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Polarized Imaging Nephelometer for Field and Aircraft Measurements of Aerosol Phase Matrix Elements

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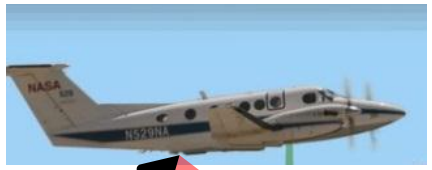
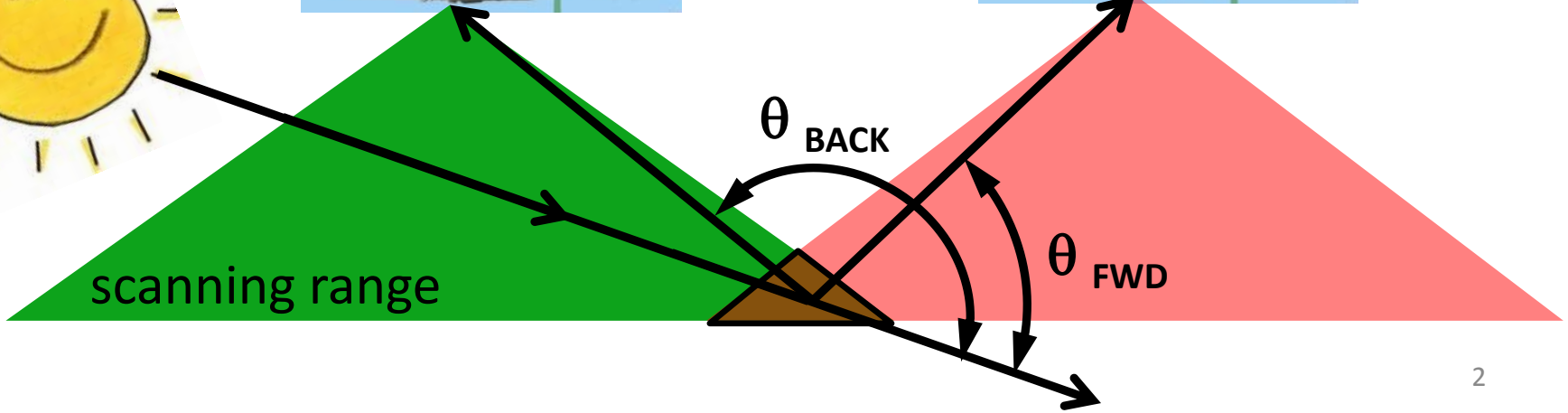
Light Scattering and Remote Sensing

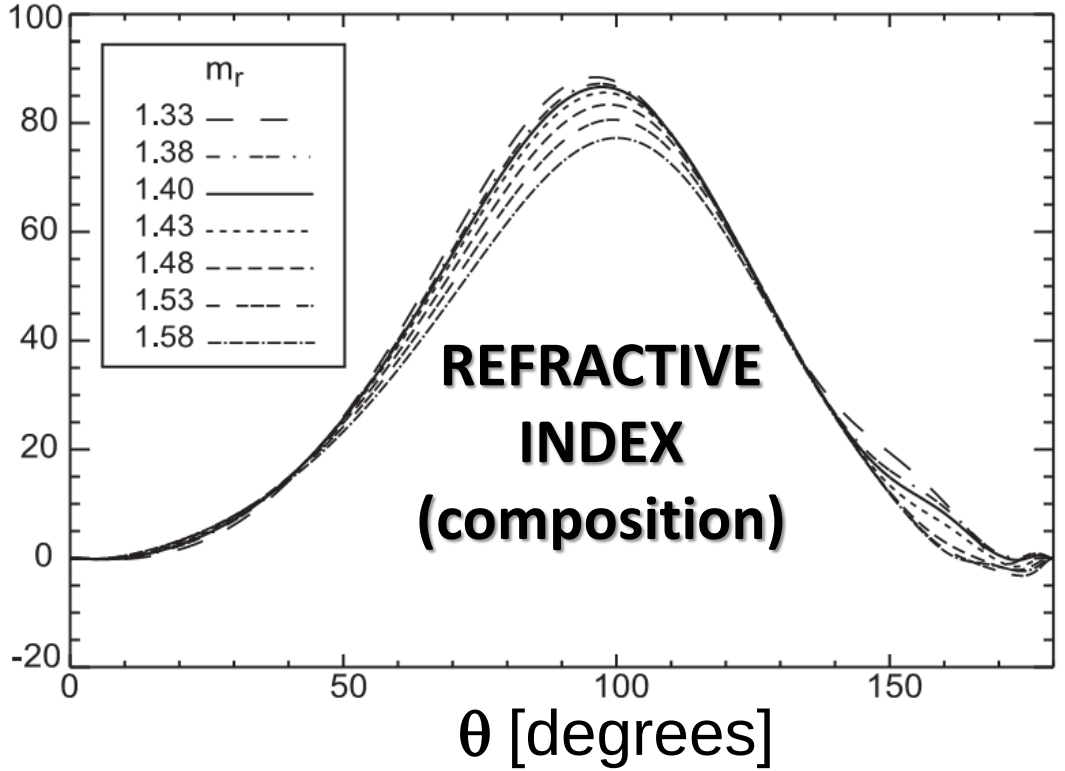


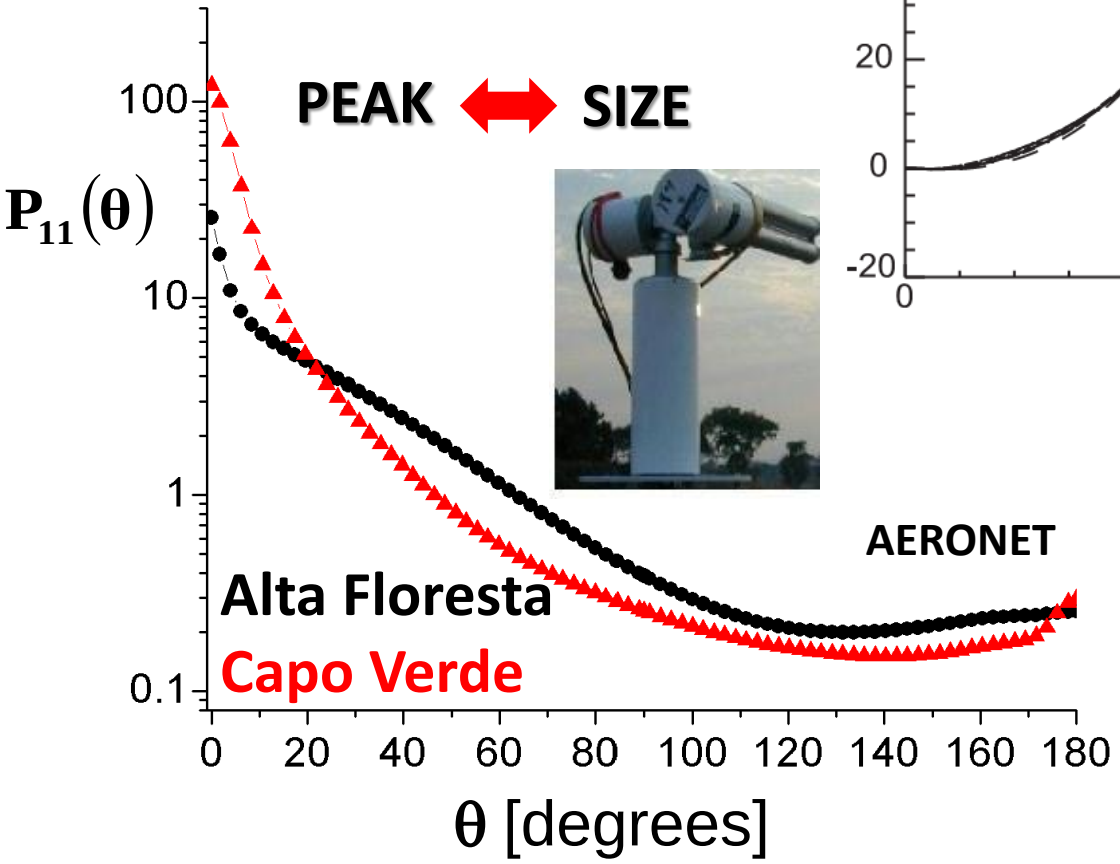


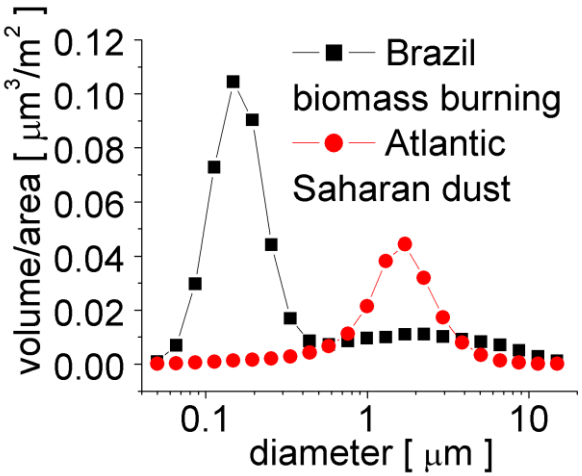
P11, P12 Measurement Motivation

$$-\frac{P_{12}(\theta)}{P_{11}(\theta)}$$

Boesche, et al, 2006, Applied Optics







Scattering Matrix

$$\begin{pmatrix} I_{sca}(\theta) \\ Q_{sca}(\theta) \\ U_{sca}(\theta) \\ V_{sca}(\theta) \end{pmatrix} = \frac{\sigma \cdot \Delta V}{4\pi \cdot r^2} \cdot \overline{\overline{P(\theta)}} \cdot \begin{pmatrix} I_{in} \\ Q_{in} \\ U_{in} \\ V_{in} \end{pmatrix}$$

$$\begin{pmatrix} \mathbf{P_{11}(\theta)} & \mathbf{P_{12}(\theta)} & \mathbf{0} & \mathbf{0} \\ \mathbf{P_{12}(\theta)} & \mathbf{P_{22}(\theta)} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{P_{33}(\theta)} & \mathbf{P_{34}(\theta)} \\ \mathbf{0} & \mathbf{0} & \mathbf{-P_{34}(\theta)} & \mathbf{P_{44}(\theta)} \end{pmatrix}$$

$$\begin{pmatrix} I_{in}(\Psi) \\ Q_{in}(\Psi) \\ U_{in}(\Psi) \\ V_{in}(\Psi) \end{pmatrix}$$

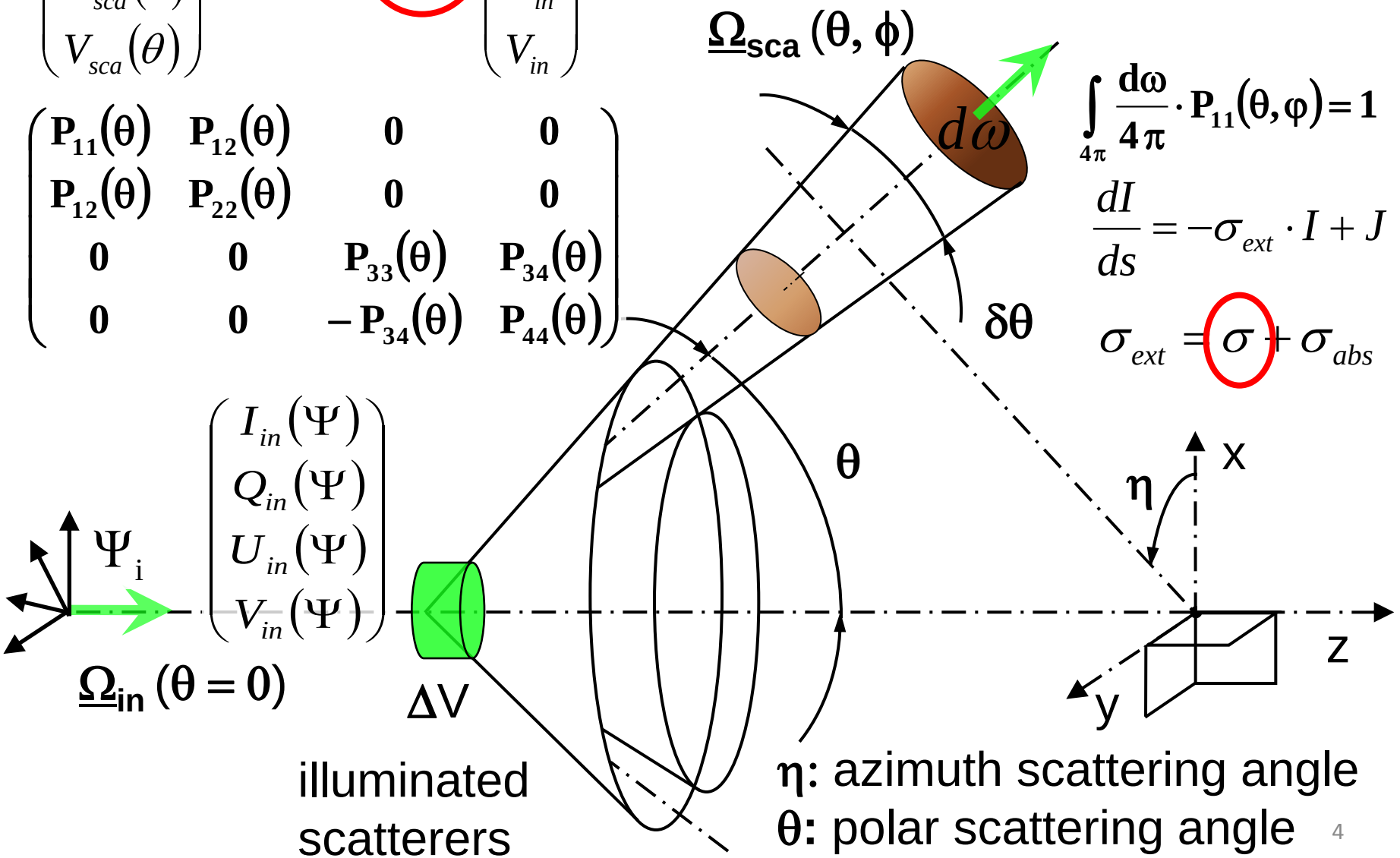
$\underline{\Omega}_{sca}(\theta, \phi)$

$\underline{\Omega}_{in}(\theta = 0)$

$$\int_{4\pi} \frac{d\omega}{4\pi} \cdot \mathbf{P_{11}}(\theta, \varphi) = \mathbf{1}$$

$$\frac{dI}{ds} = -\sigma_{ext} \cdot I + J$$

$$\sigma_{ext} = \sigma + \sigma_{abs}$$

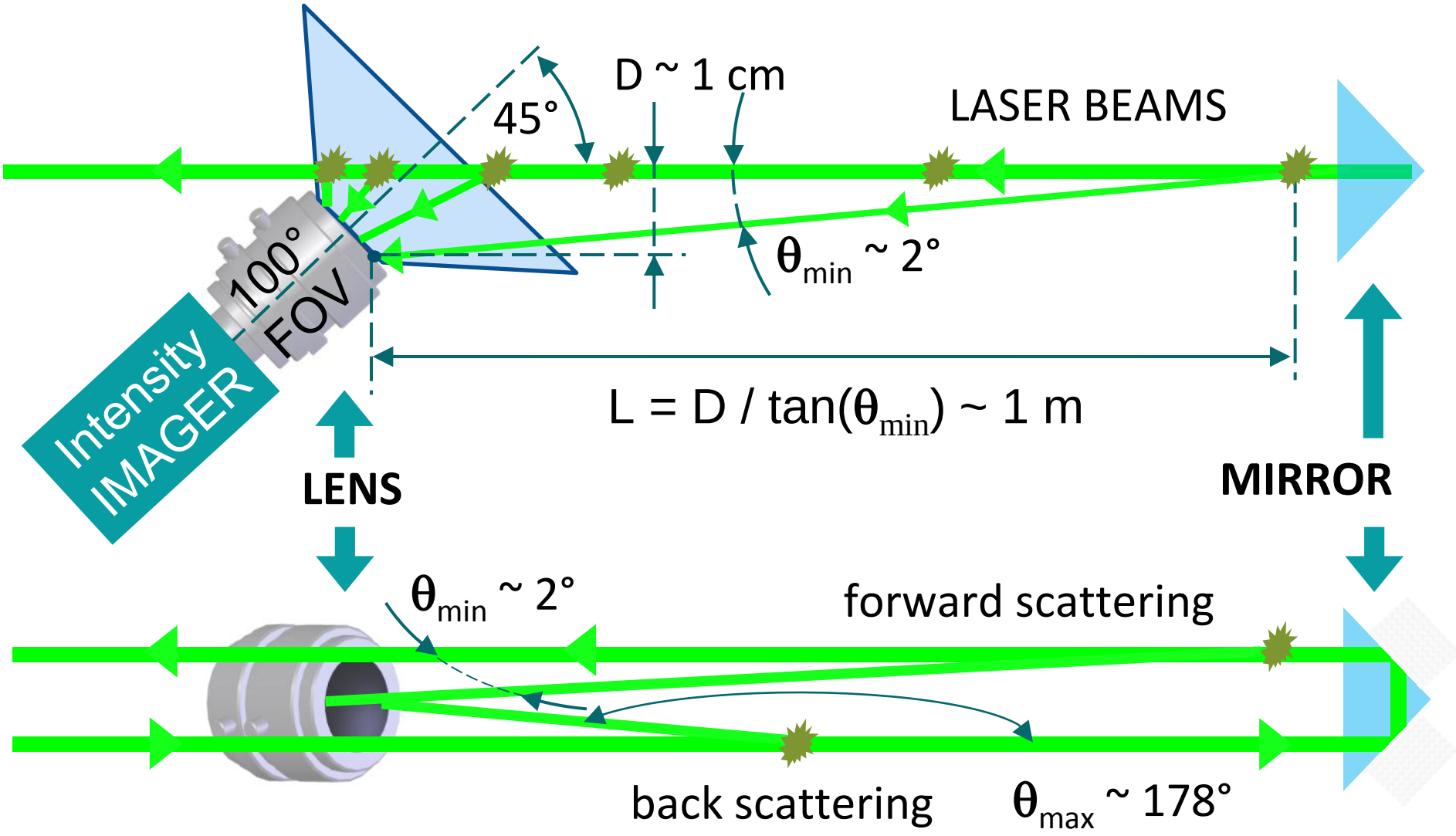


illuminated scatterers

η: azimuth scattering angle

θ: polar scattering angle

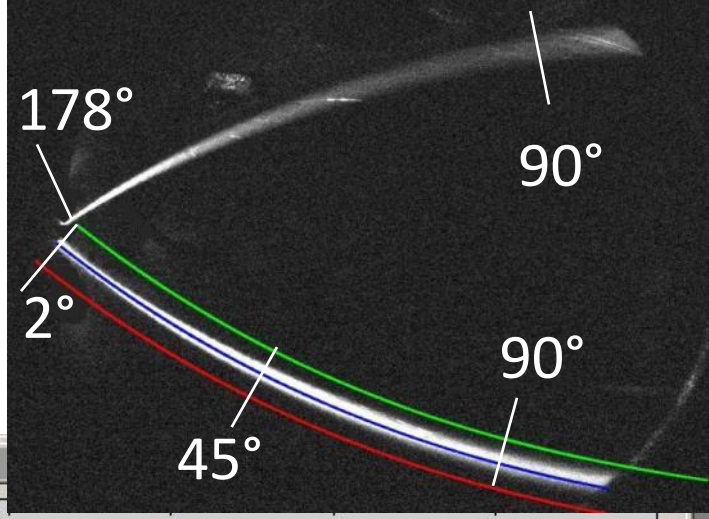
Polarized Imaging Nephelometer

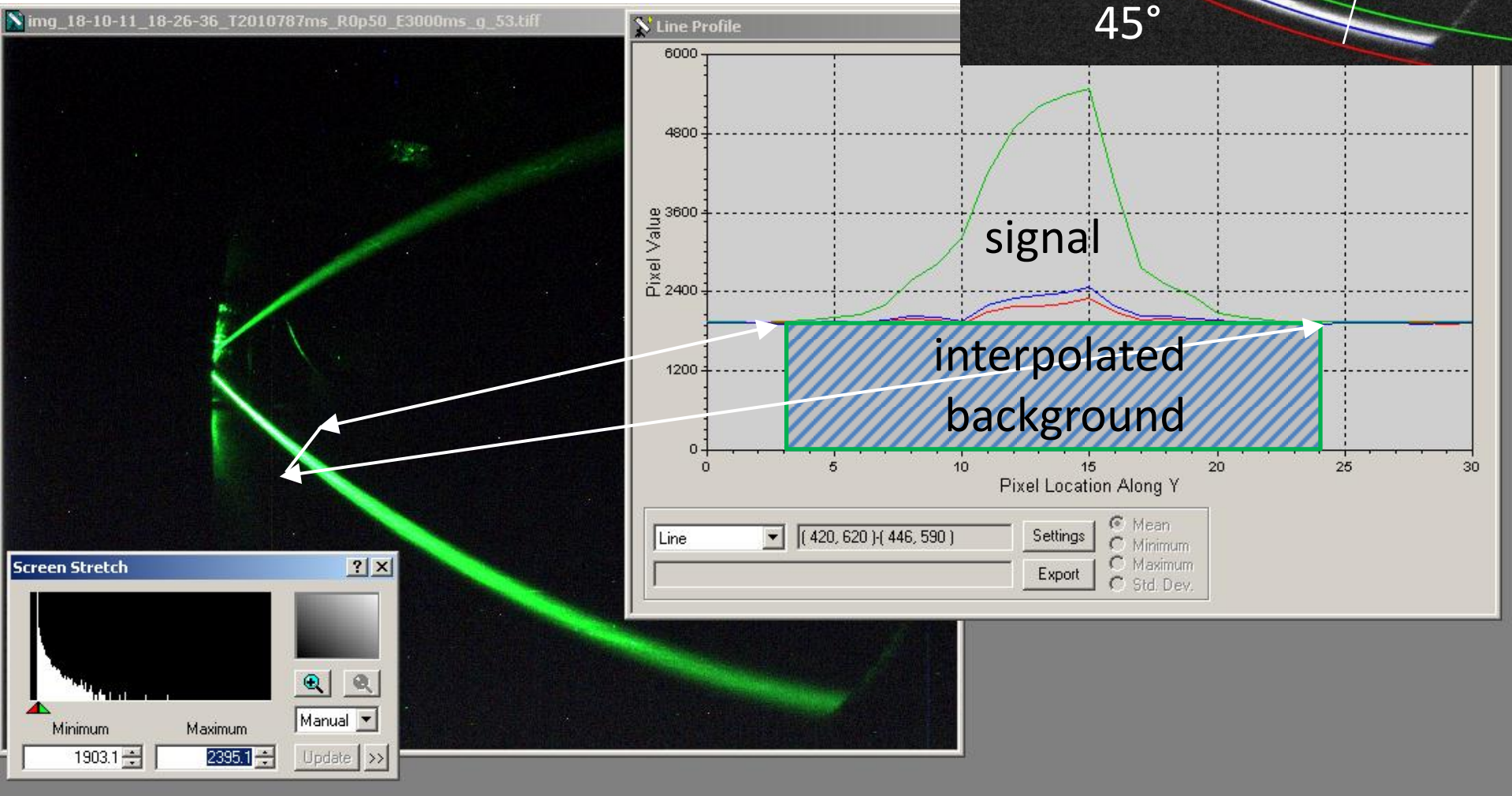


PI-Neph , Laboratory for Aerosols, Clouds and Optics (LACO)

Image Data Reduction

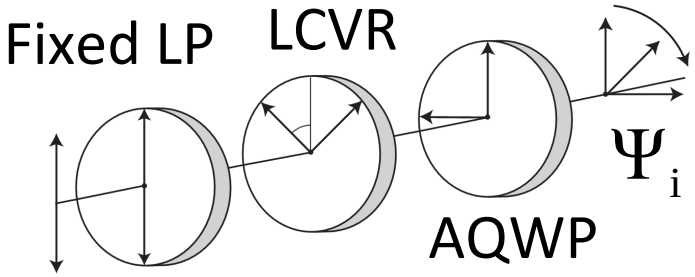
RGB image: Green channel >> Red or Blue
signal = (total area) – (interpolated background)

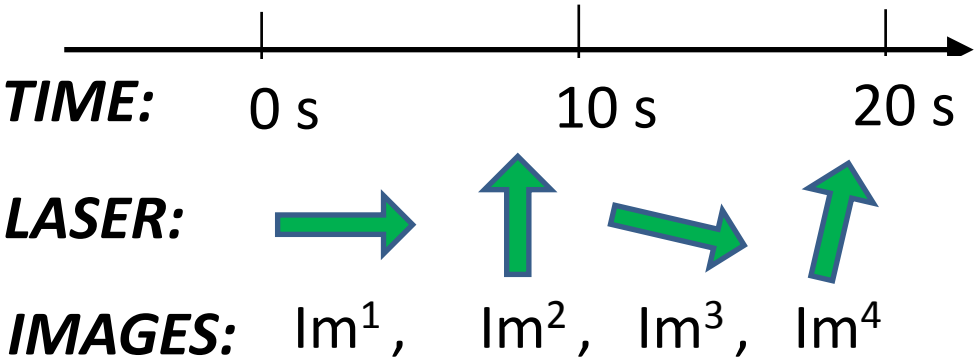




Measurement equation

532 nm (473, 671)
150 mW CW DPSS

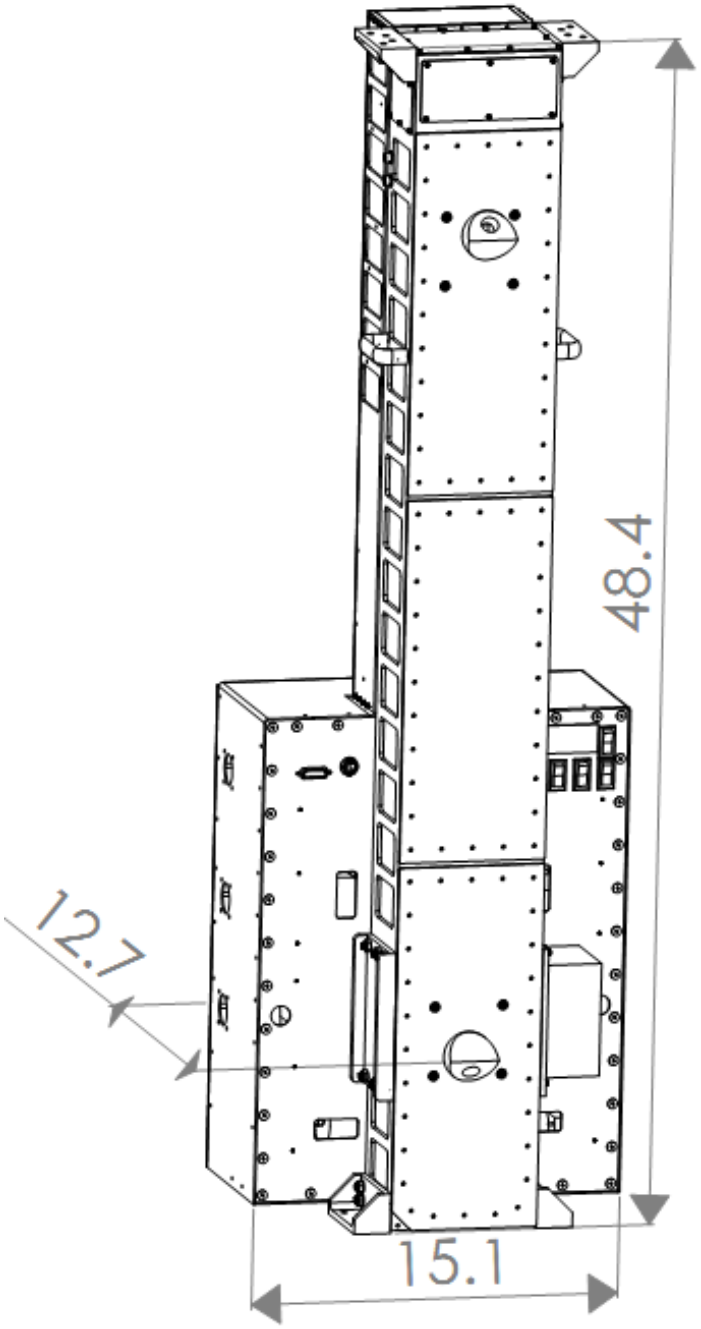




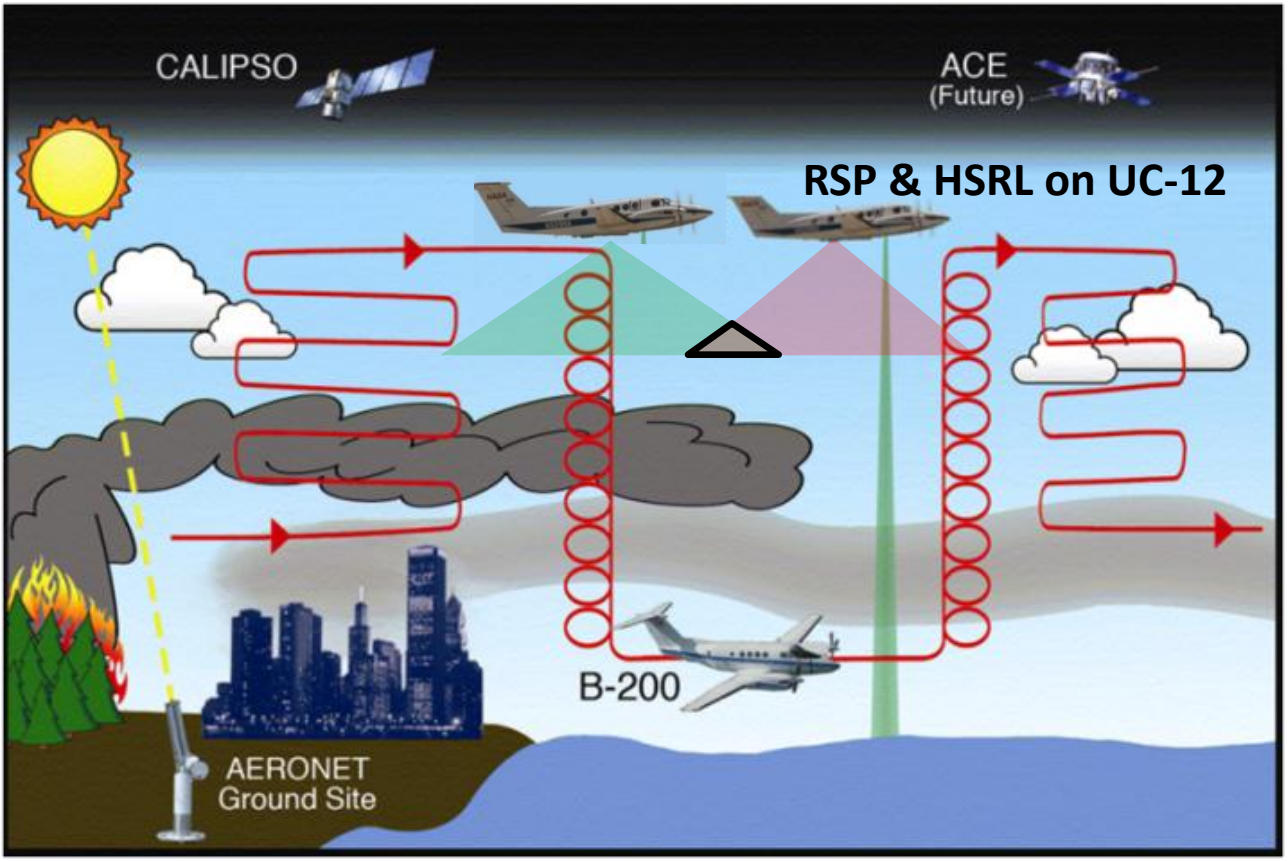
$$\sigma \cdot \overline{\overline{P(\theta)}} \cdot \begin{pmatrix} I_{in} \\ Q_{in}^{\Psi_i}(\theta) \\ U_{in}^{\Psi_i}(\theta) \\ V_{in} \end{pmatrix} = \sigma \cdot \begin{pmatrix} I_{in} \cdot P_{11}(\theta) + Q_{in}^{\Psi_i}(\theta) \cdot P_{12}(\theta) \\ I_{in} \cdot P_{12}(\theta) + Q_{in}^{\Psi_i}(\theta) \cdot P_{22}(\theta) \\ U_{in}^{\Psi_i}(\theta) \cdot P_{33}(\theta) + V_{in}^{\Psi_i} \cdot P_{34}(\theta) \\ -U_{in}^{\Psi_i}(\theta) \cdot P_{34}(\theta) + V_{in}^{\Psi_i} \cdot P_{44}(\theta) \end{pmatrix}$$

$$I_{in} \cdot (\sigma \cdot P_{11}(\theta)) + Q_{in}^{\Psi_i}(\theta) \cdot (\sigma \cdot P_{12}(\theta)) = SIG_{\mathrm{Im}^i}(\theta)$$

$$\begin{bmatrix} I_{in} & Q_{in}^{\Psi_1}(\theta) \\ I_{in} & Q_{in}^{\Psi_2}(\theta) \end{bmatrix} \cdot \begin{bmatrix} (\sigma \cdot P_{11}(\theta)) \\ (\sigma \cdot P_{12}(\theta)) \end{bmatrix} = \begin{bmatrix} SIG_{\mathrm{Im}^1}(\theta) \\ SIG_{\mathrm{Im}^2}(\theta) \end{bmatrix}$$

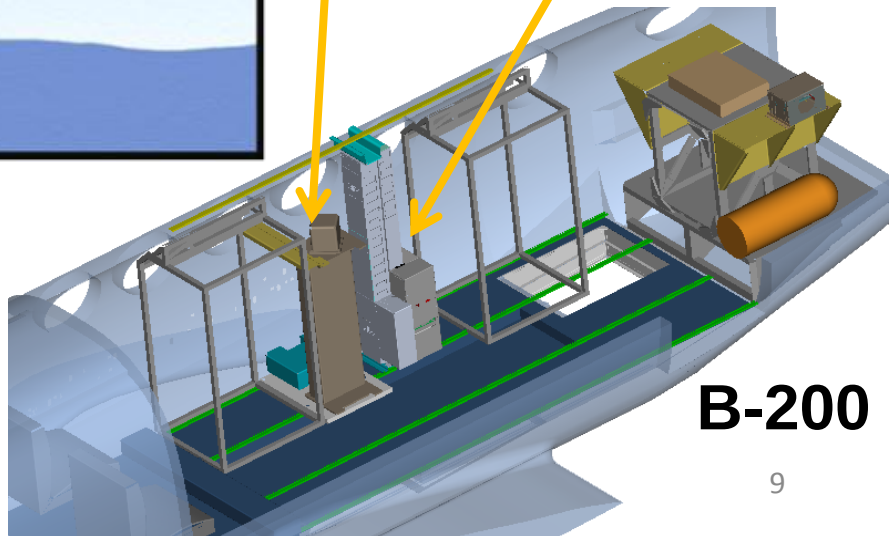

48.4
12.7
15.1

DEVOTE Flights



TSI-Neph

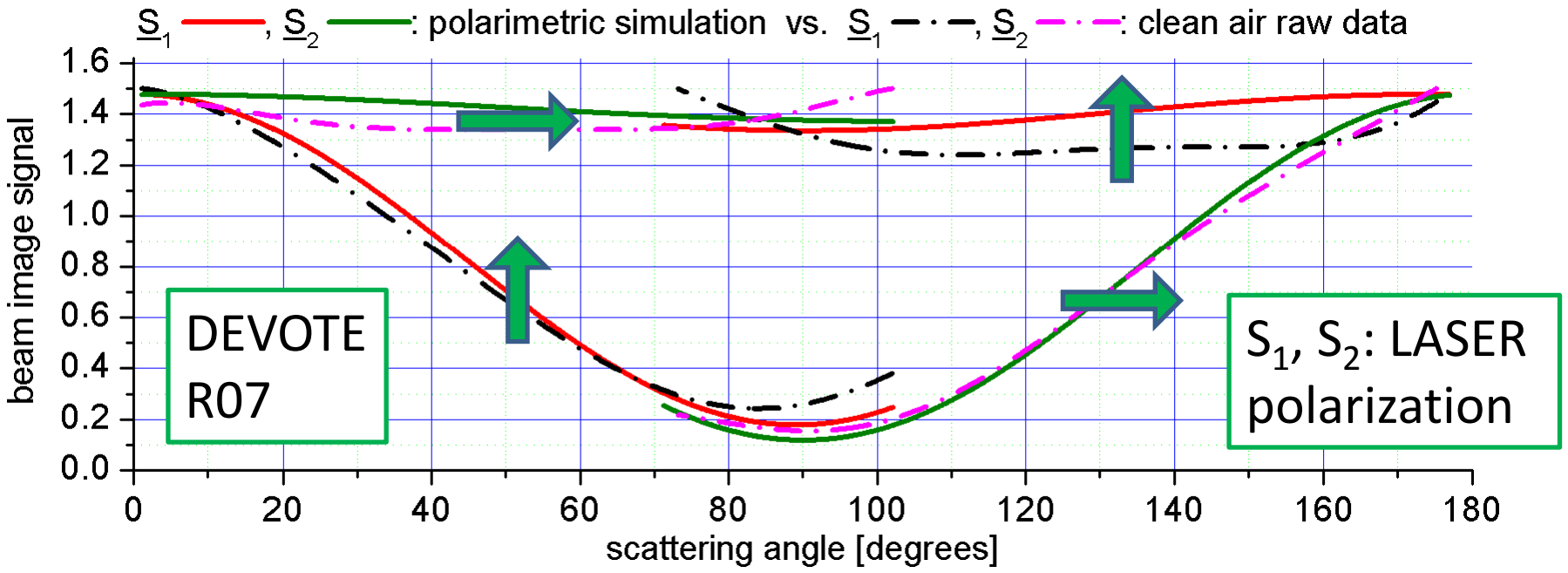
PI-Neph

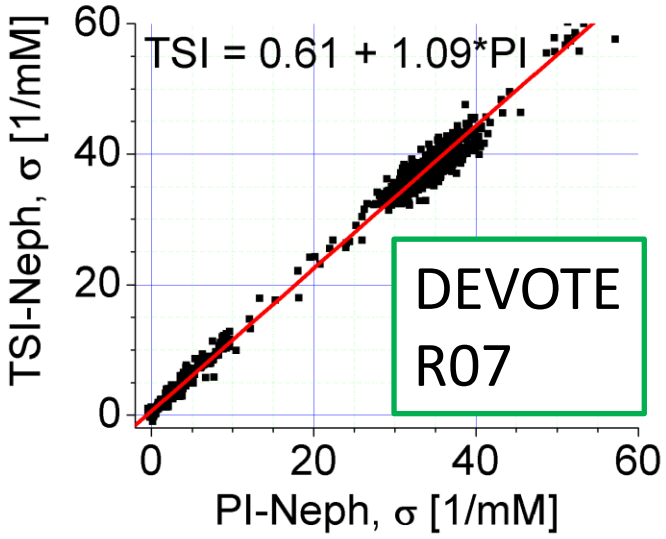


B-200

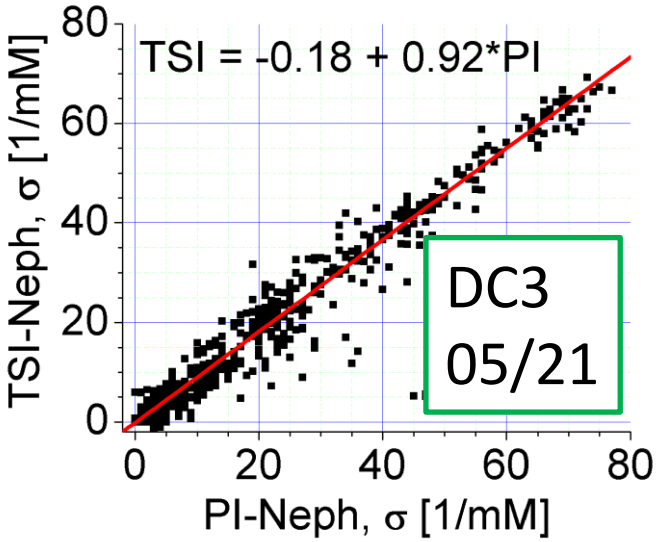
In-situ and remote sensing aircraft
11 coordinated flights total 35 hours
16 spirals over AERONET sites

Rayleigh Calibration & Volume Scattering

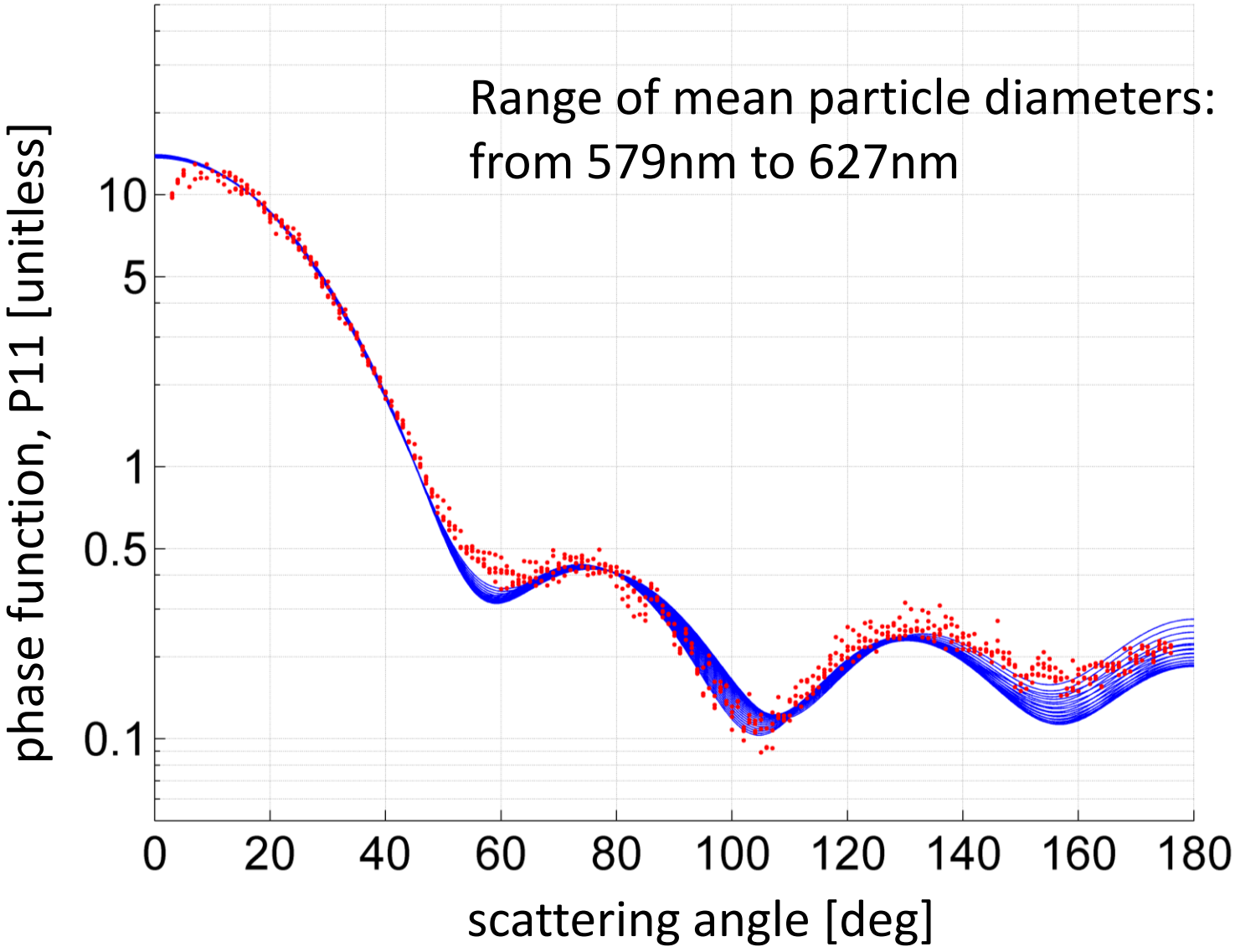




TSI data courtesy of LARGE group.
3 wavelength data interpolated with Angstrom formula to 532 nm

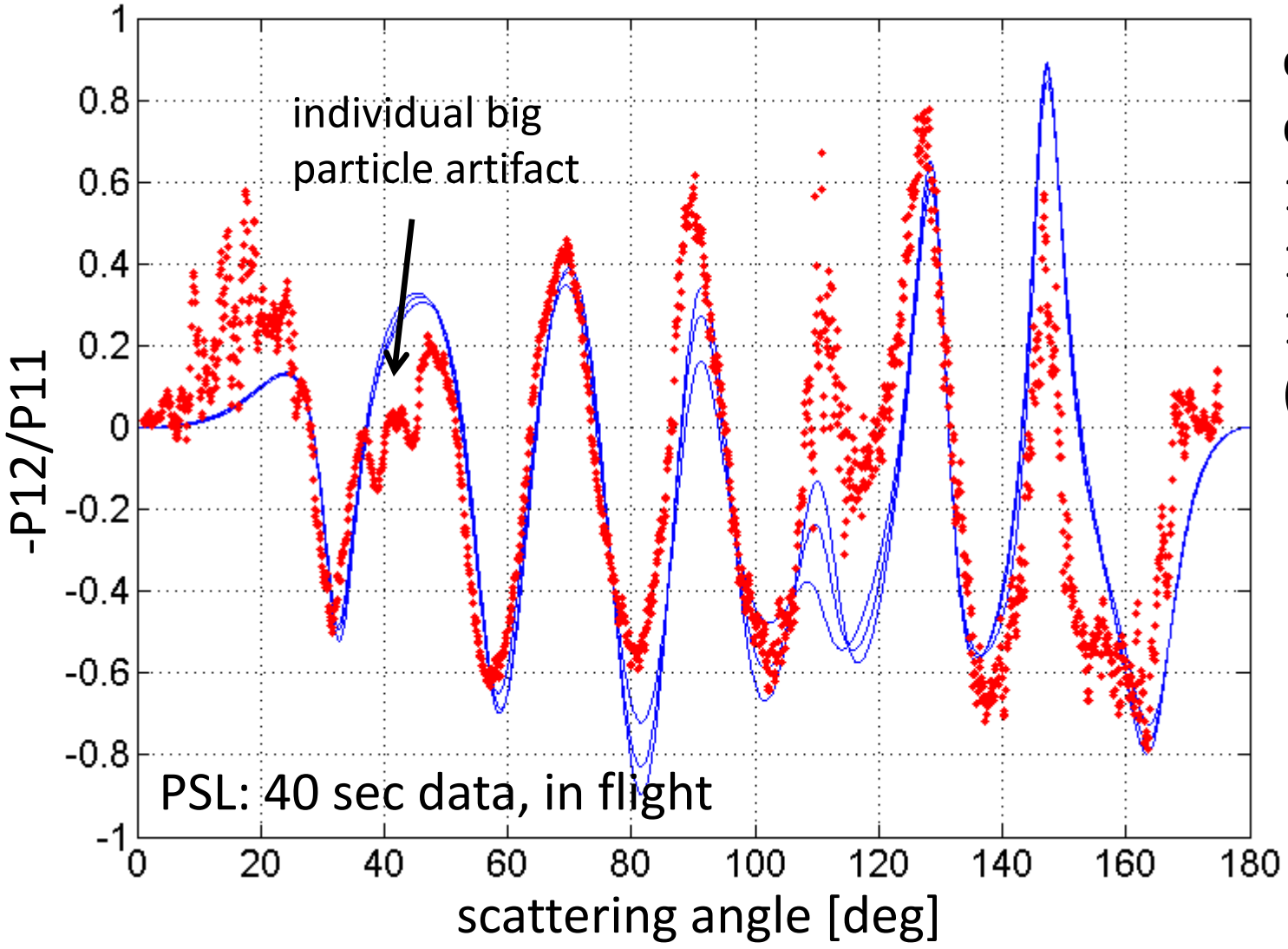


P11 PSL sphere data vs. Mie theory



preliminary results before application of final calibration

P12 PSL sphere data vs. Mie theory



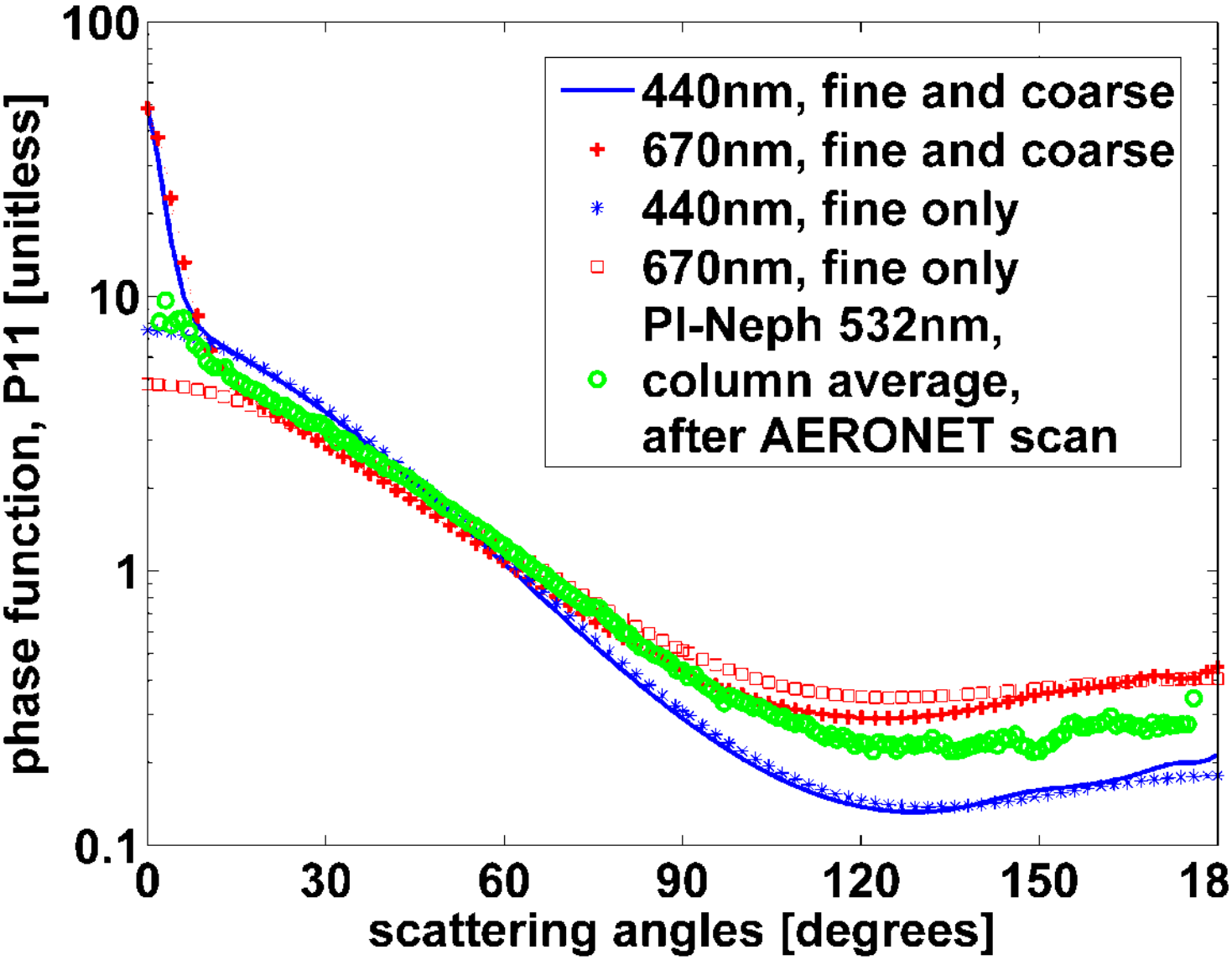
center diameters :
1354 nm
1359 nm
1363 nm
(blue curves)

preliminary results before application of final calibration

PSL sphere data vs. Mie theory

- Data from DEVOTE, 2011, October
- In flight experiments by LARGE group
- PSL (polystyrene latex) spheres, properties:
  index of refraction = 1.5987
  STDEV of SD = 4nm
  nebulized from water solution
  NIST traceable mean diameter range
- All calibrations are independent of the PSL measurements
- P12: Polarization pairs chosen with the polarization rotator result in better signal to noise of P12 in DC3 than in DEVOTE (analysis in progress). P12 is very sensitive to angular calibration and if one of the images used to derive P12 has a big particle, that will show up in the data as an artifact
- Fit to only **P12 constrains the mean size of PSL particles to a 10 nm interval**, better than usual electron microscopy and more than 5 times better than the specification by the manufacturer (NIST traceable)

Phase function vs. remote sensing



10/18/2011

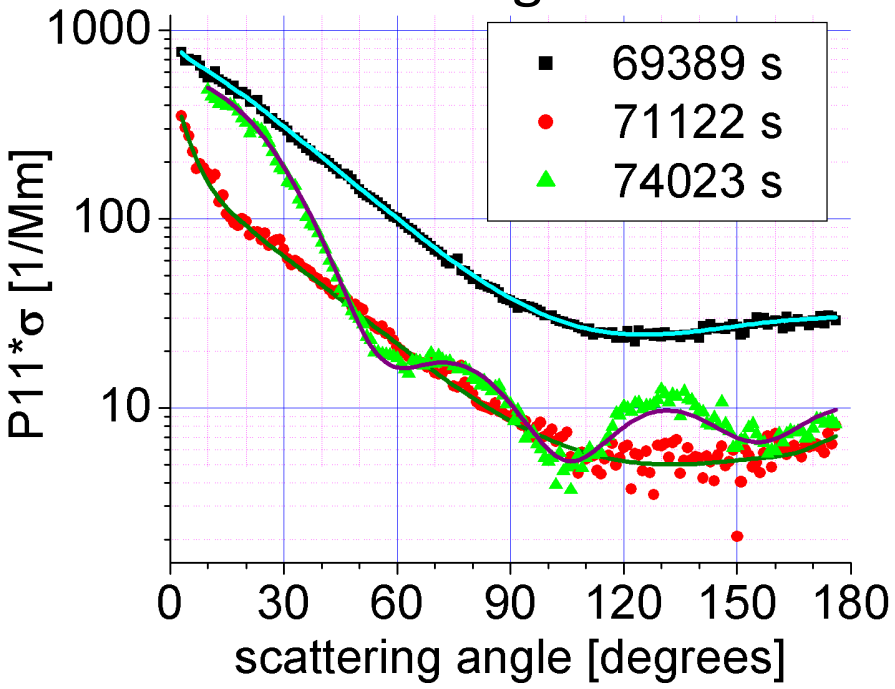
DEVOTE
Fligth R07

AERONET
at NASA
Wallops
Flight Facility

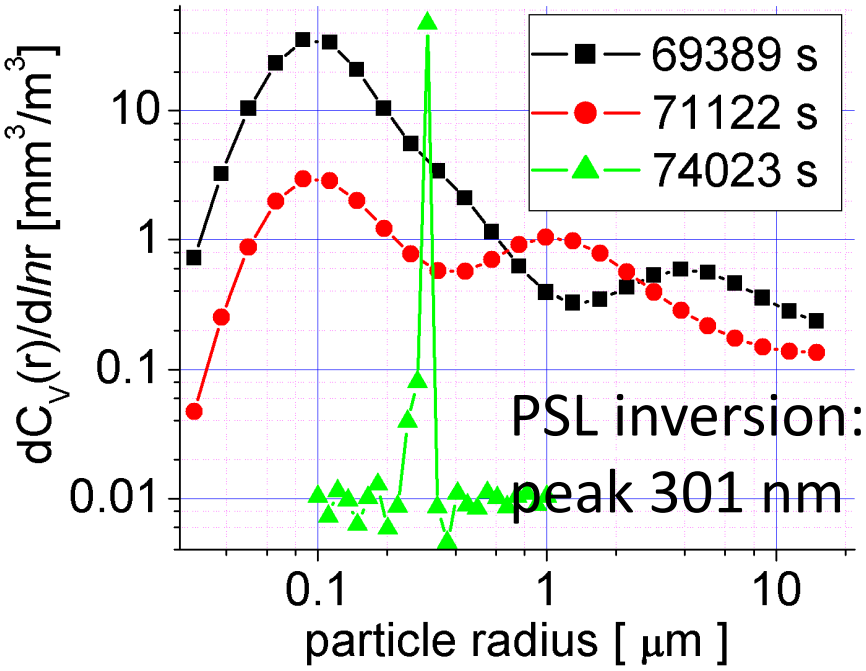
Inlet: RH and
size effects

Inversions of DEVOTE R04 data

30s scattering data and fits



inverted size distributions (SD)



UTC [s]	σ [Mm^{-1}]	SSA	n	k
69389	100	0.94	1.39	0.005
71122	25	0.86	1.60	0.023
74023	47	0.915	1.636	0.020

AERONET style, 25 size bins

1st and 2nd: biomass burning (?)

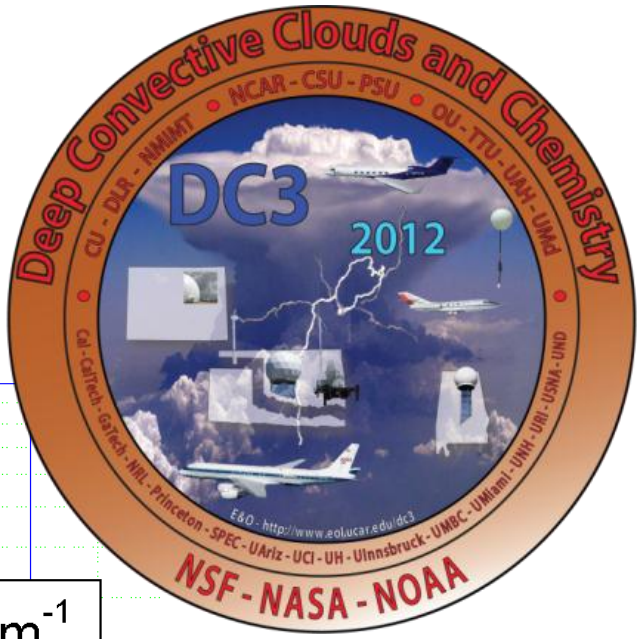
3rd: PSL, NIST < r > = (300±5)nm

n_{web}-$n_{retrieved}$ = 0.037 = Δn

n_{web}: http://refractiveindex.info/?group=PLASTICS&material=PS

$\Delta n_{required}$ = 0.02 Mishchenko, et al, JQSRT, 2004

DC3 campaign



120 hours in CO, AL and OK, below/around/above storms

74162 s, 17 Mm^{-1}

70728 s, 44 Mm^{-1}

71481 s, 64 Mm^{-1}

Examples of 30 sec data for various loadings

phase function, P11 [unitless]

10

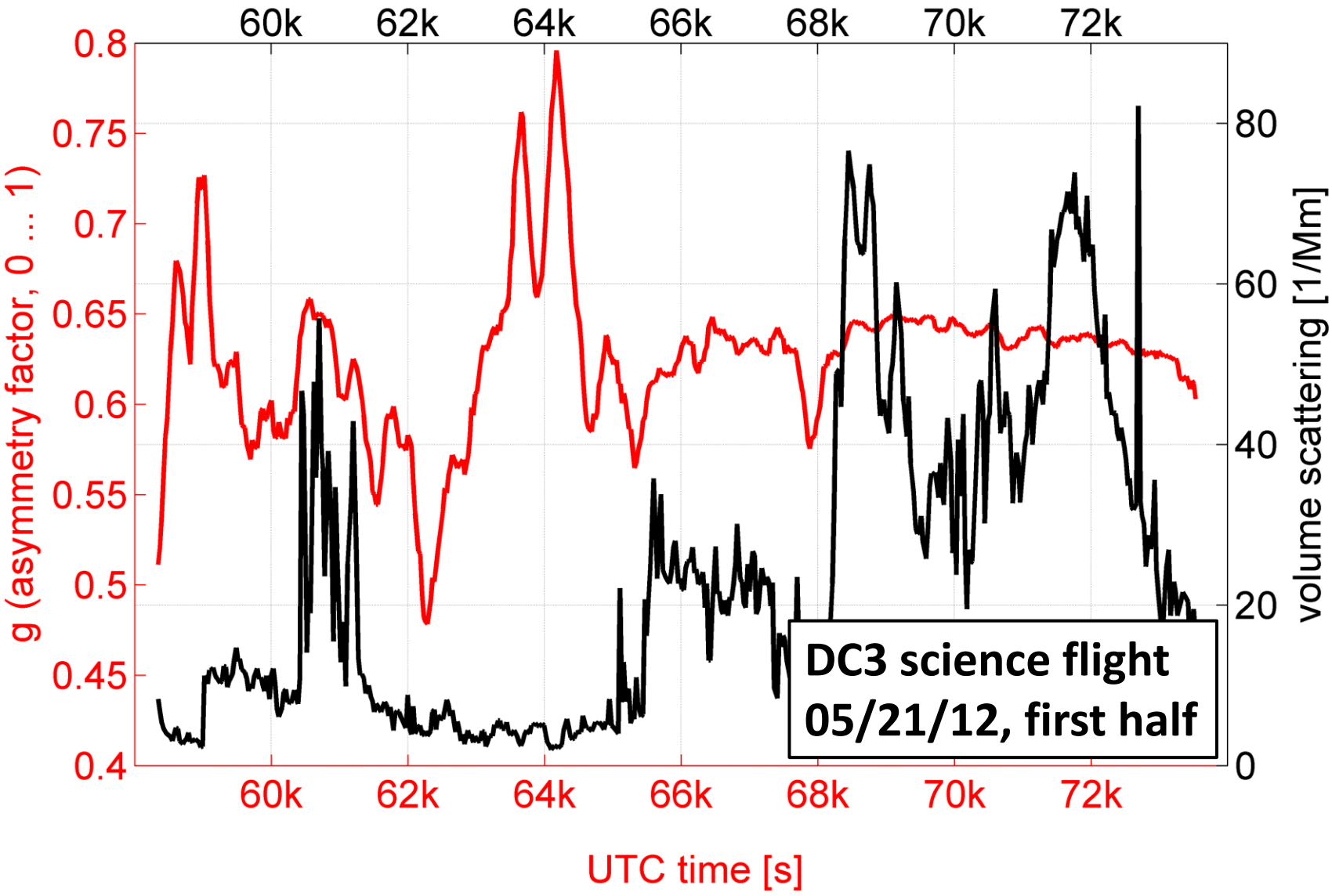
1

0.1

0 20 40 60 80 100 120 140 160 180

scattering angle [degrees]

Asymmetry factor: potential product



PI-Neph data products

Directly Measured:

- Phase function, P11
- Degree of linear polarization, P12
- Scattering angles: 1 to 178 deg by 1 deg
  (at times smaller range due to stray light)
- Volume scattering coefficient: 5 to 1000 1/Mm
- Asymmetry factor
- Lidar ratio

Retrieval Products

- Size distribution, 24 bins, AERONET type
- Index of refraction
  (real part is more accurate than imaginary part)

Website for data products

versus angle at each time: P11, -P12/P11

versus time: SCAT, P, T, RH ALT, LAT, LON

Science Flight 2

laco03.umbc.edu/pineph/new/data.php?group=dc3&flight=r02

Back

Optimized for Chrome & Firefox

Graph Time (Seconds)

- + 80527 sec

Mid time (UTC): 80527 sec

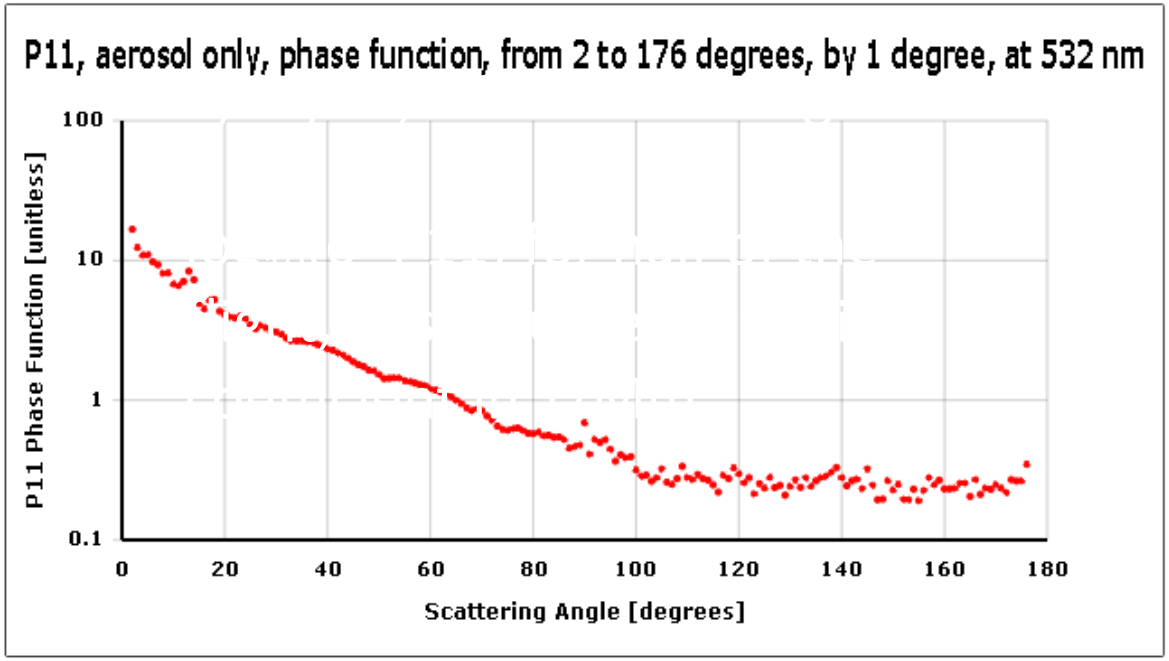
Start UTC: 80522 sec
End UTC: 80532 sec
HH:MM:SS UTC: 22:22:07

SCAT: 31.00 1/Mm
PRES: 58446.00 Pa
TEMP: 294.00 K

RH1 (Inlet): 8.00%
RH2 (Chamber): 3.00%
RH3 (Outlet): 5.00%

Aircraft Latitude: 34.039096°
Aircraft Longitude: -99.704296°
GPS Altitude: 5428.44 feet

DC3 - R02 | **Science Flight 2** | 2012-



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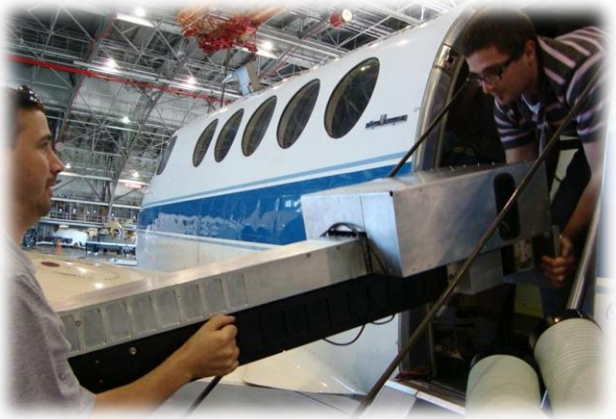
Plans

- Data website (under construction)
- Revise the flight data for DEVOTE and DC3
- Implement automatic real time data reduction and display
- Use DC3 data to establish aerosol P11 and P12 library for various types of aerosols
- Use Discover AQ data from January and February of 2013 to compare to AERONET retrievals in the Central Valley of California



Acknowledgments

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We thank the organizers and participants of the DEVOTE and DC3 field campaigns, being a contributing to the rich DC3 and DEVOTE dataset for instrument debut and validation.
We thank the LARGE group at NASA Langley Research Center, in particular Bruce Anderson, Luke Ziemba and Andreas Beyersdorf, for supporting our integration during both the DEVOTE and DC3 field campaigns, and for sharing their sample flow and resources. Without their help we would not have been able to fly in both the DEVOTE and DC3 field campaigns.
We thank Brent_Holben and Didier Tanre for their effort in maintaining the AERONET sites at NASA Wallops Flight Facility, Alta Floresta in Brazil and the Republic of Capo Verde
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