Reno Aerosol Optics Study
June, 2002

PRELIMINARY

John Ogren
NOAA/CMDL

Objectives

- Characterize new and existing instruments for measuring aerosol light absorption and extinction
- Quantify the uncertainty in the measurements of aerosol light absorption coefficient used by NOAA and ARM
- Derive methods for determining spectral aerosol absorption from multi-wavelength measurements of absorption and (extinction - scattering)

PRELIMINARY

Participants

- NOAA/CMDL (Ogren, Sheridan)
- DRI (Arnott, Moosmüller, Varma)
- U. Washington (Covert, Virkkula, Ahlquist)
- NASA/Ames (Strawa, Schmid) and Picarro Networks, Inc. (Owano, Provencal)
- Thermo Andersen/DLR (Schloesser, Petzold)
- Portland State U. (Atkinson)

PRELIMINARY

Absorption Coefficient Measurements

- **Photoacoustic**
  - #1 532 nm
  - #2 1047 nm
- **Filter-based**
  - Particle/soot absorption photometer (PSAP)
    - #1: 565 nm
    - #2 460, 540, 660 nm
  - Aethalometer
    - #1 370, 470, 521, 590, 660, 880, 950 nm
    - #2 370, 430, 470, 521, 565, 700, 950 nm
  - Carusso (multi-angle)
    - #1: 670 nm

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Extinction Coefficient Measurements

- **Folded path extinction cell (6.6 m path)**
  - #1 460, 540, 660 nm
- **Cavity-ring down (CRD)**
  - #1: 532 nm
  - #2: 690, 1550 nm
  - #3: 532, 1064 nm

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Scattering Coefficient Measurements

- **TSI 3563 integrating nephelometer**
  - #1 450, 550, 700 nm
- **Radiance M903 integrating nephelometer**
  - #1: 530 nm
- **DRI integrating sphere nephelometer**
  - #1: 532 nm
- **NASA/Ames CRD nephelometer**
  - #1: 690 nm

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Aerosol characterization

- **Size distribution**
  - scanning mobility particle spectrometer
- **Number concentration**
  - TSI condensation particle counters
- **Mass concentration**
  - TEOM
- **Chemical composition**
  - elemental carbon
  - organic carbon
- **Morphology**
  - electron microscopy

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Experimental Target Matrix

ϖ_0	σ_e (Mm^{-1}) Low (5-100)	Med (100-300)	Hi (300-600)
1.00	AS,PSL	AS	AS,PSL
0.98	K	K,G	K
0.95	K	K,G	K
0.90	K	K,G	K
0.80	K	K,G	K
0.70	K	K	K
all black	K,D,G	K	K
Other	A,F		

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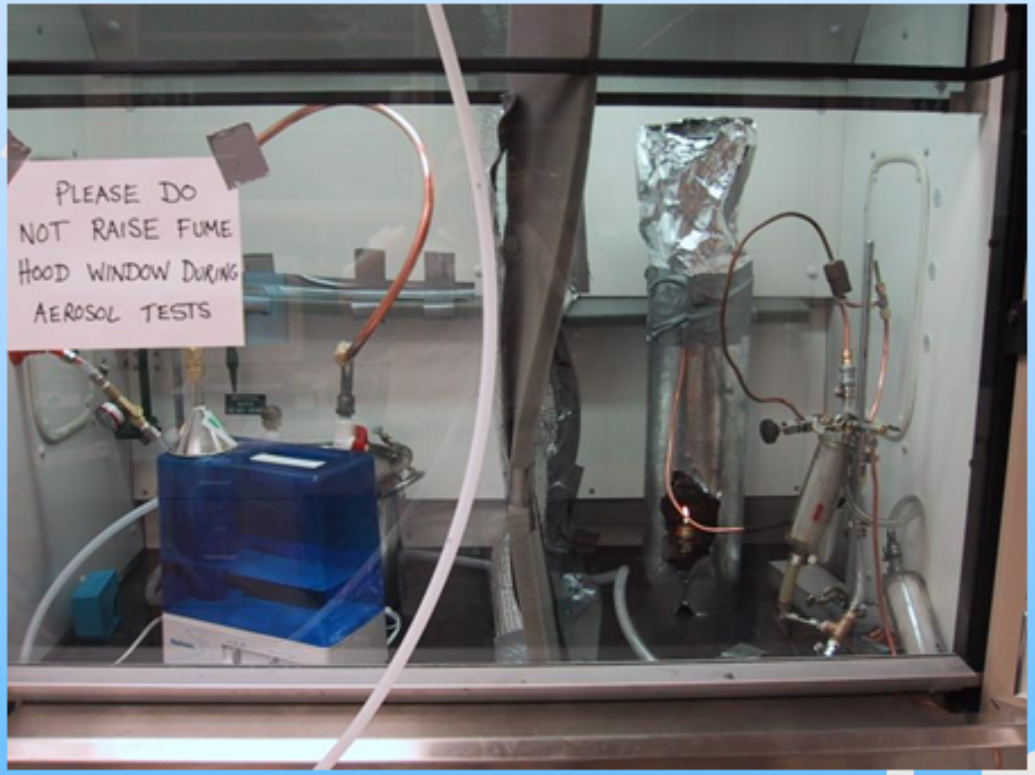
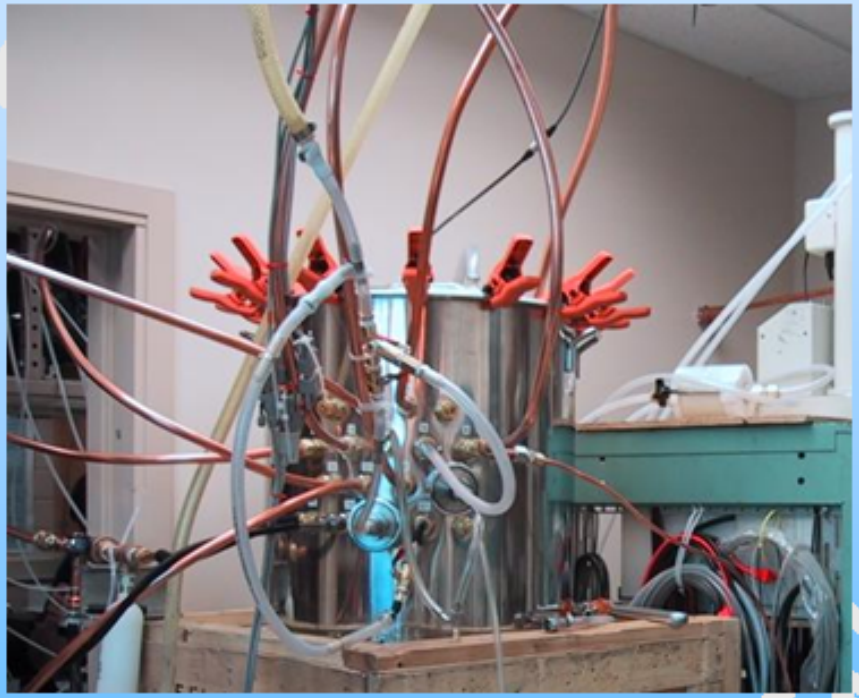
White aerosols: ammonium sulfate (AS), polystyrene latex 0.5 μm dia. (PSL)
Black aerosols: kerosene soot (K), diesel soot (D), graphite (G)
Other: ambient air (A), filtered air (F)

Aerosol Generation System



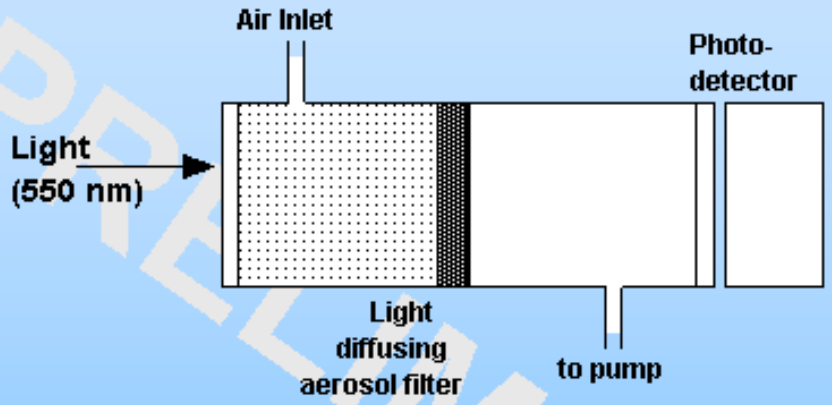
White aerosols produced from ammonium sulfate in ultrasonic humidifier (left)
Black aerosols produced by kerosene lamp (right)

Aerosol Mixing and Distribution



Stirred mixing chamber (76 liters) provides a uniform aerosol to all instruments. Variable mixtures of white particles, black particles, and filtered air can be provided.

Filter Methods for Light Absorption



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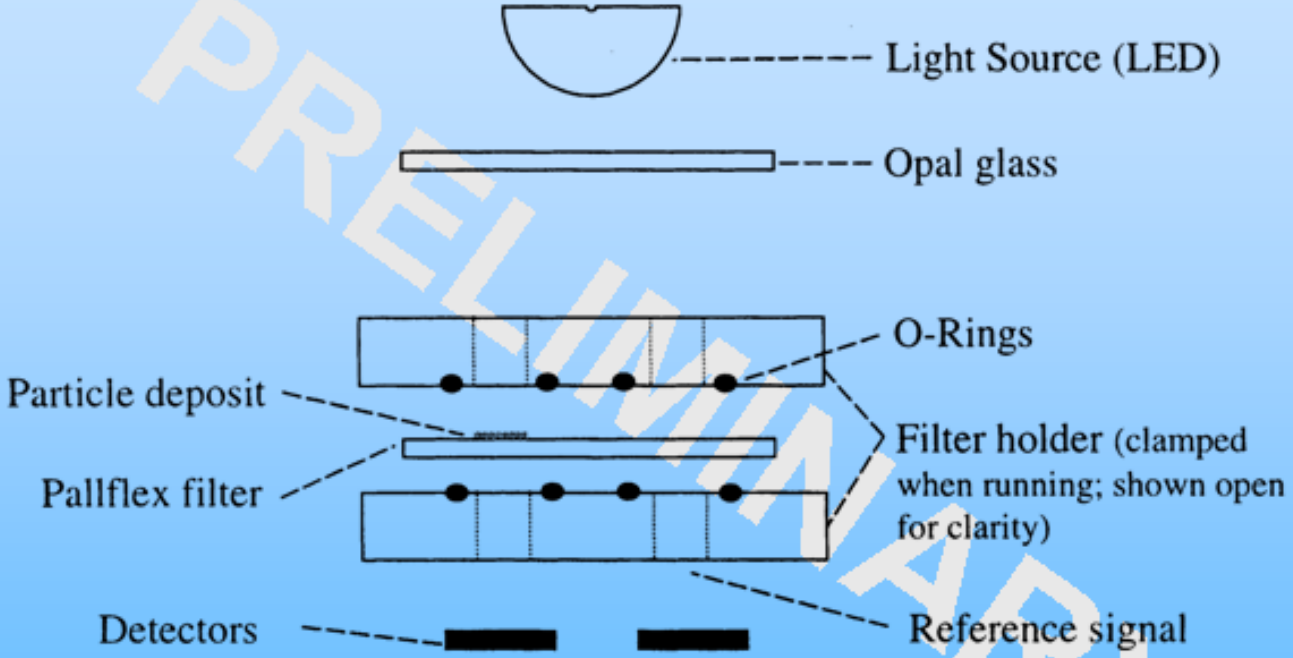
- Particles are deposited on the filter, which is a light-diffusing, multiple scattering substrate.
- Light absorbing particles reduce the light power at the photodetector.
- Light scattering particles don't reduce power in principle.
- Non-linear effects of aerosol loading (blocking)??

PSAP Optical Configuration



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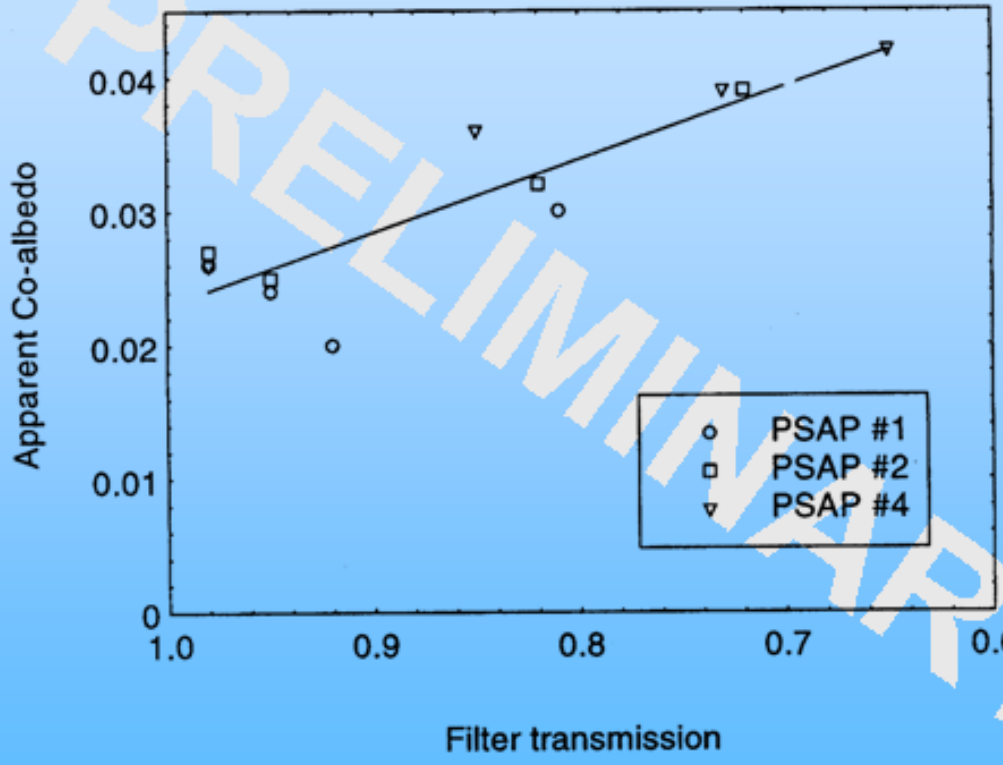
PSAP: Particle/Soot Absorption Photometer
Source: Bond et al., 1999

PSAP Filter Holder

Particle-loaded filter on the left, reference filter on the right. Compare light transmission through these filters as a measure of light absorption

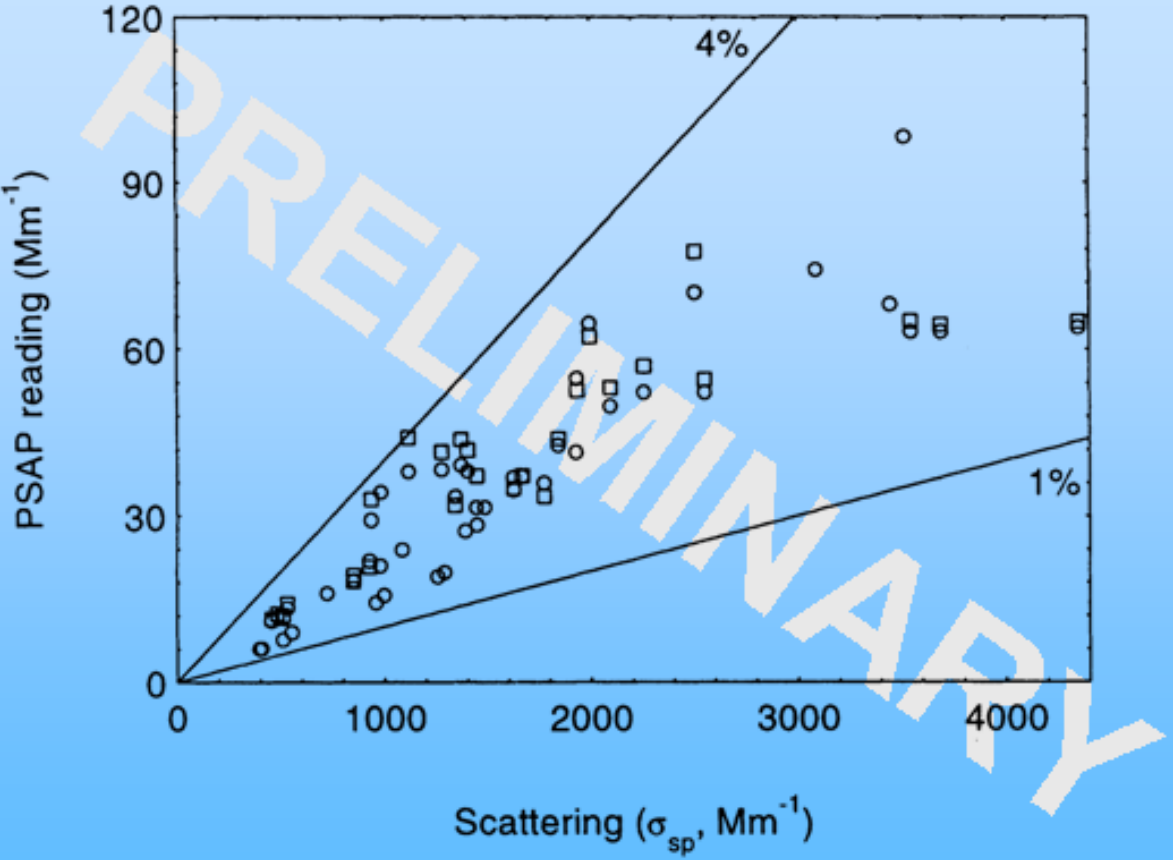
PSAP Response to Non-Absorbing Particles Depends on Filter Loading



PRELIMINARY

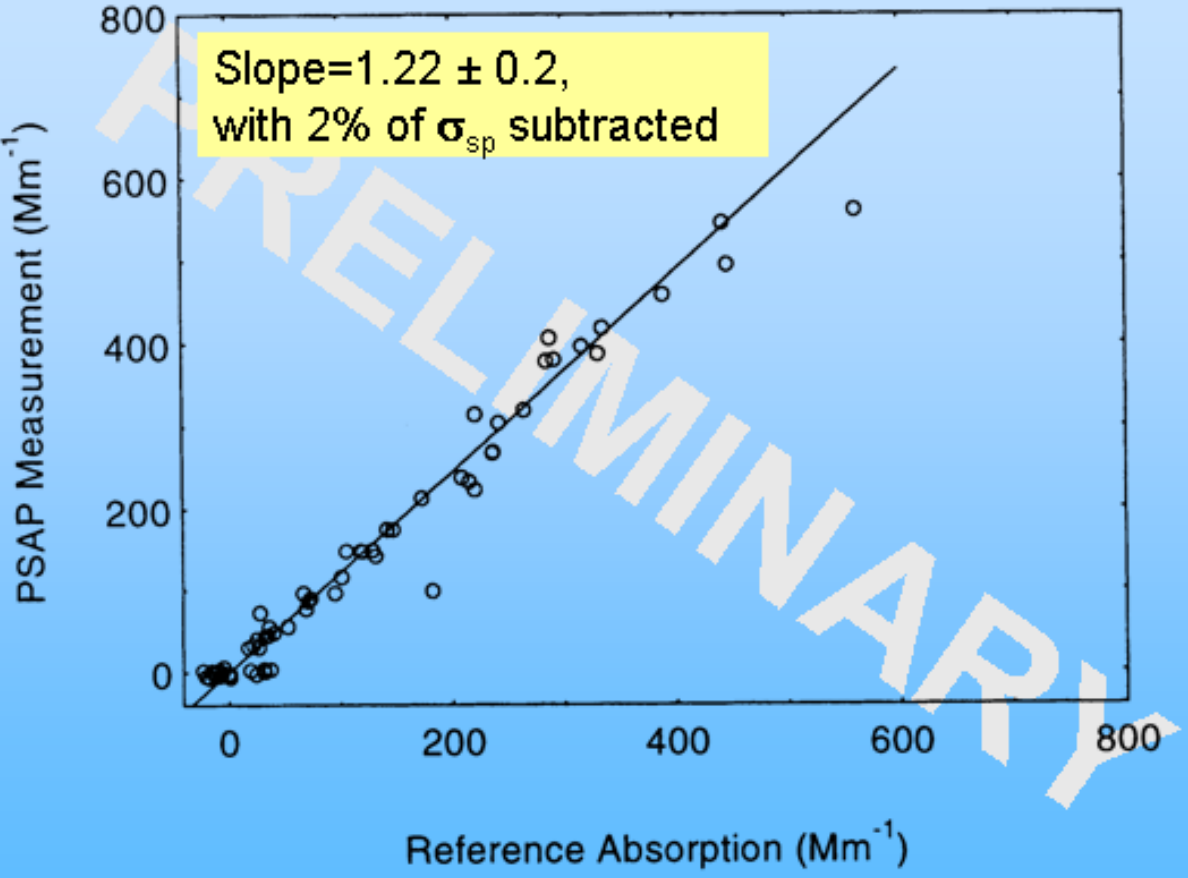
Source: Bond et al. (1999)

PSAP Response to Scattering



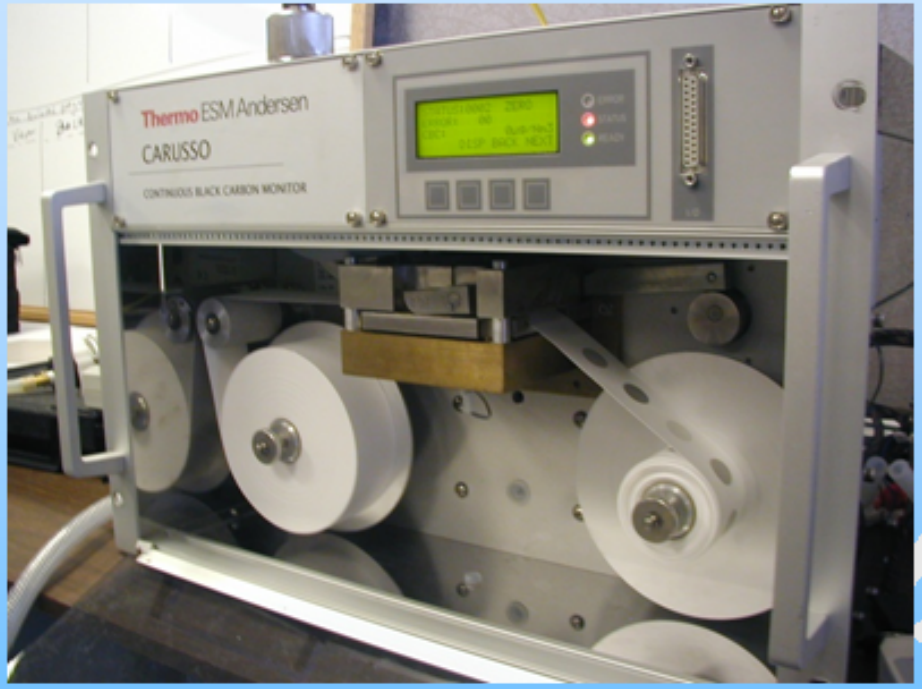
Source: Bond et al. (1999)

PSAP Calibration Results



Source: Bond et al. (1999)

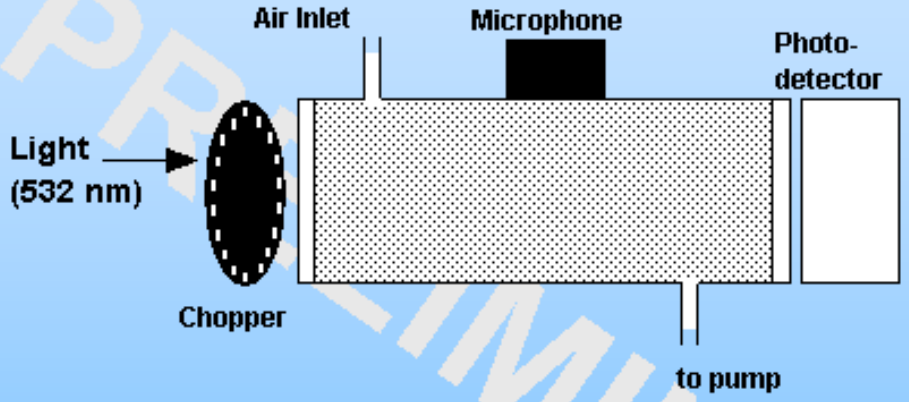
Multi-Angle Absorption Photometer



- **Simultaneously measures light (670 nm) transmitted and reflected by aerosol deposit on filter**
- **A two-stream radiative transfer model is used to derive the aerosol absorption coefficient, accounting for light scattering by particles and filter.**
- **Detection limit ~ 1 Mm^{-1} for 2-minute average at 16.7 lpm flowrate.**

Source: A. Petzold[1] , M. Schönlinner[2] , H.Kramer[2] and H. Schloesser[2]
[1]German Aerospace Center, Oberpfaffenhofen, Germany
[2]ESM Andersen Instruments, Erlangen, Germany

Photoacoustic Absorption Measurement



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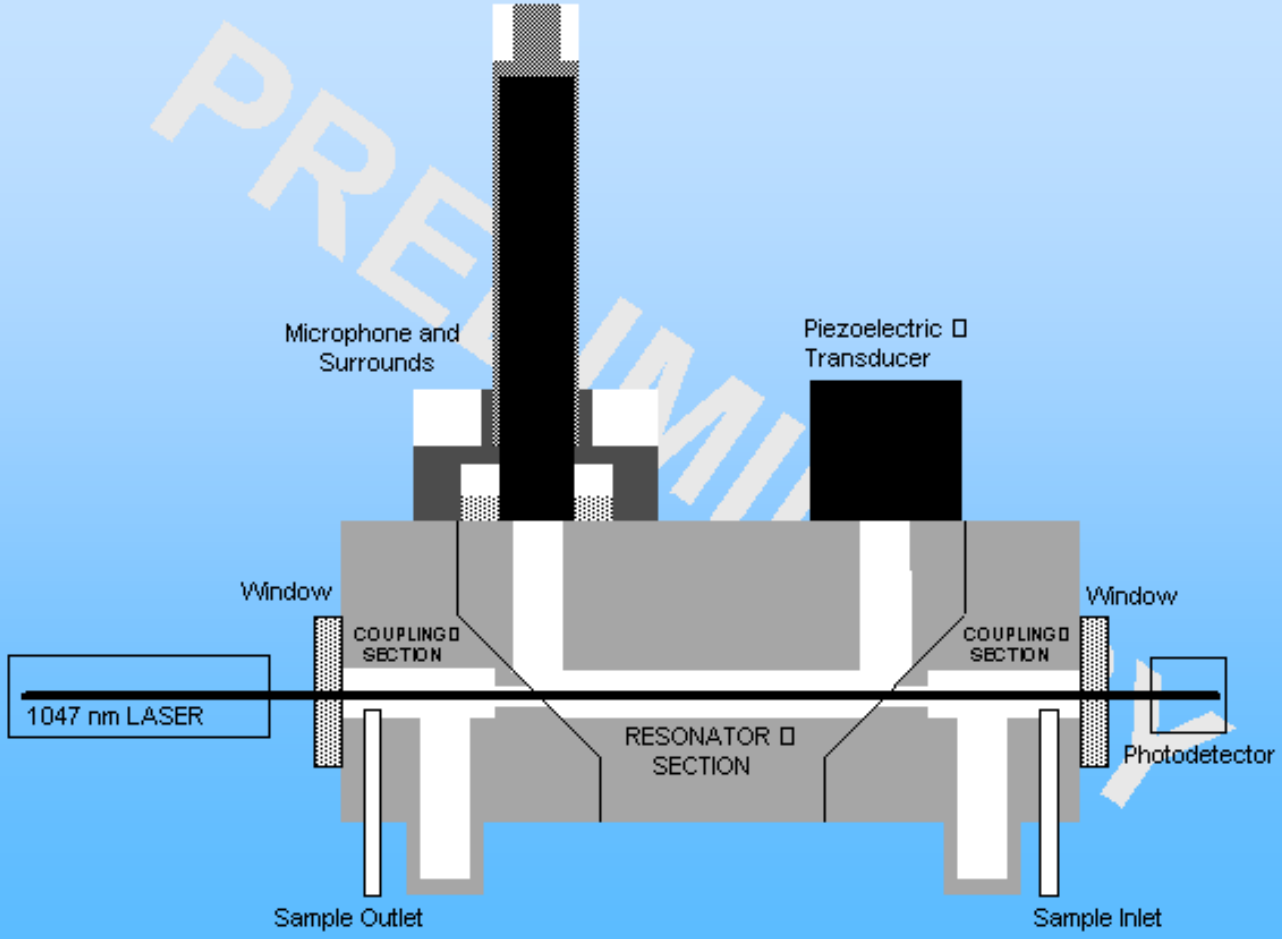
- Laser light is power modulated by the chopper.
- Light absorbing aerosols convert light to heat - a sound wave is produced.
- Microphone signal is a measure of the light absorption.
- Light scattering aerosols don't generate heat.

Photoacoustic Instrument Sketch



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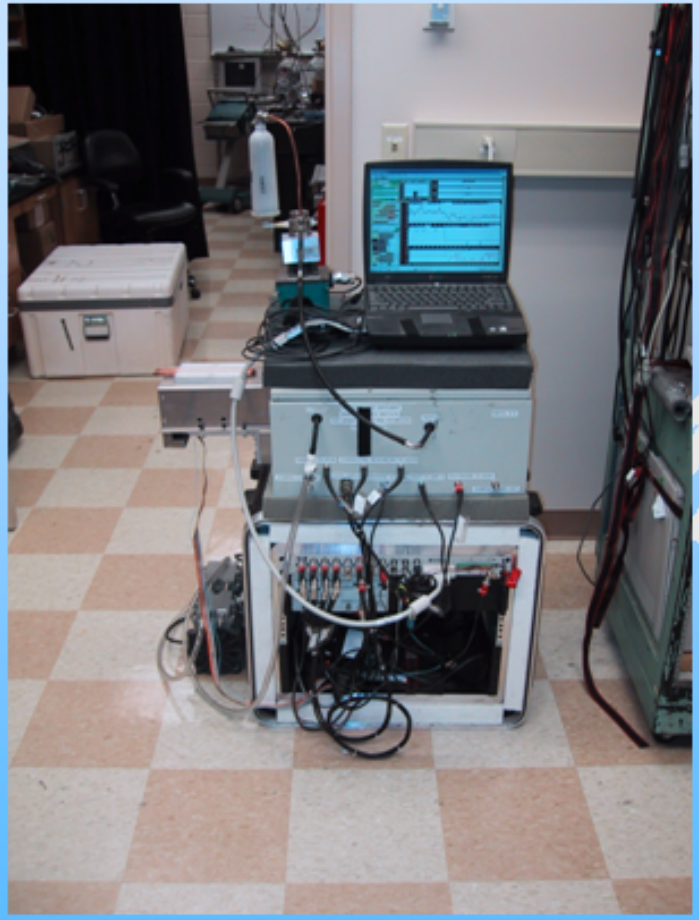
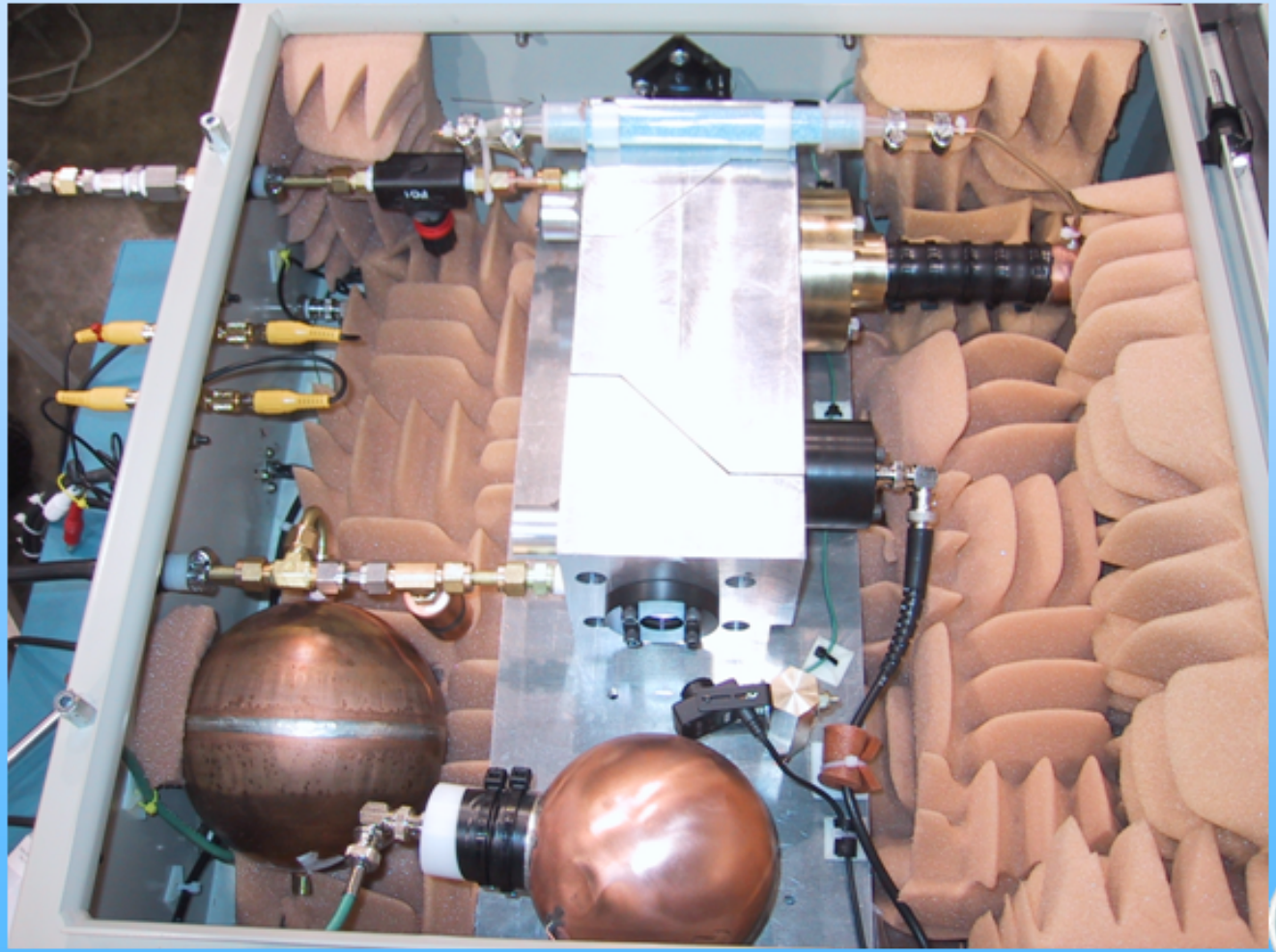
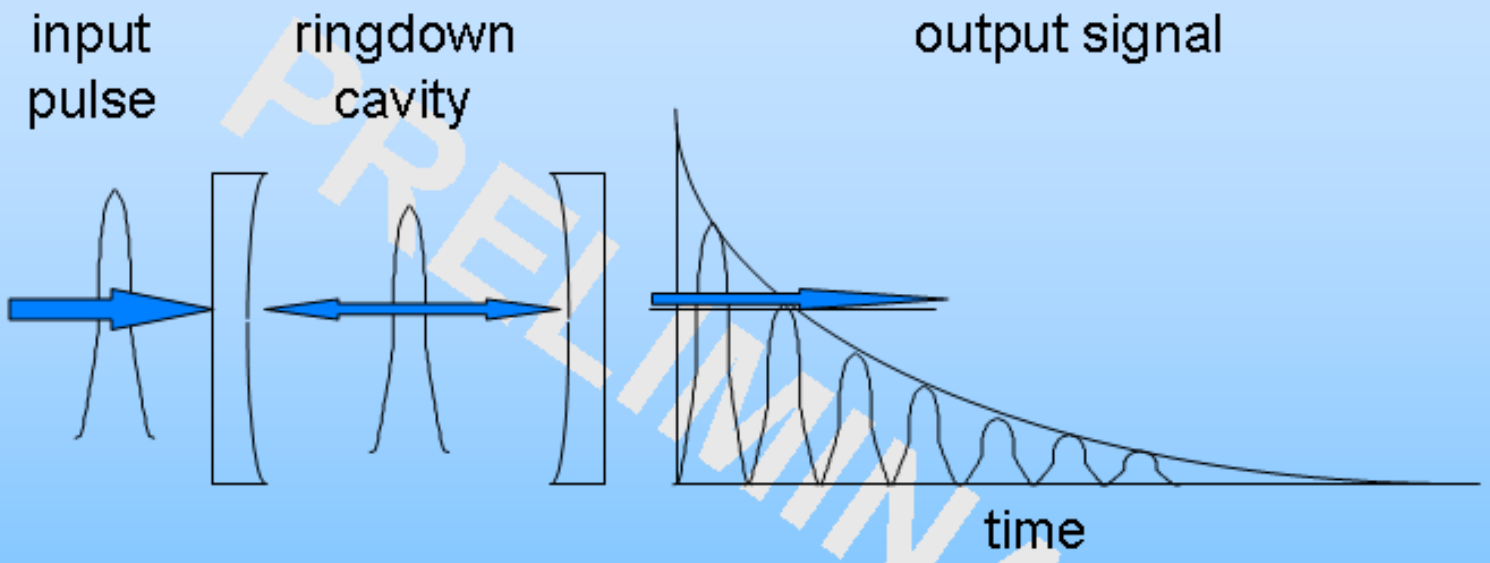
DRI Photoacoustic Instrument



DRI Photoacoustic Instrument: Interior



What is Cavity Ringdown (CRD)?



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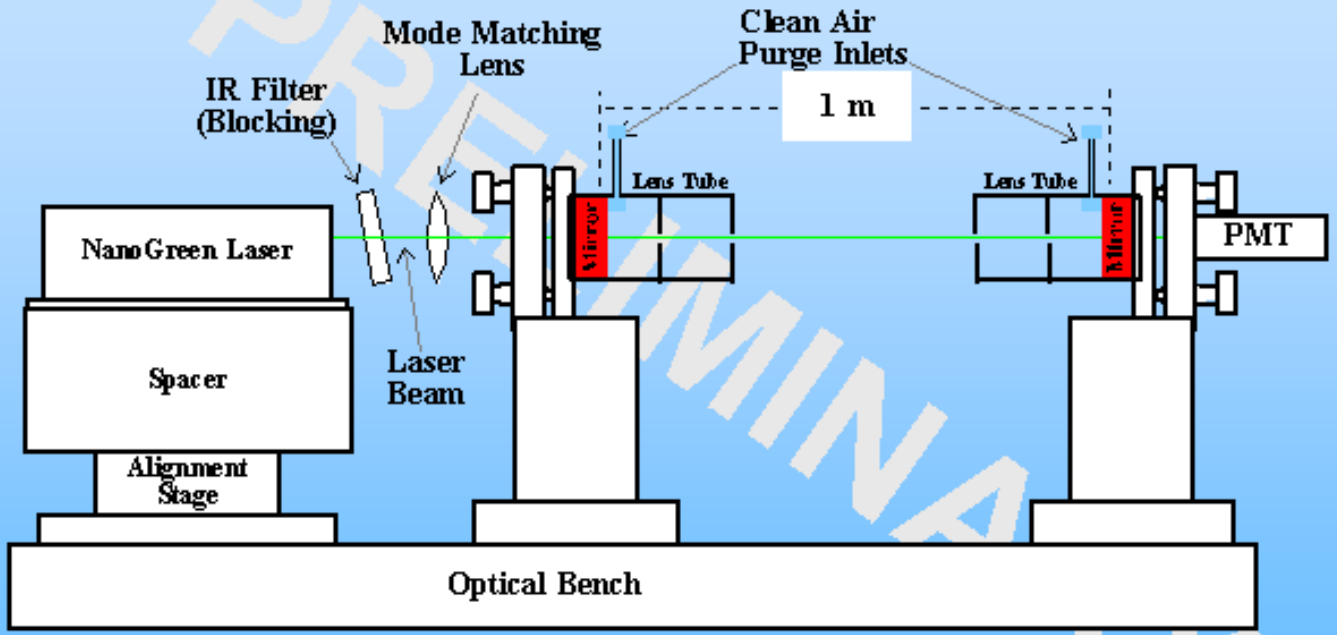
- input pulse width ~ 20 nanoseconds
- mirror reflectivity > 99.995%
- ring-down time 5-100 microseconds

DRI CRD Extinction Instrument



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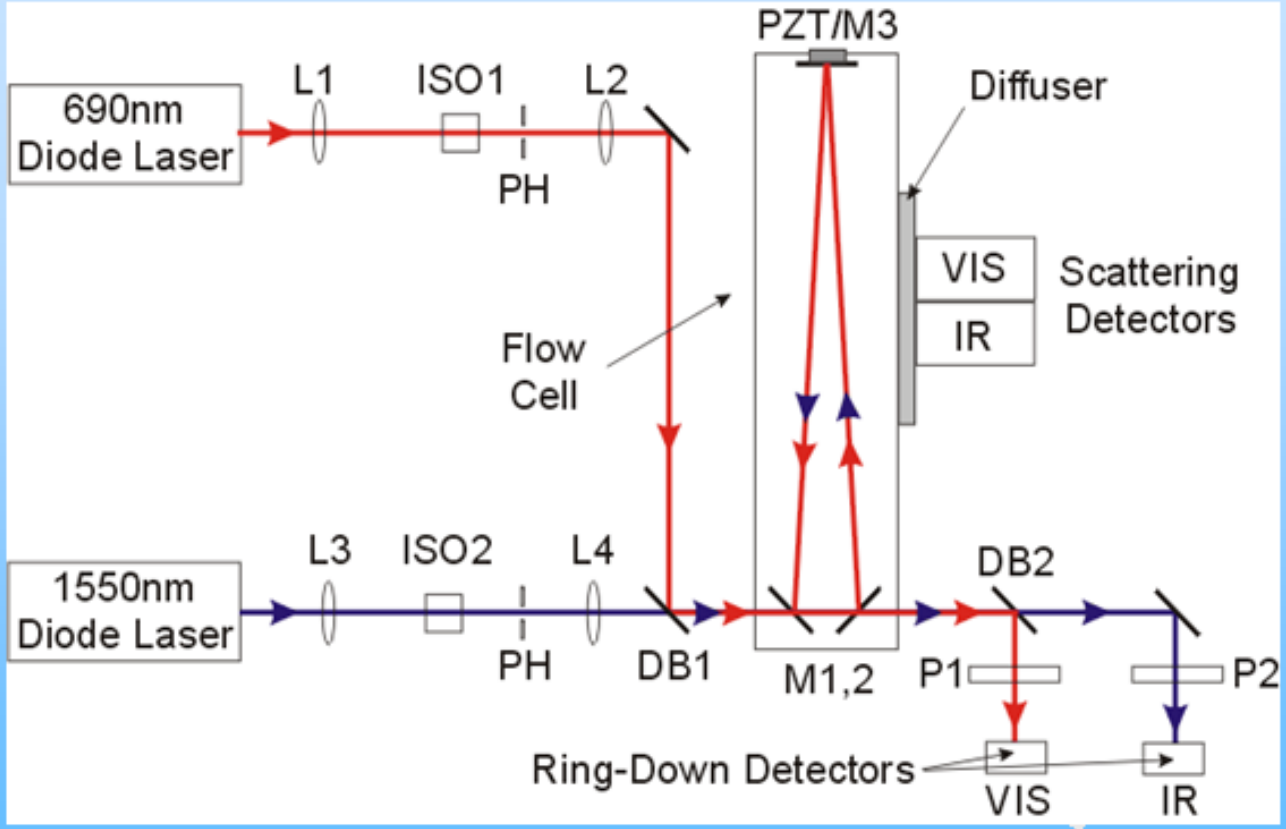
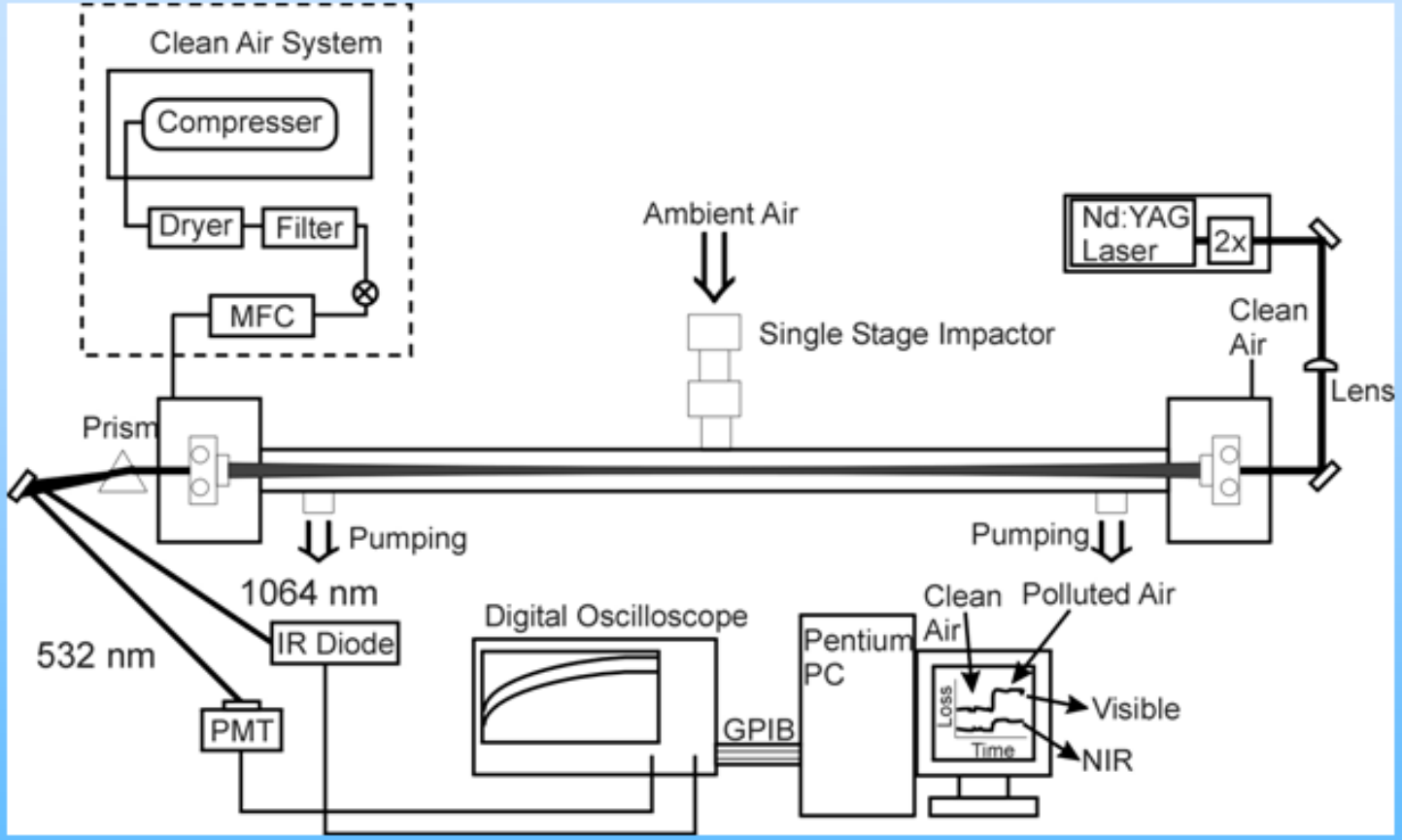
extinction measured at 532 nm
effective path length ~10 km

NASA/Ames CRD Instrument



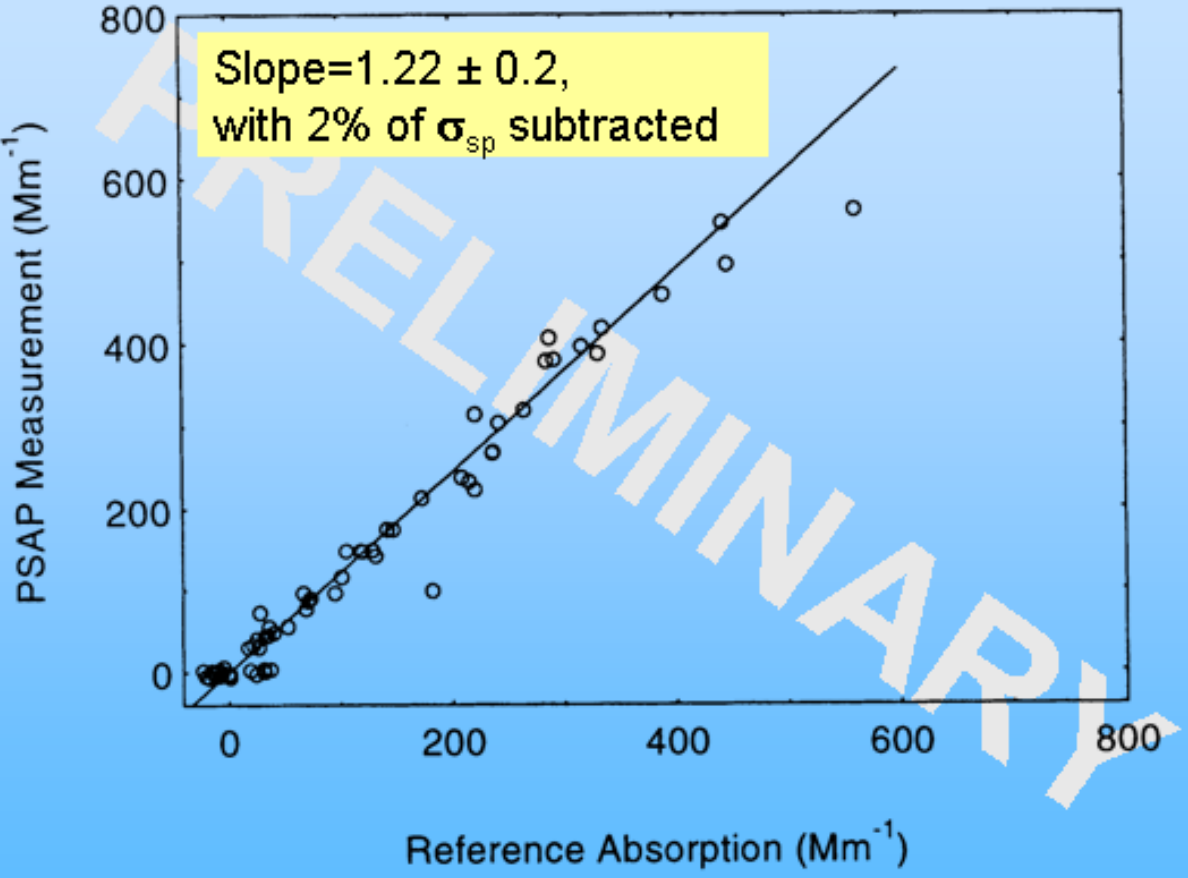
extinction measured at 690 and 1550 nm
scattering measured at 690 nm

Portland State U. CRD Instrument



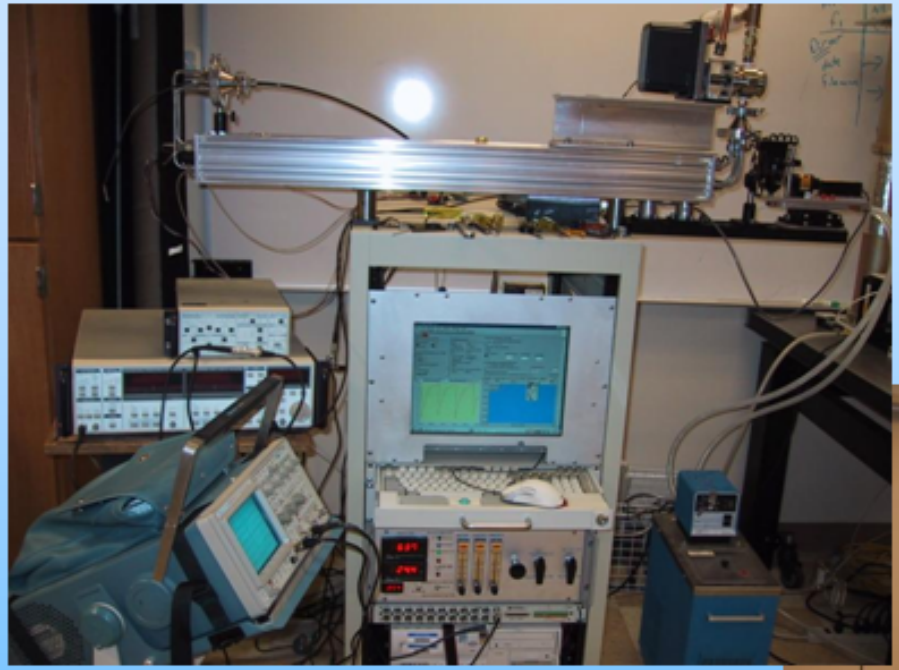
extinction measured at 532 and 1064 nm

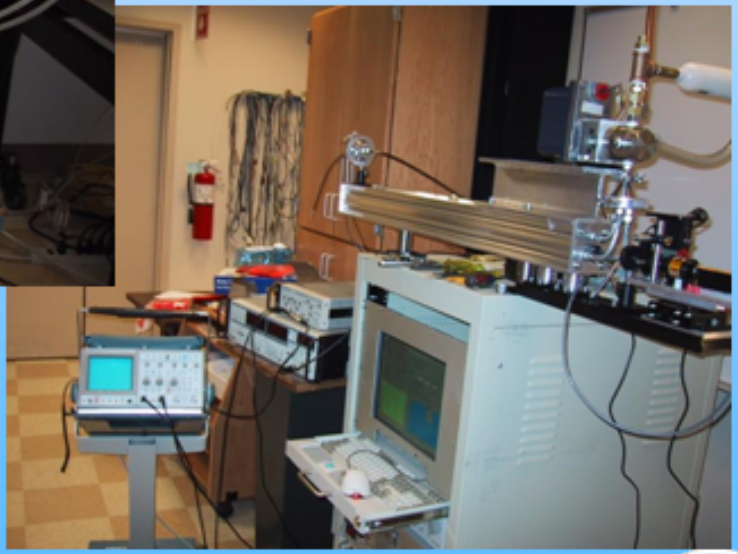
PSAP Calibration Results



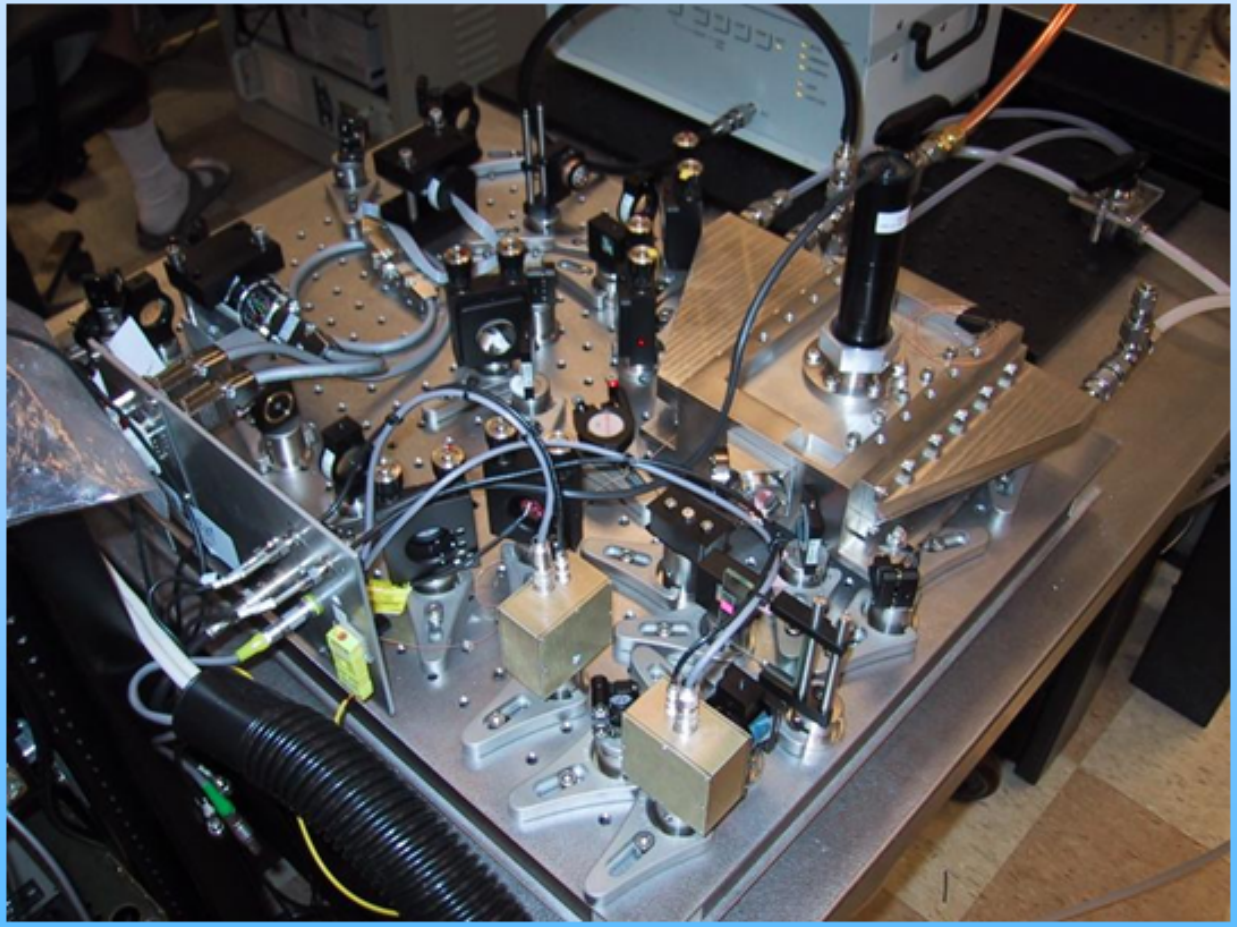
Source: Bond et al. (1999)

DRI CRD Extinction Instrument

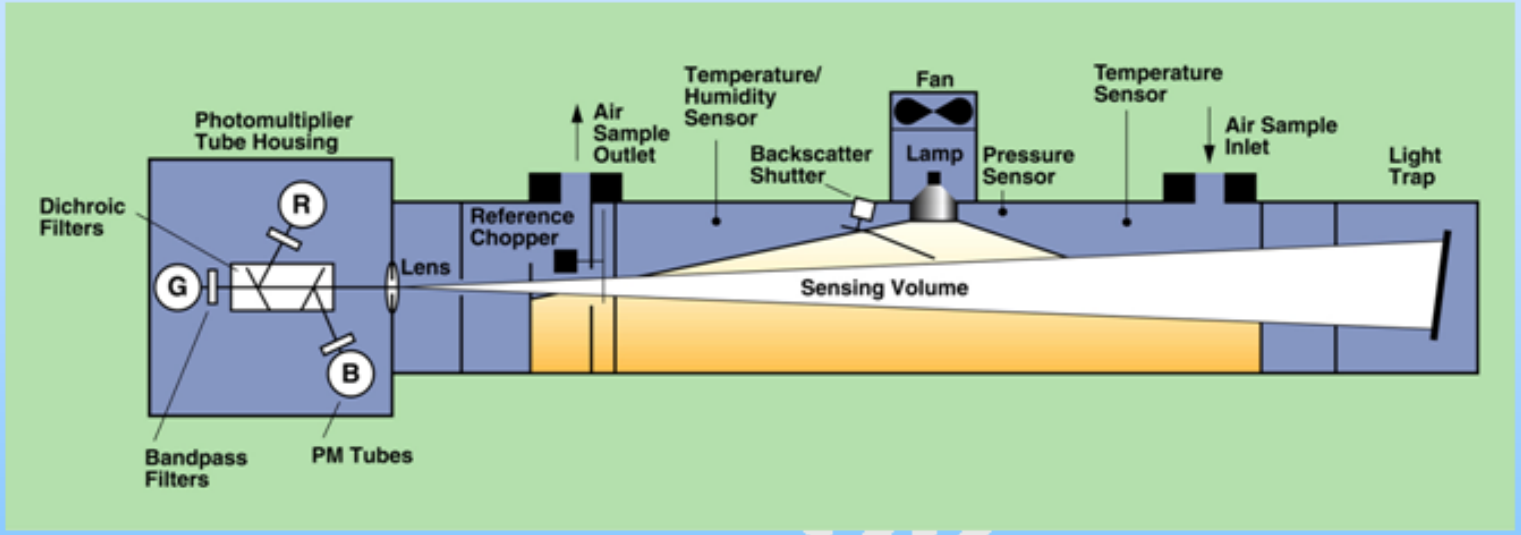




NASA/Ames CRD Instrument



TSI 3563 Integrating Nephelometer



Wavelengths: 450, 550, 700 nm

Bandwidth: 40 nm FWHM

Angular range: 7-170° (total), 90-170° (backscatter)

Sensitivity: 2-3 x 10^{-7} Mm^{-1} (60-sec average)

Source: TSI, Inc.

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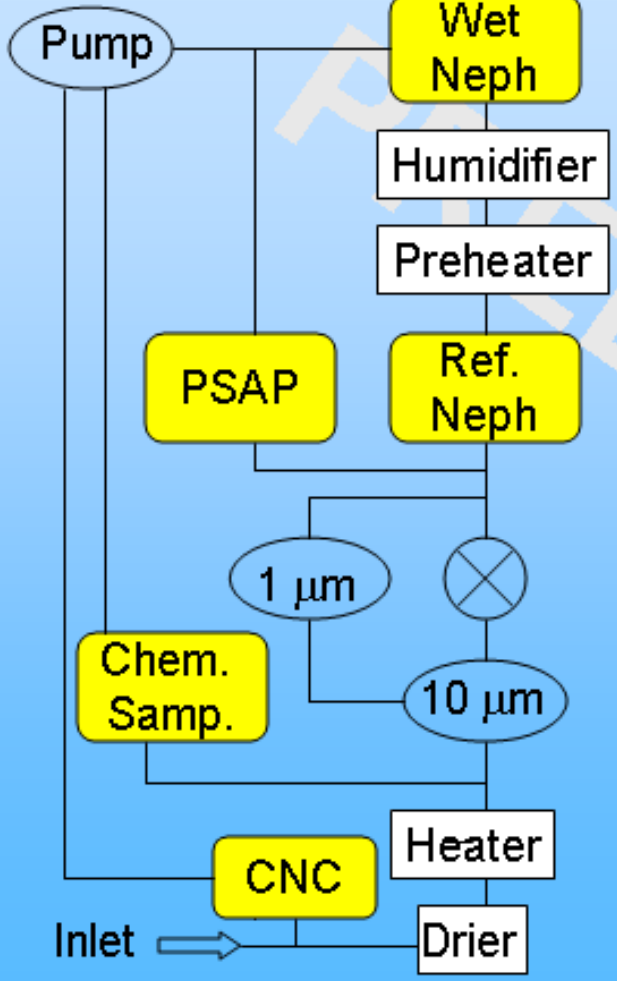
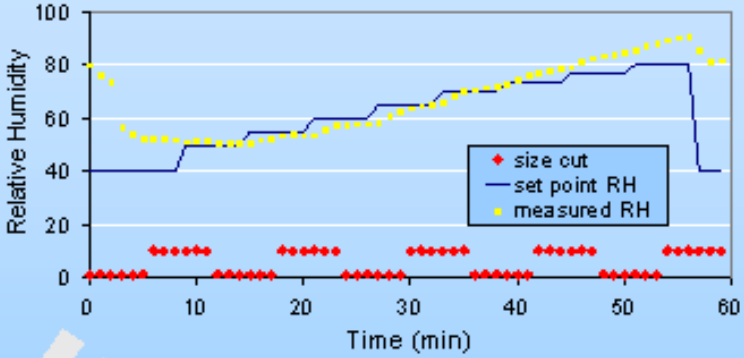
CMDL Humidograph System





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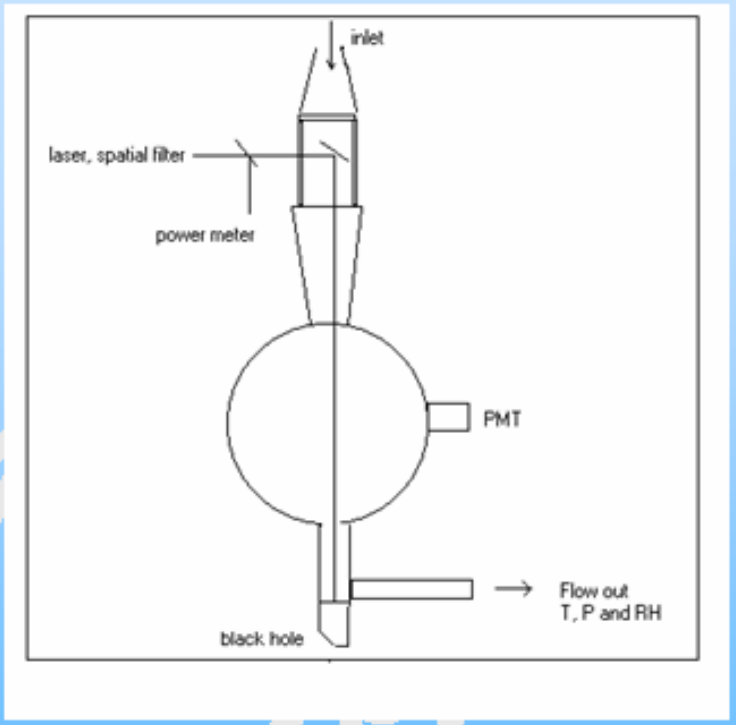
DRI Integrating Sphere Nephelometer



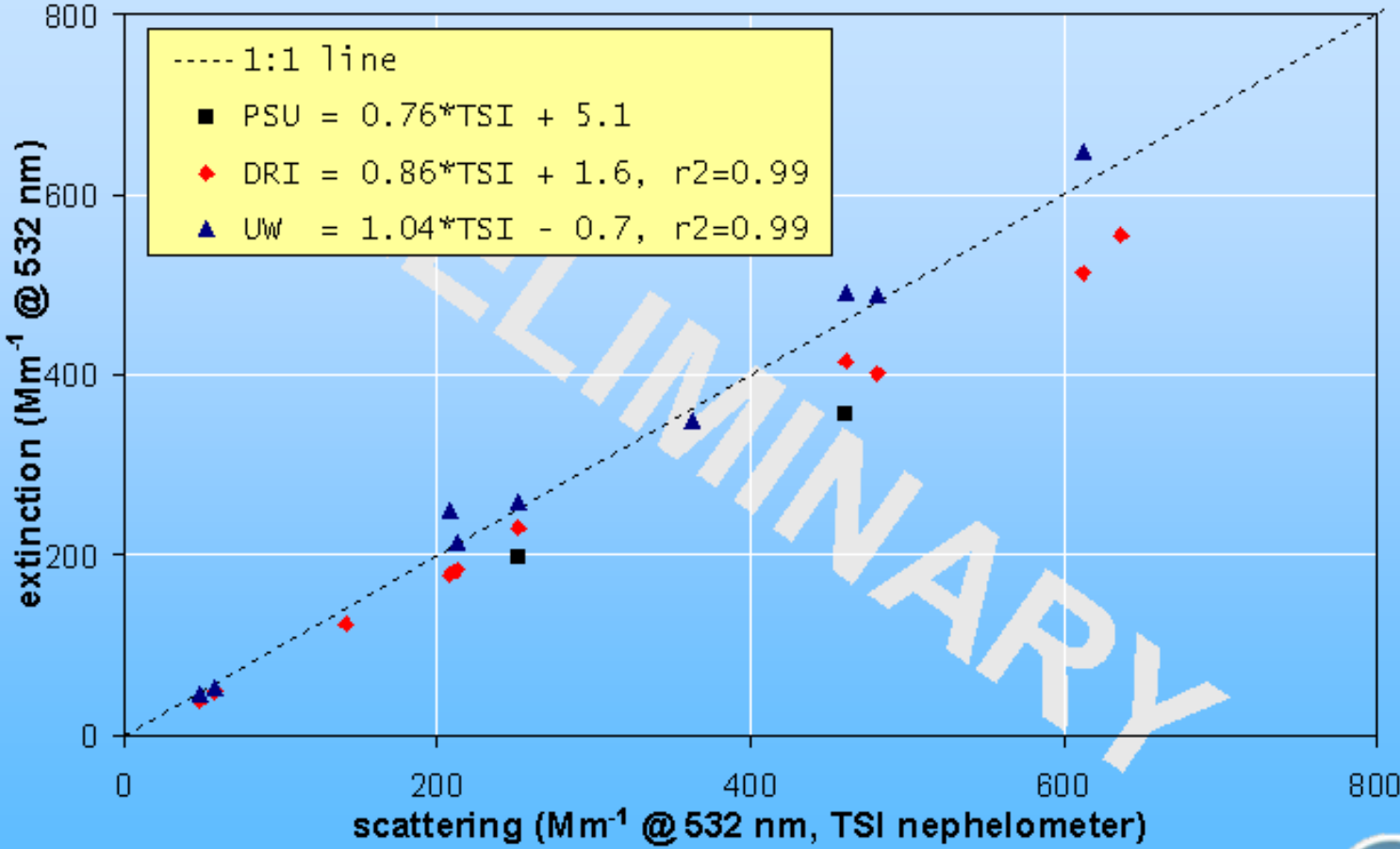
Advantage: integrating sphere yields a truncation angle of < 1 degree, important for supermicron particles

Calibration Standards

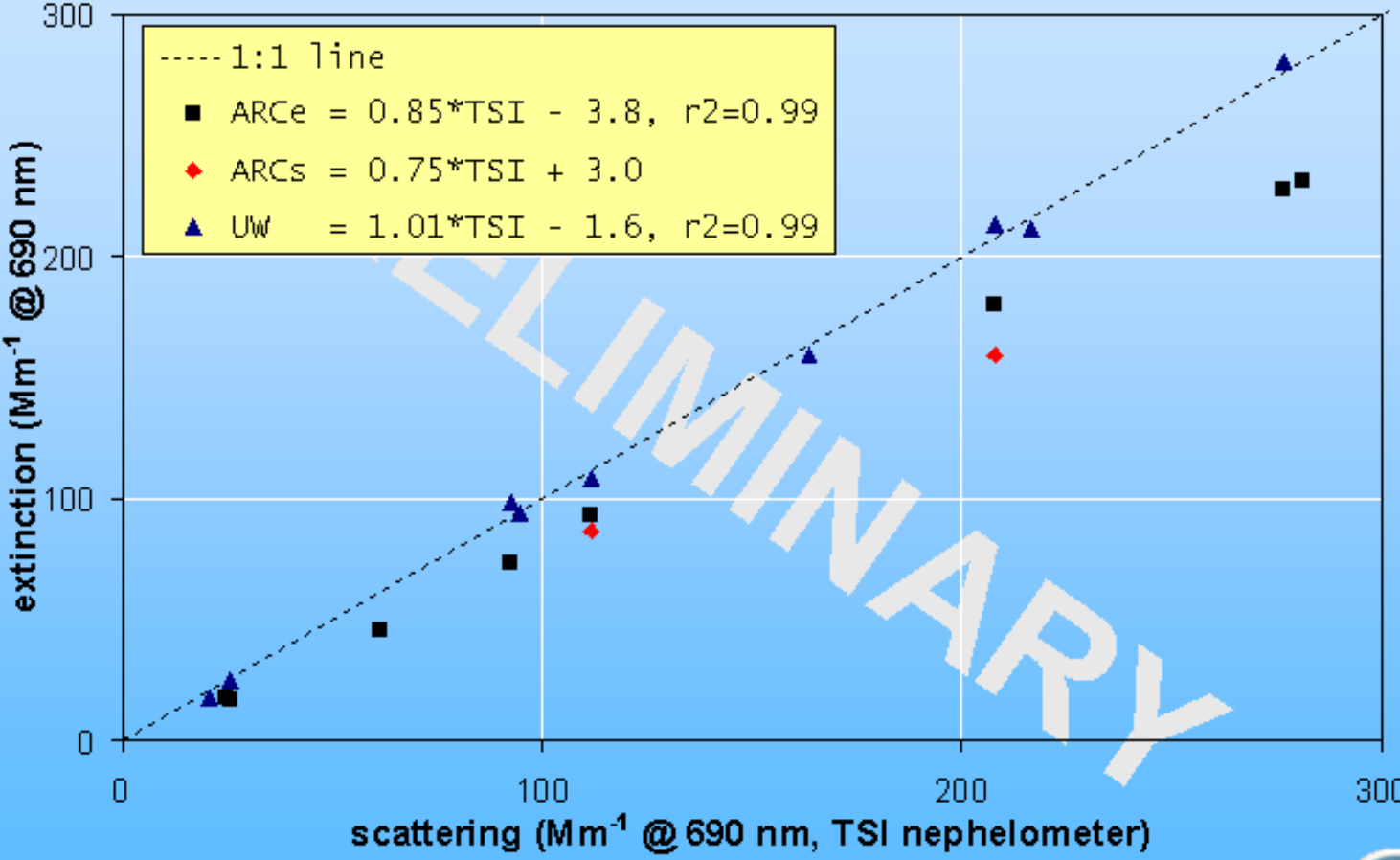
- **Scattering (nephelometer), ~10% accuracy**
  - published scattering cross-sections for CO_2 and air at STP
  - internal temperature and pressure sensors
  - wall and air signals removed by measurements of filtered air
  - truncation corrections for aerosol samples based on measured Ångström exponents (typically ~2%)
  - measured wavelength response of TSI nephelometer
- **Extinction (long-path cell), ~x% accuracy**
  - measured geometry (path length), adjusted for purge flow at ends of cell (0.x%)
  - internal temperature, external pressure sensors
  - wall and air signals removed by measurements of filtered air
  - manufacturer's wavelength response of light source and detector
- **Absorption (photoacoustic), ~x% accuracy**
  - measured geometry (path length) and measured extinction of NO_2
  - internal temperature and pressure sensors

PRELIMINARY

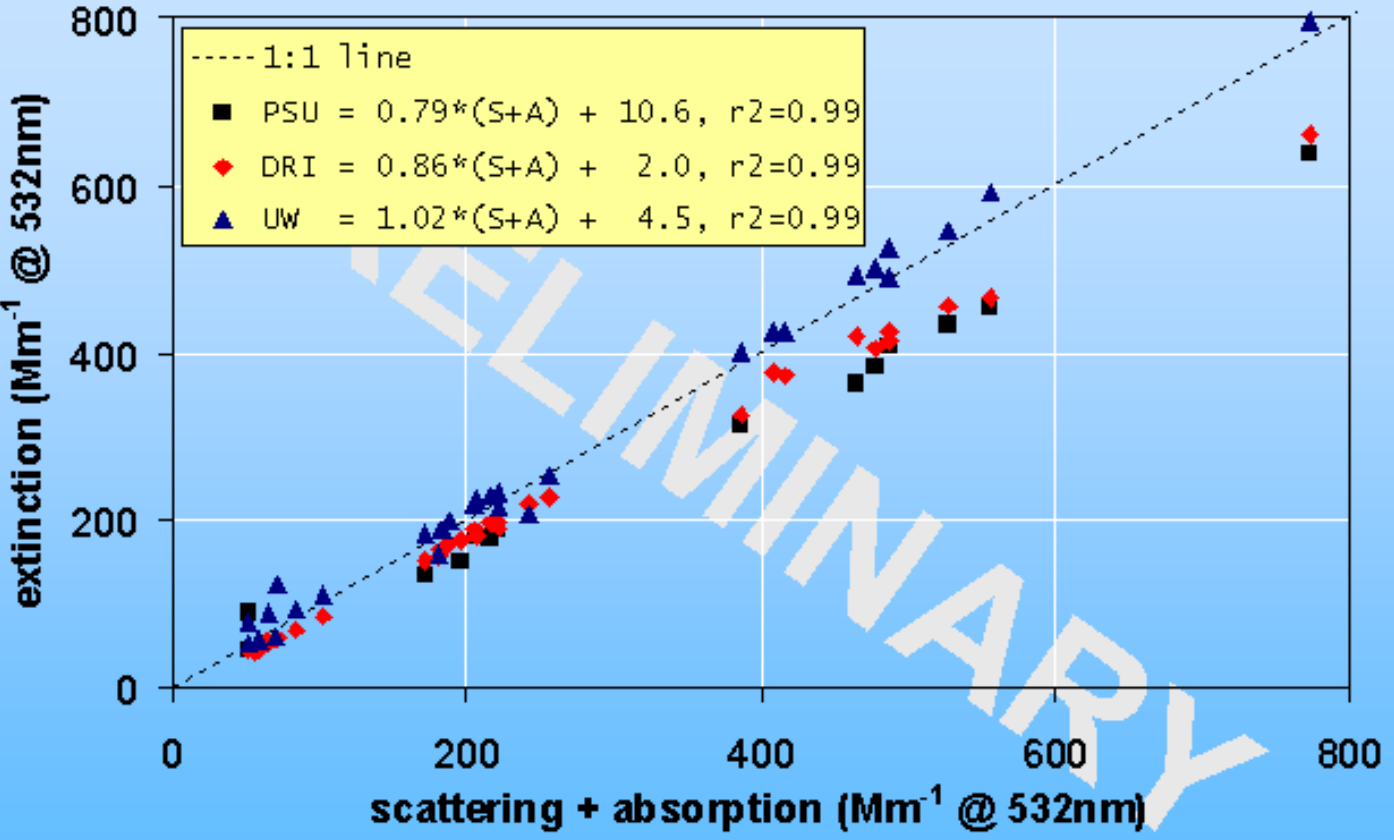
Extinction by White Aerosols (532nm)



Extinction by White Aerosols (690nm)



Extinction by Gray Aerosols (532nm)



Notes: Data points represent kerosene soot runs with varying amounts of ammonium sulfate. Scattering measured with TSI nephelometer, absorption with DRI photoacoustic instrument.

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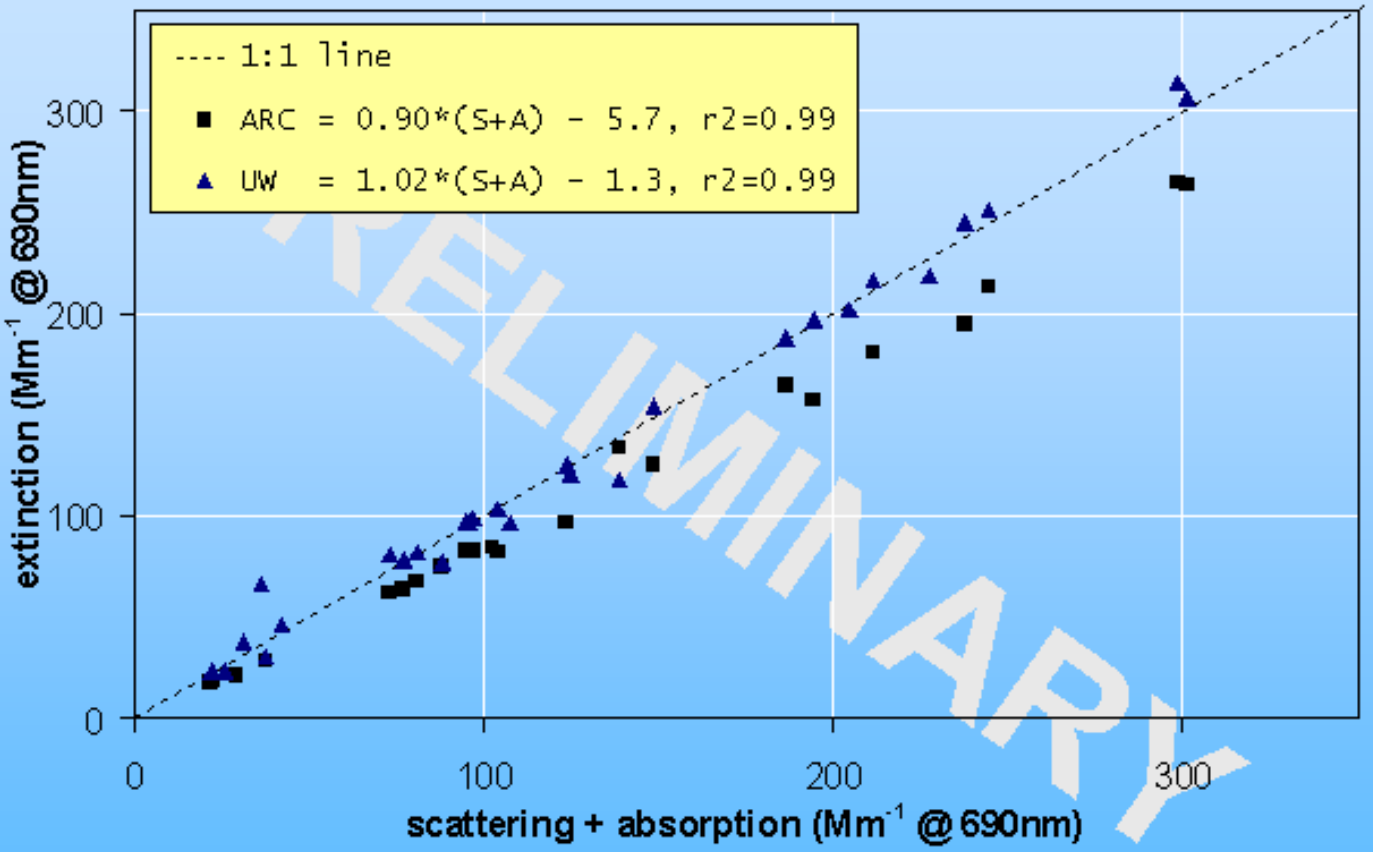
Extinction by Gray Aerosols (690nm)



Notes: Data points represent kerosene soot runs with varying amounts of ammonium sulfate. Scattering measured with TSI nephelometer, absorption with DRI photoacoustic instrument.

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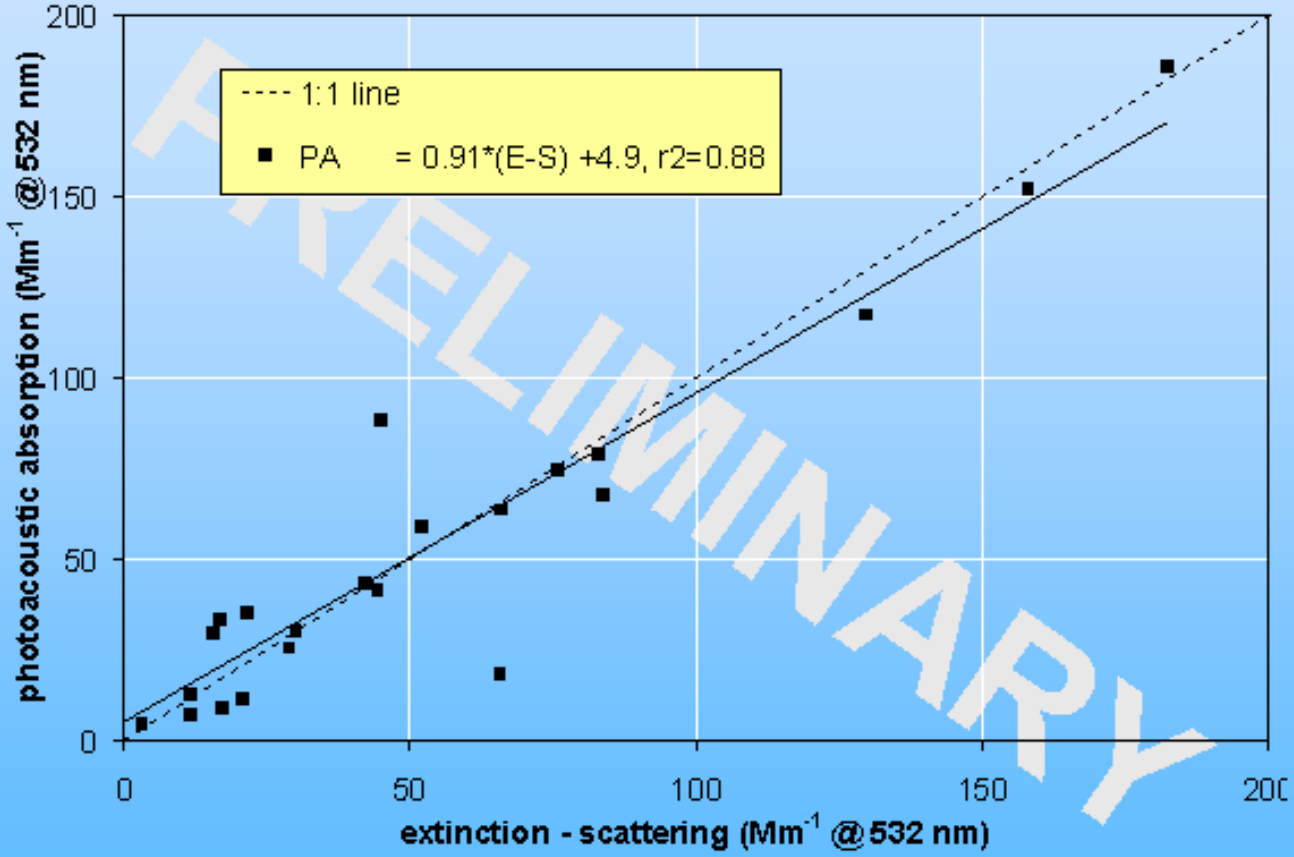
Agreement of Absorption Standards



Notes: Data points represent kerosene soot runs with varying amounts of ammonium sulfate. Extinction data were adjusted to agree with scattering measurements on white aerosols (~4% adjustment).

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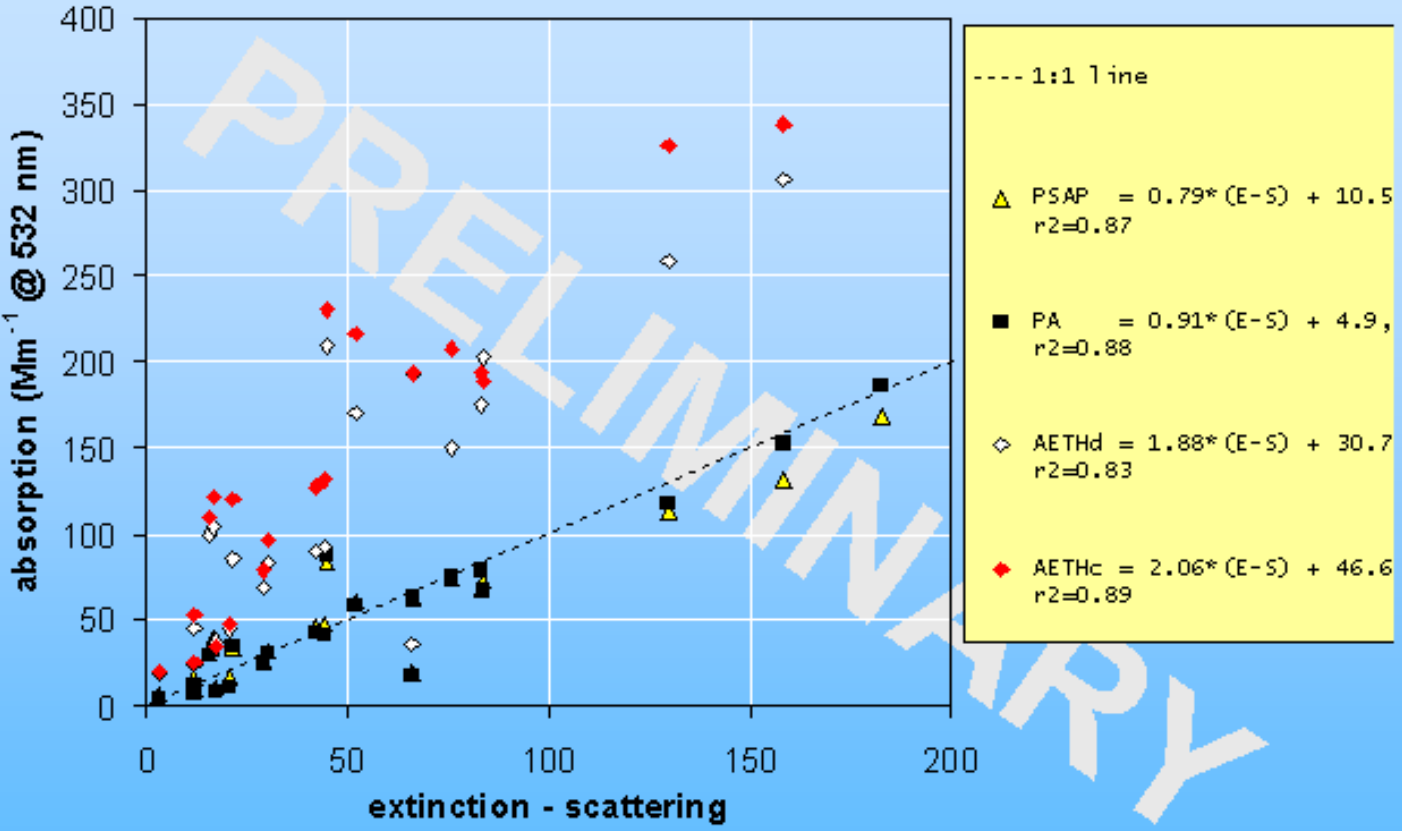
Absorption Comparison (532 nm)



Notes: Data points represent kerosene soot runs with varying amounts of ammonium sulfate. Extinction data were adjusted to agree with scattering measurements on white aerosols (~4% adjustment).

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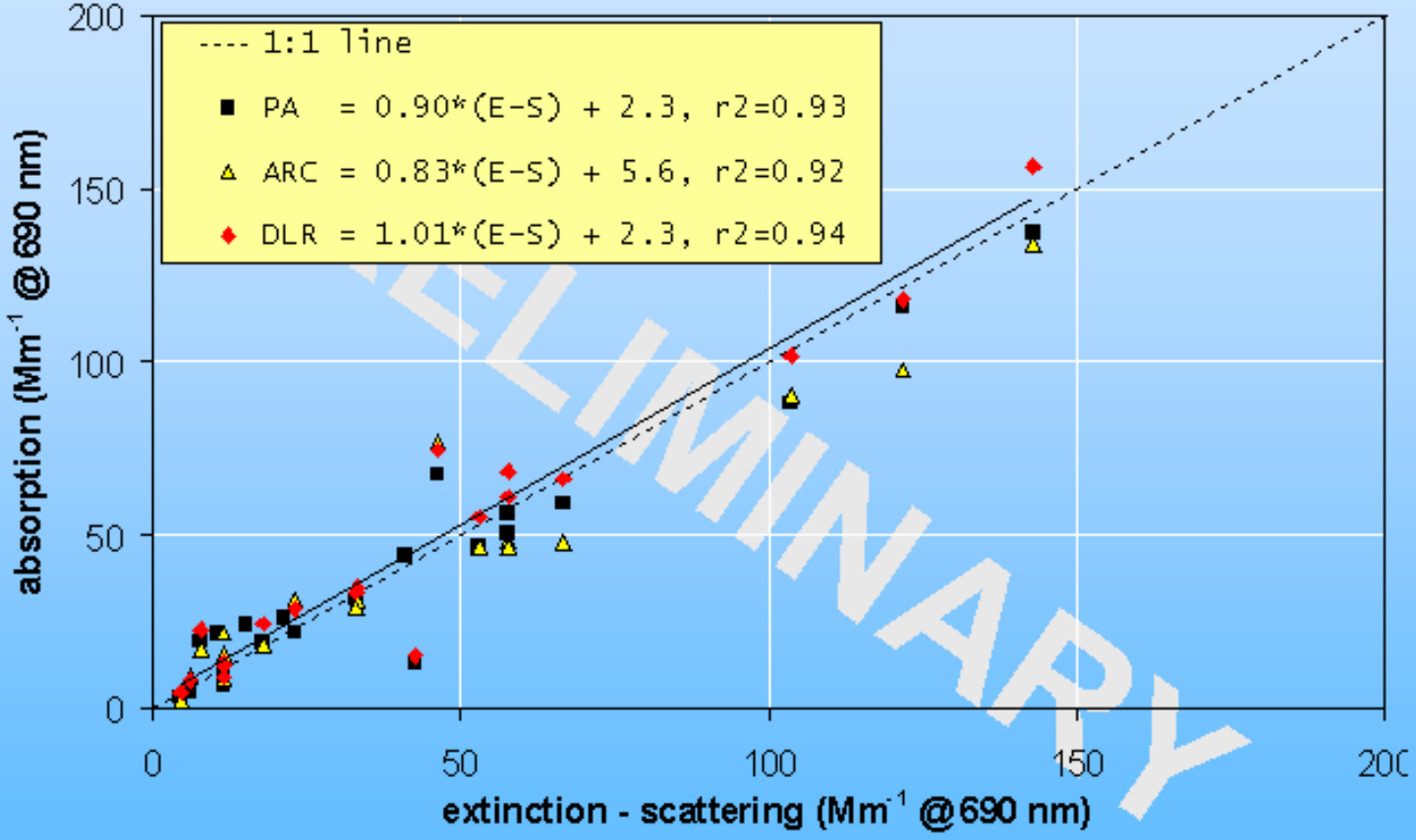
Absorption Comparison (690 nm)



Notes: Data points represent kerosene soot runs with varying amounts of ammonium sulfate. Extinction data were not adjusted to agree with scattering measurements on white aerosols (<1% difference).

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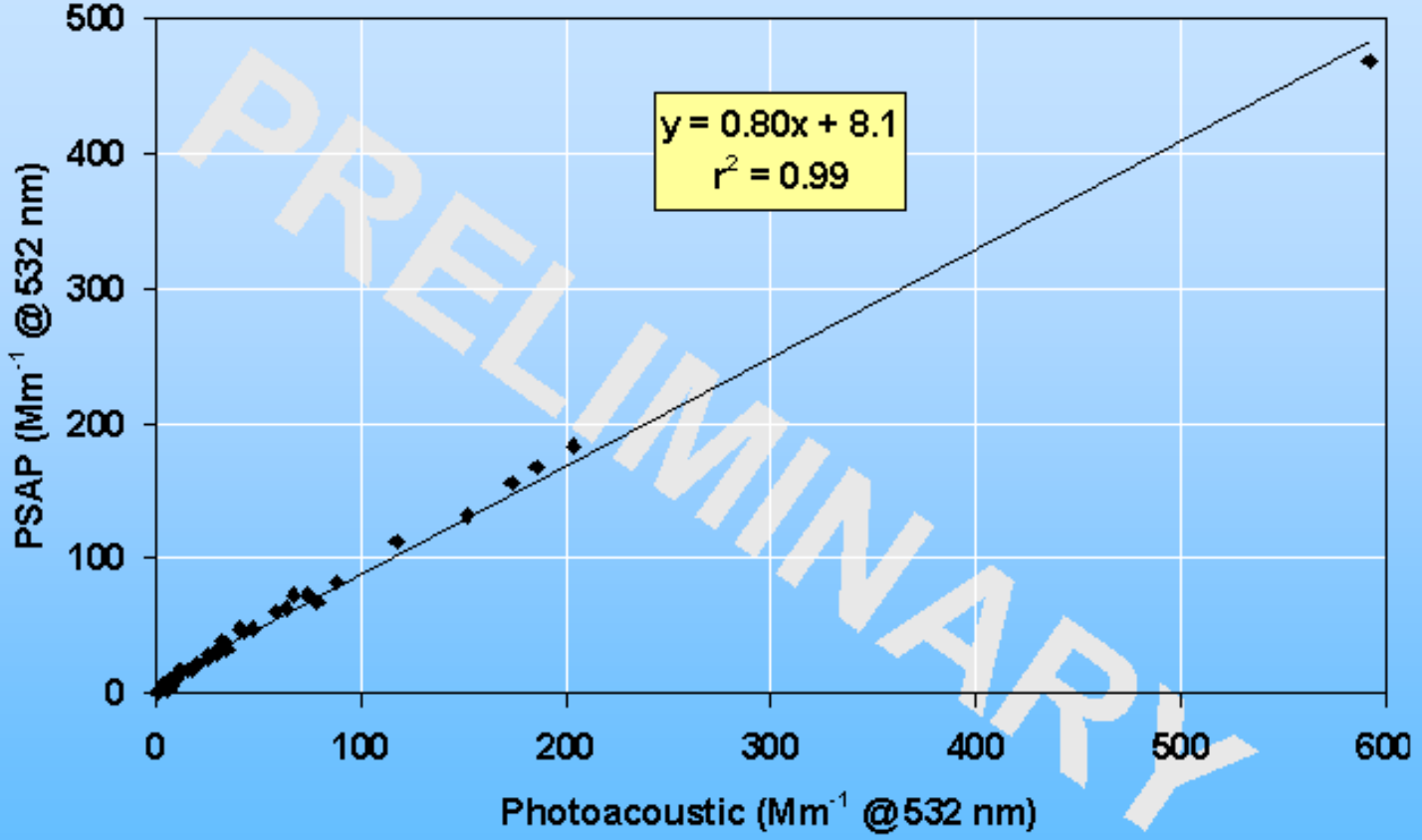
Reno2002 Light Absorption Comparison



Notes: Data points represent all kerosene soot runs with varying amounts of ammonium sulfate. Bond et al. (1999) corrections applied to PSAP data. PSAP wavelength adjusted to 532 nm assuming a λ^{-1} dependence.

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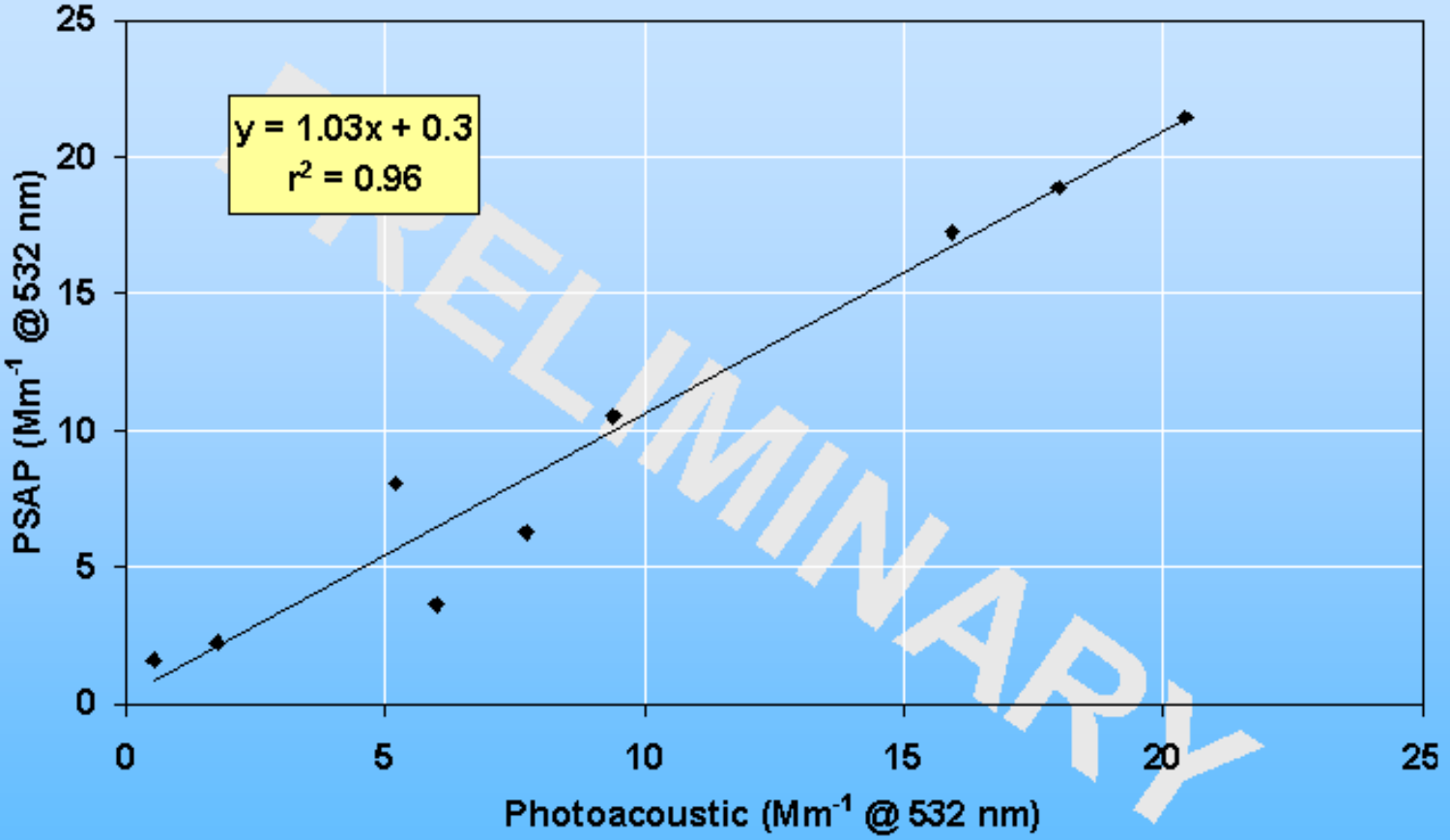
Reno2002 Light Absorption Comparison



Notes: Data points represent all ***low-extinction*** kerosene soot runs with varying amounts of ammonium sulfate. Bond et al. (1999) corrections applied to PSAP data. PSAP wavelength adjusted to 532 nm assuming a λ^{-1} dependence.

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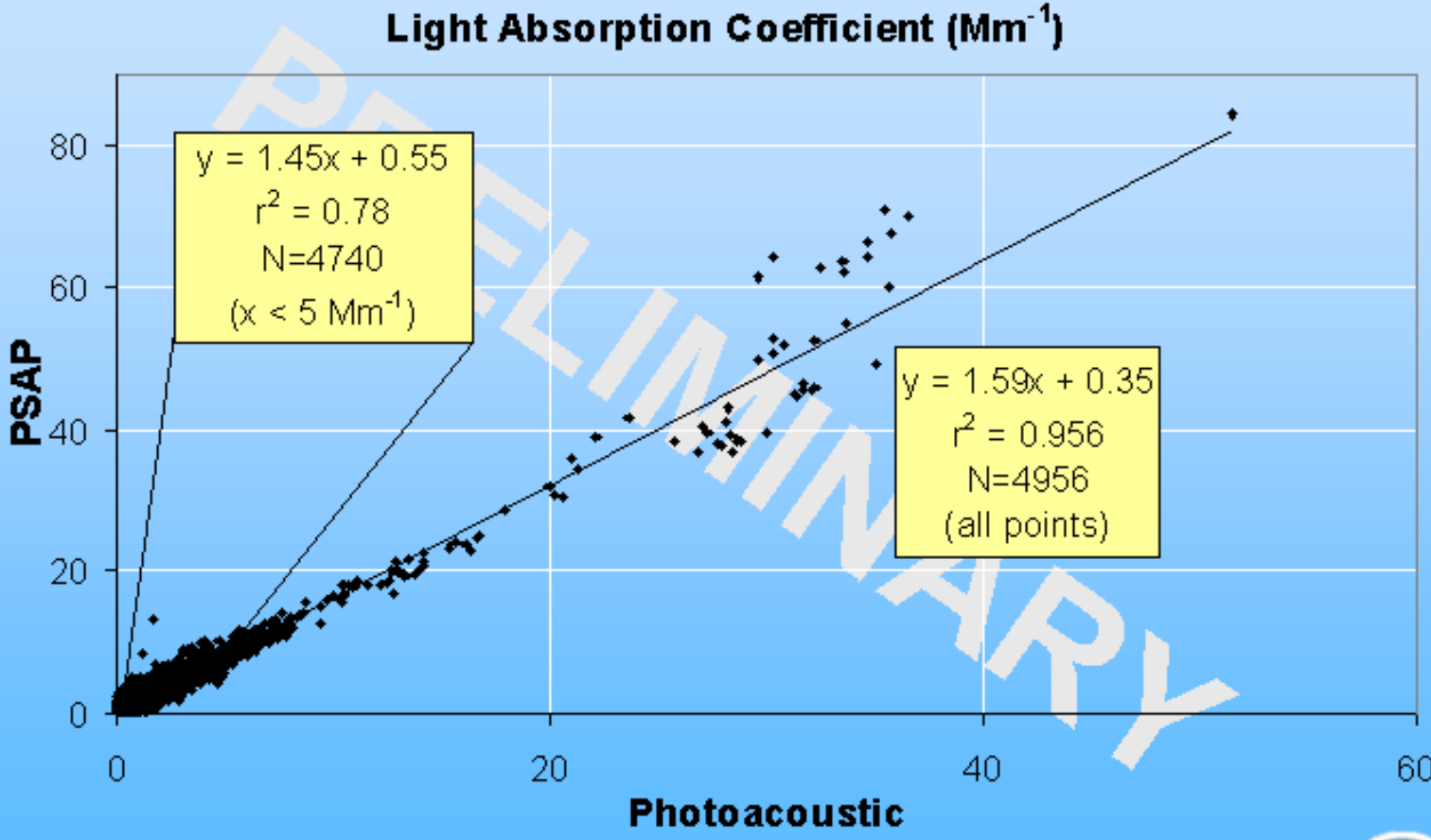
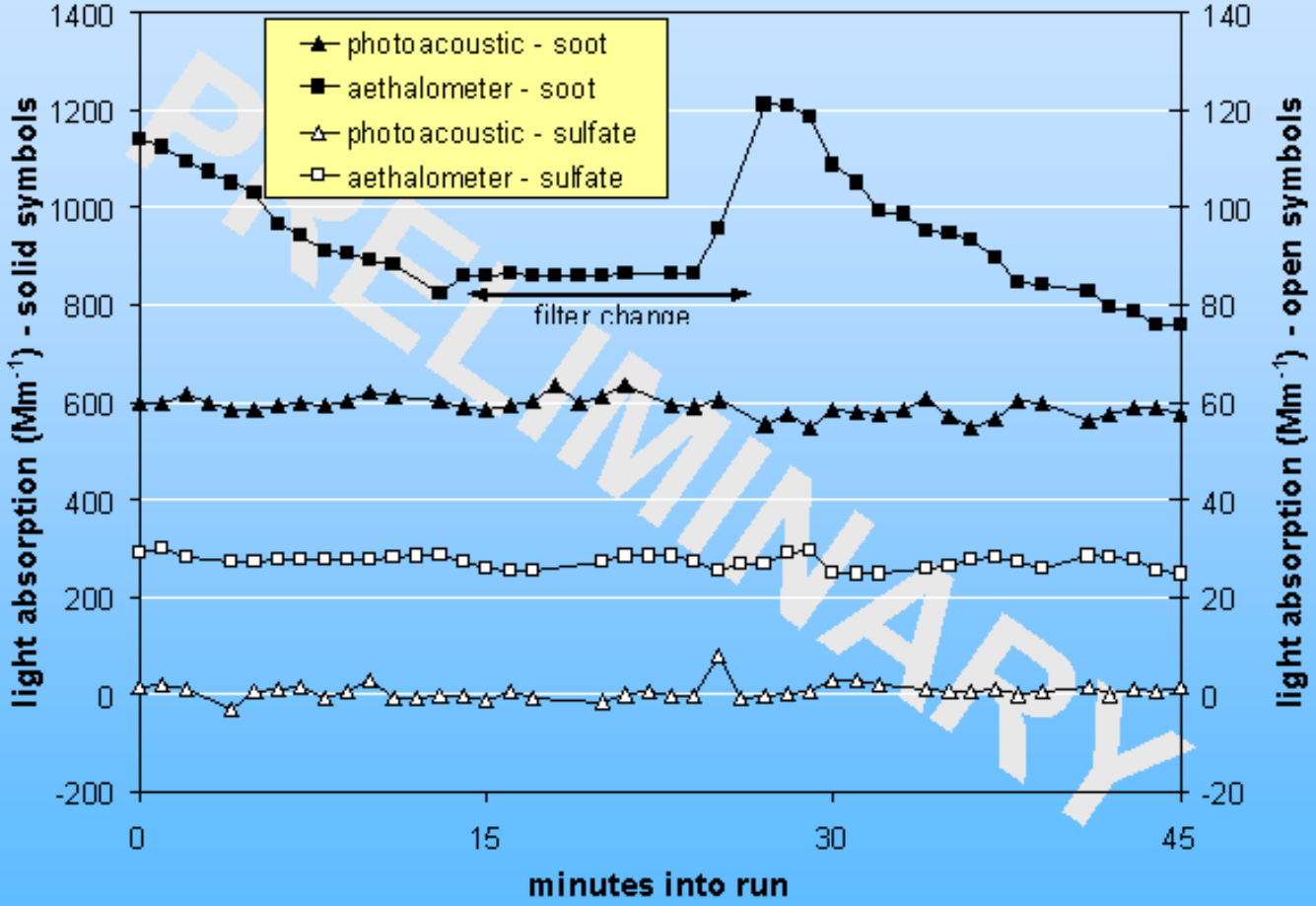
Photoacoustic IOP (SGP 2000)



Aethalometer response vs. time



Separate runs with pure soot (σ_{ext}~800 Mm^{-1}) and ammonium sulfate (σ_{ext}~450 Mm^{-1}). Photoacoustic wavelength 532 nm, aethalometer wavelength 521 nm.

Continuing analyses

- Compare results from kerosene soot with results from diesel soot and carbon vane pump exhaust
- Compare run-averaged results to 1-minute averages
- Derive wavelength-dependence of absorption, to allow application of extinction-minus-scattering calibrations to other wavelengths
- Derive correction schemes for filter-based methods (PSAP and aethalometer) at all measured wavelengths
- Compare results from ambient aerosol samples

PRELIMINARY

Acknowledgements

- **Funding support**
  - DOE Atmospheric Radiation Measurements Program
  - NOAA Aerosol-Climate Interactions Program
- **Project planning**
  - ARM Aerosol Working Group
- **Data reduction and analysis**
  - E. Andrews (NOAA/CMDL)

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