering and CPI imaging in a 1.5 kg package – shown on the Aerosonde UAV



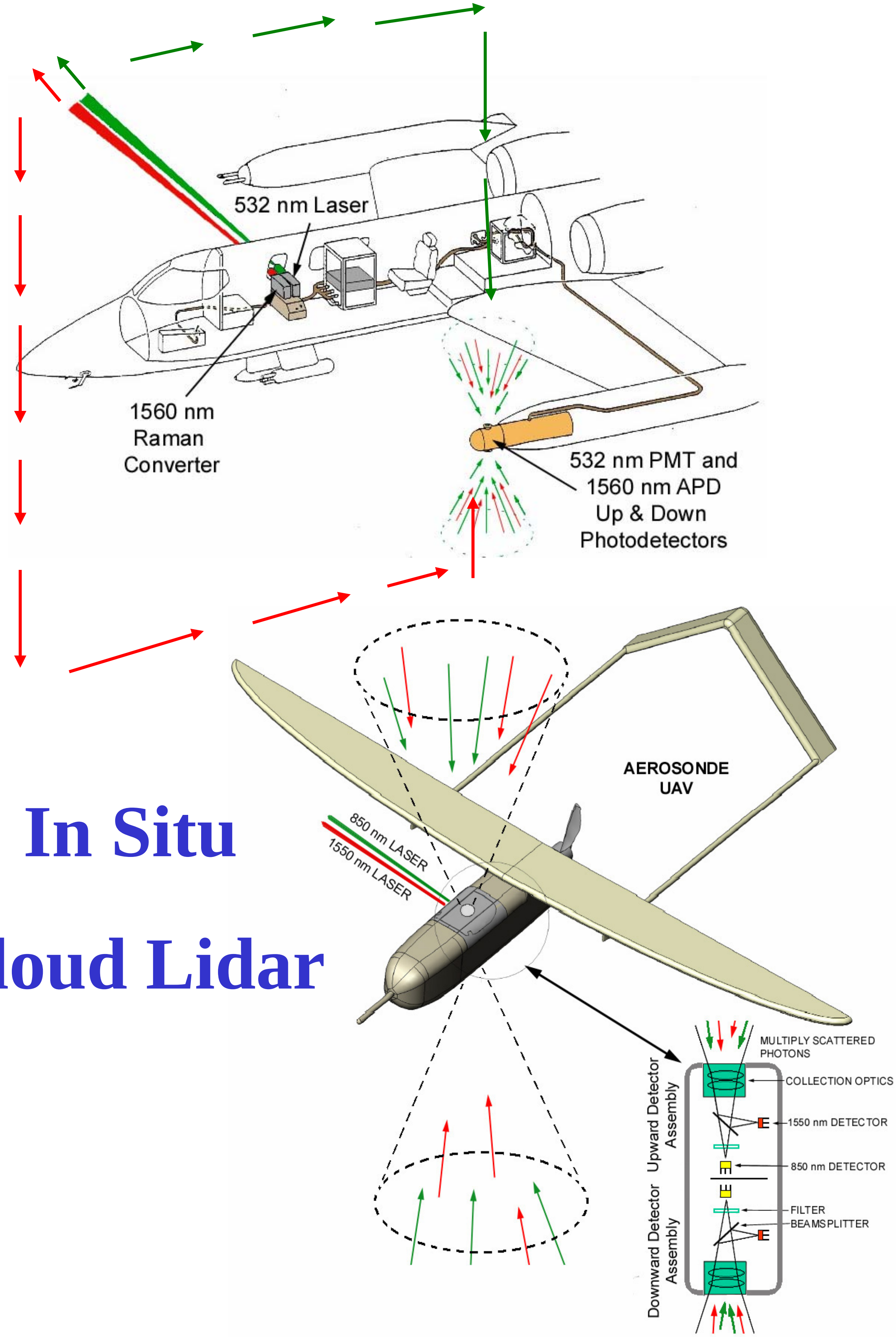
In situ Lidar fires a high-energy pulse of Nd:YAG laser light and records the time of arrival of multiply-scattered photons using off-axis detectors, yielding the volumetric extinction coefficient up to 1 km from the aircraft.



In Situ Cloud Lidar proof-of-concept demonstration flight collected measurements of volumetric extinction coefficient from 25 m to 1 km outward from the Learjet in marine stratus. Dual-wavelength version will also measure LWC and effective radius (Evans et al. 2003. 2006 *JTech*)



In Situ Cloud Lidar



SUMMARY

- **Arctic (mixed-phase) Clouds are Microphysically VERY Inhomogeneous: Supercooled Drizzle, Large Ice Aggregates, Graupel and Supercooled Liquid as cold as –37 ° C.**
- **2D-S Probe is Capable (for the first time) of Imaging Particles from 10 to 150 μm (at aircraft speeds) and Detecting Drop Splashes and Shattered Ice.**
- **New Technology Includes SID, 3V-CPI, Next Generation HVPS, Multi- λ Extinctiometer, μ-CPI for UAV, Dual-λ In Situ Lidar.**