Multiple Charging Effects on the CCN Activity of Black Carbon Particles

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ARM/ASR PI Meeting

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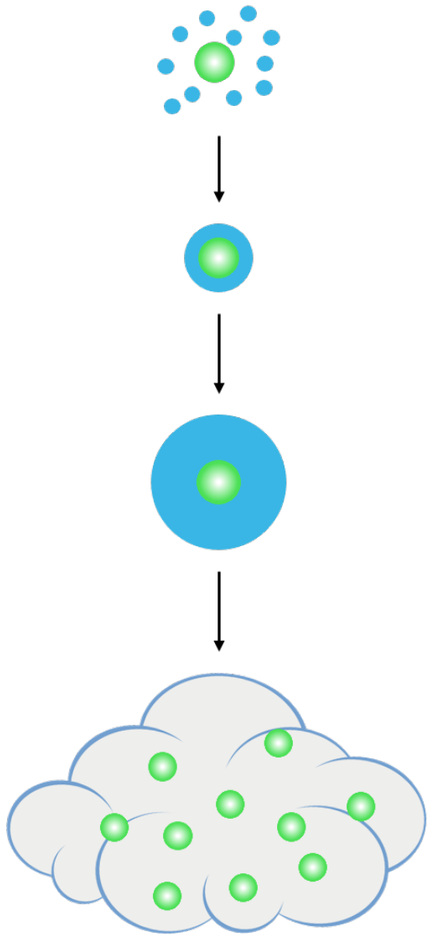
Aerosols Affect Our Climate

Aerosol-Cloud Interactions

Aerosols are seeds for cloud formation



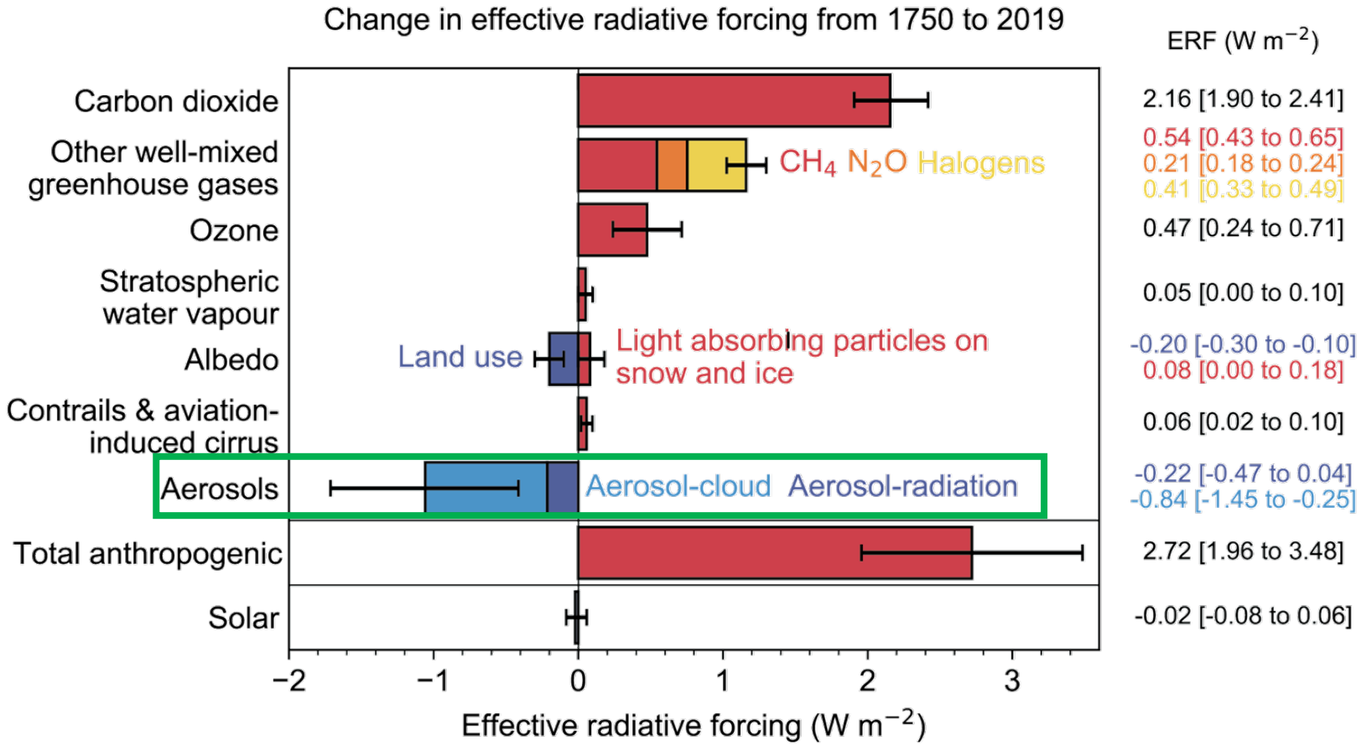
Cloud Condensation Nuclei (CCN)

Cloud Droplet

Droplet Growth

Cloud Formation

IPCC, 2021

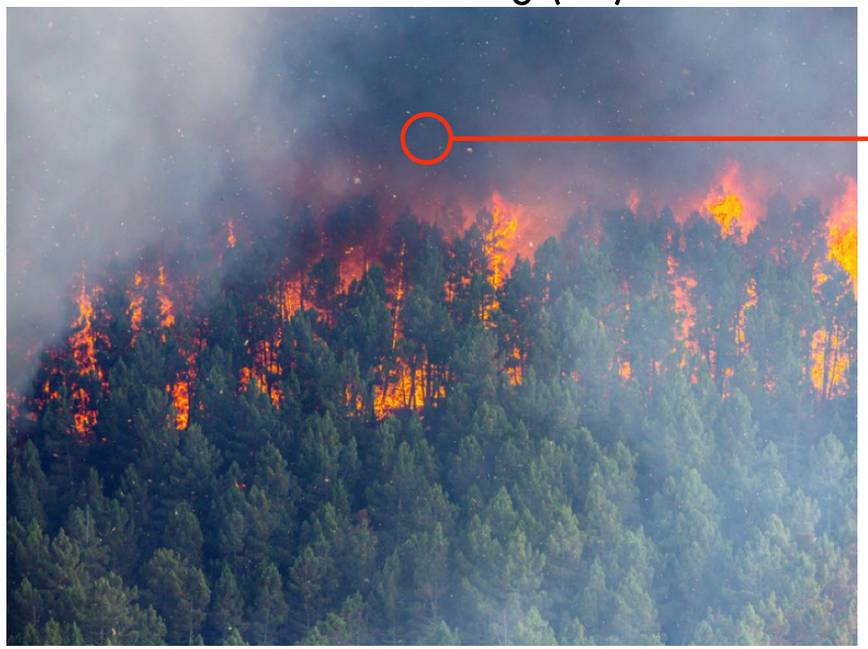


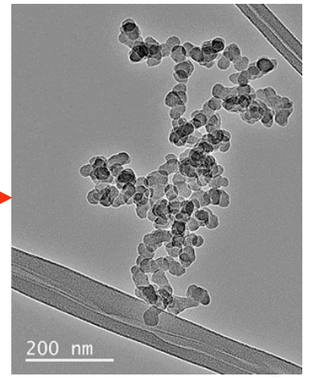
Aerosol-cloud interactions have a huge uncertainty in radiative forcing estimates

Atmospheric Soot (Black Carbon)

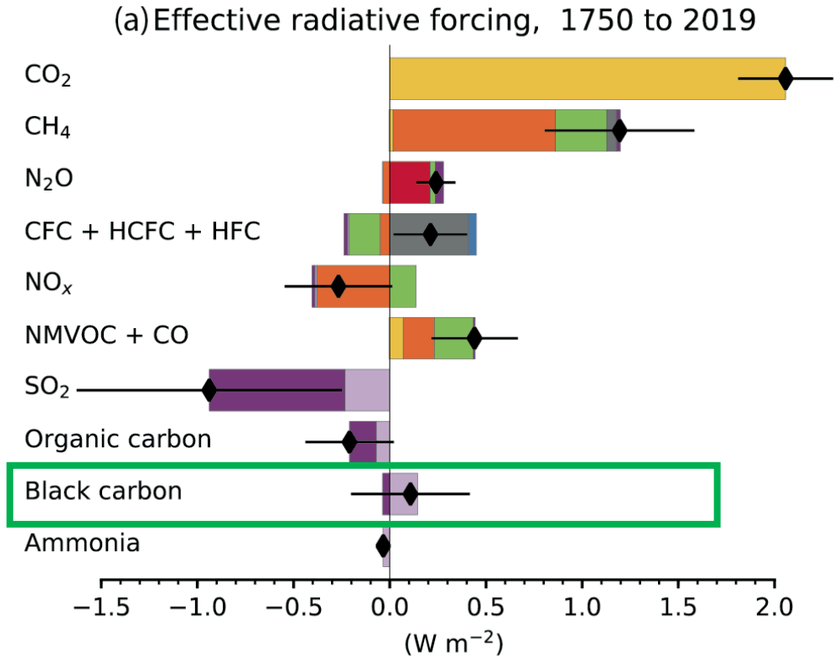
Fossil Fuels

Biomass Burning (BB)





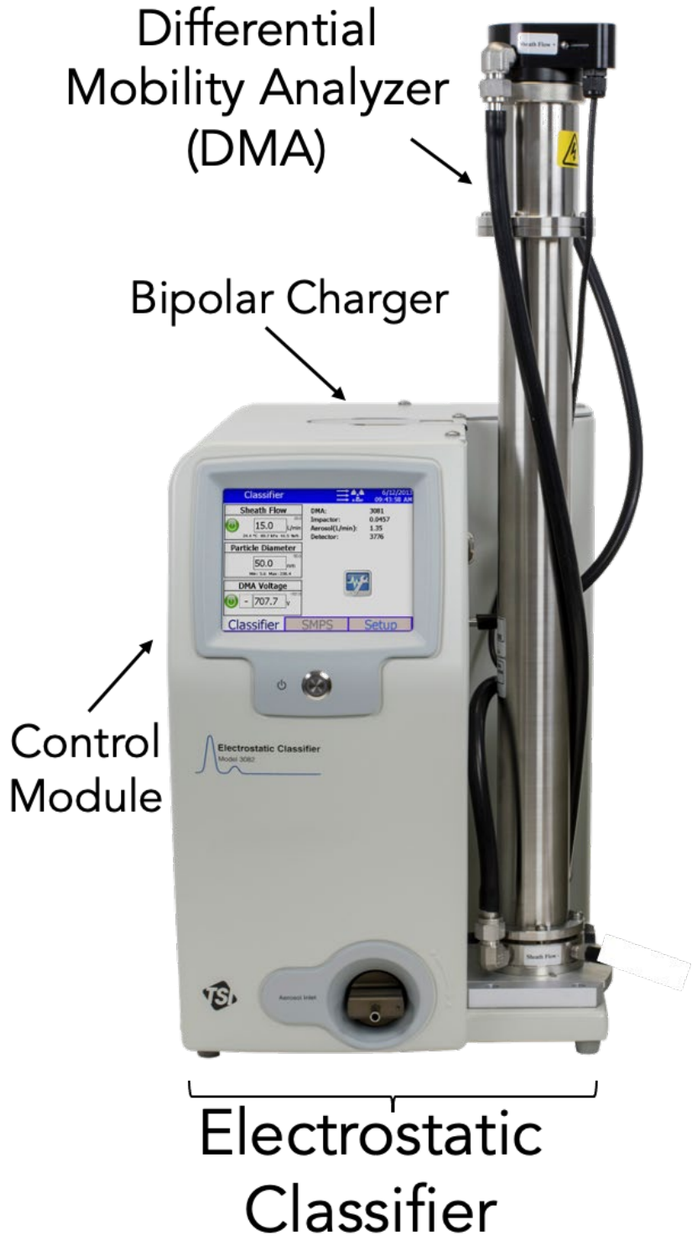
- 50 – 500 nm size
- Complex structure
- Chemically inert
- Hydrophobic
- Light absorbing



BC-water vapor interactions are of significant interest in aerosol studies

Accurate measurements of hygroscopicity and CCN activity are crucial

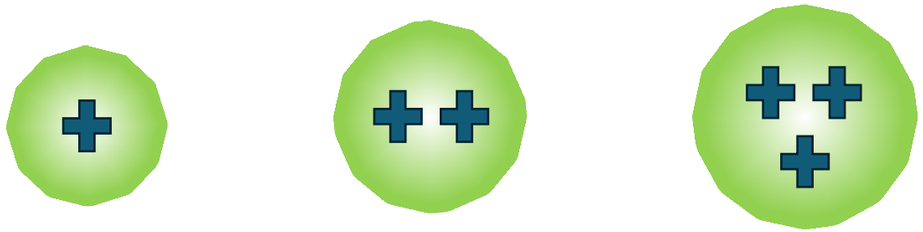
Particle Characterization: The Differential Mobility Analyzer (DMA)



TSI Model 3938

The DMA system classifies particles based on electrical mobility

$$D_{p1} < D_{p2} < D_{p3}$$



$$D_{m1} = D_{m2} = D_{m3}$$

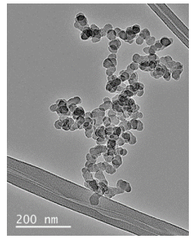
same electrical mobility

Multi-charge effect

Probability of a particle having more than one charge is higher for $D_p \geq 100$ nm

Larger particles with multiple charges introduce errors in measurements of hygroscopicity and CCN activity

Difficult to resolve errors when the particle has a complex structure like black carbon

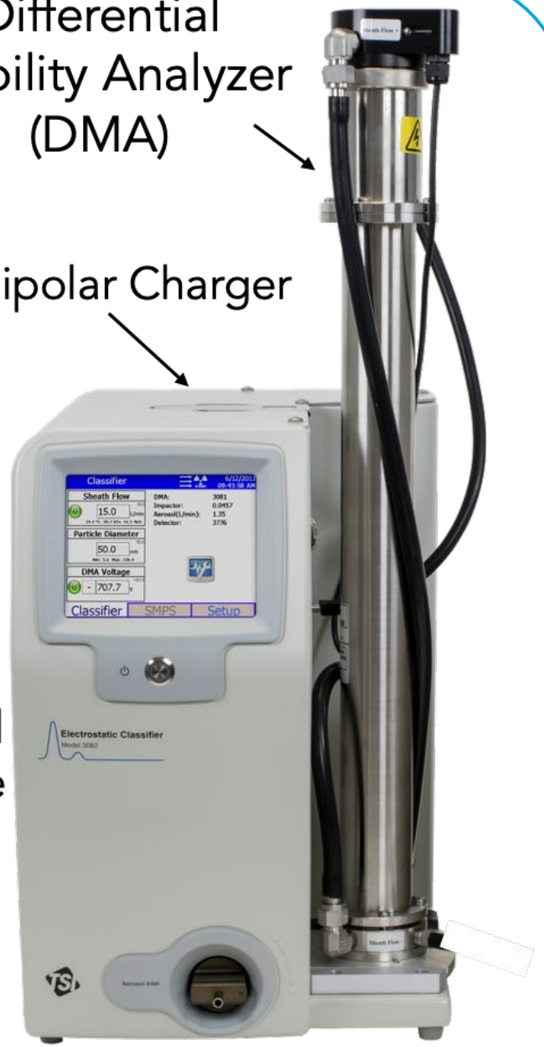


DMA-CPMA System

Differential Mobility Analyzer (DMA)

Bipolar Charger

Control Module

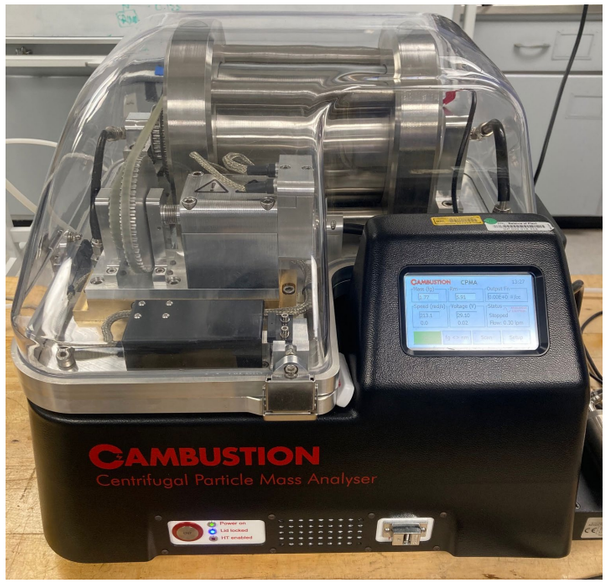


Electrostatic Classifier

Sorts particles by mobility

+

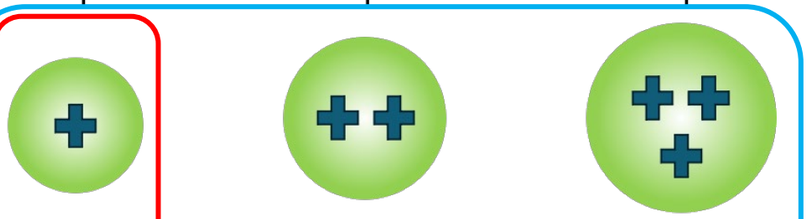
Centrifugal Particle Mass Analyzer (CPMA)



Sorts particles by mass

Particles can be selected by both mobility and mass

$D_{p1} < D_{p2} < D_{p3}$

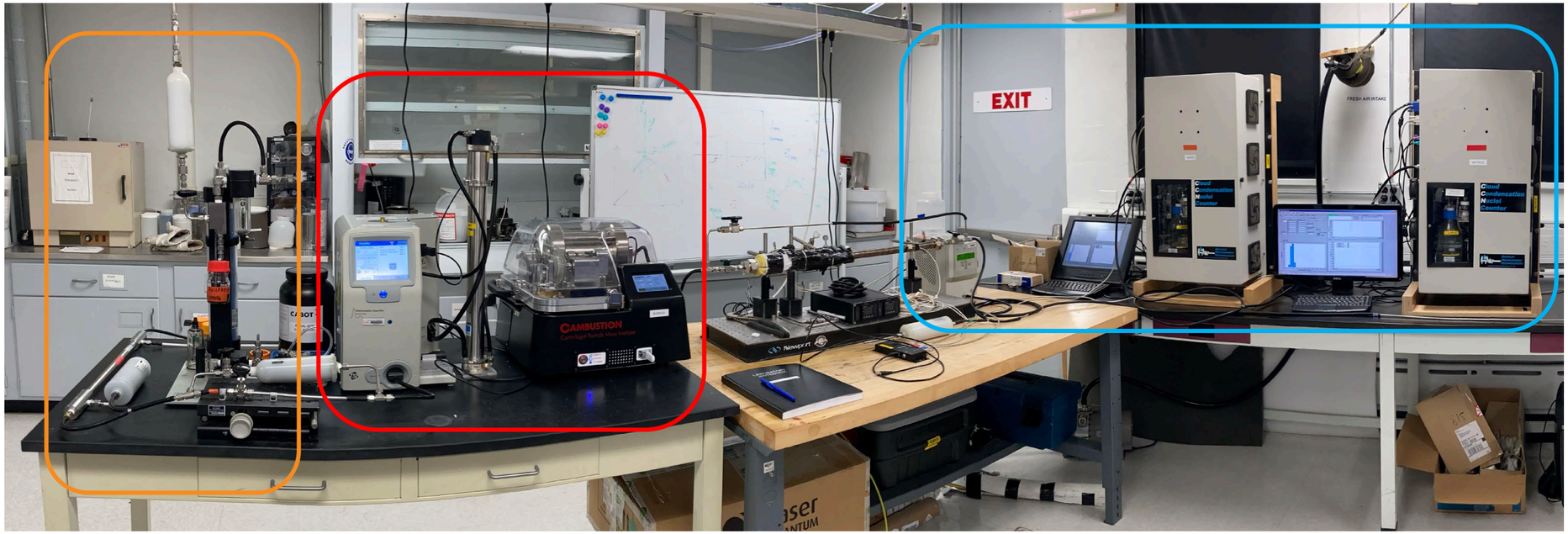


$D_{m1} = D_{m2} = D_{m3}$

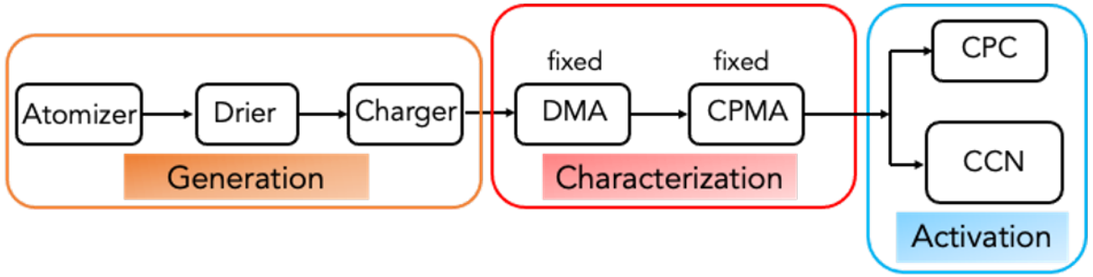
$m_1 < m_2 < m_3$

Use the DMA-CPMA system to resolve errors caused by multiple charging in the CCN activity of BC particles

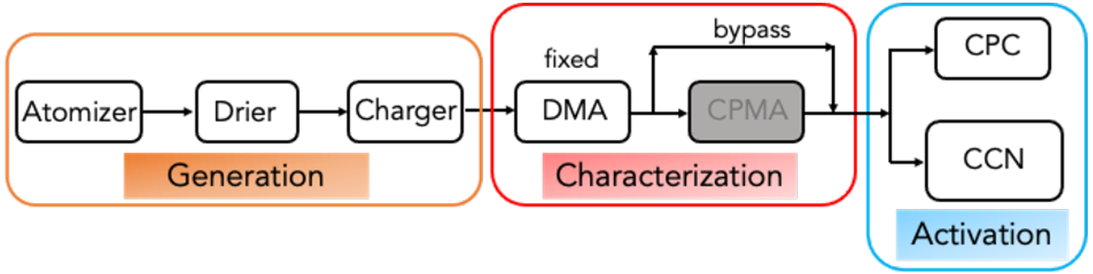
Experimental Setup



DMA-CPMA
(CPMA in fixed mode)



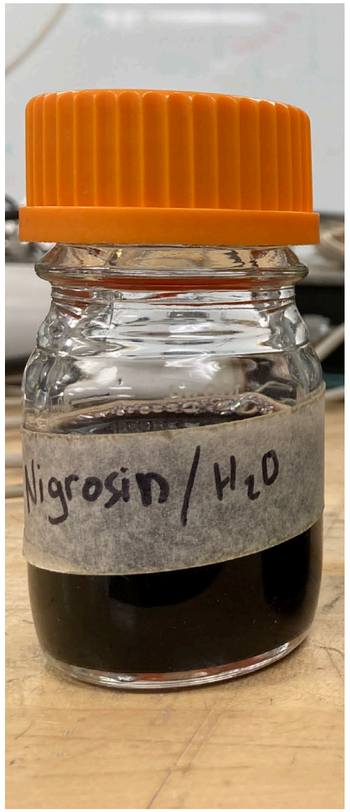
DMA-Only
(Bypassing the CPMA)

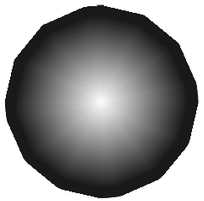


DMA: Differential Mobility Analyzer CPMA: Centrifugal Particle Mass Analyzer CPC: Condensation Particle Counter CCN: Cloud Condensation Nuclei Counter

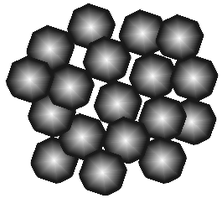
Black Carbon (BC) Surrogates

Nigrosin

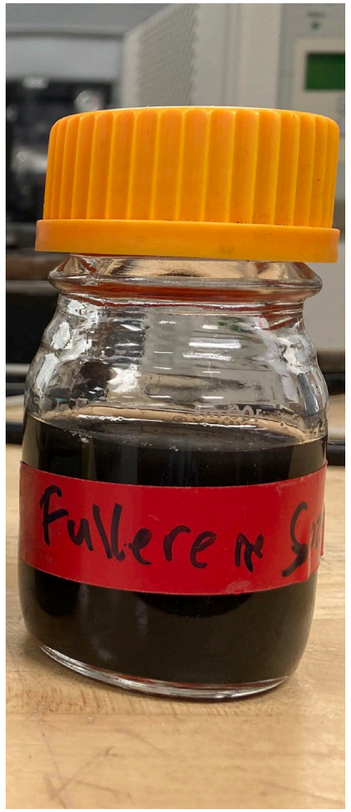


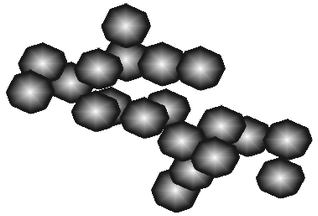


Regal Black



Fullerene Soot





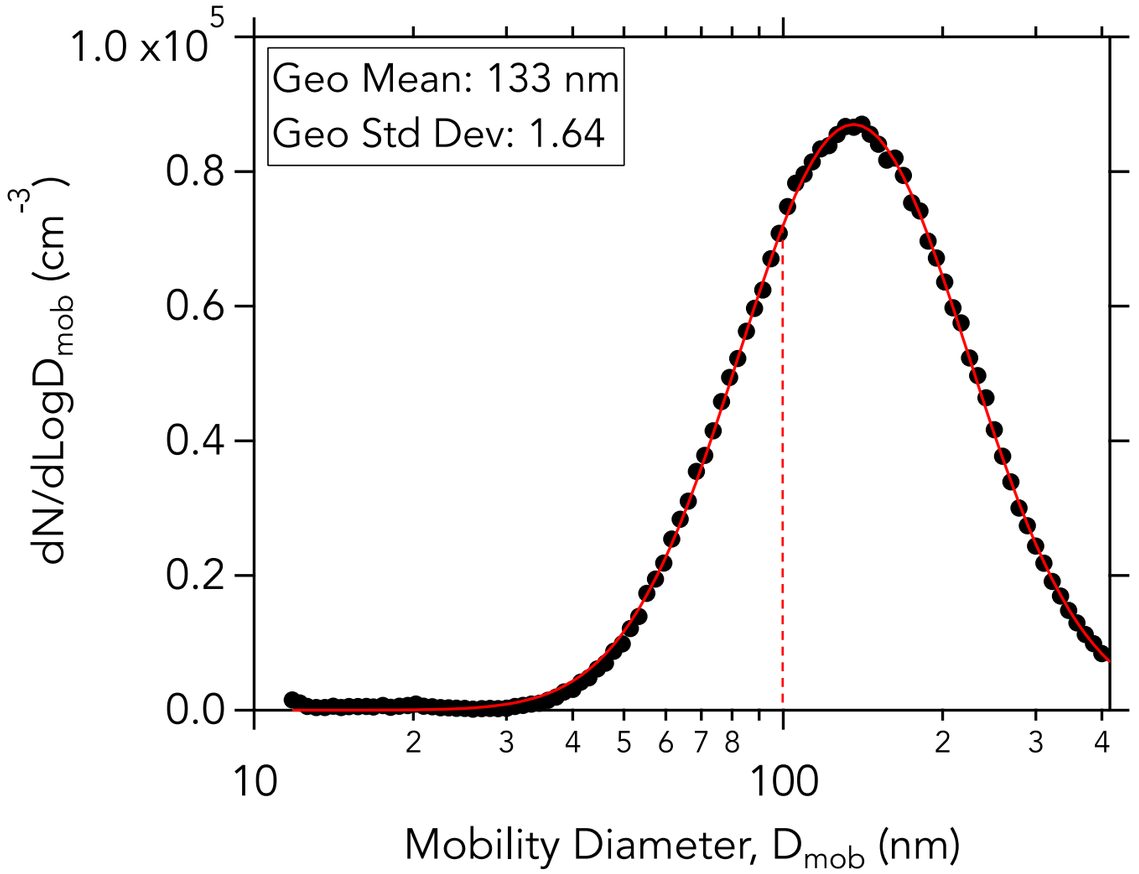
Commonly used in aerosol studies

Can explore different BC morphologies

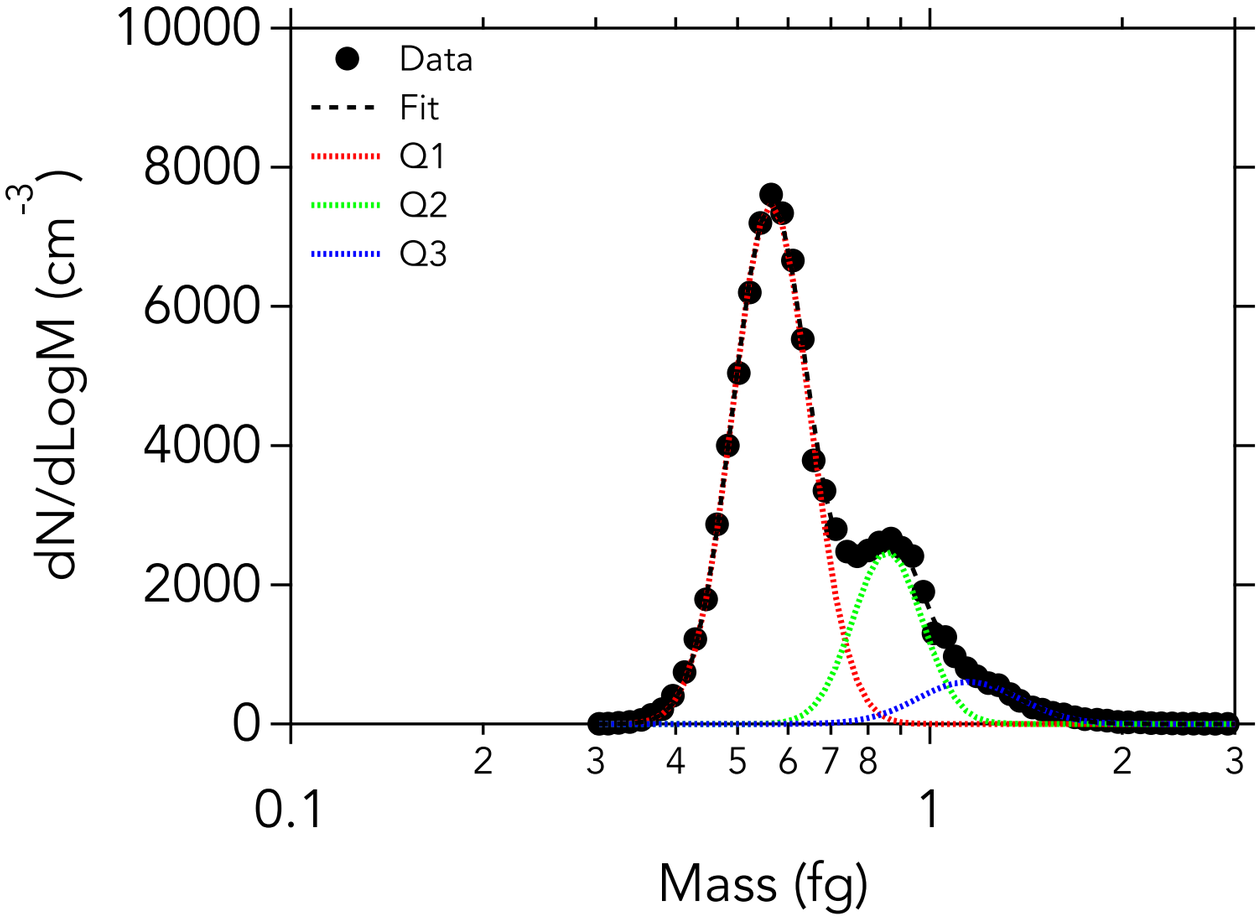
Mobility Diameters
100 nm, 125 nm, 150 nm, 200 nm

Regal Black: Particle Characterization

Number-Size Distribution

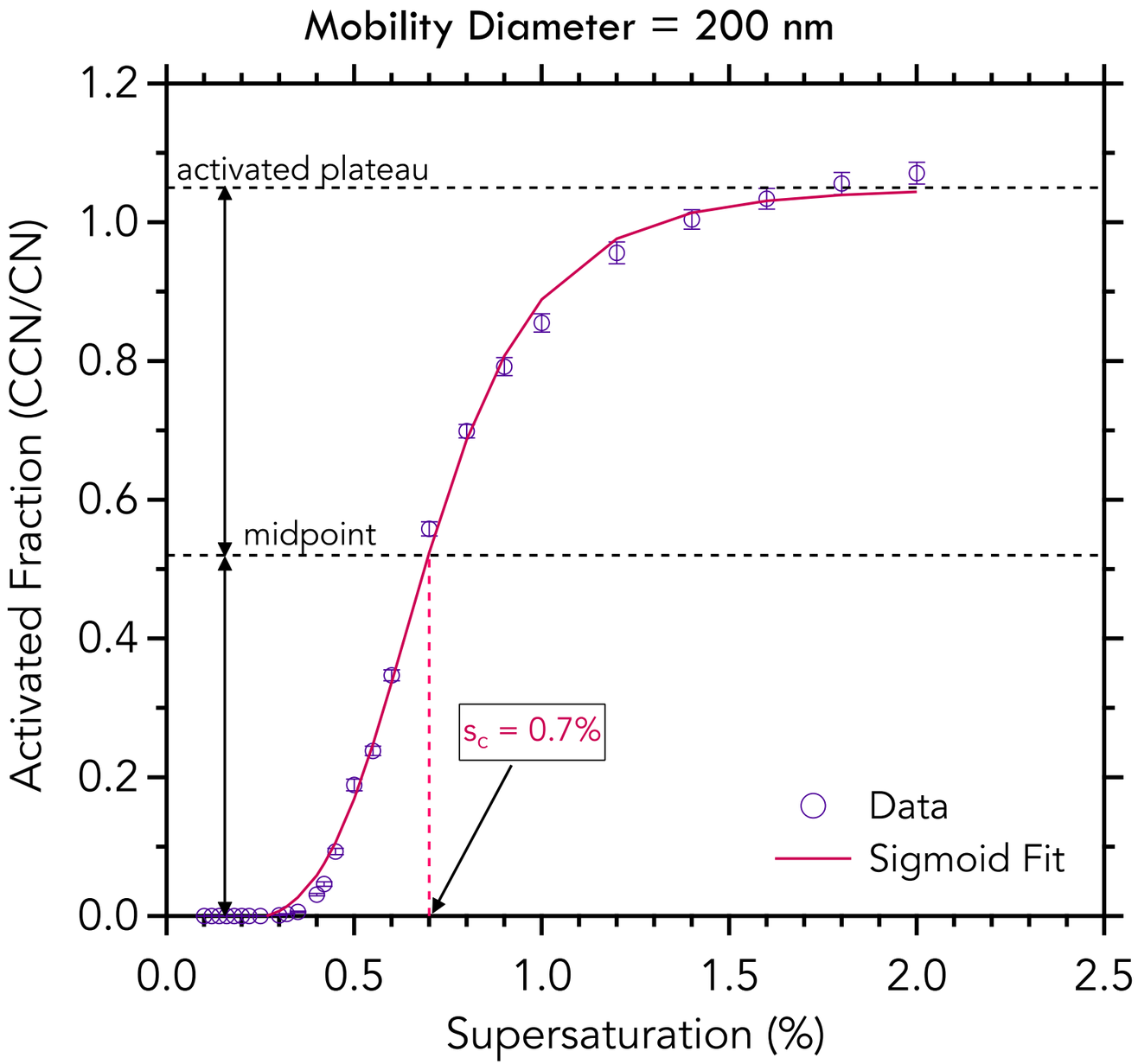


Number-Mass Distribution



Particle charge states are distinguishable with some overlap between modes

Sample Activation Curve



κ-Köhler Theory

(Petters and Kreidenweis, 2007)

$$\kappa = \frac{4}{27}\left(\frac{D_\sigma}{D_{mob}}\right)^3\left(\frac{100\ \%}{s_c}\right)^2$$

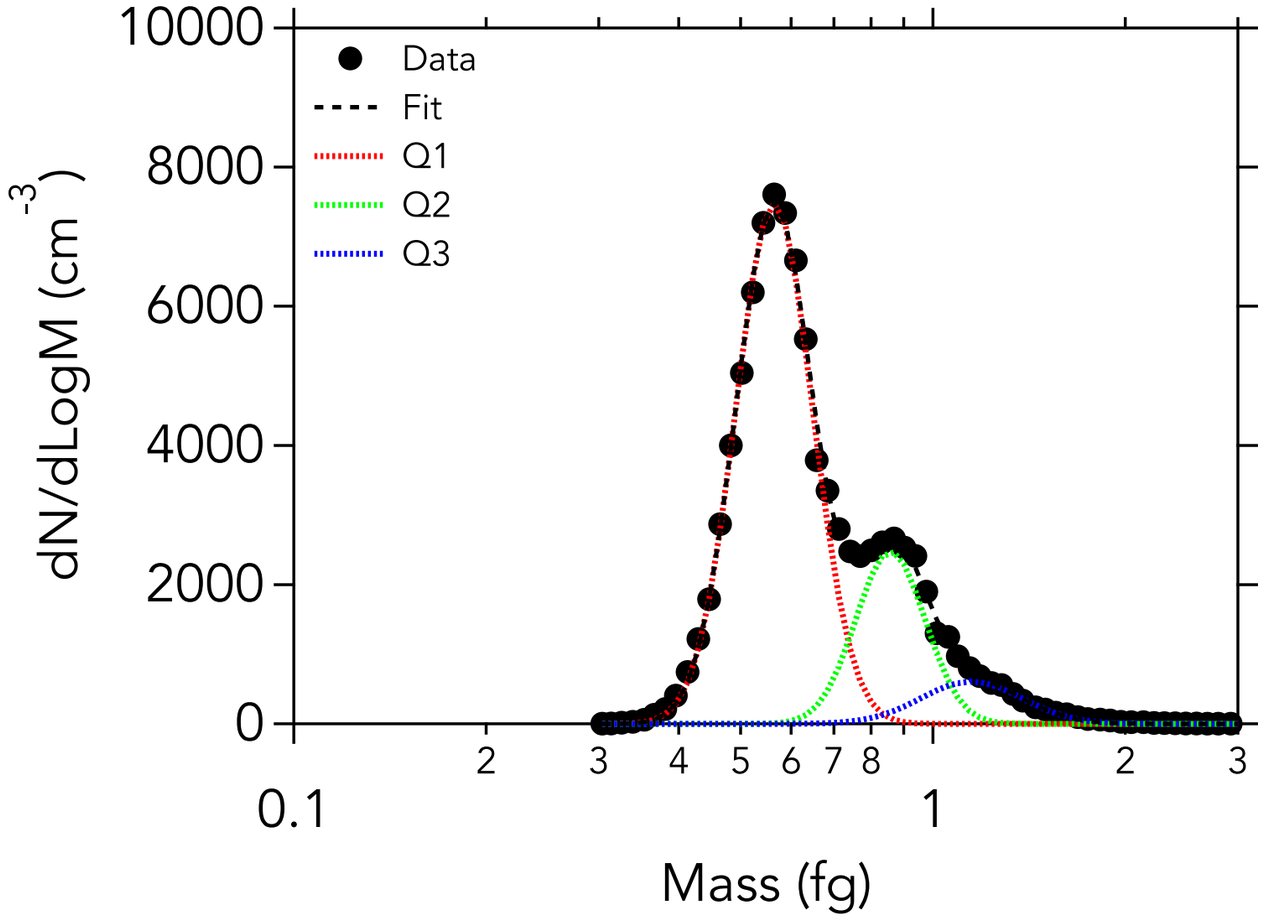
κ – hygroscopicity parameter
D_σ – Kelvin diameter (~ 2.1 nm)
D_{mob} – mobility diameter
s_c - critical supersaturation, %

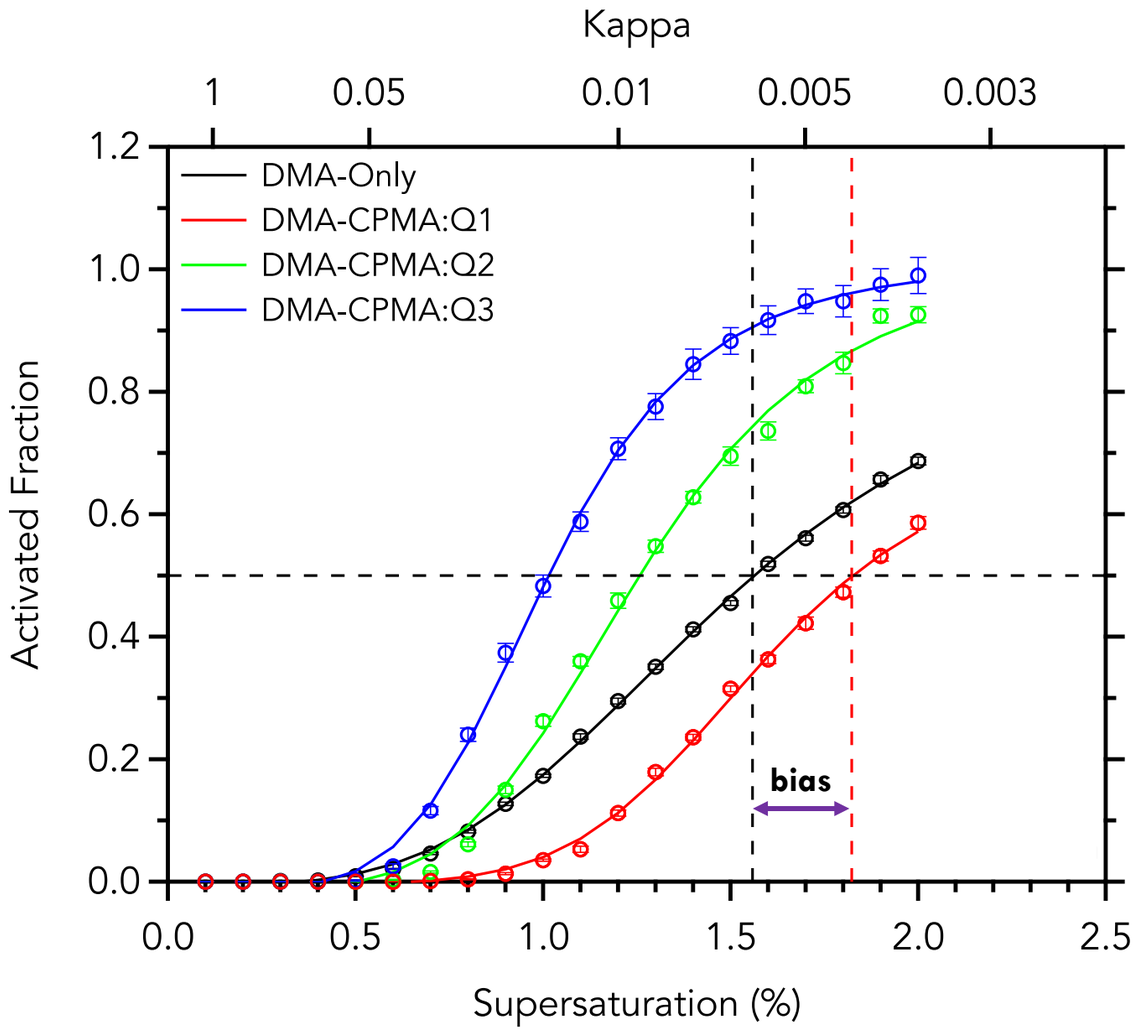
$\kappa \rightarrow 1$: hygroscopic
$0.01 < \kappa < 0.5$: moderately hygroscopic
$\kappa \rightarrow 0$: insoluble

For D_{mob} = 200 nm and s_c = 0.7%, κ = 0.004

Regal Black: CCN Activity

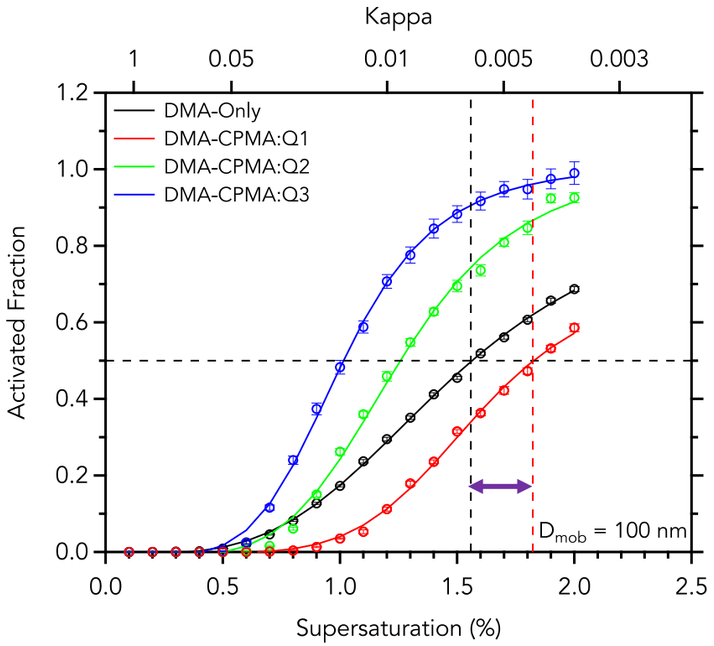
Mobility Diameter = 100 nm

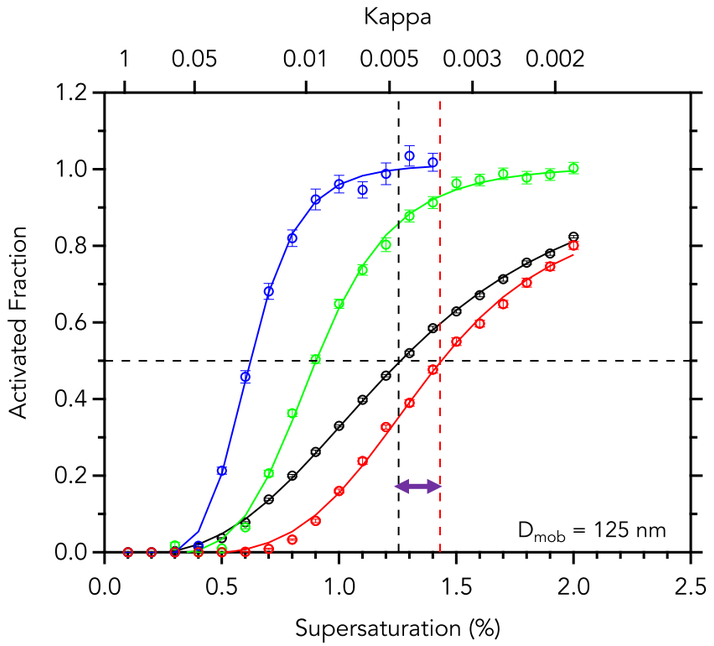


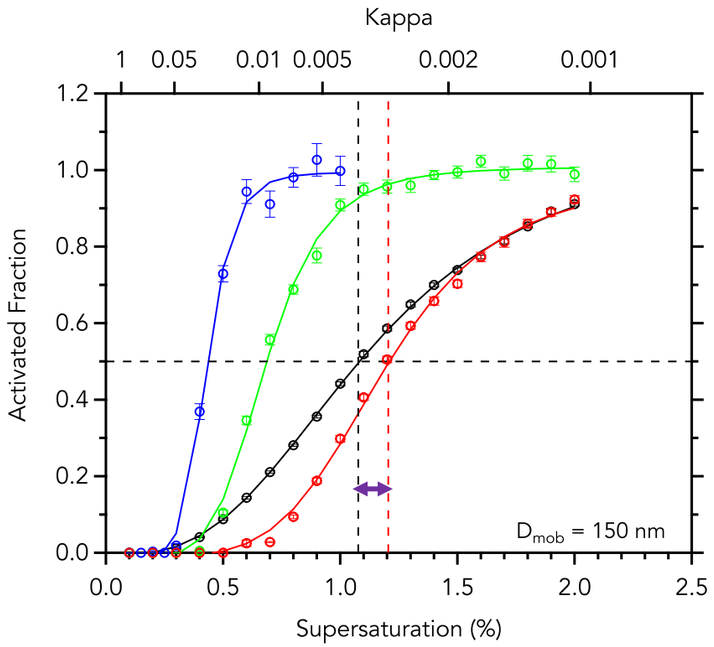


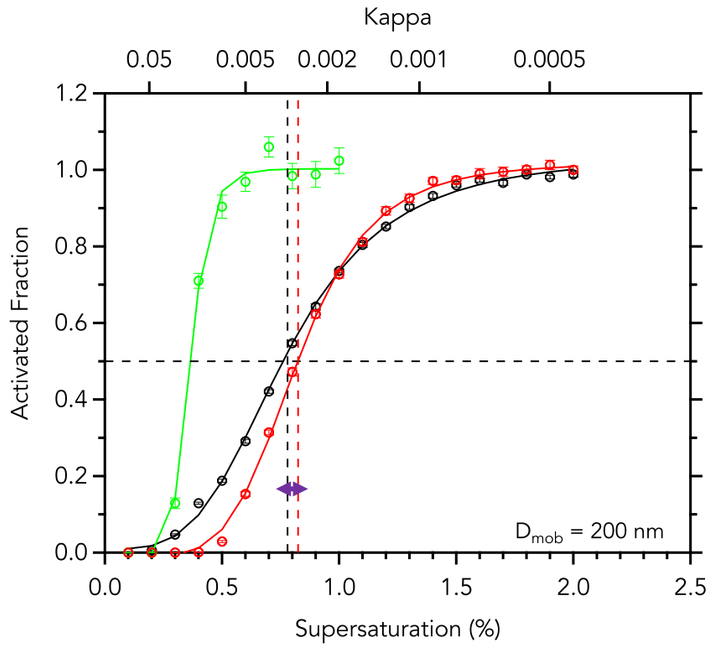
Mobility diameter-based method alone produces CCN curve that is a combination of the different charge states

Regal Black: CCN Activity









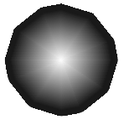
Overestimation in kappa decreases with increasing mobility diameter

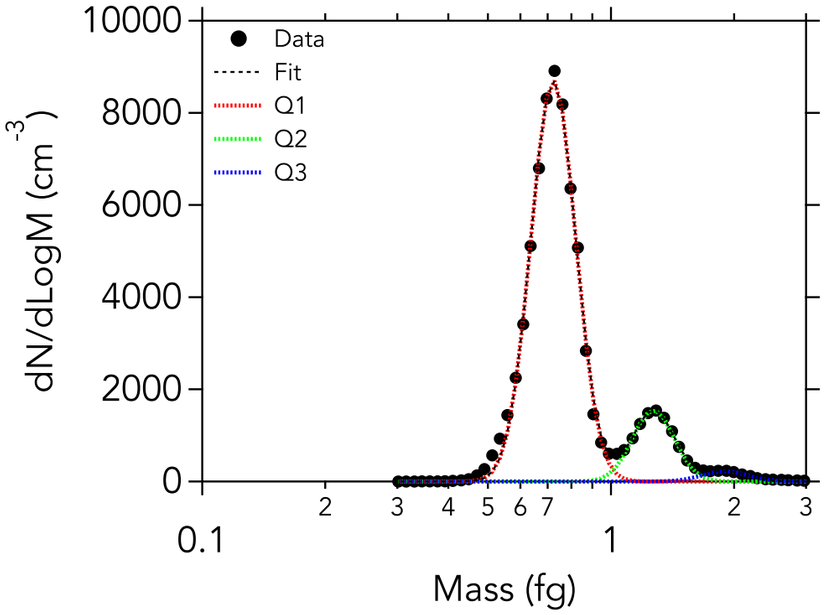
The DMA-CPMA system can be used to resolve errors in CCN activity measurements

Number-Mass Distributions of BC Particles

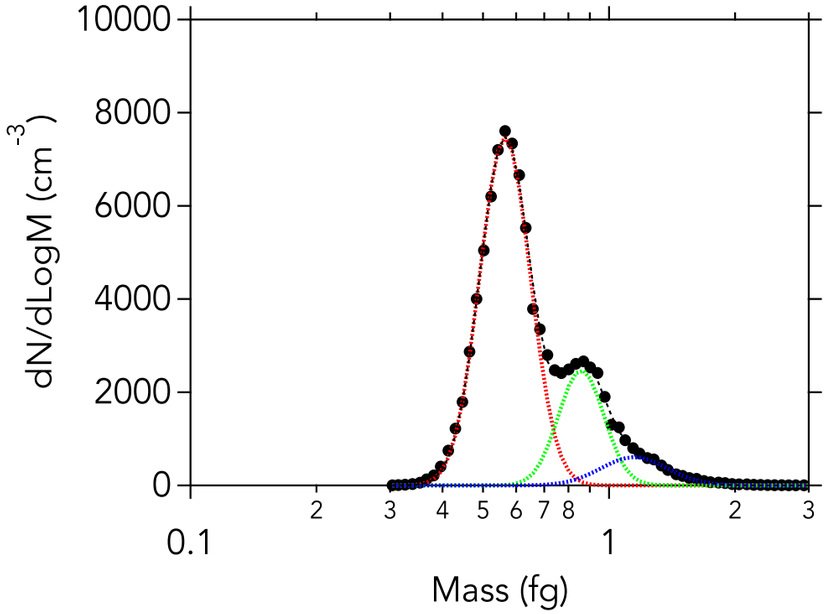
Mobility Diameter = 100 nm

Nigrosin

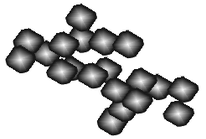


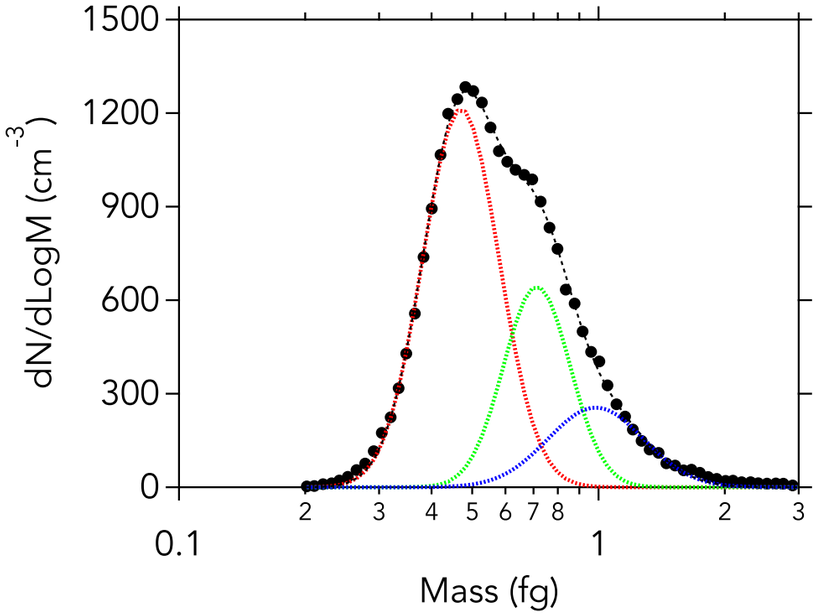


Regal Black



Fullerene Soot



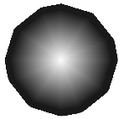


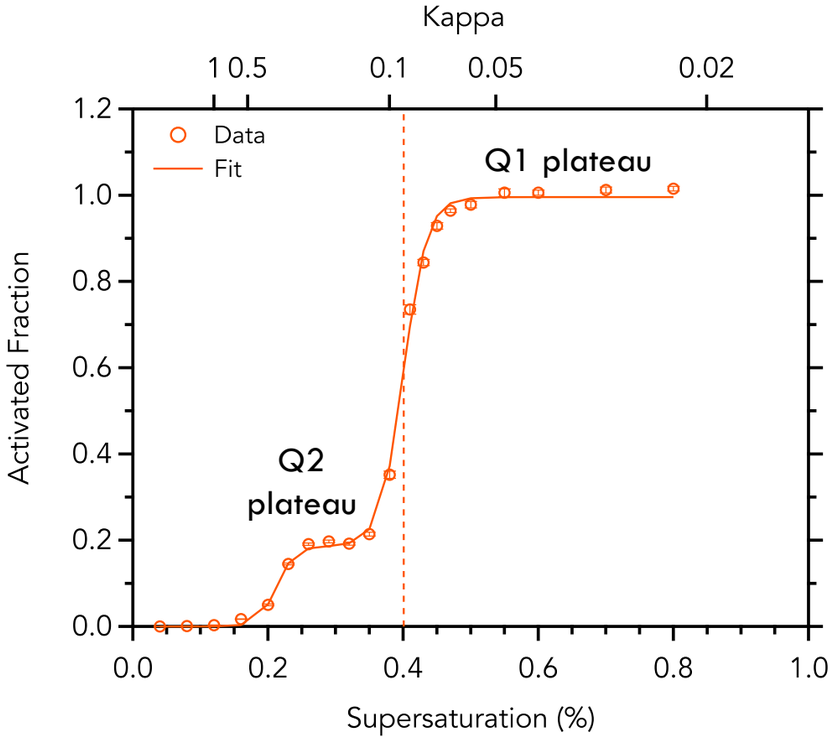
Particle charge states for Nigrosin exhibit the largest separation while significant overlap is observed for Fullerene Soot

CCN Activity of BC Particles

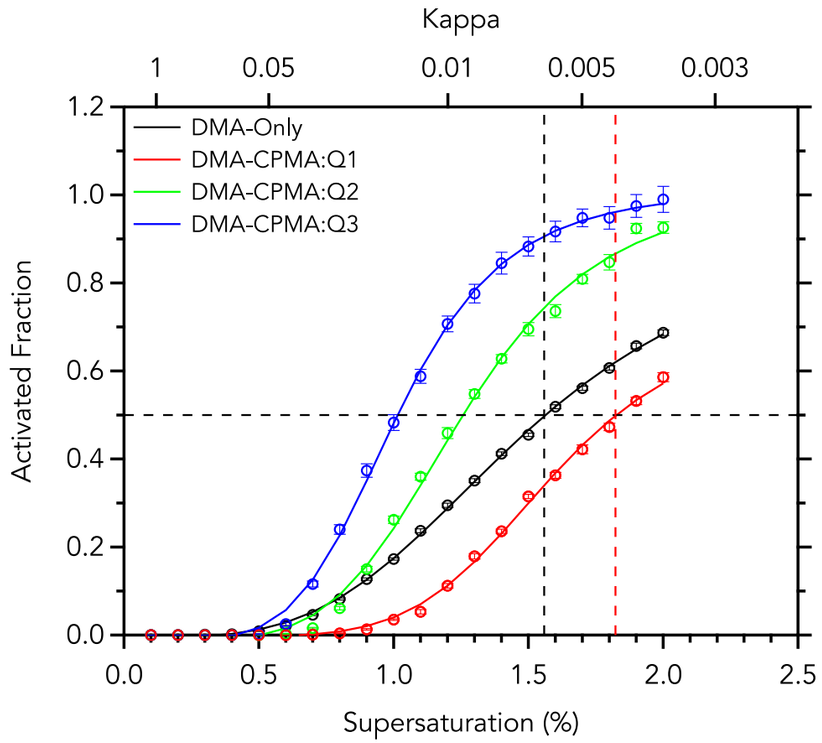
Mobility Diameter = 100 nm

Nigrosin

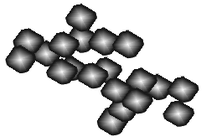


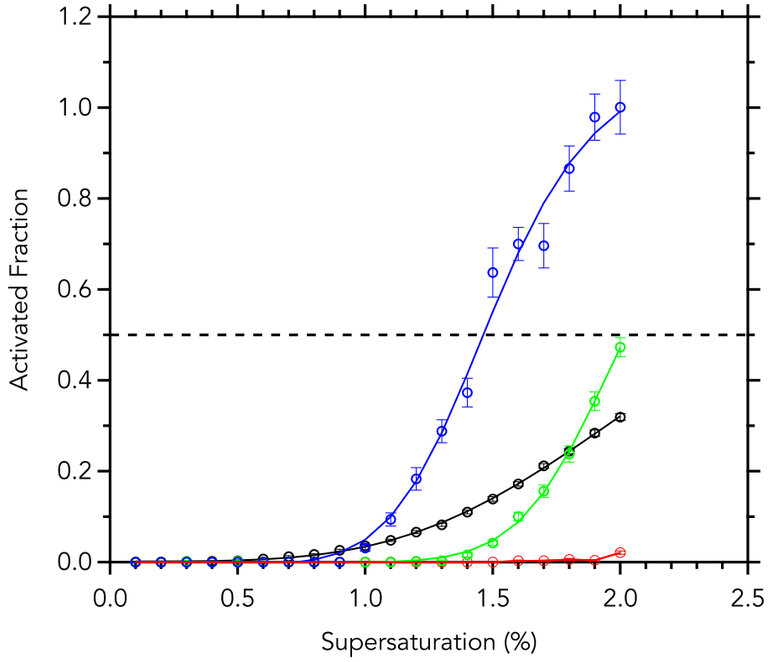


Regal Black



Fullerene Soot



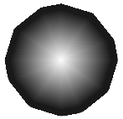


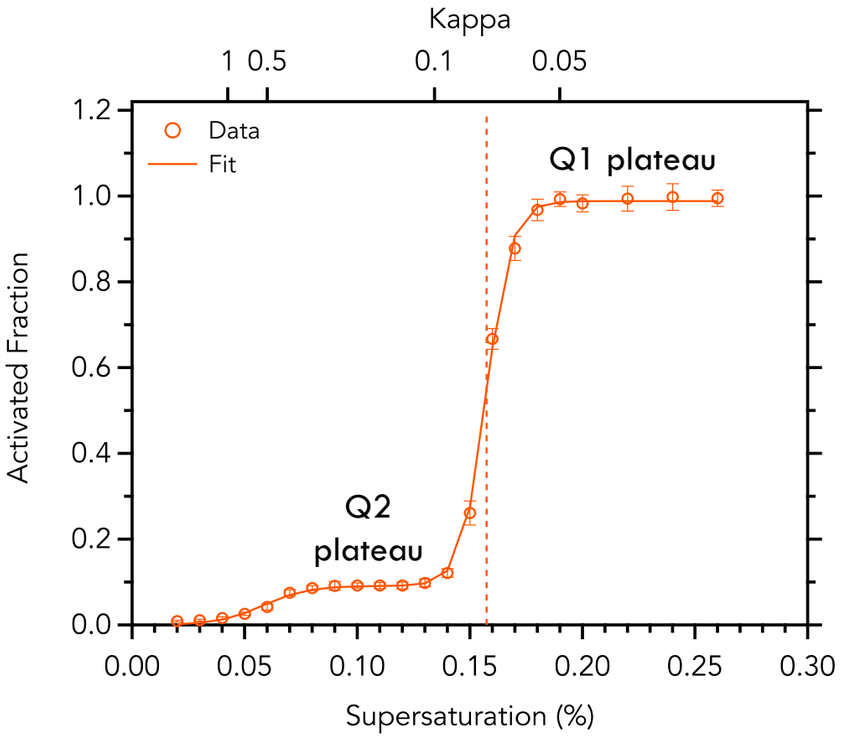
Error in kappa is larger for more complex aggregate morphology

CCN Activity of BC Particles

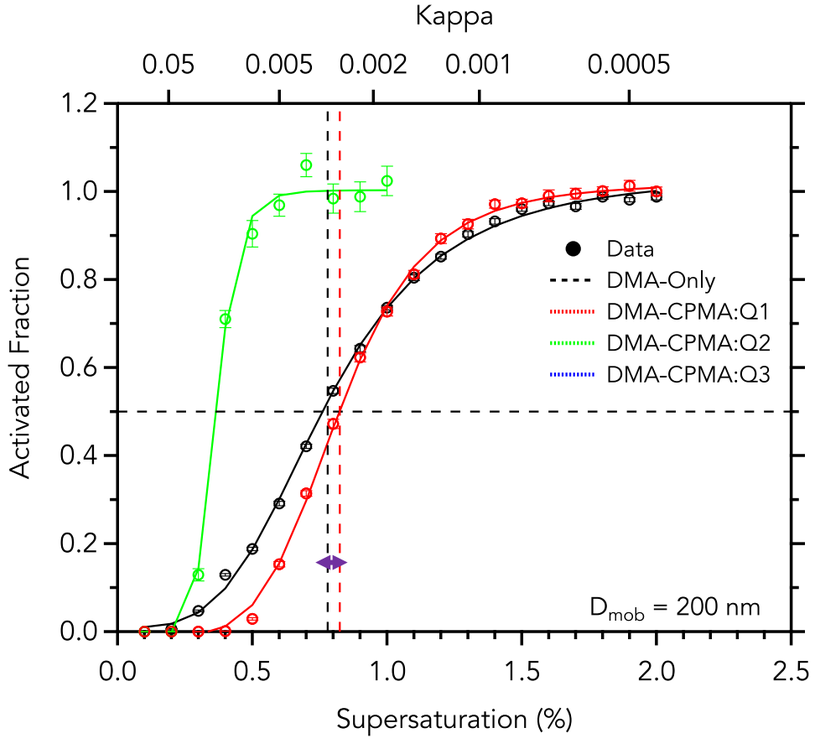
Mobility Diameter = 200 nm

Nigrosin

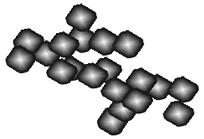


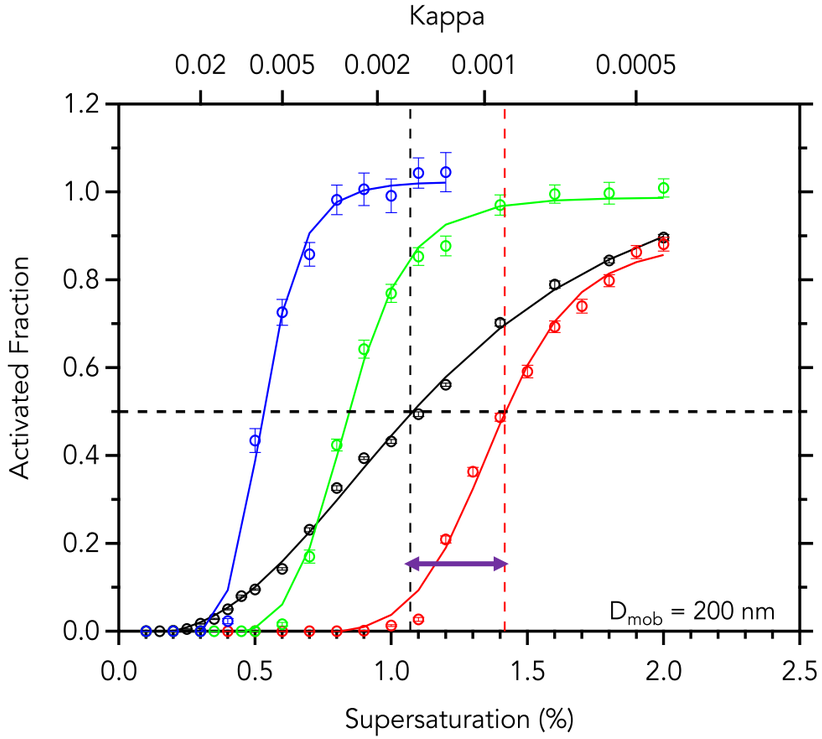


Regal Black



Fullerene Soot





Kappa for Fullerene Soot was overestimated by a factor of 1.78

Summary

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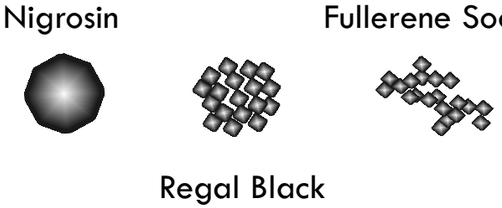
Poster Session 4, #4

- BC particles selected only by their mobility diameter produce CCN curves that are a combination of the individual charge states in the particle population.

- A DMA-CPMA system eliminated errors associated with multiple charging in the CCN activity of three BC surrogates.

- Calculated errors in kappa were larger for Regal Black and Fullerene Soot because their aggregate morphologies but negligible for Nigrosin particles because of their spherical morphology.



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O.Enekwizu et al. in preparation for AS&T