State of the art ambient ultrafine particle monitoring: the blind spot of current methods

Tiwari, A.J., Schmitt, S.H., Tritscher, T., Koczak, J.S., **Wright, T. P.**

National Ambient Air Monitoring Conference 2022

Air pollution and health

Ambient air monitoring efforts play a critical role in:

- Alerting us to air pollution hazards exceeding established levels (regulatory scale)
- Creating datasets that help to identify new hazards / levels (research scale)

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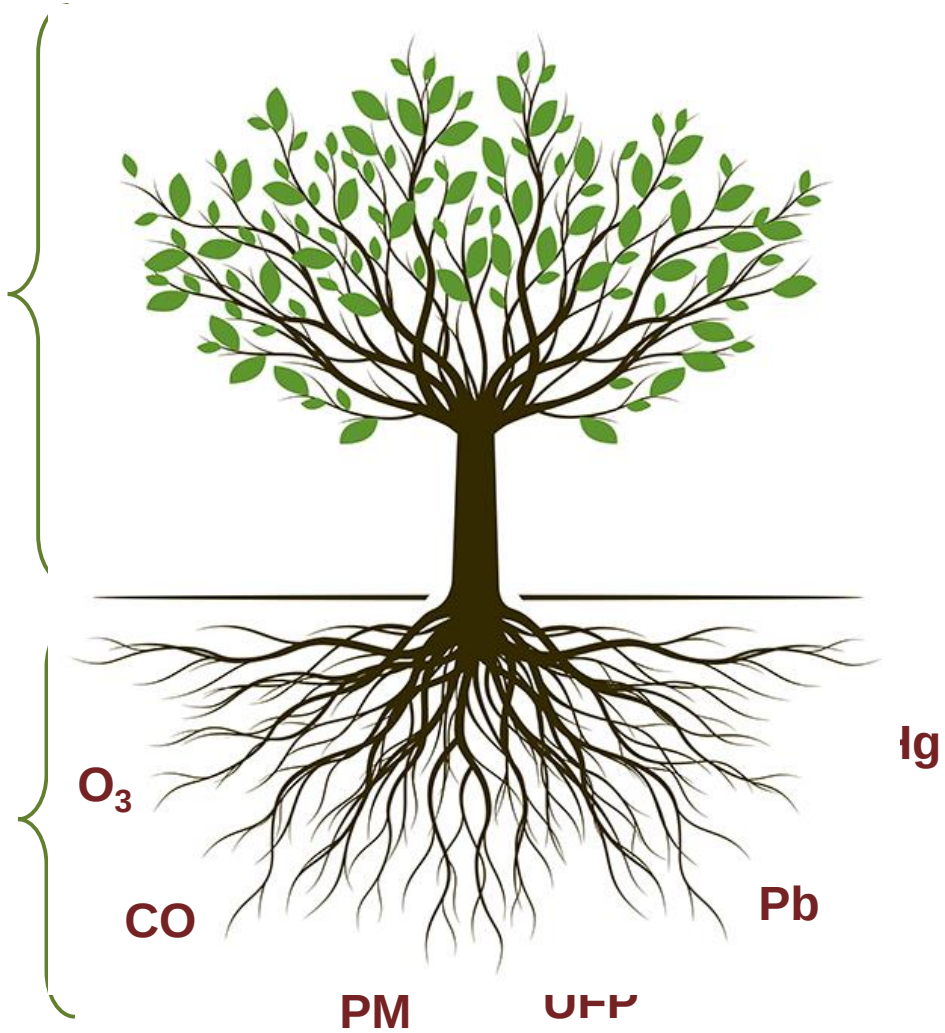


PM2.5 is a health hazard, is regulated

Ambient PM2.5 exposure associated with:

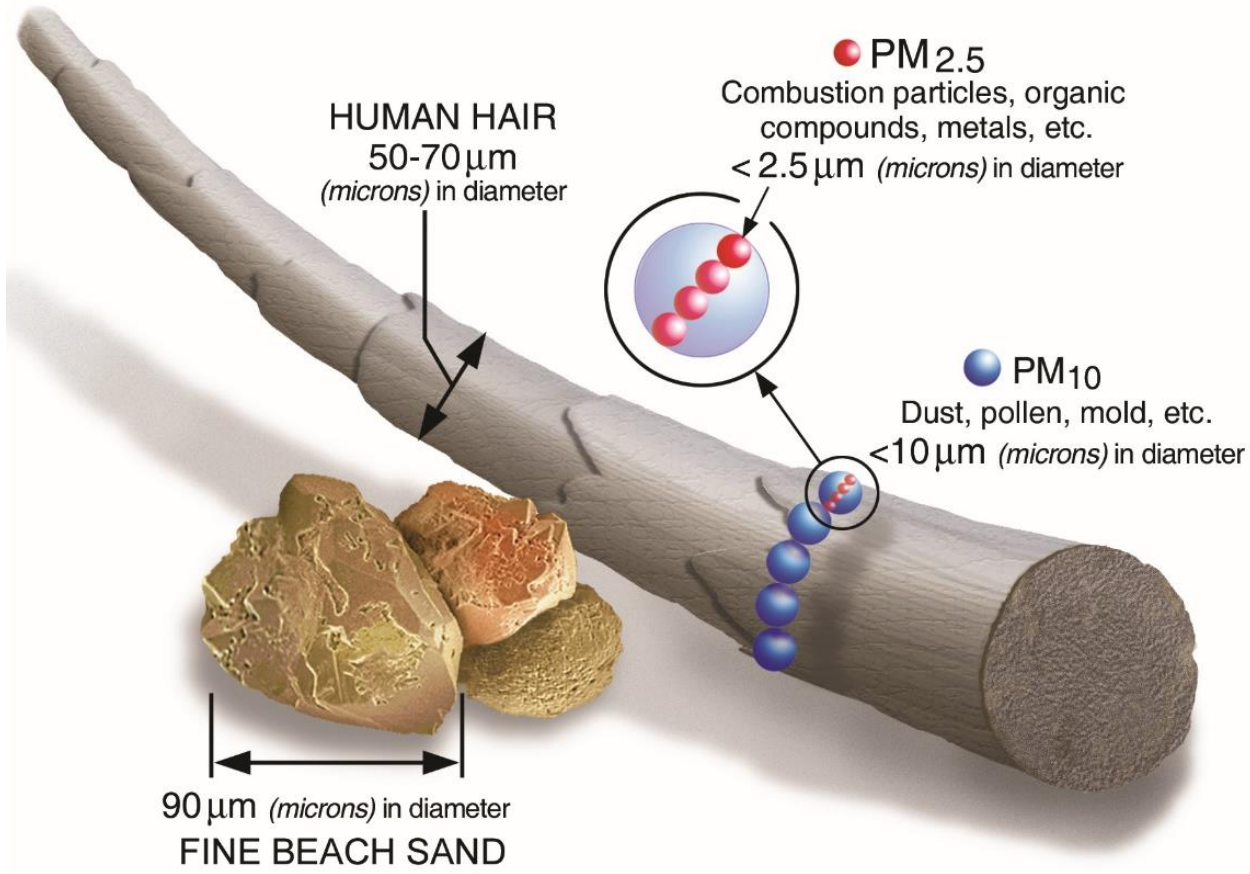
- Respiratory illnesses
- Cardiovascular diseases
- Globally, ~3.5 million cases of COPD and ~220,000 lung cancer deaths annually

- *Miller et al 2018 and references therein*

PM2.5 accounts for > 90% of monetized social costs of air pollution

- Heo et al 2016 and references therein

Particulate Matter (PM): PM_{10} and $PM_{2.5}$

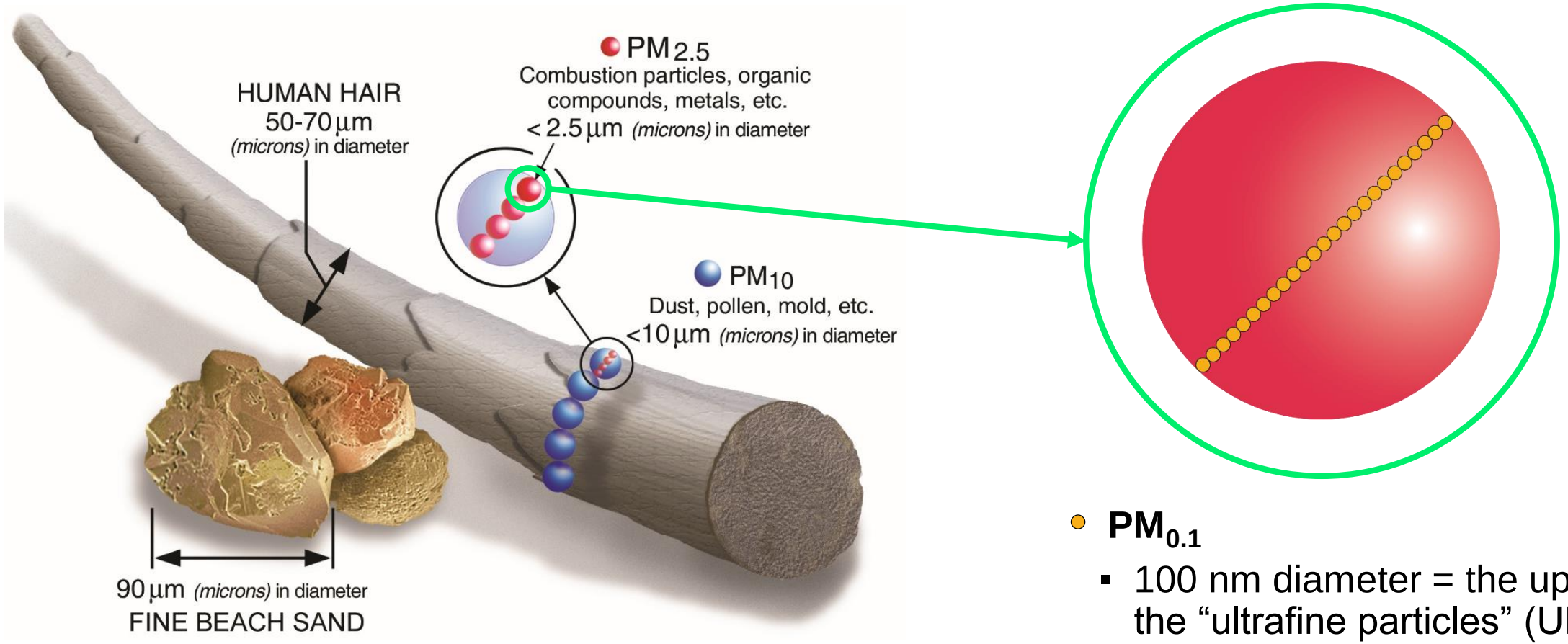


NAAQS

- PM10
  - 150 µg/m^3 (24 hr)
- PM2.5
  - 12 µg/m^3 (1 yr)
  - 35 µg/m^3 (24 hr)
- Standardized methods (FRM and FEM) list

Particulate Matter (PM) Basics | US EPA

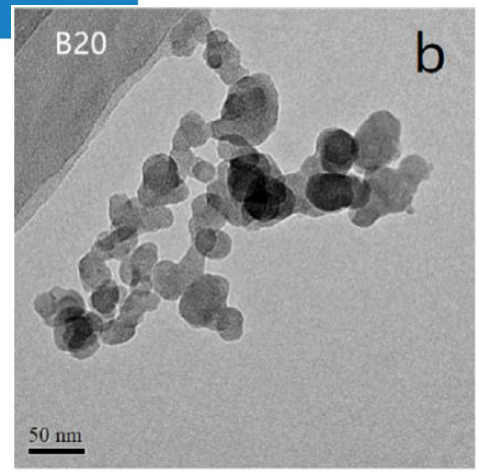
Particulate Matter (PM): zooming in



- **$PM_{0.1}$**
  - 100 nm diameter = the upper end of the “ultrafine particles” (UFP) range
  - Includes particles down to 1 nm

[Particulate Matter (PM) Basics | US EPA]

Where do UFP's come from?



Zhang et al 2020 Fig 2b
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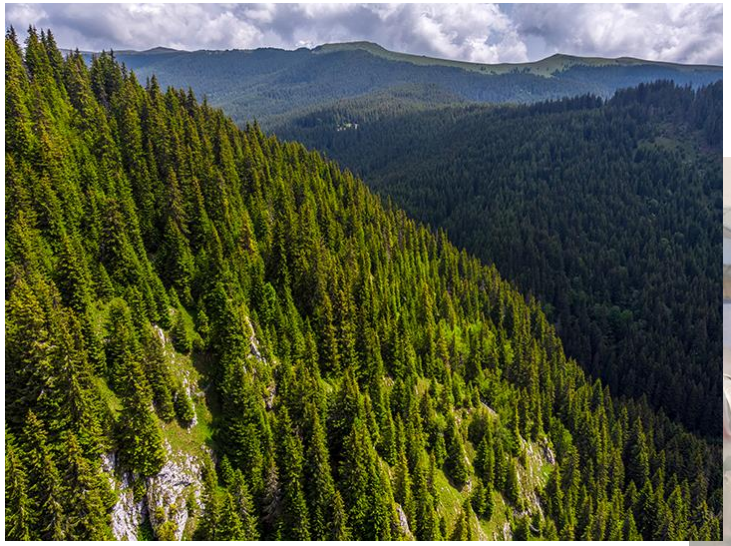
Emitted as primary particles

- Transportation, industry, biomass burning, etc.



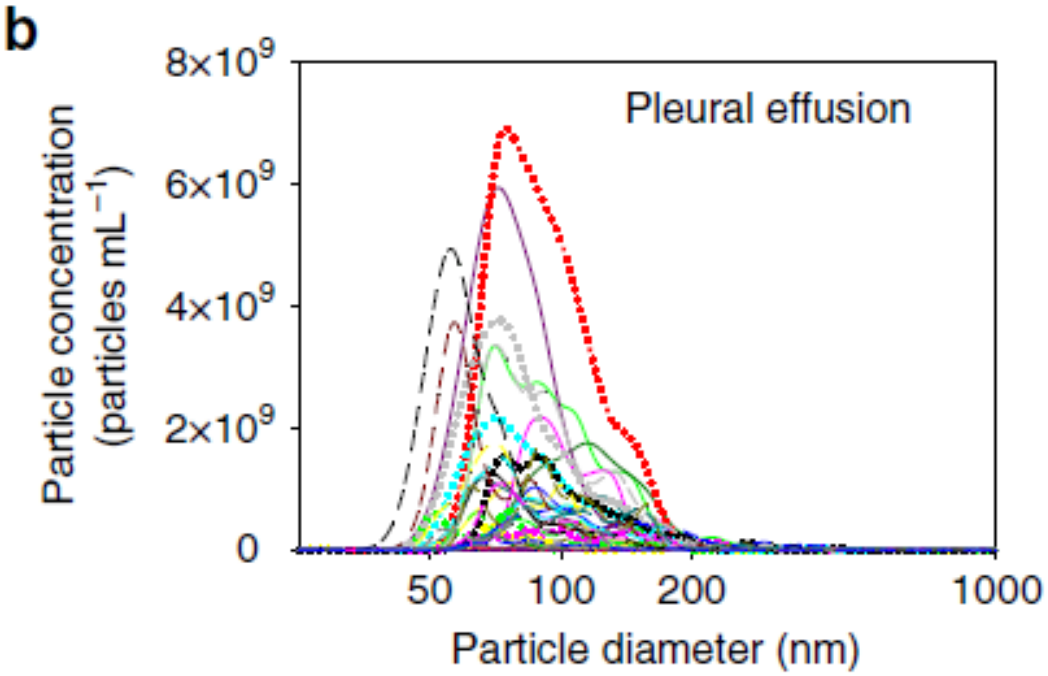
Via nucleation of gas-phase precursors

- Natural precursors
- Anthropogenic precursors

UFPs deposit, translocate in the human body

In humans:

- Exogenous nanoparticles found in human lung fluid (pleural effusion) (Lu *et al* 2020)

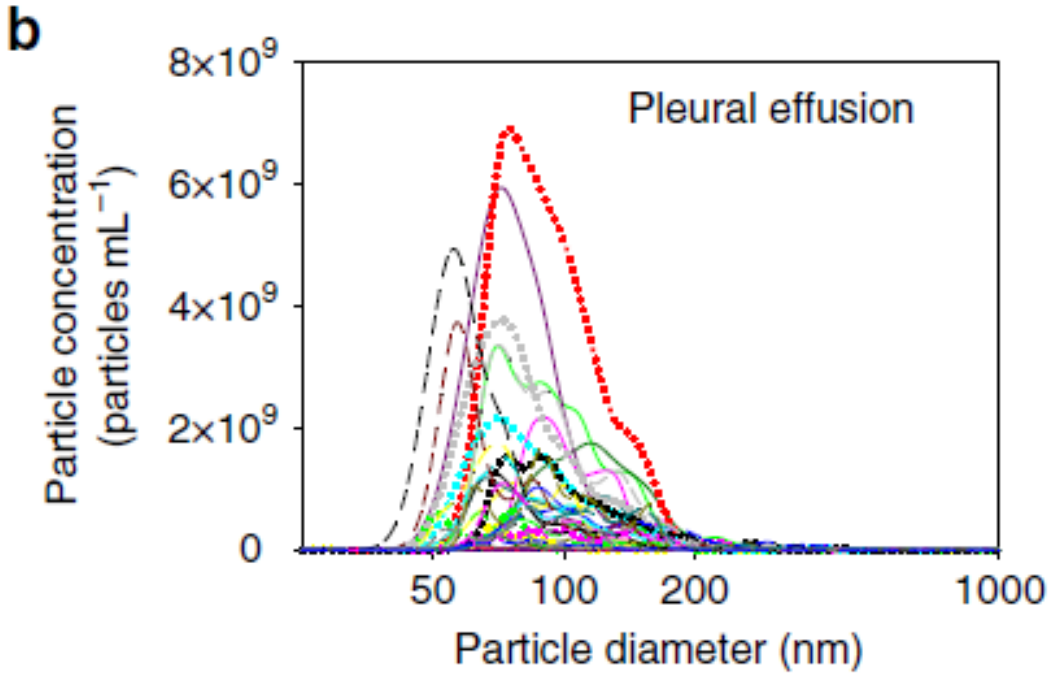


Lu et al 2020 Fig 1a
Open Access license

UFPs deposit, translocate in the human body

In humans:

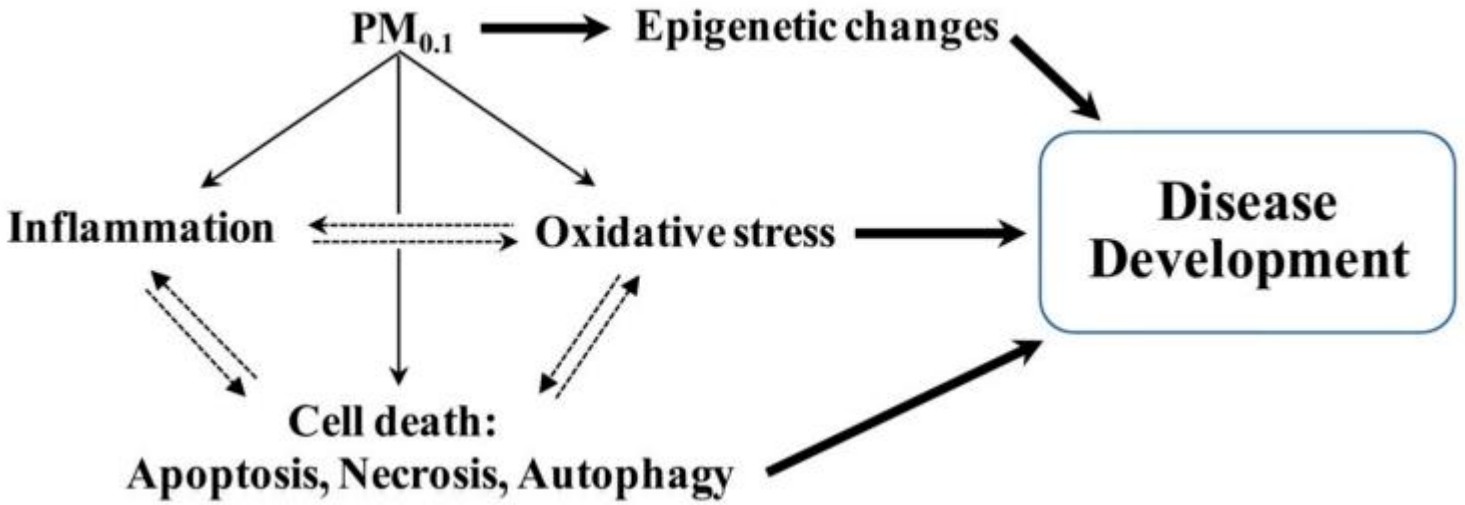
- Exogenous nanoparticles found in human lung fluid (pleural effusion) (Lu *et al* 2020)
- Human volunteers inhaled 5 nm and 30 nm gold nanoparticles (Miller *et al* 2017):
  - detected in blood and urine within 24 h,
  - still present after 3 months
  - levels were greater for 5 nm than for 30 nm



Lu et al 2020 Fig 1a
Open Access license

Health hazards: UFP is distinct from PM2.5

- UFP ($PM_{0.1}$) may contribute to disease via molecular and/or epigenetic mechanisms (Traboulsi *et al* 2017)
- Perinatal exposure to UFP's linked to onset of asthma in children, independent of PM2.5 (Lavigne *et al* 2019)

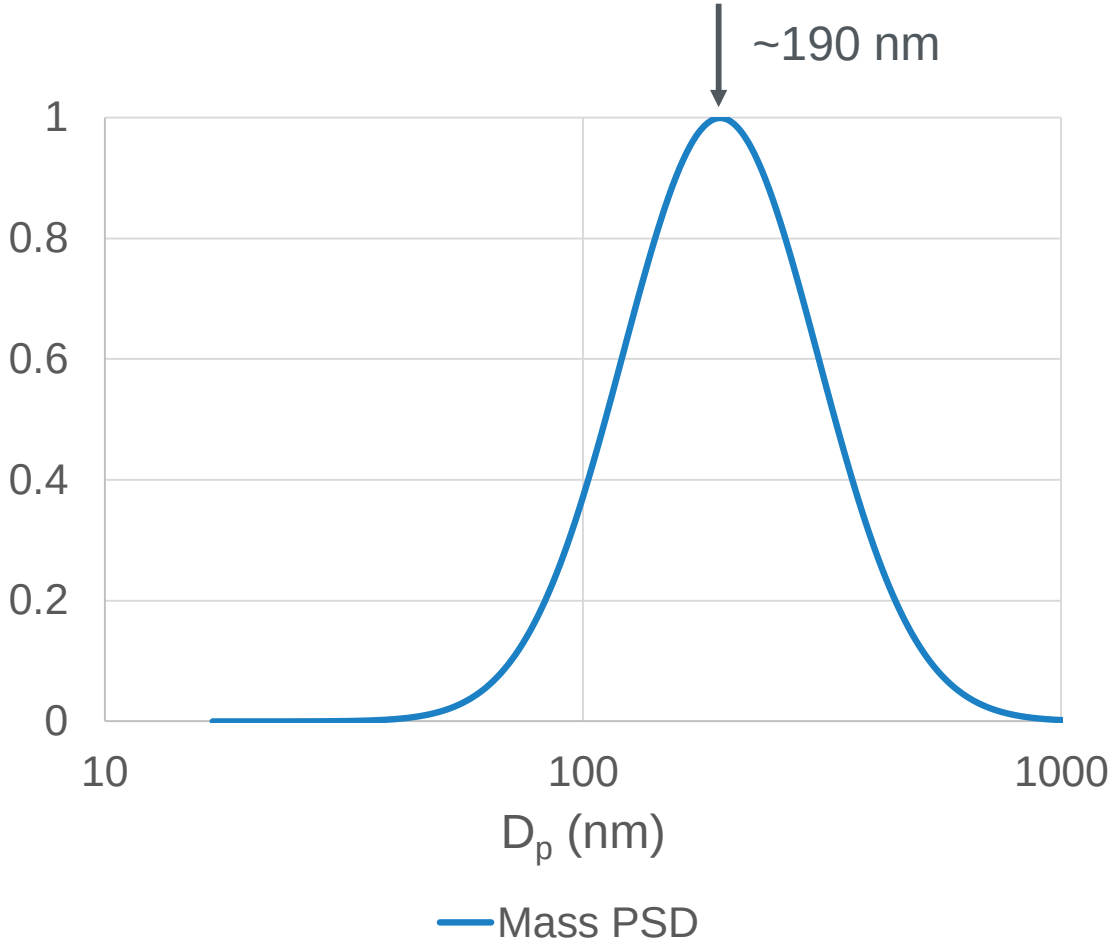


Traboulsi *et al* 2017 Fig 2 Open Access

UFP and NAAQS: hiding in plain sight

Many established FRMs, FEMs are insufficiently sensitive to UFPs:

- Gravimetric
- Light scattering
- Beta attenuation
- TEOM



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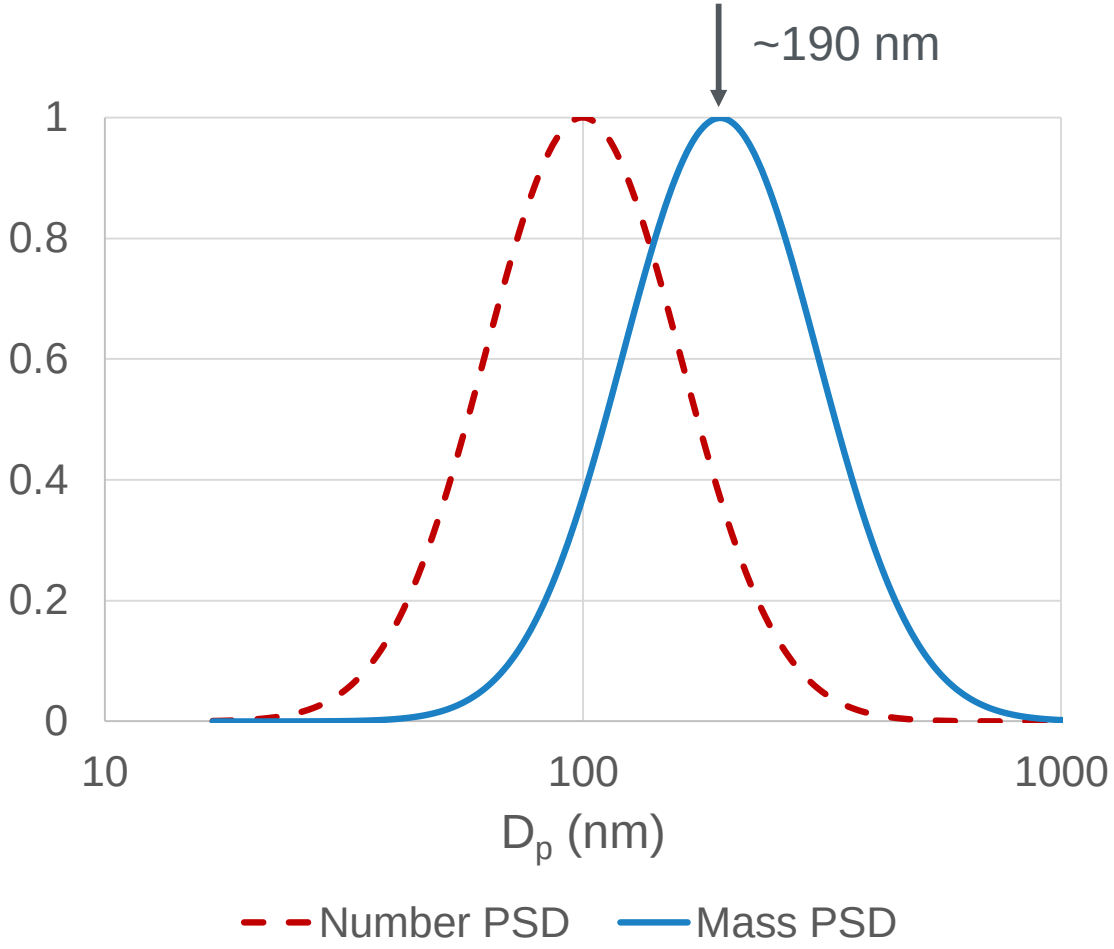

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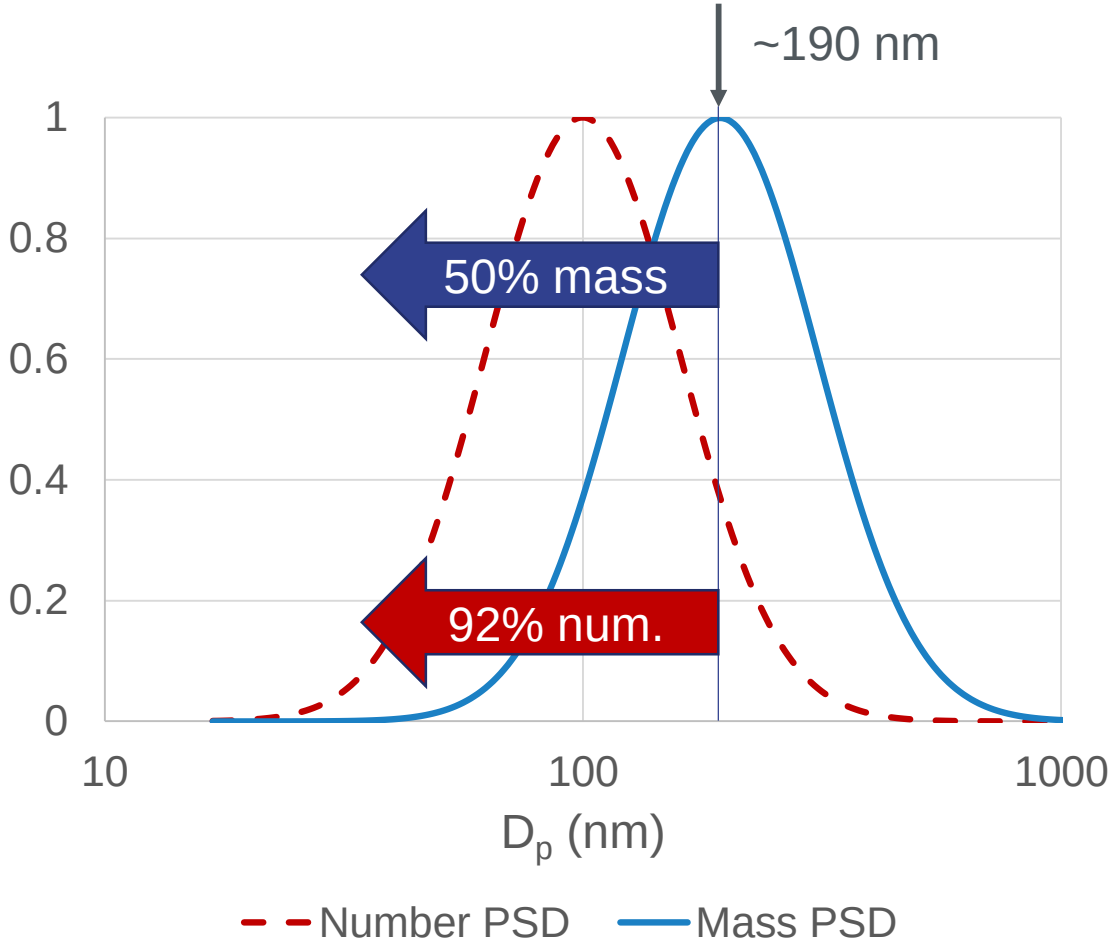
Particles smaller than 190 nm make up:

~50% of the mass, but

~92% of the particle count



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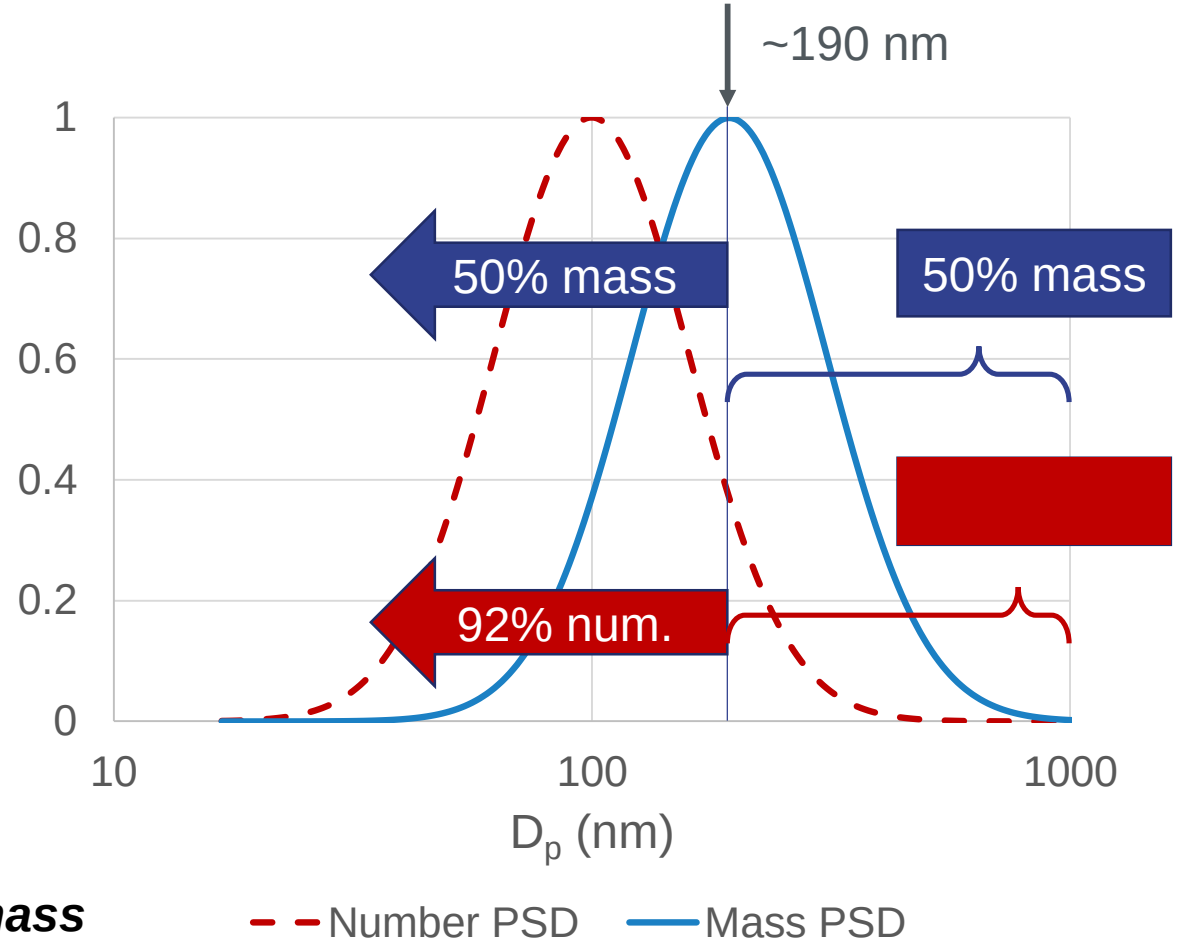
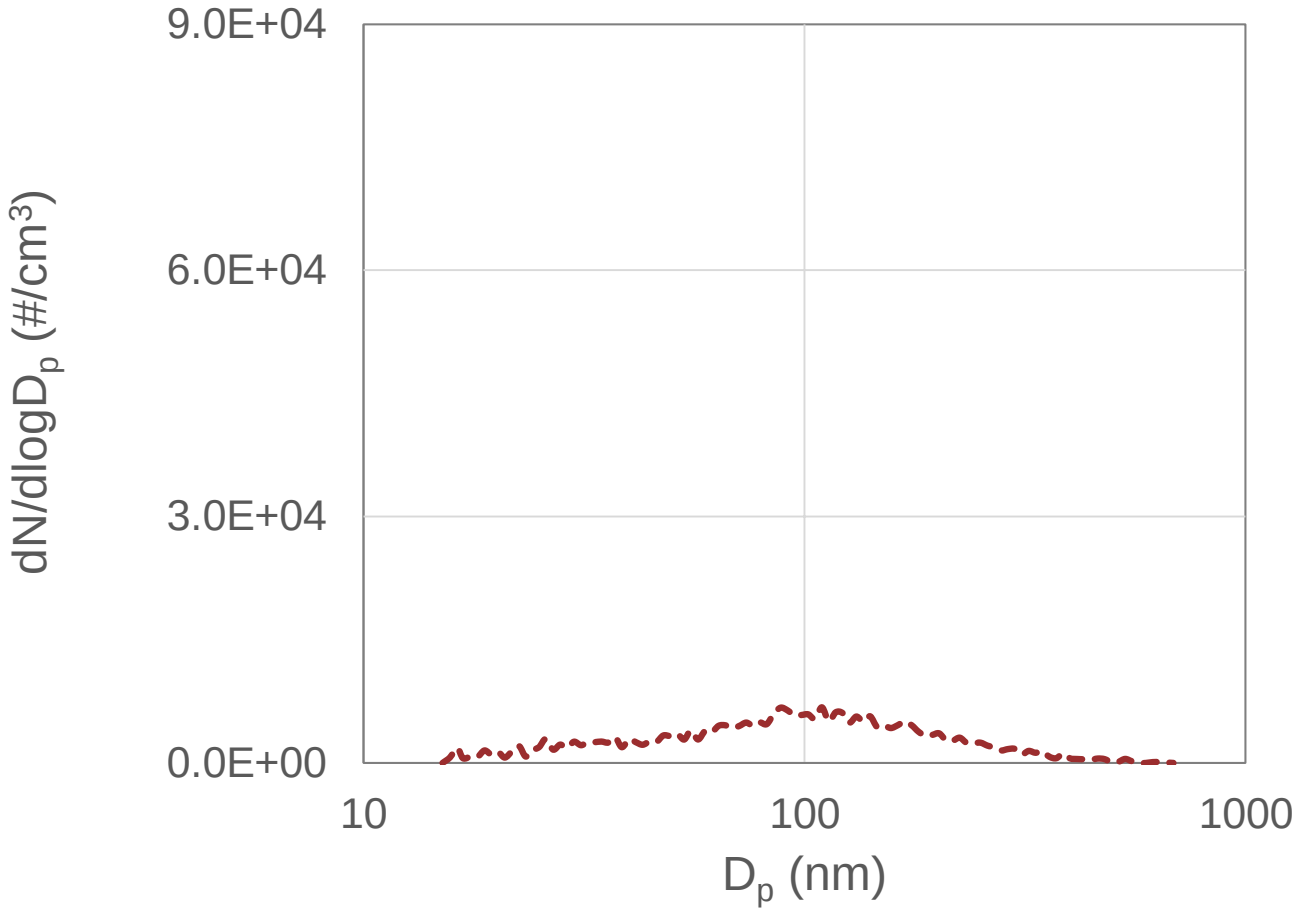
→ 8% of the number contributes 50% of the mass



UFPs and NAAQS: hiding in plain sight

- PM2.5 does include UFPs, but…
- Identical re: mass ≠ identical in every way

Two real ambient samples		
Sample	**PM0.7 (µg/m³)**	**Number conc. (#/cm³)**
------	12.3	4.47×10^3



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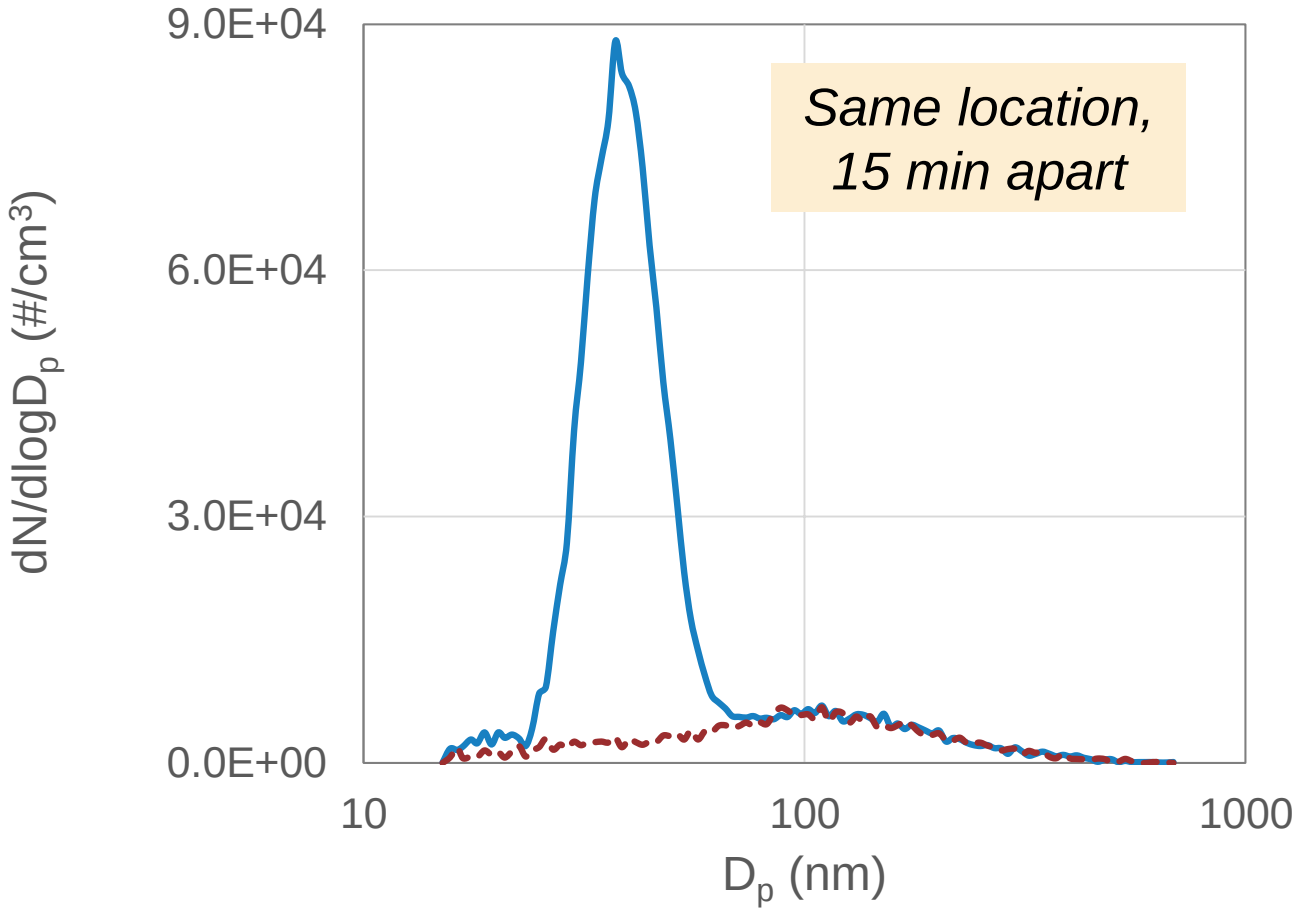

Suitable monitoring techniques for UFP's

DON'Ts

- Be mass-based
  - Gravimetric
- Be biased toward larger particles
  - Light scattering
  - Beta attenuation
  - TEOM

DOs

- Count (number-based)
- Measure particle size

UFP Monitoring: TSI in research networks

- ACTRIS
  - 22 countries, 79 observational platforms
  - Data at https://actris.nilu.no/
    - 42 sites – particle number
    - 58 sites – particle size distributions

UFP Monitoring: standardization in EU

- CEN: standardization body in EU

CEN/TS #	Scope	Technology			TSI Product
		Principle	Specific requirements		
16976	Number Concentration	CPC	Butanol-based	D50: 10 nm (standard is changing from 7 to 10 nm)	
17434	Size Distribution	Electrical Mobility sizing	DMA: 10-800 nm (single scan)	CPC: compliant w/ above	

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16976	Number Concentration	CPC	Butanol-based	D50: 10 nm (standard is changing from 7 to 10 nm)	CPC 3750
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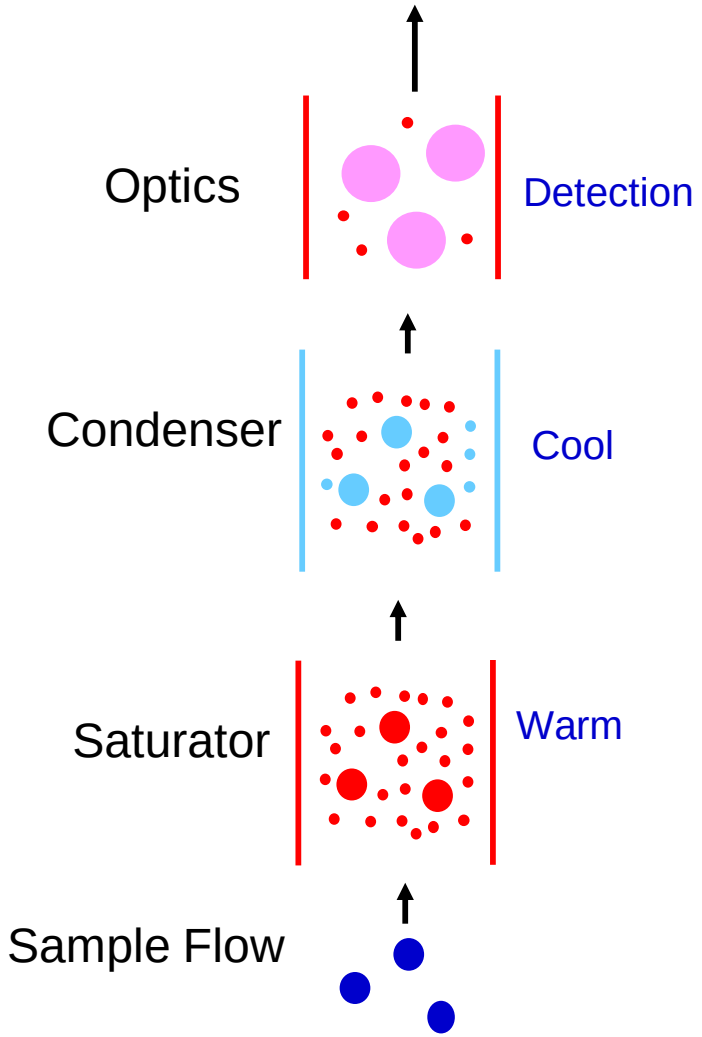
UFP Monitoring: counting single particles

Condensation Particle Counter (CPC)

- Established technology for many applications
  - ambient air, filter testing, cleanrooms, etc.
- Concept
  - Condense liquid onto particles to grow them large enough for laser detection



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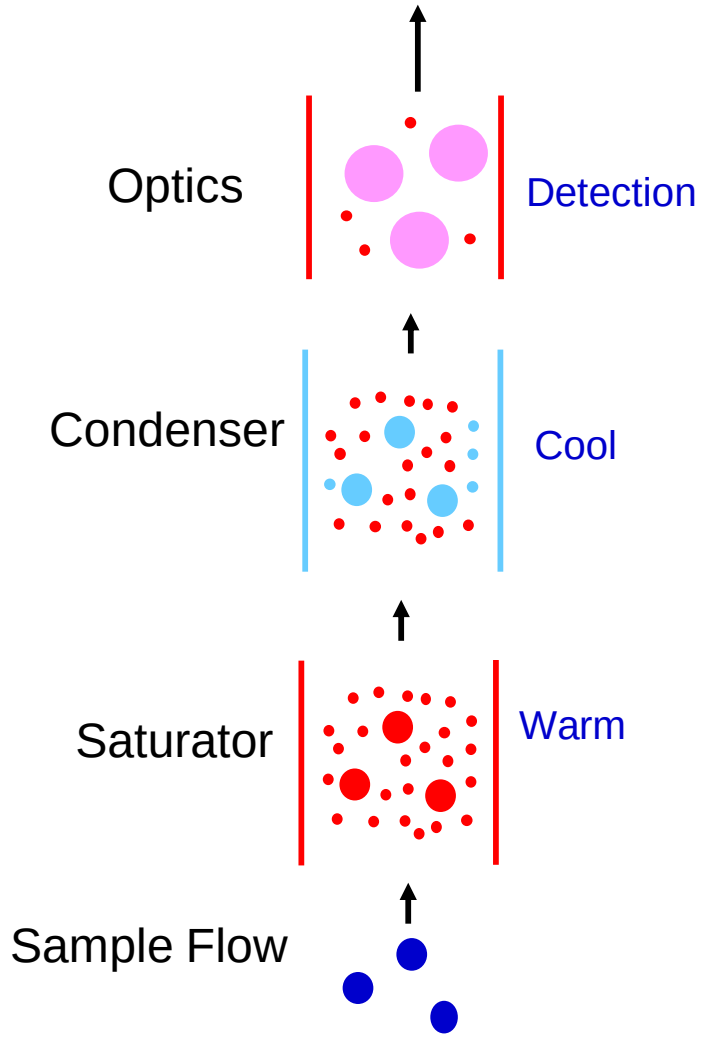
  - ambient air, filter testing, cleanrooms, etc.
- Concept
  - Condense liquid onto particles to grow them large enough for laser detection
- Key instrument specifications:
  - D50: how small of particles can be detected
  - Concentration range
  - Other considerations:
    - Butanol *vs.* water as working fluid
    - Inlet flow rate(s)



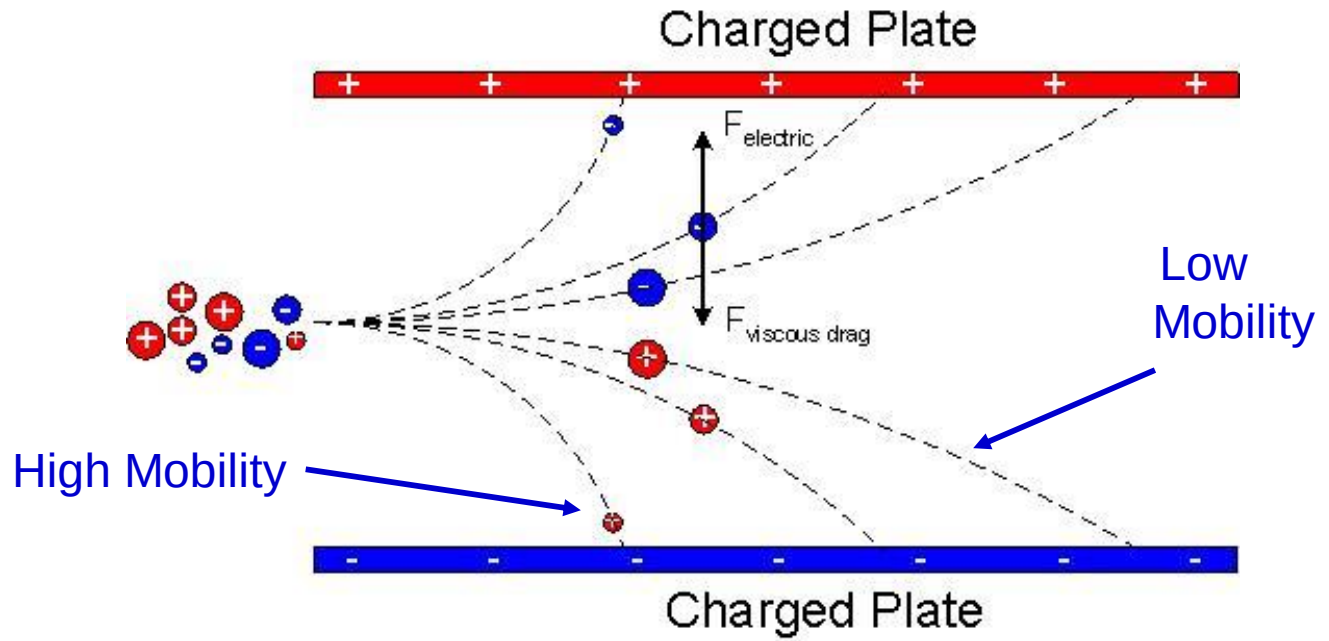
UFP Monitoring: counting single particles

- CEN compliant
  Condensation Particle Counter (CPC) 3750
- Key specs, attributes:
  - D50 = 7 nm (10 nm also available)
  - Concentration range: up to 100,000 #/cm^3
  - Other considerations:
    - Working fluid: butanol
    - Inlet flow rate: 1 L/min
- Other models also available
  - Ex. 3789 uses **distilled water**

UFP Monitoring: sizing ultrafine particles

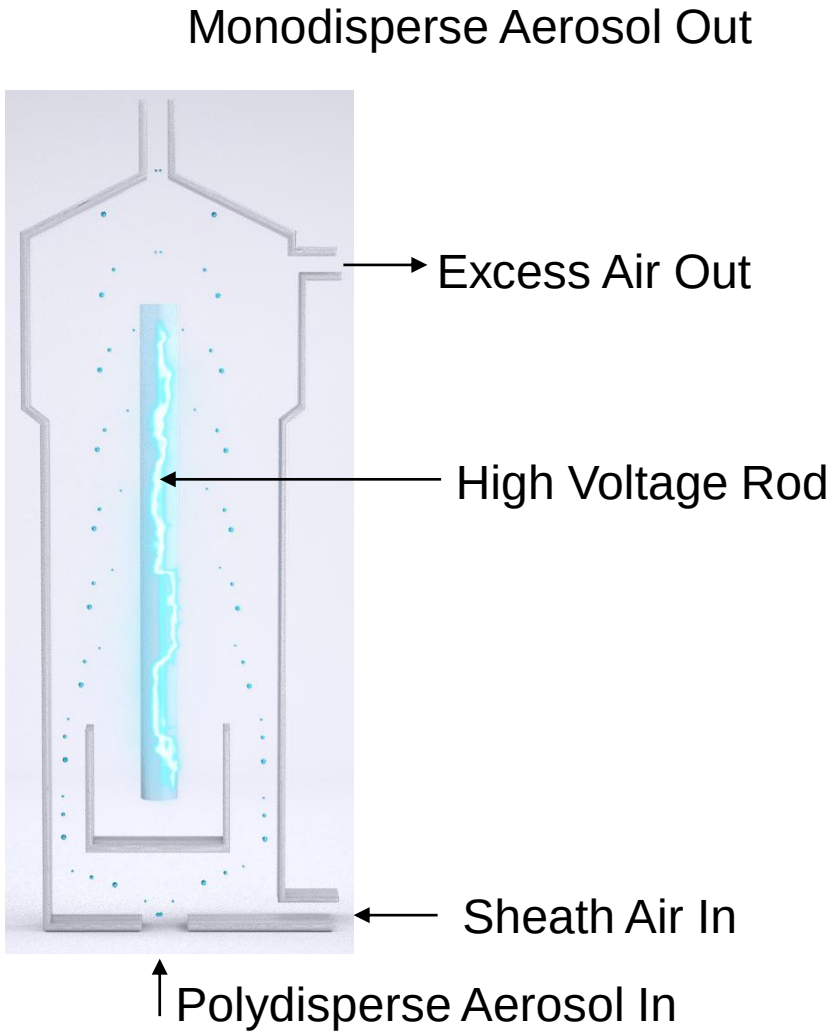
$$Z_p = \frac{Particle\ Velocity}{Electric\ Field\ Strength} = \frac{v}{E} = \frac{n_p e C}{3\pi\mu D_p}$$

- Optical particle sizing has a lower limit ~100 nm
  - → not suitable for UFP
- Electrical mobility: the ability of a (charged) particle to move in an electric field
  - ISO 15900



UFP Monitoring: sizing ultrafine particles

- Differential Mobility Analyzer (DMA): hardware component that performs electrical mobility size determination
- Well-established technology
  - used at NIST to measure particle size standards
- Annular, interior space has electric field due to high voltage on inner rod
- Can be used to:
  - emit just one size (voltage constant), or
  - scan across particle sizes (voltage changes)



UFP Monitoring:
Scanning Mobility Particle Sizer (SMPS™)

1) Polydisperse aerosol sample into DMA…

UFP Monitoring:
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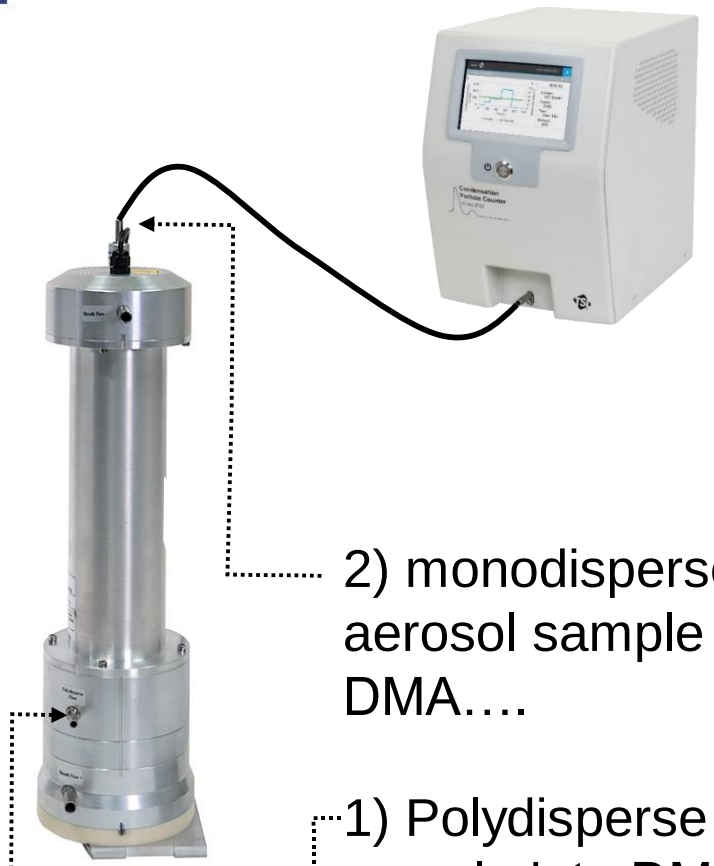

2) monodisperse aerosol sample out of DMA….

1) Polydisperse aerosol sample into DMA…

UFP Monitoring:
Scanning Mobility Particle Sizer (SMPS™)

3) …to CPC for counting

2) monodisperse aerosol sample out of DMA….

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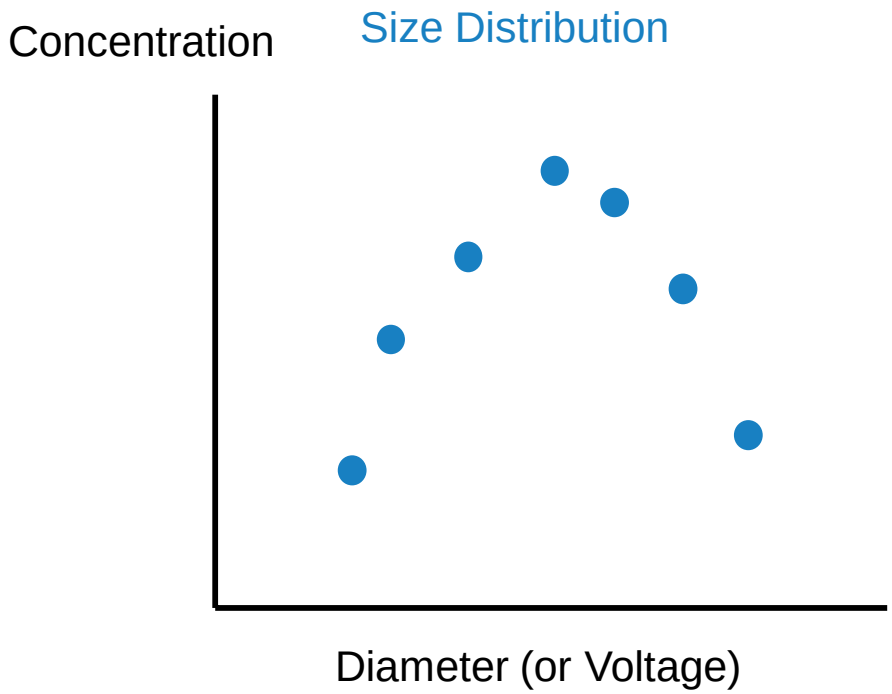

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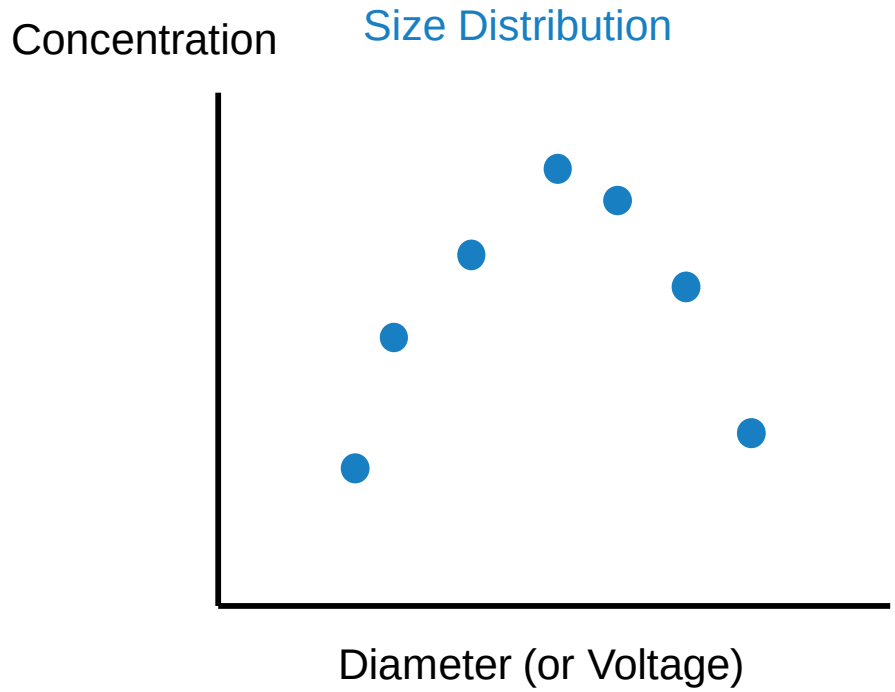

Wide-Range DMA:

10-800 nm in a single scan

UFP Monitoring: sampling

Removal of particles > 10 µm, 2.5 µm

- Representative sampling of ambient UFPs is challenging:
  - Smaller particles – diffusional losses
  - Larger particles interfere with UFP size measurements

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Removal of particles > 10 µm, 2.5 µm

Flow is split into two streams: sampling and drying

Drying flow is filtered, then used to dry the sample flow

UFP Monitoring: sampling

- Representative sampling of ambient UFPs is challenging:
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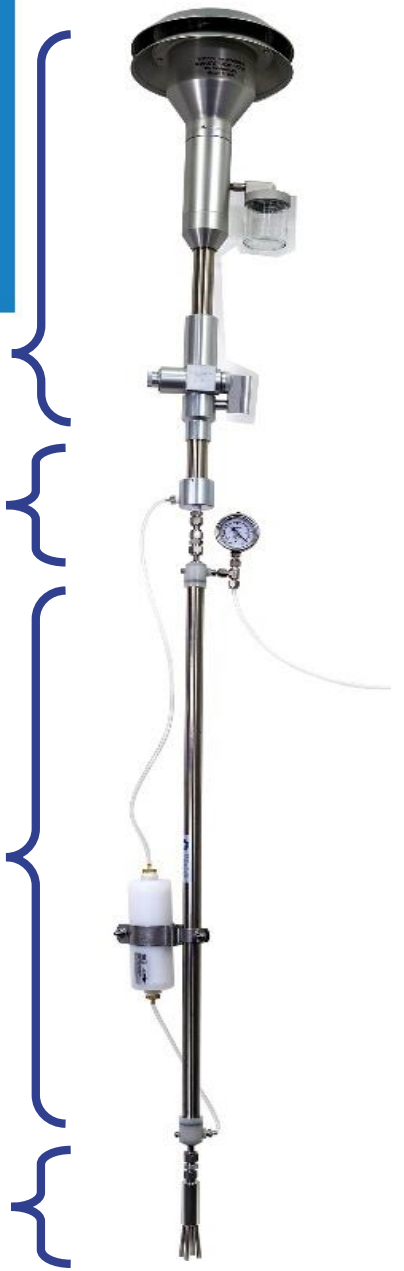


UFP Monitoring: full solution

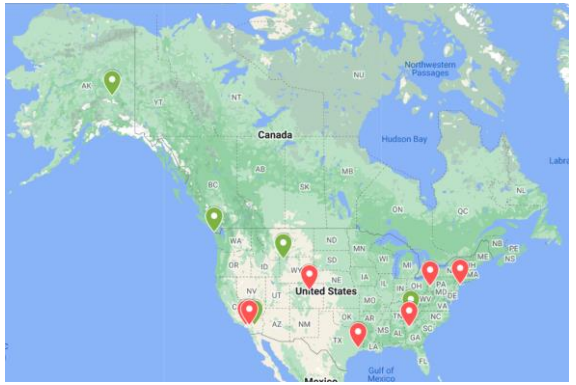
- Sampling System for Atmospheric Particles
  - 3750200
- CPC (total # concentration)
  - 3750 or 3789
- SMPS (size distribution)
  - 3938W50 or 3938W89
  - **Utilizes NEW**: DMA capable of 10-800 nm in a single scan
- Accessories
  - RHT3000 Humidity sensor
  - 3032 Pump

Entire solution described in Brochure, Video

UFP Monitoring: TSI in research networks

- ACTRIS
  - 22 countries, 79 observational platforms
  - Data at https://actris.nilu.no/
    - 42 sites – particle number
    - 58 sites – particle size distributions

- ASCENT
  - New monitoring network in US
  - 12 sites – particle size distributions



UFP Monitoring: Summary

- UFPs are ubiquitous, come from various sources
- UFPs pose a public health hazard that is distinct from that posed by PM2.5
- Current US air quality regulations are mass-based, which leaves UFPs nearly invisible
- UFP monitoring is growing in the US; ASCENT network
- TSI offers UFP-capable instrumentation designed for continuous unattended monitoring installations

Bibliography and Resources

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10. Additional resources found at: www.tsi.com/ultrafines and Water-based Wide-range Ambient Monitoring Scanning Mobility Particle Sizer (SMPS) 3938W89 | TSI

Thank you!

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