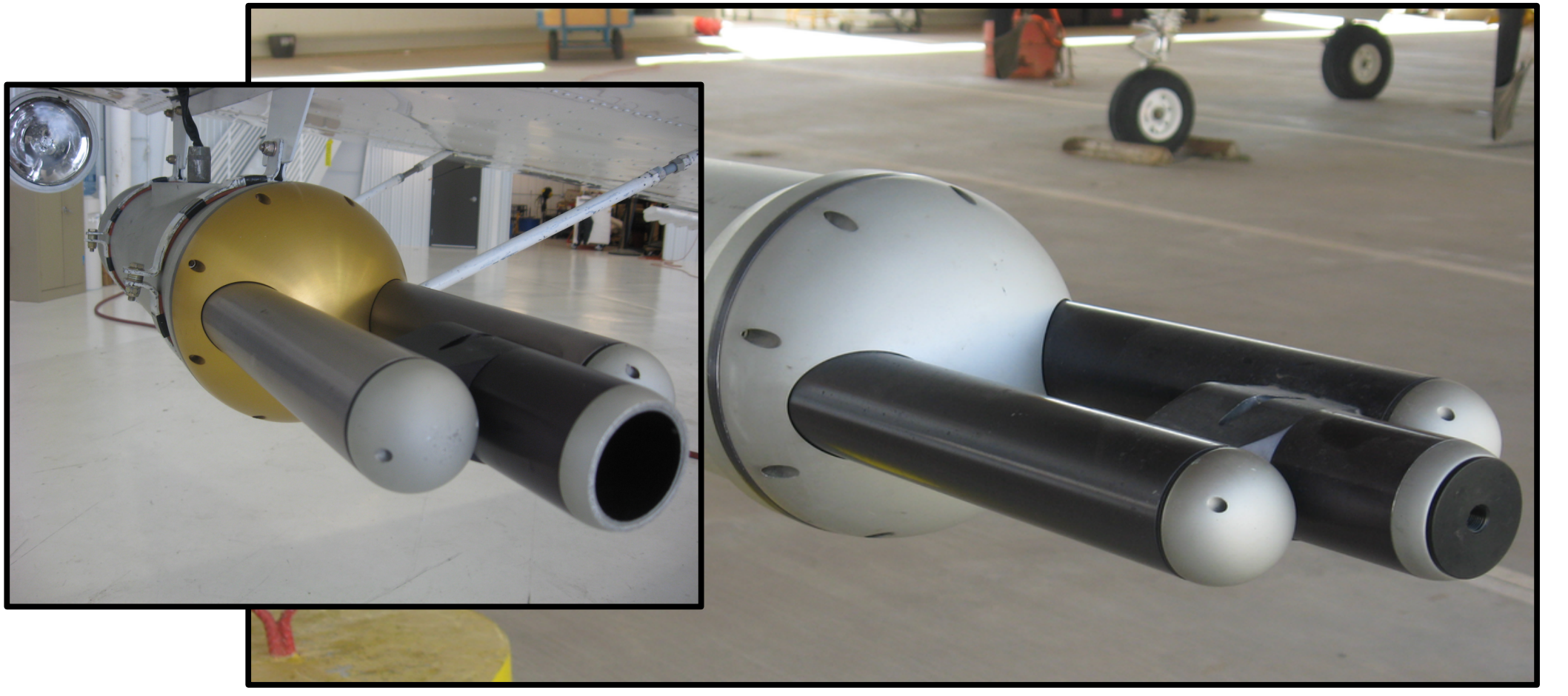
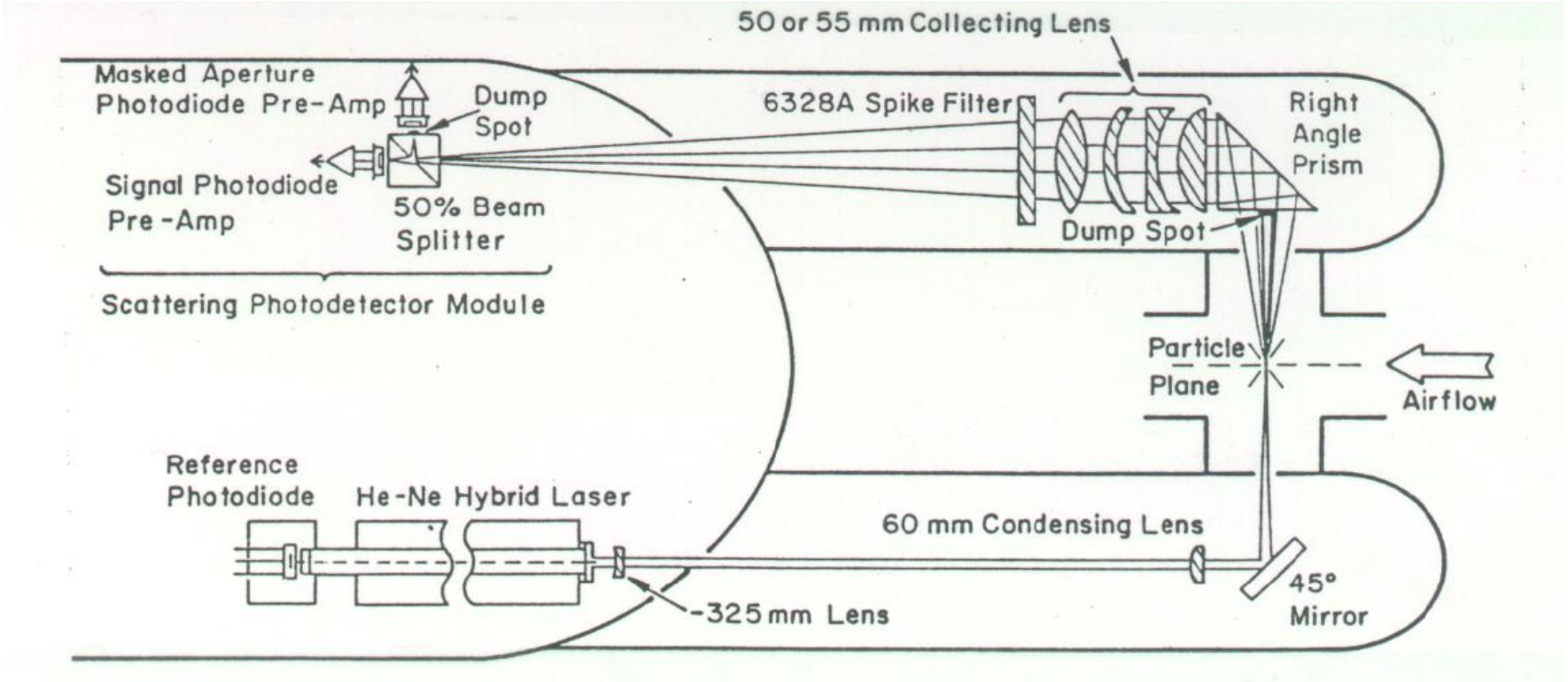
Cloud Scattering Probes (FSSP / CDP)

Cloud Droplet Probe with Anti-shattering Tips

Image from: http://www.dropletmeasurement.com/cloud-droplet-probe-cdp-2

Forward Scattering Spectrometer Probe (FSSP)





- The beam splitter divides the scattered light onto two photodetectors.
- One photodector is optically masked to not receive scattered light from near the laser beam's center of focus.
- Droplets are rejected as being out of the depth of field when the signal from the masked detector exceeds that from the unmasked detector.

FSSP schematic is taken from Dye and Baumgarnder, [1984]

FSSP Effective Sample Volume

Sample Volume = TAS*DOF*BD*(Tc/Ts)

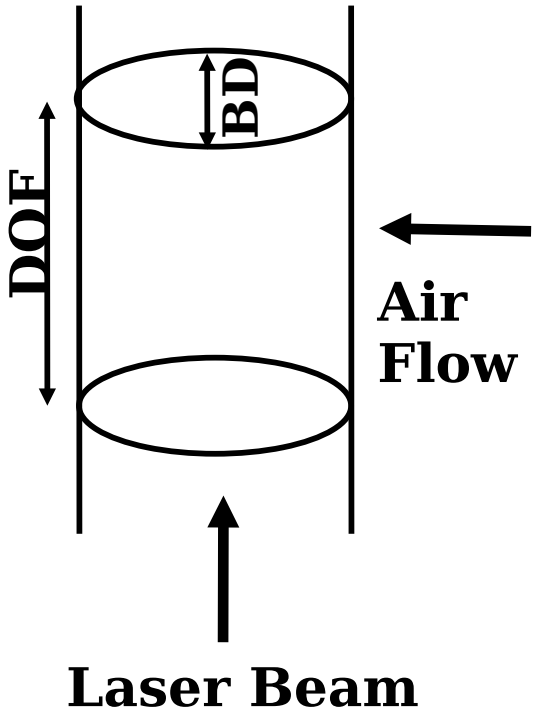
TAS – Aircraft True Air Speed (~100 m/s)

DOF – FSSP Depth of Field (~2.9 mm)

BD – Laser Beam Diameter (~0.2 mm)

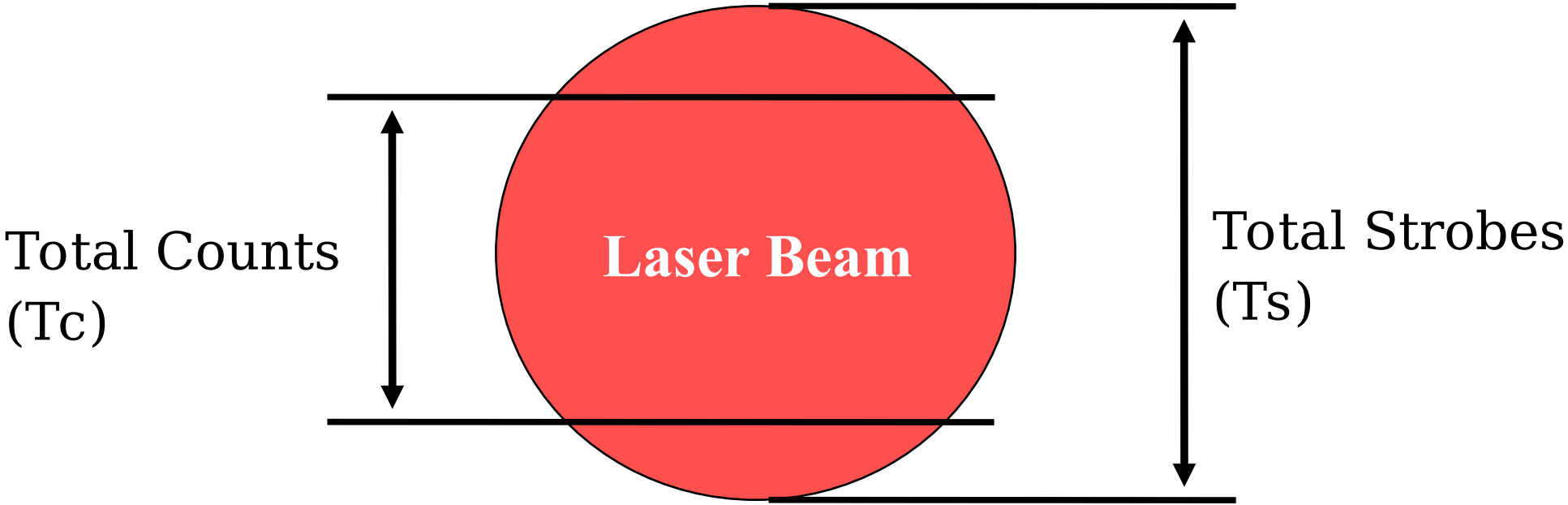
Tc – Number of Droplets Sized (Total Counts)

Ts – Number of Droplets within the DOF (Total Strobes)



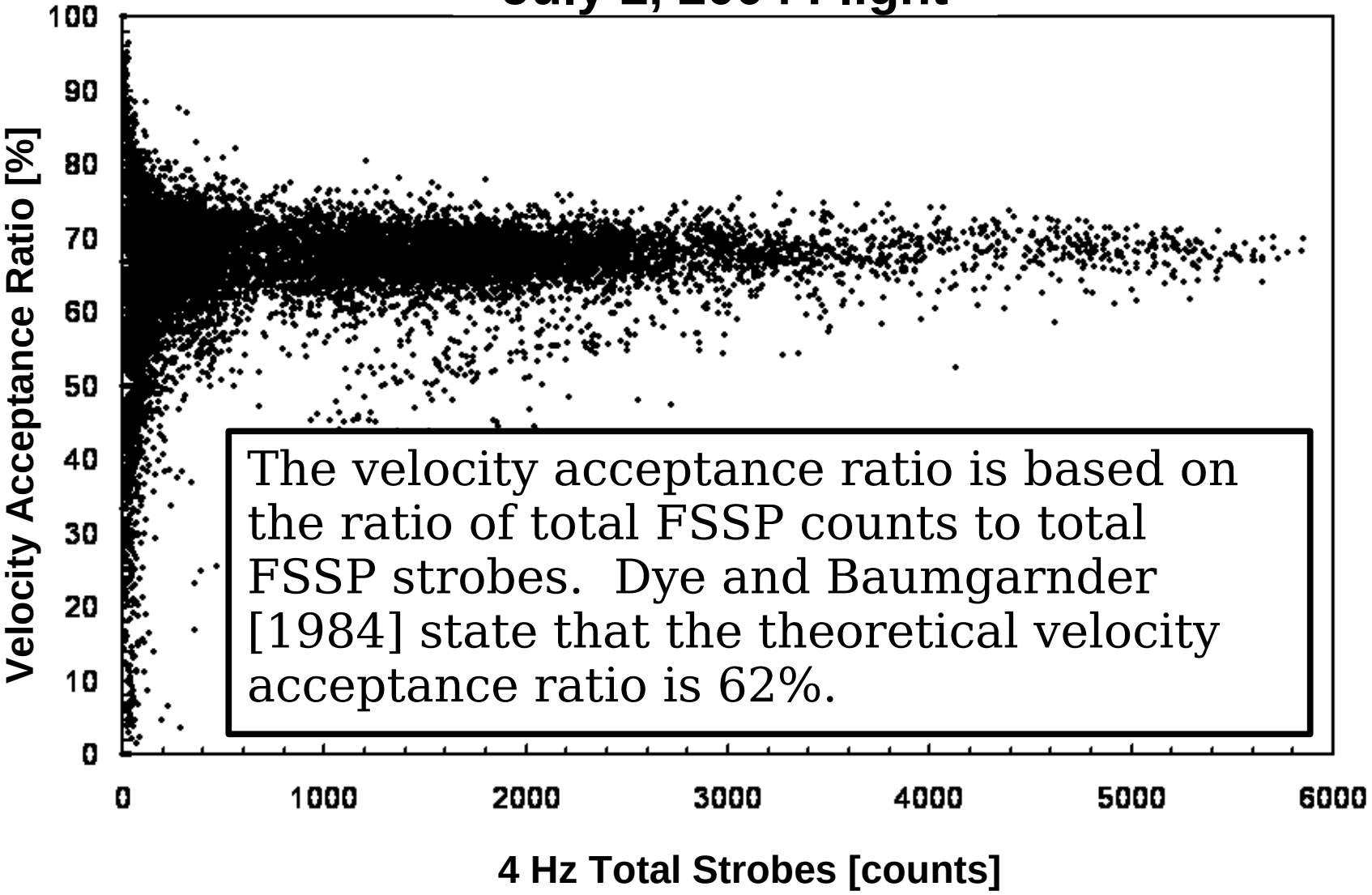
Laser Beam Fraction Correction

Effective Laser Beam Diameter (Tc/Ts)



- The effective laser beam diameter is the fraction of the total diameter where droplets are within the laser beam long enough so they can be sized.
- A running average of droplet transit time through the beam is maintained. If the droplet time within the laser beam is less than the average, it is rejected from sizing but included in the running average.

July 2, 2004 Flight

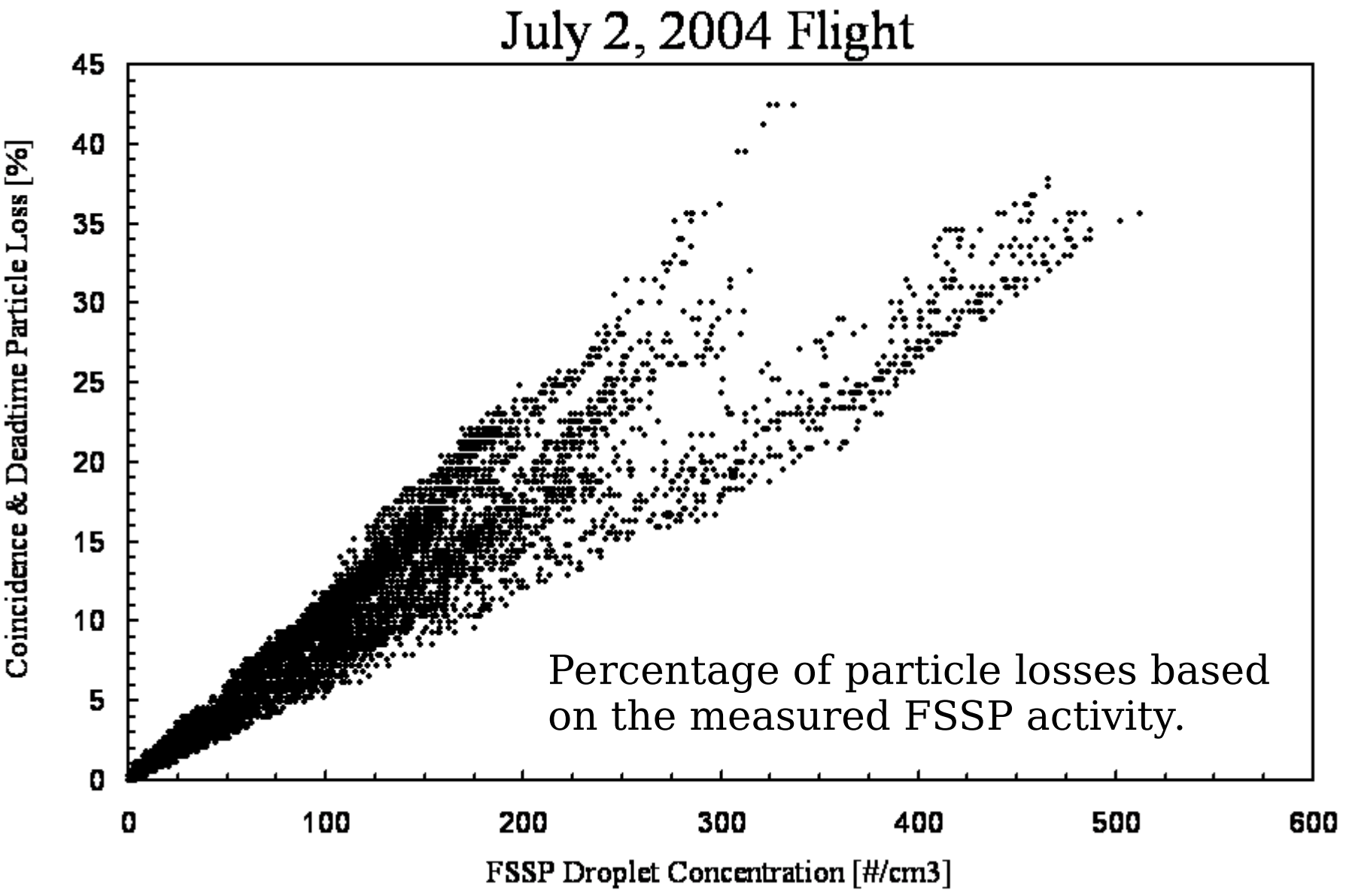


Coincidence and Dead-time Corrections

$$cf = \frac{1}{1 - 0.73 * F_a}$$

cf – Correction factor F_a – Activity Fraction

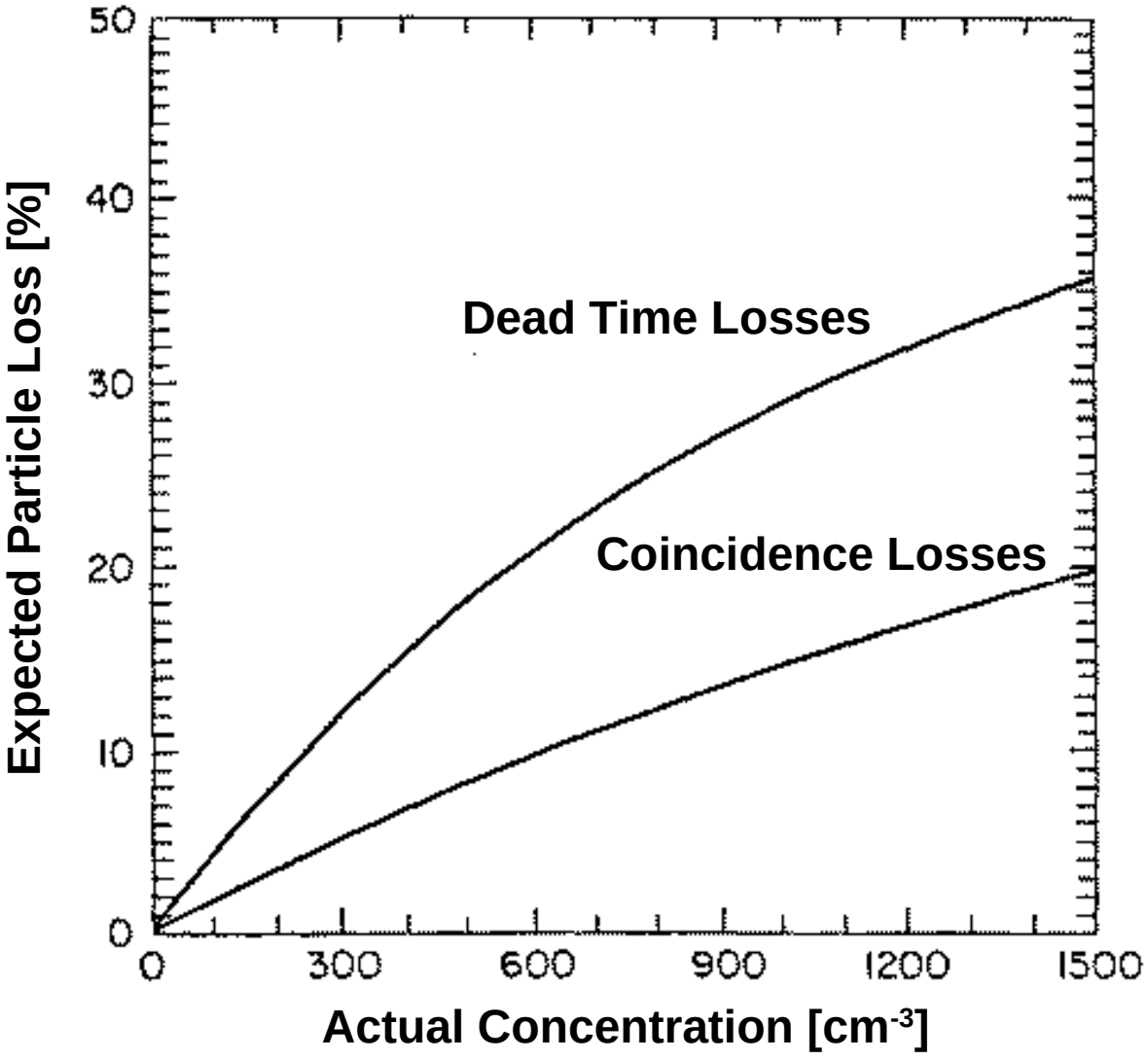
The 0.73 constant is an empirical factor found from computer simulations which takes into account particles which are still in the beam at the end of a reset delay period. This factor is described by Baumgardner [1983] and Baumgardner et al [1985].


July 2, 2004 Flight
Coincidence & Deadtime Particle Loss [%]
0
5
10
15
20
25
30
35
40
45
0
100
200
300
400
500
600
FSSP Droplet Concentration [#/cm3]
Percentage of particle losses based on the measured FSSP activity.

Theoretical Loss Correction

Plot of the expected loss of the NCAR Research Aviation Facility's FSSP probe flying at 100 m/s.

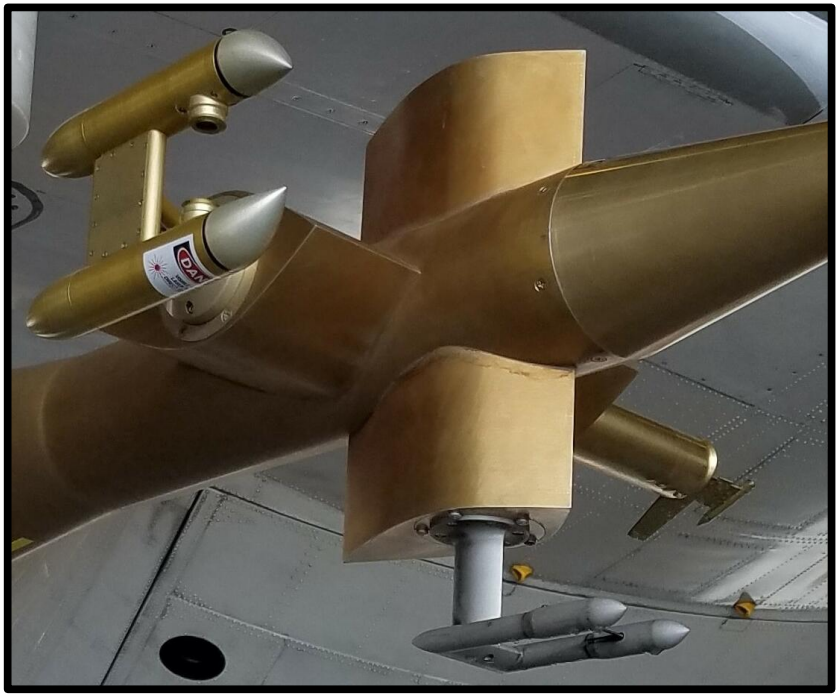
Figure taken from the NCAR Research Aviation Facility Bulleting No. 24.



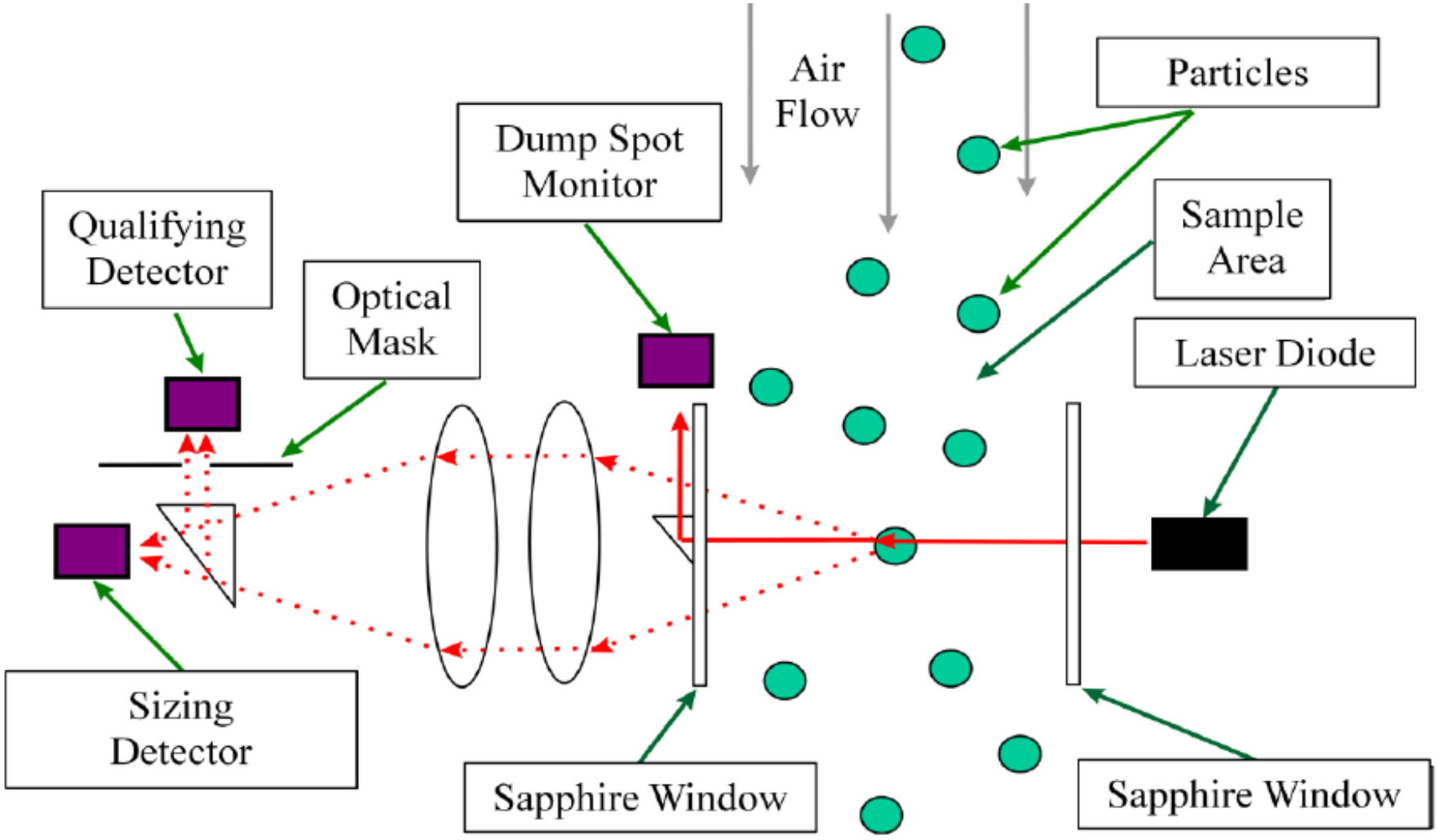
Cloud Droplet Probe (CDP)

Cloud Droplet Probe Overview

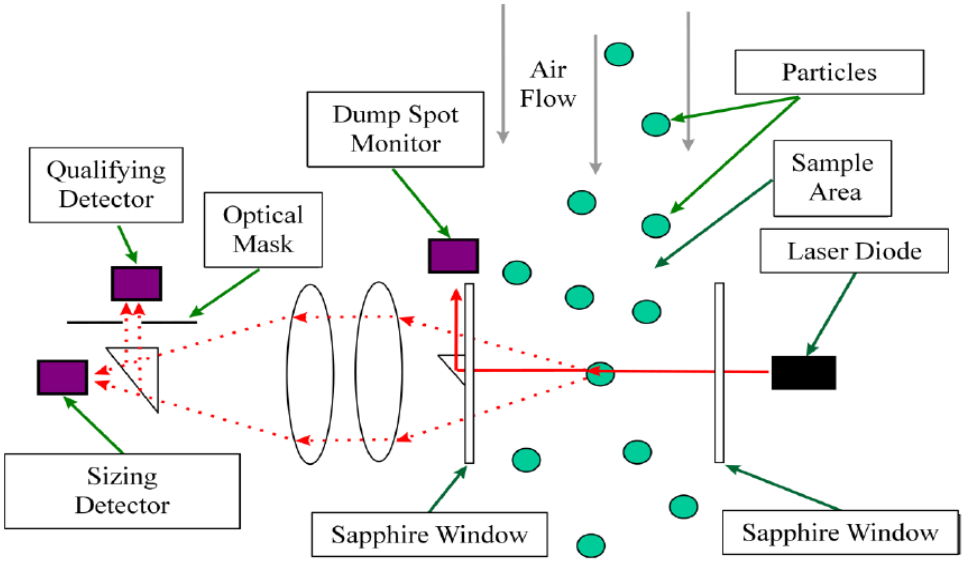
Technique: Light-scattering
Channels: 10, 20, 30, or 40 size bins
Size Range: 2 – 50 microns
Sample Area: 0.24 mm^2
Air Speed Range: 10 – 200 m/s
Frequency: Selectable, 0.1 to 10 Hz
Refractive index: Non-absorbing, 1.33
Light Collection Angles: 4–12 degrees
Laser: 658 nm, up to 50 mW
Data System Interface: RS-232 or RS-422
Calibration: Precision Glass Beads



Cloud Droplet Probe: Optical Path

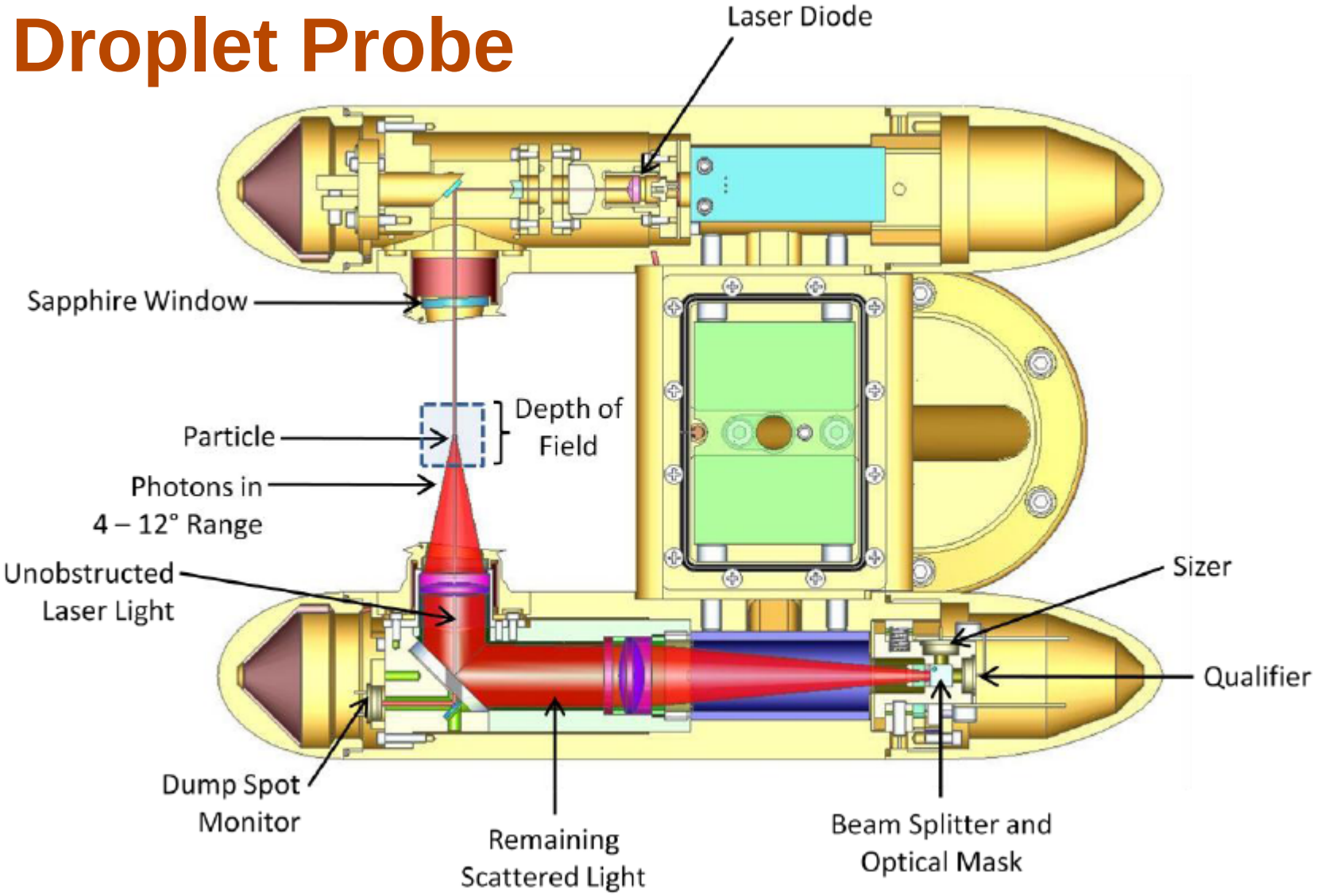


Depth of Field

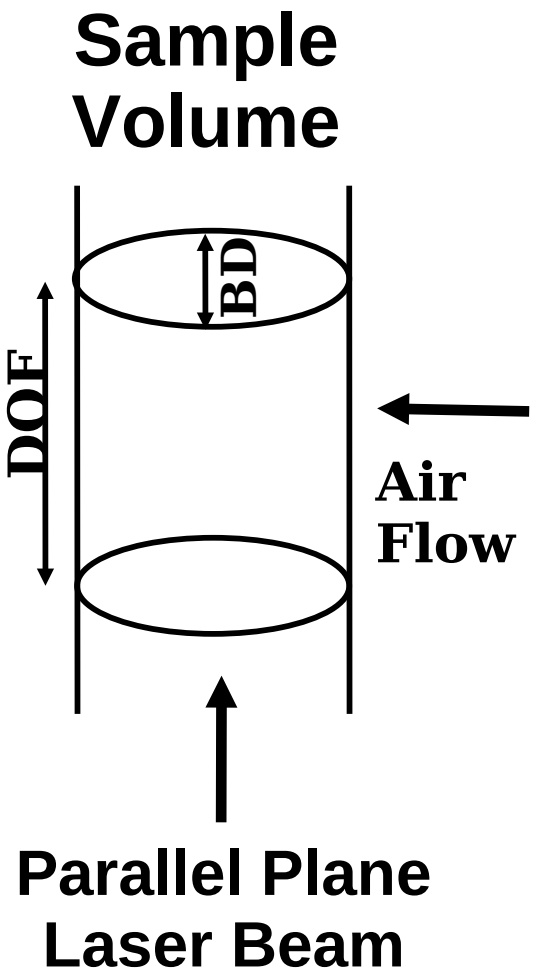


- Forward-scattered photons within a 4 to 12 degree cone from the laser beam are collect. A 50/50 optical beam splitter divides the light into a pair of photodetectors.
- An optical mask filters the optical signal going to the qualifier. Only signals from particles that fall within the laser's depth of field reach the qualifier in significant quantity.
- Both photodetectors convert the photon pulses into electrical pulses. The pulse from the qualifier is multiplied by two. If the resulting signal exceeds the pulse from the sizer, the particle is considered within the depth of field.

Cloud Droplet Probe



Depth of Field (DOF)



- Only particles that pass through the uniform power region of the laser beam can be sized accurately.
  - By definition, this region is the depth of field.
- The CDP "qualifies" particles that fall within the depth of field, and the instrument only sizes these particles.

“Qualified” Particle

- Light rays denoted red indicate the scattering from a droplet within the qualifier depth of field.
- Blue light rays denote a droplet outside of the qualifier depth of field.

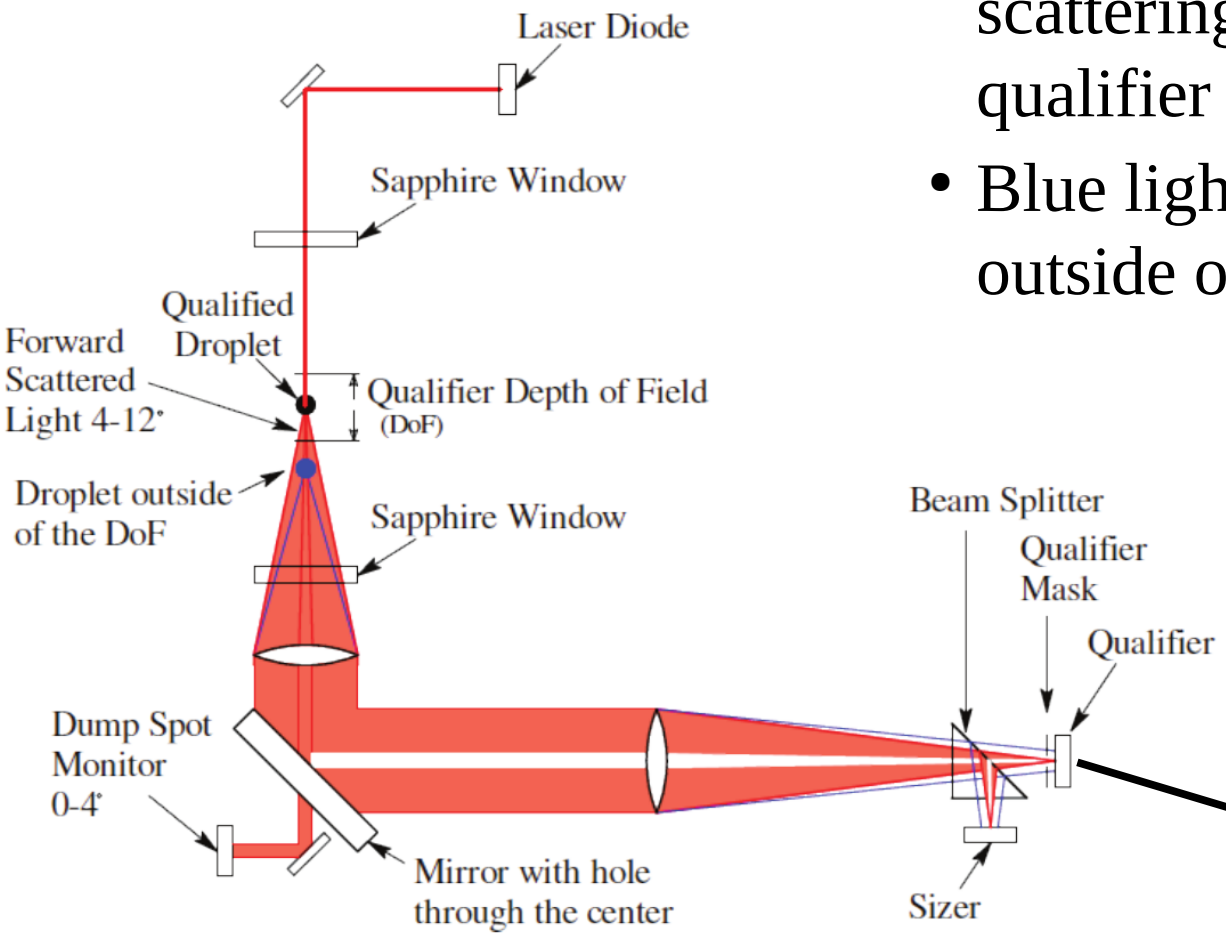
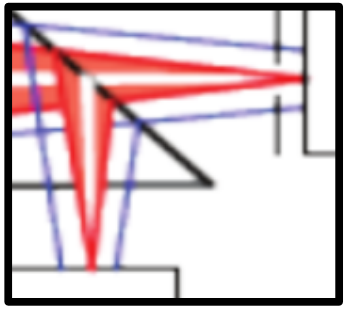


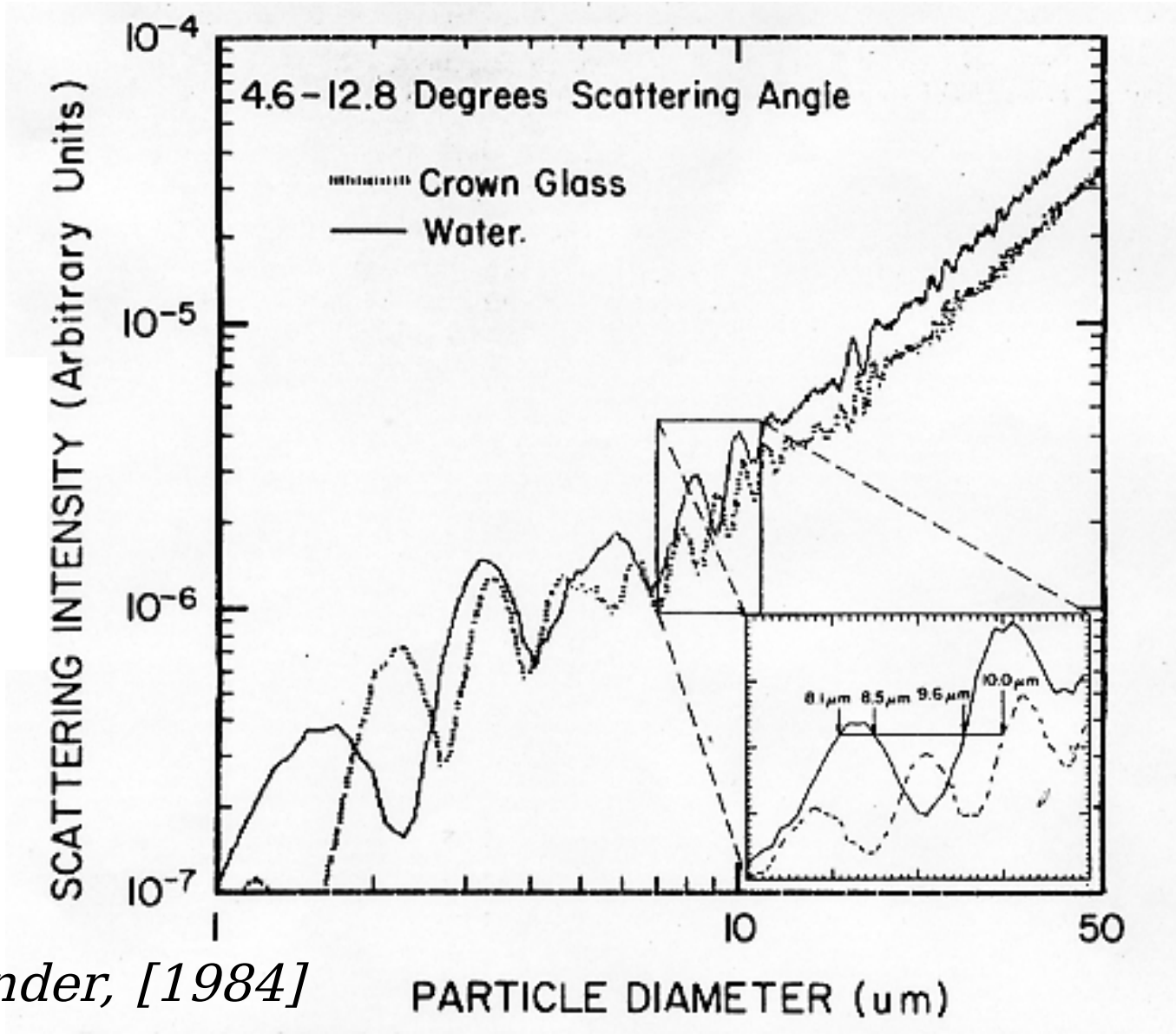
Image from Lance et al., 2010

Droplets within the depth of field have a qualifier pulse multiple by 2 that is larger than the sizer pulse.



Sizing Calibration Mie Function

The detected scattered laser light in the forward direction is used to size the particles.



Mie Function is taken from Dye. and Baumgarnder, [1984]

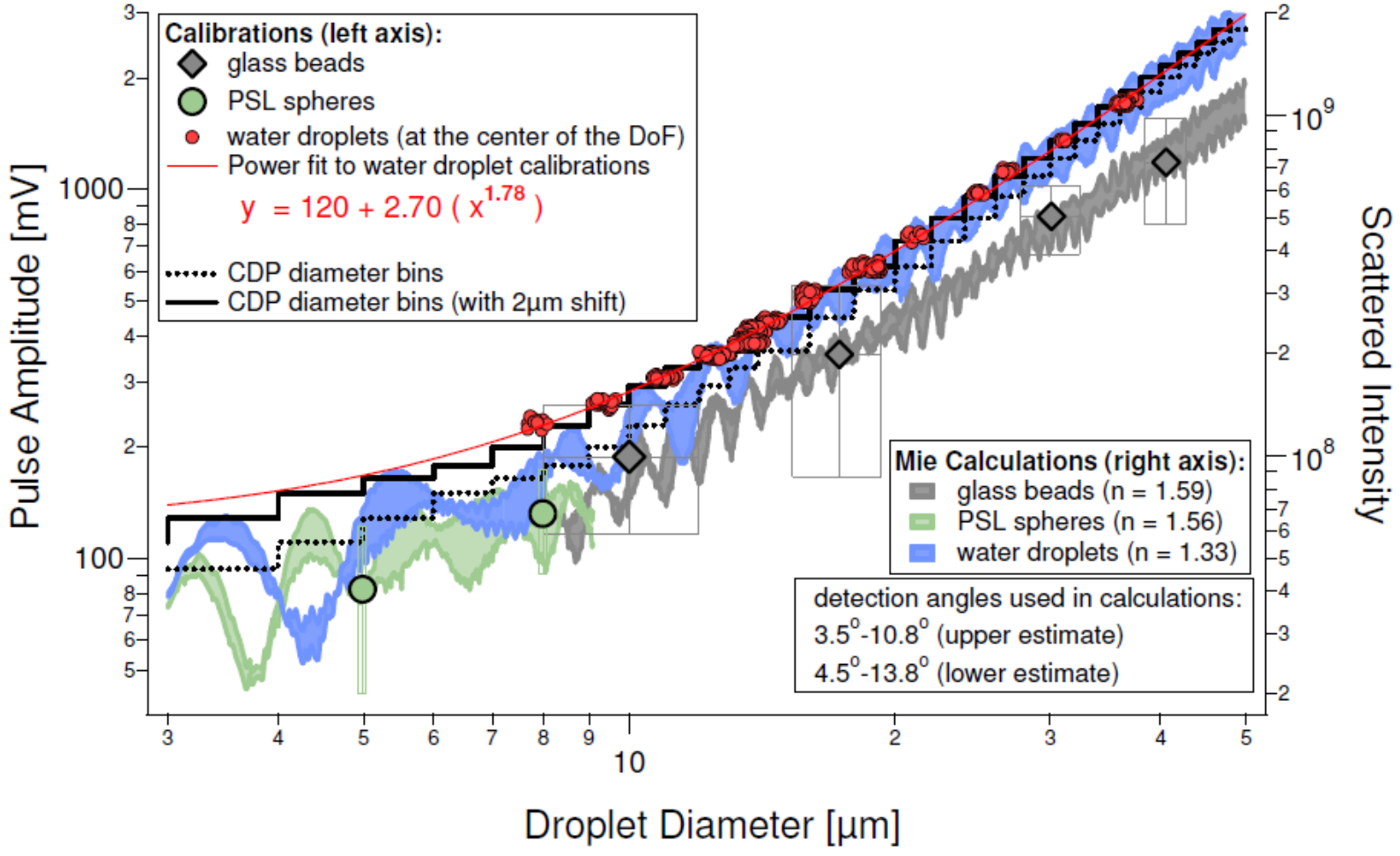
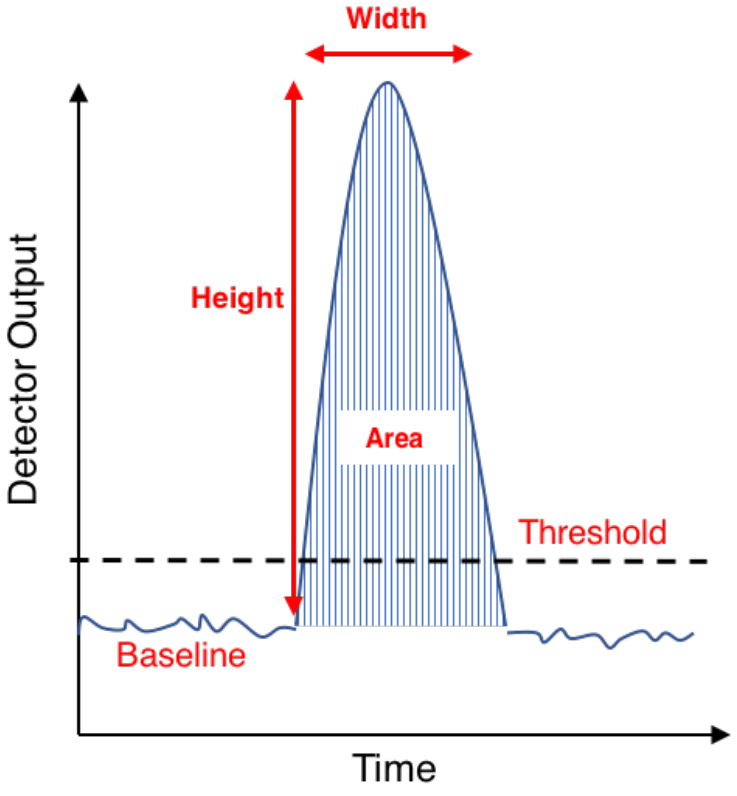
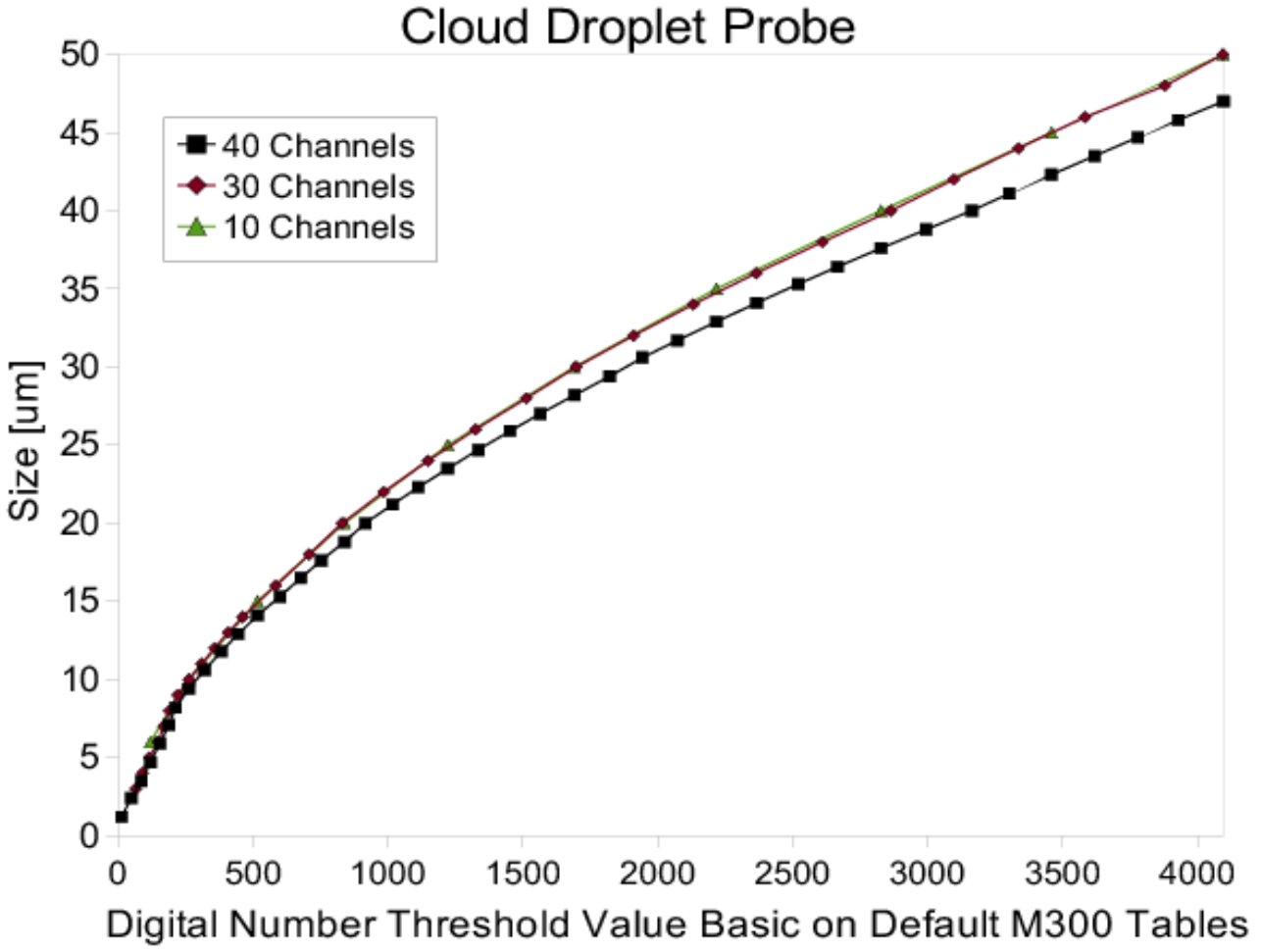


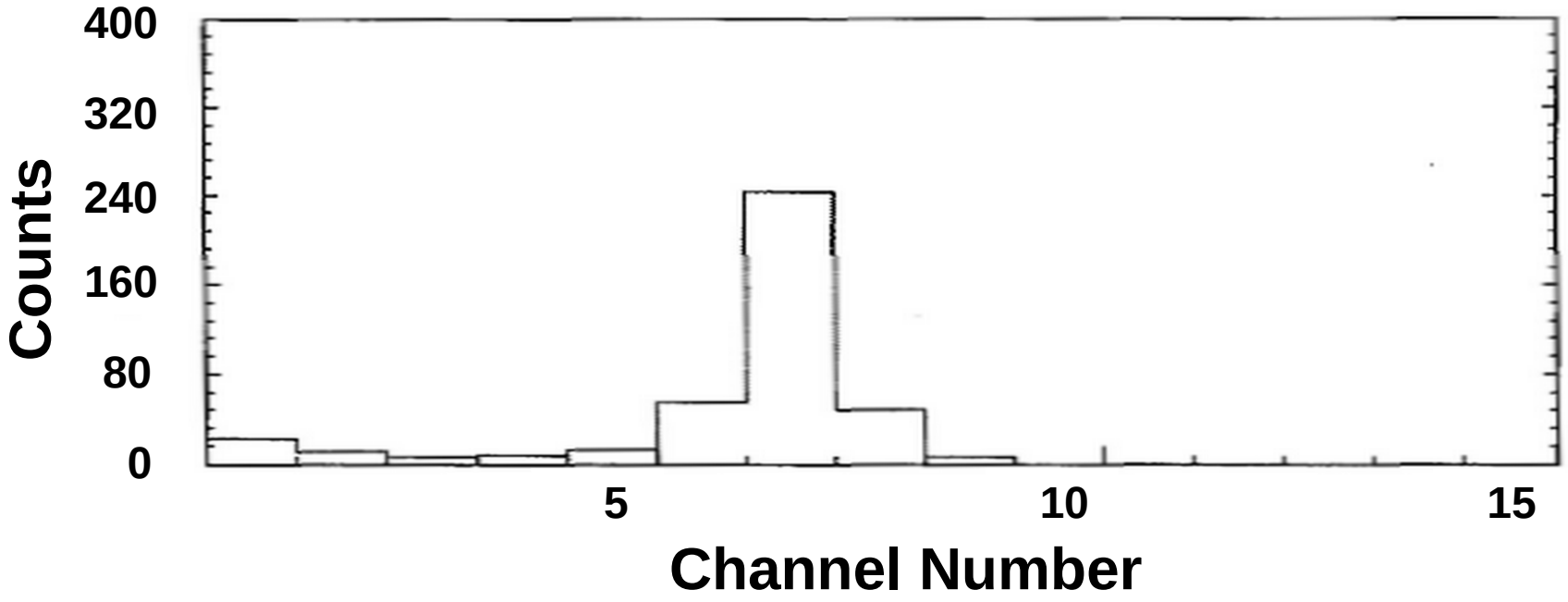
Figure is from Lance et al. [2010]: Atmos. Meas. Tech. Discuss., 3, 3133–3177, 2010, www.atmos-meas-tech-discuss.net/3/3133/2010/ doi:10.5194/amtd-3-3133-2010

Sizing using Threshold to Set Channel Boundaries





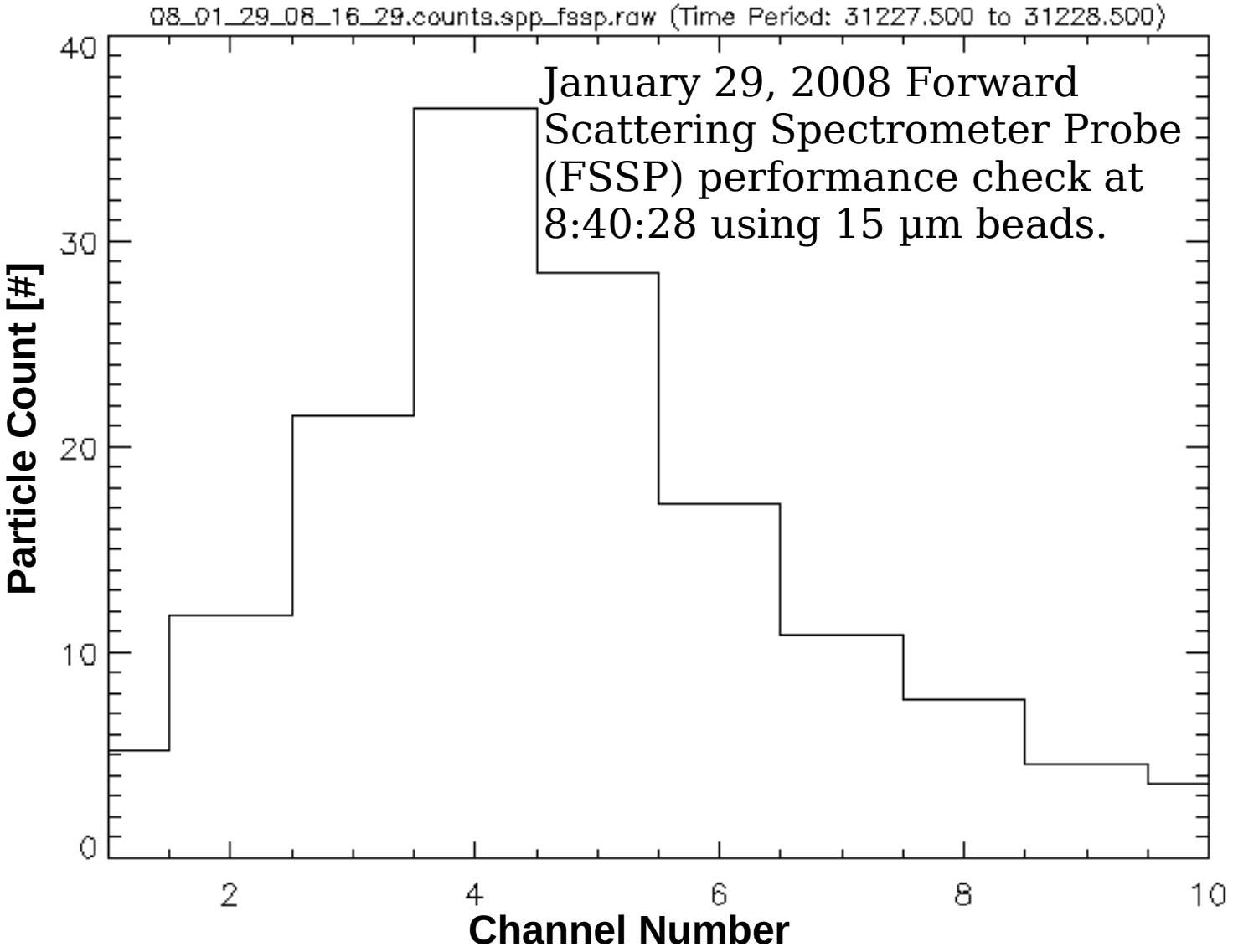
Sizing Performance Check



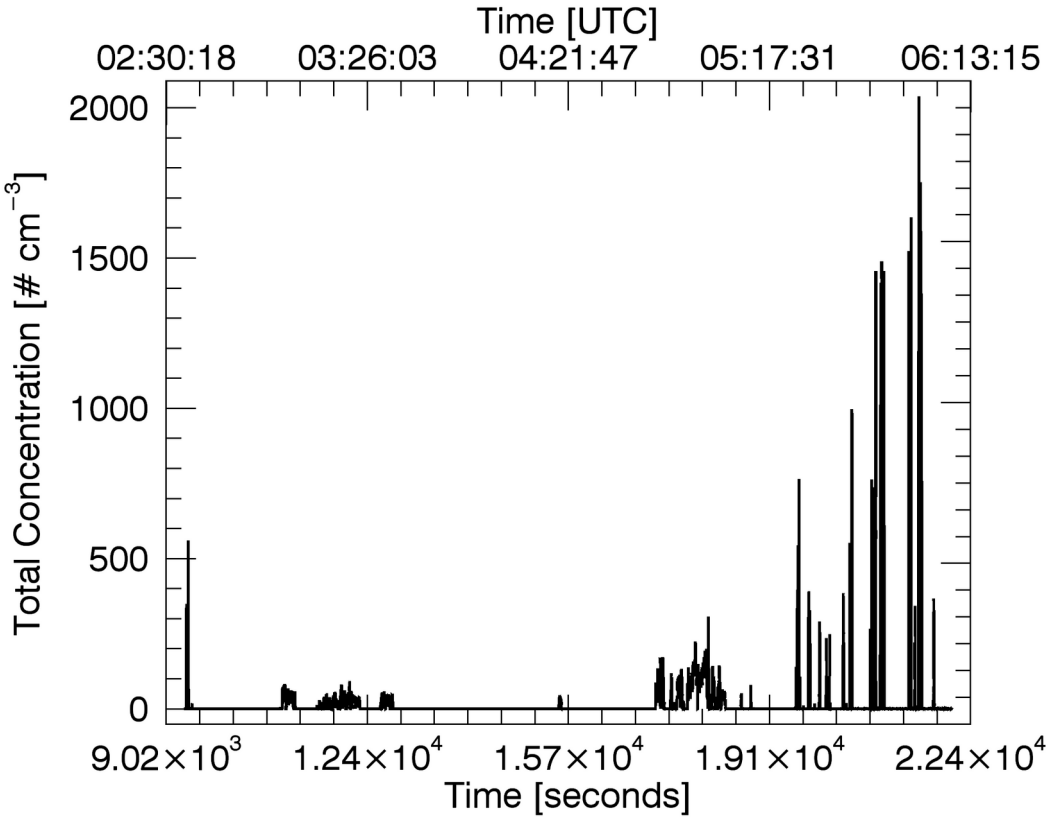
Channel	Count
1	22
2	11
3	5
4	8
5	12
6	55
7	243
8	49
9	6
10	0

Sizing check is done to determine the instrument's channel size boundaries by using the channel counts obtained from measurements on beads of known size.

FSSP Check Results



Level 3 Data Processing

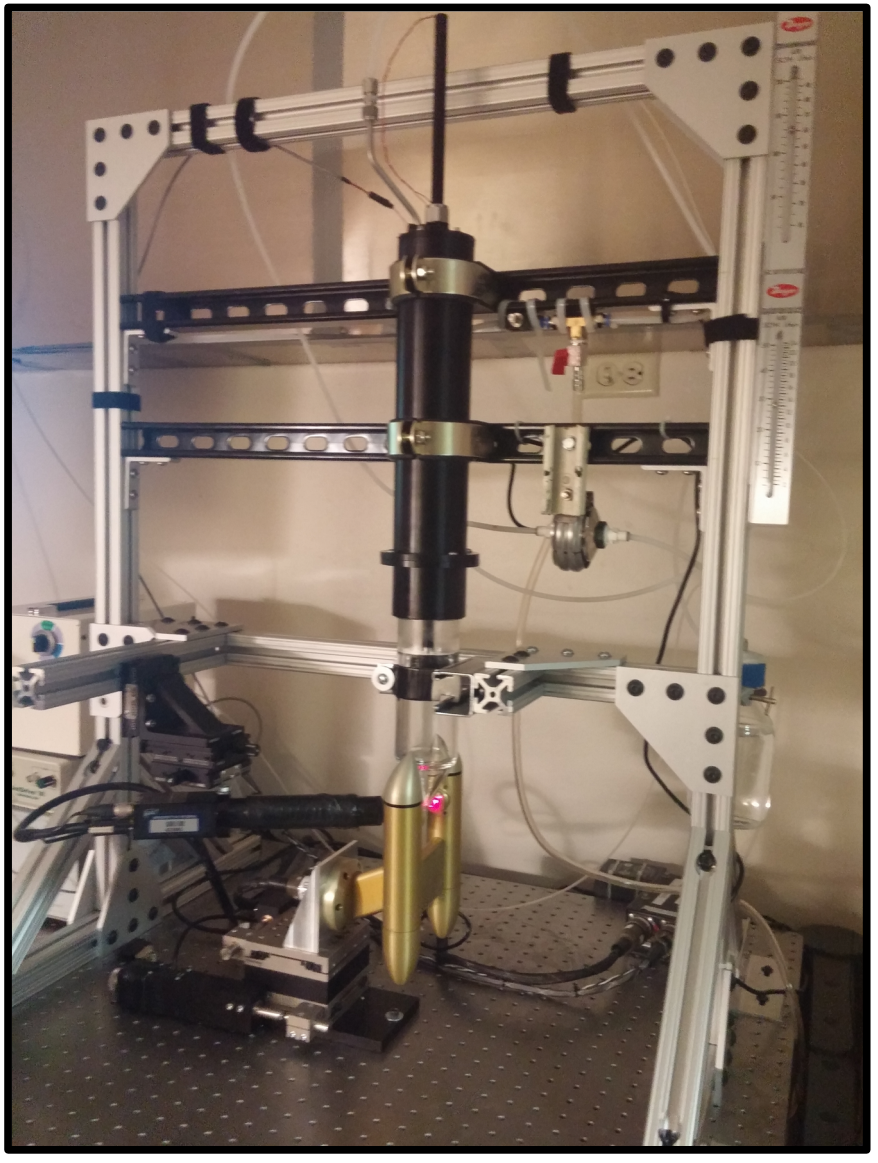


- No level 2 processing for CDP data.
- Level 3 processing (cdp_counts2conc.pro) uses true air speed from *.physical.raw file to convert channel counts into concentrations [# cm^{-3}].
- Auxiliary data are converted from engineering units into physical units.

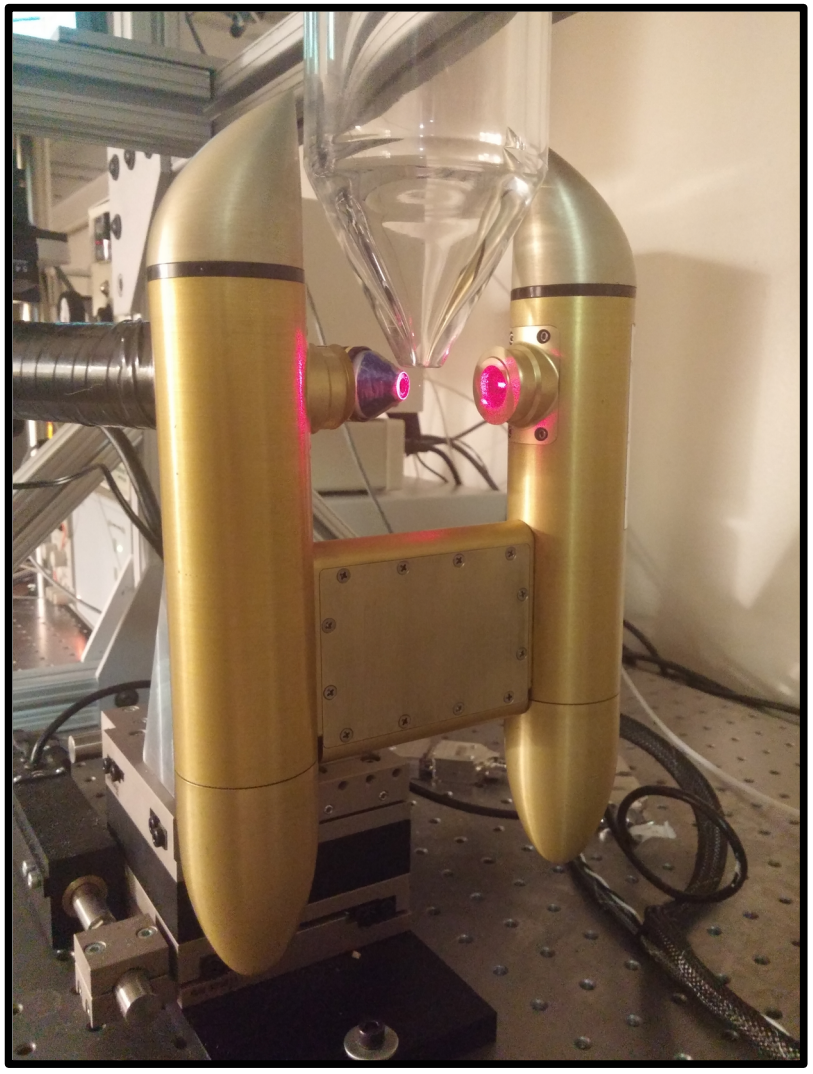
Sample Area for two Cloud Droplet Probes (CDPs)

David Delene

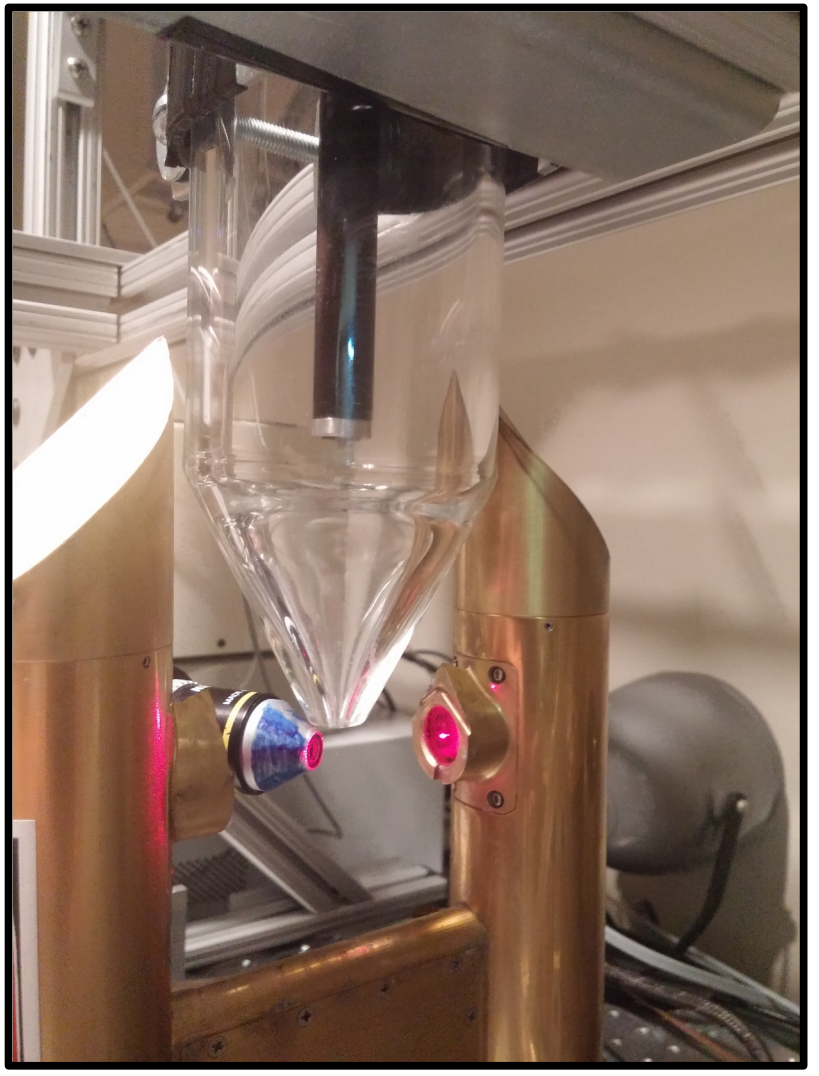
University of North Dakota



UND-CDP (SN 0901-48)

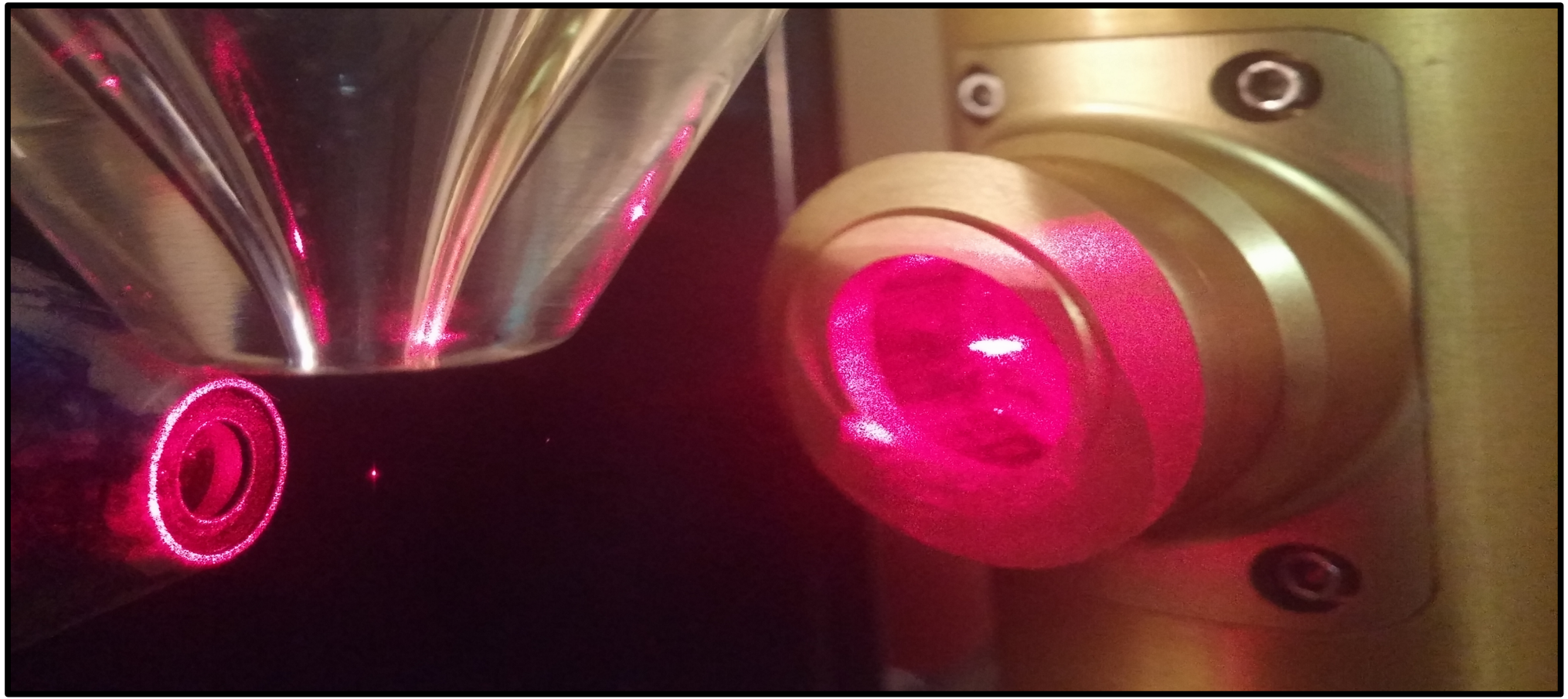


WMI CDP (SN 1406-085)



Typical Sample Area

Cloud droplet probe manual (DOC-0029, Revision M, page 8) states the sample area is **0.24 mm²**.



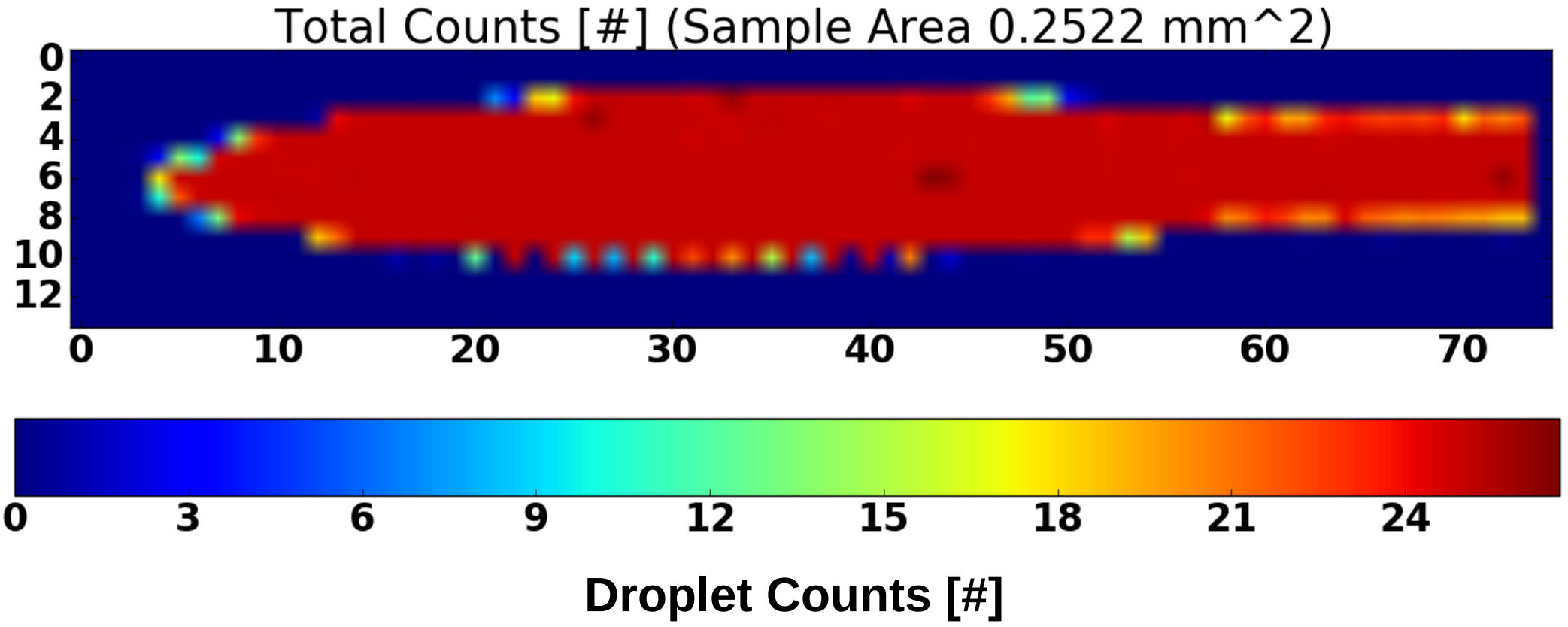
Instrument Comparison Table

	UND Probe			WMI Probe		
Size [um]	**X Dimension**	**Y Dimension**	**Offset**	**X Dimension**	**Y Dimension**	**Offset**
15	74	13	2	74	13	3
28/30	68	13	3	80	15	2
40	74	13	3	74	13	3

convert_cdp2nasa.py
process_MotionControl
convert_MotionControl2nasa.py
cdp_samplevolume.py

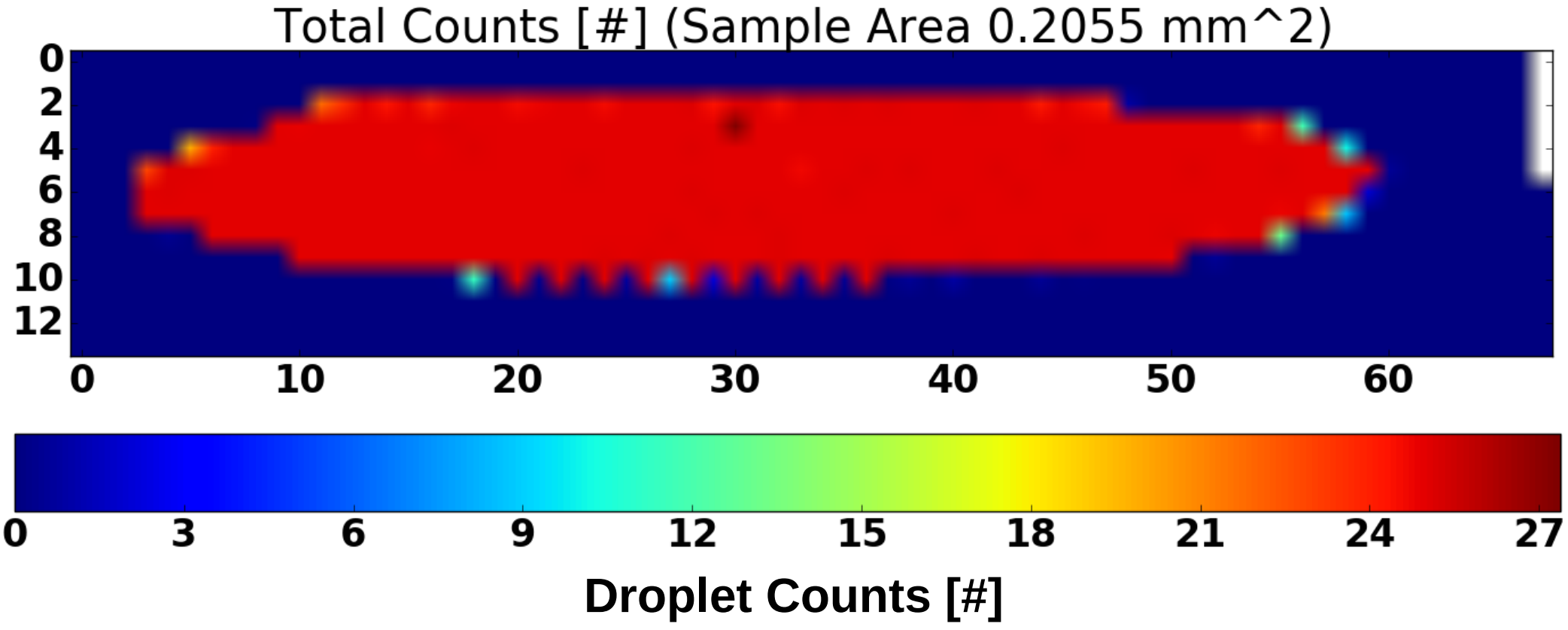
UND-CDP ~15 um Droplets

Sample area defined as greater than 50 % of maximum total counts.
The pixel area is 507.38 um^2.



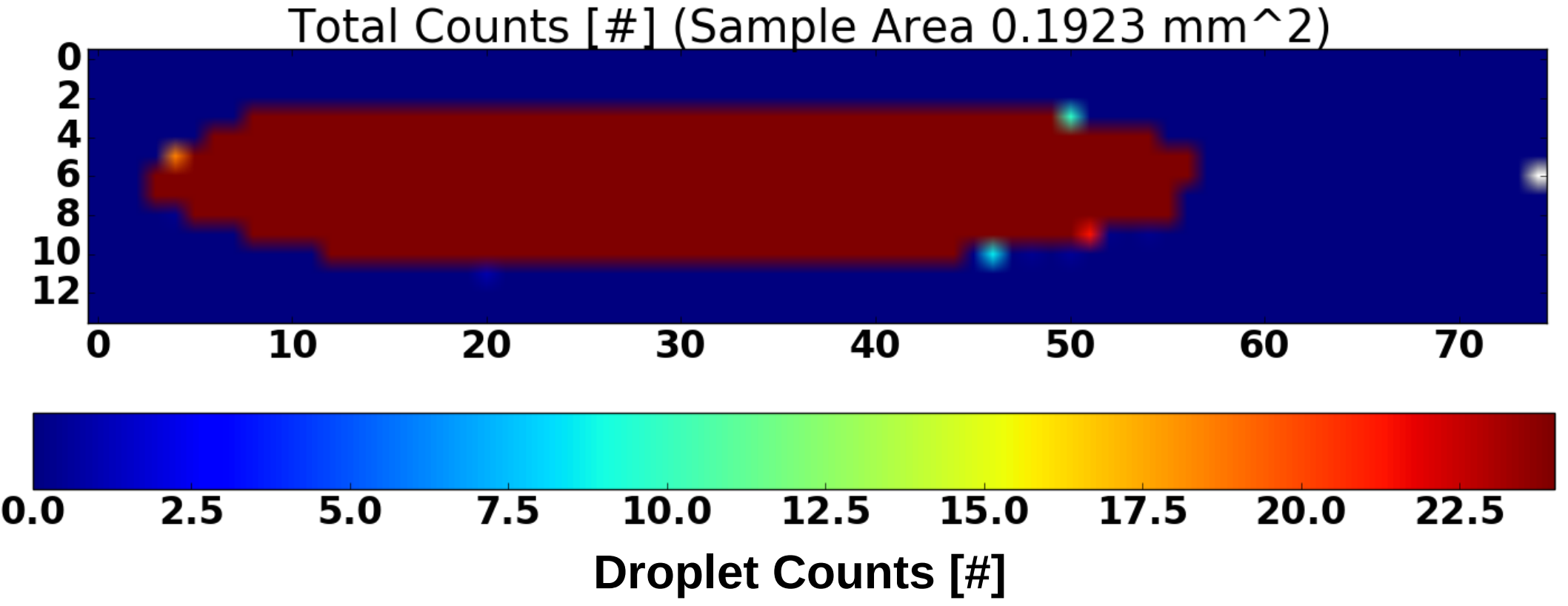
UND-CDP ~28 um Droplets

Sample area defined as greater than 50 % of maximum total counts.
The pixel area is 507.38 um^2.



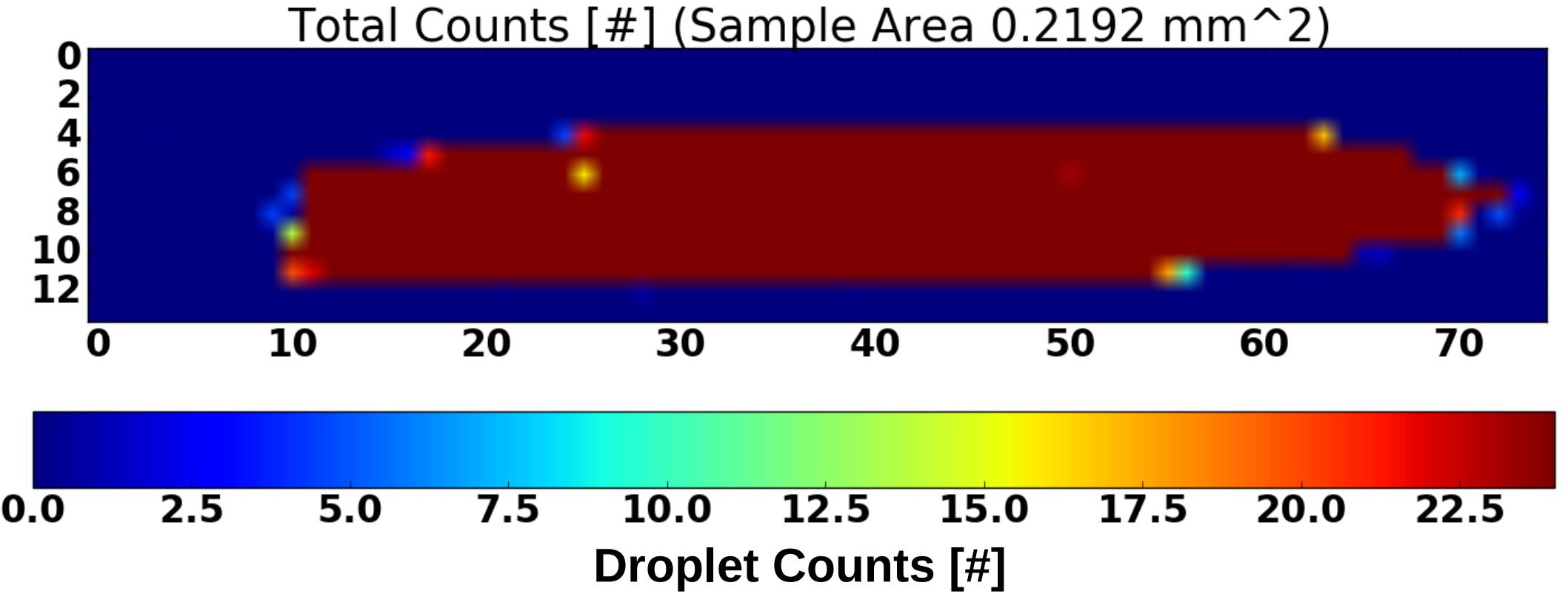
UND-CDP ~40 um Droplets

Sample area defined as greater than 50 % of maximum total counts.
The pixel area is 507.38 um^2.



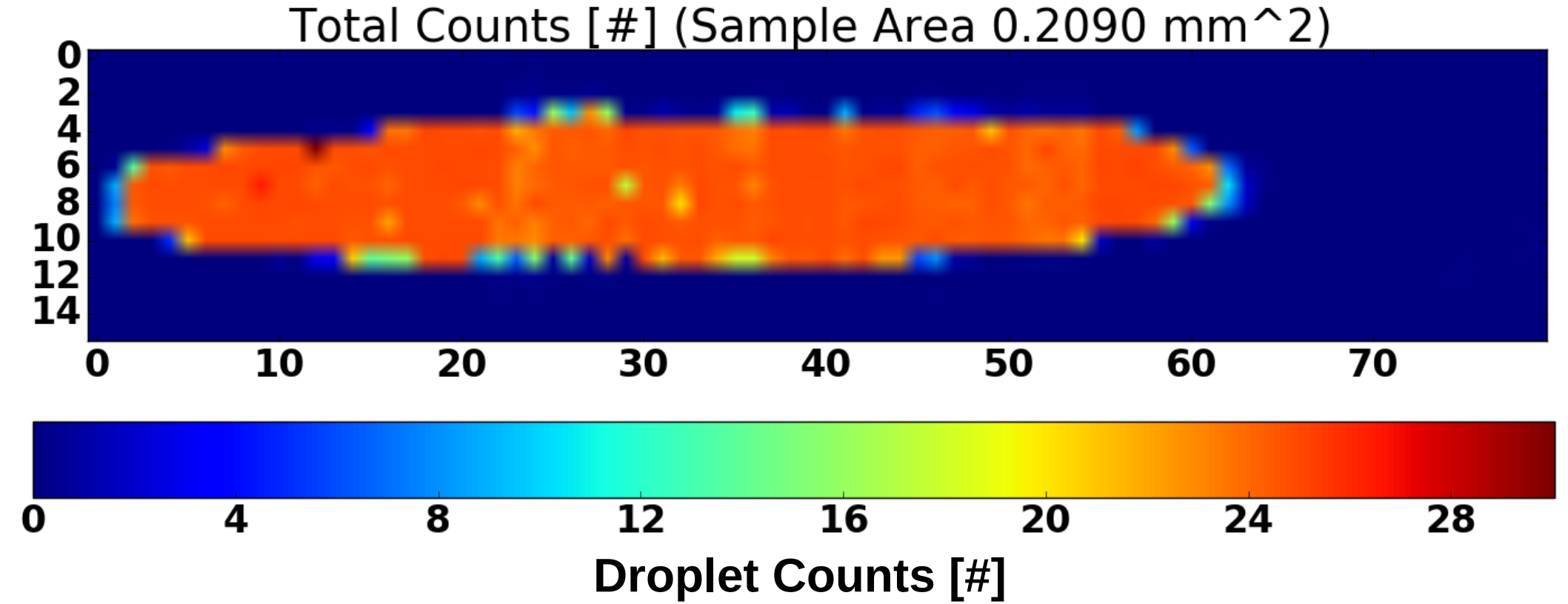
WMI-CDP ~15 um Droplets

Sample area defined as greater than 50 % of maximum total counts.
The pixel area is 507.38 um^2.



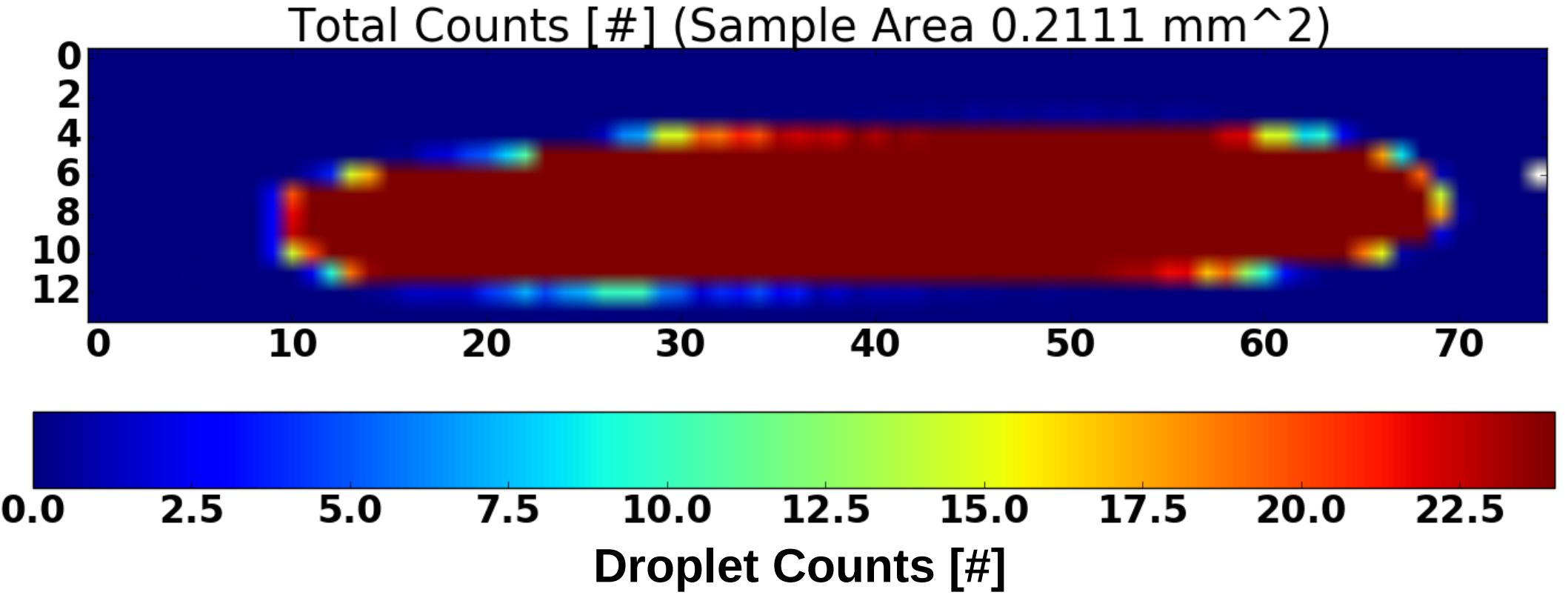
WMI-CDP ~30 um Droplets

Sample area defined as greater than 50 % of maximum total counts.
The pixel area is 507.38 um^2.



WMI-CDP ~40 um Droplets

Sample area defined as greater than 50 % of maximum total counts.
The pixel area is 507.38 um^2.



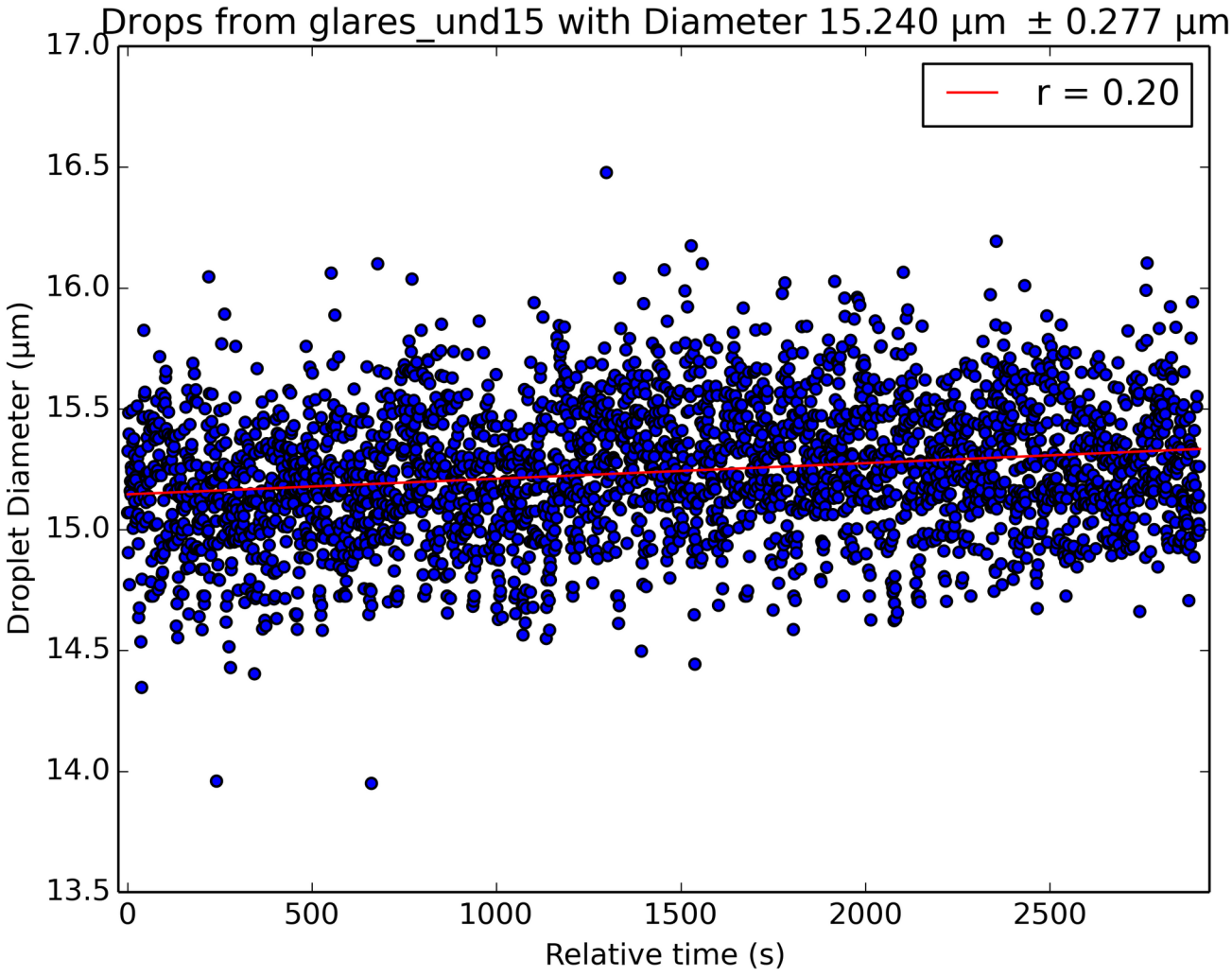
Instrument Measured Sample Area

	UND Probe		WMI Probe	
Size [um]	**Sample Area**	**Relative Error**	**Sample Area**	**Relative Error**
15	0.2522 mm^2	4.8 %	0.2192 mm^2	9.5 %
28/30	0.2055 mm^2	16.8 %	0.2090 mm^2	14.8 %
40 um	0.1923 mm^2	24.8 %	0.2111 mm^2	13.7 %

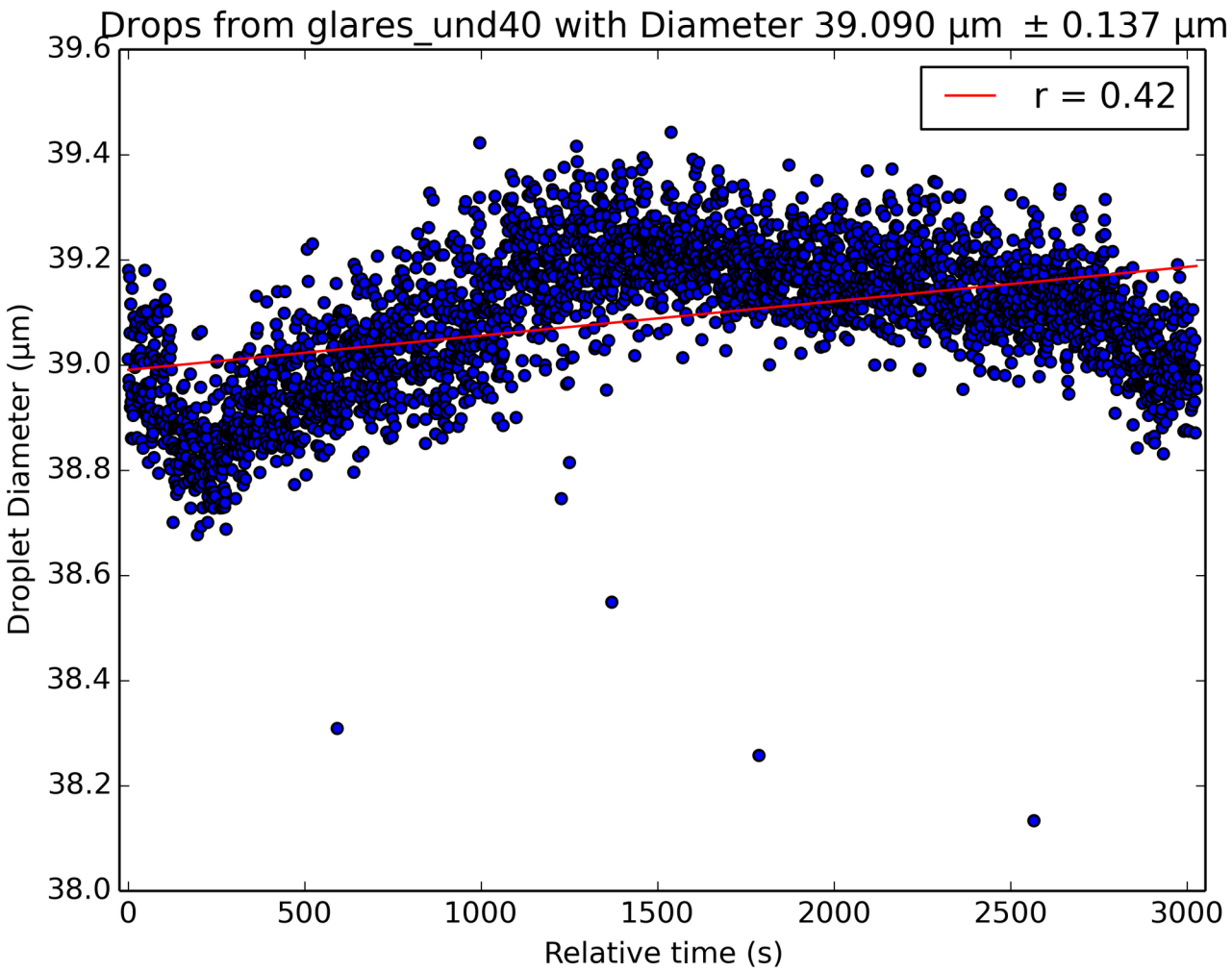
Drop Size Estimated from Glares Photographs

- Program: PixelWidth_Multi.py
- Takes a date and time and calculates the width of each drop based on the whiteness bands in the image.
- The mean and standard deviation are then calculated, and a plot of the overall data is produced, along with a linear regression line.

Glares Photographs Drop Size



Glares Photographs Drop Size



Processing Method and Software

https://adpaa.sourceforge.io/wiki/index.php/.:cdp:Lab

Scripts

convert_cdp2nasa.py
process_MotionControl
convert_MotionControl2nasa.py
cdp_samplevolume.py

Image Processing

PixelWidth_Multi.py