


UCR

Understanding the Hygroscopic Properties of BC/OC Mixing States: :

Connecting Climate and Health Impacts of Anthropogenic Aerosol

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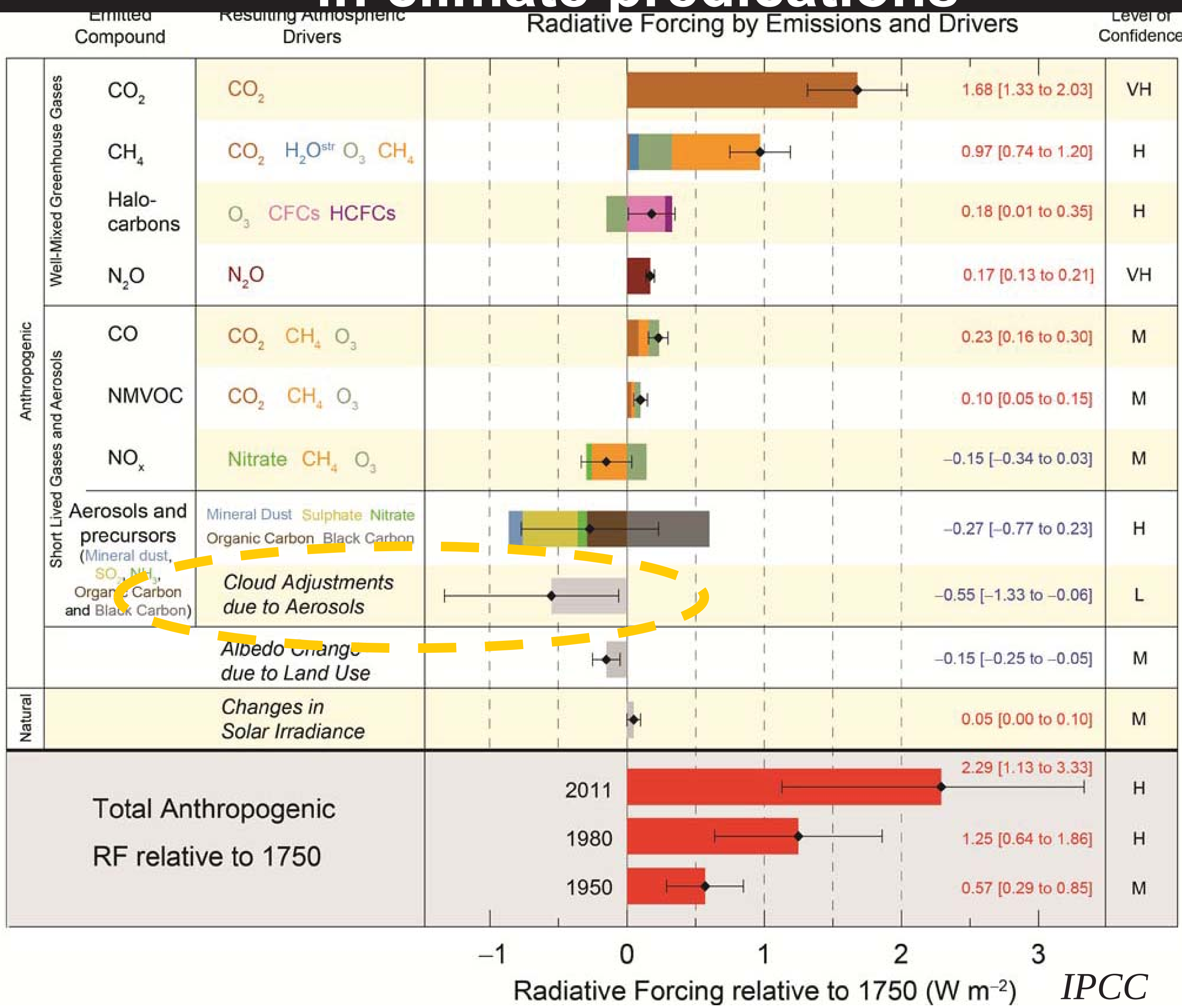
Center of Environmental Research and Technology

Funding: EPA Black Carbon STAR

November 13th, 2014

UNIVERSITY OF CALIFORNIA, RIVERSIDE

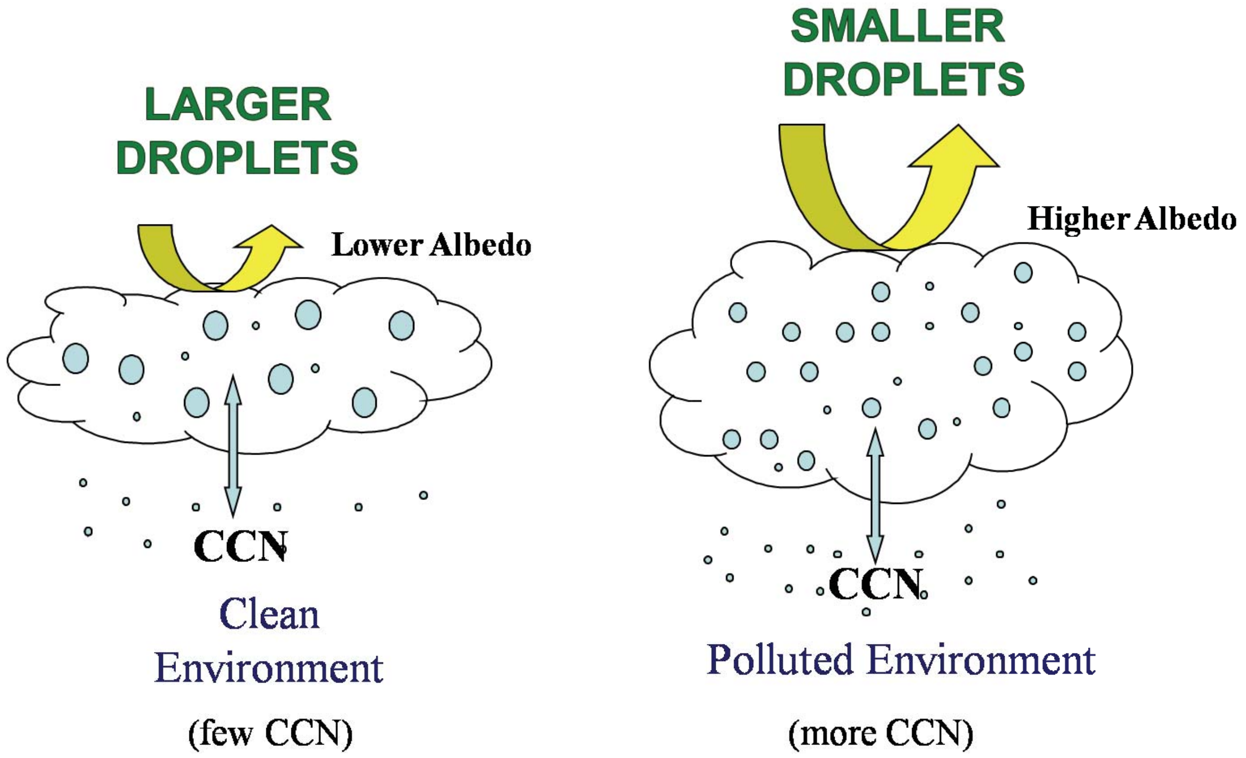
Clouds contribute the greatest uncertainty in climate predications



RELEVANT PROPERTIES OF COMPLEX CCN

Cloud condensation nuclei (CCN) activate and become cloud droplets

The ability to be CCN depends on particle size and chemistry



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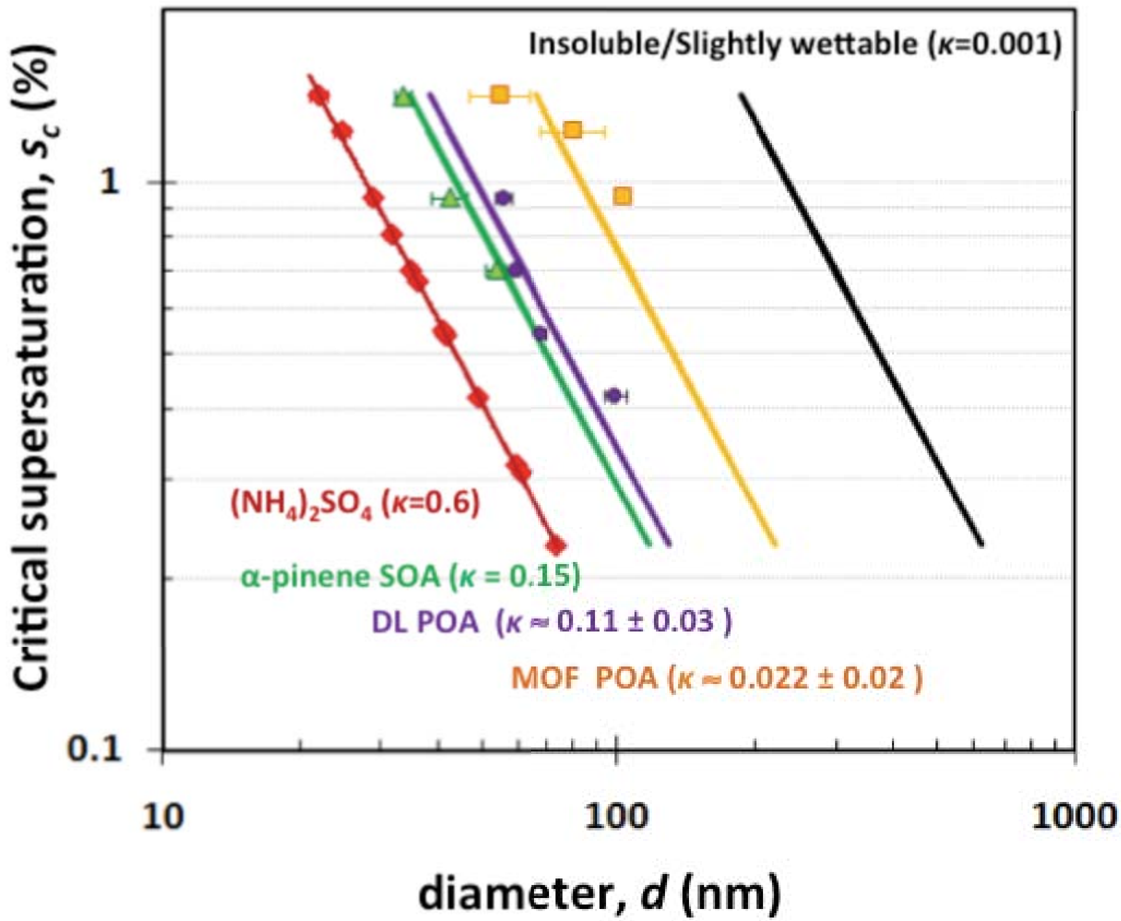
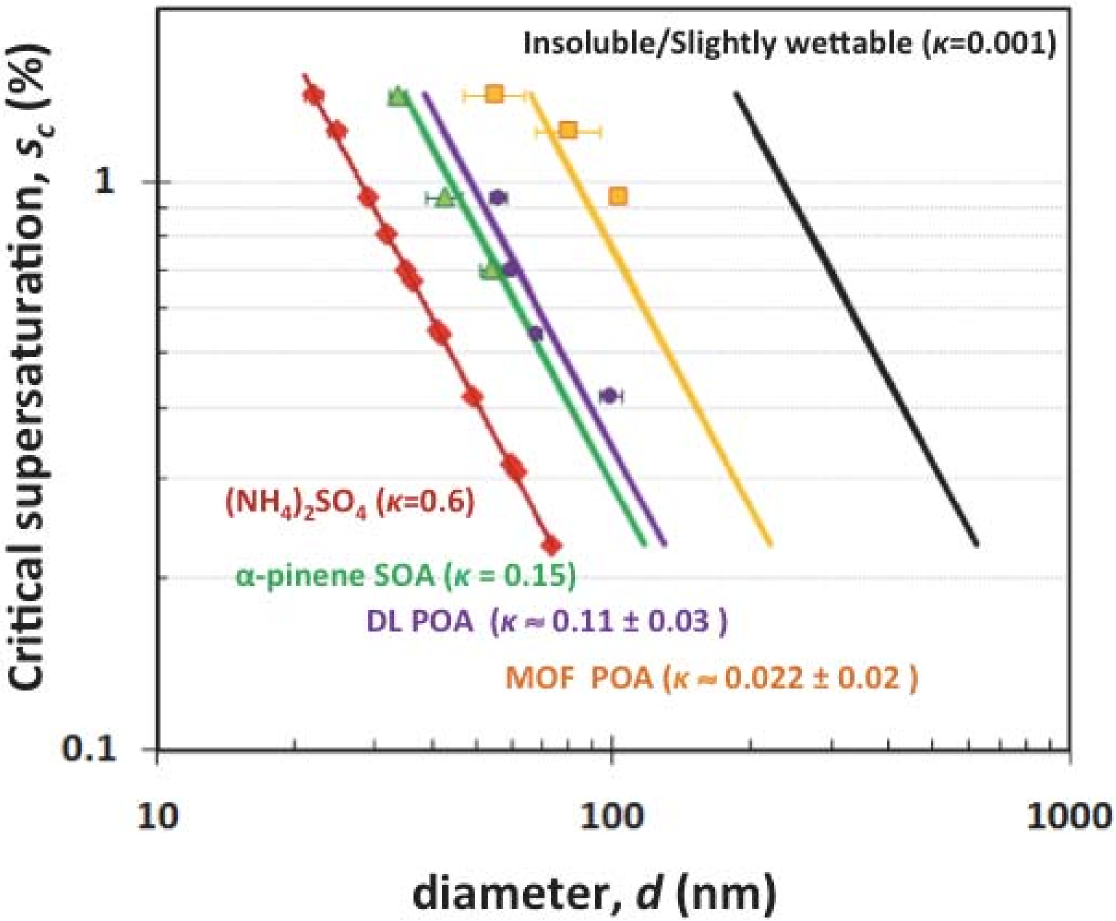


The more complex the aerosol source,

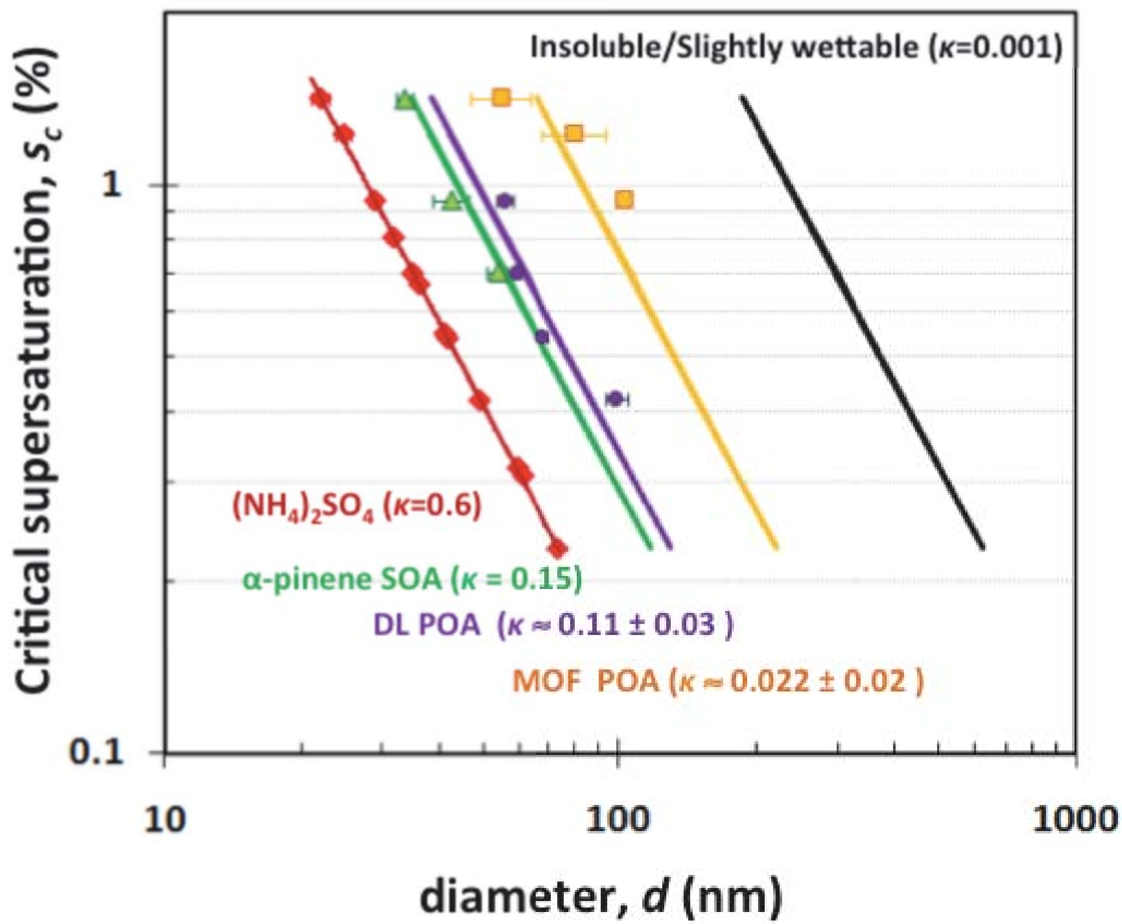
the more difficult it becomes to characterize the changing chemical and physical properties of the CCN.

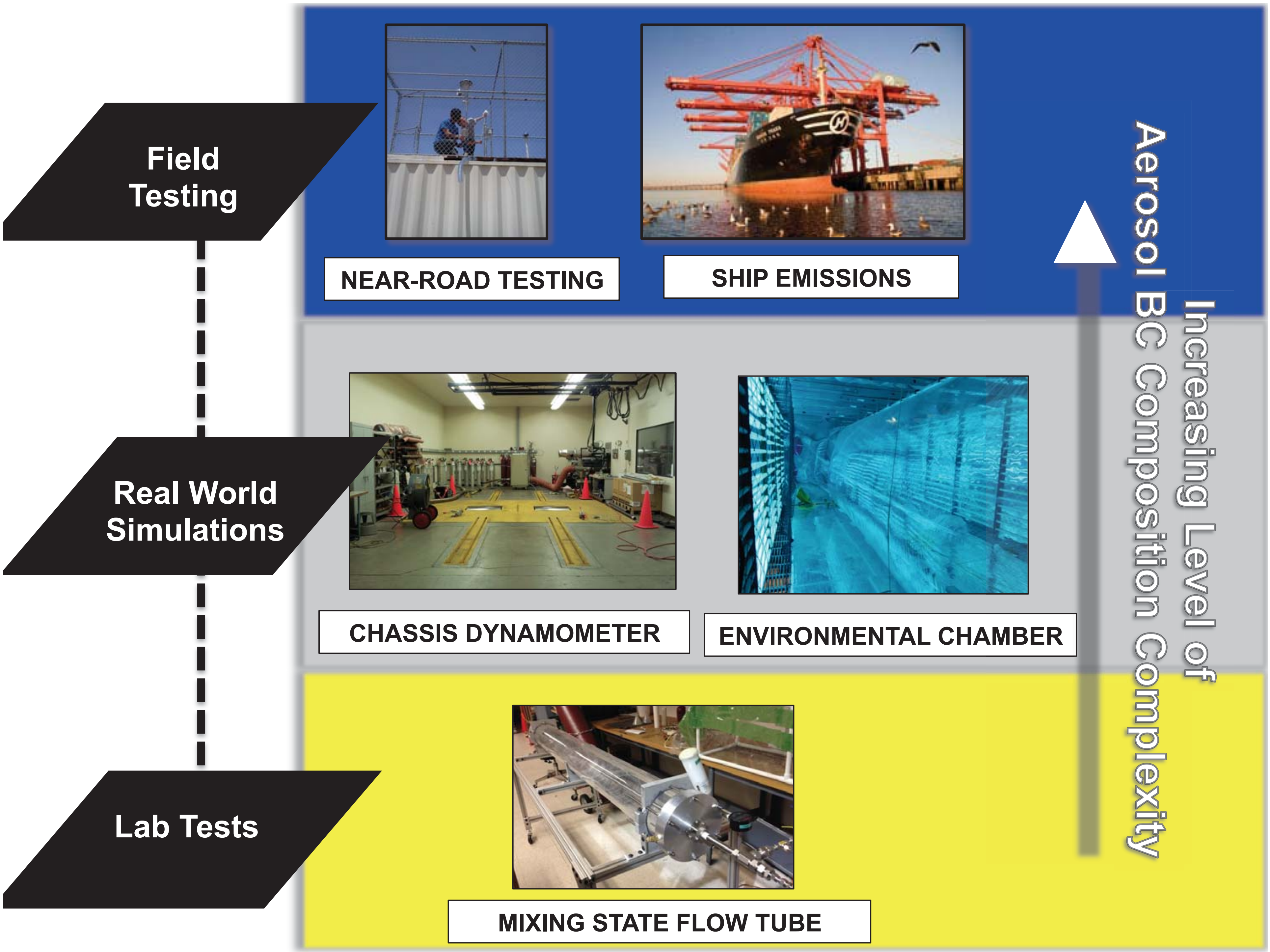


RELEVANT PROPERTIES OF COMPLEX CCN

The apparent hygroscopicity of complex CCN can be modified

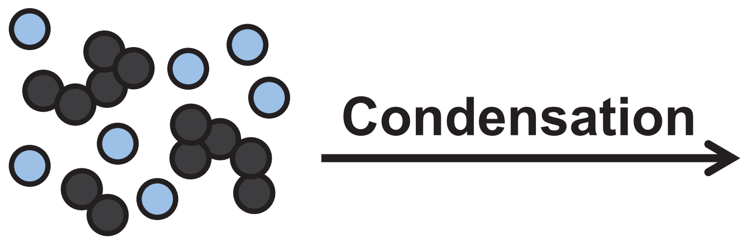
Prevalent assumptions can shift the perceived the single hygroscopicity parameter *κ for complex CCN by 100% or more*

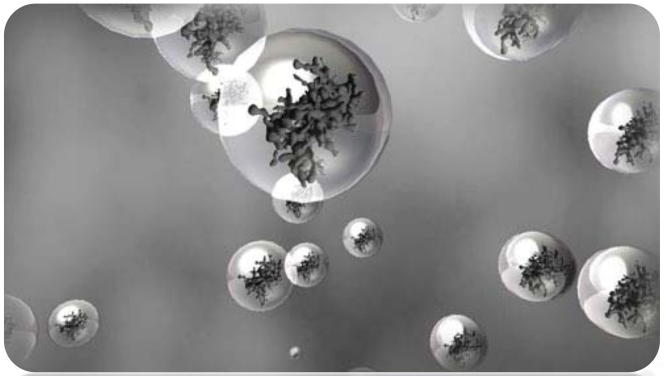




Field Testing
Real World Simulations
Lab Tests
NEAR-ROAD TESTING
SHIP EMISSIONS
CHASSIS DYNAMOMETER
ENVIRONMENTAL CHAMBER
MIXING STATE FLOW TUBE
Increasing Level of Aerosol BC Composition Complexity

OUR APPROACH TO COMPLEX HYGROSCOPIC PARTICLES





Source: NASA : *Black Carbon Cloud Droplets (artist rendition)*

(1) Provide Fast Measurement Techniques for Real-World BC Sources

(2) Characterize changes in Physical and Chemical Properties that can alter perceived Hygroscopicity of BC sources

(3) Refine Analysis Methods for complex CCN Mixing States

NEAR-ROAD TESTING

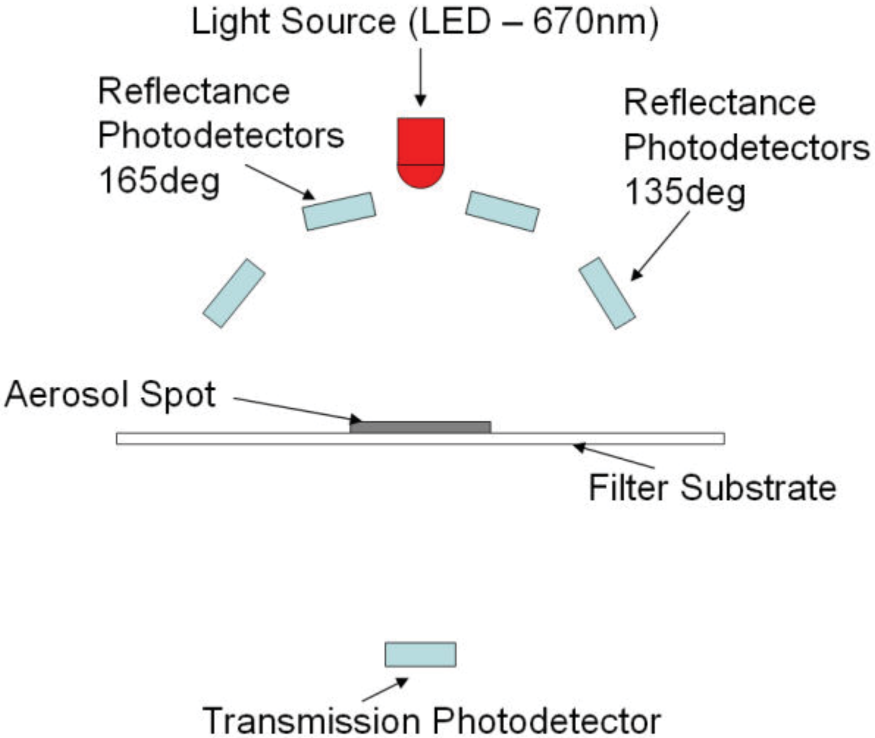
CHASSIS DYNAMOMETER

Part 1:
Vehicle Emission Sources

1) Traffic-related sources are a known emitter of particulate matter and black carbon aerosol
2) Exposure within 30 m of roadway traffic has been known to affect respiratory functions

Multi-Angle Absorption Photometer

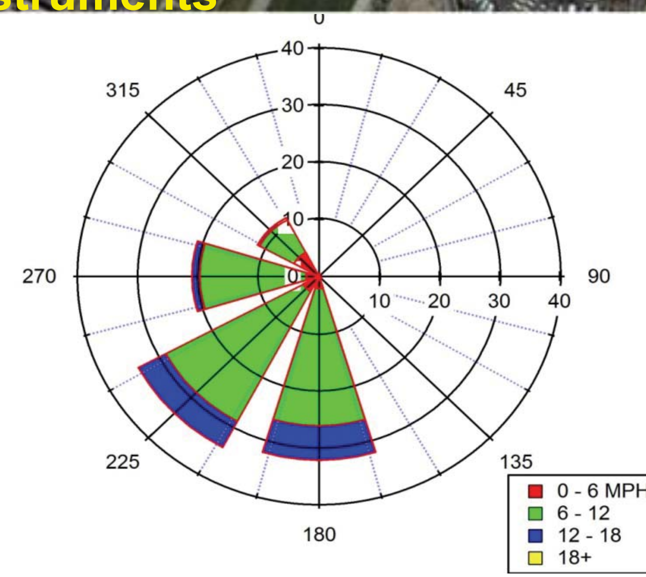
- ★ Black Carbon **(BC)** is measured with a Multi-Angle Absorption Photometer (MAAP)
- ★ The MAAP uses multiple light sources to determine the reflective aerosol properties



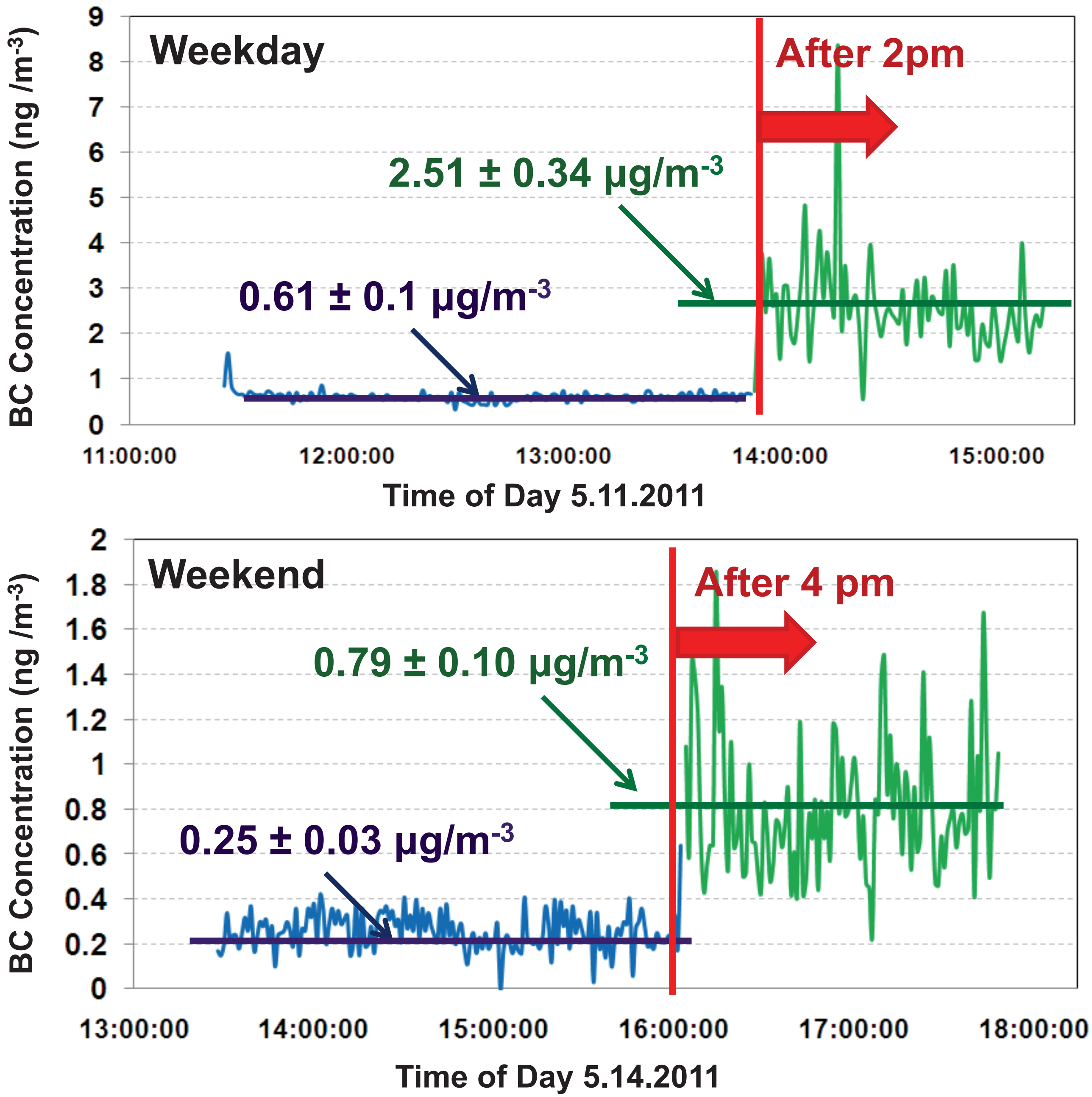
**University of Manchester, Centre for*

I-710 Highway Field Measurements

- Instrument trailer was located 15 meters downwind of freeway
- Study focuses on measurements from two different days
  - **Weekday - May 11th and**
  - **Weekend - May 14th**



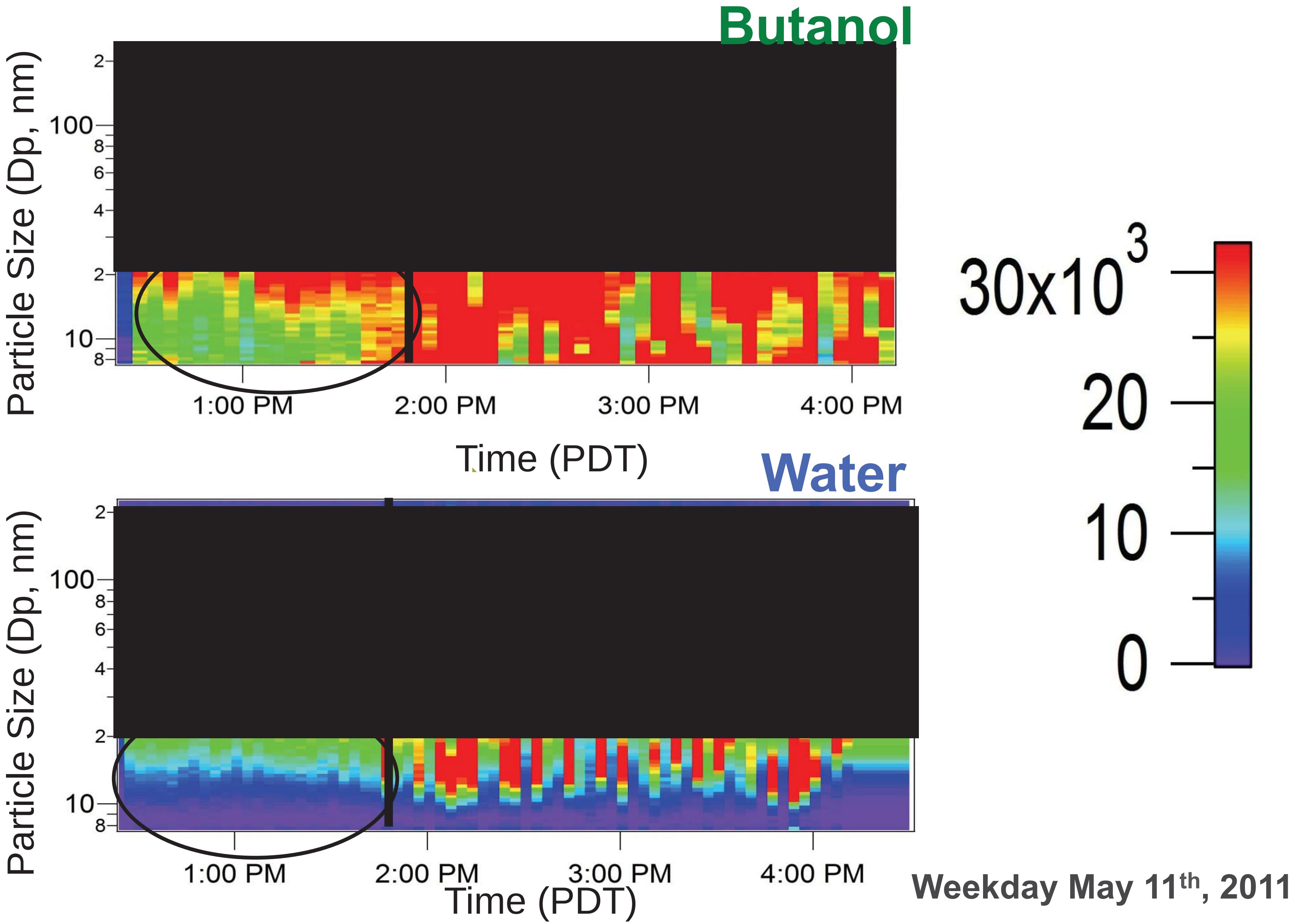
Changes in BC Concentration due to Wind Direction



Weekday Aerosol contains ~ 3x as much BC as Weekend BC concentrations

- ★ All instruments capture change in air mass
- ★ **Changes in Particle Number Concentration (size) and BC Mass Concentration (composition) correlate to changes in wind direction**

Differences in Weekday Particle Distribution



Weekday May 11th, 2011

How are Particles sized?

TSI 3081 Electrostatic Classifier

- Dry Particles are first size selected with an electrostatic classifying system

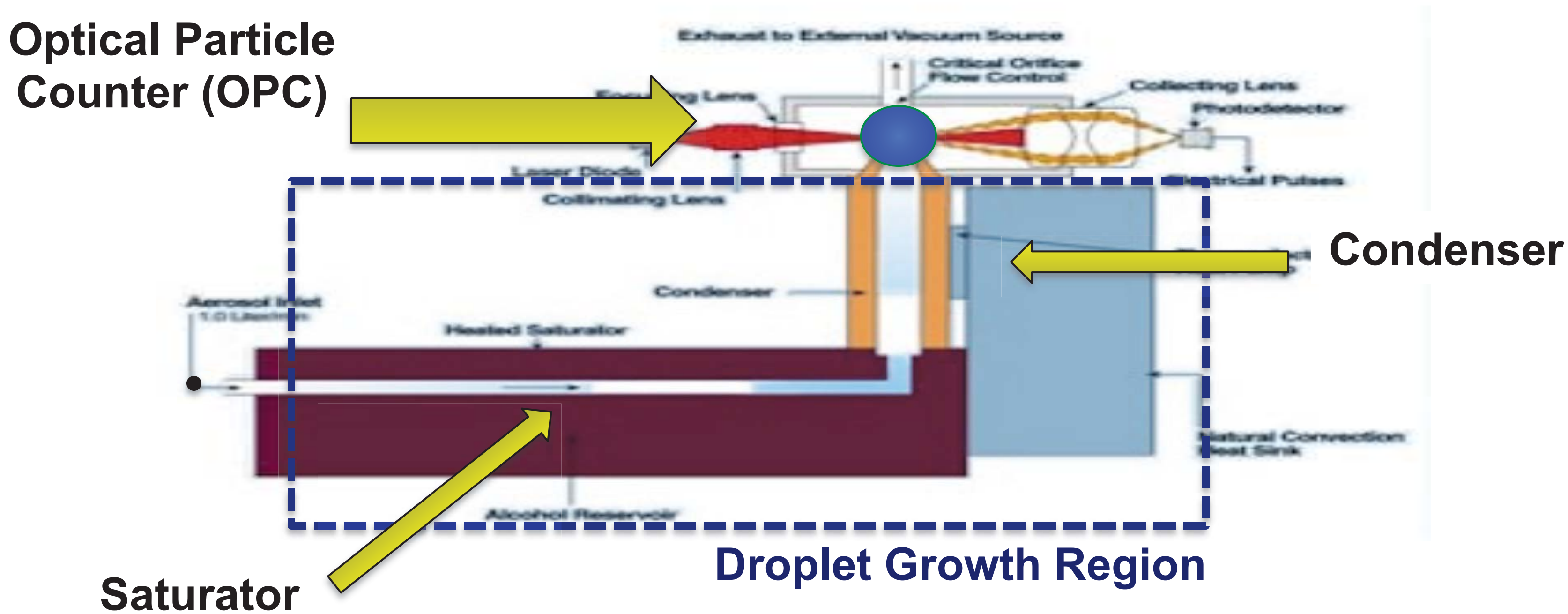
  Scanning Mobility Particle Sizer (SMPS)

  - Long DMA (TSI 3081) selects sizes in the range of 5 to 350 nm
  - Uses a Kr-85 radiation source to charge the aerosol
  - Then applies a voltage in which electron mobility will size select the particles

  Mono-disperse particles then flow into the Condensational Particle Counter (CPC) to be counted

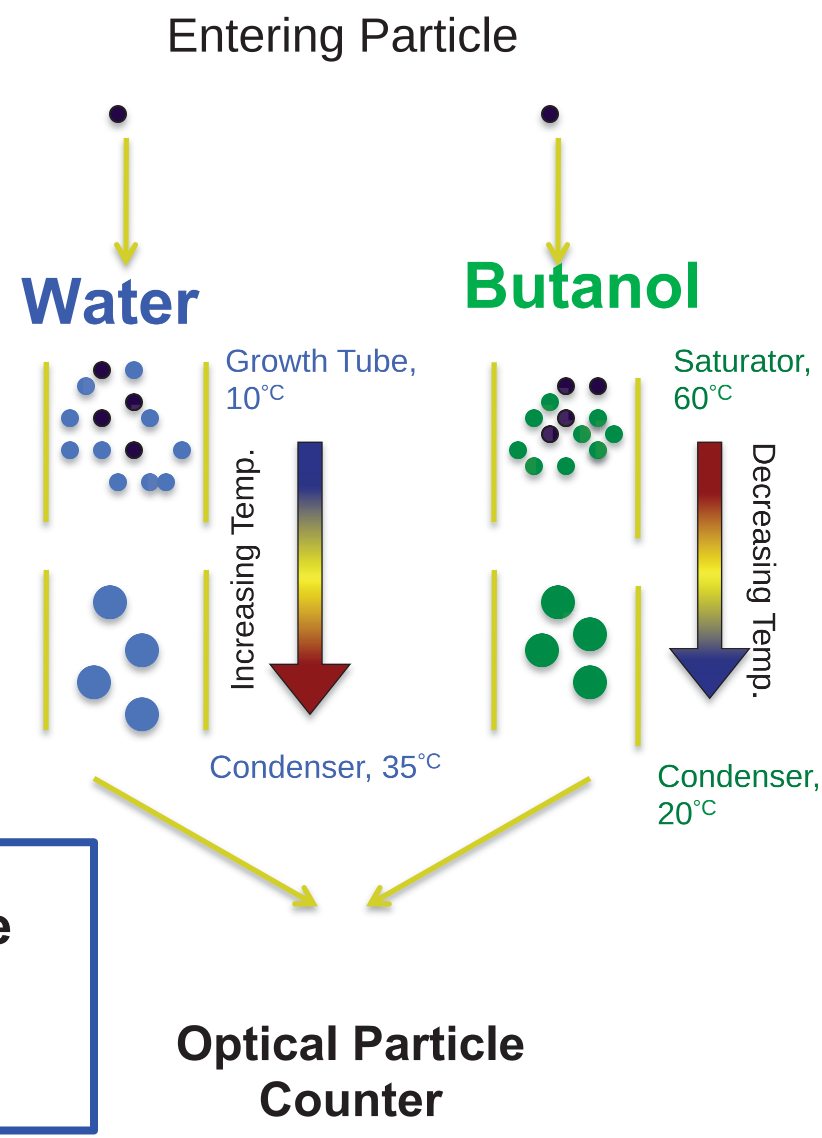
How are Particles counted?

- ★ Dry nanoparticles are exposed to a supersaturation region in which wetted droplets are grown to micron sizes
- ★ **Condensational Particle Counters (CPC)** detects larger micron size droplets with an optical particle counter (OPC)
- ★ CPC supersaturation is generated with two different working fluids, **Butanol (TSI 3772)** and **Water (TSI 3785)**



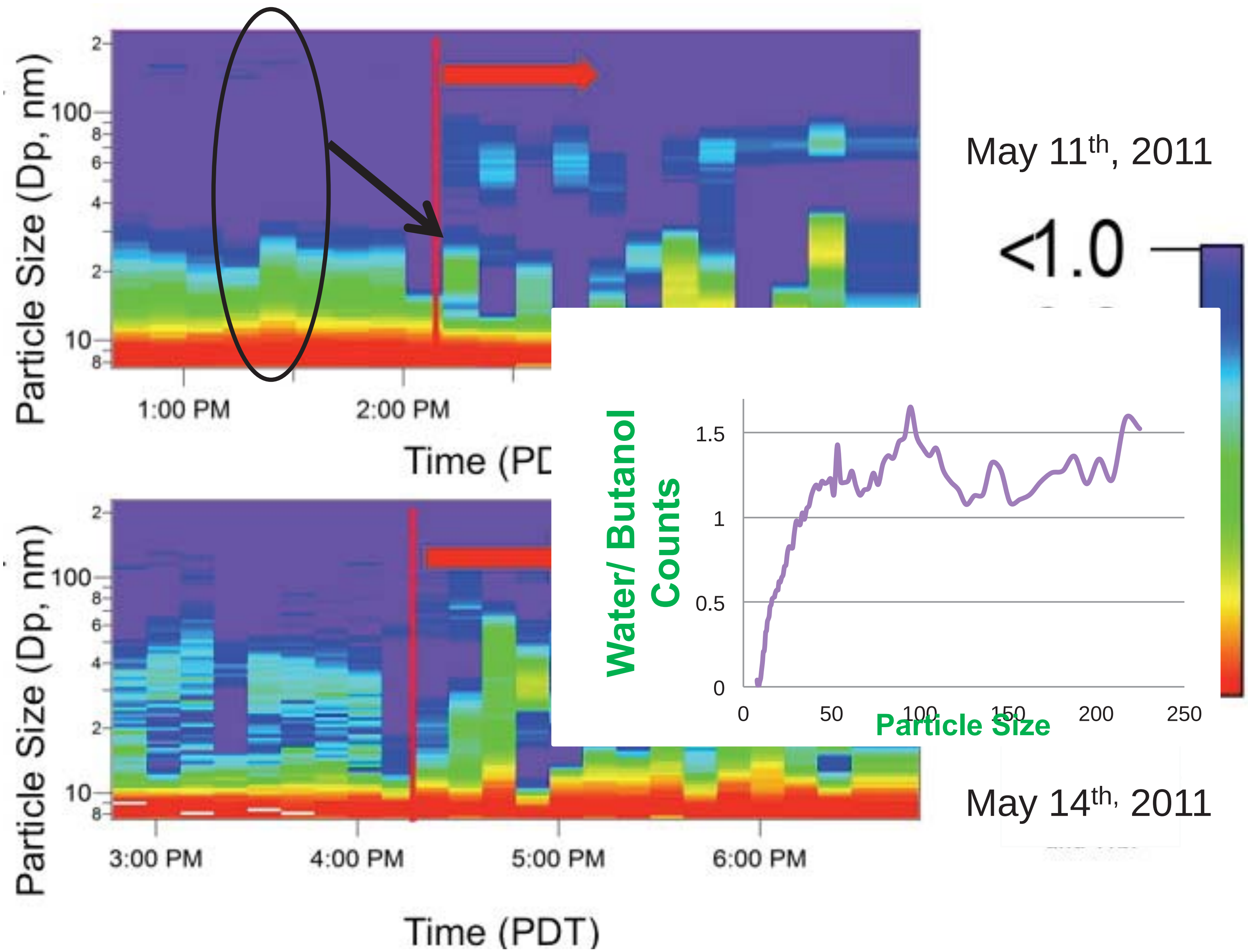
Understanding Particle Counters

- **Water** and **Butanol** CPCs exploit temperature and mass transfer principles to grow droplets
  - **Butanol** has a lower vapor pressure than and is larger in size (> Mol. wt) than air
  - Larger **Butanol** vapors diffuse more slowly than both air and water
  - **Butanol vapors are *cooled* to condense and grow droplets**

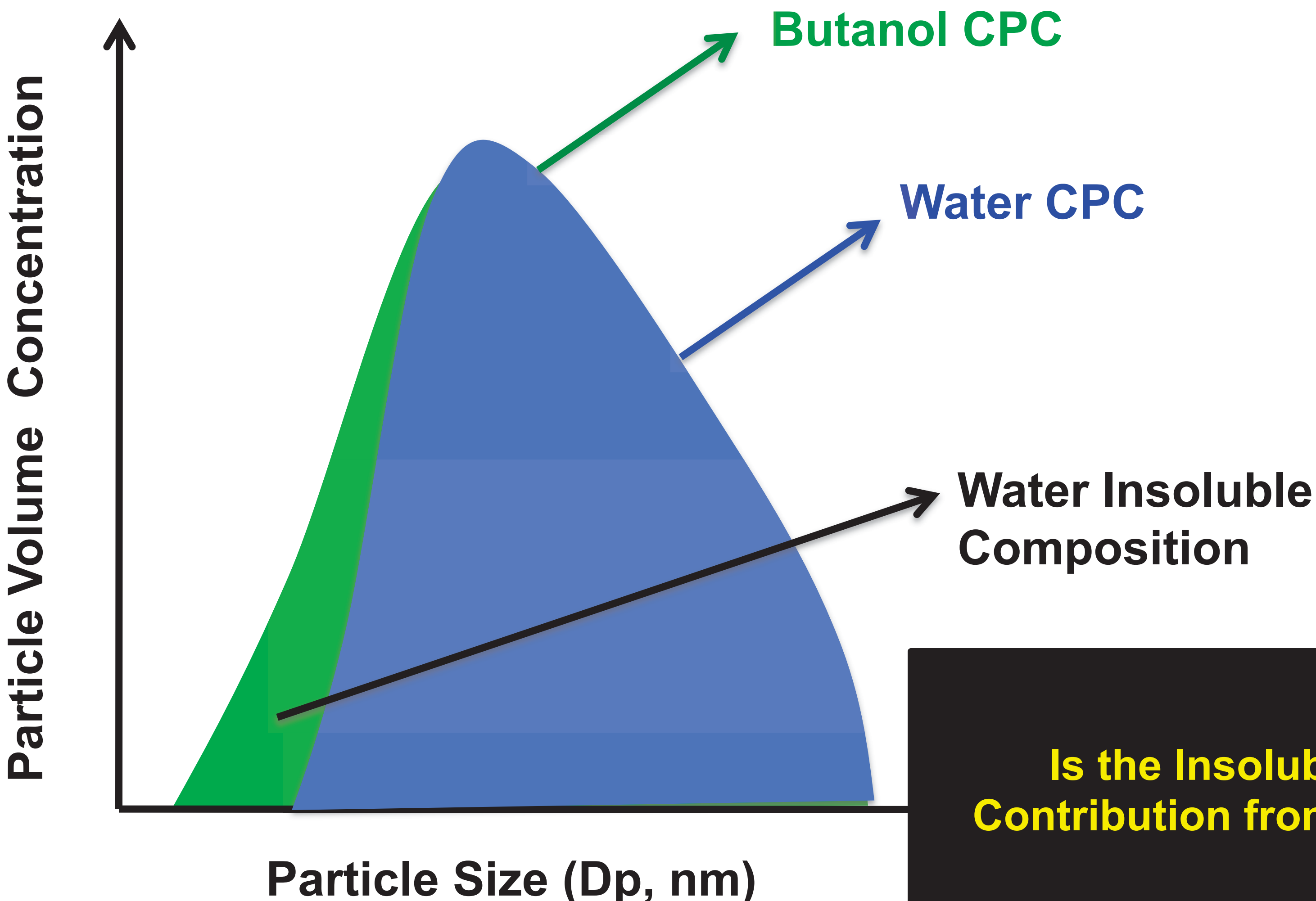


Water vapor from wetted walls diffuse *faster* than air and must be *heated* to condense on dry particles

Counting Efficiency, Ratio of Water / Butanol



Why the Difference?



Is the Insoluble Contribution from BC?

Summary

Aerosol Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uast20

A Unique Online Method to Infer Water-Insoluble Particle Contributions

Daniel Short[ab], Michael Giordano[ab], Yifang Zhu[c], Phillip M. Fine[d], Andrea Polidori[d] & Akua Asa-Awuku[ad]

[a] Department of Chemical and Environmental Engineering, University of California—Riverside, Riverside, California, USA

[b] College of Engineering, Center for Environmental Research and Technology, University of California—Riverside, Riverside, California, USA

[c] Department of Environmental Health Sciences, University of California—Los Angeles, Los Angeles, California, USA

[d] South Coast Air Quality Management District, Diamond Bar, California, USA

Accepted author version posted online: 23 Apr 2014.Published online: 25 Jun 2014.

- ★ **BC is prevalent at all times in near-roadway measurements**
- ★ **The Butanol (TSI 3772) and Water based (TSI 3785) CPCs report significantly different particle size and number concentrations for traffic-related aerosol.**

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- **On average, there are more butanol particle counts than there are water particle counts for sizes less than 100nm.**
  - Below 30nm, the W-CPC is less than 50% efficient

Can we apply these measurements to controlled vehicle tests?

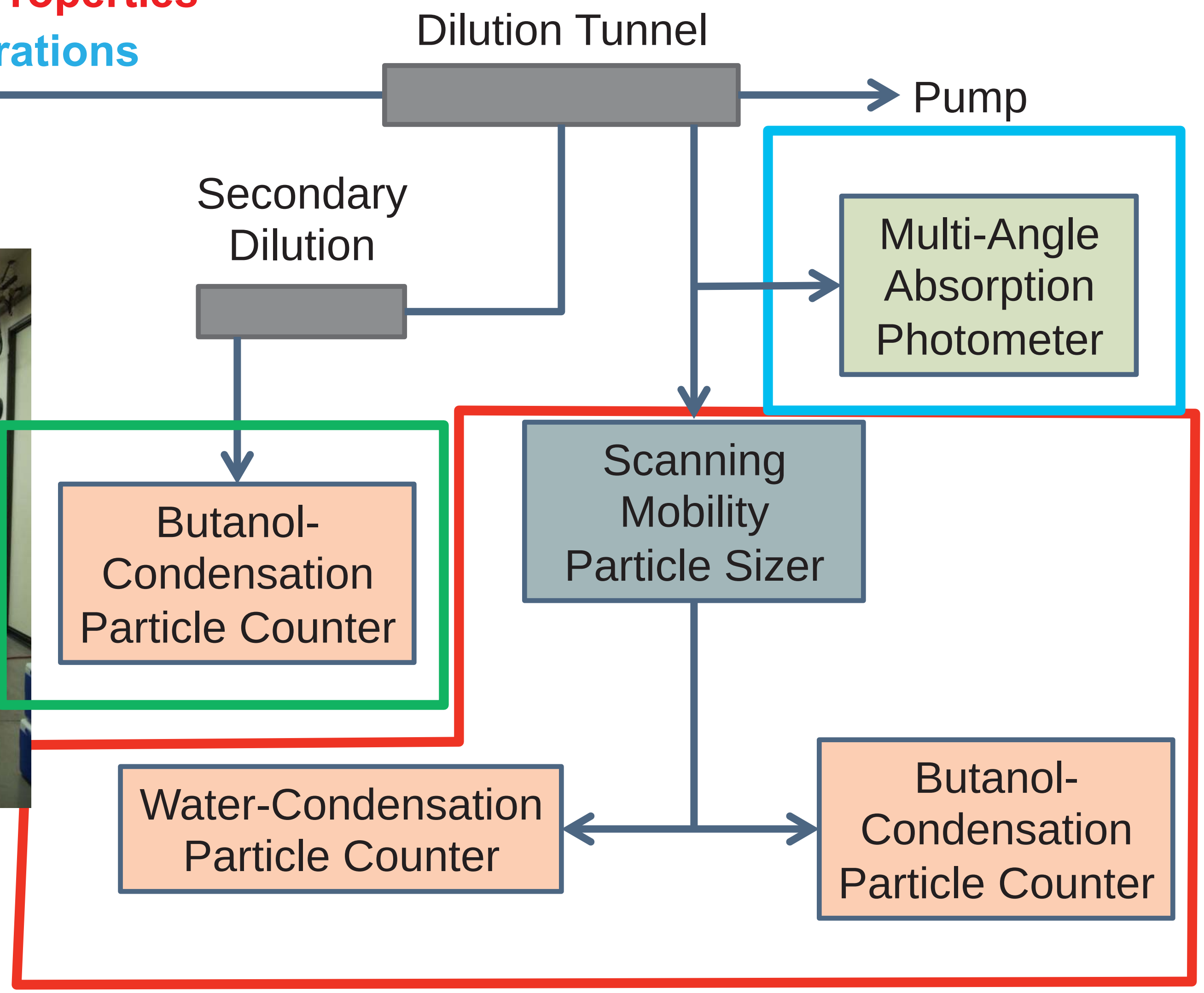
UCR CE-CERT Dynamometer Facilities

Total Particle Concentrations

Nucleation /Solubility Properties

Black Carbon Concentrations

Light Duty Chassis Dynamometer



Impacts of BC Emissions

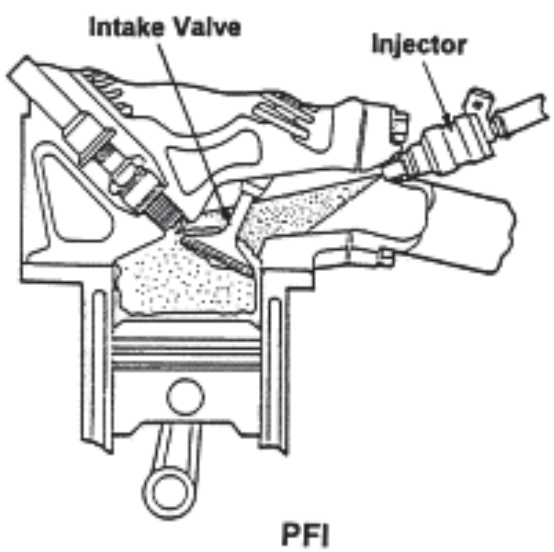
How will changes in 1) vehicle technology and 2) fuels impact emissions?

- Vehicles emit carbonaceous particles that can be water-insoluble and or black carbon concentration
  - Changes in water-insoluble/ BC composition will modify heterogeneous particle nucleating behavior
- Changes in fuel combustion will modify vehicular emissions
  - Gas phase, particle composition and concentration
- Changes in Vehicle Technology cam modify vehicular emissions

2 Gasoline Engine Technologies Tested

Port Fuel Injection (PFI)

Gasoline Direct Injection (GDI)



- **PFI is the most common light-duty engine system in use today**
  - Mixes fuel and air together before injection into the combustion chamber (Zhao et al. 1999)

- **Vehicles tested using this technology:**
  - 2007 Honda Civic and Dodge Ram
  - 2012 Toyota Camry

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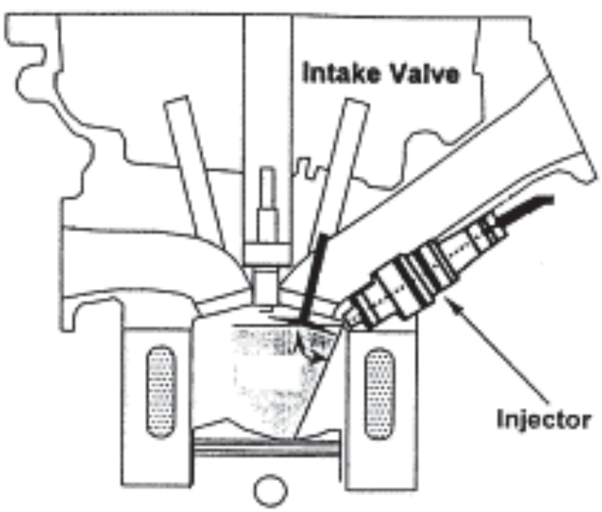
Gasoline Direct Injection (GDI)



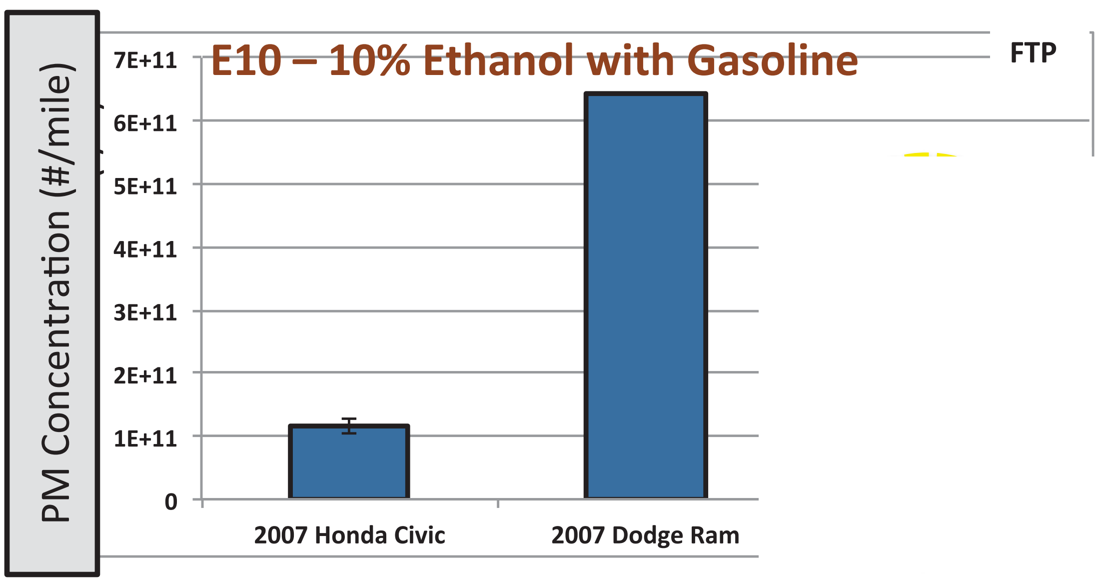
GDI

- **GDI Vehicles have increased fuel efficiency when compared to the typical PFI** (Zhao et al. 1999)
  - Gasoline and air are mixed in the combustion chamber;

- **Vehicles tested using this technology:**
  - 2012 Kia Optima
  - 2012 Chevy Impala

PFI vs. GDI Engine Technology impacts PM Number

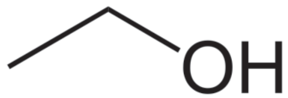
- **Larger Volume Engines will produce more Particles**
  - 2007 Dodge Ram- 5.7L 8-Cylinder Engine
  - 2007 Honda Civic- 1.8L 4-Cylinder Engine
- **The Newer PFI Technology can produce fewer particle emissions**
  - 2012 Toyota Camry- 3.5L 6-Cylinder Engine
- **PFI vehicles produce fewer particles than GDI.**
  - 10 times the order of magnitude of particle emitted by a GDI than a PFI



Port Fuel Injection Vehicles (PFI)

Fuel Chemistry and Alcohol Blends

Ethanol



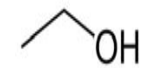
- Molecular Weight = 46.07 g mol^{-1}
- Flash Point is 15°C
- Renewable Fuel made from corn and other biomaterials
- Pure Form has a higher Octane Number than Gasoline
- **95% of U.S. gasoline contains ethanol fuel blend (E10)**

Butanol

- Molecular Weight = 74.12 g mol^{-1}
- Flash Point is 35°C
- Butanol can be produced using existing ethanol production facilities with few modifications
- **Butanol, compared to ethanol, has a lower vapor pressure and is more easily blended with gasoline**
- B16 is the oxygenated equivalent of E10 fuel

Seven Alcohol Fuel Blends

Ethanol



Butanol

E10- 10% Ethanol with 90% Gasoline

E15- 15% Ethanol with 85% Gasoline

E20- 20 % Ethanol with 80% Gasoline

B16- 16% Butanol with 84% Gasoline

B24- 24% Butanol with 76% Gasoline

B32- 32% Butanol with 6 % Gasoline

E10/B8- 10% Ethanol, 8% Butanol and 82% Gasoline

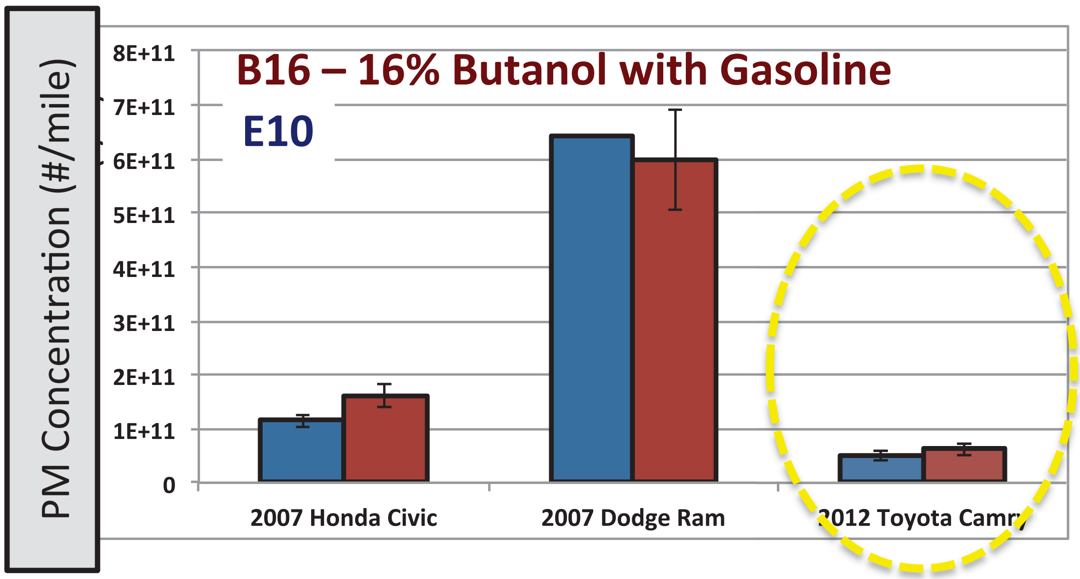
Equivalent Oxygen Content

Equivalent Oxygen Content

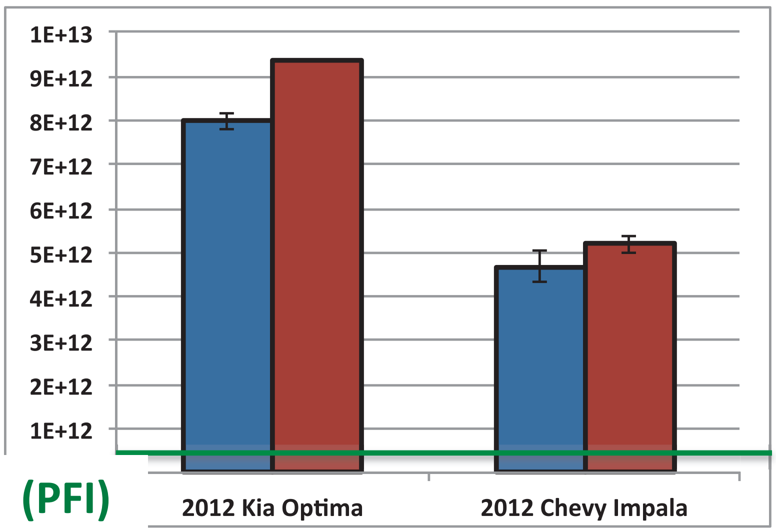
Equivalent Oxygen Content

B16 and E10 Emissions

- **Again PFI vehicles produce fewer particles than GDI vehicles.**
- **B16 Fuel blends can produce more particles than E10 emissions**
  - Butanol has a lower vapor pressure, easily mixed with gasoline, and more likely to form lower-vapor pressure products during combustion

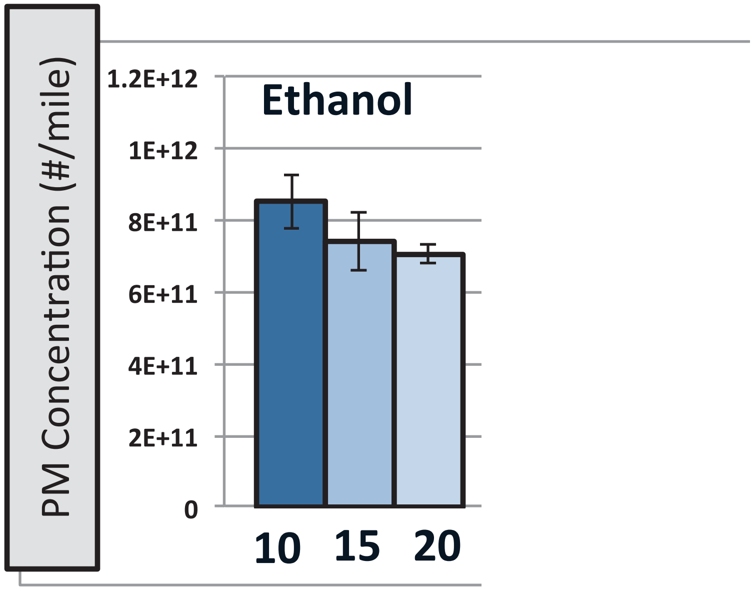


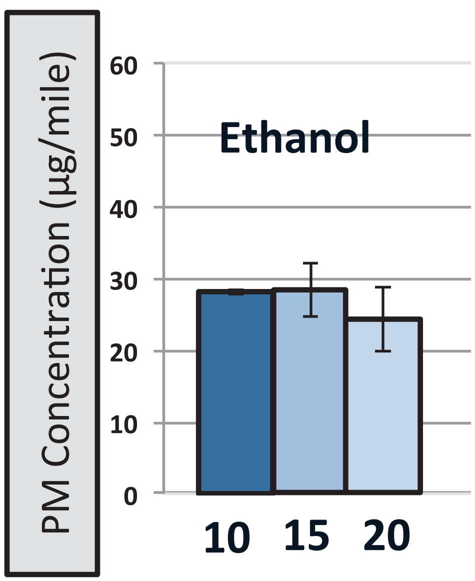
Port Fuel Injection Vehicles (PFI)



Gasoline Direct Injection (GDI)

Fuel Blend Composition Affects PM Number





Port Fuel Injection Vehicle (PFI)

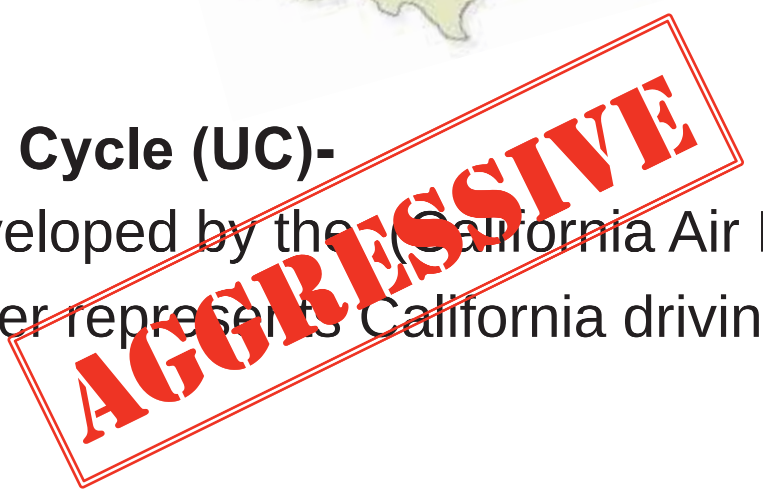
Does Driving Cycle/ Measurement Protocol Matter? Yes!

- **Higher Oxygenated Content for a given fuel blend reduces PM Number and Mass concentrations for the FTP cycle**
- **Equivalent oxygenated Butanol Fuels B24 and B32 produce less particles than Ethanol Blend Counterparts.**

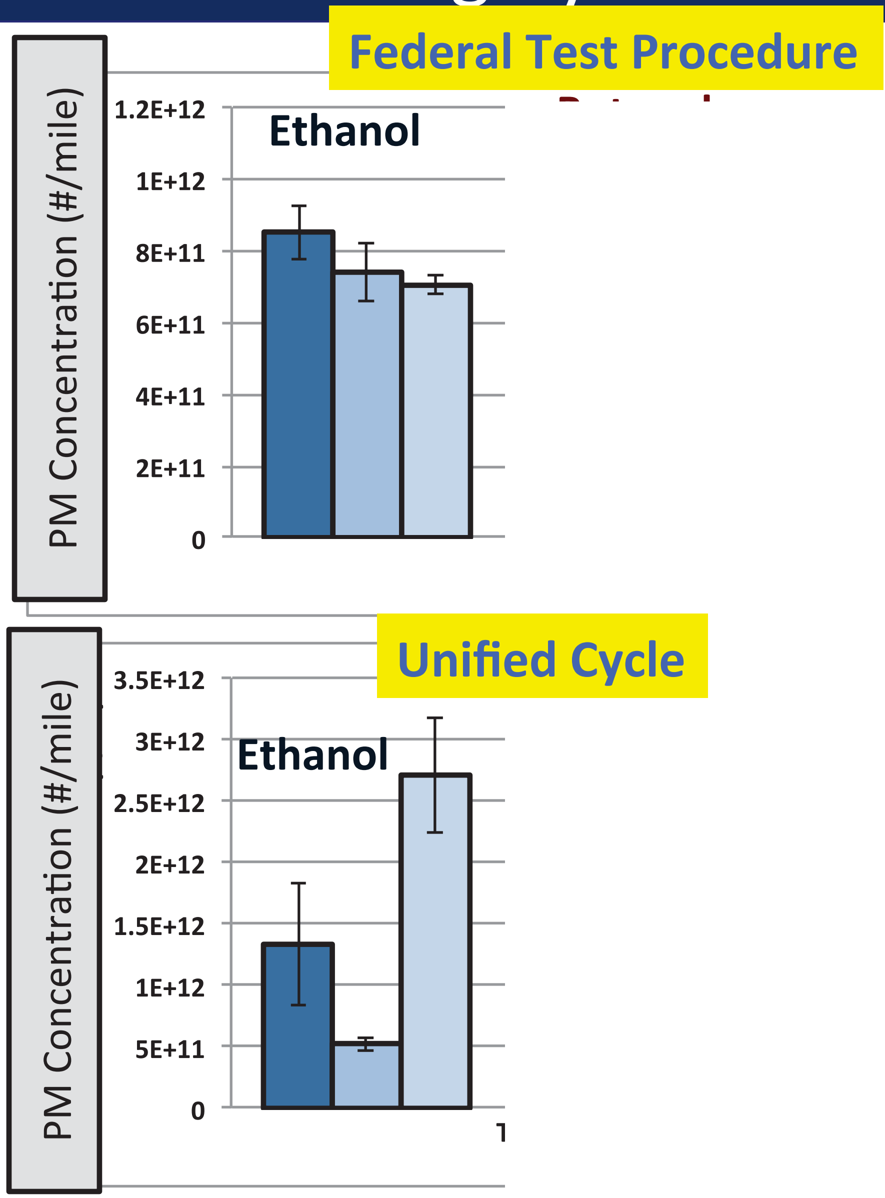
Driving Cycles

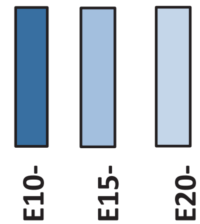
- **Federal Test Procedure (FTP)**
  - Developed by the Environmental Protection Agency

- **Unified Cycle (UC)-**
  - Developed by the (California Air Resources Board)
  - better represents California driving styles



Driving Cycle Affects PM Concentrations

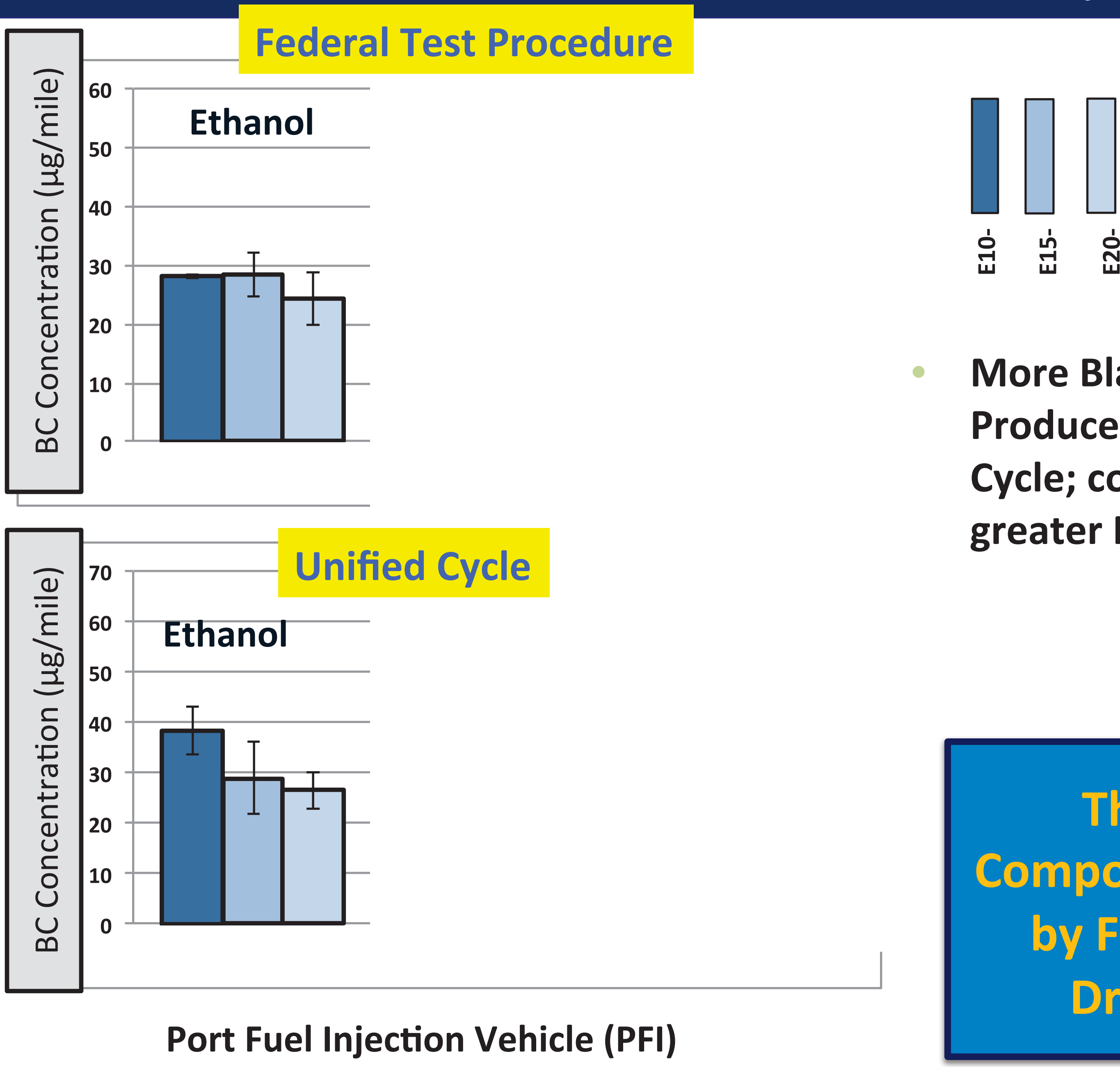




- **More particles can be produced in the Unified Cycle with the Toyota Camry**
- **And there is a greater variation in fuel emission results**

Port Fuel Injection Vehicle (PFI)

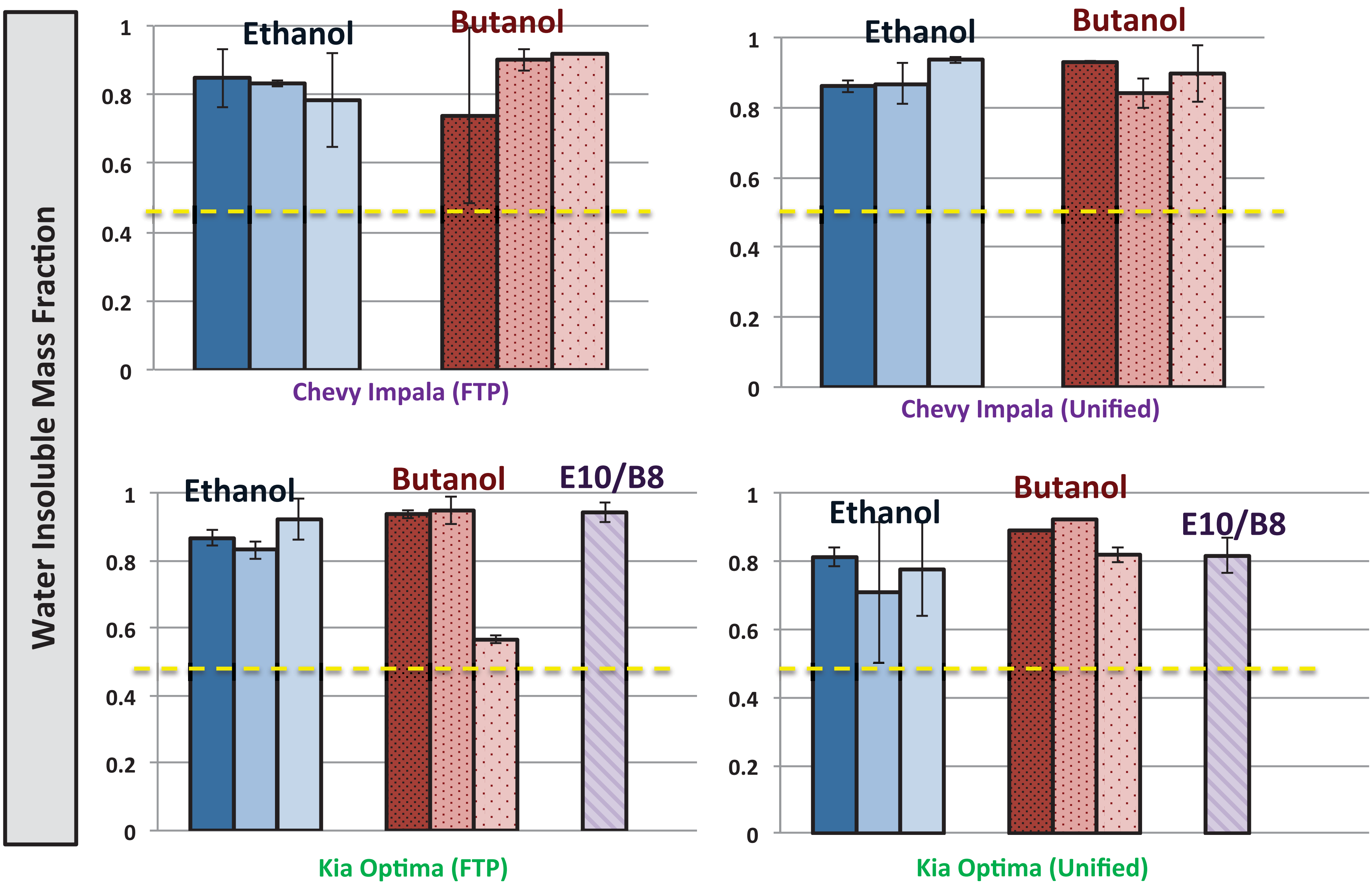
Black Carbon Concentrations modified by Fuel Blends



- **More Black Carbon Produced in Unified Cycle; consistent with greater PN concentration**

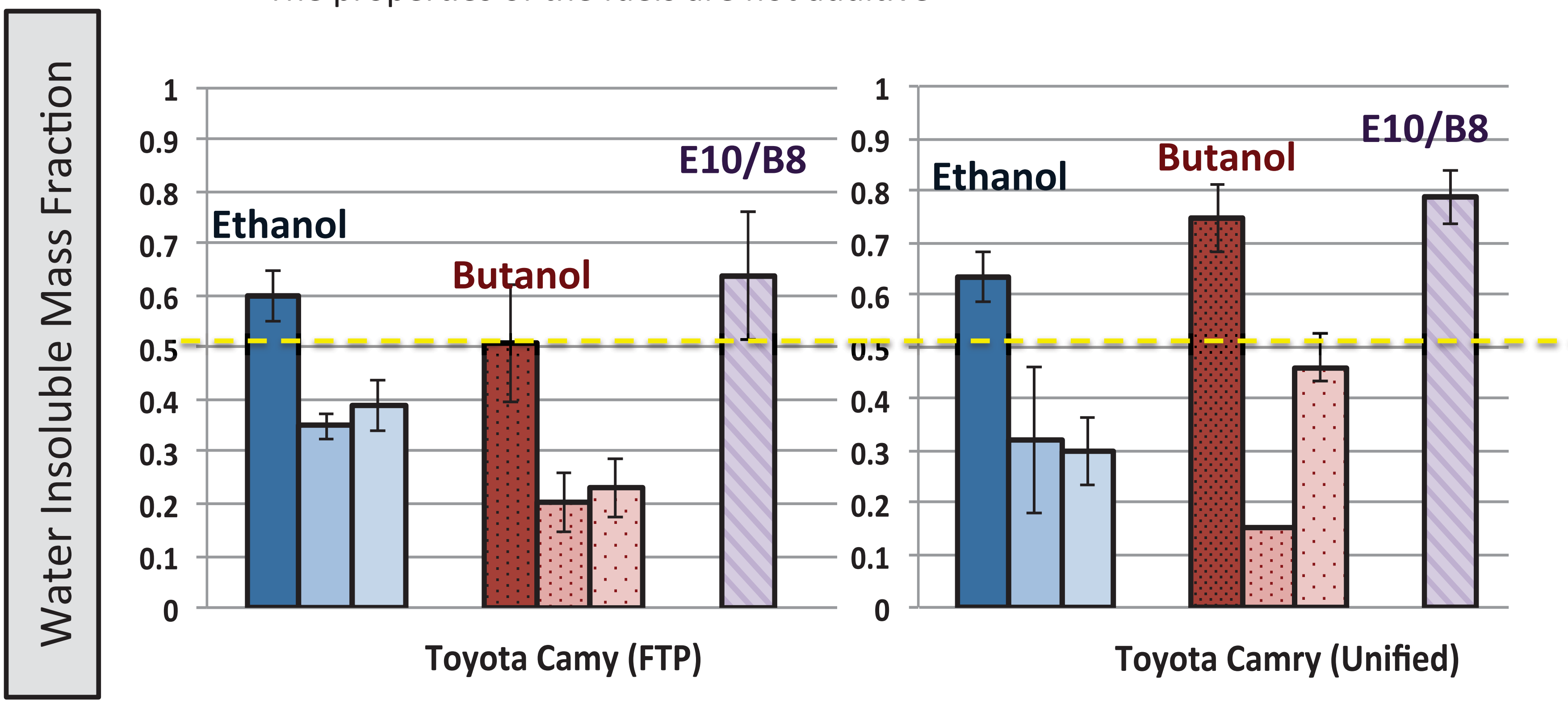
The Particle Composition will vary by Fuel type and Driving Cycle

GDI Water Insoluble Mass Fraction

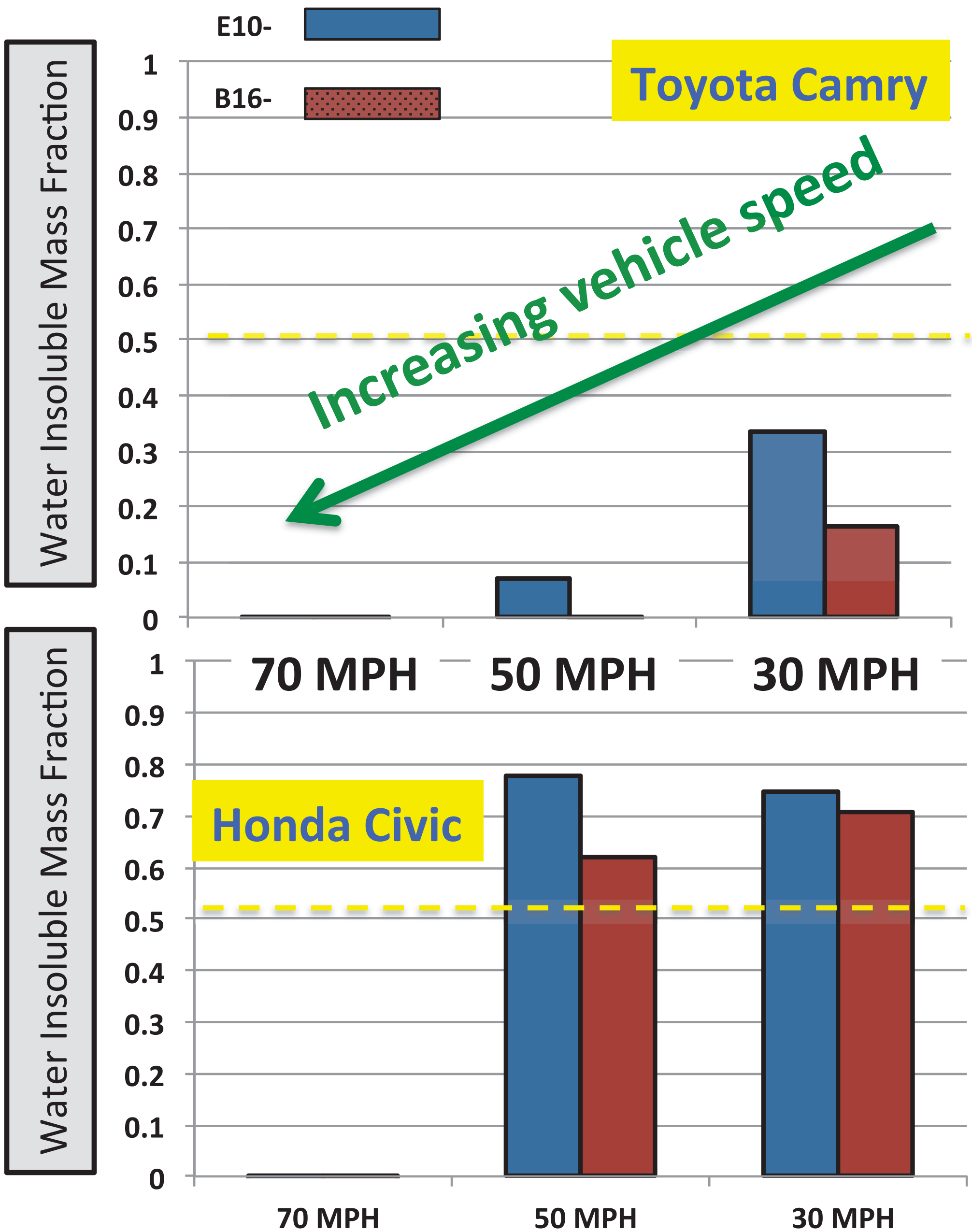


PFI Water Insoluble Mass Fraction

- **2012 Toyota Camry produces mostly water soluble aerosol**
  - Oxygen content for and butanol the hygroscopicity of the particles
  - E10/B18 produces the most insoluble particles.
    - The properties of the fuels are not additive



Higher speeds produce water-soluble particles



- The chemical composition of aerosol from steady-state emissions is NOT the same as the emissions tested on driving cycles.
- This is true for Varying Fuels, Vehicles, and Cycles

Summary

- On average, PN and BC concentrations were shown to decrease with larger concentrations of butanol and ethanol gasoline mixtures
  - Alcohol fuel blends can modify particle size, number, mass, and composition,
- GDI Vehicles emit 10 times more particles than PFI vehicles, even though they have better fuel economy.
- Of the vehicles tested the 2012 Toyota Camry had the fewest PM emissions for every fuel type
- PFI emissions can be more water-soluble compared to the GDI particle emissions
- Emission Particle hygroscopicity is dependent on vehicle speed.

Summary

SAE INTERNATIONAL

Evaluating Particulate Emissions from a Flexible Fuel Vehicle with Direct Injection when Operated on Ethanol and Iso-butanol Blends

2014-01-2768
Published 10/13/2014

George Karavalakis, Daniel Short, Vincent Chen, Carlos Espinoza, Tyler Berte, Thomas Durbin, Akua Asa-Awuku, and Heejung Jung
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Leonidas Ntziachristos and Stavros Amanatidis
Aristotle University of Thessaloniki

Alexander Bergmann
Instrumentation and Control Systems

CITATION: Karavalakis, G., Short, D., Chen, V., Espinoza, C. et al., "Evaluating Particulate Emissions from a Flexible Fuel Vehicle with Direct Injection when Operated on Ethanol and Iso-butanol Blends," SAE Technical Paper 2014-01-2768, 2014, doi:10.4271/2014-01-2768.

ELSEVIER

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Evaluating the regulated emissions, air toxics, ultrafine particles, and black carbon from SI-PFI and SI-DI vehicles operating on different ethanol and iso-butanol blends

CrossMark

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ENVIRONMENTAL CHAMBER

Part 2:
BC from Biomass Burning Sources

Biomass Burning (BMB)

- **Biomass burning is a widespread phenomena that is a major source of global aerosol emissions (2-5 petagrams C/yr)** *(Crutzen and Andreae, 1990)*
  - Burning can be anthropogenic: it is a common agricultural practice in land use management, especially in the tropics
  - It can also be biogenic: eg. Wildfires
- **Biomass burning emissions are a complex mixture gases and aerosols**

The Rim Fire in Yosemite National Park (8/22/2013) which covered over 340 mi^2. Source: NASA Earth Observatory

- **Biomass burning aerosol emissions can directly absorb or scatter light**
- **Emissions from biomass can be cloud condensation nuclei (CCN) active** *(e. g. Englehart et al., 2012; Petters et al., 2009; Giordano et al 2013; 2014)*

Getting closer to Ambient:

From Filters to Chambers

★ Manzanita and Chamise are common shrubs in Southern California (Keeley and Davis, 2007)

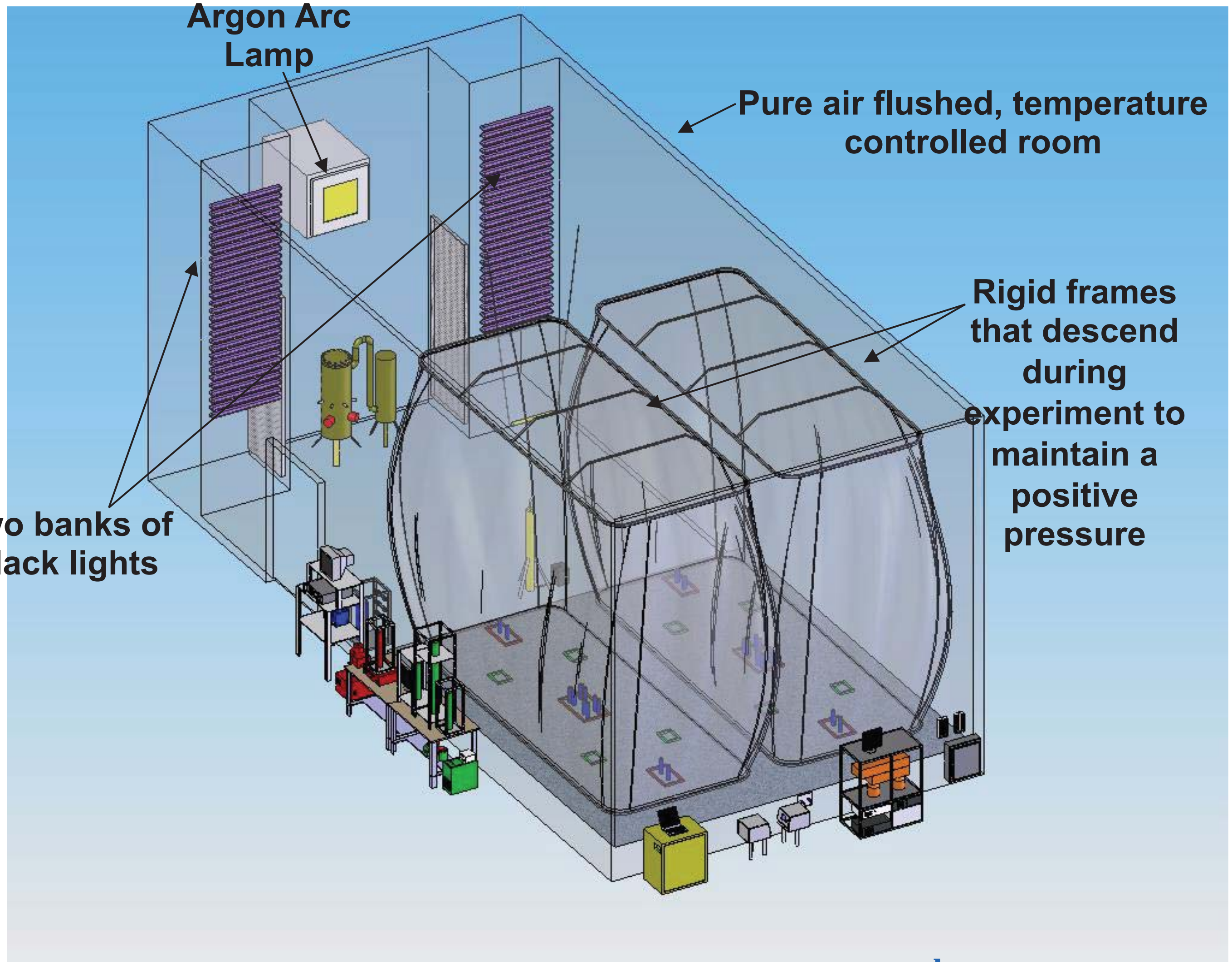
★ in wildfires shrubs can account for nearly 80% of all biomass burned (Clinton et.al.,2006)

Manzanita

Chamise

We explore online aging of dilute concentrations of BMB aerosols with particular attention to CCN ability as a function of photochemical aging.

UCR/CE-CERT Environmental Chamber



- Dual 90 m^3 Teflon reactors
- Entire room is temperature controlled (5-45C ±1°C)
- 200 kW Argon arc lamp or 80 115 W 4-ft blacklights
- Humidification (dry <0.1 % to humid)
- Enclosure continually flushed with pure air

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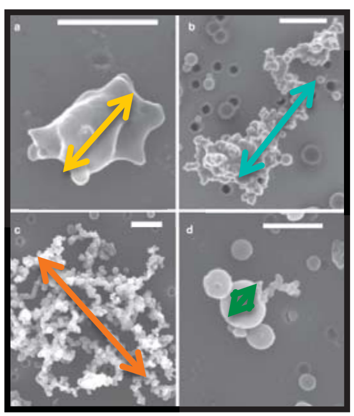
CCN RELEVANT PROPERTIES OF BIOMASS BURNING

(3) Time changes everything

(2) Chemistry is Important



(1) Size Does Matter

Online Instrumentation Offline

Online

- Particle Composition (Aerodyne Aerosol Mass Spectrometer)
- Particle Size [Scanning Mobility Particle Sizer] (TSI 3080, CPC 3772)
- Particle Hygroscopicity (DMT CCN Counter)
- Particle Volatility (Volatility Tandem Differential Mobility Analyzer, Homemade)
- Particle Density (Kanomax APM)
- Particle Scattering [Black Carbon] (Thermo Fisher Multi-Angle Absorption Photometer)
- Gas Phase (NO/NO_x, O_3, CO/CO_2, H_2O, GC-FID)

Filters are extracted in de-ionized ultra filtered (~18 MΩ) H_2O

Clean Air
300 x dilution

Offline

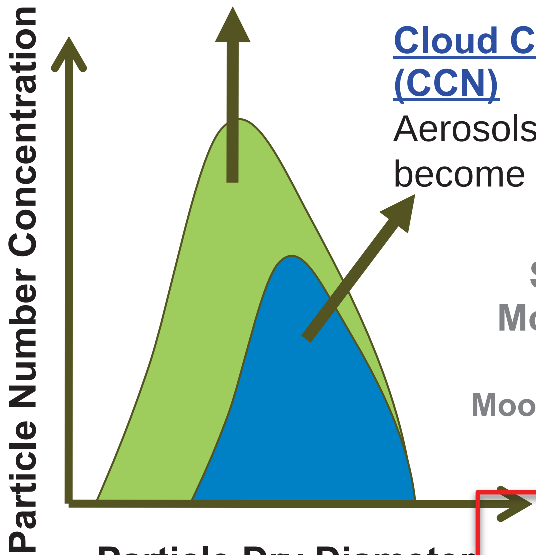
- Elemental/ Organic Carbon (Sunset EC/ OC)
- Surface Tension (Attension Theta Tensiometer)
- Water Soluble Organic Carbon (900 Sievers, GE Analytical)

CCN Measurements

Shifts in Kappa are due to changes in composition, assuming *constant water droplet surface tension*

Condensation Nuclei (CN)
Entire Aerosol Distribution

Cloud Condensation (CCN)
Aerosols that ***activate*** and become cloud droplets

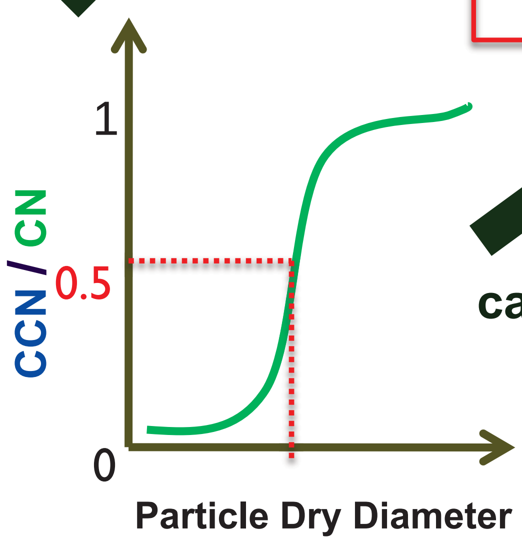


Scanning Mobility CCN Analysis
Moore, and Nenes, *2010)*

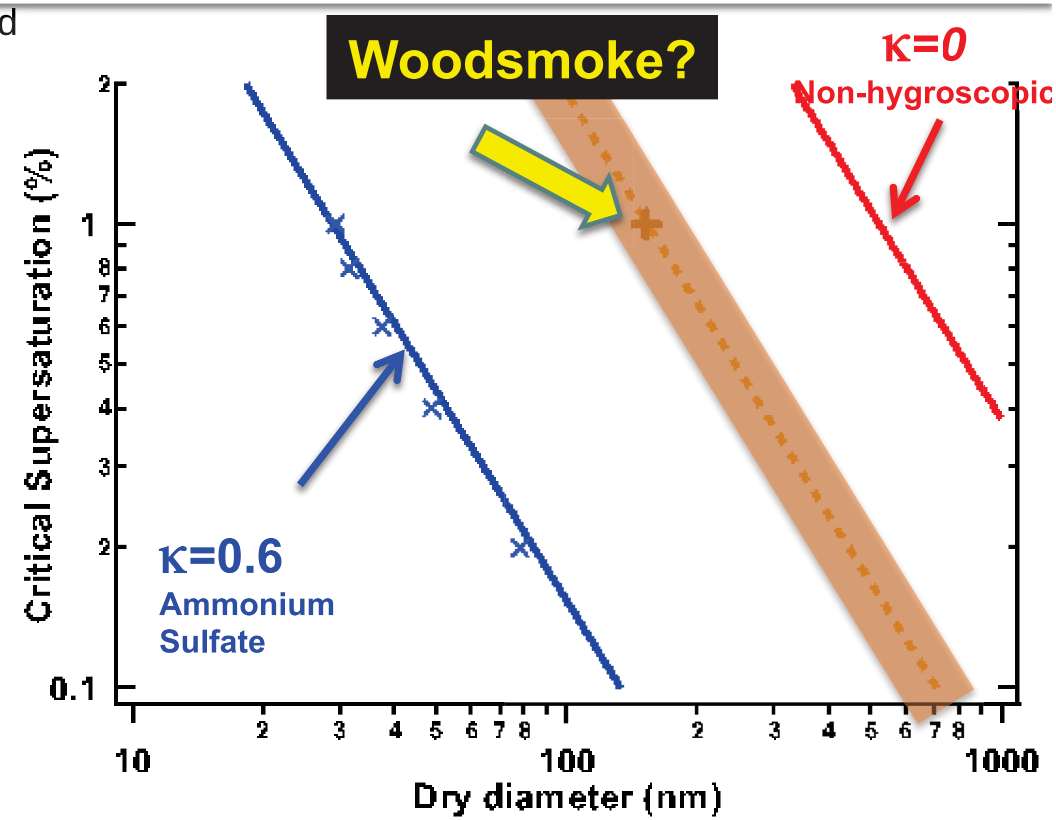
$$\kappa = \frac{4A^3}{27D_d^3 \ln^2 S_c}$$

$$A = \frac{4\sigma_{s/a} M_w}{RT\rho_w}$$

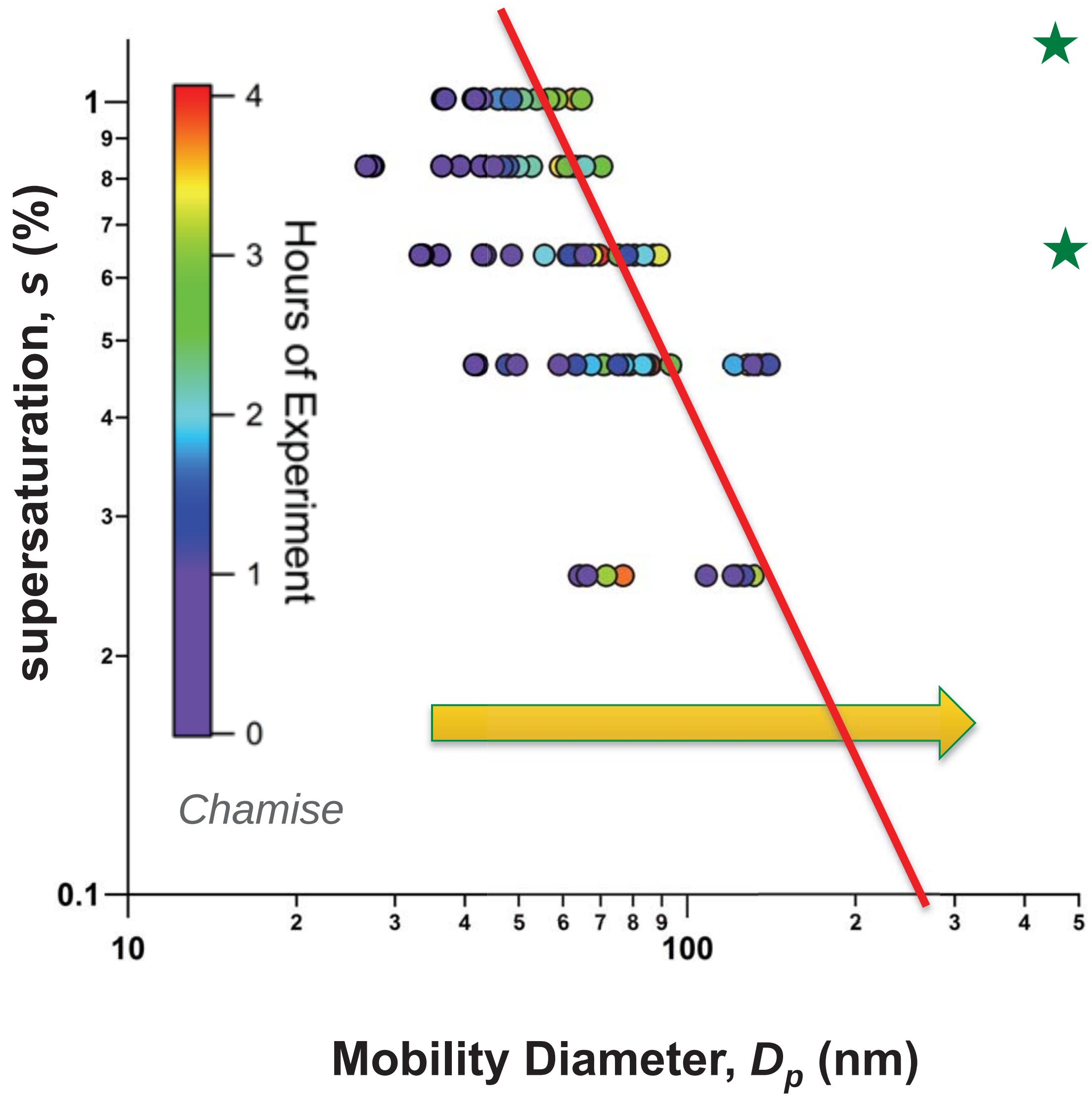
Constant *s*



calculate d_c for varying s



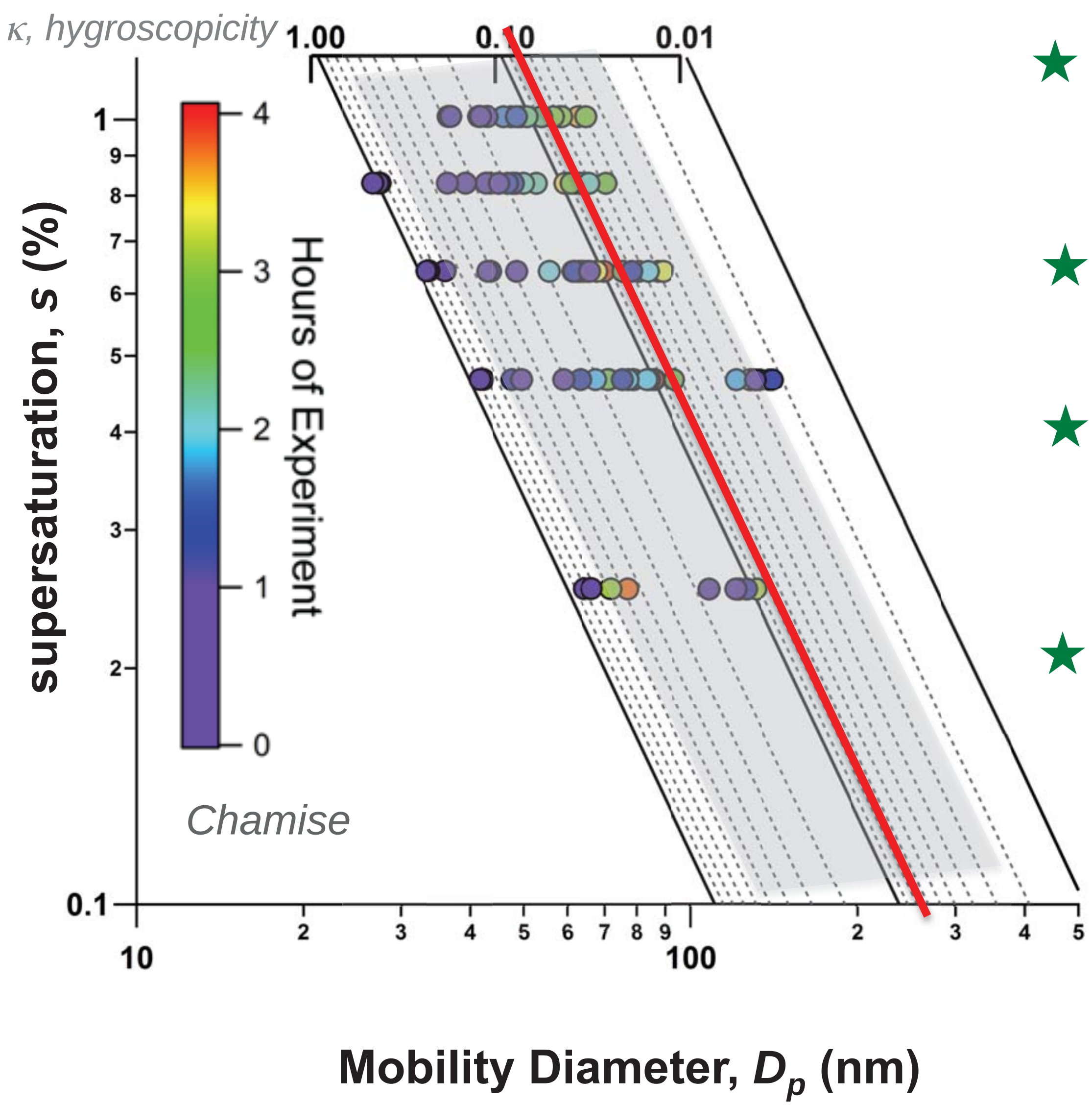
CCN Activity depends on:
1) Particle Size
2) Composition
3) Surface Tension



★ **Chamise becomes less hygroscopic with time**

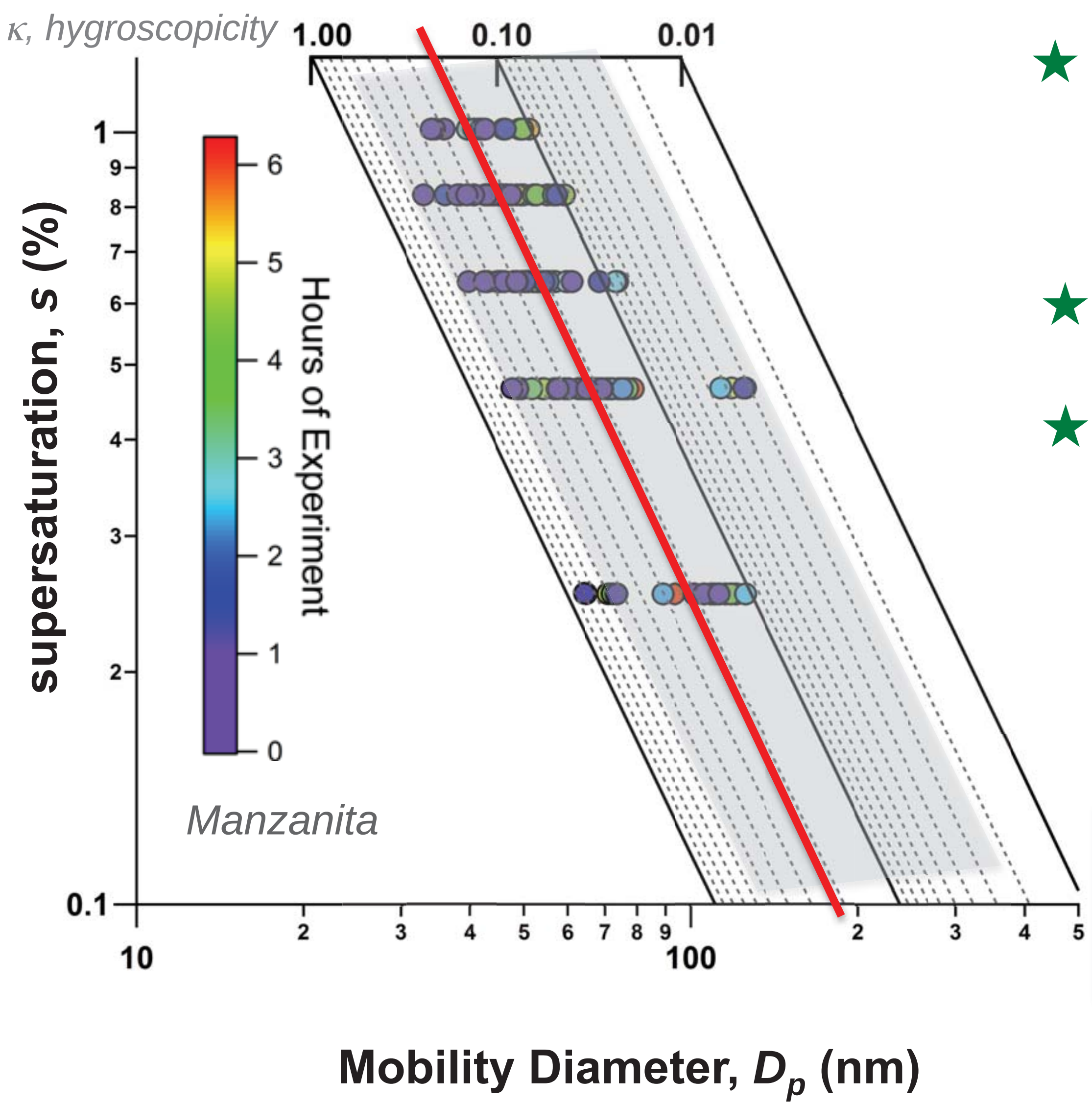
★ **Average κ~ 0.098**

Giordano et al., 2013, ES&T



- ★ Chamise becomes less hygroscopic with time
- ★ Average κ~ 0.098
- ★ 2 OOM change in hygroscopcity,
- ★ Single Parameter, κ, can decrease from 1 to 0.04 within 4 hours of chamber ageing

Giordano et al., 2013, ES&T



- ★ **Manzanita also becomes less hygroscopic with time**
- ★ **Average κ ~ 0.238**
- ★ **2 OOM change in hygroscopicity**

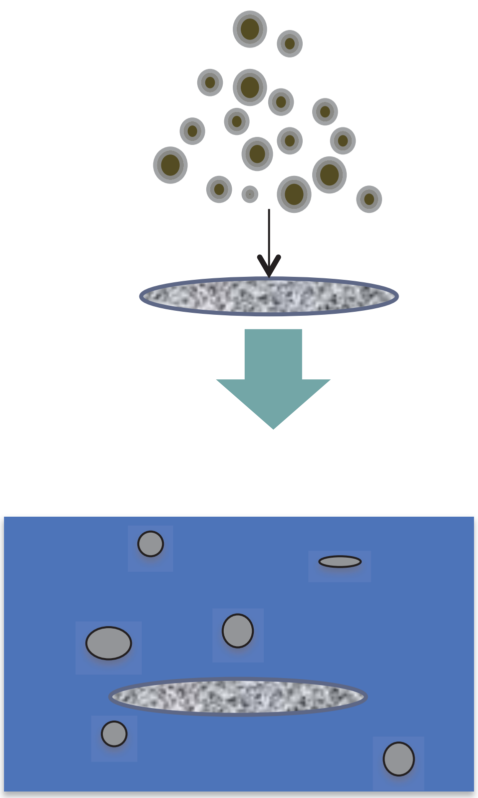
Why the Shift?

Giordano et al., 2013, ES&T

Surface Tension Measurement

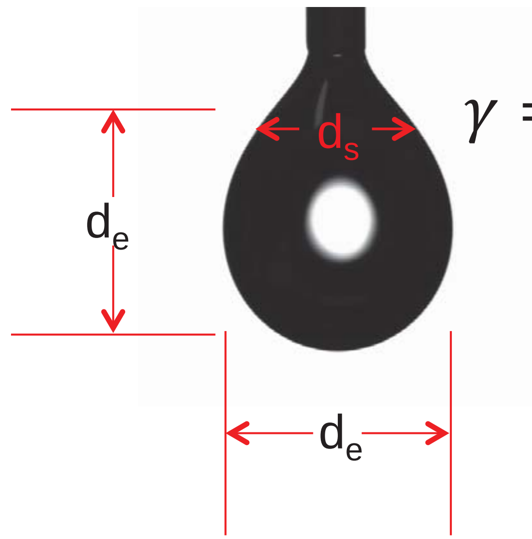
UC RIVERSIDE
UNIVERSITY OF CALIFORNIA

Aerosols are deposited onto a Teflon filter



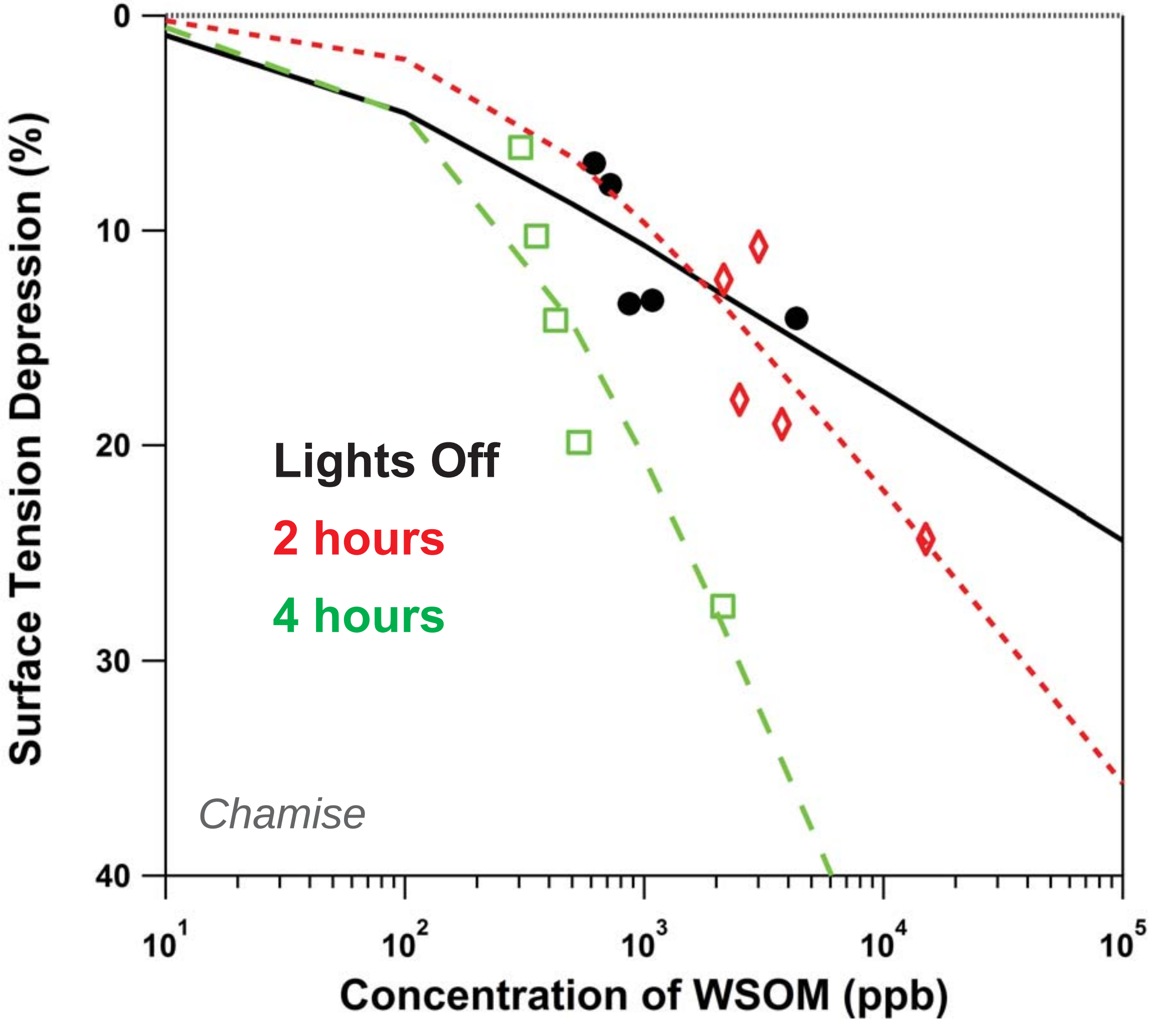
Filters are sonicated in MilliQ water

Samples are photographed with a Pendant Drop Tensiometer (PDT) and the *Young-Laplace Equation*



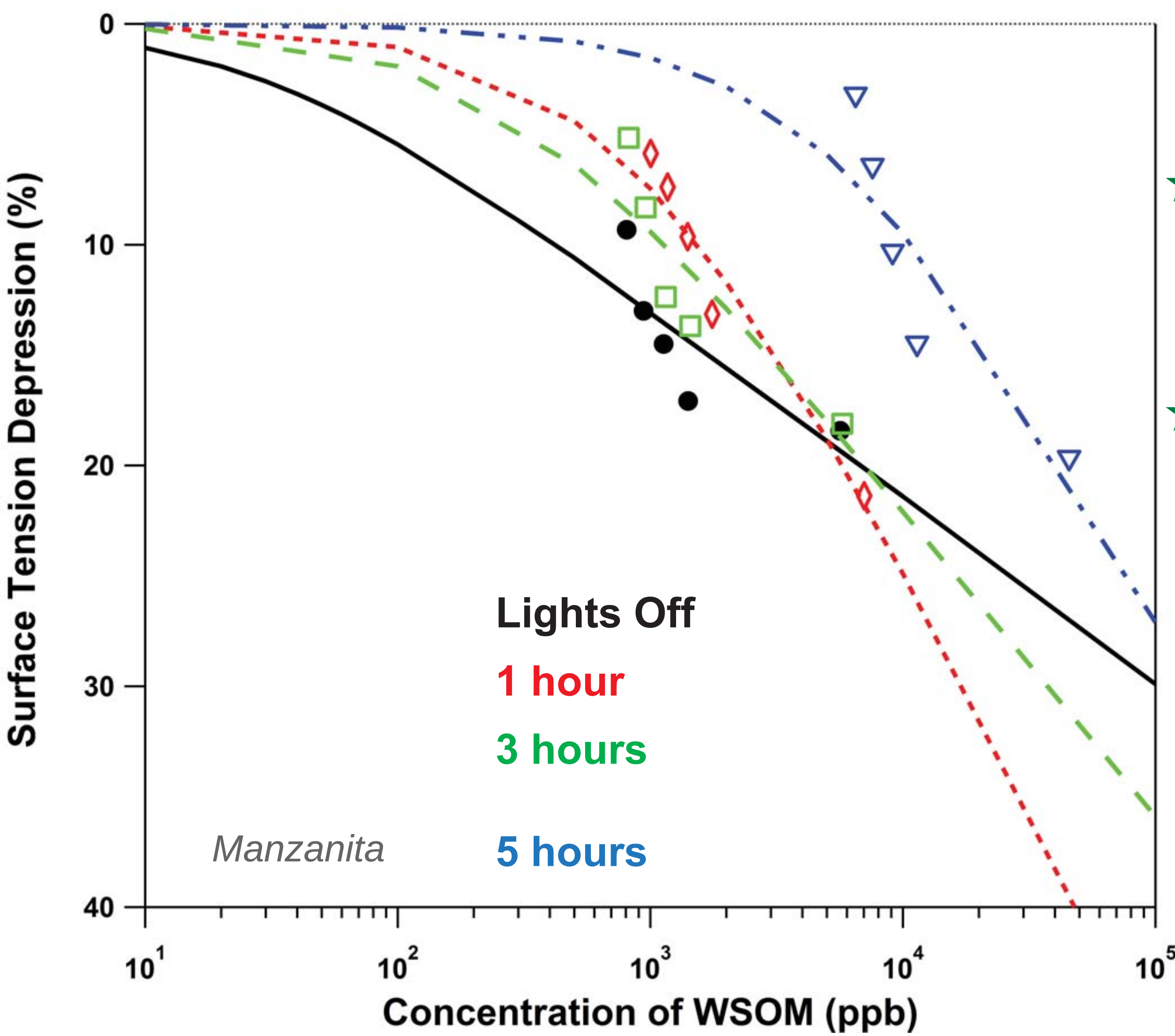
$$\gamma = g \times \rho \times \frac{d_e^2}{H}$$

$H = \textit{correction factor based on } d_e/d_s$



More surfactants with time

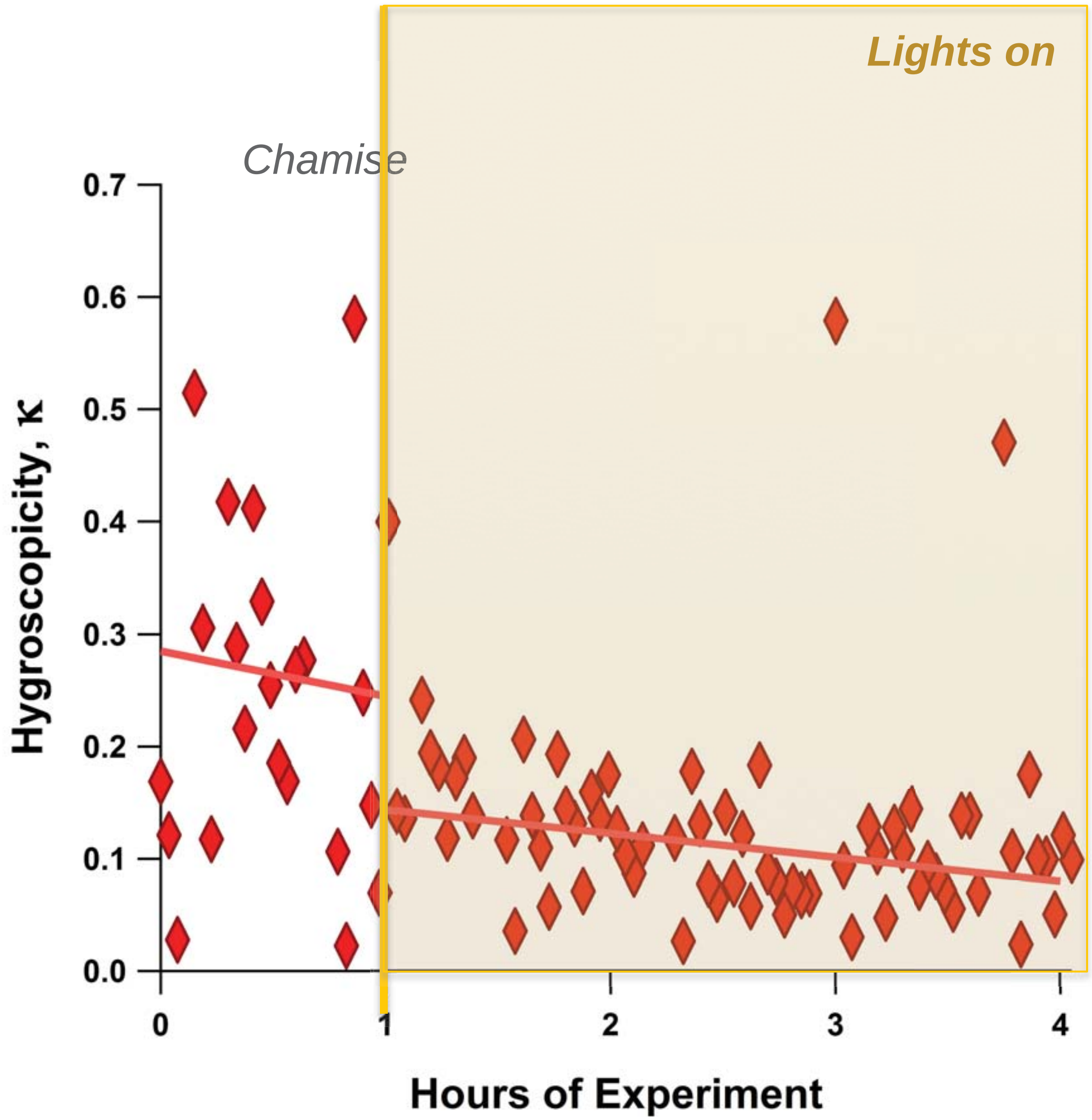
Giordano et al., 2013, ES&T



- ★ **Reverse for Manzanita.**
- ★ **Ageing can reduce the amount of surface active materials in the aerosol**

Giordano et al., 2013, ES&T

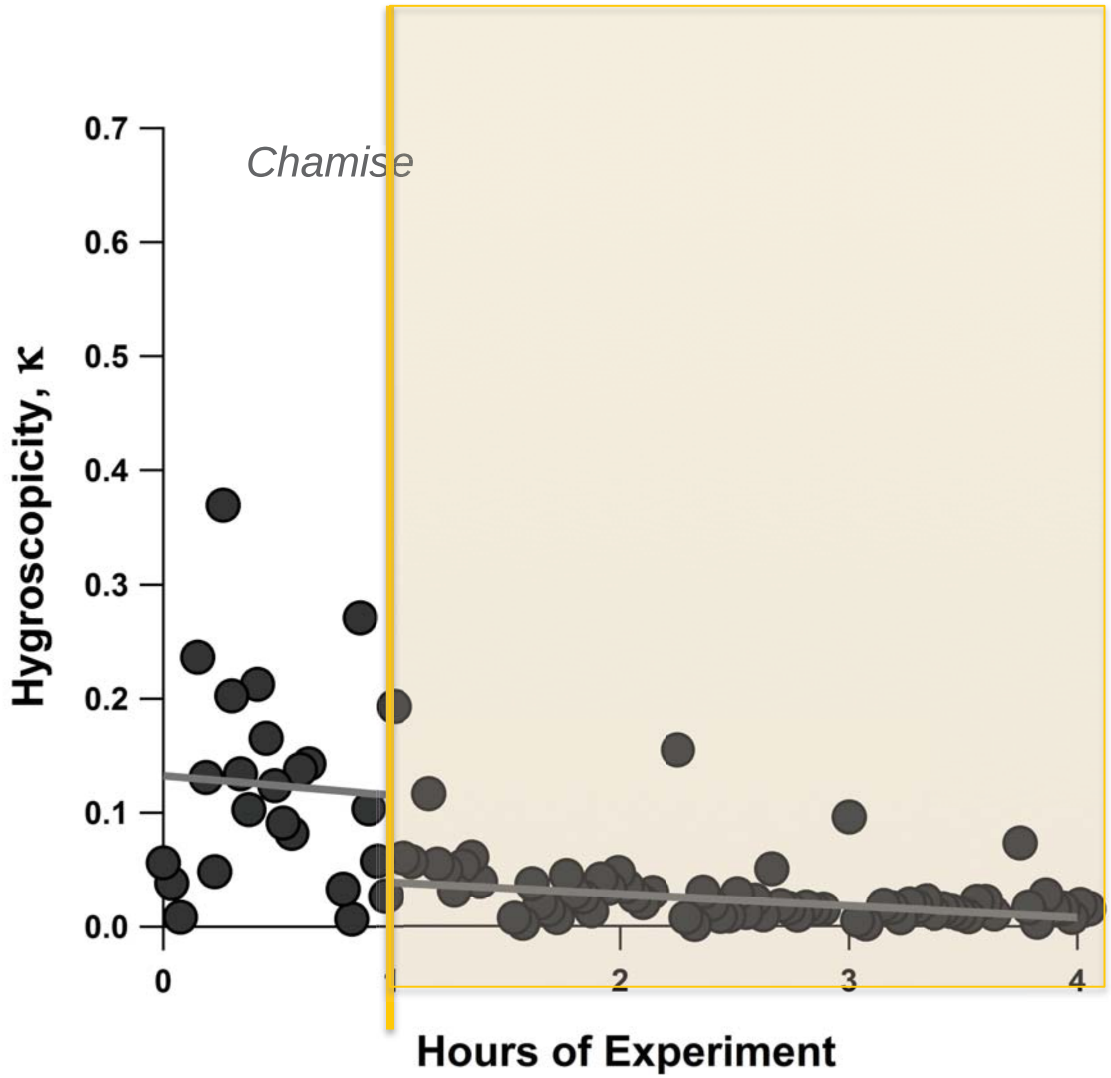
Correcting for Surfactants



- ★ **The apparent κ** shows the material is hygroscopic
- ★ solute κ *must be corrected for σ*

Giordano et al., 2013, ES&T

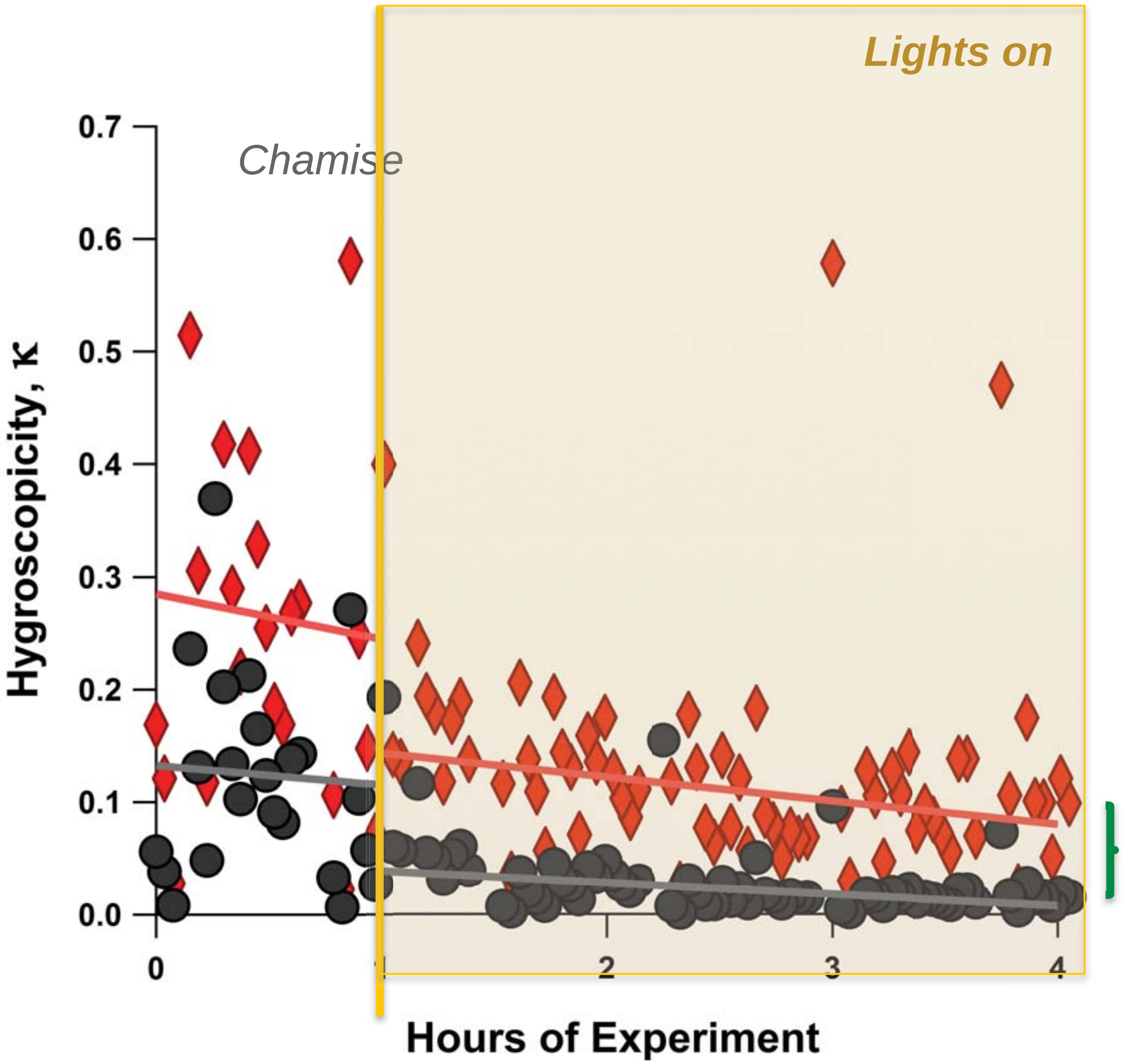
Correcting for Surfactants



- ★ The corrected CCN *κ* derived values are much lower
- ★ Lower values Consistent with values observed with HTDMA data sets

Giordano et al., 2013, ES&T

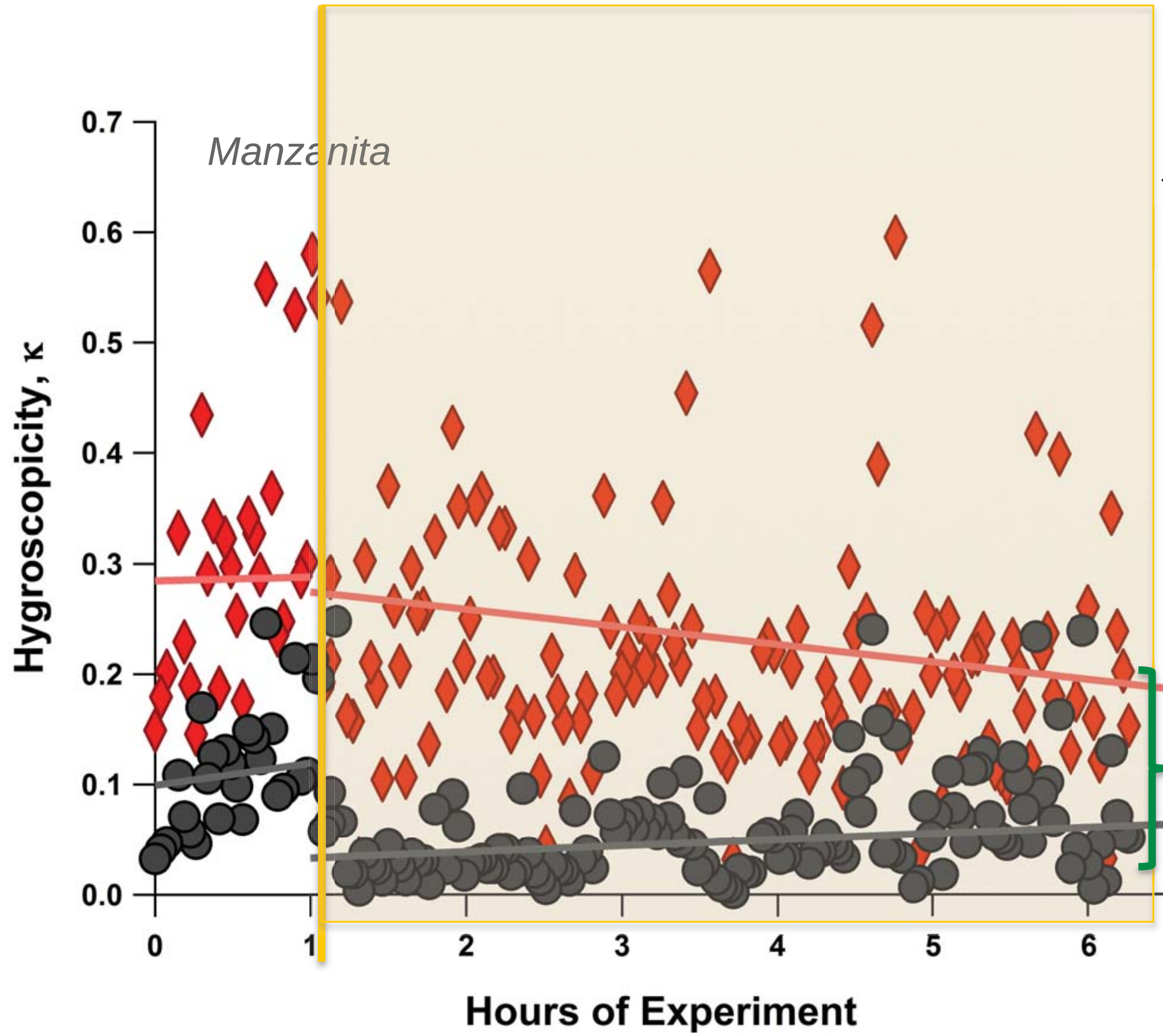
Correcting for Surfactants



★ **SURFACTANTS ARE REAL!**

Giordano et al., 2013, ES&T

Correcting for Surfactants



★ SURFACTANTS ARE REAL!

★ And their effects can be significant!

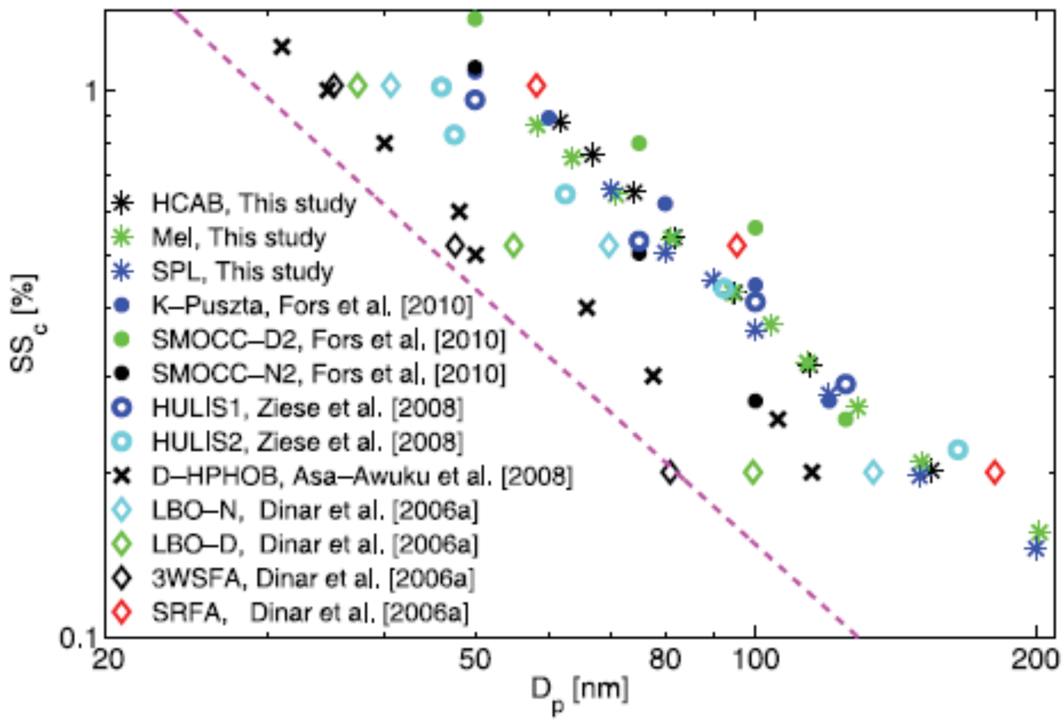
Giordano et al., 2013, ES&T

Surfactants are never the same!

Hygroscopic growth and CCN activity of HULIS from different environments

Thomas B. Kristensen,[1] Heike Wex,[2] Bettina Nekat,[2] Jacob K. Nøjgaard,[3] Dominik van Pinxteren,[2] Douglas H. Lowenthal,[4] Lynn R. Mazzoleni,[5] Katrin Dieckmann,[2] Christian Bender Koch,[1] Thomas F. Mentel,[6] Hartmut Herrmann,[2] A. Gannet Hallar,[7] Frank Stratmann,[2] and Merete Bilde[1]

Received 21 June 2012; revised 21 September 2012; accepted 29 September 2012; published 28 November 2012.



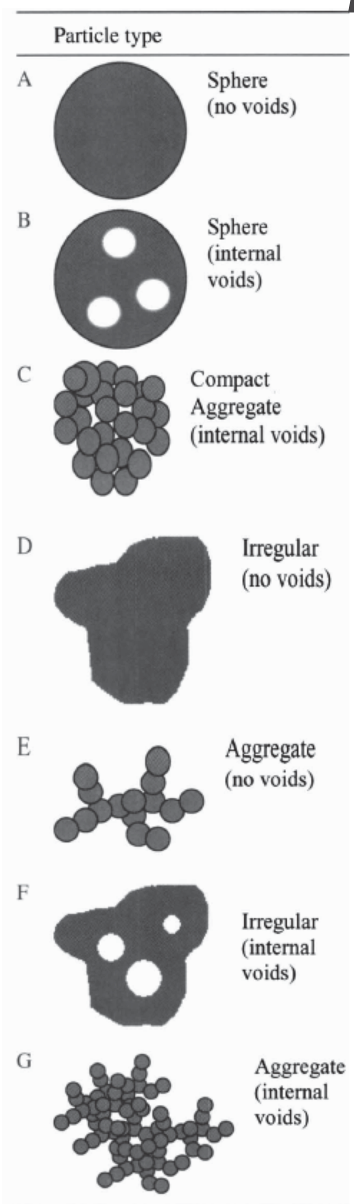
(3) Time changes everything

(2) Chemistry is Important

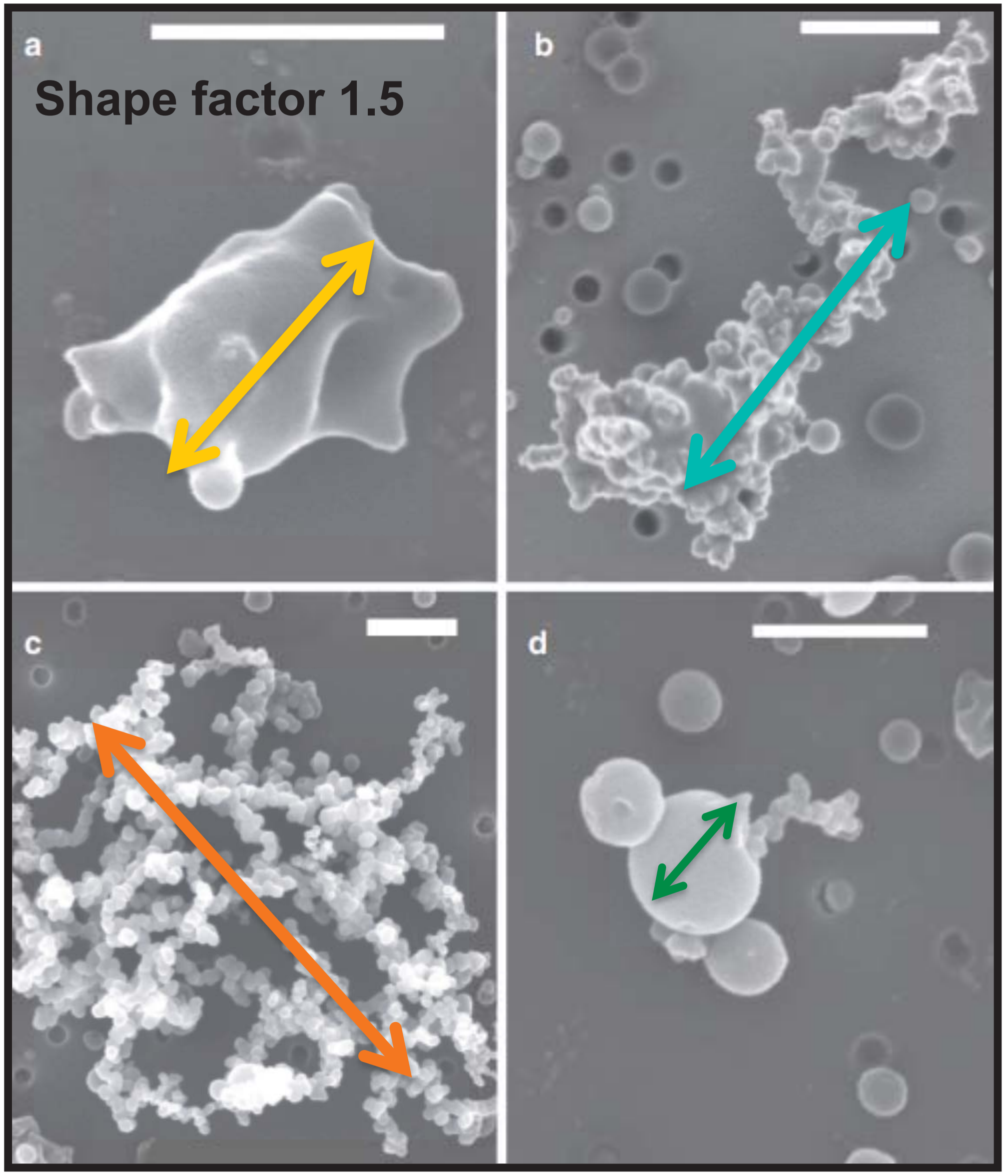
Figure 1. CCN activities of atmospheric HULIS samples as reported in the literature, together with values obtained in this study. For comparison SRFA is included, and the dashed line gives the theoretical values for ammonium sulfate. For details about the studies and samples see Table 1.

Size Does Matter!

DeCarlo et al., 2010 ACP

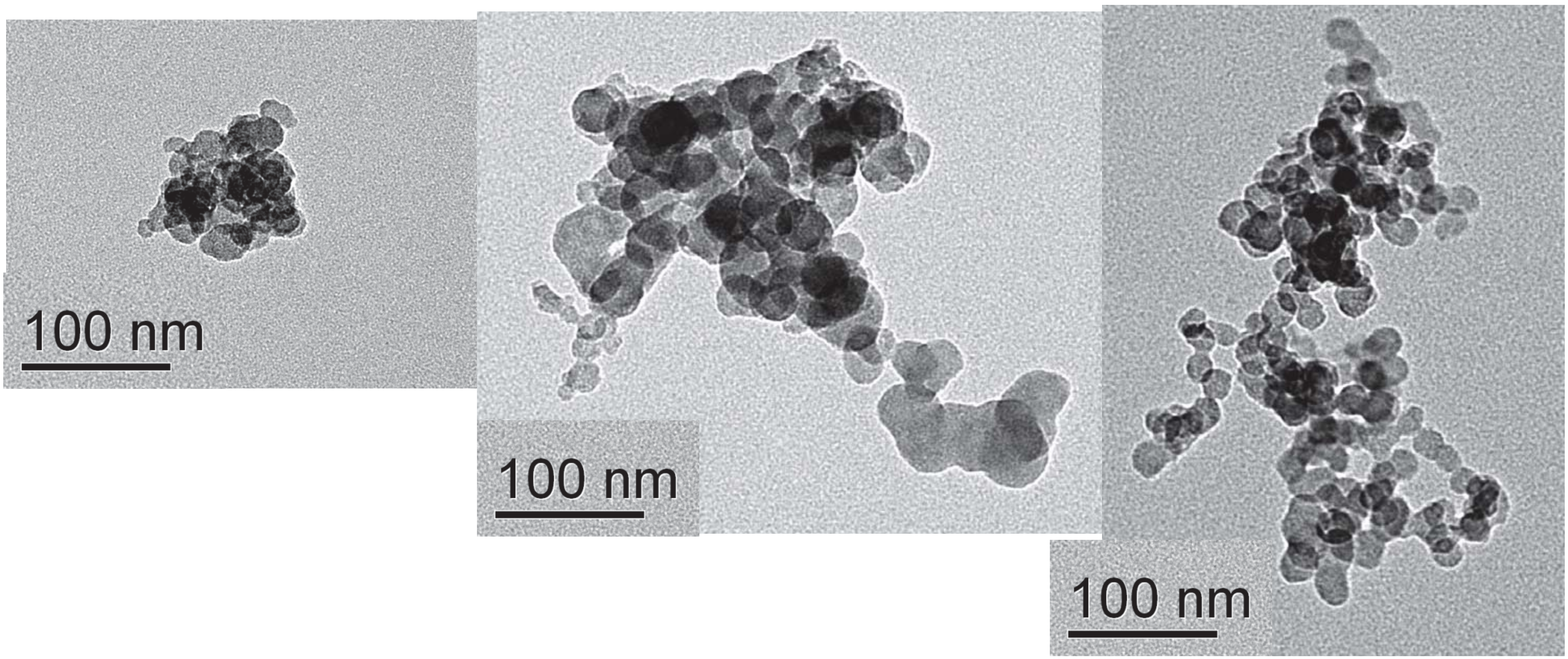


China et al., 2013; Nature



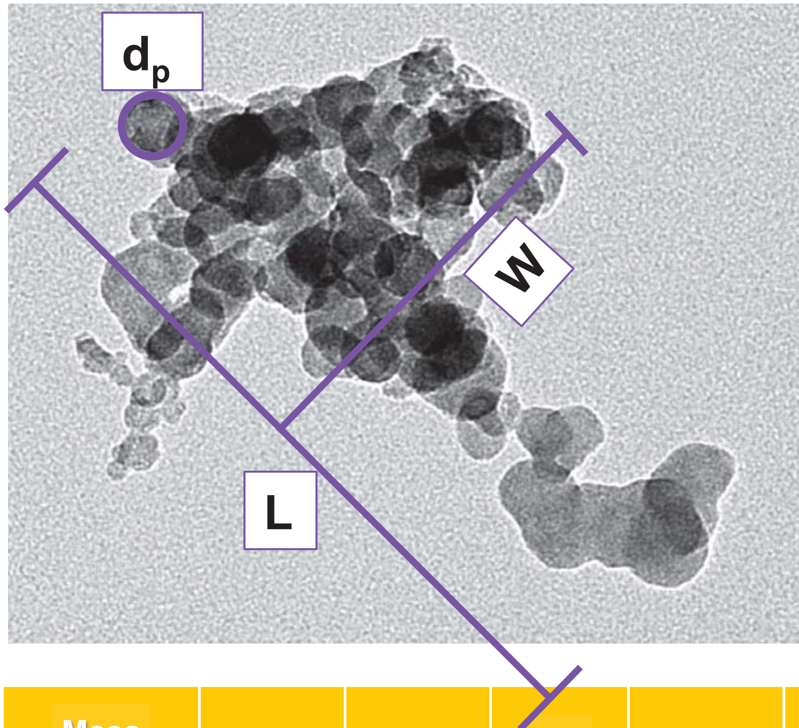
Shape Factor (χ)

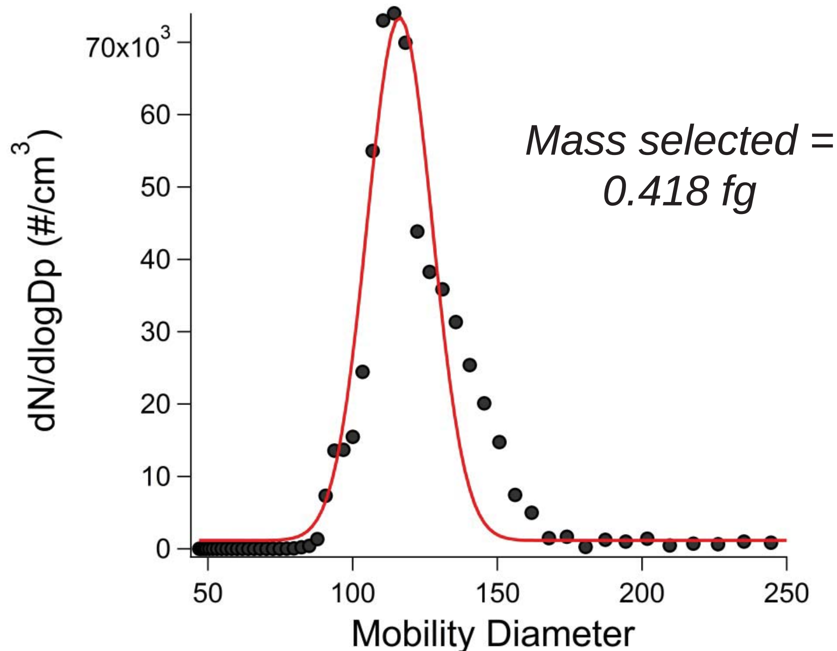
- Use APM to select a single particle mass
  - Electrostatically precipitate onto a TEM grid



Giordano et al., 2014, ACP

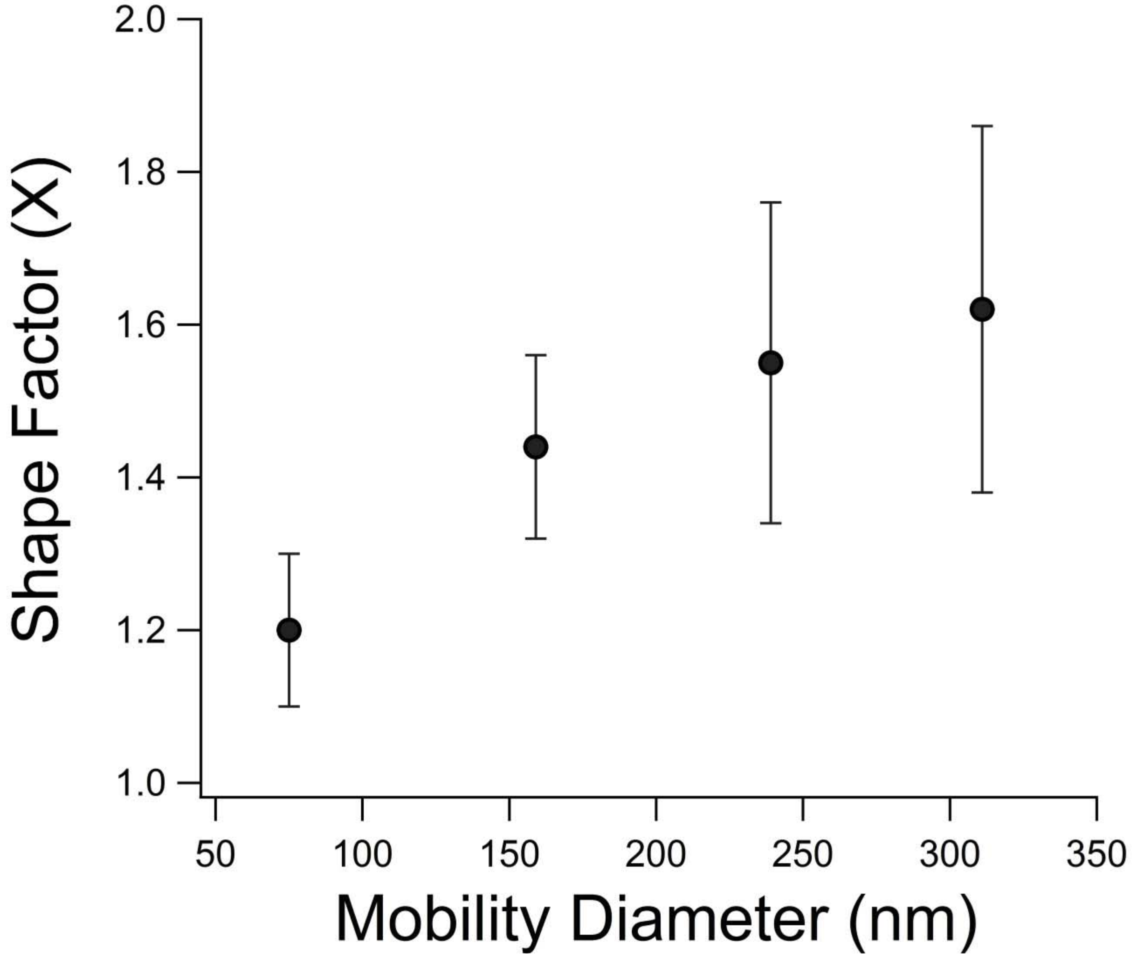
Shape Factor (χ)





Mass selected (fg)	n	L (nm)	W (nm)	N	d_p (nm)	V_{calc} (nm^3)	d_{calc} (nm)	Mobility Diameter	Shape Factor (χ)
0.177	8	157 ± 42	120 ± 27	60 ± 15	16 ± 4	1.29E+05	**62 ± 4**	**75**	**1.20 ± 0.1**
0.418	13	238 ± 90	139 ± 45	167 ± 34	20 ± 3	7.00E+05	**110 ± 9**	**159**	**1.44 ± 0.12**
0.82	14	403 ± 98	266 ± 90	299 ± 101	23 ± 4	1.90E+06	**153 ± 15**	**239**	**1.55 ± 0.21**
1.41	19	570 ± 199	322 ± 104	510 ± 199	24 ± 5	3.69E+06	**191 ± 22**	**311**	**1.62 ± 0.24**

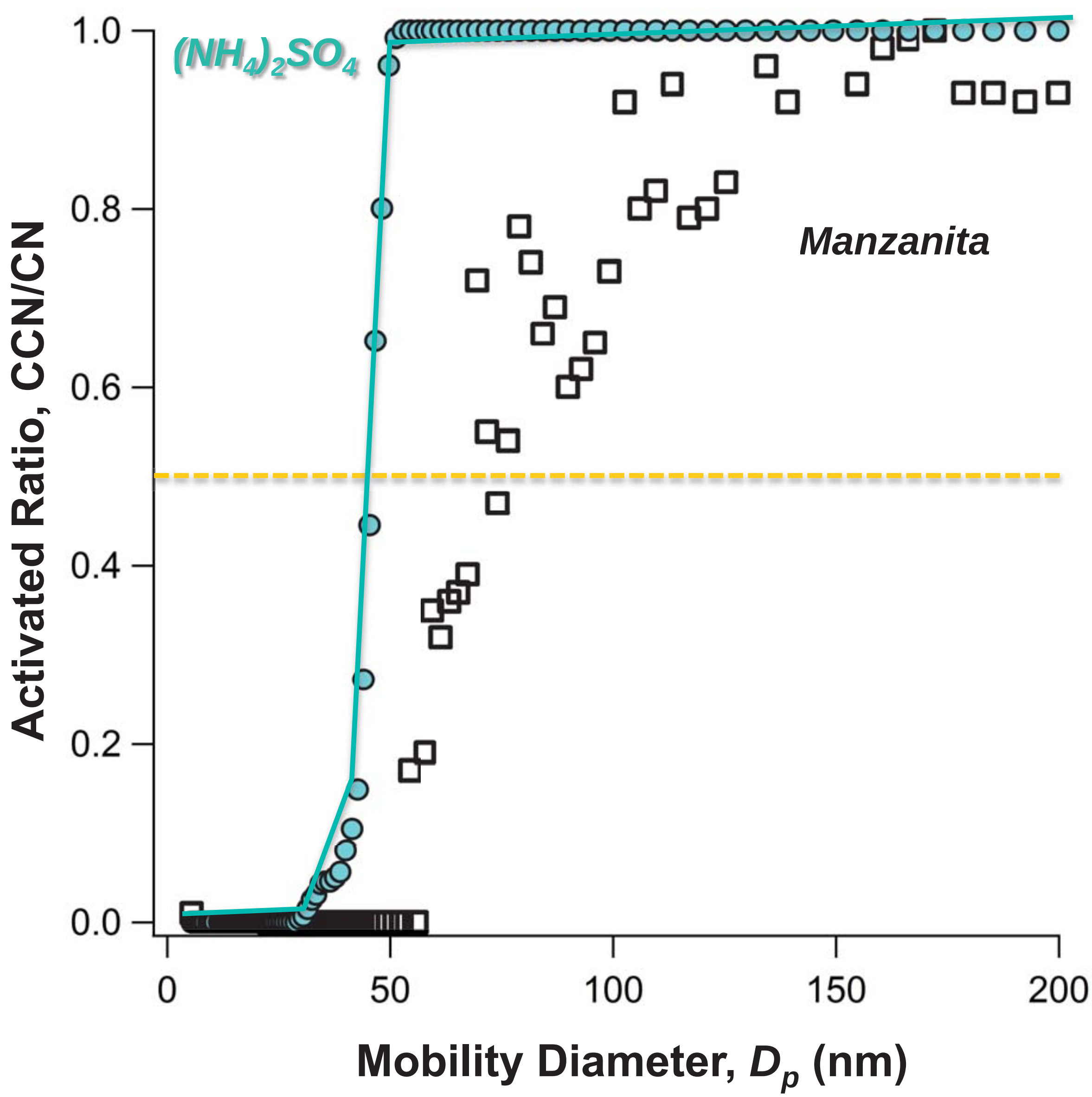
Shape Factor (χ)



How does this affect CCN calculations?

Giordano et al., 2014, ACP

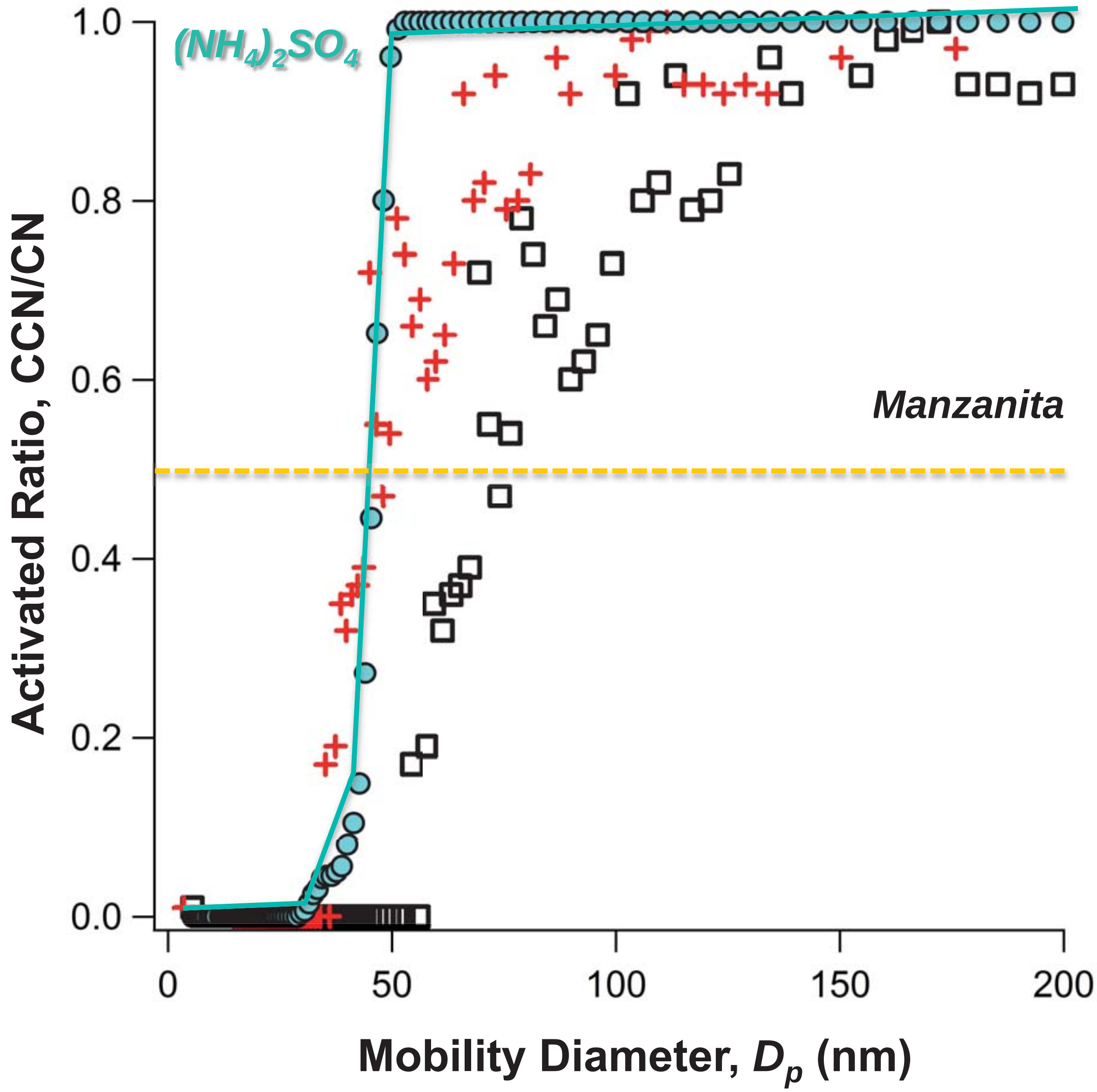
- For CCN, mobility diameter alone is ***inadequate***
- We need effective density/fractal dimension and shape factor information to correct data points



Giordano et al., 2014, ACP

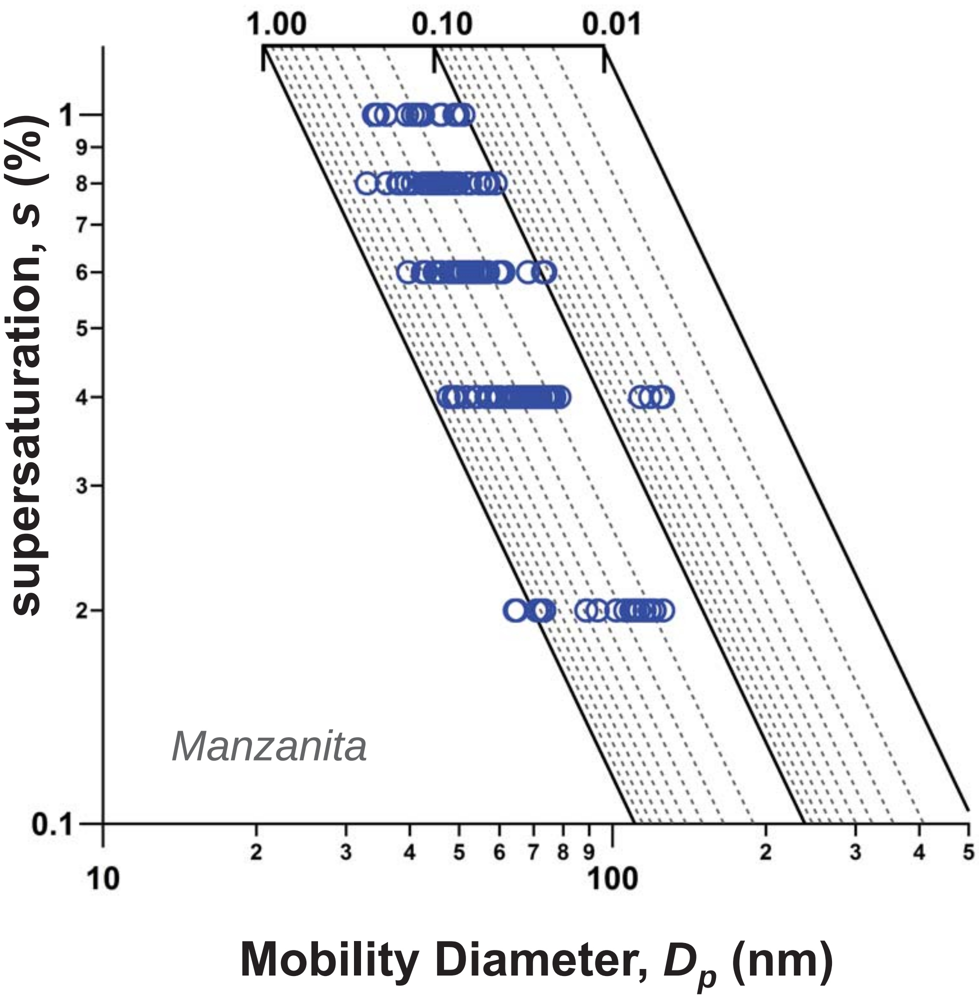
Volume Equivalent Diameter - Corrected data points

Size Matters!



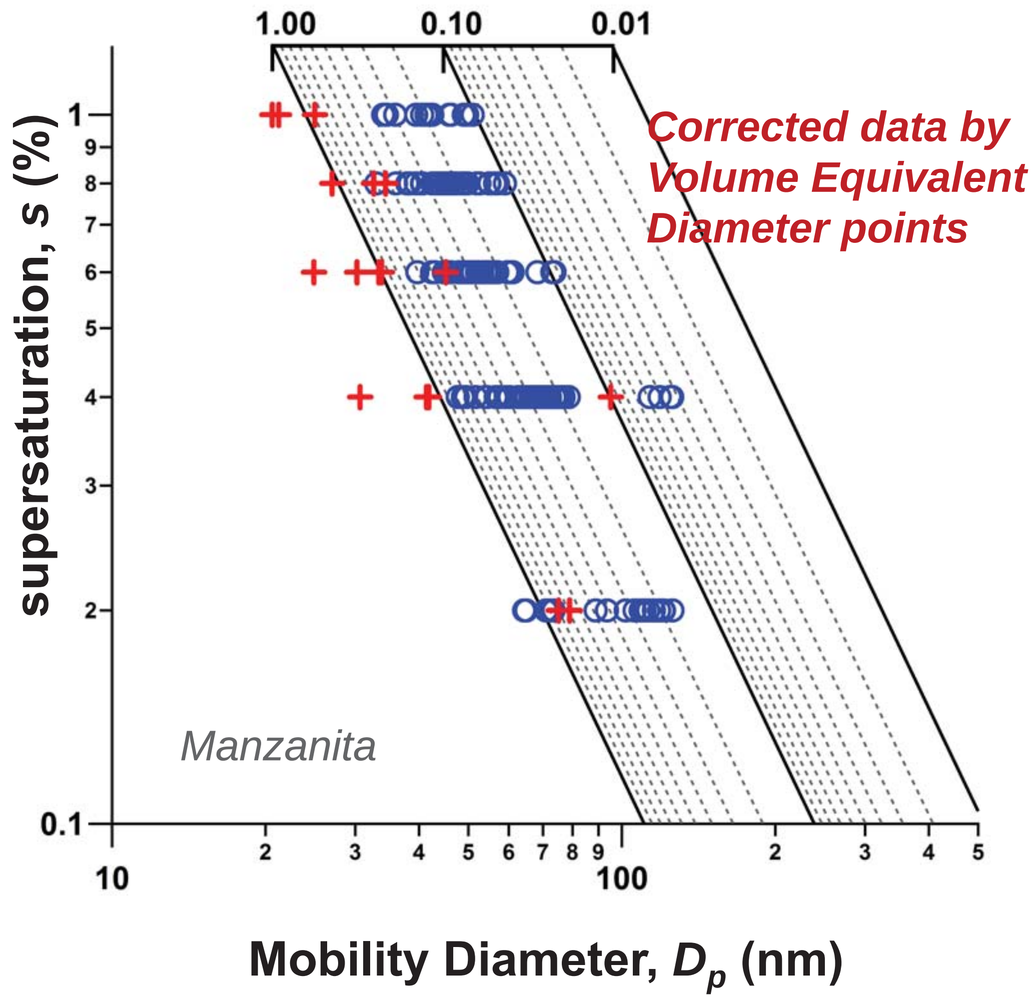
Giordano et al., 2014, ACP

κ, hygroscopicity



Giordano et al., 2014, ACP

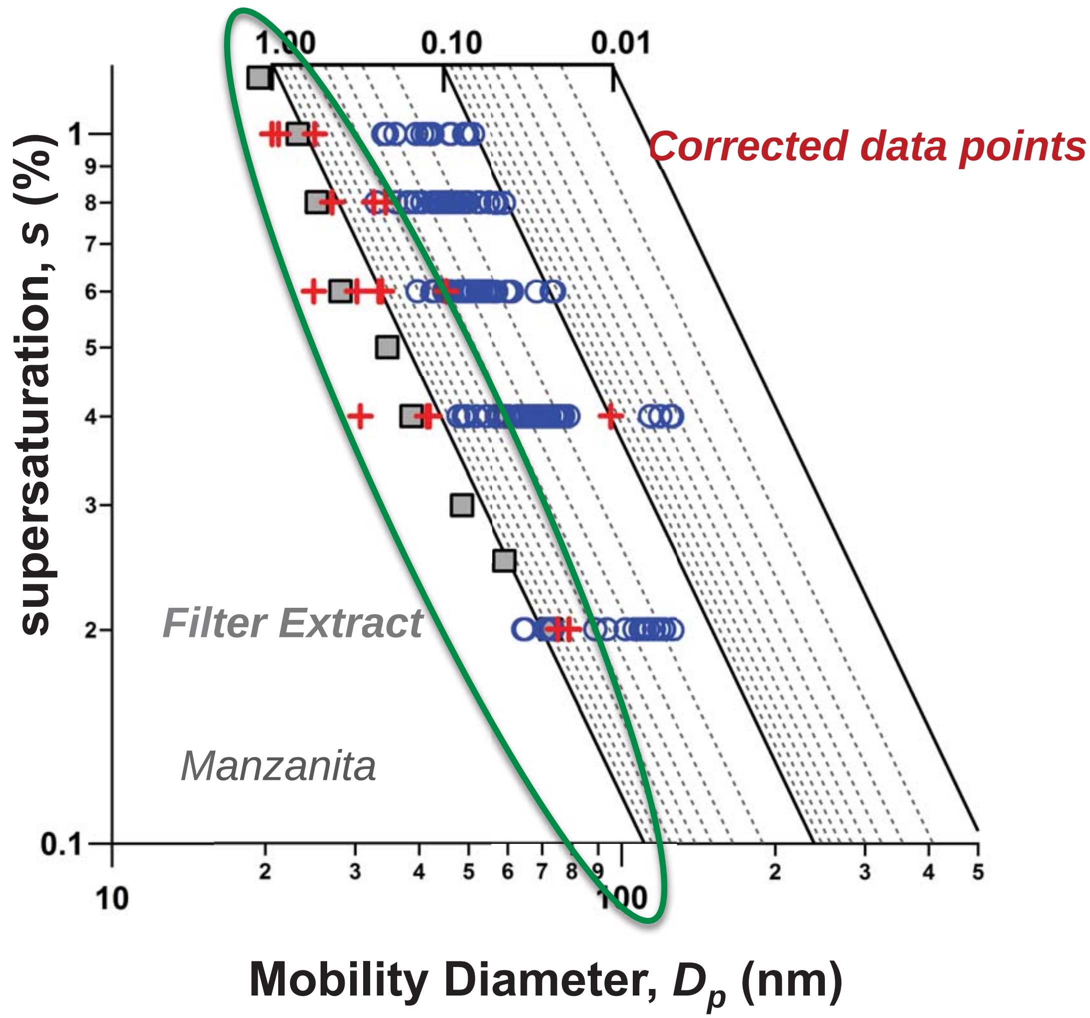
κ, hygroscopicity



- Correcting for available solute mass shifts activity to the left

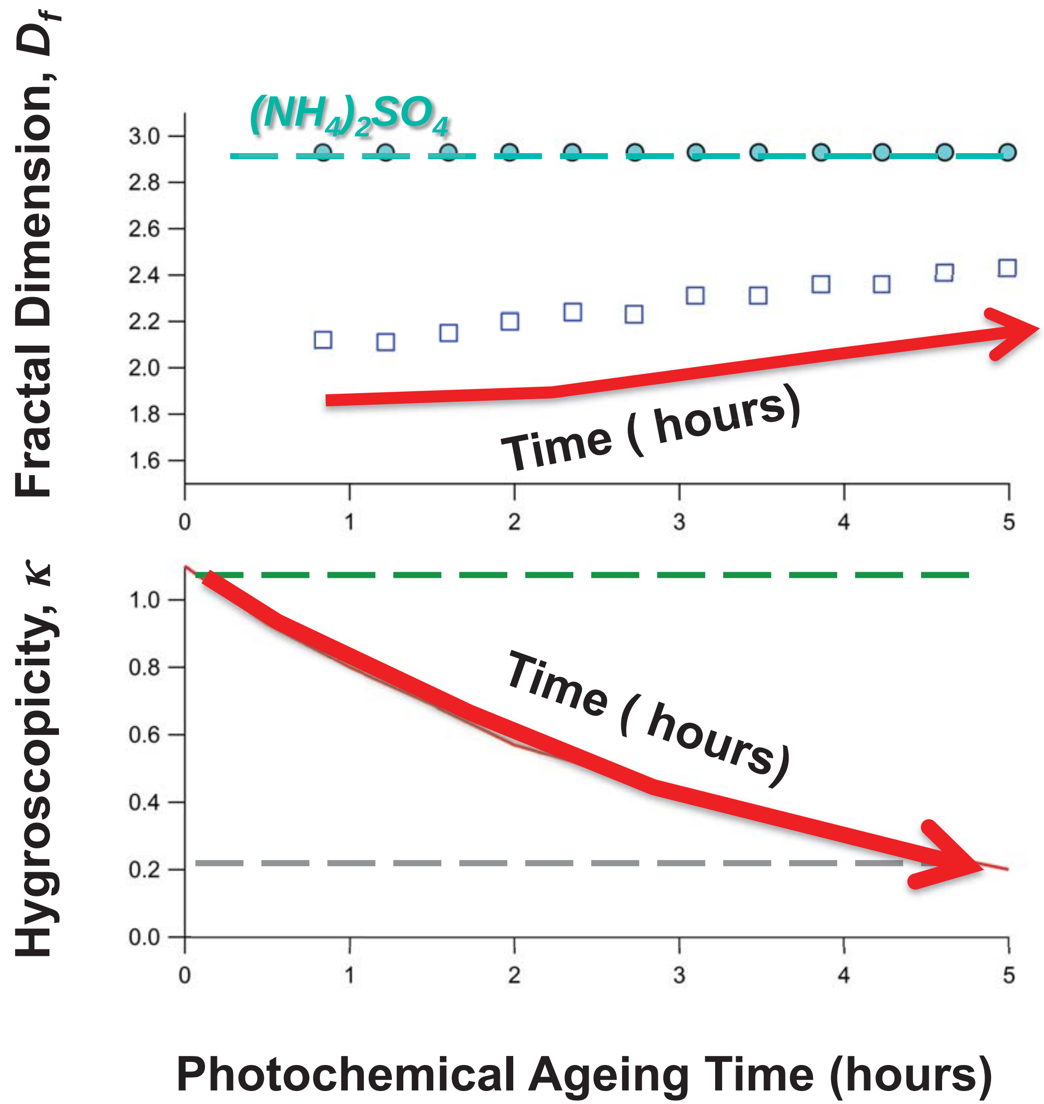
Giordano et al., 2014, ACP

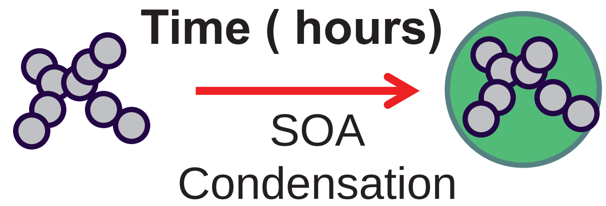
κ, *hygroscopicity*



- Correcting for available solute mass shifts activity to the left

Shifting from non-spherical to spherical





- Secondary Ageing, reduces fractal nature and hygroscopicity also decreases

Photochemical ageing will change sphericity

Giordano et al., 2014, ACP

Conclusions

- **Surfactants are Real**
  - Surfactants are indeed present in aerosol systems, can be generated under controlled conditions, and may alter observed hygroscopicity and droplet formation ability by twofold.
  - Surfactant properties depend on aerosol aging and can be ephemeral thus explaining the lack of consensus in the current body of literature, .
- **The changing fractal/sphericity of fresh and aged biomass burning aerosol can be accounted for in CCN Analysis**
- **Size, Chemistry and Time are critical and relevant properties for CCN Biomass Burning Analysis.**

Giordano et al., 2013, EST

Environmental Science & Technology

Article

pubs.acs.org/est

Changes in Droplet Surface Tension Affect the Observed Hygroscopicity of Photochemically Aged Biomass Burning Aerosol

Michael R. Giordano,[†,‡] Daniel Z. Short,[†,‡] Seyedehs...
and Akua A. Asa-Awuku*[,†,‡]

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[‡]College of Engineering—Center for Environmental Research and...
[§]Department of Mechanical Engineering, University of California–...

Supporting Information

Atmos. Chem. Phys. Discuss., 14, 12555–12589, 2014
www.atmos-chem-phys-discuss.net/14/12555/2014/
doi:10.5194/acpd-14-12555-2014

Atmospheric Chemistry and Physics
Discussions
Open Access

Experimentally measured morphology of biomass burning aerosol and its impacts on CCN ability

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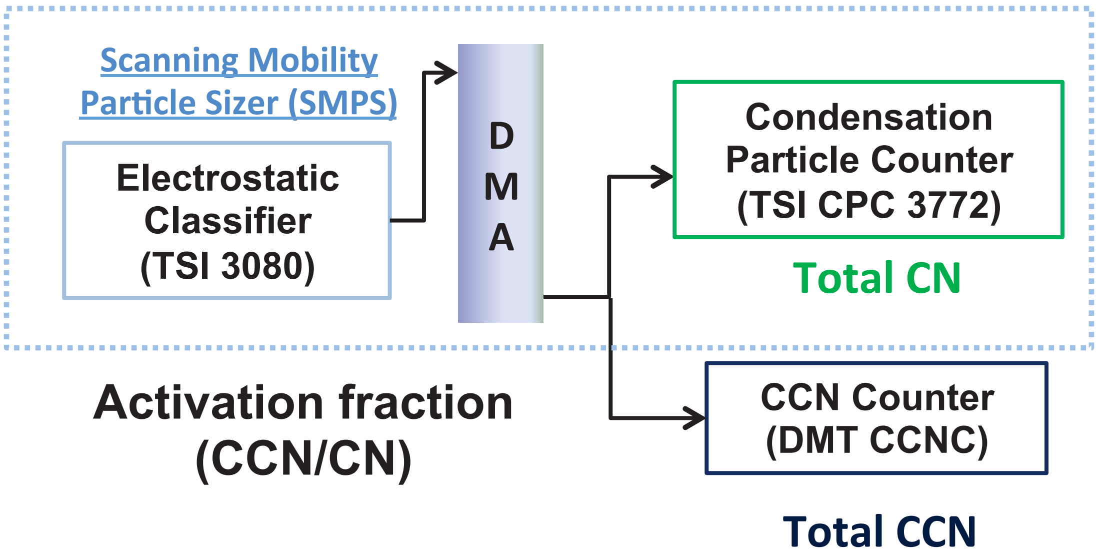
Giordano et al., 2014, in press

MIXING STATE FLOW TUBE

Part 3:
BC/OC Mixing State CCN

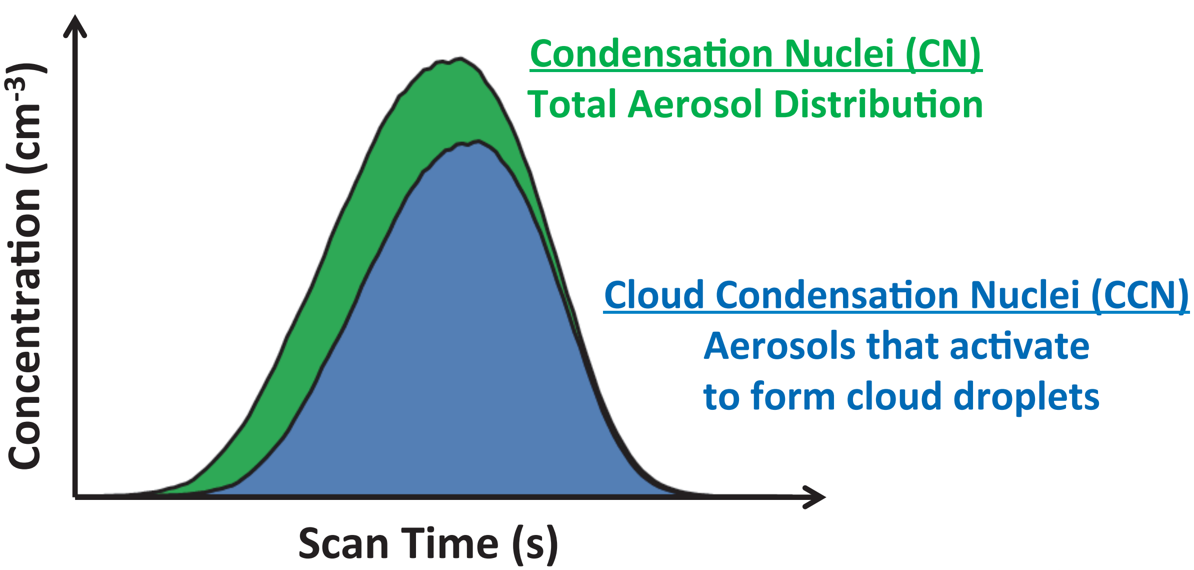
Measuring CCN Activity

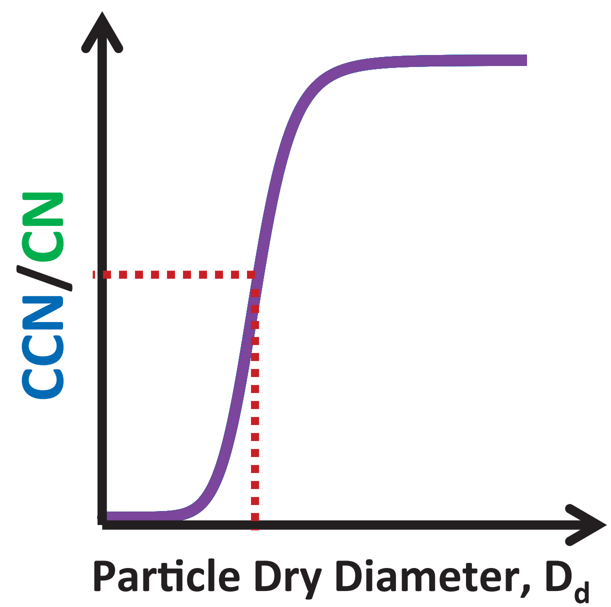


Scanning Mobility CCN Analysis:

(Moore et al. 2010)

Determines D_d for various supersaturations

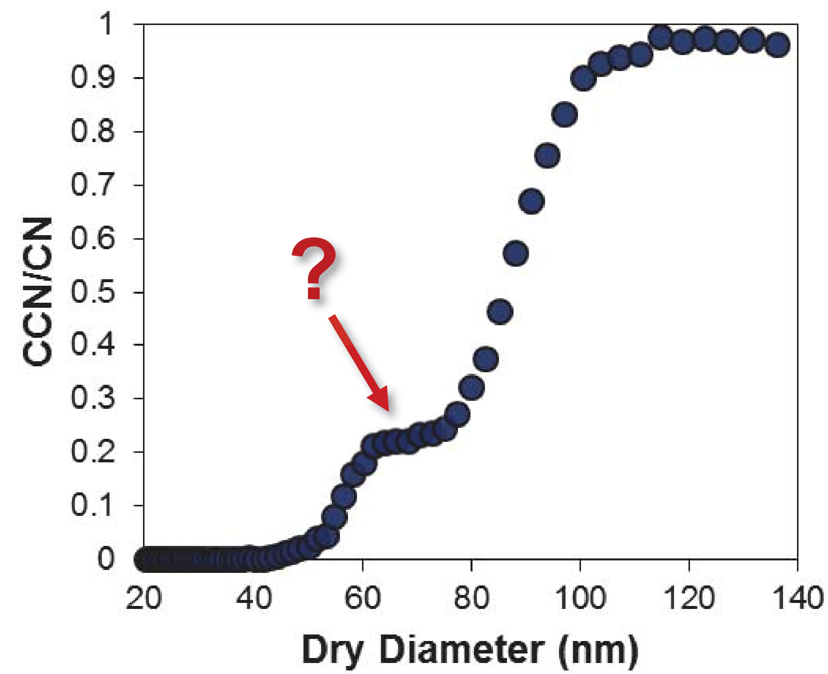




Vu et al., in prep

Real Data Sets

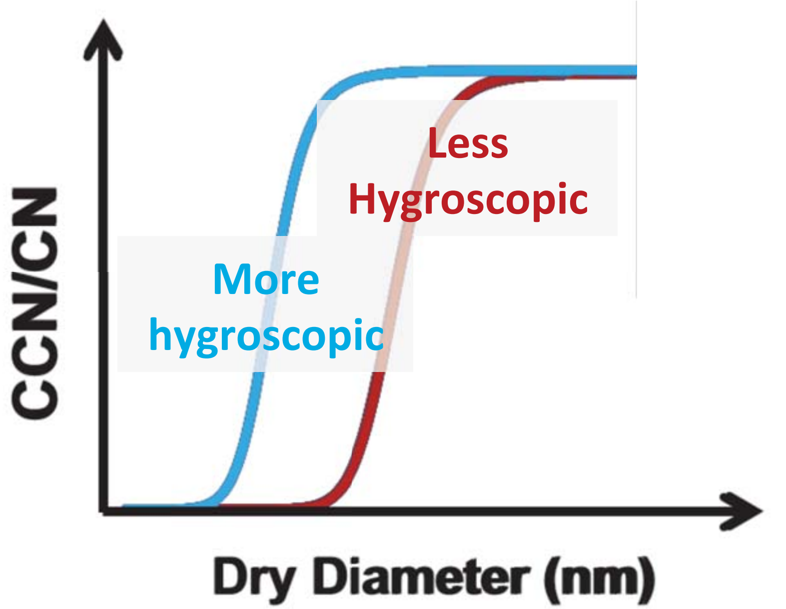
- **CCN** data sets from ambient and environmental chamber studies can consist of complex mixtures of organic and inorganic aerosols
- **Common assumptions**
  - – Doubly charged aerosols
  - – Uniform composition
  - → Single fit
- **Multiple activation curves**…?
  - – Different components?
  - – Mixing state? Type / Extent? Complex mixtures?

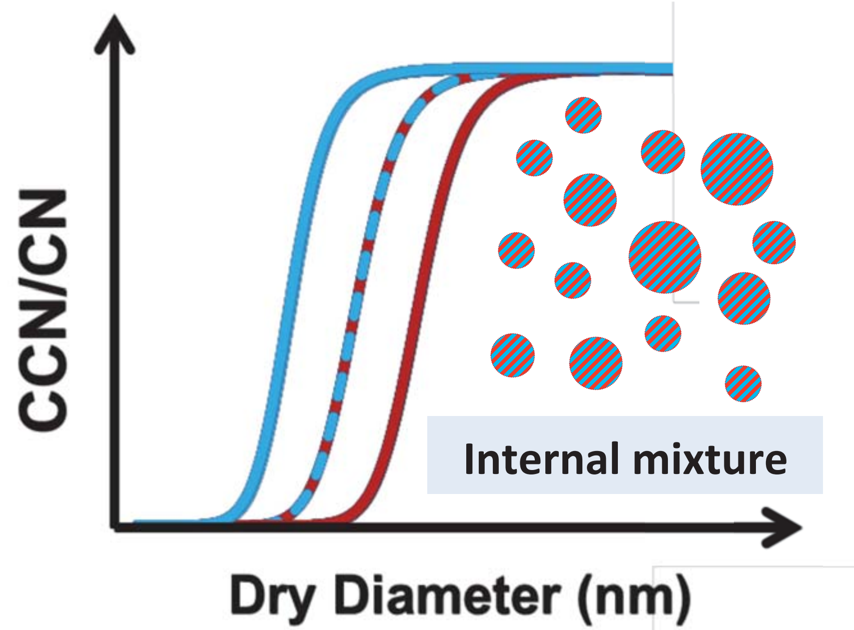


α-Pinene / Diesel Exhaust Mixture
Environmental Chamber CCN activation data
data from Asa-Awuku et al. 2009

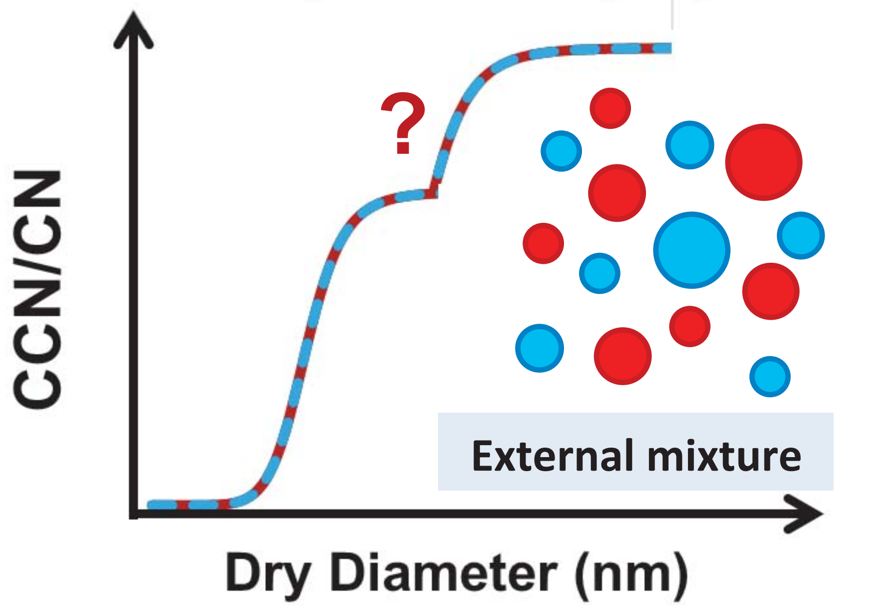
GOAL: Improve experimental analysis techniques of CCN of complex mixtures

<u>Mixing States</u>: Internal / External Mixtures





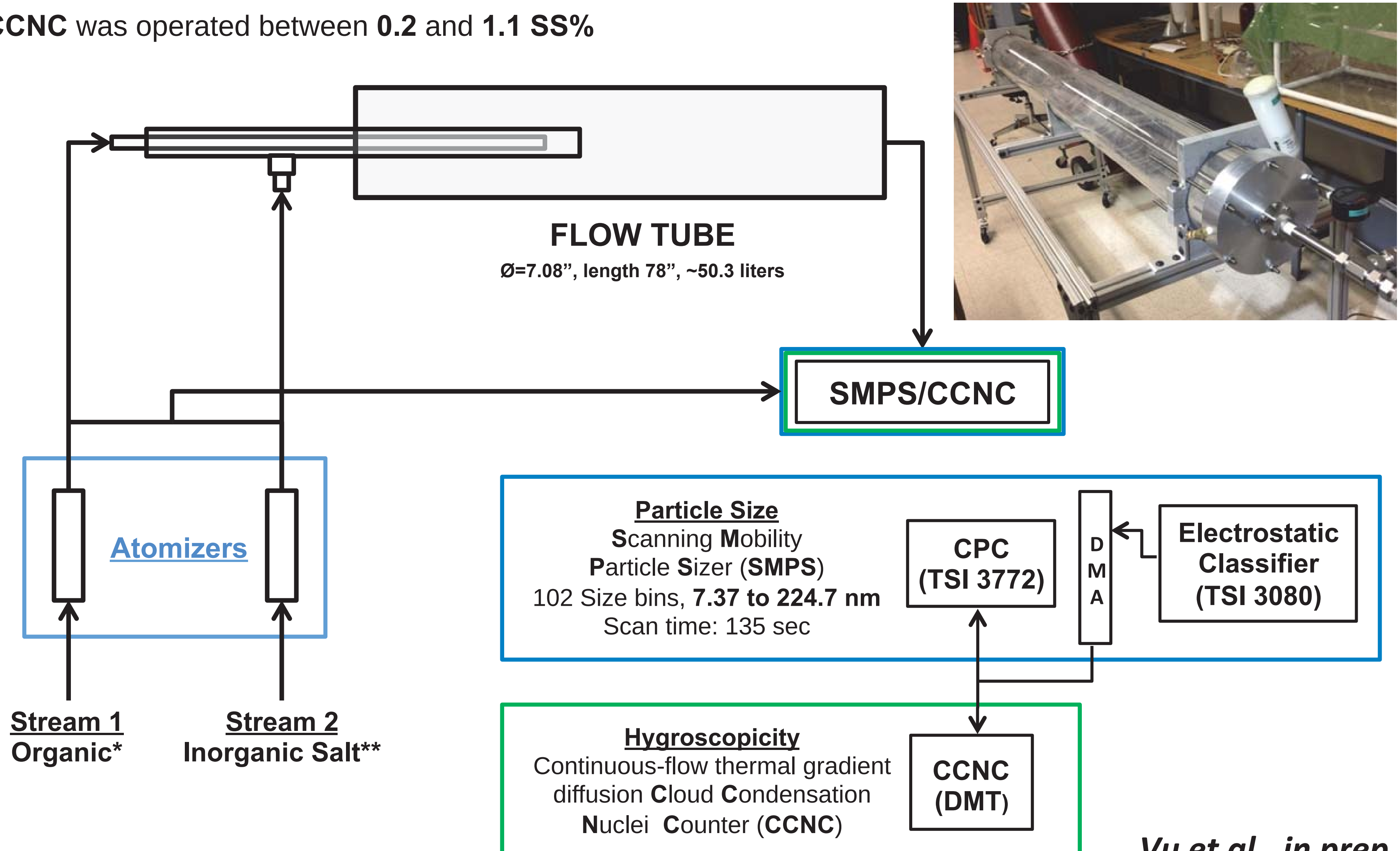
Atmospheric aerosols are often **mixed** and comprised of **multiple components**



Vu et al., in prep

Recreating Activation Curves: Known Mixtures

CCNC was operated between **0.2** and **1.1 SS%**



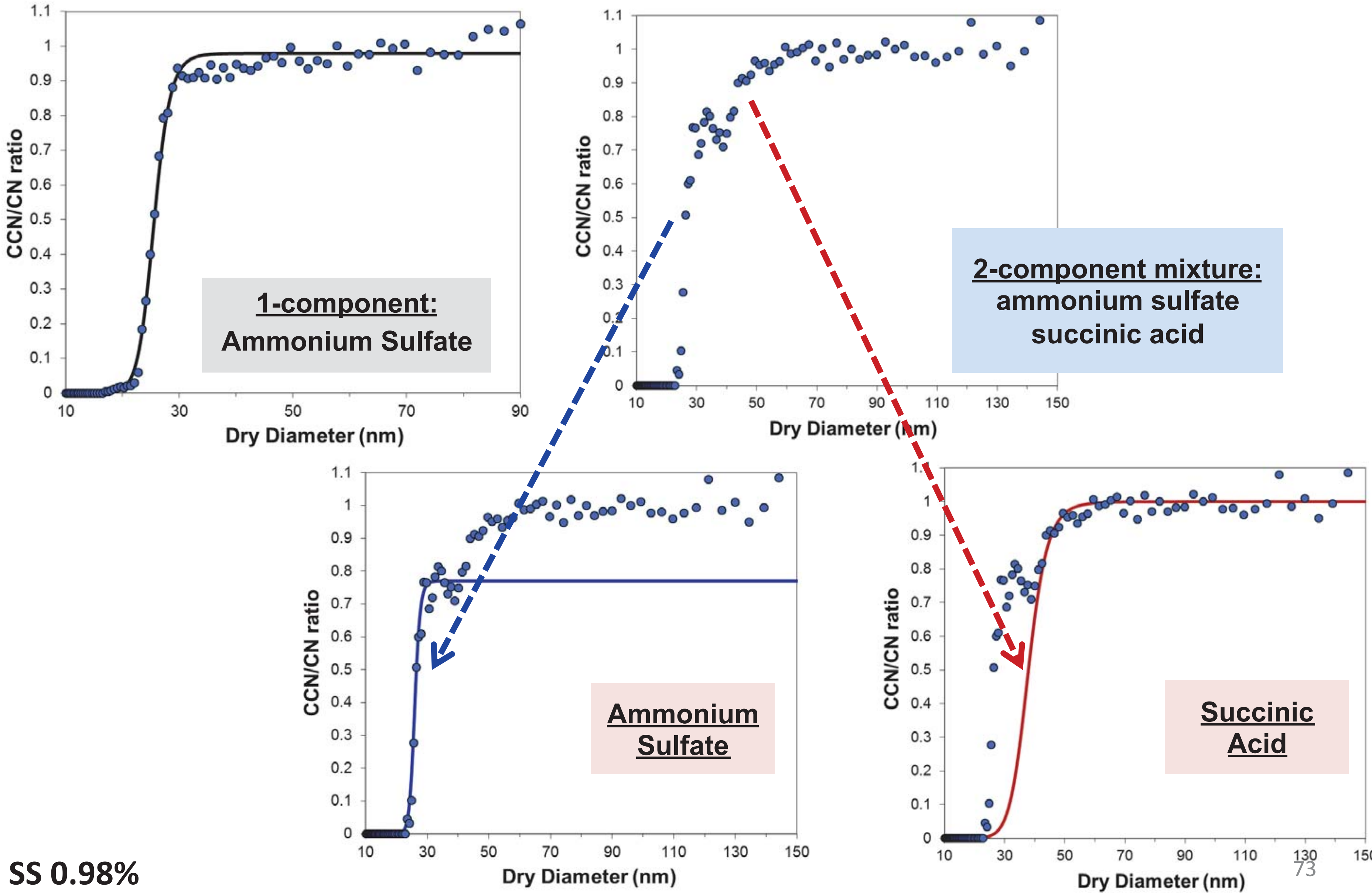
Vu et al., in prep

*<u>Organic</u>: **Succinic Acid, $C_4H_6O_4$**

<u>Inorganic Salt</u>: **Ammonium Sulfate, $(NH_4)_2SO_4$, Sodium Chloride, NaCl

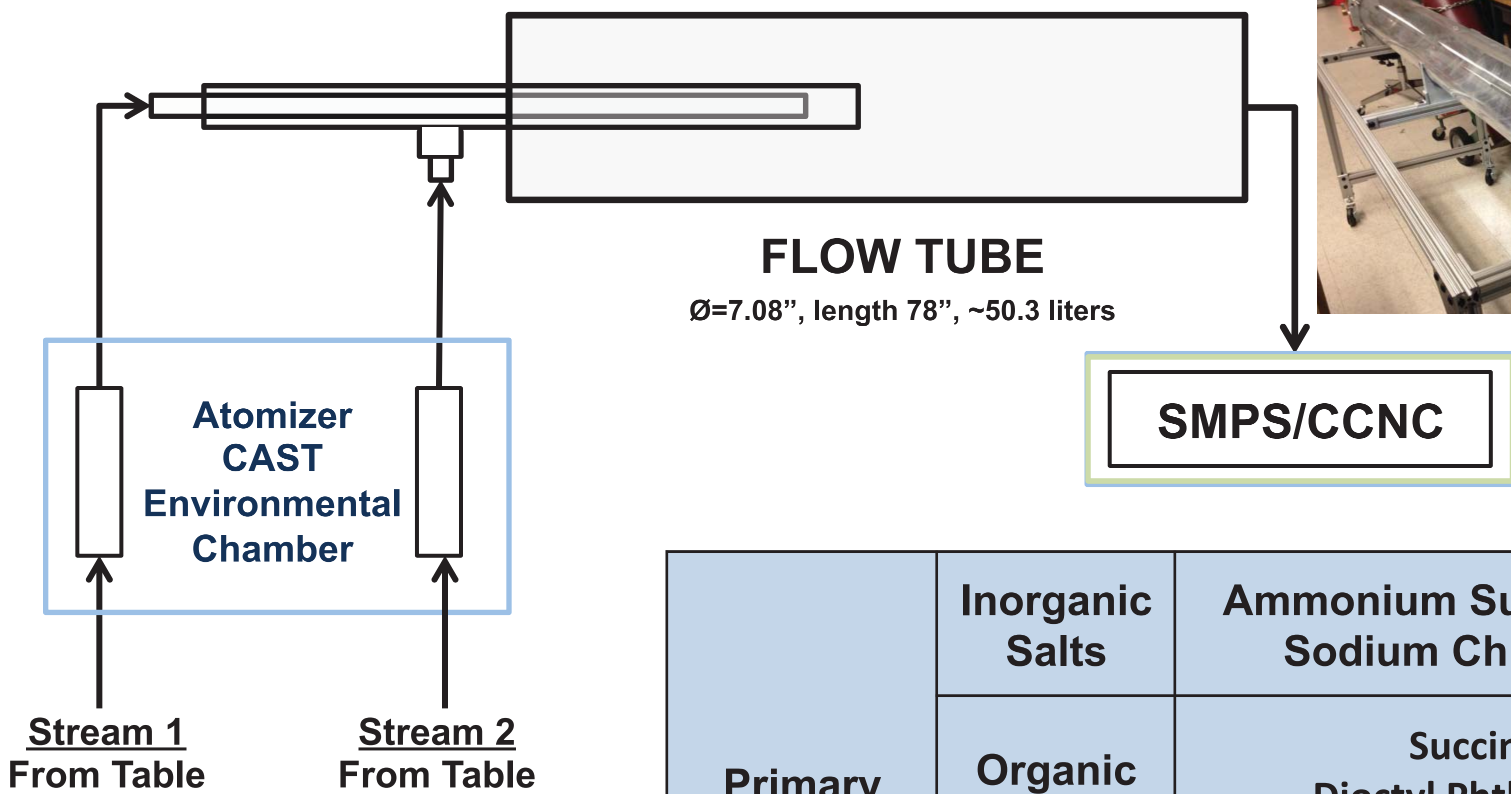
Multiple Activation Curves: External Mixtures

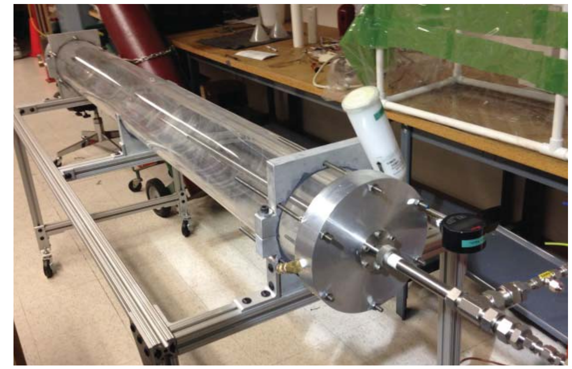
Data sets yielding multiple activation curves were recreated by mixing two well characterized compounds



SS 0.98%

Future Work

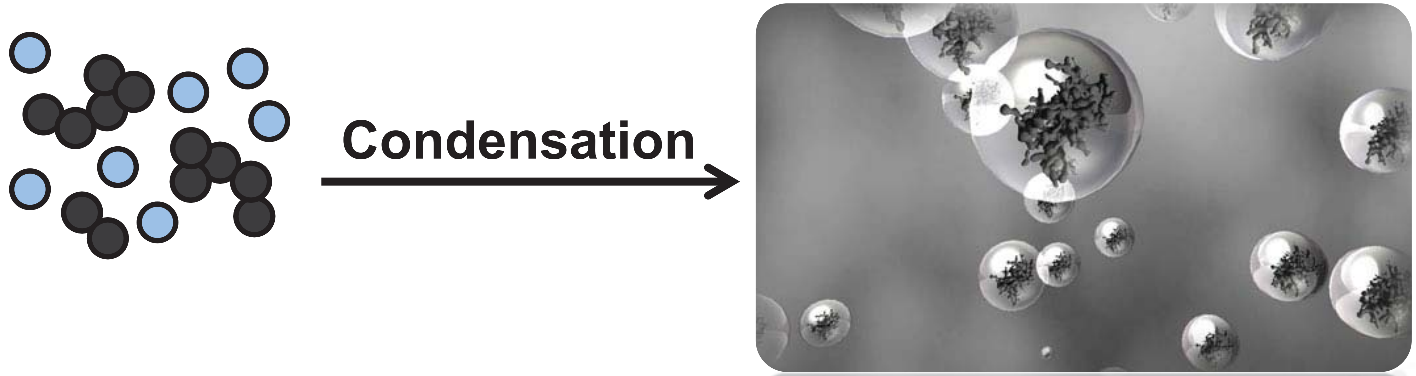




Extend data analysis to include more complex mixed systems from both primary and secondary sources

Primary	**Inorganic Salts**	**Ammonium Sulfate $(NH_4)_2SO_4$** **Sodium Chloride (NaCl)**
	Organic	**Succinic Acid** **Dioctyl Phthalate (DOP)**
	Black Carbon	Combustion Aerosol Standard (CAST): **soot particles** generated similar to soot derived diesel engines
Secondary	**Biogenic SOA**	**Isoprene** **-pinene**

OUR APPROACH TO COMPLEX HYGROSCOPIC PARTICLES



Source: NASA : *Black Carbon Cloud Droplets (artist rendition)*

(1) Provide Fast Measurement Techniques for Real-World BC Sources

(2) Characterize changes in Physical and Chemical Properties that can alter perceived Hygroscopicity of BC sources

(3) Refine Analysis Methods for complex CCN Mixing States

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Karavalakis, G., Short, D., Chen, V., Espinoza, C., Berte, T., Durbin, T., Asa-Awuku, A., Jung, H. 2014. "Regulated Emissions, Air Toxics, and Particle Emissions from SI-DI Light-Duty Vehicles Operating on Different Iso-Butanol and Ethanol Blends", SAE Technical Paper, *2014*

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Aerosol-Climate Effects Group









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UCR




Understanding the Hygroscopic Properties of BC/OC Mixing States: :

Connecting Climate and Health Impacts of Anthropogenic Aerosol

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Center of Environmental Research and Technology

EPA Black Carbon STAR Meeting
November 13th, 2014

UNIVERSITY OF CALIFORNIA, RIVERSIDE