Ultrafine particles in a changing landscape of engines and emissions control

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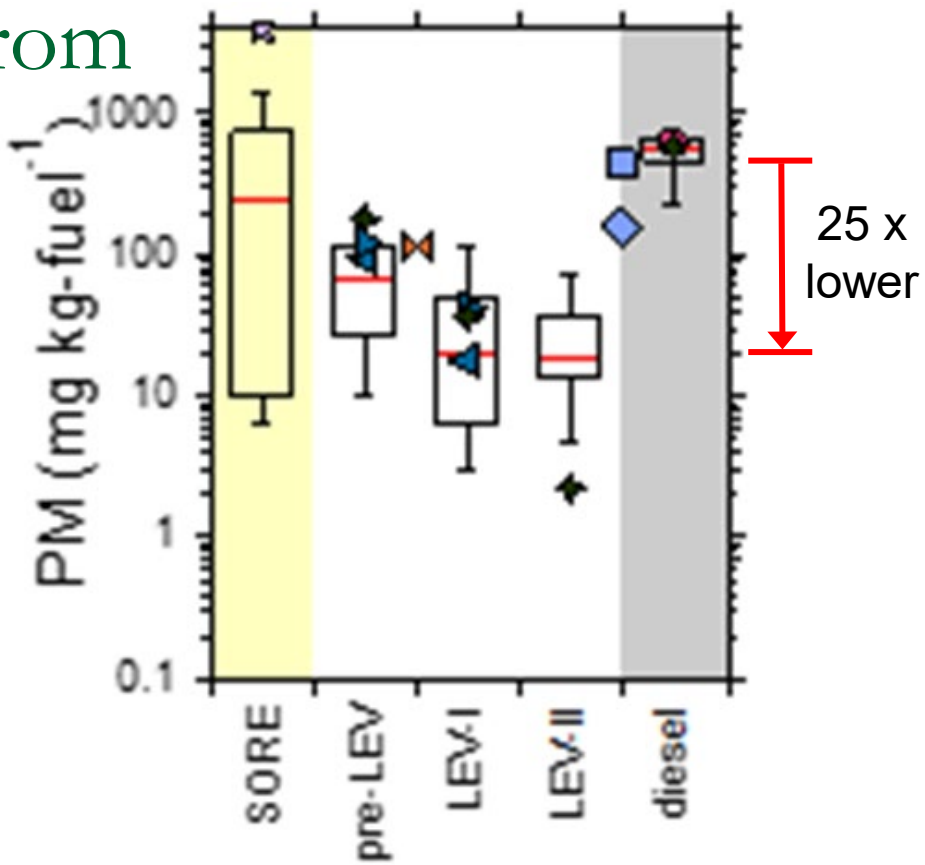
Outline

- Where we've come from: Overview of technology and PM emissions changes over the past 15 years
  - Size, composition, number, etc.
  - Implications for interpretation of older studies?
- Where we are now: Implications of current and near term technology developments for UFPs in US/Europe.
  - LEV III, Tier 3, and solid PN
  - Gasoline direct injection technology
- Where are we headed in the future?
  - UK rules to abandon the internal combustion engine…
  - How do they compare, e.g. to brake and tire wear emissions?
  - Hybrids, smart vehicles and other fuel/technology developments?

Where we've come from

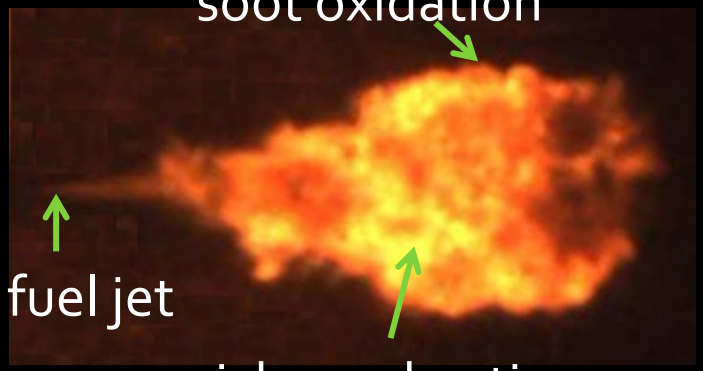
- Diesel
  - 2007 – US EPA regs require <10 mg/bhphr PM emissions
  - 2011 – EU5b introduces solid particle # standard 6×10^{11}/km

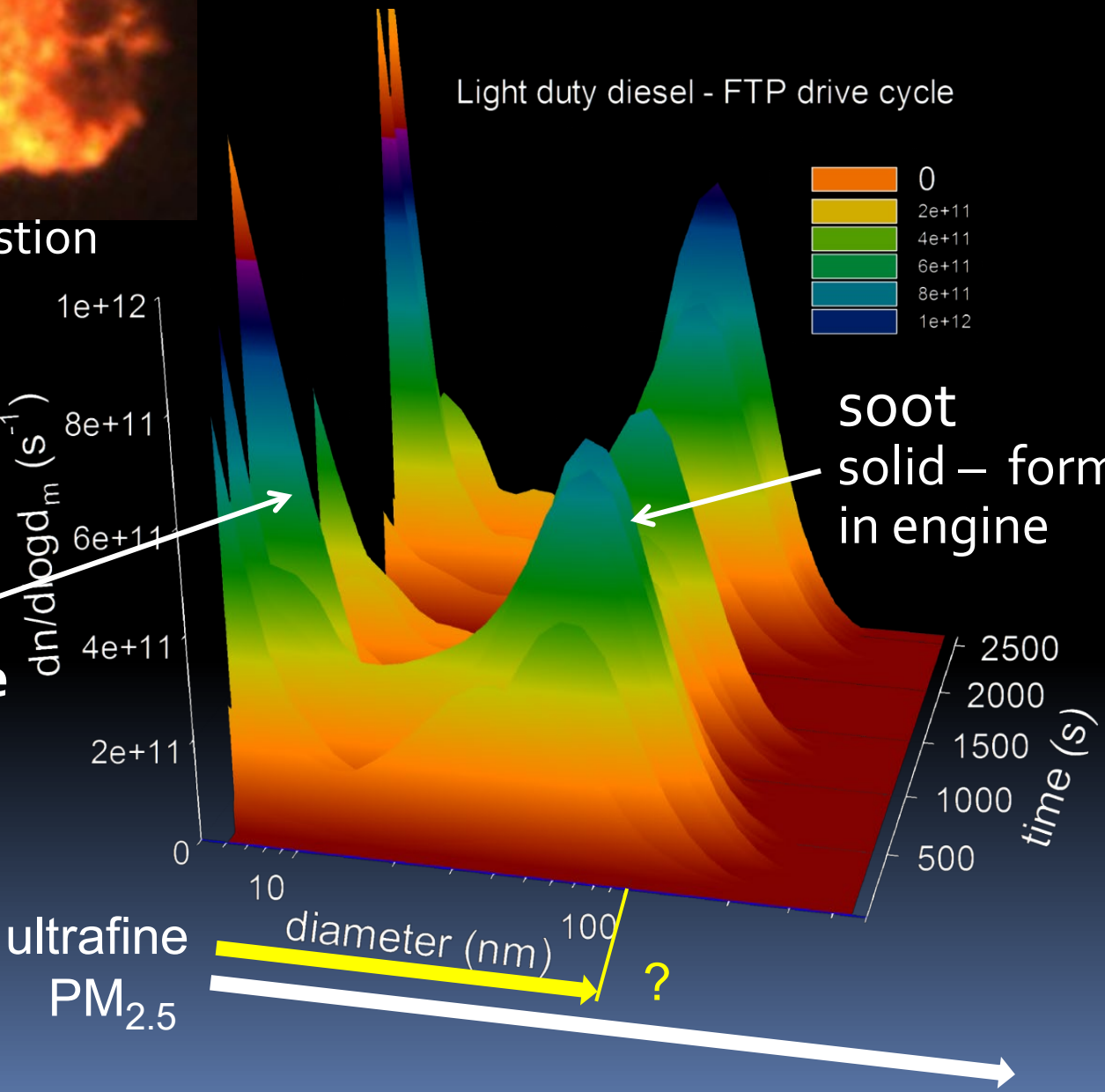


- Gasoline
  - Engines utilize port fuel injection
  - Air / fuel control to make catalyst work also ensures low PM

May et al., Atmos. Environ 88, 2014

Diesel engine PM



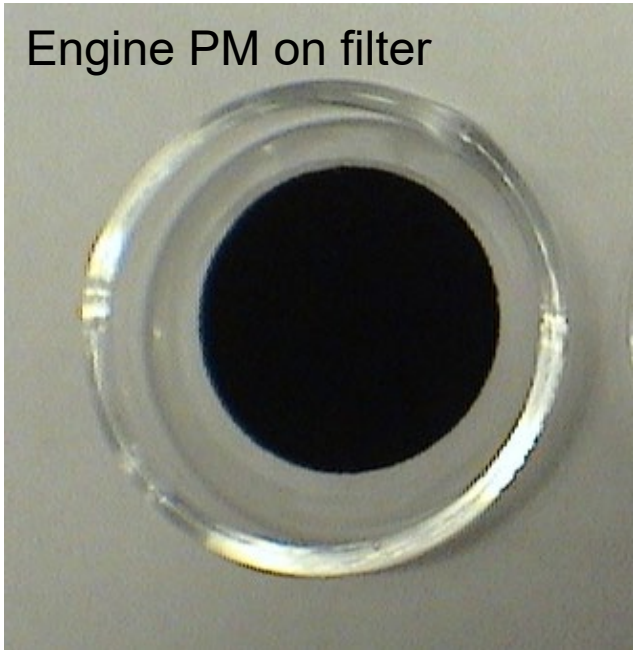


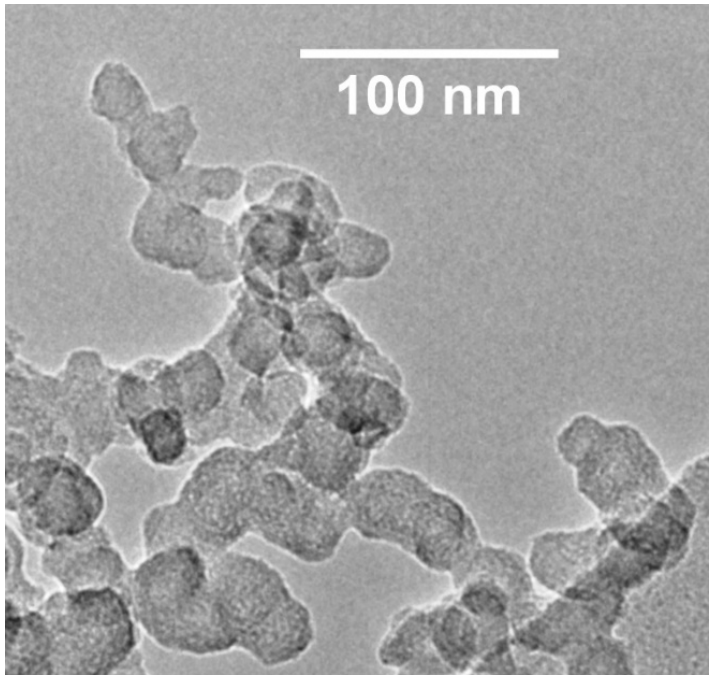
nucleation mode
liquid – forms as exhaust cools

soot
solid – forms in engine

ultrafine $PM_{2.5}$

PM emissions pre 2007



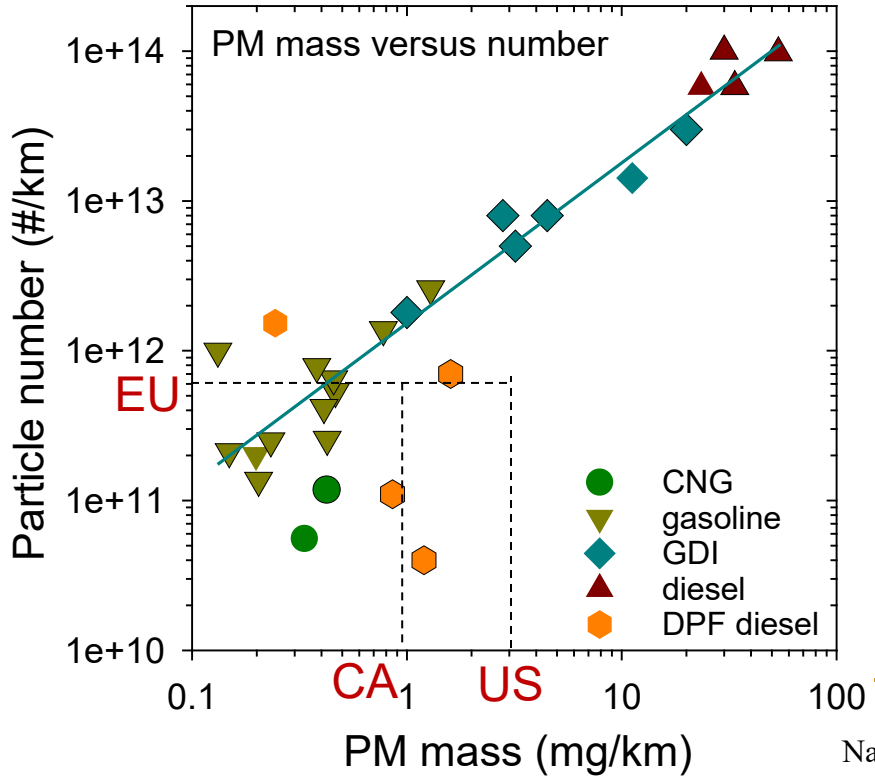


Typical PM break down:

- ~75% soot
- ~25% semivolatile
  - Heavy hydrocarbons, e.g., lube oil
  - Sulfate from fuel (300 ppm S)

Where we are now

- GDI engines introduced to improve fuel economy & CO_2
- Lev III and Tier 3 promulgated to avoid backsliding
- EU extends solid PN regs to GDI



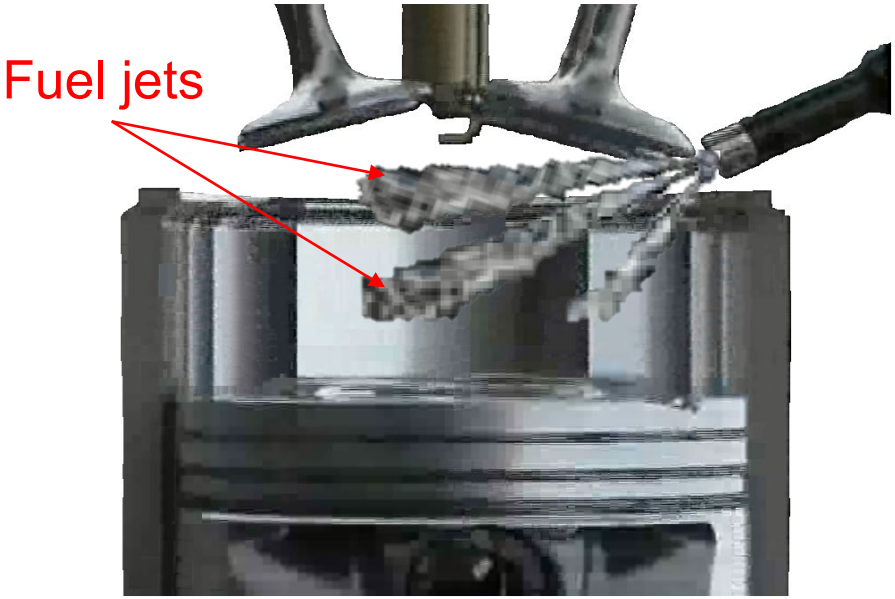
- Filters remain nearly white
- Filter weight – 150 mg
- PM collected ~ 0.04 mg
- Gaseous artifact ~0.01 mg
- Composition ~75% soot & 25% semivolatile ?

Nanoparticles in medicine & environ., Springer, 2010

GDI combustion

Direct fuel injection:

- Increases fuel economy
- Decreases CO_2
- Higher air fuel inhomogeneity increases PM

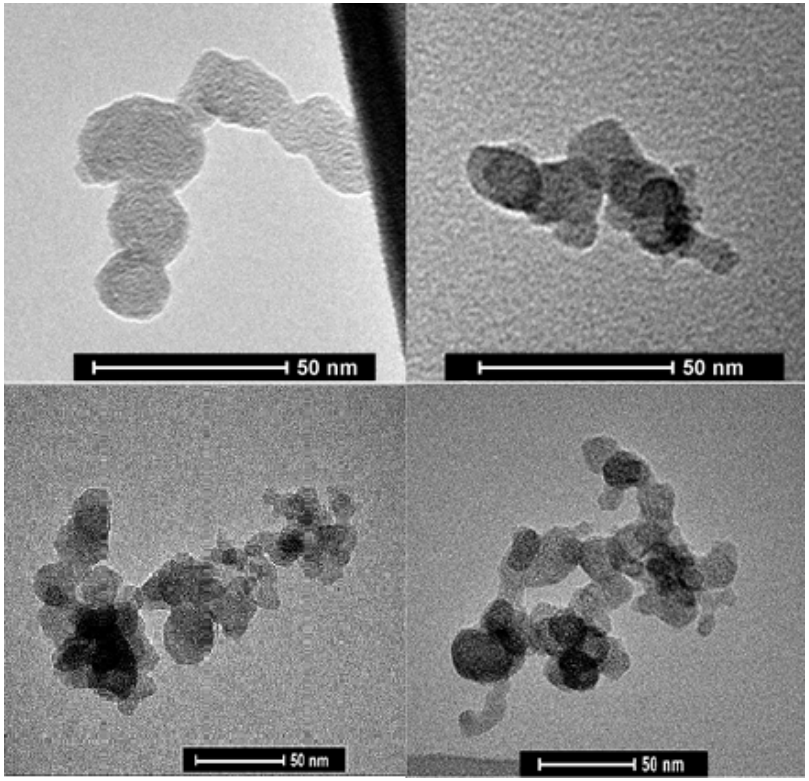


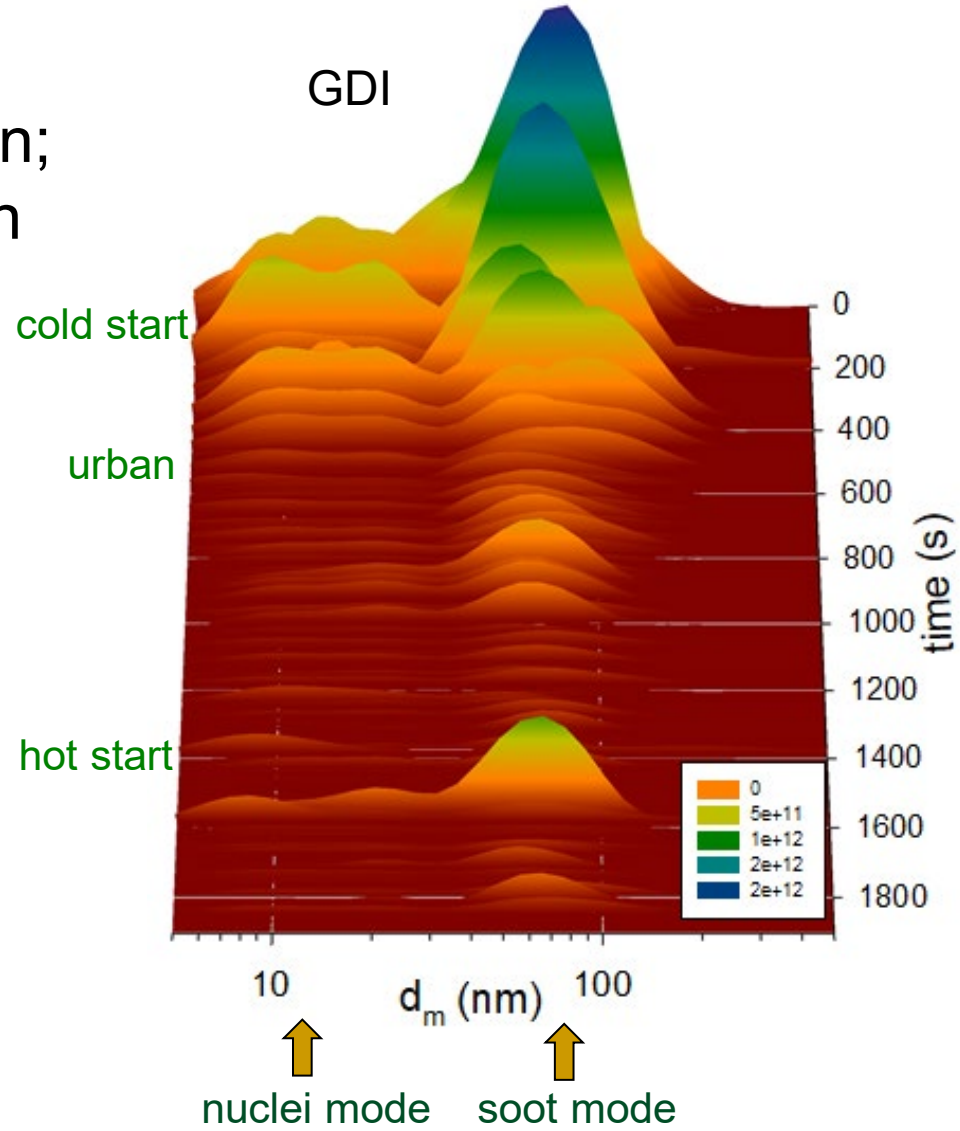
GDI fuel injection

Soot formation

GDI engines PM characteristics

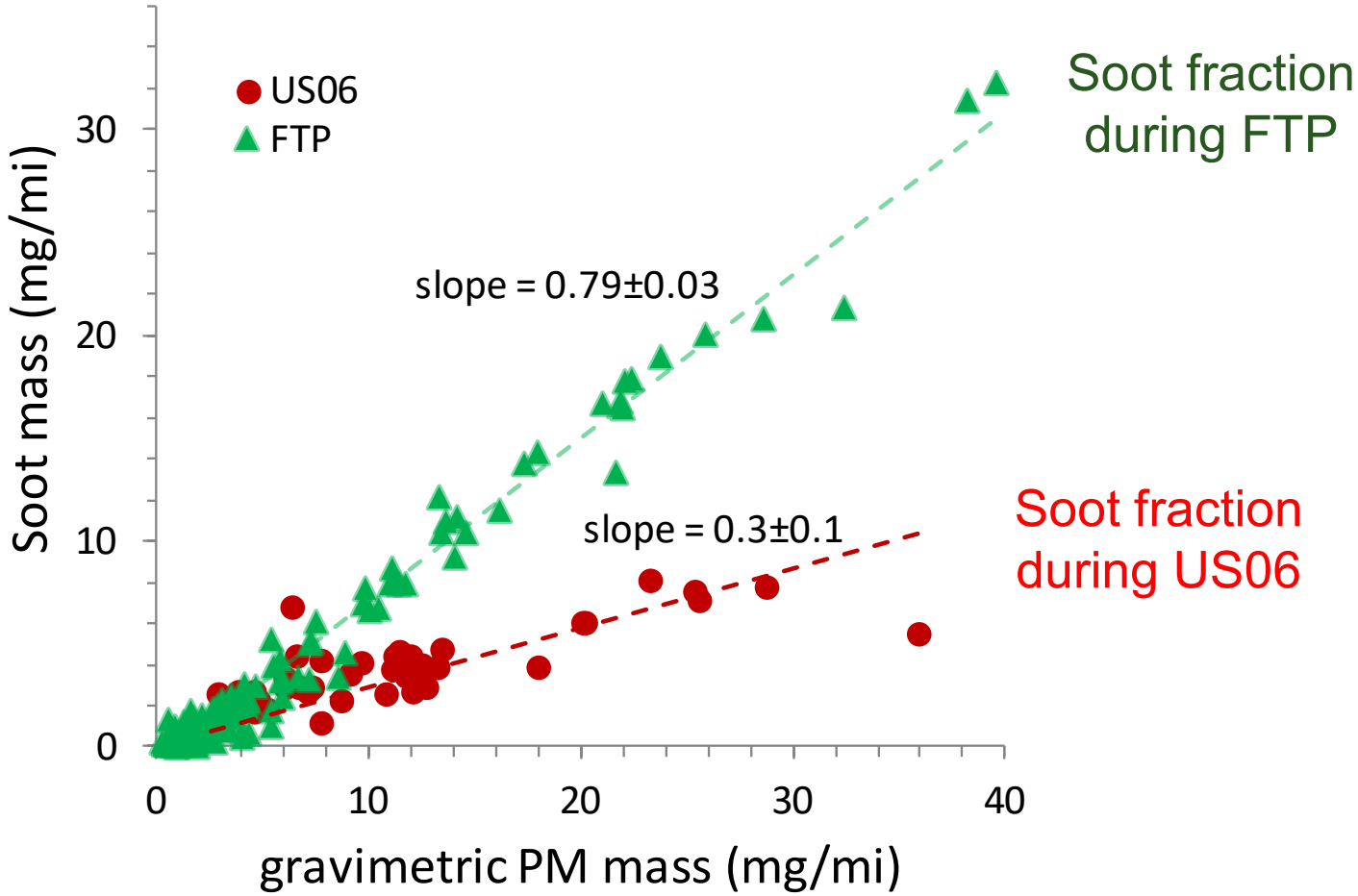
- PM mostly similar to diesel
- Varies with driving condition; e.g., cold start, acceleration





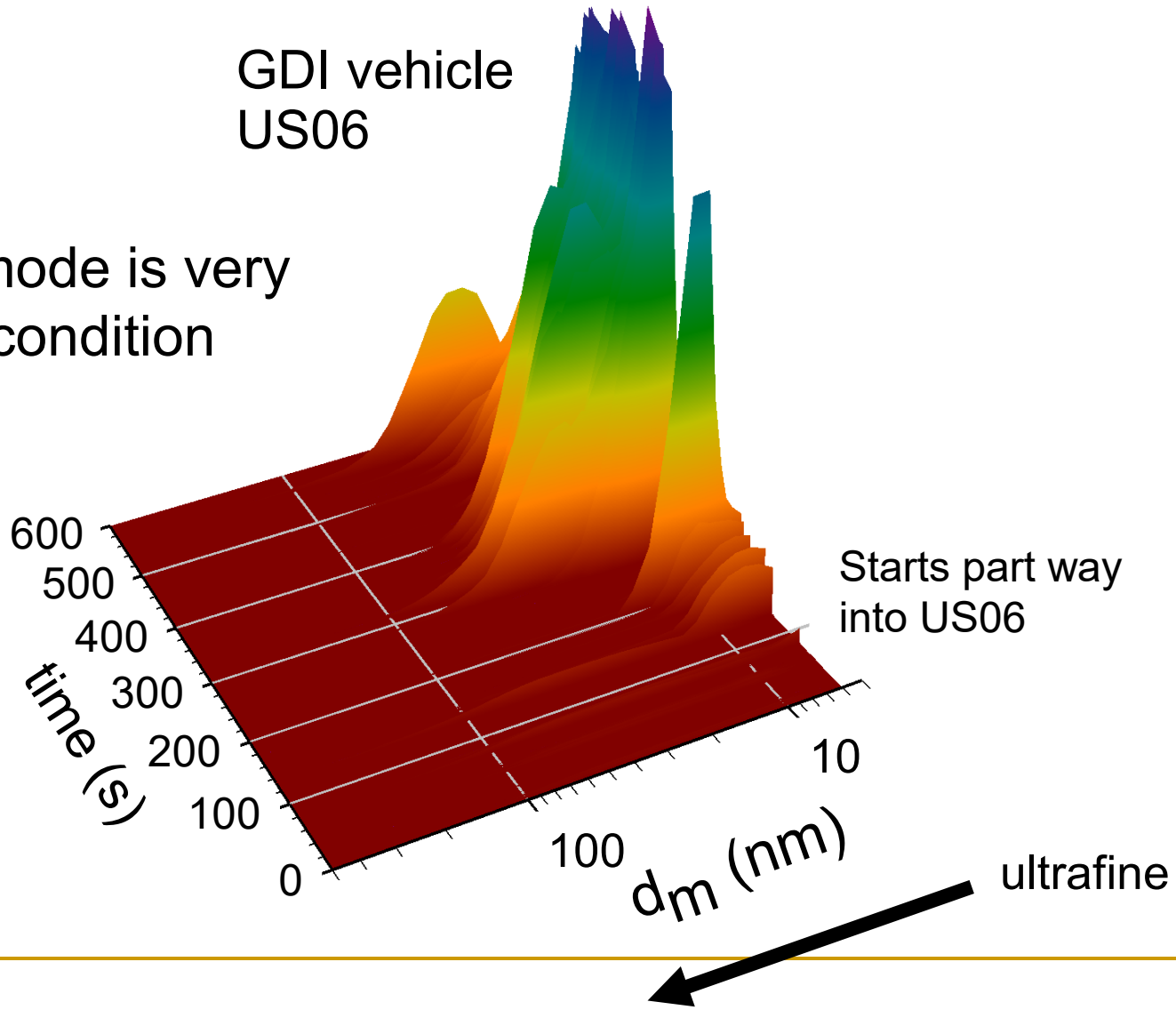
ultrafine → ?

PM composition depends on driving condition



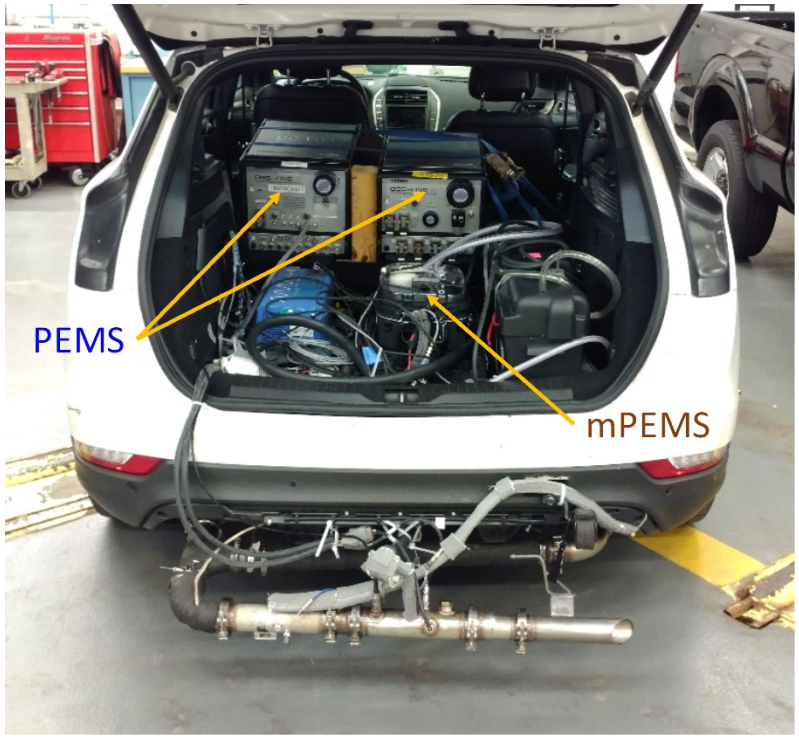
Particle size depends on driving condition

Nucleation mode is very vehicle and condition dependent



Where are we headed?

- Real world emissions
- Gasoline particulate filters
- Hybrid & plug in hybrids
- Brake and tire PM



Hybrid vehicles

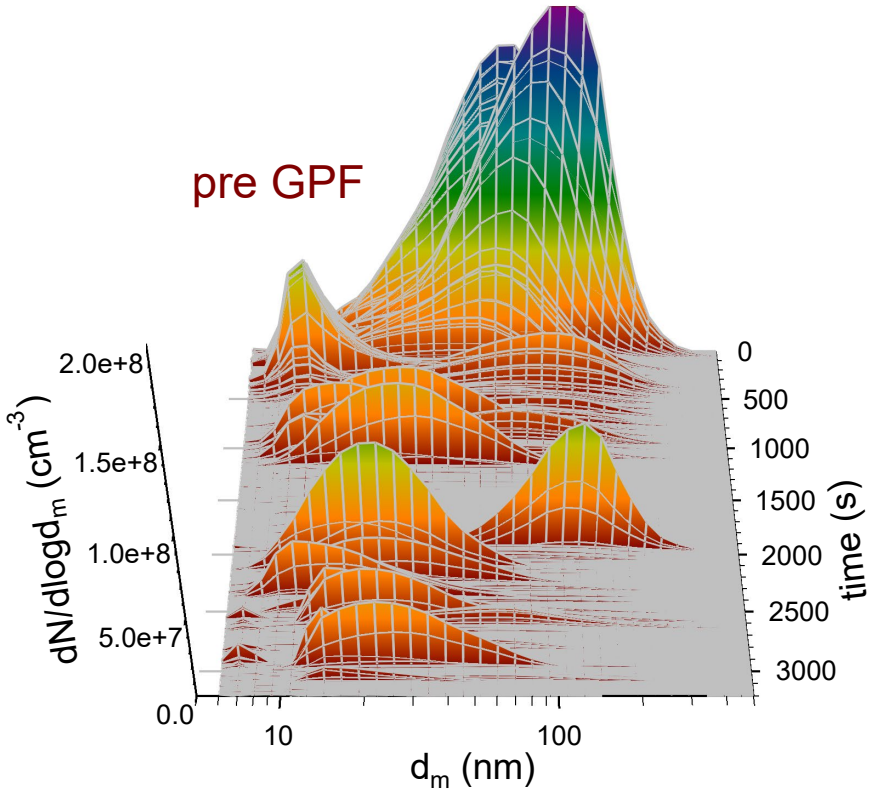
Electric motor allows engine to be run at higher efficiency and lower PM than conventional vehicle

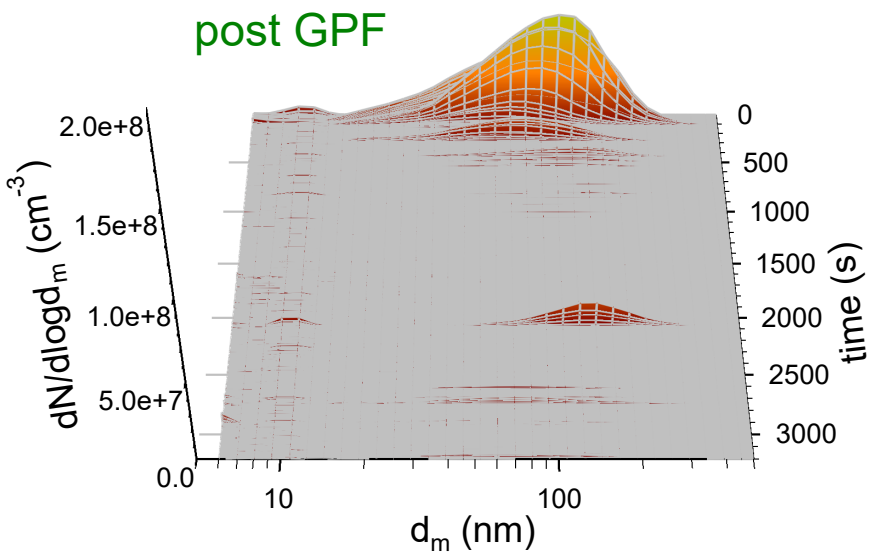
Smart vehicles

- Traffic information
- Connectivity
- Autonomous driving

Gasoline particulate filters can significantly reduce PM

Challenge remains to design GPFs that don't reduce fuel economy

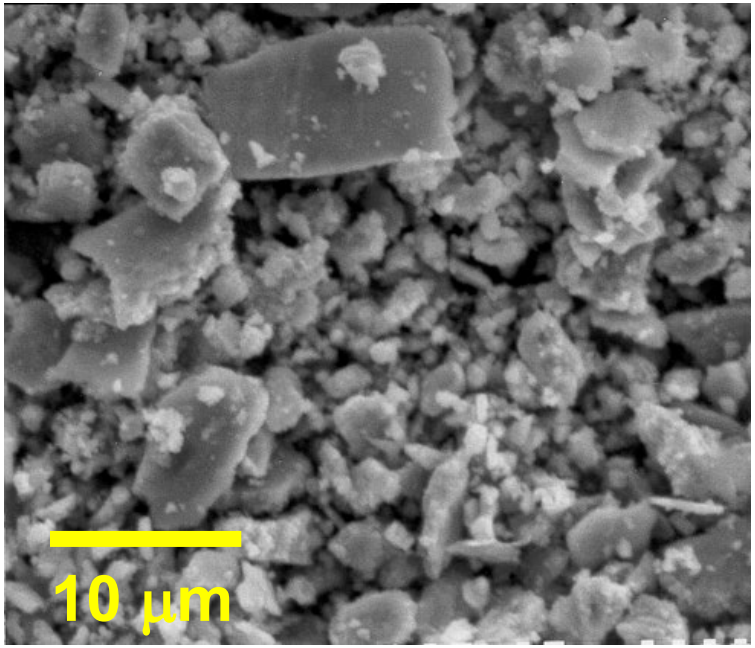




Non-tailpipe PM

Brake particles:

- Grinding – PM_{10} & $PM_{2.5}$
- “combustion” - ultrafine



Summary

- Past, present, future of ultrafine PM
  - PM mass and number emissions have decreased substantially to keep pace with regulations
  - Particle types remain the same: accumulation mode, solid soot ~100 nm; nucleation mode, mostly semivolatile, ~20 nm
  - Relative composition: soot & sulfate down, organic up

- How does “ultrafine” fit into the health effects picture?
  - Use in literature is ambiguous
  - No clear demarcation to define UFP – perhaps “sub half micron”?
  - Size is important (penetration into lung) - but
  - Other properties determine impact e.g., liquid particles dissolve, solid translocate (see talks in “Particle Components & Associated Health Effects webinar)