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PublicHealth
ENVIRONMENTAL HEALTH LABORATORY
AIR QUALITY SECTION

Wildfire smoke and ash:
Particle size, chemistry, and measurement needs

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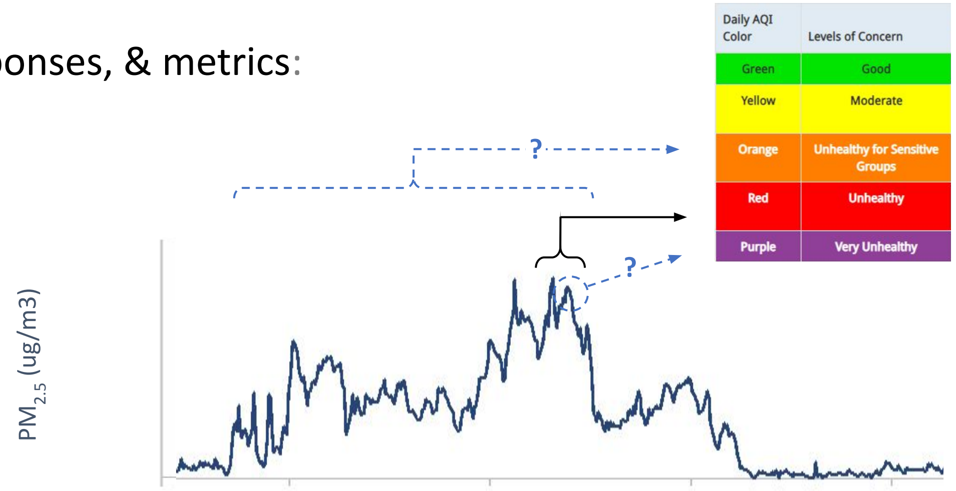
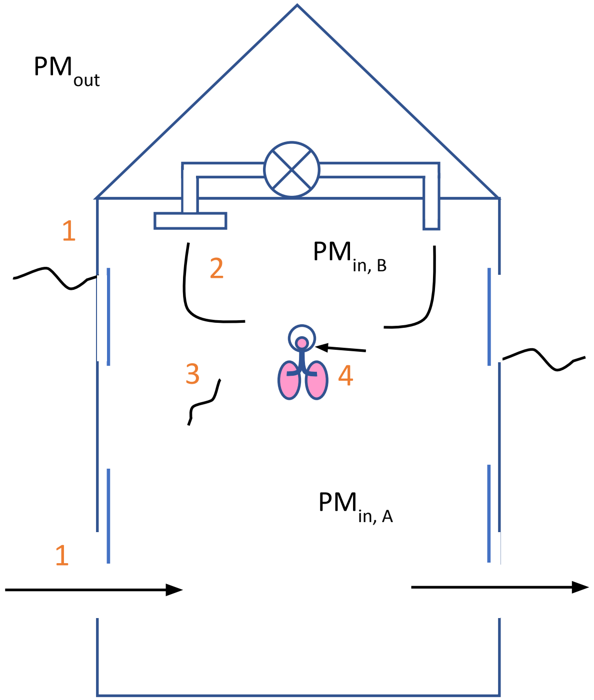
Smoke & Ash Exposure & Measurement Issues

- Wildfire smoke exposures associated with increased hospitalization rates and symptoms (respiratory, cardiovascular, and cerebrovascular) [4, 5, 21, 36, 43, 45]
- Assessing indoor smoke risk with $PM_{2.5}$ sensors alone possesses several challenges:
  - Wildfire emissions = mixture of particle- and gas-phase chemicals produced by incomplete combustion of various fuels (biomass + building materials and vehicles)
  - AQI for wildfire smoke based on health effects of non-wildfire mean $PM_{2.5}$ exposure for 24 hr
  - Wildfire exposures have potentially different health effects, sensor responses, & metrics:
    - Different potential toxics (organic carbon, VOCs, and metals)[4]
    - Different PM optical properties depending on mix of smoke/urban/rural, size distributions [46]
    - $PM_{2.5}$ may not track subcomponents (PM_1) or PM_{10} (PM_{coarse})
    - PM sensors report elevated smoke excursions (hours or weeks) of unknown significance

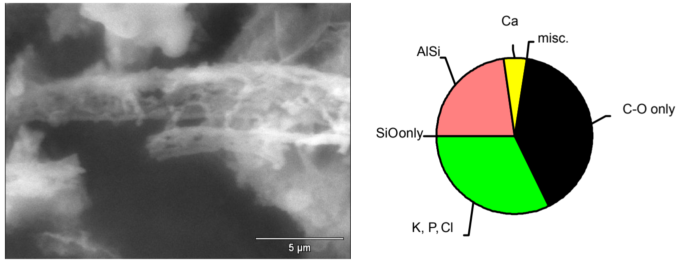


Particle size distribution impacts indoors:

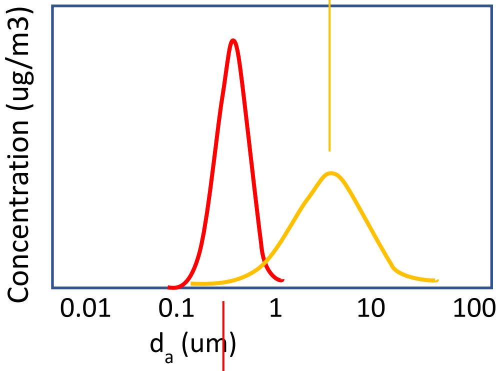
1) infiltration
2) filtration
3) deposition
4) inhalability



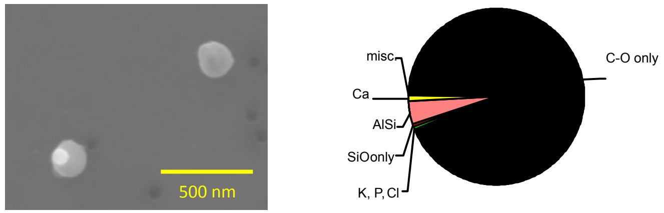
Ash ~ $PM_{10-2.5}$



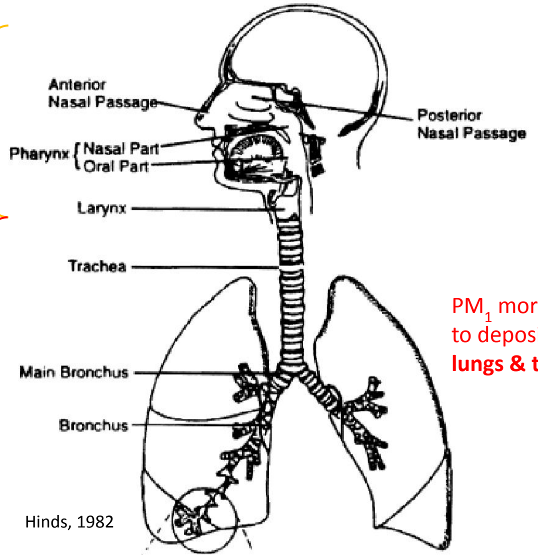
Wagner et al, 2012



Tar balls ~ PM_1



$PM_{10-2.5}$ more likely to deposit in **nose and throat**

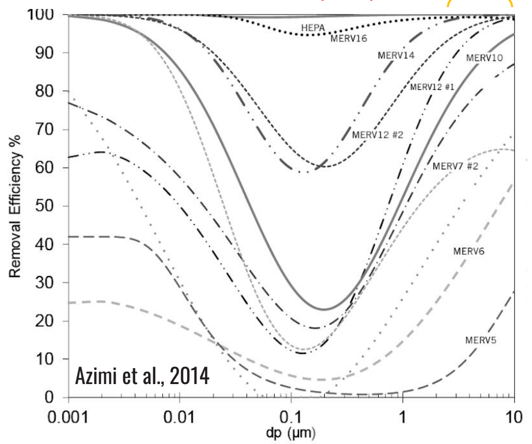


Hinds, 1982

PM_1 more likely to deposit in **lungs & trachea**

$PM_{10-2.5}$ filtered with **higher eff.**

PM_1 filtered with **lower eff.**



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Wildfire PM Size & Chemistry

- **Organic carbon (OC)** - 100-500 nm spherical "tar balls" with minor K [37, 47, 48]
  - Dominant in smoldering biomass (wildfires, cookstoves, crop burning) [1, 10, 15, 30, 33, 37, 41]
  - Carboxylic acids, polycyclic aromatic hydrocarbons (PAH = potential carcinogens) [7, 34, 47]
  - OC PM from peat fires causes decreased cardiac function [22]

- **Elemental carbon (EC [BC])** - chain agglomerates of 20-60 nm soot with sorbed OC
  - Minor component of biomass fires [1, 37]
  - Short term health effects stronger for diesel BC than general PM (heart rate variability) [3, 14, 35]

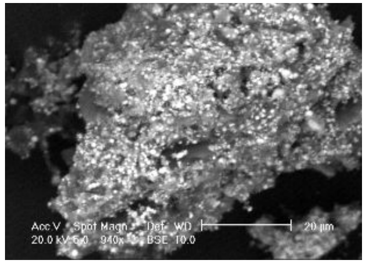
- **Ash** - > 1 um inorganic remnants of plants and building materials [37, 49]
  - Plant ash: K, Cl, Ca, Si, S, Na; enriched Cr(VI), As, Mn, Pb, and Sb [8, 23, 25, 32, 44]
  - Building materials: asbestos, fiberglass, Pb, Cr, As, Cu, Hg from paint, electronics, solder, pipes
  - Inhalation of $PM_{10\text{-}2.5}$ causes inflammation and irritation [2]; caustic (pH = 10-12)[7]

- **Burning petroleum and plastic emissions** - 150 nm - 10 um OC
  - Oil: coarse PM_{10} coke with V and Ni; impacts heart rate variability more than normal PM_{10} [20, 27, 28, 29]
  - Wood composites: >10x more $PM_{2.5}$ than burning wood, increases with fraction of adhesives [12]
  - Vinyl polymers (e.g. PVC pipe, siding, furniture) produce ash + PAHs

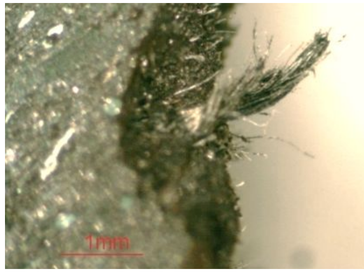
Wildfire tar balls

Non-wildfire diesel

Wildfire ash



Paint with 1 um Pb [40]



Asbestos in brakes [11]

Wildfire Gas Chemistry

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- Wildfire smoke gas hazard types, measured close to fire [12, 38, 39]

Type of gas-phase hazard	Gas species
Asphyxiants	CO, CO_2, H_2S
Irritants and allergens	NH_3, HCl, NO_x, phenol, SO_2, isocyanates
Carcinogens	benzene, styrene, formaldehyde

- Gas chemical concern groups based on Hazard Ratios = EF / TLV [5]

Hazard ratio groups	Gas species
Group 1	CO, formaldehyde, acrolein, NO_x
Group 2 (One order of magnitude less)	benzene, CO_2, [PAH], NH_3, furfural
Group 3 (Two orders of magnitude less)	acetaldehyde, 1,3-butadiene, methane, methanol, styrene, acetonitrile, propionaldehyde, toluene, methyl bromide, methylethylketone, acetone, methyl chloride, xylenes, phenol, tetrahydrofuran, methyl iodide, mercury

- Hazardous gas emissions from associated burning products and building materials [12]
  - Polystyrene plastics: benzene, phenols, and styrene
  - Vinyl compounds: acid gases (HCl and HCN) and benzene
  - Wood products: formaldehyde, formic acid, HCN, and phenols
  - Roofing materials: SO_2 and H_2S

Wildfire PM and Gas Measurement Options

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Wildfire emissions measurement type	Reported Analyte	Measured quantity
Continuous monitors/sensors (fastest response and time resolution)		
Laser photometers; optical particle counters*	$PM_{2.5}$, (PM_1, PM_{10})	Light scattering (d_{min} = ~0.3 um for low cost)
Beta attenuation	$PM_{2.5}$, PM_{10}	Beta radiation absorption
Aethalometers	BC or UVPM	Light absorption
Aerodynamic/electrodynamic particle sizers	PM size distributions	Single particle TOF/electric mobility
Photoionization/photoelectron detectors	Total VOCs/PAHs	Ionization current
Long path UV spectrometers	VOCs, NO_x	UV absorption
Electrochemical/MOx sensors or colorimetric tubes*	VOCs/total HCs, CO, NO_x	Chemical reaction with substrate
Portable GC-MS or PTR-MS	VOCs	Retention time & m/Q
NDIR or OP-FTIR	VOCs, NOx, CO, CO_2	IR absorption
Samplers (need to take back to lab to analyze)		
Filters or impactors	$PM_{2.5}$, $PM_{10-2.5}$, PM_{10} ; PAHs, metals	Gravimetric PM; Retention time & m/Q
Electron microscopy (Impactors, ESP, thermal, passive samplers*)	PM size distributions, shape, chemistry	Single particle electron/X-ray energy
Active or passive* sorbent tubes, badges, or gas canisters	VOCs, NOx, PAHs, formaldehyde	Retention time & m/Q
Other		
Satellite/remote sensing (outdoor only)	$PM_{2.5}$, $PM_{10-2.5}$, PM_{10}	Aerosol optical depth

*Lowest-cost devices

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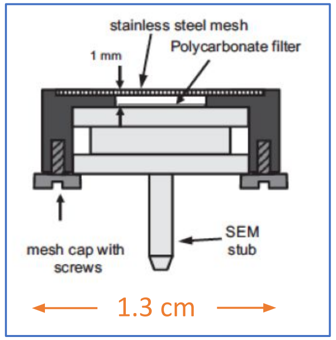
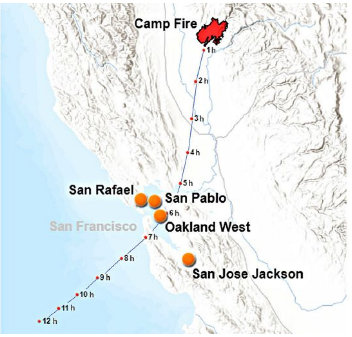
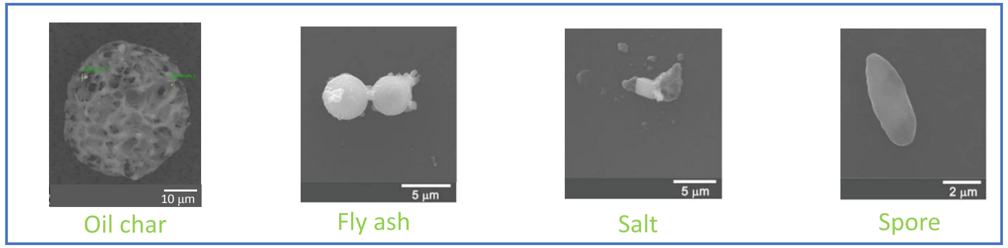
Measurement example: PM size distributions, Sources = smoke + ash + urban PM background





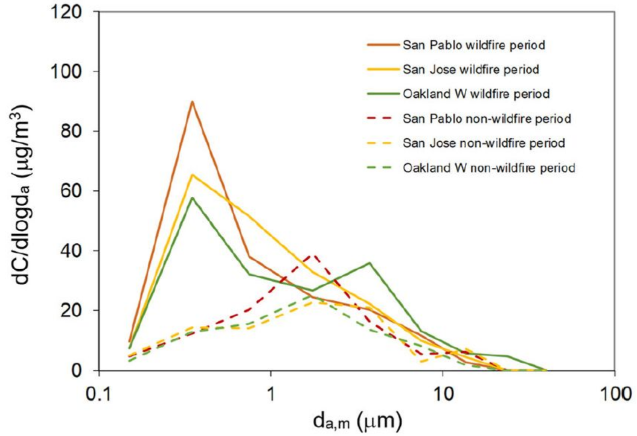
Passive PM samplers + BAM 1020, SF Bay Area Nov 2017-18
(NASA HAQAST study with BU, SJSU, RJLG, and QC-CUNY)

Non-wildfire PM types

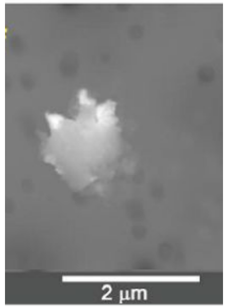


Castillo et al, *Atmos. Environ*, 2020

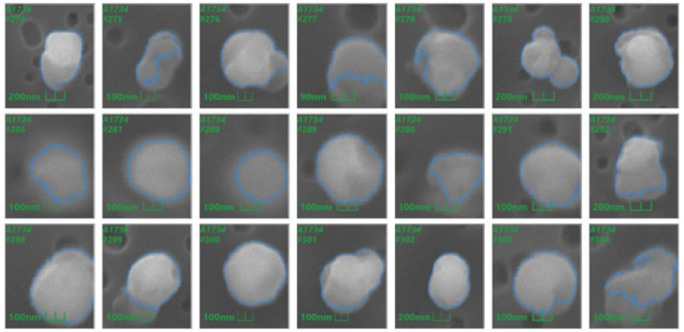
1-month samples dominated by PM1 from 2-week smoke episode



Wildfire PM (Fine and coarse C with Cu, Zn, and Ni)



Wildfire PM (200-500 nm tar balls)



Sparks and Wagner, *Aerosol Sci & Technol.*, 2021

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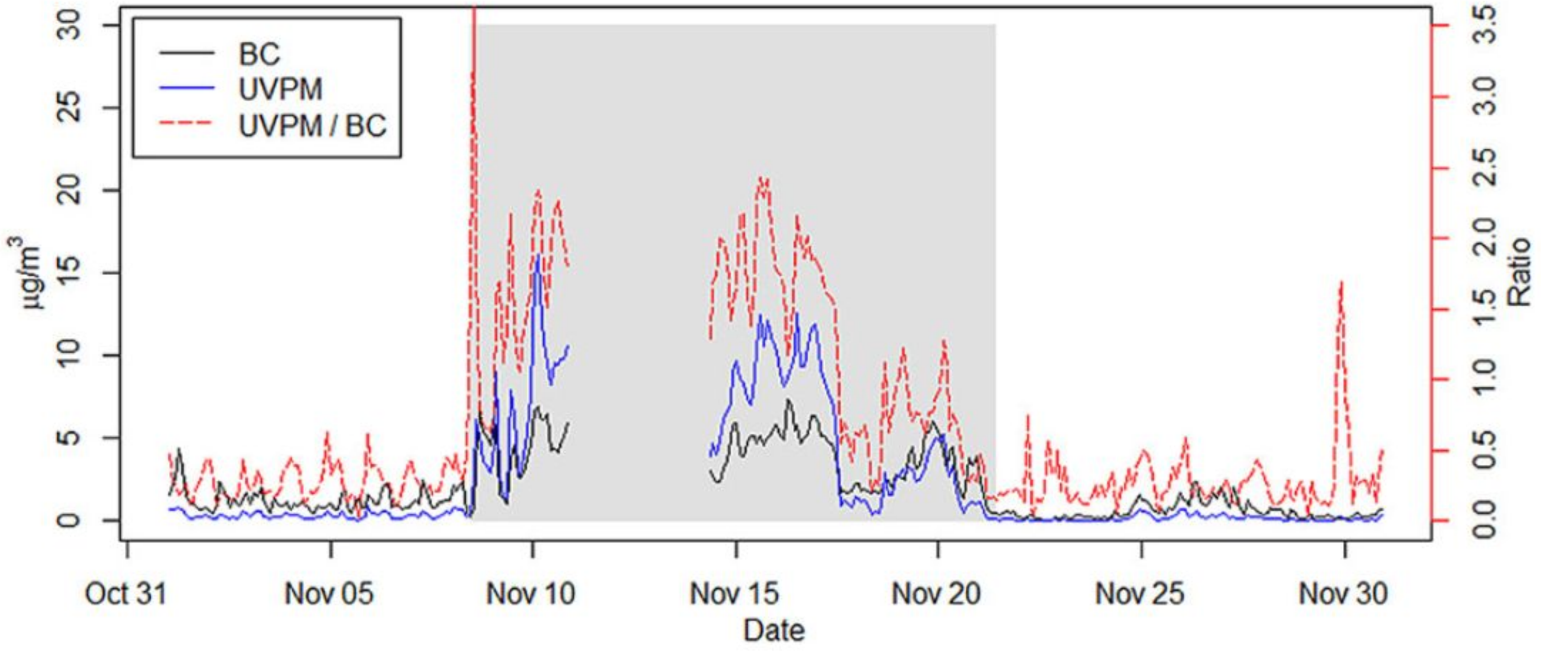
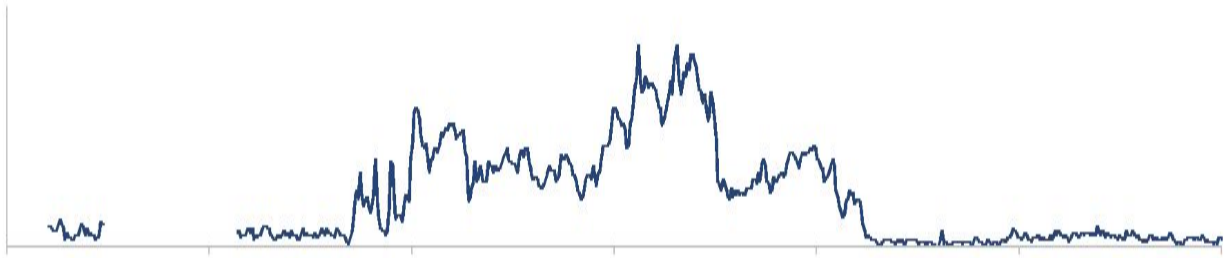
Measurement example: Wildfire smoke-specific tracers



Smoke Episode,
SF Bay Area 2018



Multi-wavelength aethalometer (UVPM/BC)

- best indicator of biomass smoke presence in PM

Sparks and Wagner, *Aerosol Sci & Technol.*, 2021

Measurement example: Smoke event I/O size distribution ratio + indoor metals

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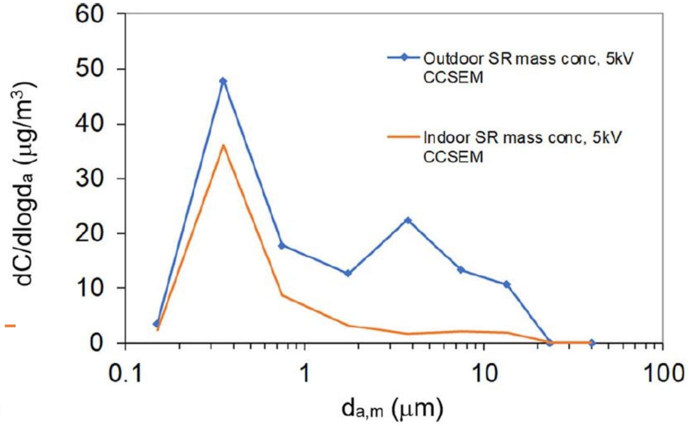
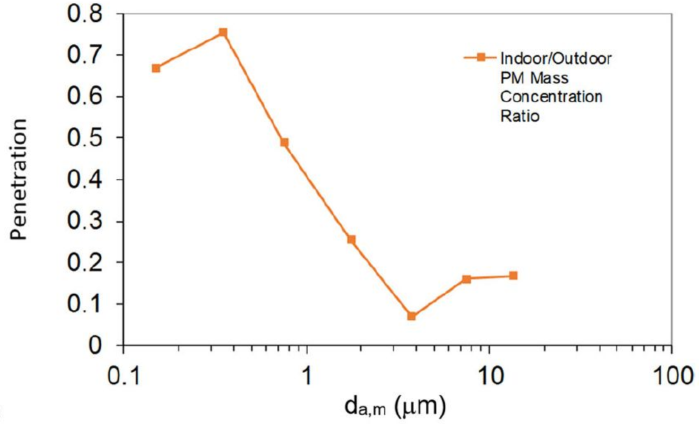
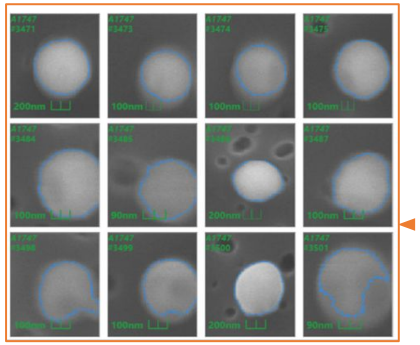
Passive Sampler Indoor + Outdoor PM size distributions

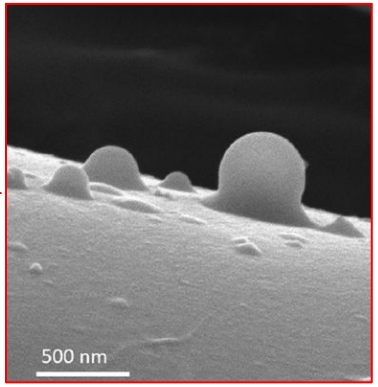




Wildfire PM collected on MERV11 furnace filter

- Multi-room, intermittent air cleaner
- Filter = low cost, opportunistic sample (SEM, ICP)
- Lower reductions possible with dedicated air cleaners[18]





Enriched indoor PM metals during wildfire

- consistent with outdoor data from same episode (CARB, 2021)

	Accumulation rate* (ng/cm²/day)		Ratio
	Wildfire	Background	(wildfire/background)
Copper	0.40	0.23	1.73
Zinc	3.35	1.12	2.98
Lead	0.21	0.06	3.70

*Accumulation rate is the measured mass of metal per area of filter, minus that of the blank filter, per day furnace filter was in use. The wildfire filter was in use 44 days and the background filter was in use 156 days.

Sparks and Wagner, *Aerosol Sci & Technol.*, 2021

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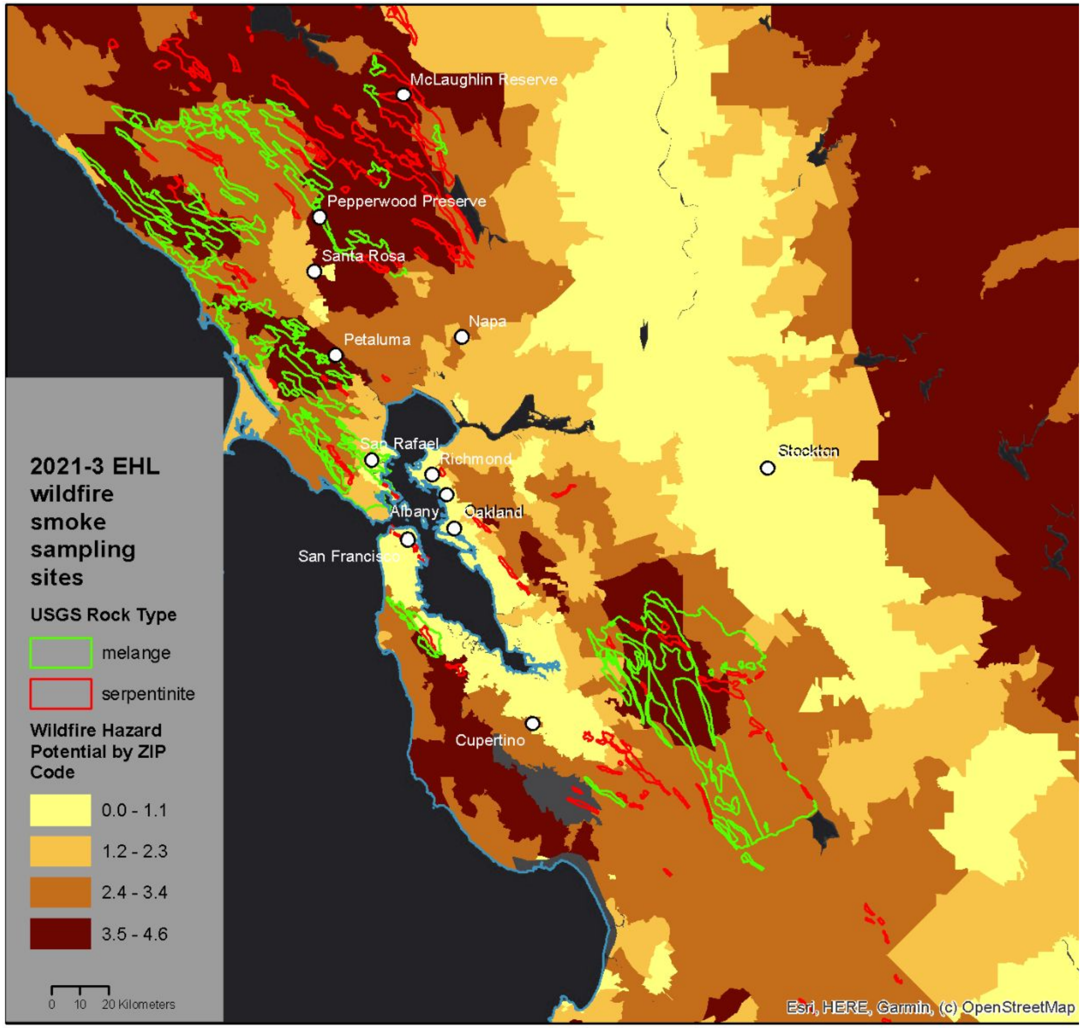
Ongoing CPDH projects combining sensors-samplers

- 2021-23 PM + air cleaner intervention in farm community homes (swamp coolers) (with PHI/UCSF/IIT/Central CA EJ Network)
- 2021-23 PM + BC + PAH + noise exposures inside AB617 homes in CA Central Valley (with UCB/UCM)
- 2021-22 PM + Cr (VI) in PM_{10} ash in communities near fires (with Stanford)
- PM + VOC + PAH + metals + oxidative stress in vulnerable communities (proposal submitted with PHI/NYU/CCEJN)



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Smoke & Ash Measurement Needs

- Low-cost PM sensors are good tools for assessing key questions:
  - What are indoor exposures during fire episodes, and how can clean air spaces be achieved in vulnerable communities?
  - What is the spatial variability across complex topography during a smoke episode? Within buildings operating air cleaners?
- The use of multiple, complementary measurement methods are needed to answer other questions:
  - Can the above be demonstrated for specific compounds or PM sizes?
    - Smoke tracers (UVPM; PM_1)
    - Ash tracers ($PM_{10\text{-}2.5}$)
    - Toxics (PAHs, metals, VOCs)
  - What measurable health effects are associated with <24 hr exposures? Multiple days/weeks?
  - What is the wildfire contribution to PM exposure burdens for urban and rural communities?
  - Can window opening guidance be improved using indoor/outdoor PM/temperature sensors?