Instrumentation for Ambient Ultrafine Particle Measurement

historic perspectives
and
recent developments

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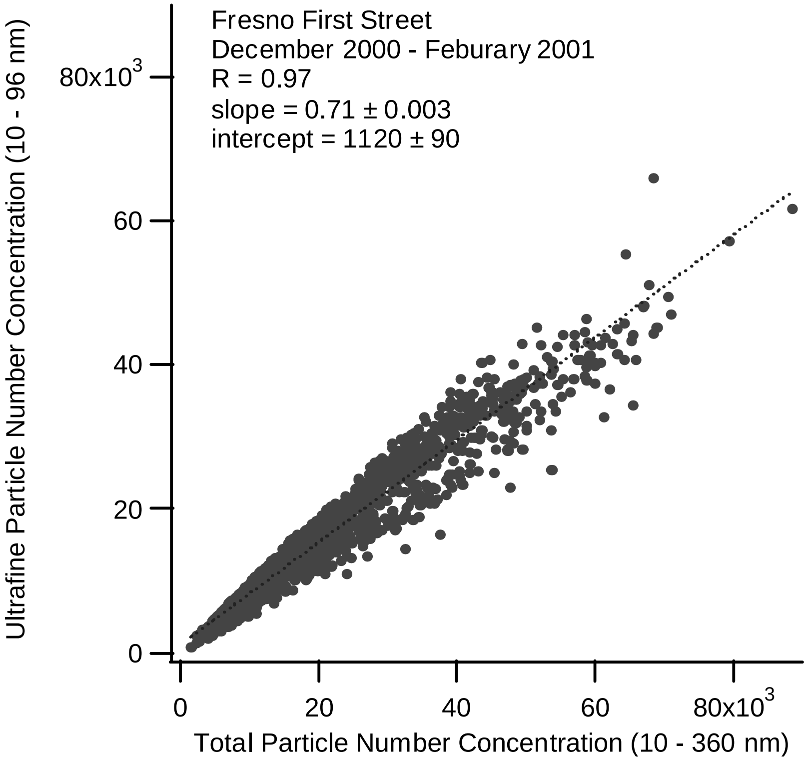
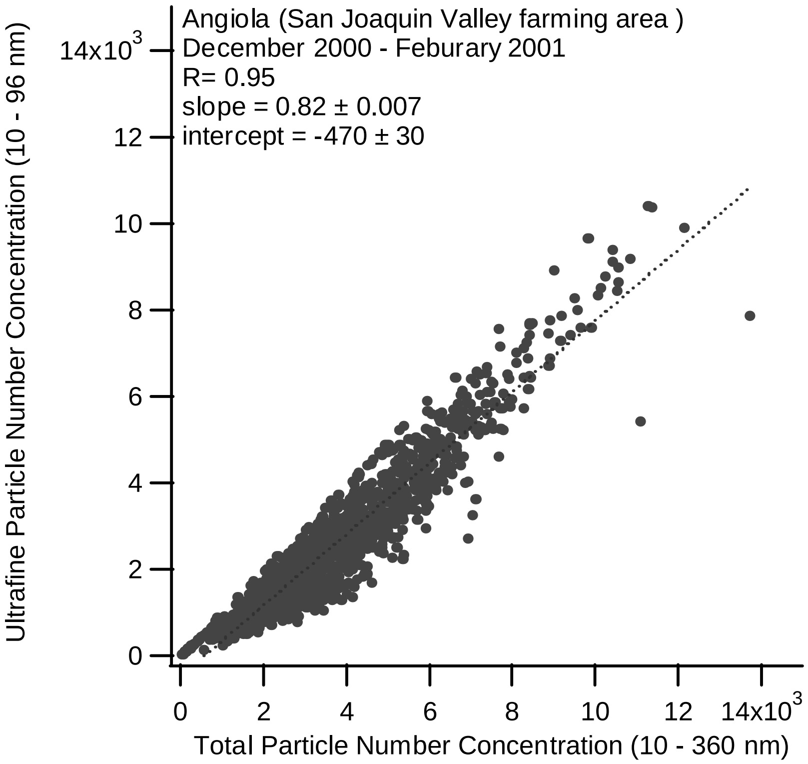
Ultrafine Particles Dominate Particle <u>Number</u> Concentrations

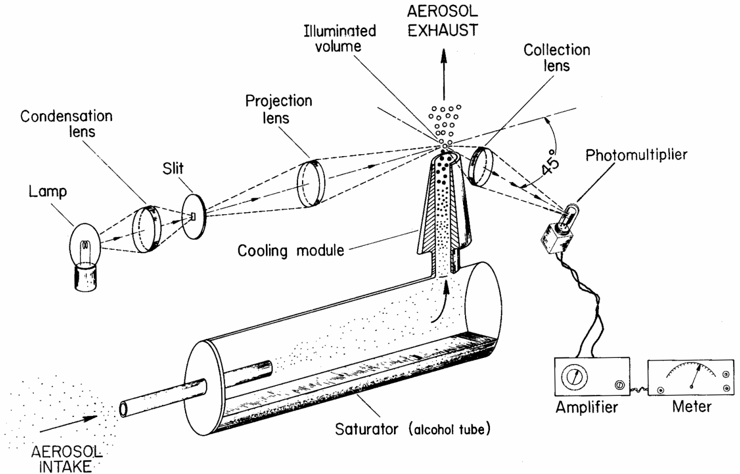




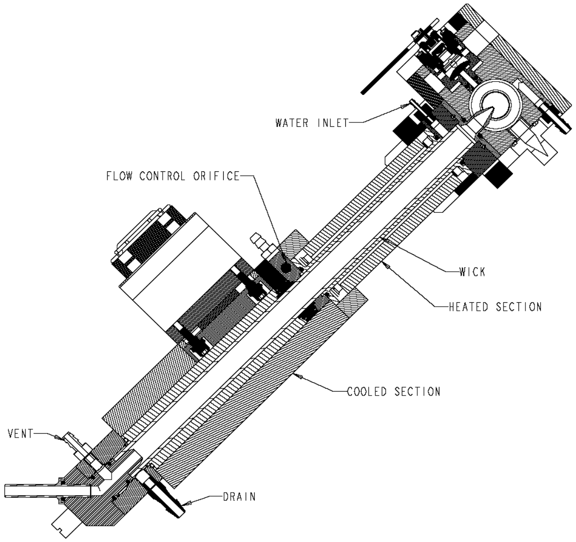
Rural and Urban Sites : Similar Relationship between Ultrafine Particle Number Concentrations and Total Particle Number Concentrations

Simplest Indicator for Ultrafine Particles:

Particle Number Concentration



Bricard et al, 1976



Hering et al, 2005

1889: First Measurement of Atmospheric Particle Number Concentrations

John Aitken,

“On the Number of Dust Particles in the Atmosphere”,

Transactions of the Royal Society of Edinburgh, 1889

J. AITKEN ON THE NUMBER OF DUST PARTICLES IN THE ATMOSPHERE.

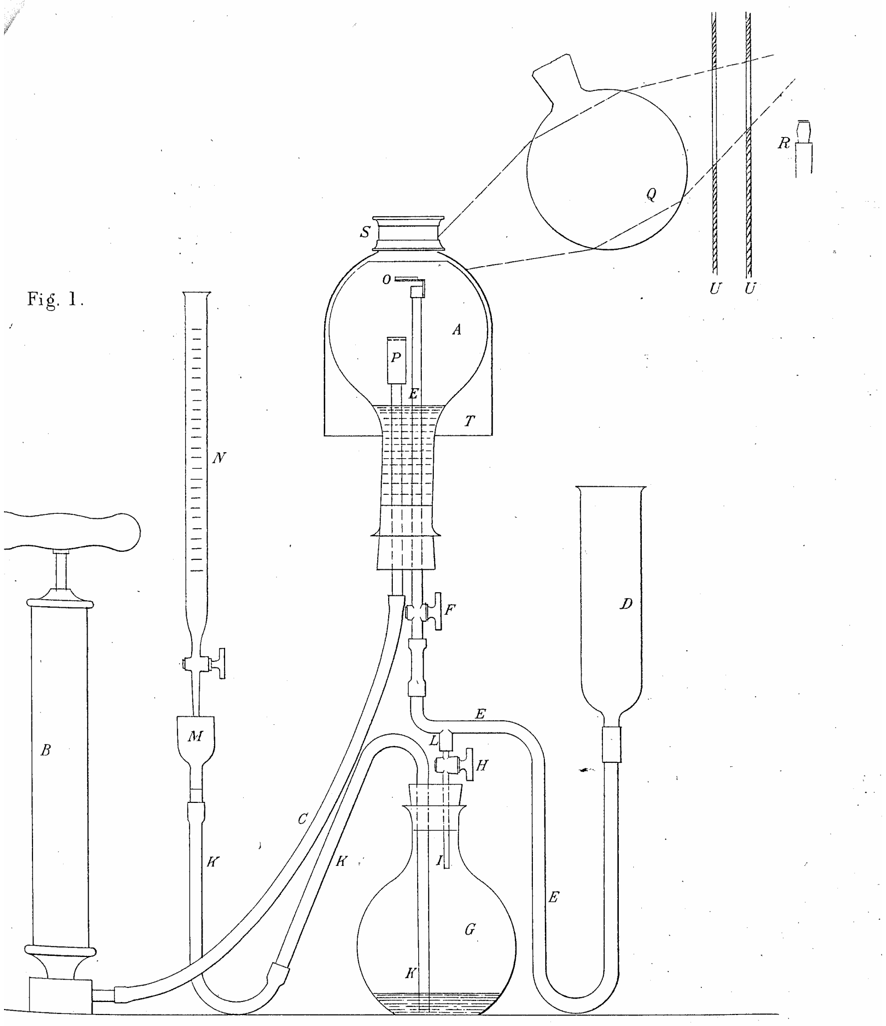


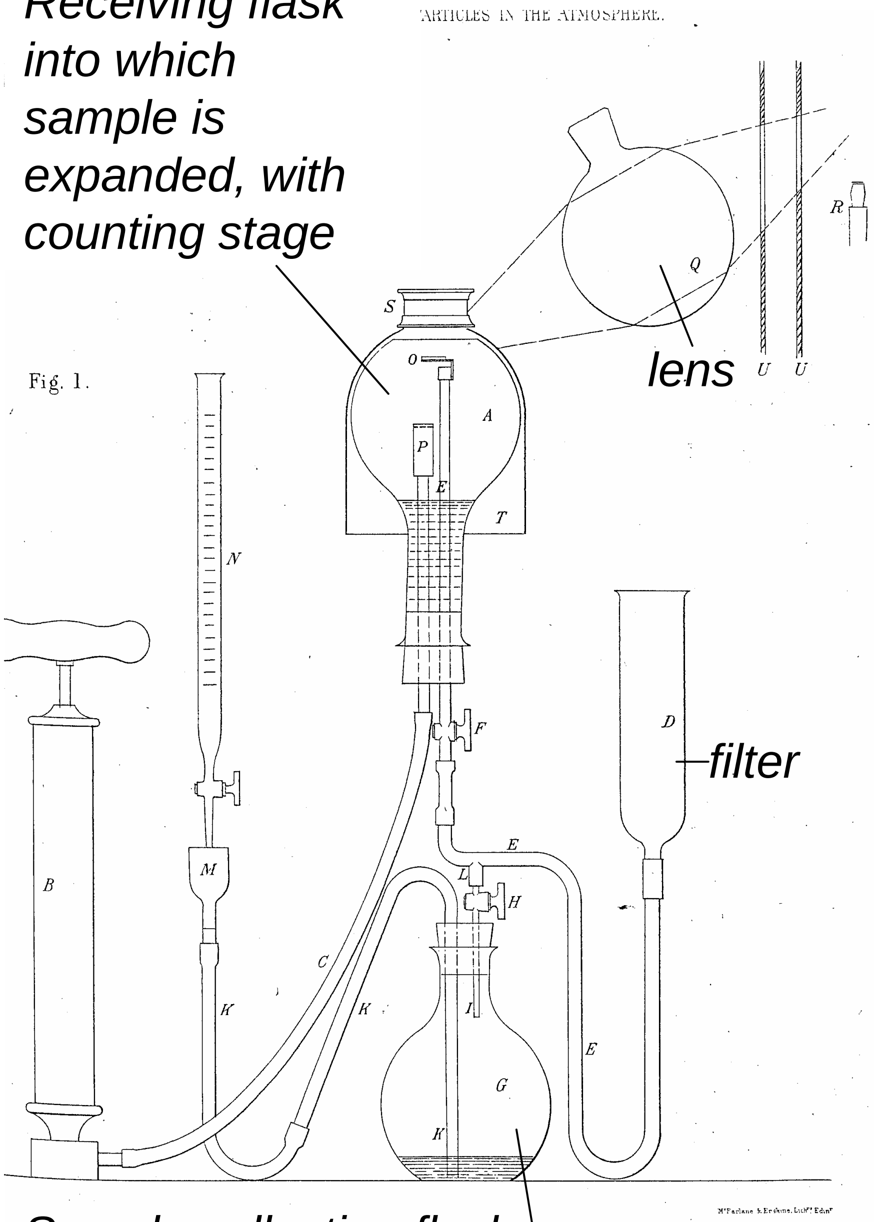
Fig. 1.

McFarlane & Erskine, Lithrs Edinr

How Aitken's Instrument Worked

- **Humidified air sample**
- **Expanded adiabatically**
- **Droplets formed around particles, which then settled**
- **Counted manually**
- **Repeated with dilution**

Fig. 1.



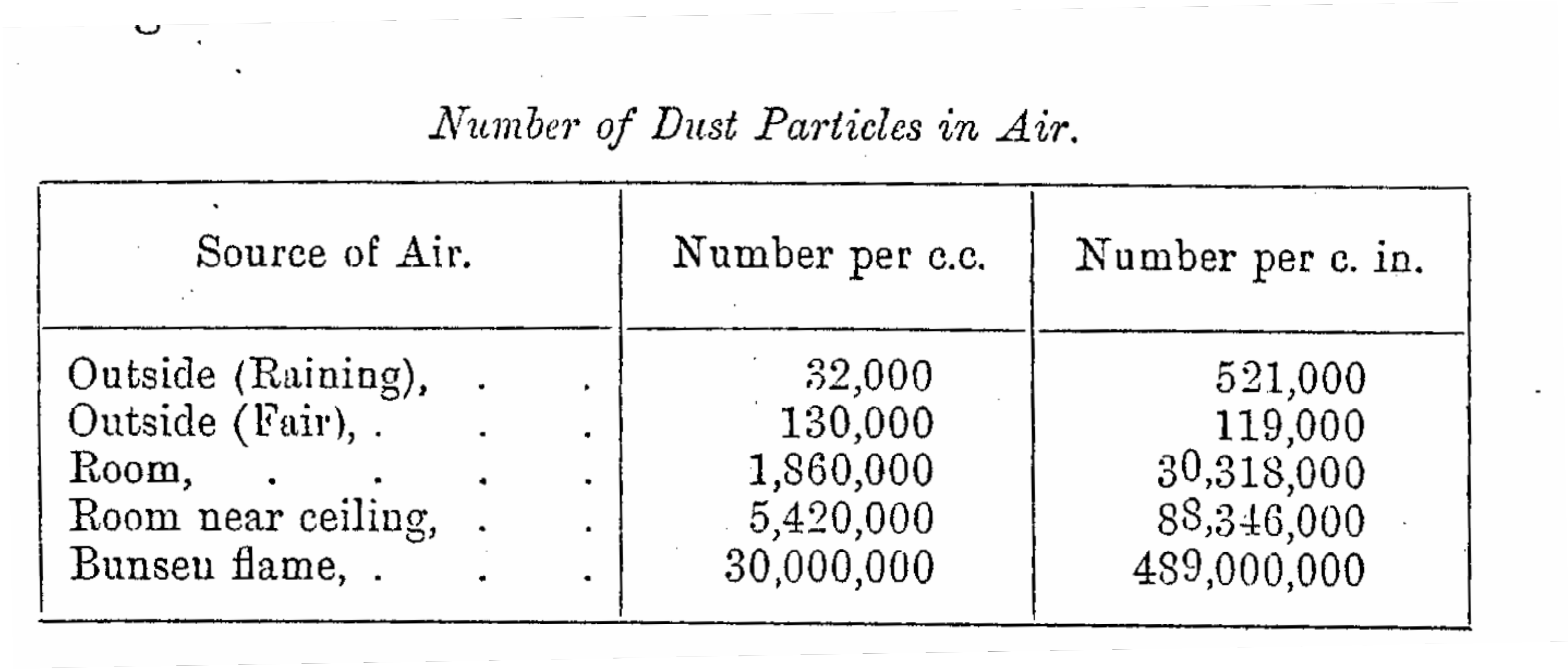
Receiving flask into which sample is expanded, with counting stage

lens

filter

Sample collection flask

What Aitken Observed:



Number of Dust Particles in Air.

Source of Air.	Number per c.c.	Number per c. in.
Outside (Raining),	32,000	521,000
Outside (Fair),	130,000	119,000
Room,	1,860,000	30,318,000
Room near ceiling,	5,420,000	88,346,000
Bunseu flame,	30,000,000	489,000,000

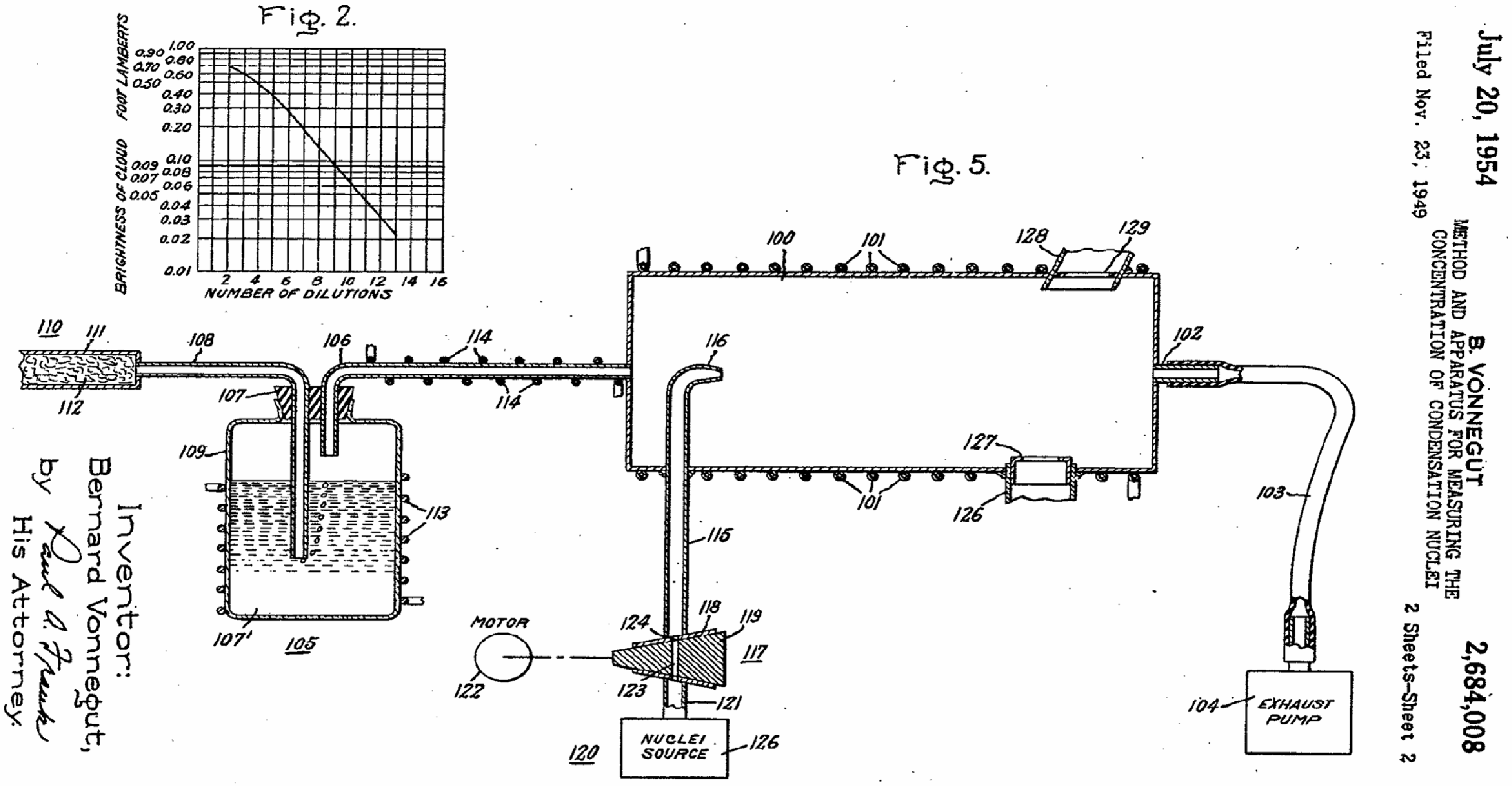
"The reason of the greater number of particles in the room than that found outside was due to the particles produced by the two gas flames burning in the room at the time."

- **1912: Wilson Cloud Chamber**
  - **1929: Nobel Prize for particle physics**
  - **<u>Determined precise expansion ratios</u> for avoiding homogeneous and ion-induced nucleation of particles**

- **1930s: Scholz: <u>Automated expansion</u> for particle counting**

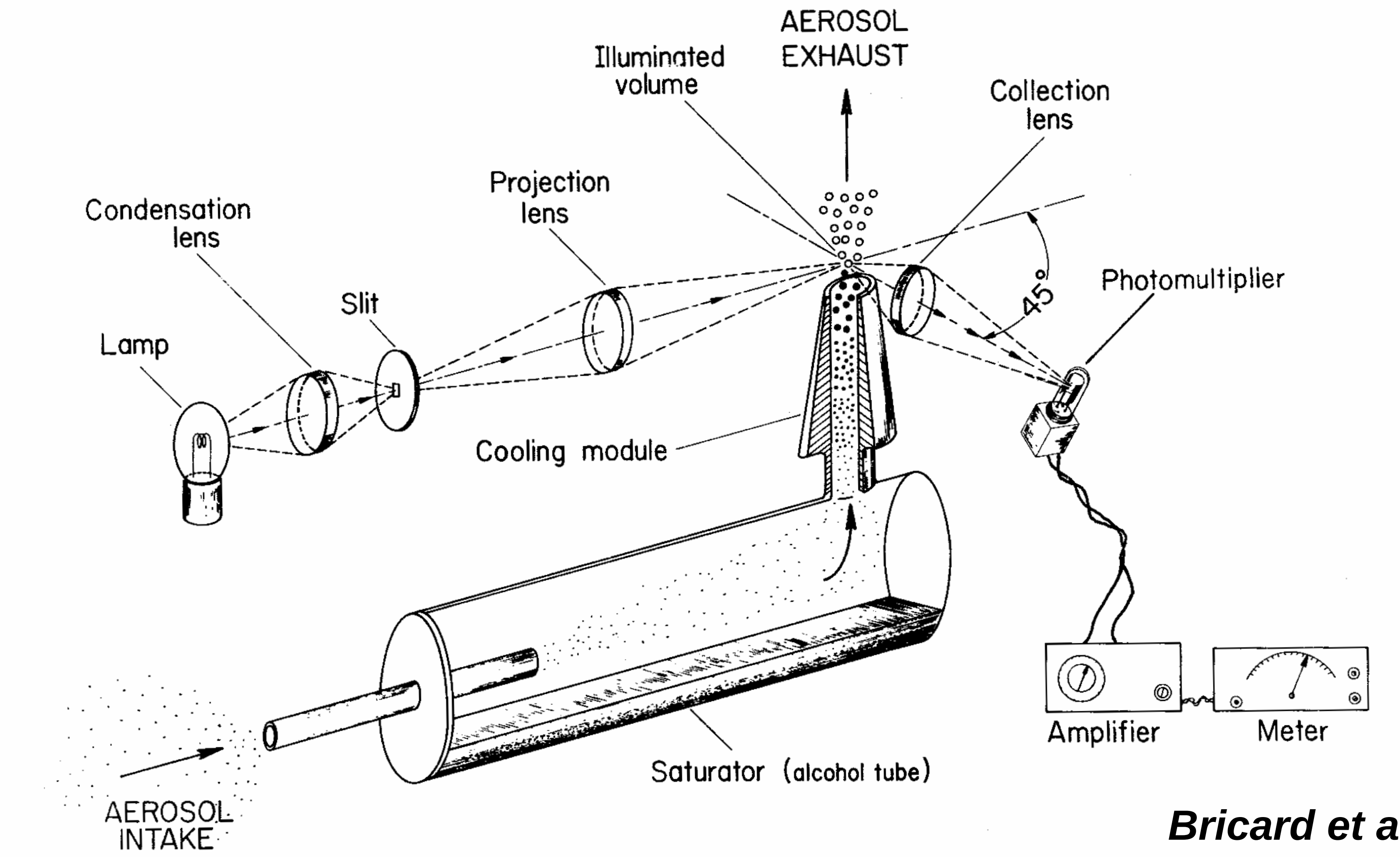
- **1950s: Vonnegut: <u>Automated counting</u> by recognizing particles grow to uniform size.**

1950s: Vonnegut, Automated Counting



Automated, but not continuous
(condensing vapor: water)

1970s: Thermally Diffusive Condensation Particle Counter (CPC)



Bricard et al, 1976

Automated & Continuous (condensing vapor: butanol or other alcohol)

Widely used, suitable as detector for size distribution instruments

Many models, sold by several companies

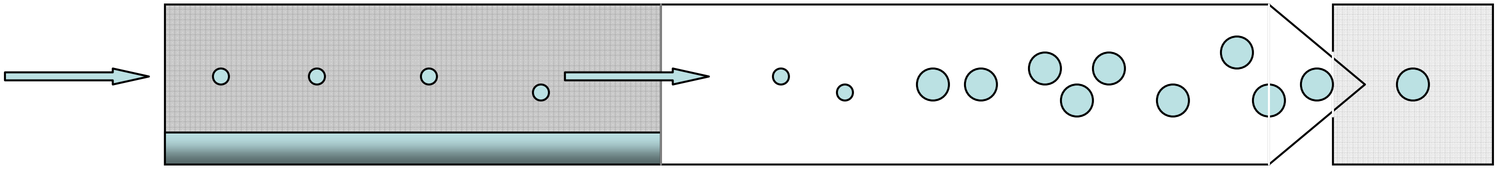
Can you have a Continuous, Automated Particle Counter without Butanol?

- **Challenge**: too small for direct optical detection
- **Approach:** Create region of supersaturation to activate particle growth => form droplets
- **Why Supersaturation?** Equilibrium vapor pressure over a droplet is greater than over a flat surface due to free energy associated with surface (surface tension)
- **Kelvin Relation:**

$$P_{\text{droplet}} = P_{\text{flat surface}}\ \exp(\ 2\ \underset{\substack{\nearrow \\ \textit{Surface tension}}}{\sigma}\ v\ /\ kT\rho\ \underset{\substack{\nwarrow \\ \textit{Particle radius}}}{R}\ )$$

Thermally Diffusive CPCs: Operational Principle

- **Saturate flow with vapor**
- **Flow into cold-walled tube**
- **Vapor condenses on particles**
- **Requires slowly diffusing vapor (e.g. butanol)**



Saturator, 35℃

Condenser, 10℃

Optics Head

Thermal Diffusivity,
air = 0.215 cm^2/s

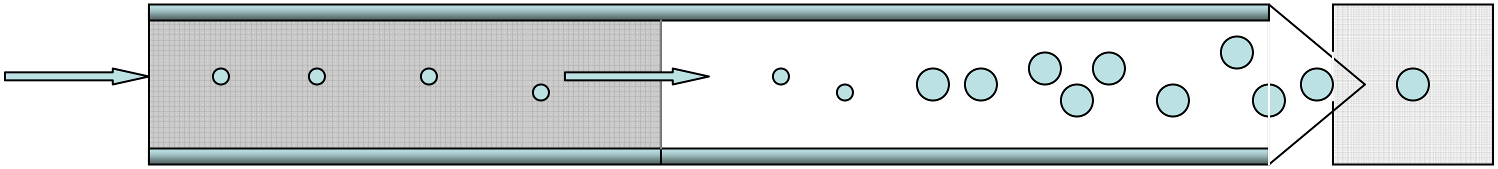
Mass Diffusivity,
butanol = 0.081 cm^2/s

Note: diffusivity of water = 0.265 cm^2/s > air

Does not work well with water

2003: Water Condensation Particle Counter (WCPC)

- Cold flow enters warm wet-walled tube
- Water vapor diffuses more quickly than flow warms
- Supersaturation, particle activation and growth occurs inside of a warm, wet walled tube.



Optics Head

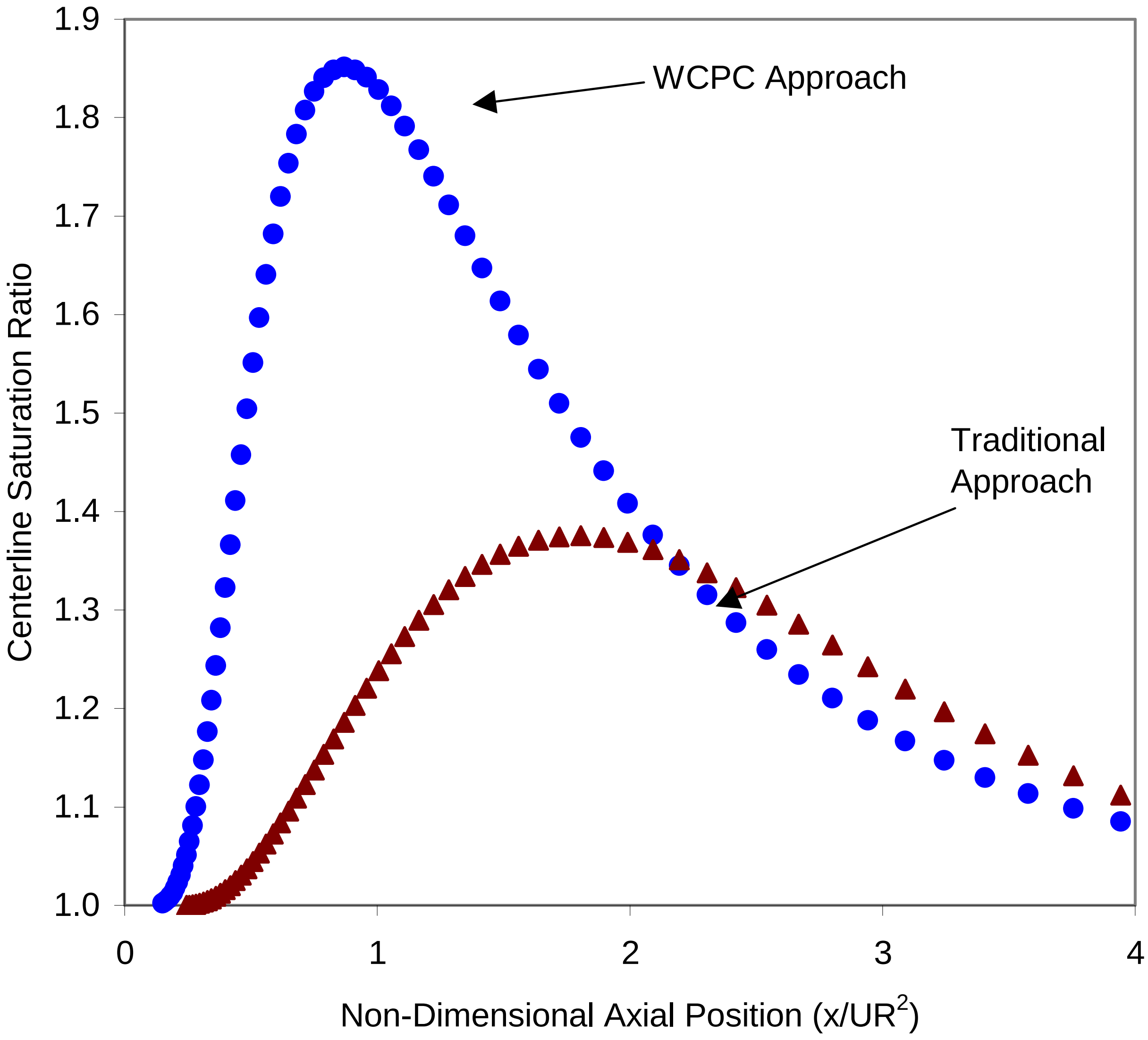
2003 WCPC (~5 nm) : Saturator, 20C Condenser, 60C

2004: Nano-WCPC (~2.5 nm) Saturator, 12C Condenser, 75C

Thermal Diffusivity, air = 0.215 cm²/s

Mass Diffusivity, water = 0.265 cm²/s

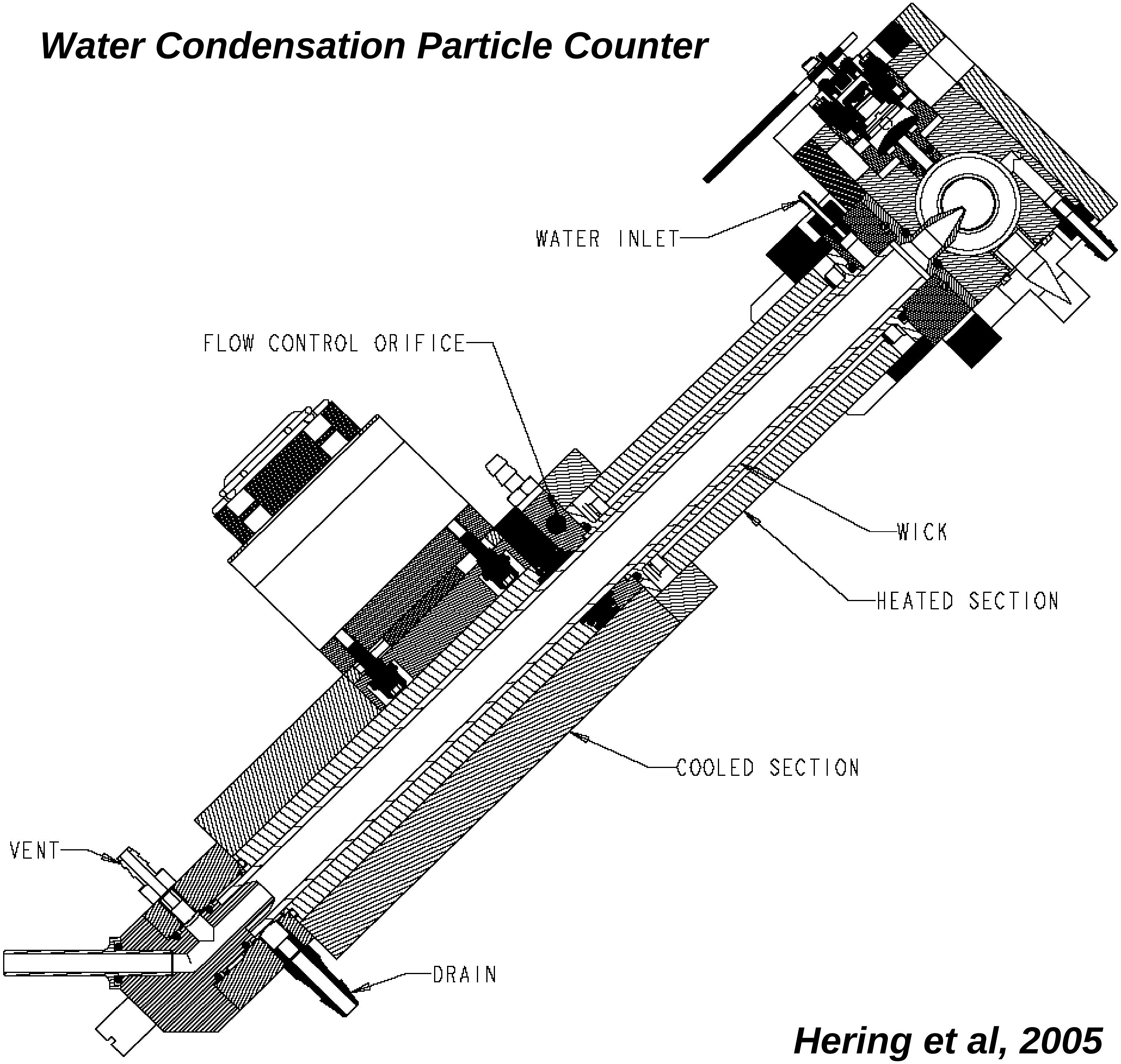
Comparison of Centerline Water Saturation Ratios



WCPC: Inlet flow at 20℃ & 100%RH,
Wetted walls at 60℃

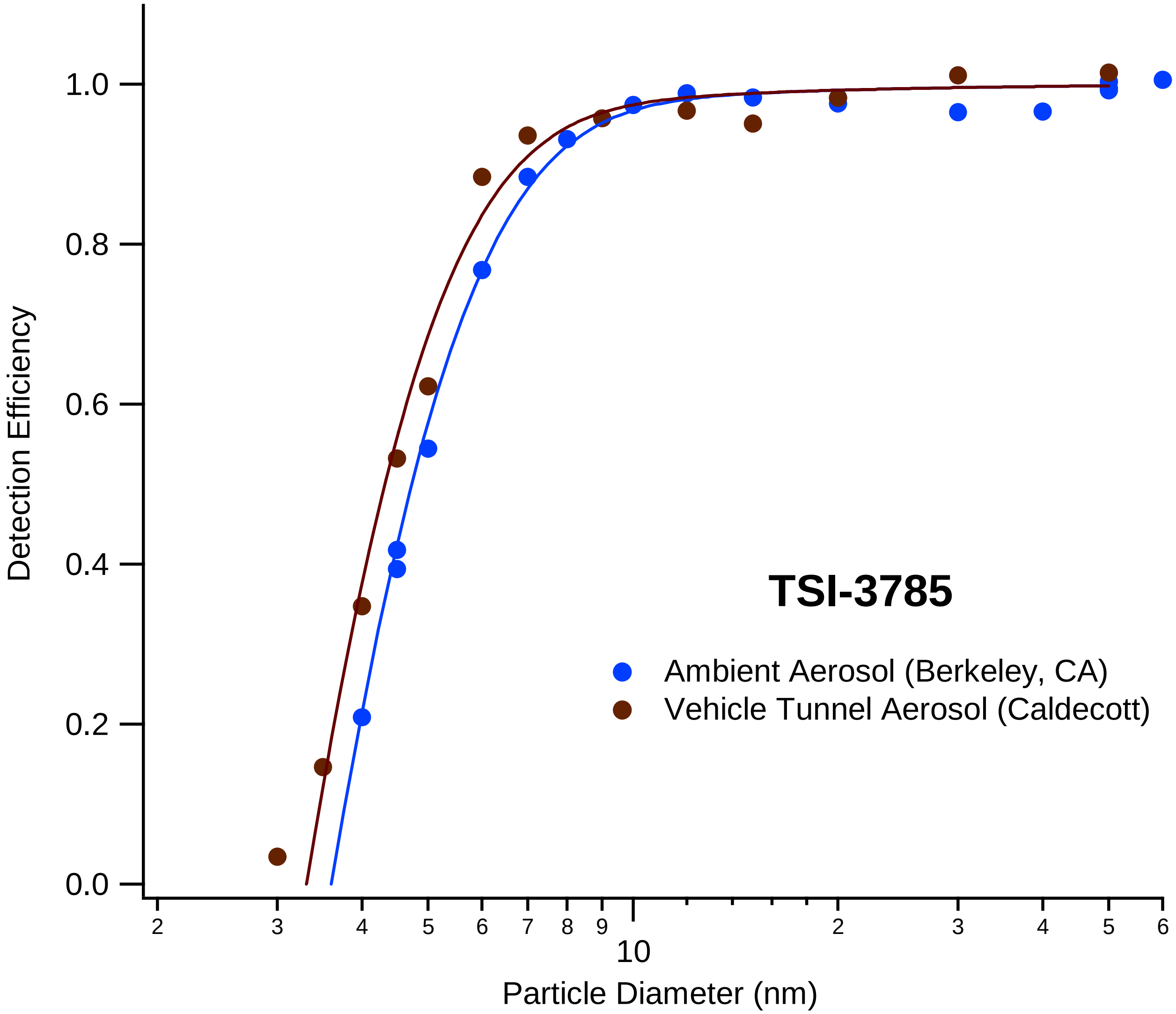
Traditional: Inlet flow 60℃ & 100%RH
Wetted walls at 20C

Water Condensation Particle Counter



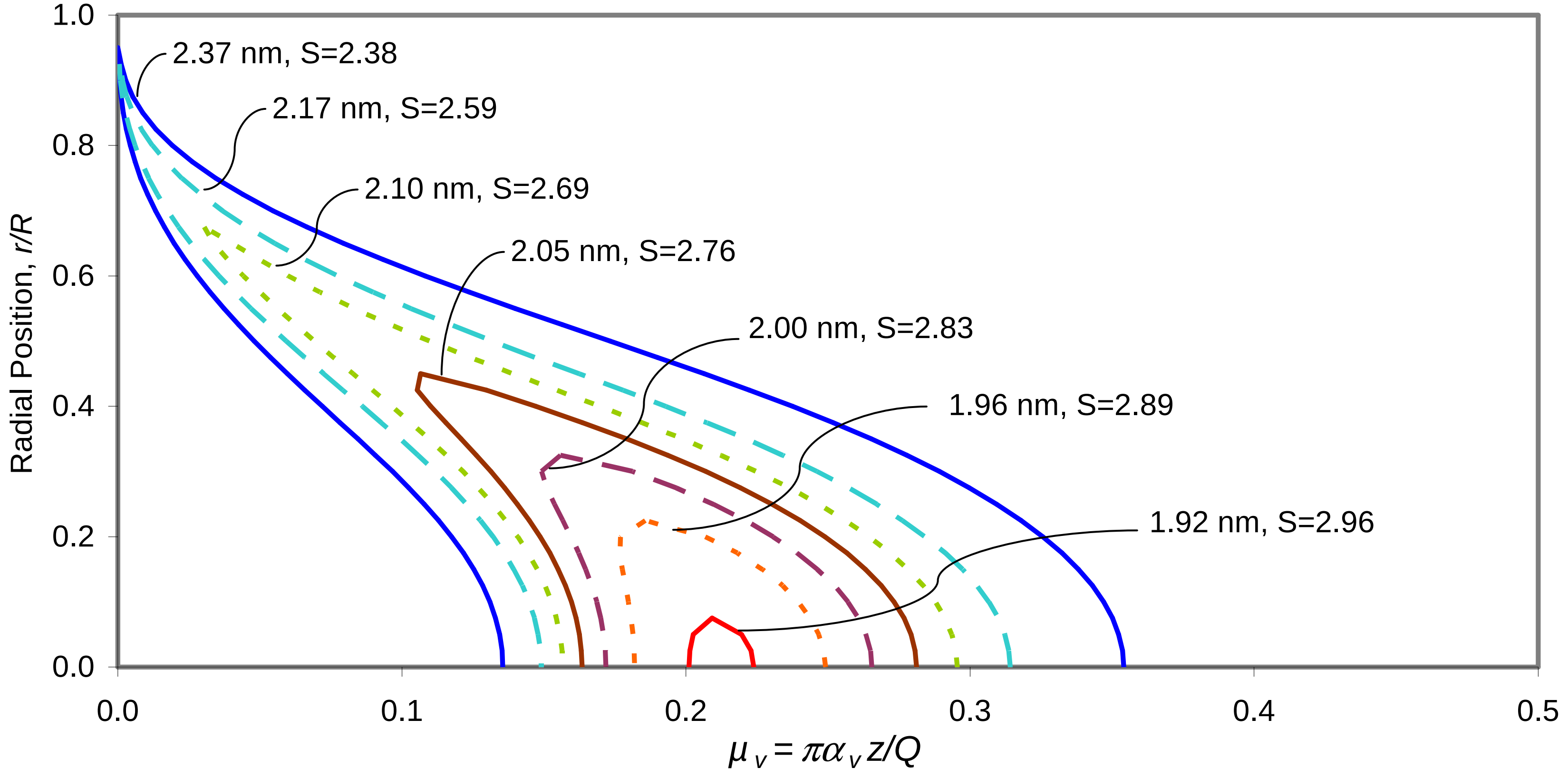
Hering et al, 2005

First laminar-flow WCPC Response to Ambient Aerosols & Vehicle Emissions



Tunnel Measurements with Antonio Miguel, Arantza Eiguren-Fernandez, UCLA

Calculated Supersaturation Profiles within the Ultrafine Water – CPC

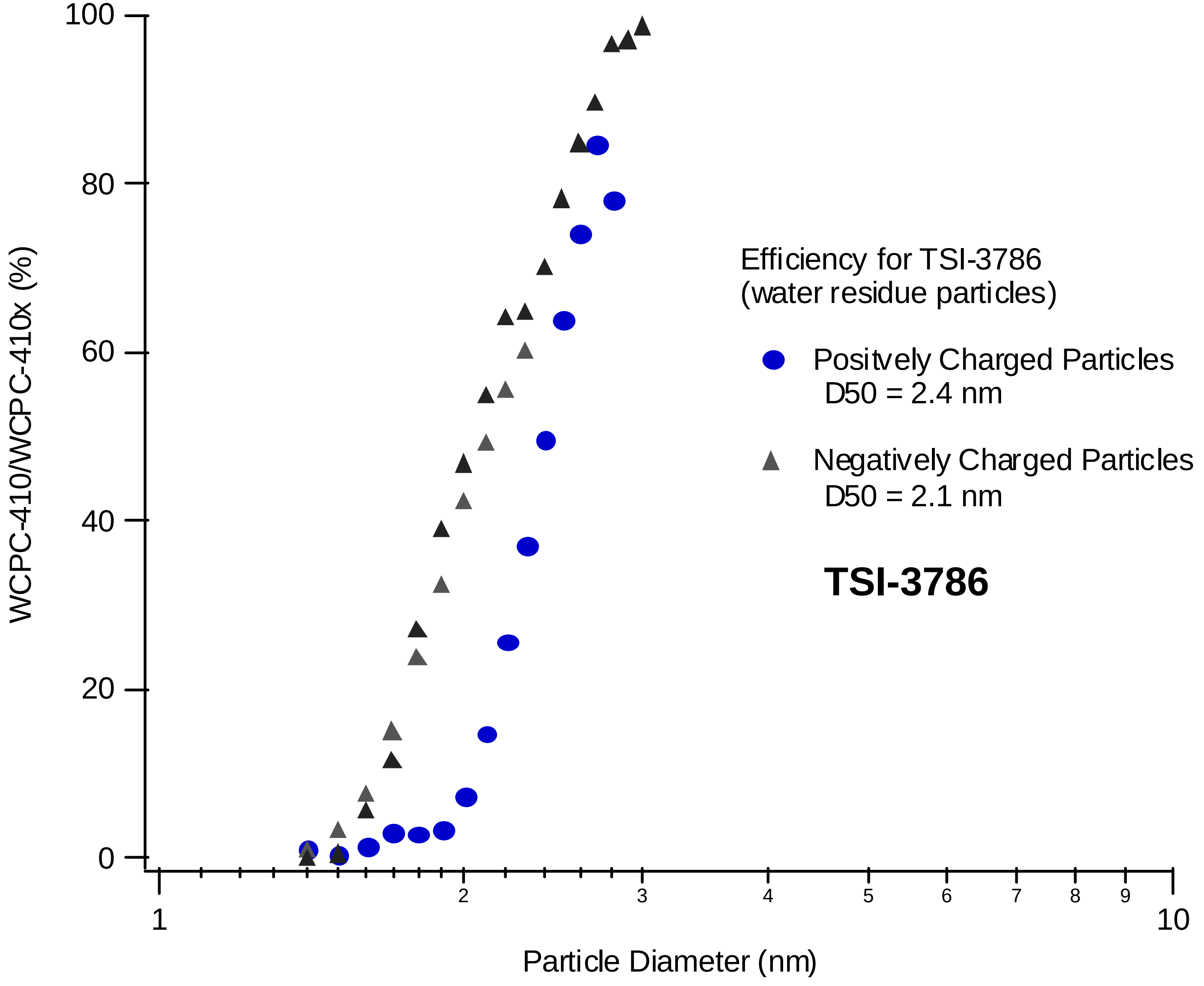


α_v = *vapor mass diffusivity*

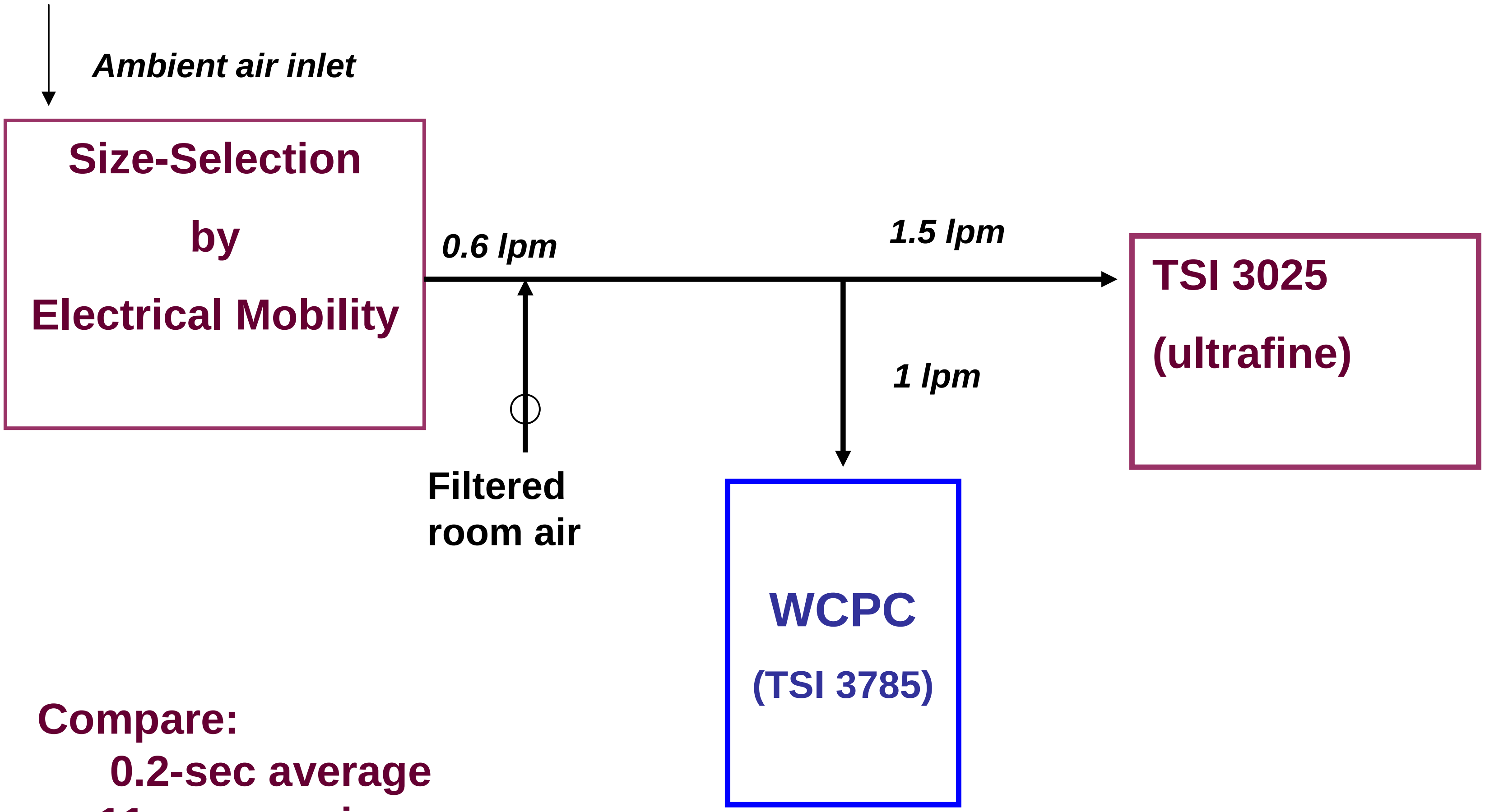
z = *axial distance*

Q = *volumetric flow rate*

Calibration of the Ultrafine WCPC
Water Residue Particles



Comparison of Water CPC and TSI Ultrafine,
Queen's College, NY (Univ. at Albany, EPA Supersite)



Ambient air inlet

Size-Selection

by

Electrical Mobility

0.6 lpm

1.5 lpm

TSI 3025

(ultrafine)

1 lpm

Filtered
room air

WCPC

(TSI 3785)

Compare:
- **0.2-sec average**
- **11-sec running average**

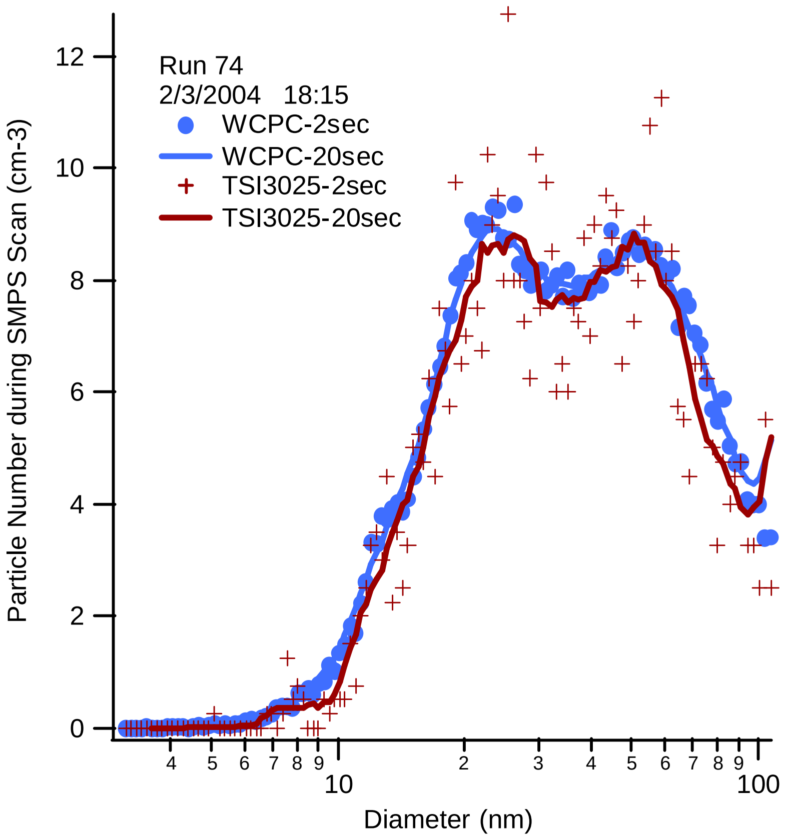
counts/cm^3 measured below nanoSMPS
(not ambient size distribution – no charging correction)

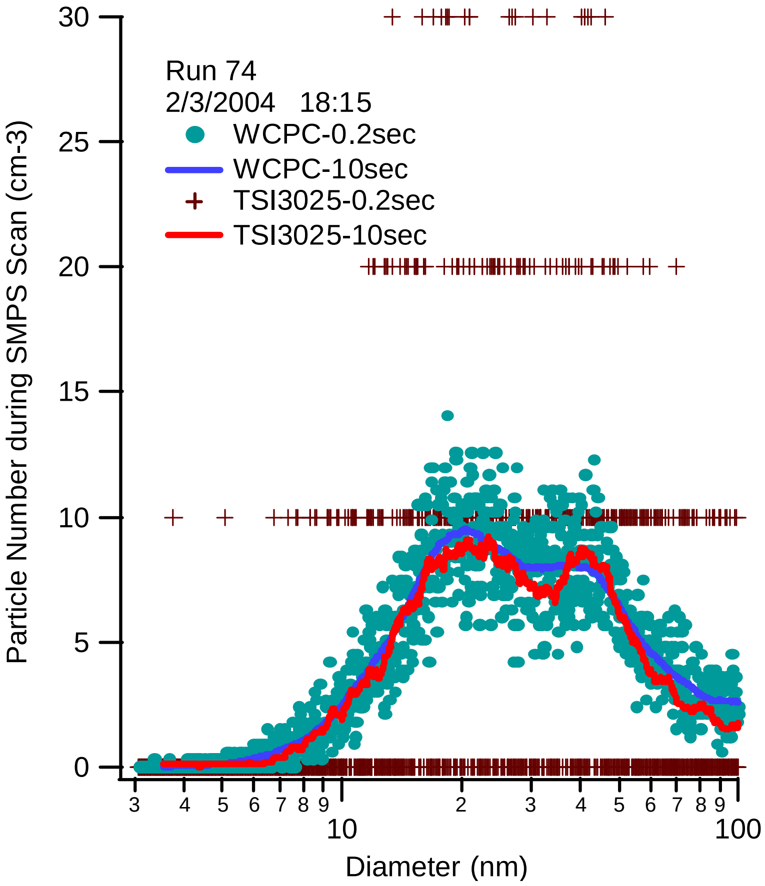
Comparison to Butanol Ultrafine CPC with Nano-DMA

Particle counts per 0.2 sec window (average over two scans)

TSI-3025: 1.1±1.0 particles (0.5cc/s)

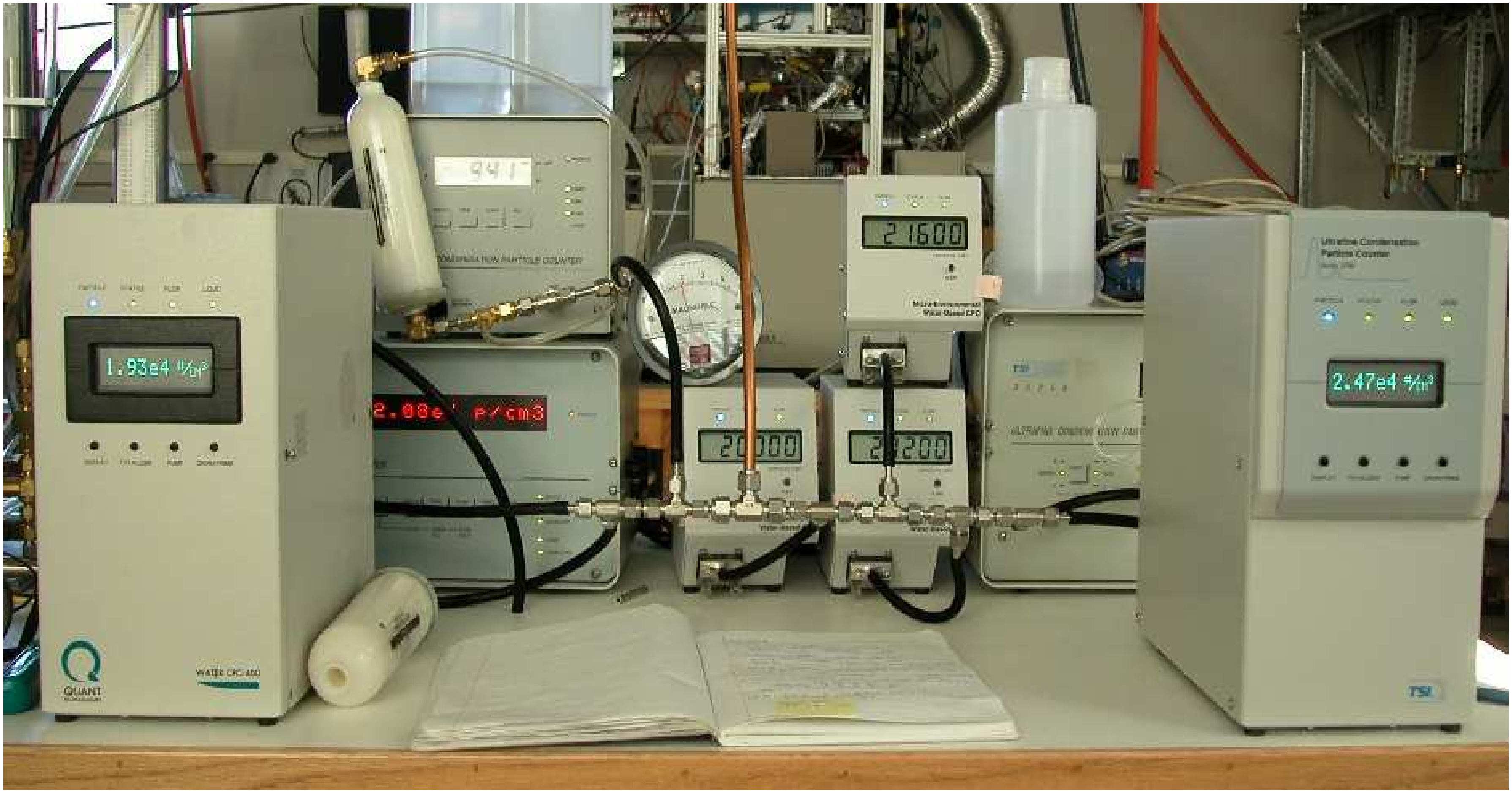
WCPC: 35 ± 6 particles (16.7 cc/s) --- much better counting statistics





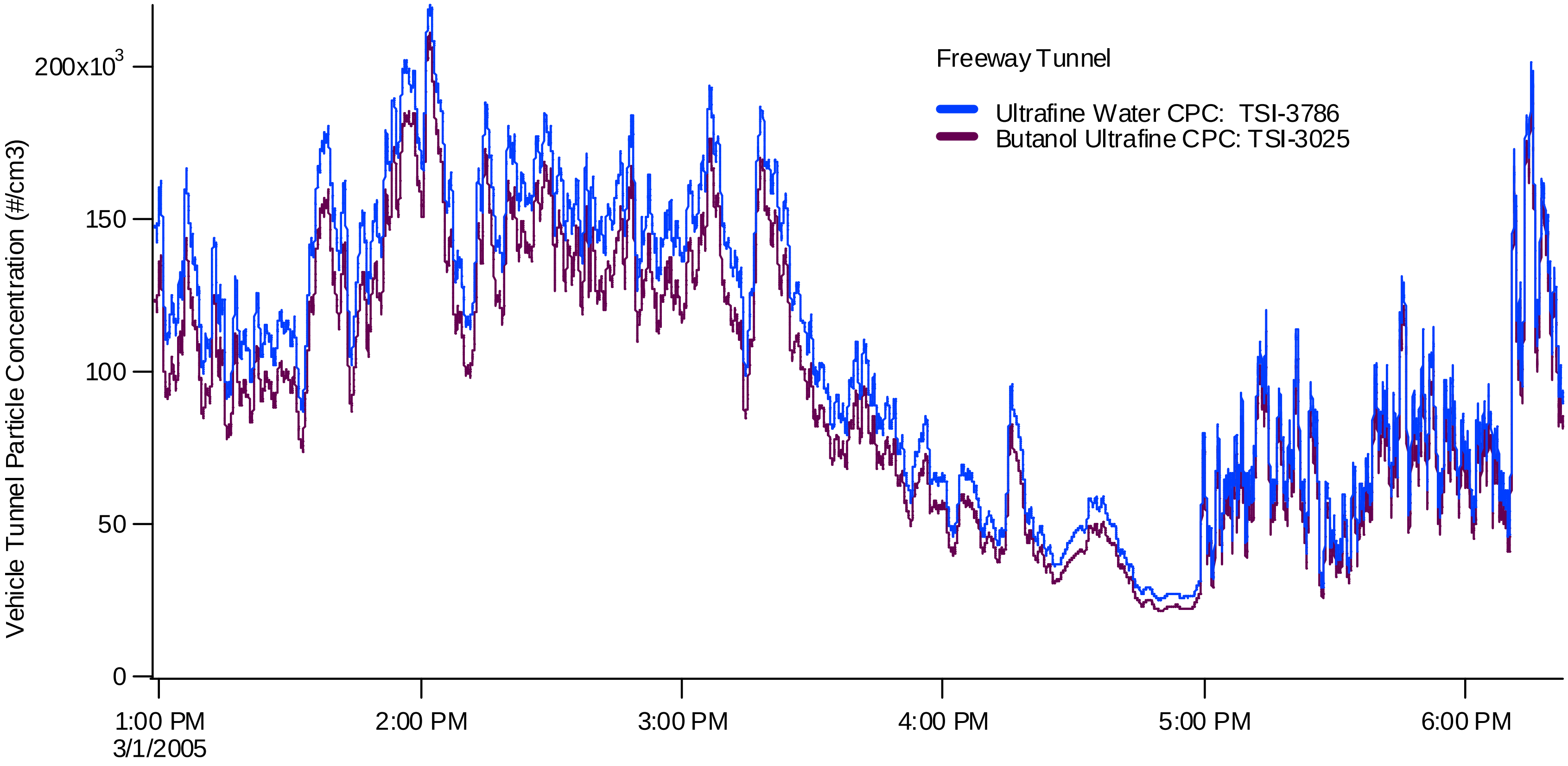
In collaboration with ASRC, University at Albany

Field Comparisons Among CPCs

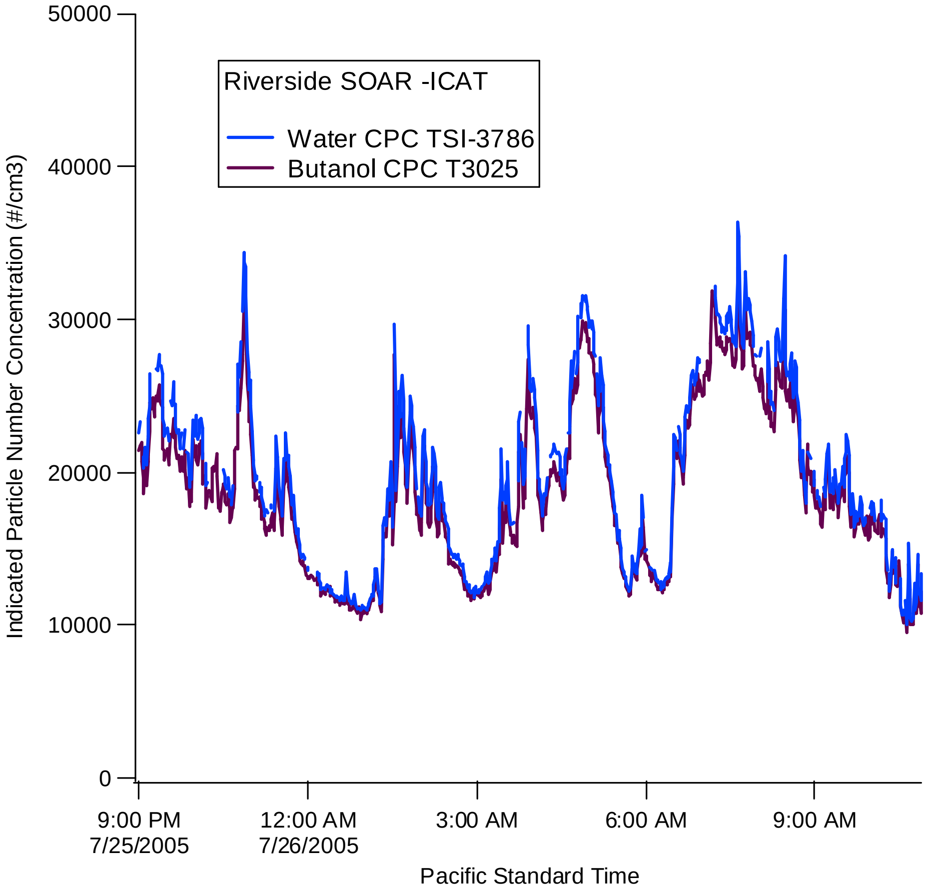


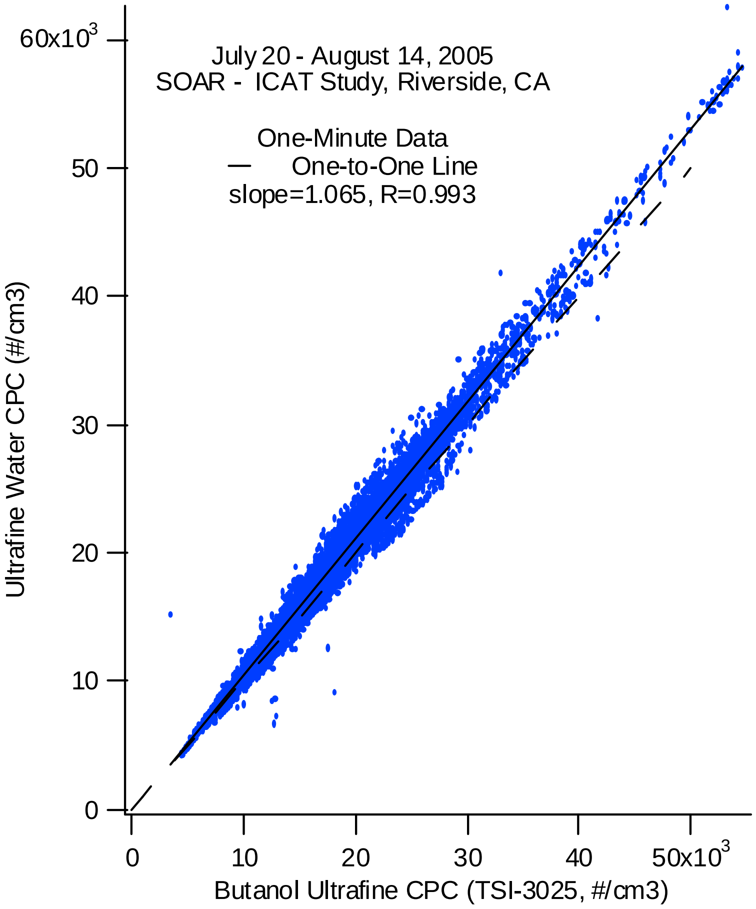
Total Particle Number Concentrations for Traffic Emissions

Ultrafine WCPC (TSI-3786) compared to Butanol UCPC (TSI-3025)



Ambient Sampling In Riverside, California
Ultrafine WCPC – 3786 & Butanol UCPC - 3025





2005: Micro-Environmental WCPC

Size: 7” x 7” x 5”

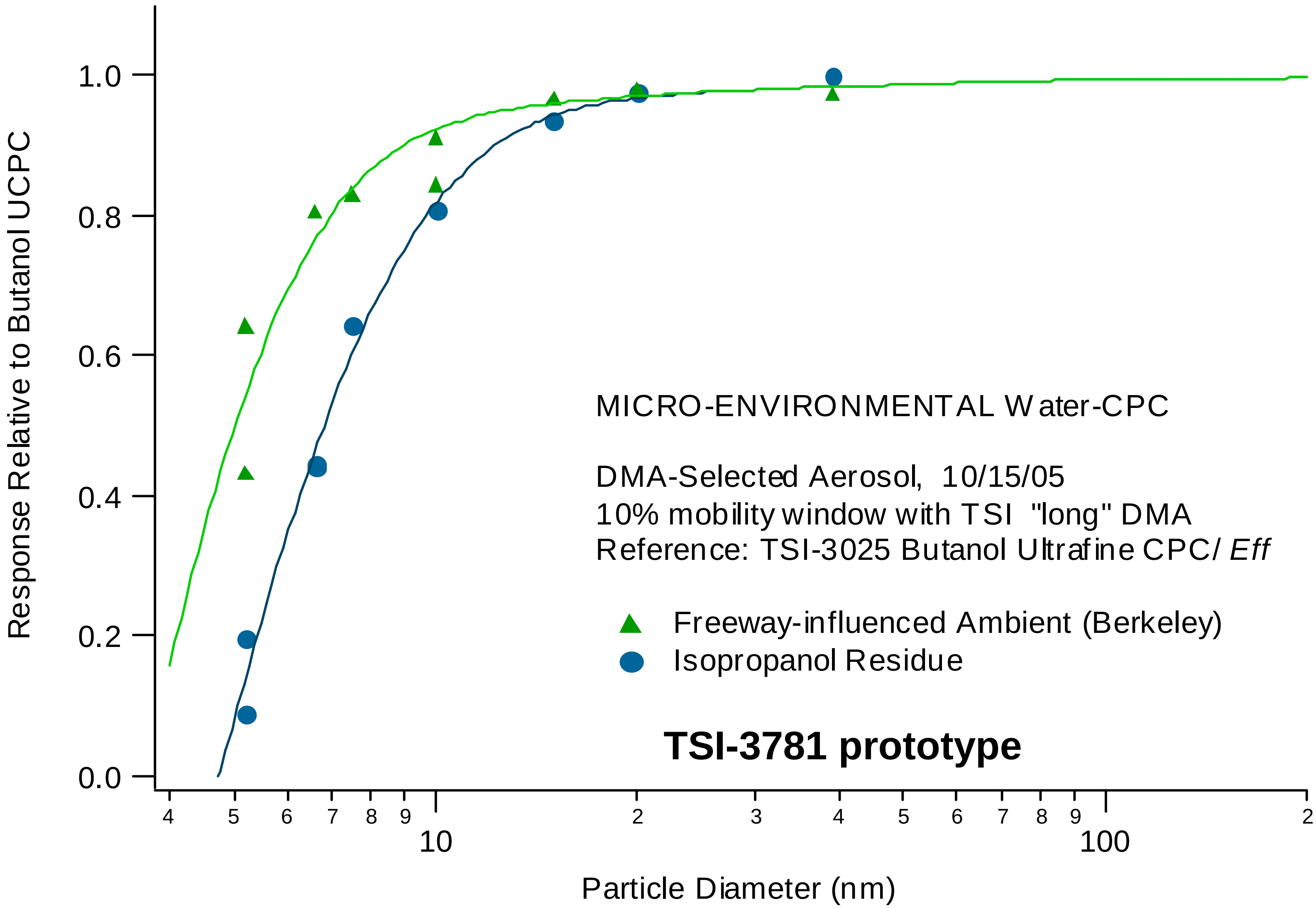
Weight: 5 lb

Power 12 V, 30 Watts

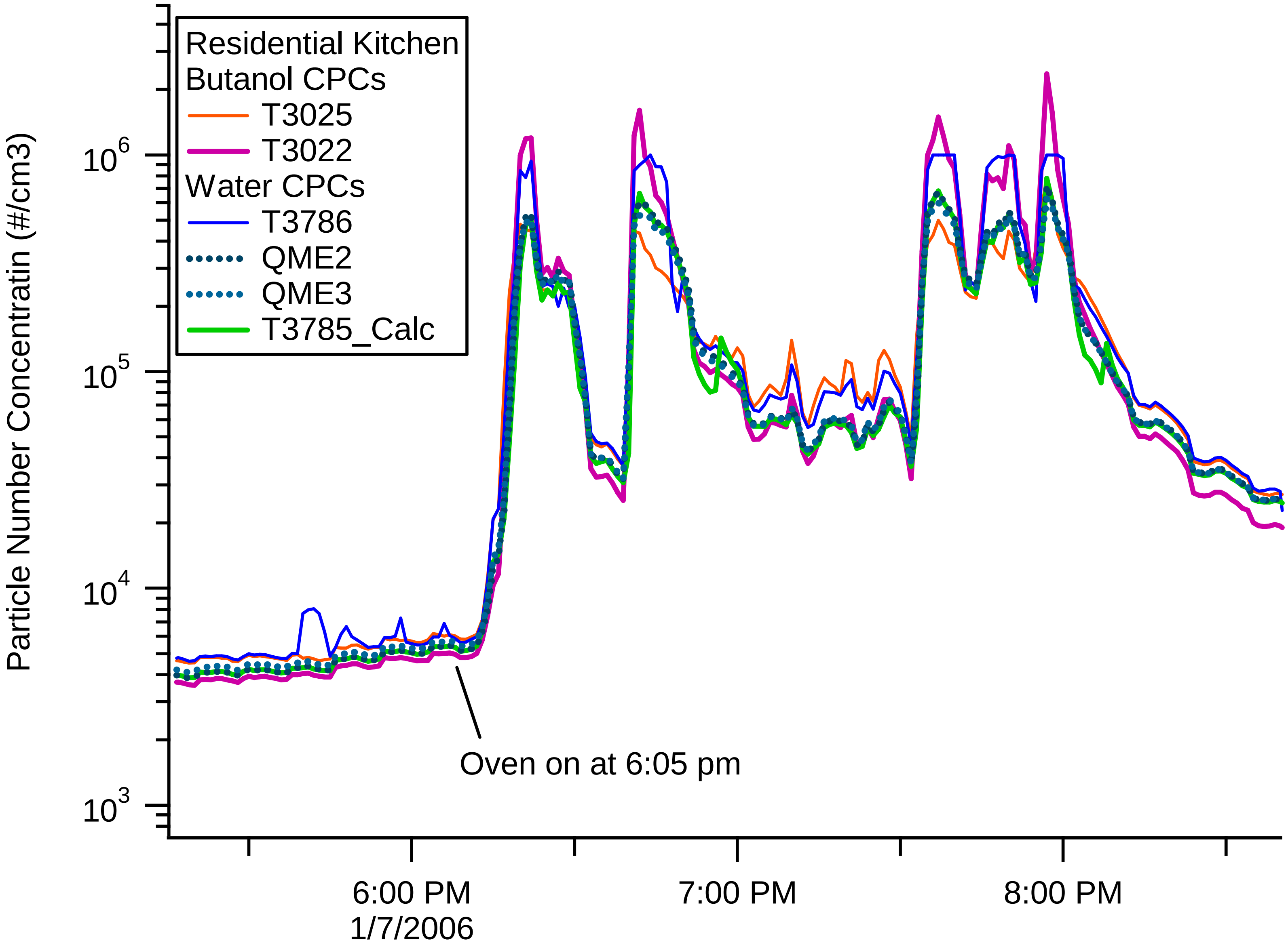
Features:

- internal data logging
- one week unattended
- up to 10^6 particles/cm^3 in single count mode

Response to Near-Monodisperse Aerosols



ME-WCPC Measurements in a Residential Kitchen



Summary

- **1890's**

  Aitken, first explorations of airborne particles number concentration

  Identified combustion as source of particles

- **1920s-1950s**

  Advances on Aitken's approach: automated instruments

- **1970's**

  First continuous flow condensation particle counters

  widely used, especially as detectors for mobility size distributions

- **2003**

  Introduction of continuous water-based condensation counters

Acknowledgements

- California Air Resources Board, who provided funding for many of the field comparisons.

- ASRC, University at Albany and the EPA Supersites Program who made possible the measurements in New York City.

- TSI Inc., who loaned equipment for our field and laboratory testing.

- Quant Technologies LLC, who provided the engineering and detailed instrument design.