A Laboratory Experiment for the Statistical Evaluation of Aerosol Retrieval (STEAR) Algorithms

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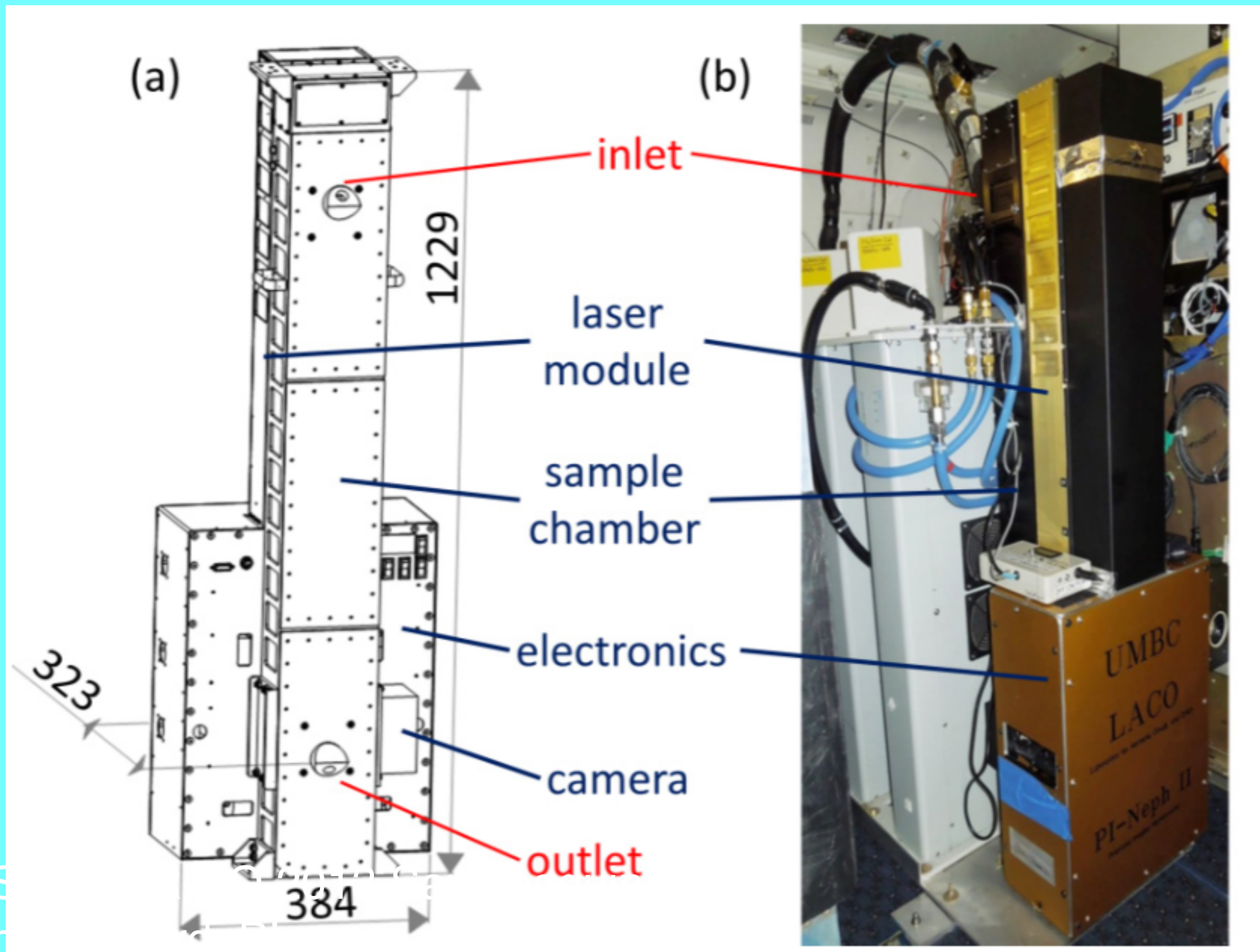
4. Universite de Lille 1/CNRS;
5. GRASP-SAS, Remote sensing developments;
6. California State University, San Bernardino, CA.

Acknowledgements

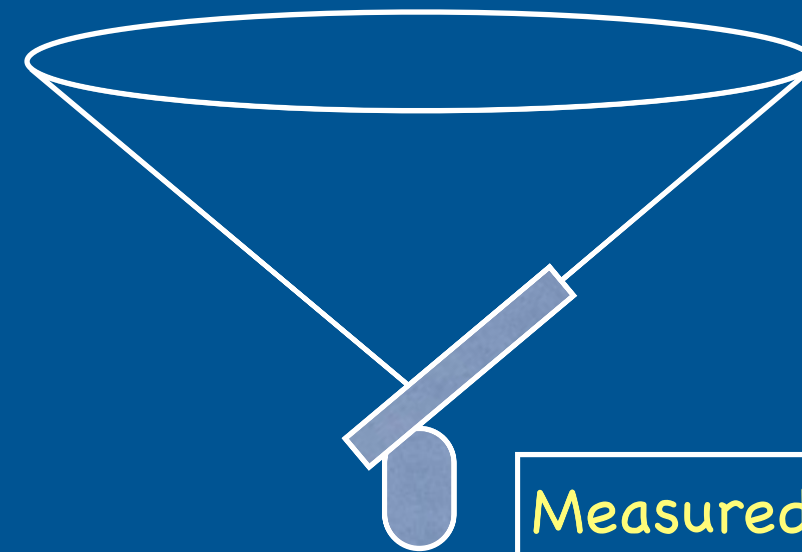
This material was supported by NASA through the ROSES Atmospheric Composition: Laboratory Research program, issued through the Science Mission Directorate, Earth Science Division.

The Difficulty of Validating AERONET Retrievals

STEAR is a laboratory experiment that
simulates AERONET radiances.



Polarized-Imaging Nephelometer (PI-Neph)
Dolgos and Martins (Optics Express, 2014)

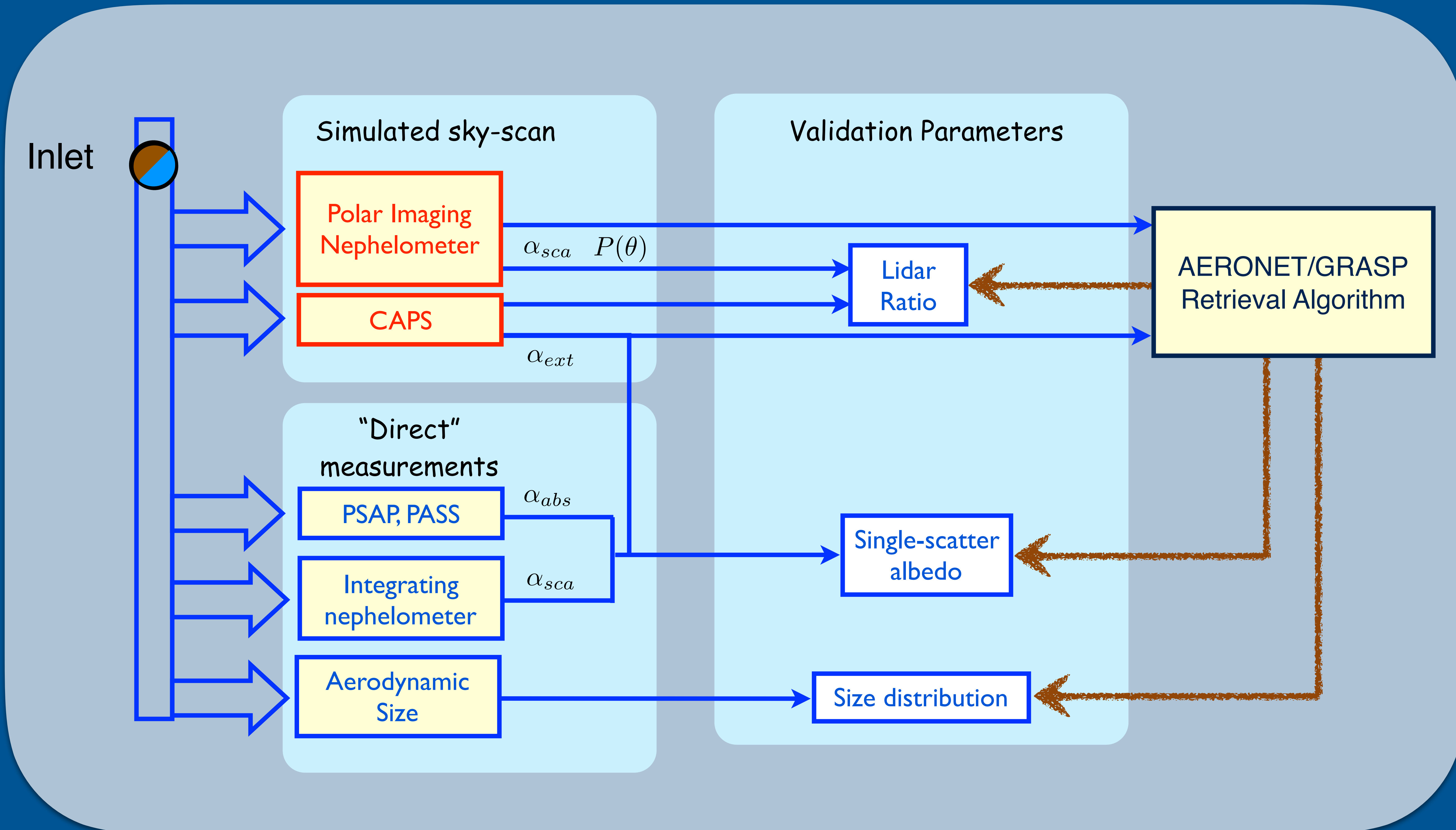


Measured Radiances

AERONET (or GRASP) retrieval
Dubovik & King (2000)
Dubovik (2000, 2006, 2008, 2011)

Volume size distribution
~~Complex refractive index~~
Single scatter albedo, AAOD, etc.

Simplified Schematic



CAPS: Cavity Attenuated Phase Shift monitor
PSAP: Particle Soot Absorption Photometer
PASS: Photoacoustic Soot Spectrometer

Tested 285 samples

Tests include humidified and dried runs for both PM1 and PM2.5.

Minerals
Hectorite
Hematite
Arizona Test Dust
Cambrianshale Imt-2
Saz-2 Ca-rich Montmorillonite
Illite-smectite
Na-Montmorillonite
Montmorillonite, STx-1b
Montmorillonite SCa-3
Israel, Negev Desert
Senegal
Ripidolite CCa-2
Palygorskite
Arginotec NX Europe
A1 ultrafine test dust
Silica Dust

Artist Pigments
Lemon Ocher
Yellow Ocher Light
Blue Ridge Hematite
Brown Ocher (Goethite)
Nicosia Yellow Ocher
Ambrogio Yellow Earth

Volcanic Ash
Mt. St. Helens
Fuego Volcano
Pinatubo
Iceland Volcano
Mt. St. Helens
Puyeheu
Spurr
Gulagong

Soot
Ashrae #2
120 nm soot
105 nm Soot
60 nm soot
25 nm soot
70 nm soot
Fullerene soot

Spheres
600 nm PSL
900 nm PSL
100 nm PSL

Standards
Ammonium Sulfate
Ammonium Nitrate
Adipic Acid

Mixtures
Mont STx + 5% Goethite (by mass)
Mont STx + 10% Goethite (by mass)
Amm Sulf + Goethite (9—26% of scat)
Amm Sulf + Amborgio Yellow Earth (11-30% of scat)
Amm Sulf + Italian Yellow Earth (11-38%)
Amm Sulf + Soot (0.78–0.97 SSA)
Internal Silica+AS
Internal Silica+fullerene
Internal Hematite+AS
Internal Goethite+AS
Internal Goethite+AS
Internal Hematite+AS
AS + Soot - 0.87–0.98 SSA
AN/Full_Int #1 + 7-15% Arginotec
AN/Full_Int #2 + 9-17% Mont. Sca-3
Mont. STx, 150–1000 Mm-1
Mont. STx, APS=0.63, 19LPM
Mont. STx, APS=0.73, 12LPM
Mont. STx, APS=0.94, 8LPM
Mont. STx, APS=1.38, 5LPM
Mont. STx, APS=1.57, 2LPM
600 (60/Mm) + 900 nm (100/Mm) PSL
600 (110/Mm) + 900 nm (100/Mm) PSL
Mont. SCa-3 + Amm. Nit. (~61%)
Mont. SCa-3 + Amm. Nit. (9–80%)
Fullerene + Amm. Nit. (external, 0.86–0.96 SSA)
Silica + Fullerene
Silica + AS (Ext, 16% Dust)
Blue Ridge Hematite + AS (Ext, 19% Dust)
Blue Ridge Hematite + AS (Ext, 16% Dust)
Arginotec + AS (Ext, 24% Dust)
Arginotec + AS (Ext, 21% Dust)
AN+Full (Ext, SSA = 0.92)
Argintoc + AN/Full_Ext (18% Dust, SSA = 0.92)
Mont. Sca-3 + AN/Full_Ext (18% Dust, SSA = 0.92)
Mont. Sca-3 + AN/Full_Ext (18% Dust when dry, SSA = 0.92)
Argintoc + AN/Full_Ext (18% Dust when dry, SSA = 0.92)

Simulating AERONET with GRASP

- Input radiances only considered at AERONET scattering angles.
- Real refr. index range: 1.33 — 1.6
- Imag. refr. index range: 0.0005 — 0.5
- Radius range: 0.05 — 15 um (22 bins)
- Residuals less than 8%

Some Inconsistencies

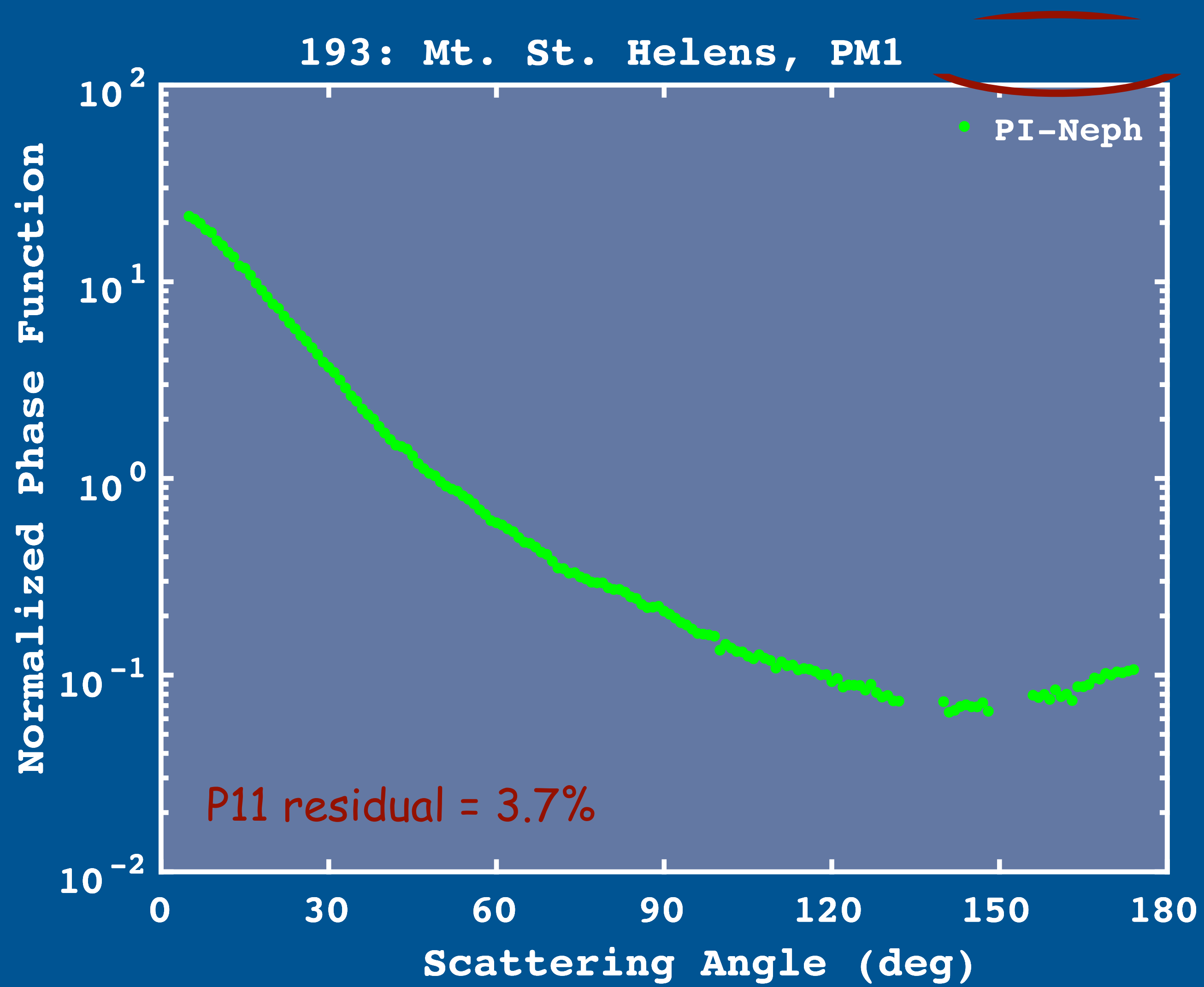
- PI-Neph wavelengths different than AERONET:
  - 473, 532, 671 nm vs 440, 675, 870, 1020 nm
- Instrument sensitivities
- No multiple scattering

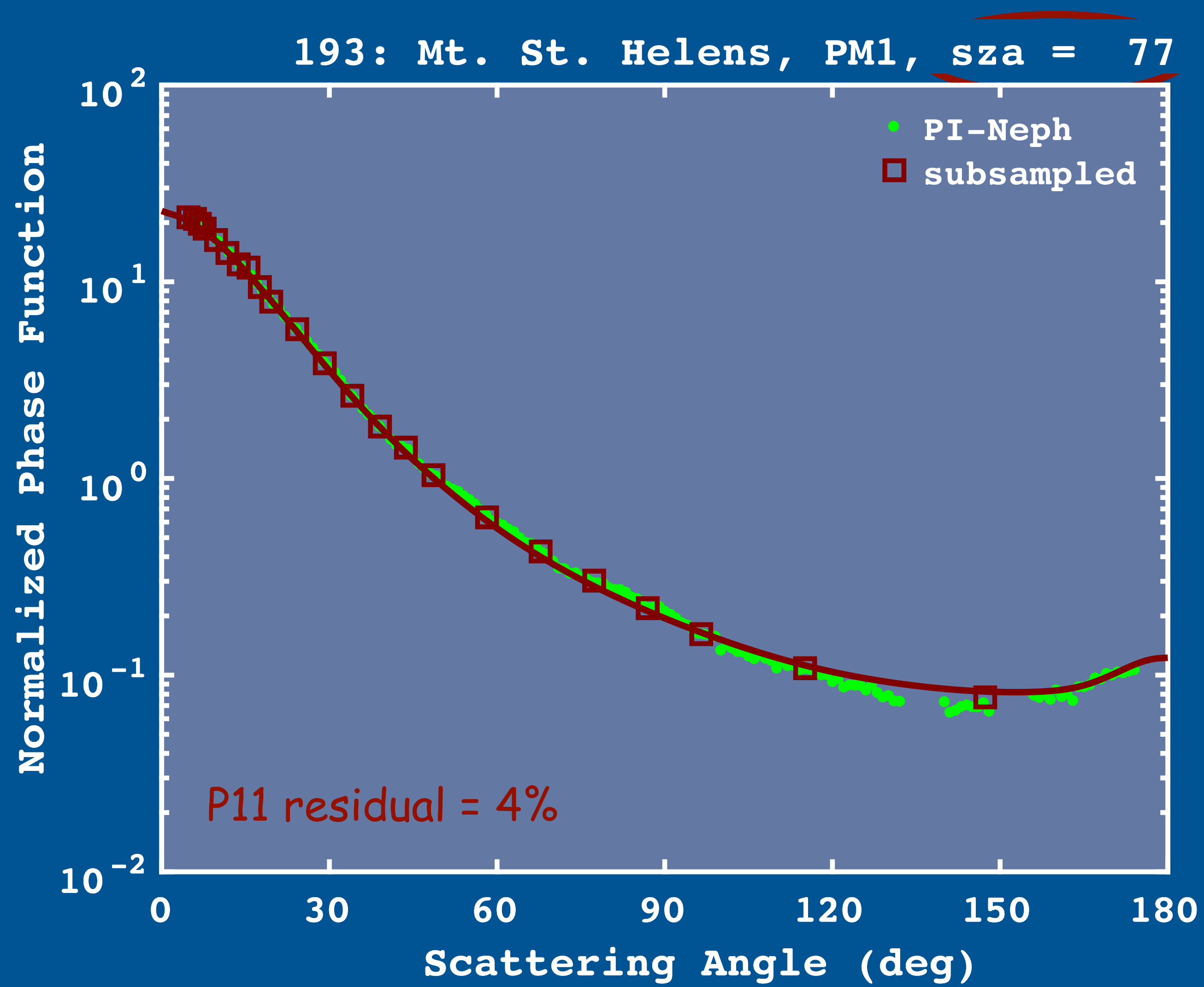
"Necessary but not sufficient" experiment

Subsampling PI-Neph to match AERONET measurement angles

- AERONET robot pauses for measurements at fixed specified azimuth angles, ϕ.
- Thus, scattering angles (Θ) are determined by the solar zenith angle $(\theta_\circ)$ and ϕ .

$$\cos\Theta = 1 - \sin^2\theta_\circ(1 - \cos\phi)$$





Note: AERONET Level 2 require residuals less than 5-8%, depending upon AOD.

Results

- Evaluate size distribution retrievals using the effective radius and effective variance
- Integrated aerosol volume
- Single-scatter albedo
- Solar zenith angle effects on the single-scatter albedo absolute bias
- Bistatic lidar ratio at 173 degrees

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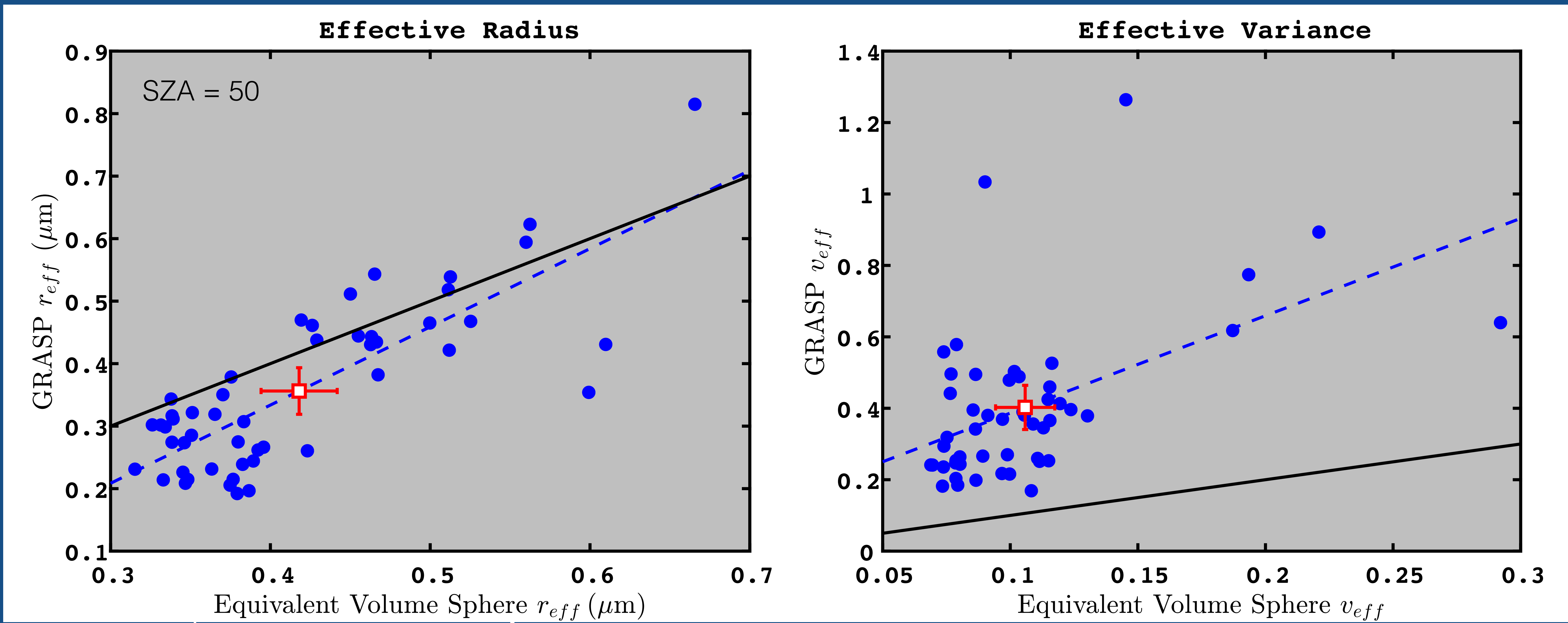
Evaluate size distribution retrievals using the effective radius and effective variance

$$r_{eff} = \frac{\int r \times \pi r^2 n(r) dr}{\int \pi r^2 n(r) dr}$$

$$v_{eff} = \frac{\int (r - r_{eff})^2 \times \pi r^2 n(r) dr}{r_{eff}^2 \int \pi r^2 n(r) dr}$$



	slope	intcpt	cc	Absolute Bias	Relative Bias (%)	RMS	N	SZA	DSF
R_eff	1.284	-0.167	0.800	-0.051	-13	0.10	50	50	vrbl
V_eff	2.276	0.114	0.511	0.297	280	0.36	50	50	vrbl

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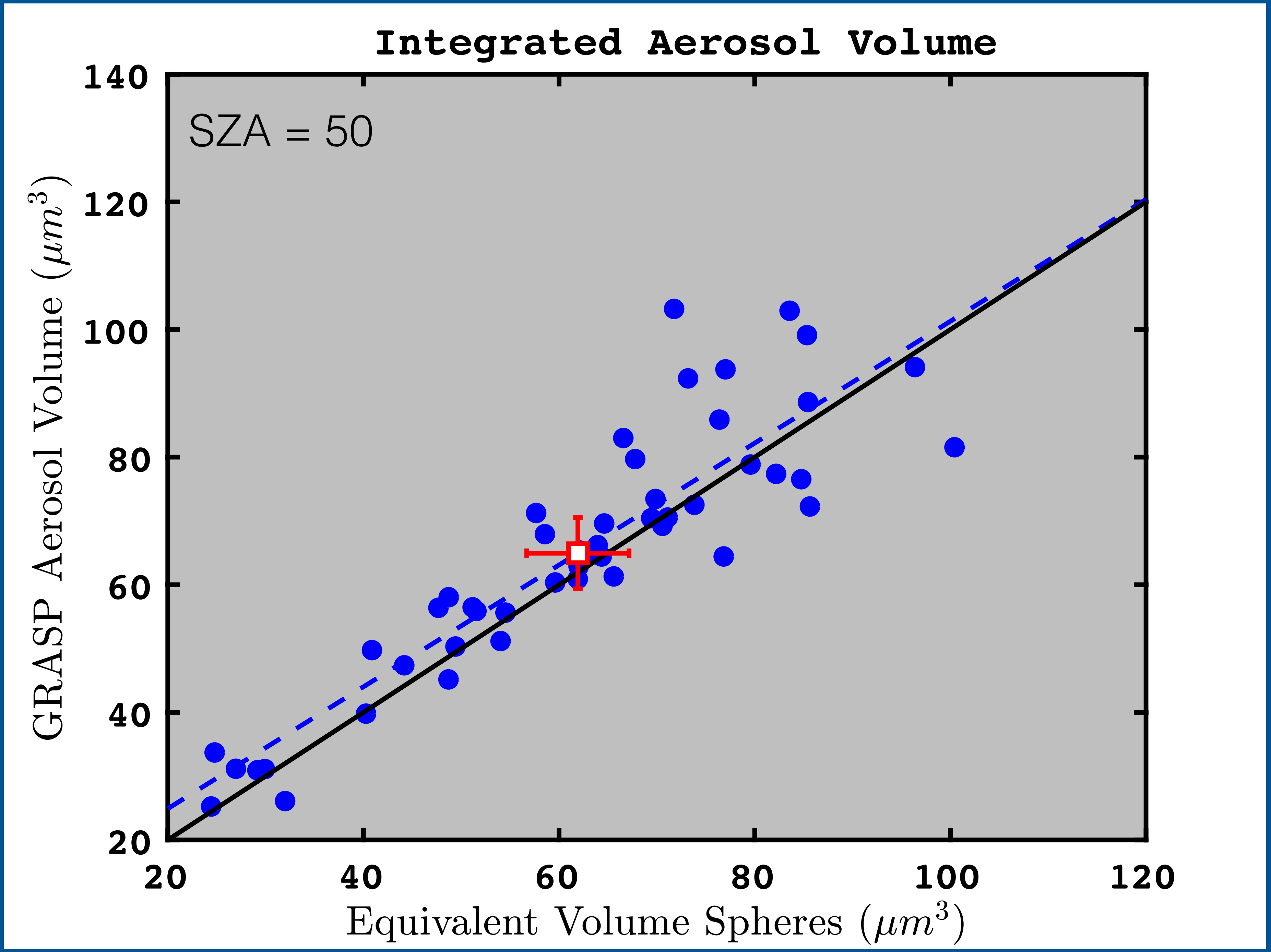
Integrated Aerosol Volume



SZA	slope	intcpt	cc	Absolute Bias	Relative Bias (%)	RMS	N	DSF
50	1.031	5.812	0.896	7.604	13	11.55	50	vrbl
77	1.100	3.482	0.844	9.363	16	14.40	45	vrbl
1-deg	1.014	10.284	0.713	11.139	18	18.50	38	vrbl

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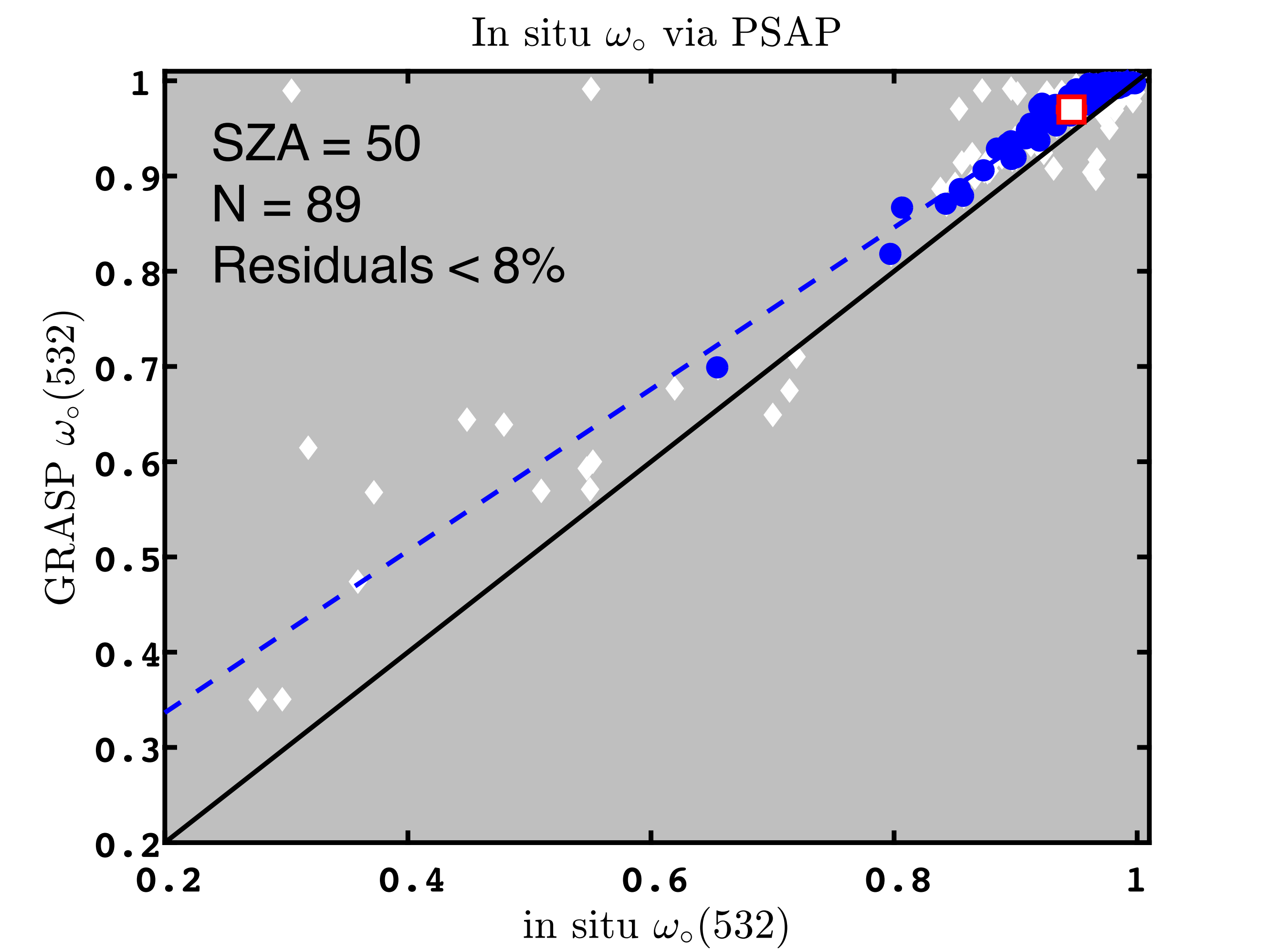
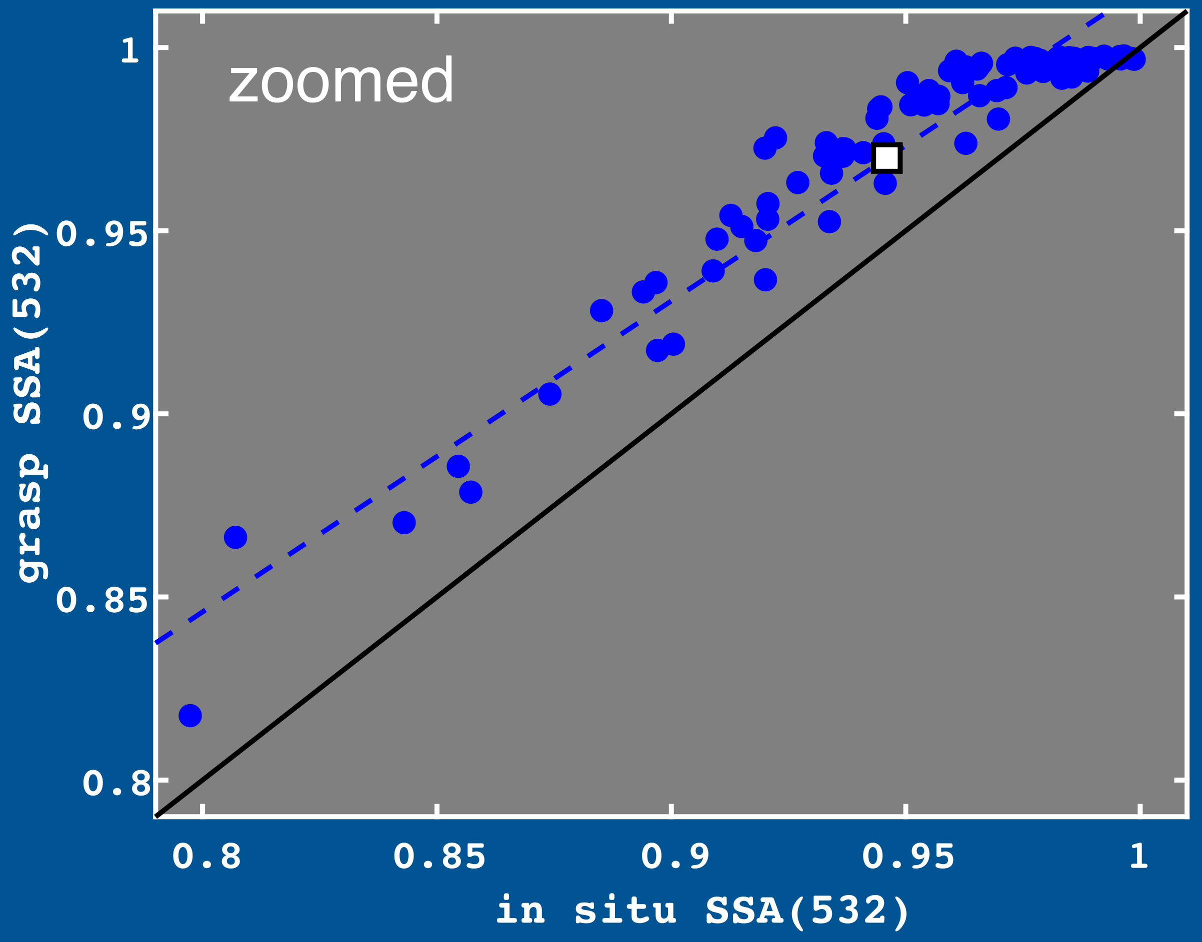
Single Scatter Albedo





	PSAP $\frac{(EXT - ABS_{psap})}{EXT}$
corr. coef.	0.971
slope	0.849
intercept	0.167
abslt bias	0.024

EXT:
Extinction via Cavity Attenuated Phase Shift Spectrometer (CAPS)

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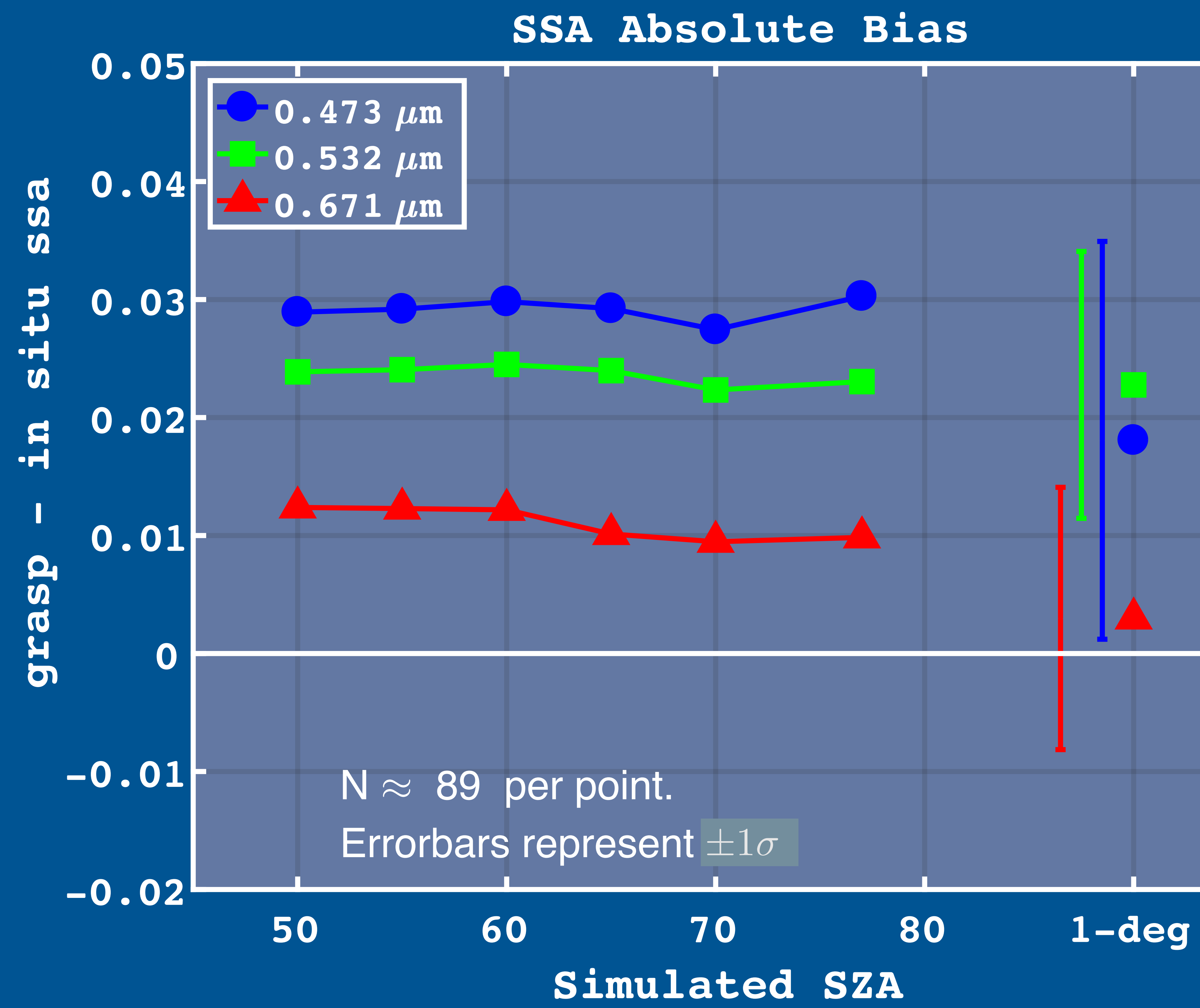
Solar Zenith Angle effects on SSA Absolute Bias



Results

- Evaluate size distribution retrievals using the effective radius and effective variance
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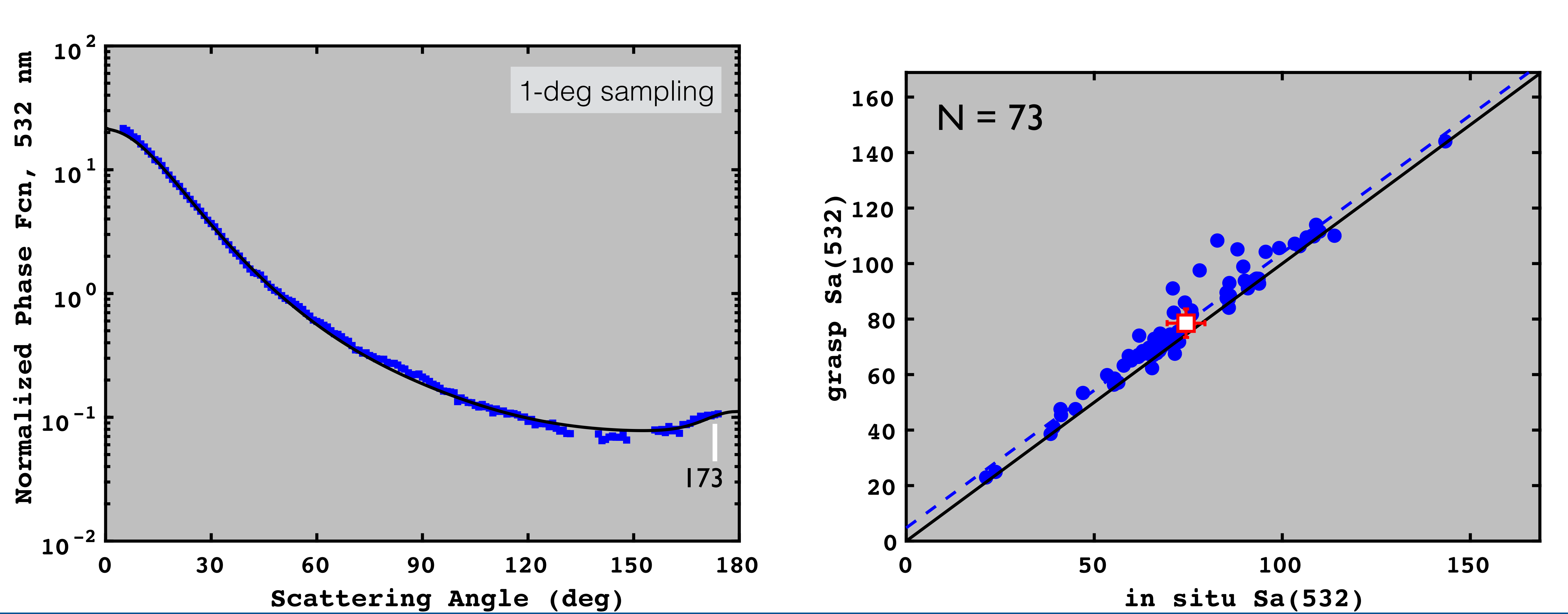
Bistatic Lidar Ratio at 173 degrees

$$S_a = \frac{\text{ext}}{\text{sca}} \frac{4\pi}{P(173)}$$



SZA:	50	77	1-deg
correlation coef	0.714	0.860	0.973
slope:	0.774	1.004	0.991
Intercept:	19.8	7.55	4.76
Relative Bias:	2%	10%	6%
Absolute Bias:	1.8 sr	7.9 sr	4.1 sr

Conclusions

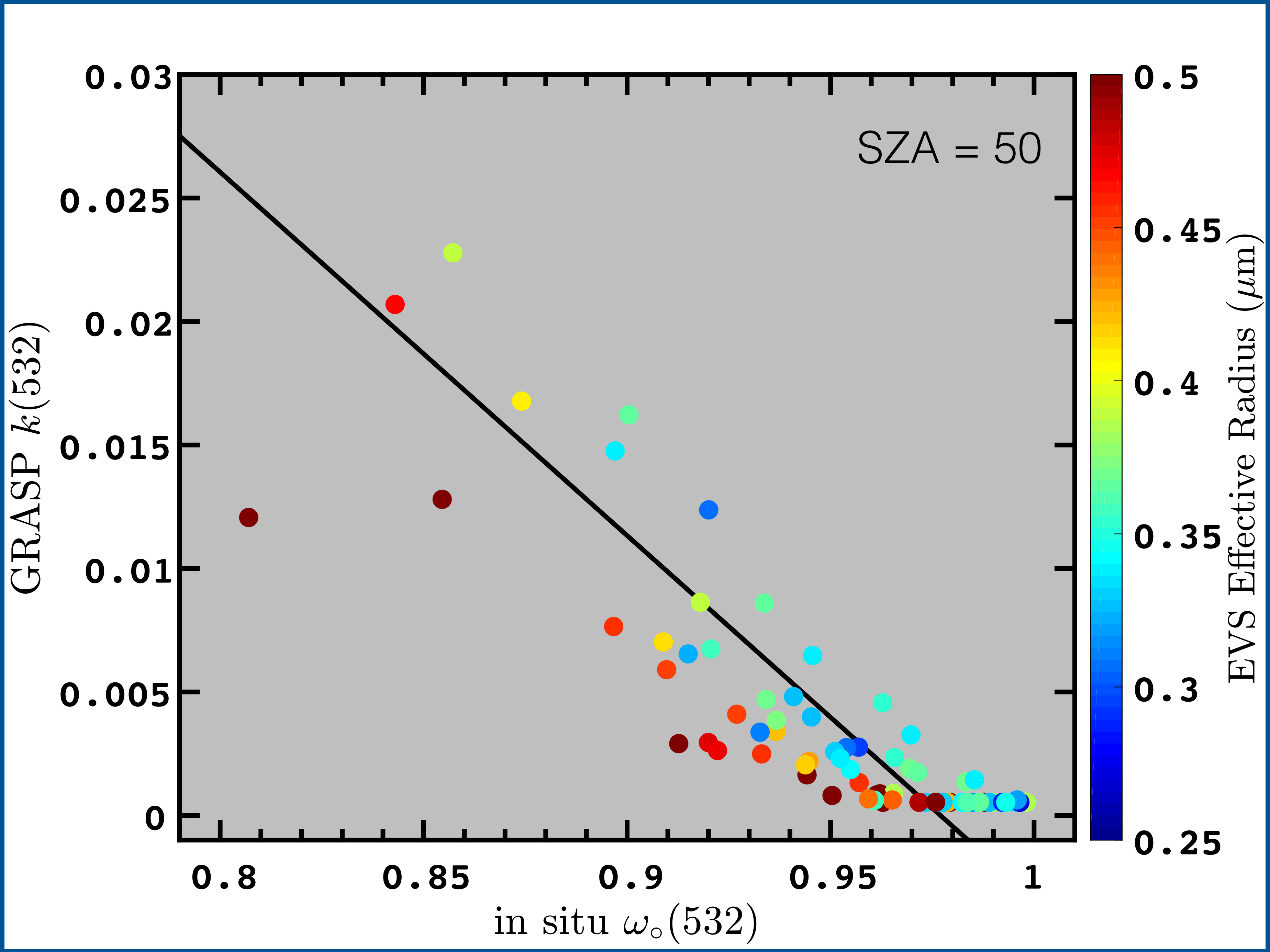
- Simulated AERONET measurements for 285 in situ sampling volumes.
- GRASP provided quality retrievals (residuals of < 8%) for ~90 samples.
- Relative bias for effective radius is -13% when dynamic shape factor is constrained by extinction.
- Relative bias for the effective variance of size distributions is 280%.
- Relative bias for the integrated aerosol volume is 13-18% (SZA-dependent).
- Absolute bias for single-scatter albedo is +0.023 at 532 nm via PSAP.
- SSA biases do not vary significantly for SZA = 50-77 degrees.
- Relative bias for bistatic lidar ratio at 173° is 2-10%, depending upon SZA.

Manuscript essentially complete. To be submitted to Remote Sensing.

Appendix

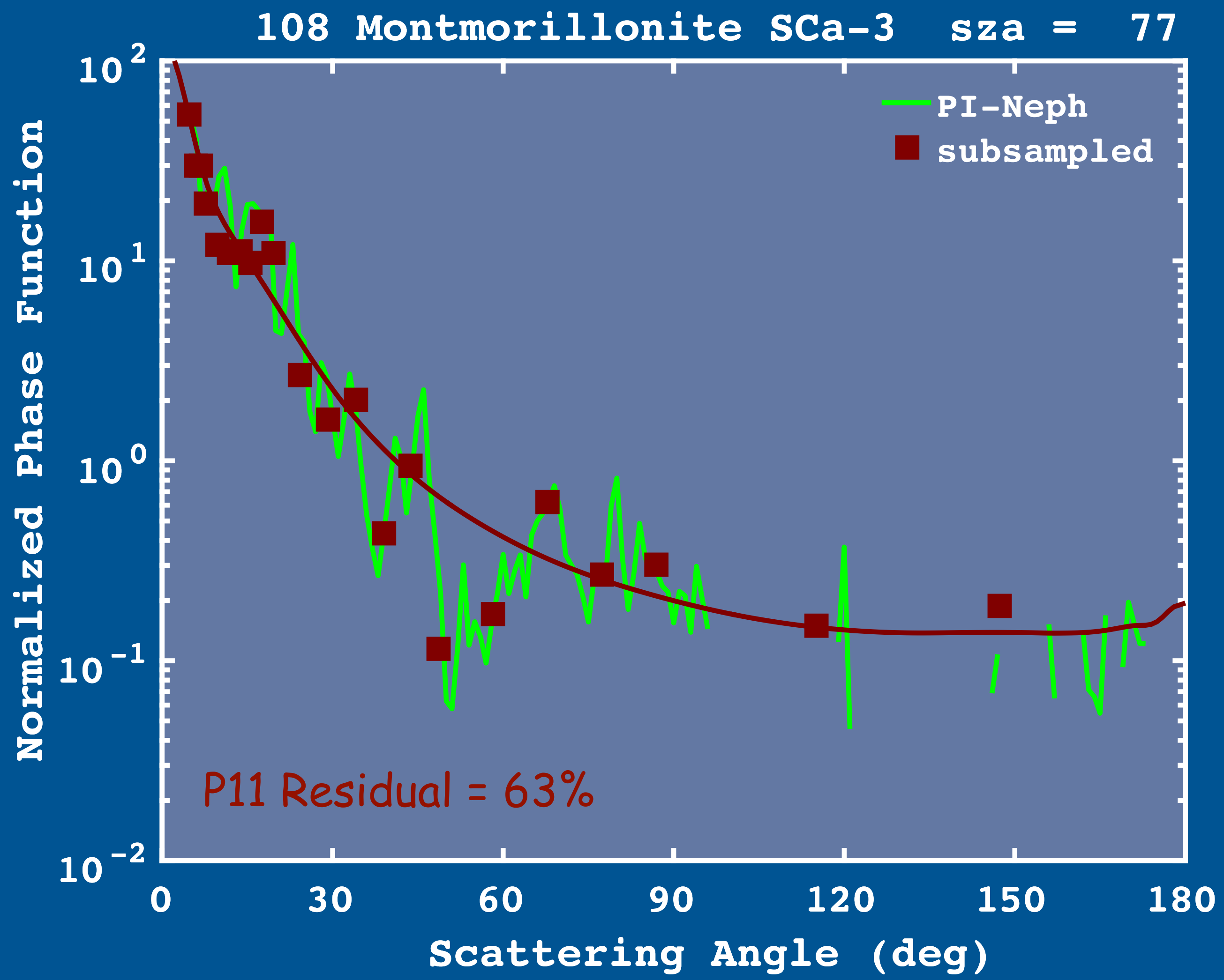
Aerosol absorption and the single-scatter albedo

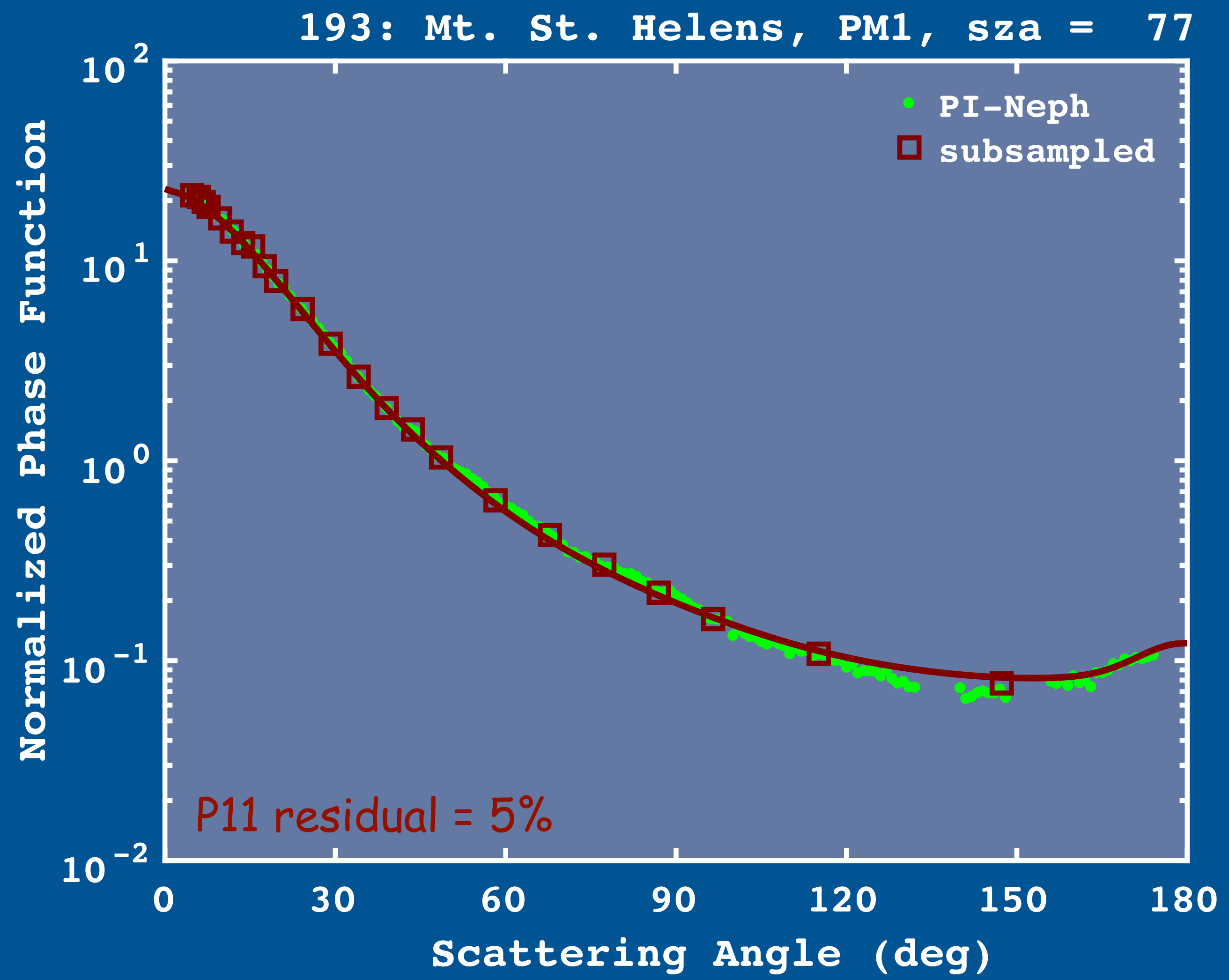
$$\alpha_{bulk}(\lambda) = \frac{4\pi k(\lambda)}{\lambda} \qquad \omega_\circ = \frac{\tau_{sca}}{\tau_{ext}} = \frac{1-\alpha}{\tau_{ext}}$$



The Importance of Residuals

Residuals measure the ability of a retrieval model to reproduce measurements

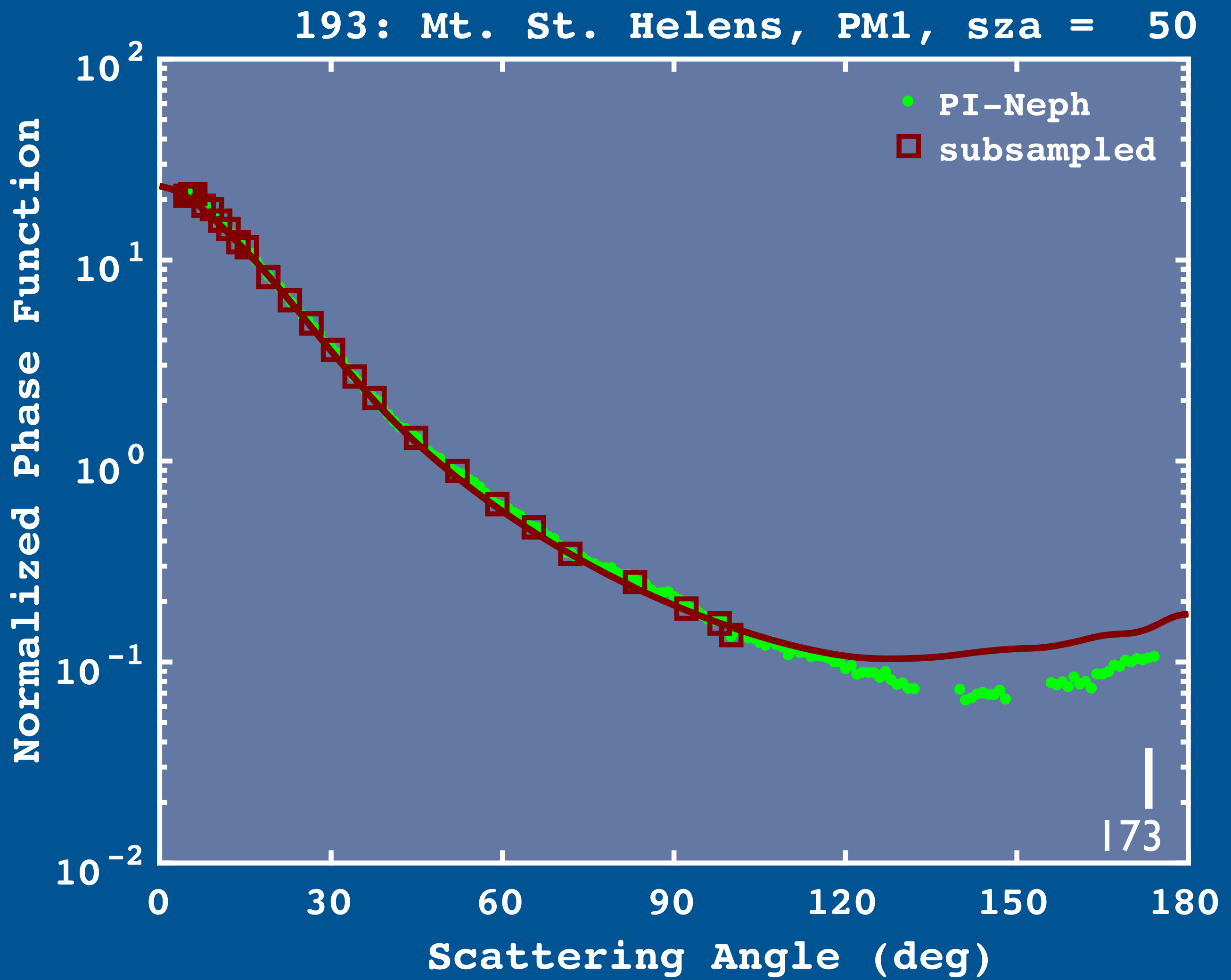


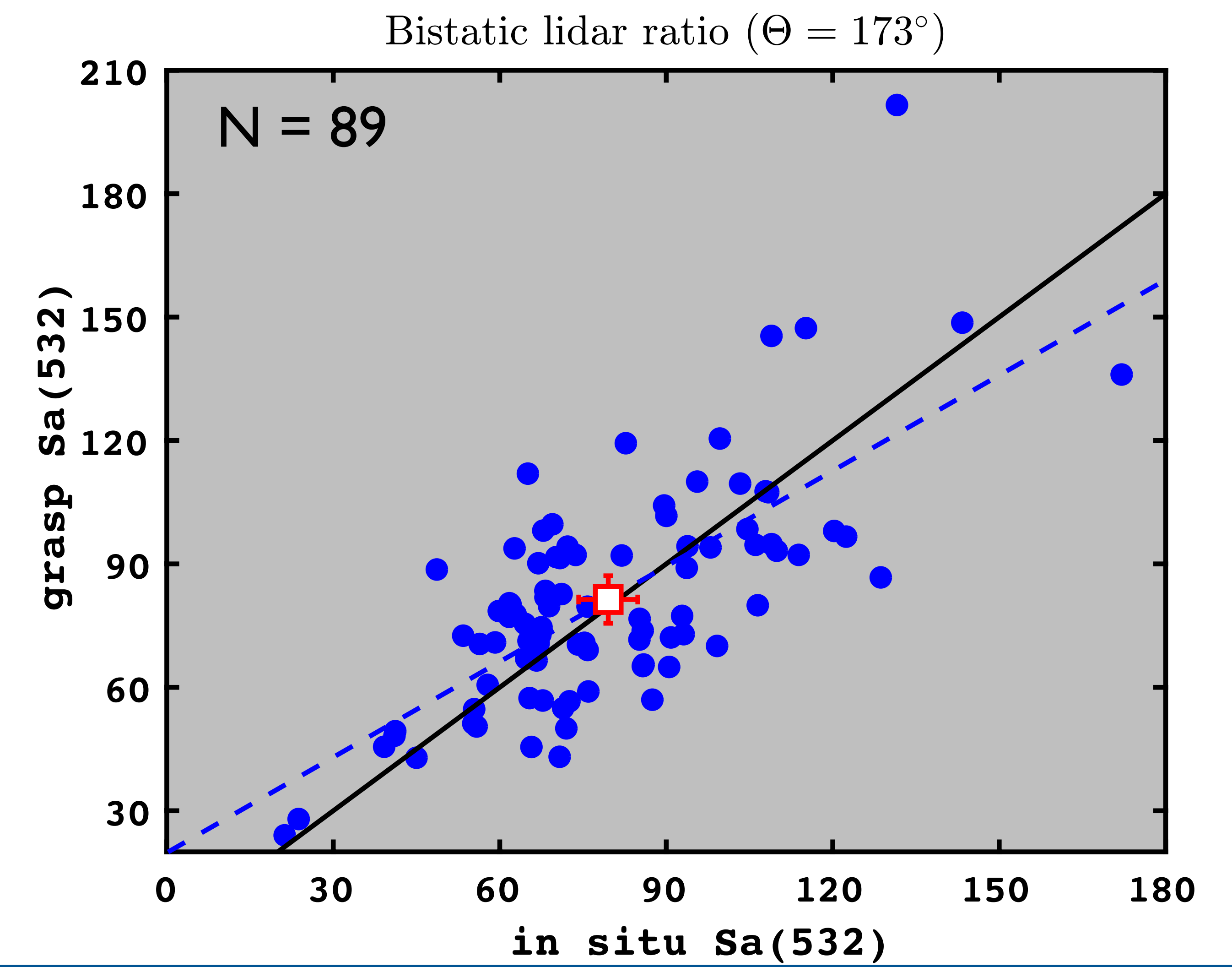


Note: AERONET Level 2 require residuals less than 5-8%, depending upon AOD.

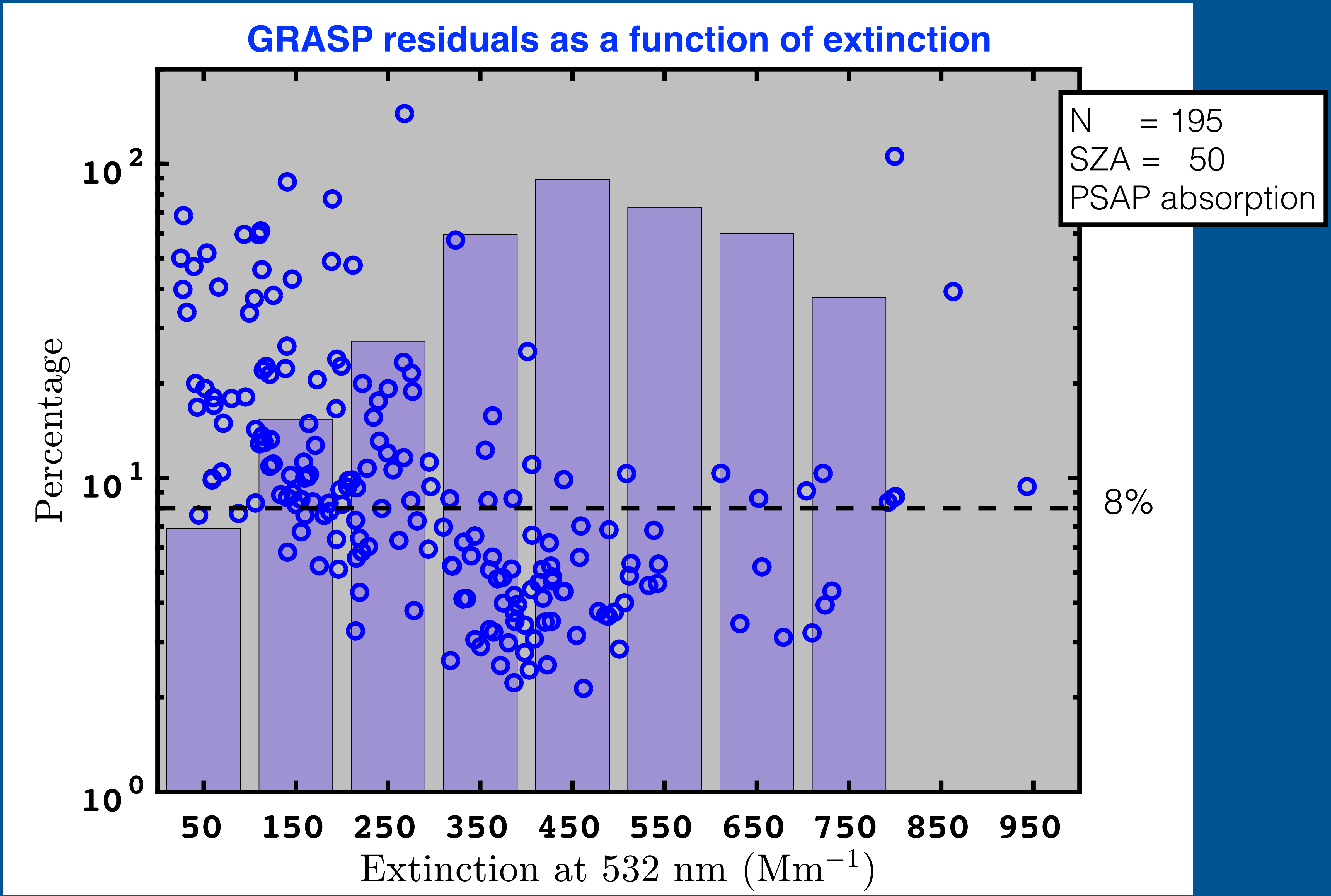
Bistatic Lidar Ratio at 173 degrees

$$S_a = \frac{\text{ext}}{\text{sca}} \frac{4\pi}{P(173)}$$





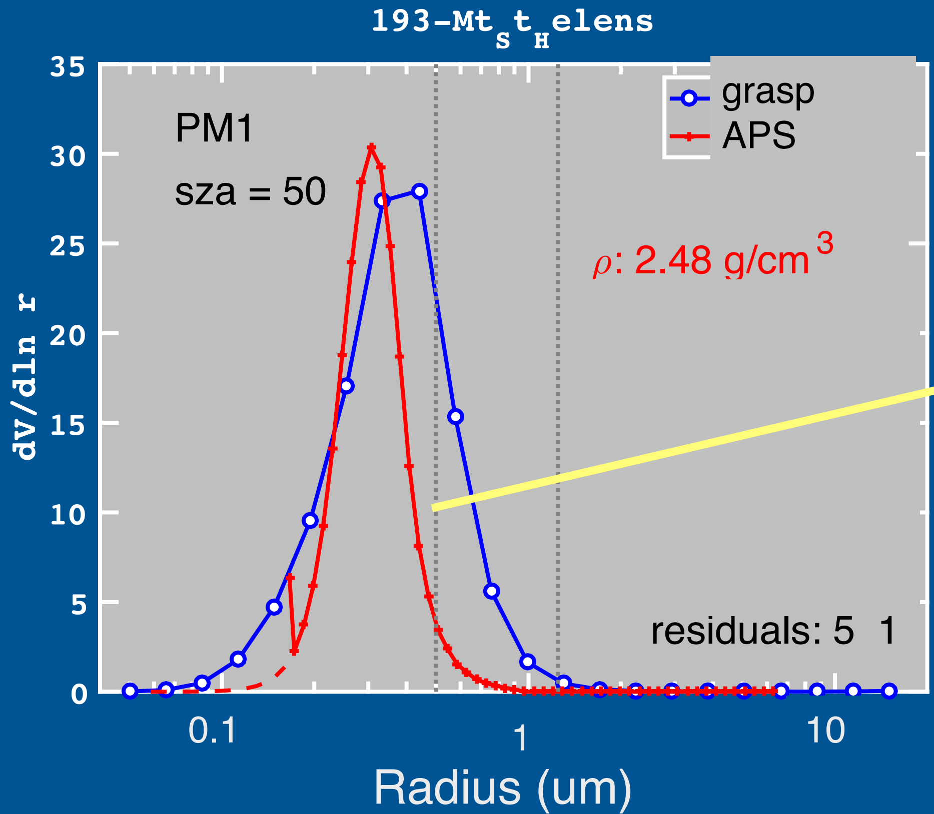
SZA:	50
correlation coef	0.714
slope:	0.774
Intercept:	19.8
Relative Bias:	2%
Absolute Bias:	1.79 sr



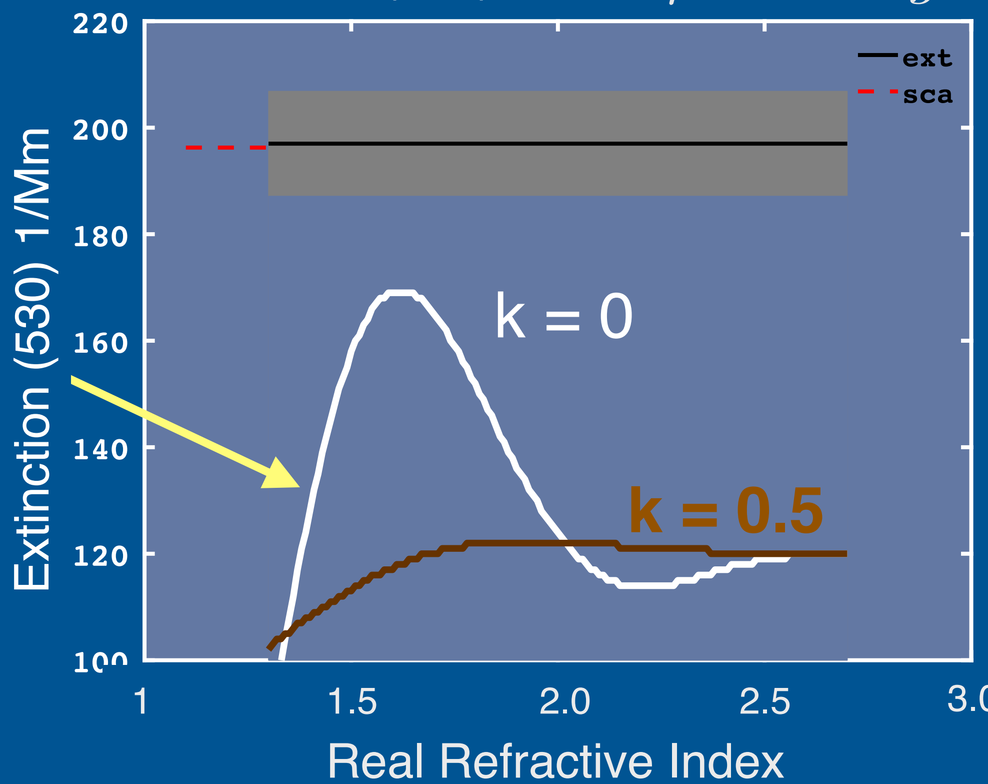
Bars indicate the percentage of retrievals that satisfy the 8% requirement in each extinction bin.

Aerodynamic-Optical Size Conversion

Require closure with extinction measurements

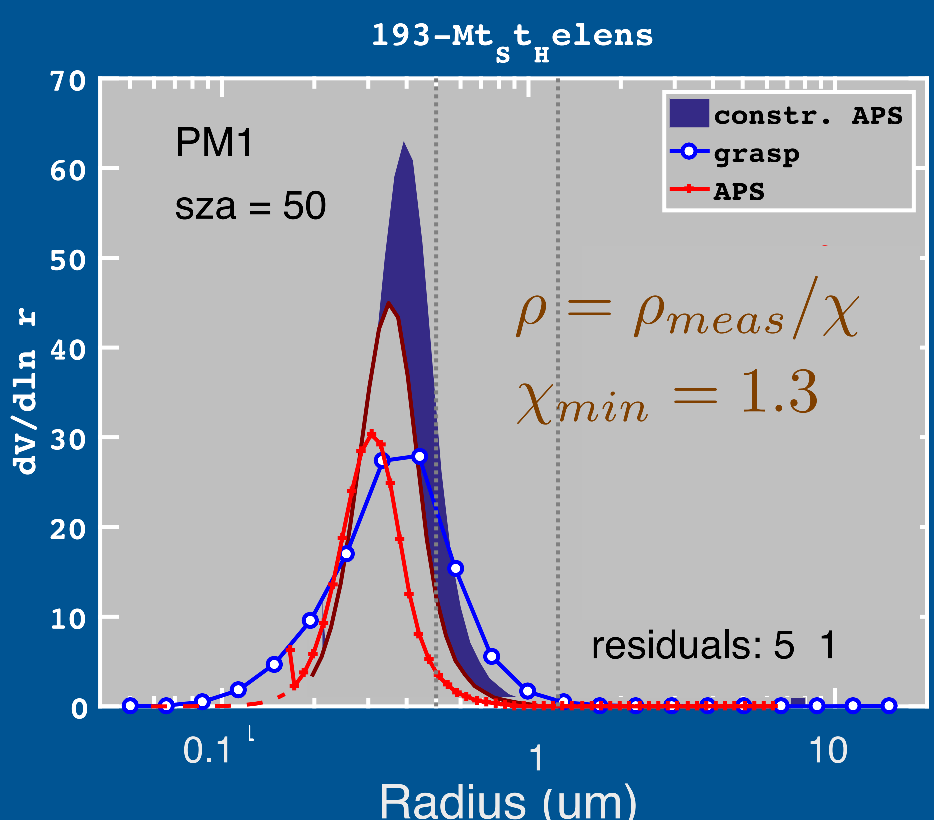


Mie Code



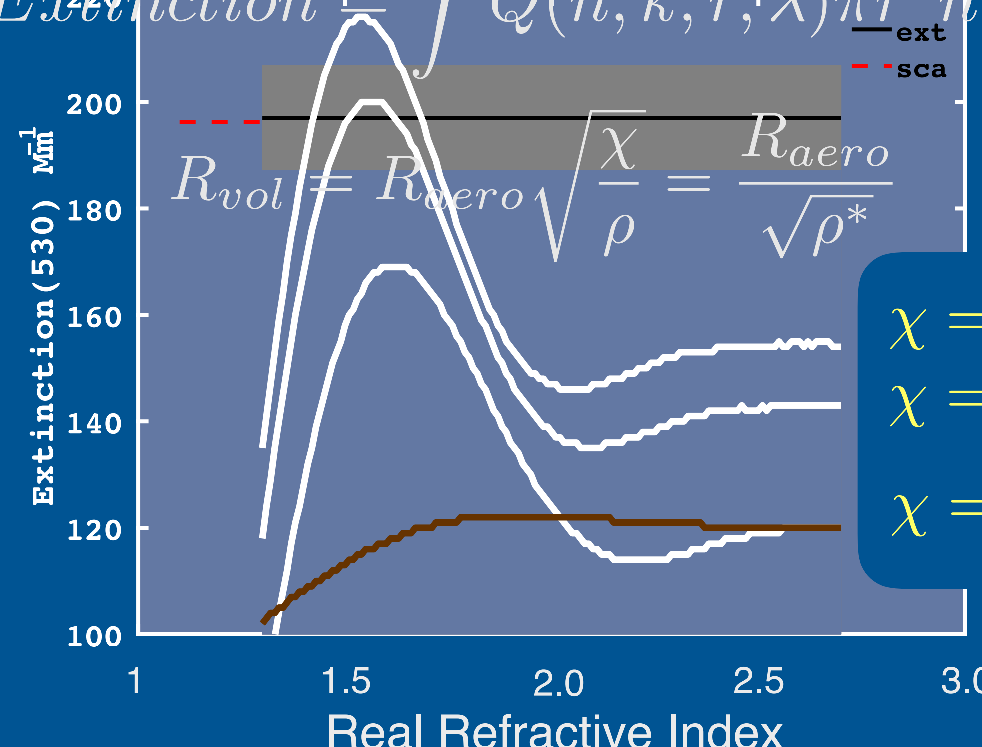
$\rho = 2.48\, g\, cm^{-3}$

Decrease Density



$\rho = \rho_{meas}/\chi$

$\chi_{min} = 1.3$



$\rho = 2.48/\chi$

$$Extinction = \int Q(n,k,r,\lambda)\pi r^2 n(r) dr$$

$$R_{vol} = R_{aero}\sqrt{\frac{\chi}{\rho}} = \frac{R_{aero}}{\sqrt{\rho^*}}$$

$\chi = 1.3$

$\chi = 1.2$

$\chi = 1$

Comparing Retrieved Size Distributions to Aerodynamic Size

Evaluate size distribution retrievals using the effective variance and effective radius.

$$r_{eff} = \frac{\int r \times \pi r^2 n(r) dr}{\int \pi r^2 n(r) dr}$$

$$v_{eff} = \frac{\int (r - r_{eff})^2 \times \pi r^2 n(r) dr}{r_{eff}^2 \int \pi r^2 n(r) dr}$$

$$\rho^* = \rho/\chi = \rho/1.3$$

$\chi = 1$