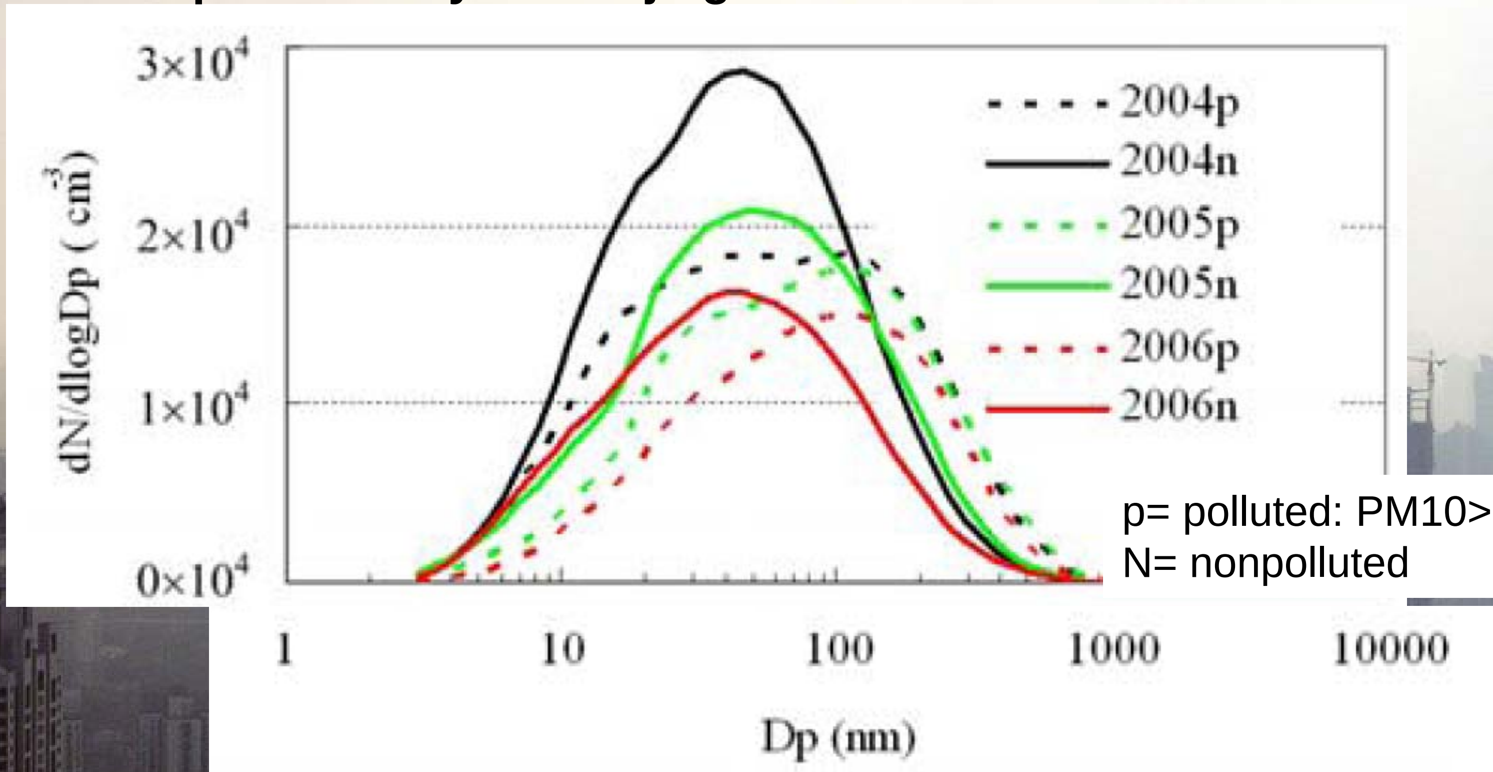
Interdependence of particle number concentration and PM 2.5 in highly polluted urban atmospheres

Martin Seipenbusch,

Markus Kasper, Mingzhou Yu

The Problem:

Number size distributions for polluted and non polluted days in Beijing:



p= polluted: PM10>150µg/m³
N= nonpolluted

Characteristics of aerosol size distributions and new particle formation in the summer in Beijing

Dingli Yue,[1] Min Hu,[1] Zhijun Wu,[1] Zhibin Wang,[1] Song Guo,[1] Birgit Wehner,[2] Andreas Nowak,[2] Peggy Achtert,[2] Alfred Wiedensohler,[2] Jinsang Jung,[3] Young J. Kim,[3] and Shawchen Liu[4]

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, D00G12, doi:10.1029/2008JD010894, 2009

Shanghai 2003 (G. Kasper)

The Problem:

Measurements made with DiSCmini by Andreas Mayer in Beijing:

120.000 p/cm³ at reported PM2.5>300µg/m³
200.000-500.000 p/cm³ at reported PM2.5<50µg/m³

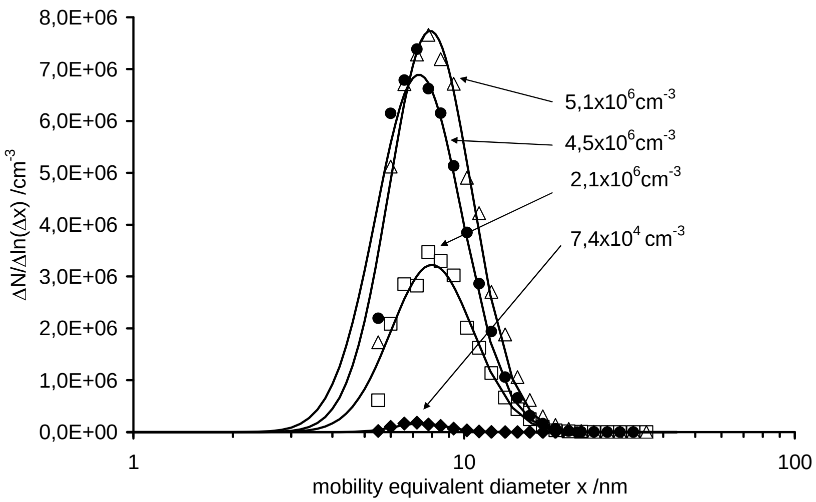
Apparent disconnect between number concentrations and PM concentrations in heavily polluted atmospheres

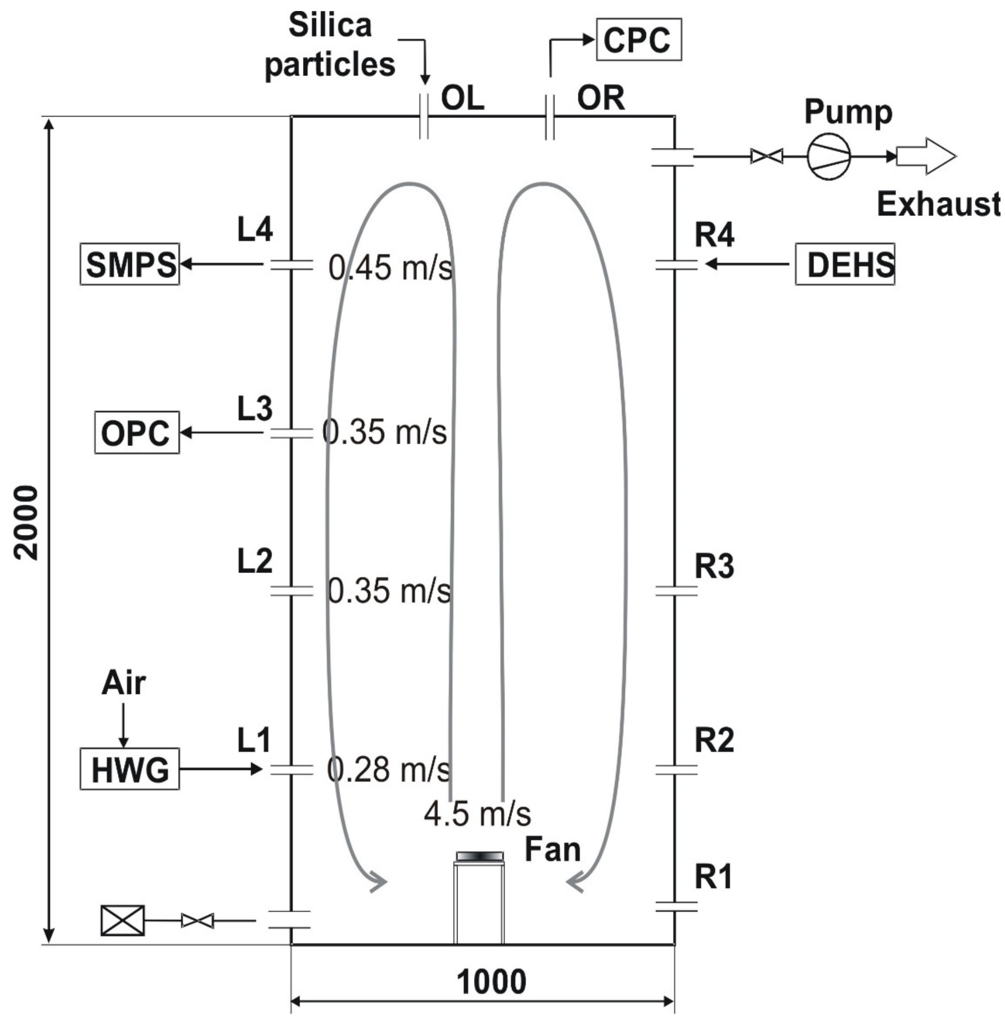
Shanghai 2003 (G. Kasper)

What is the origin of this disconnect?

- A aerosol chamber experiment:

Ultrafine particle source:





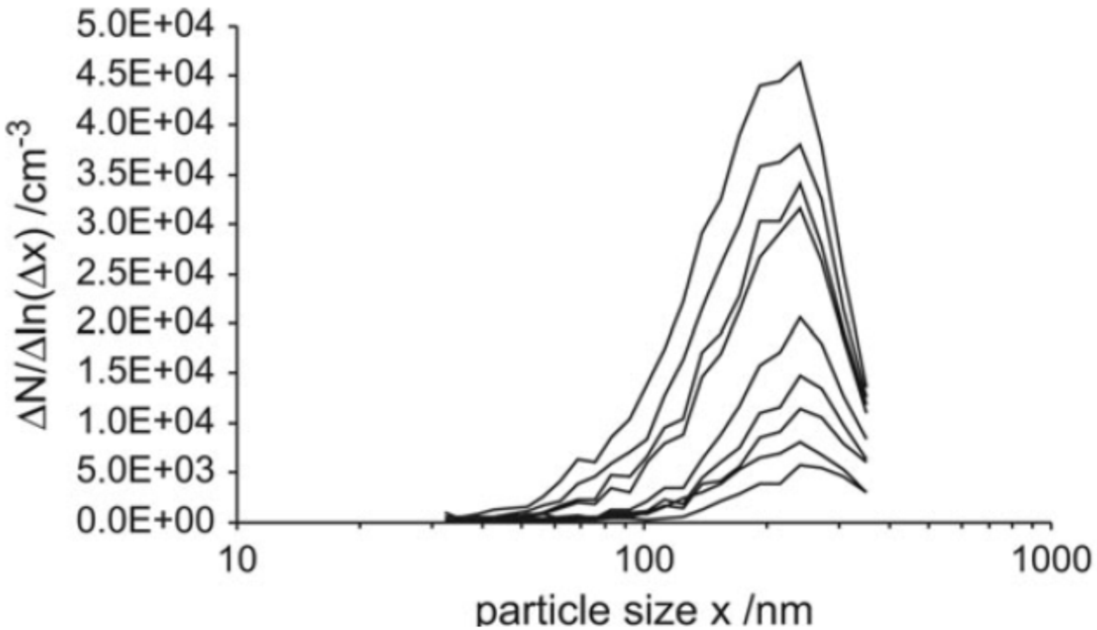
Temporal Evolution of Nanoparticle Aerosols in Workplace Exposure

M. SEIPENBUSCH*, A. BINDER and G. KASPER

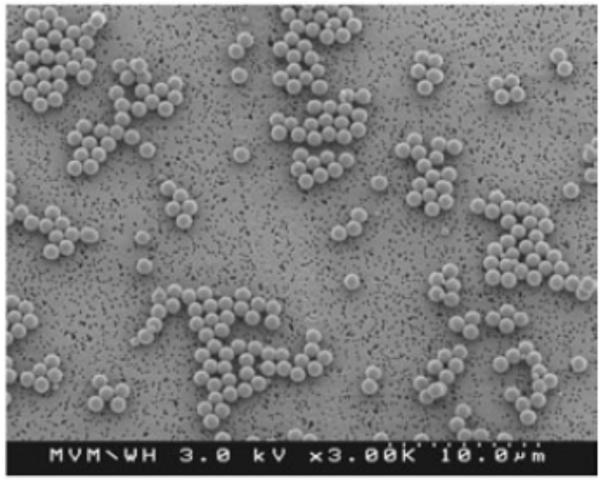
Ann. Occup. Hyg., Vol. 52, No. 8, pp. 707–716, 2008

Simulated accumulation and coarse modes

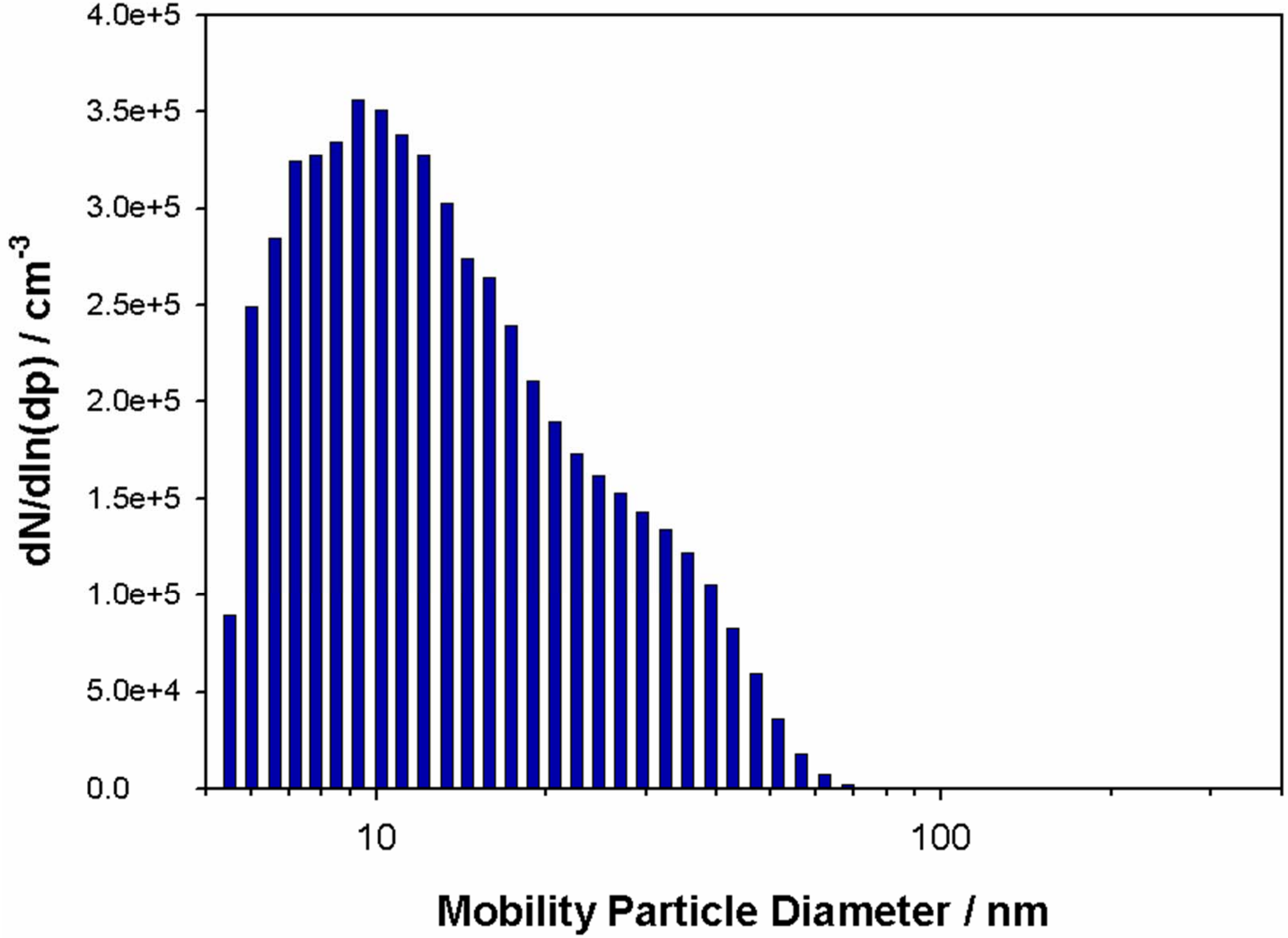
DEHS-droplets from Collison atomizer



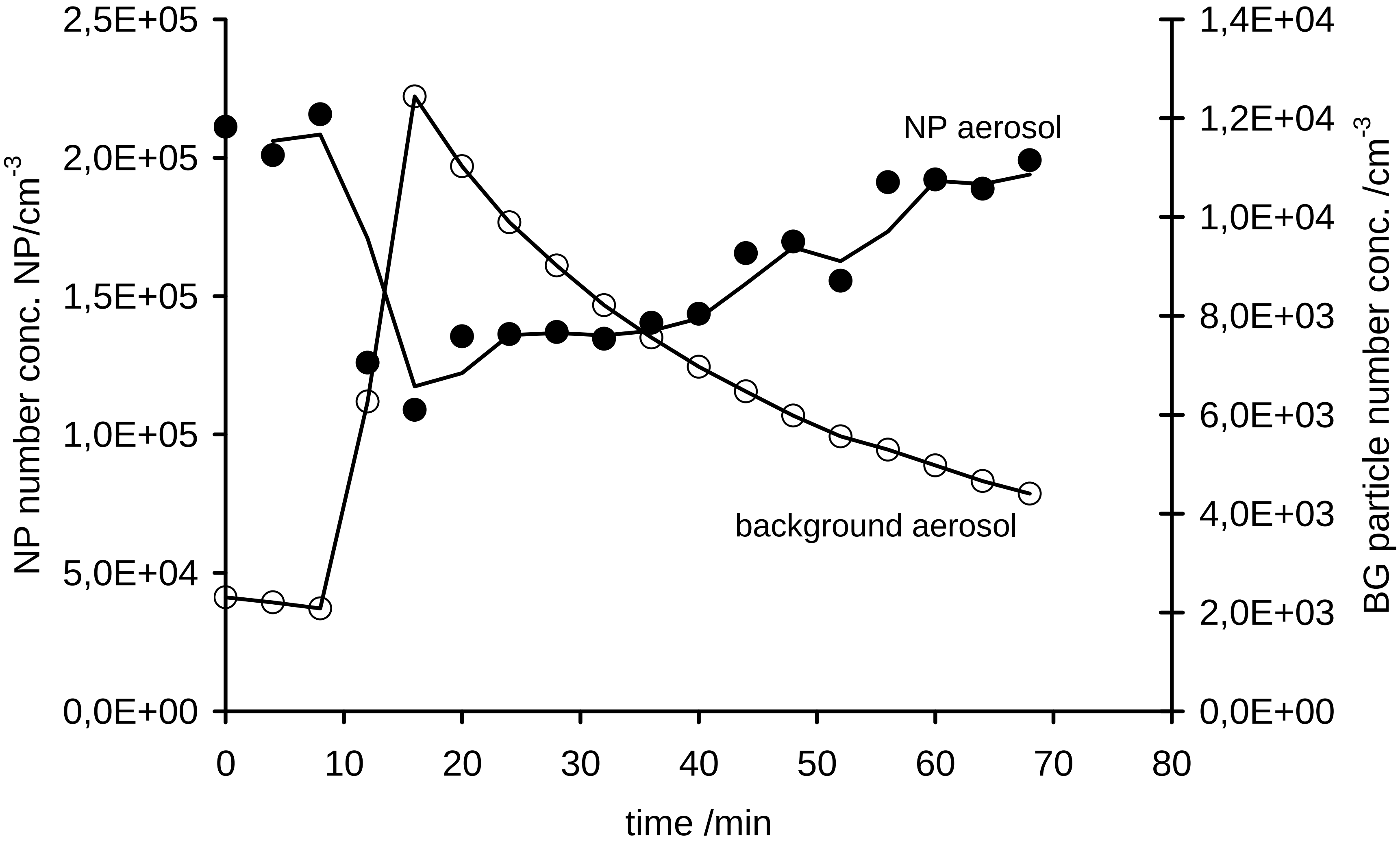
Silica microspheres



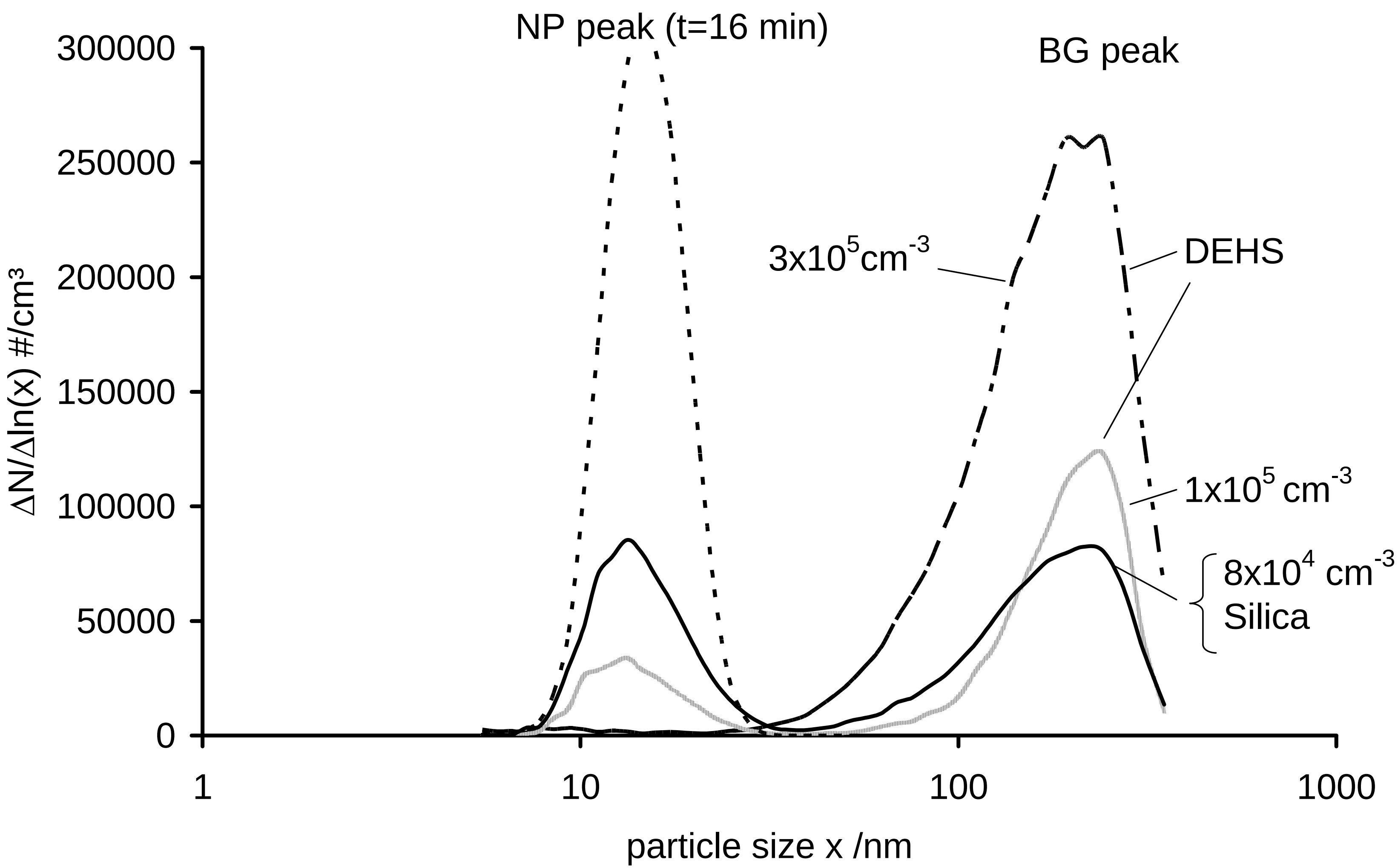
Coagulation of ultrafine aerosol with sudden addition of „accumulation mode“ particles



Coagulation of ultrafine aerosol with sudden addition of „accumulation mode“ particles



Number size distributions for various bimodal systems



Theory: heterogeneous coagulation

Smoluchowski:

$$\frac{dN}{dt} = \beta \cdot N_i \cdot N_j$$

$$\beta = 4\pi (D_i + D_j)(a_i + a_j)$$

Homogeneous coagulation:

$$D_i = D_j$$

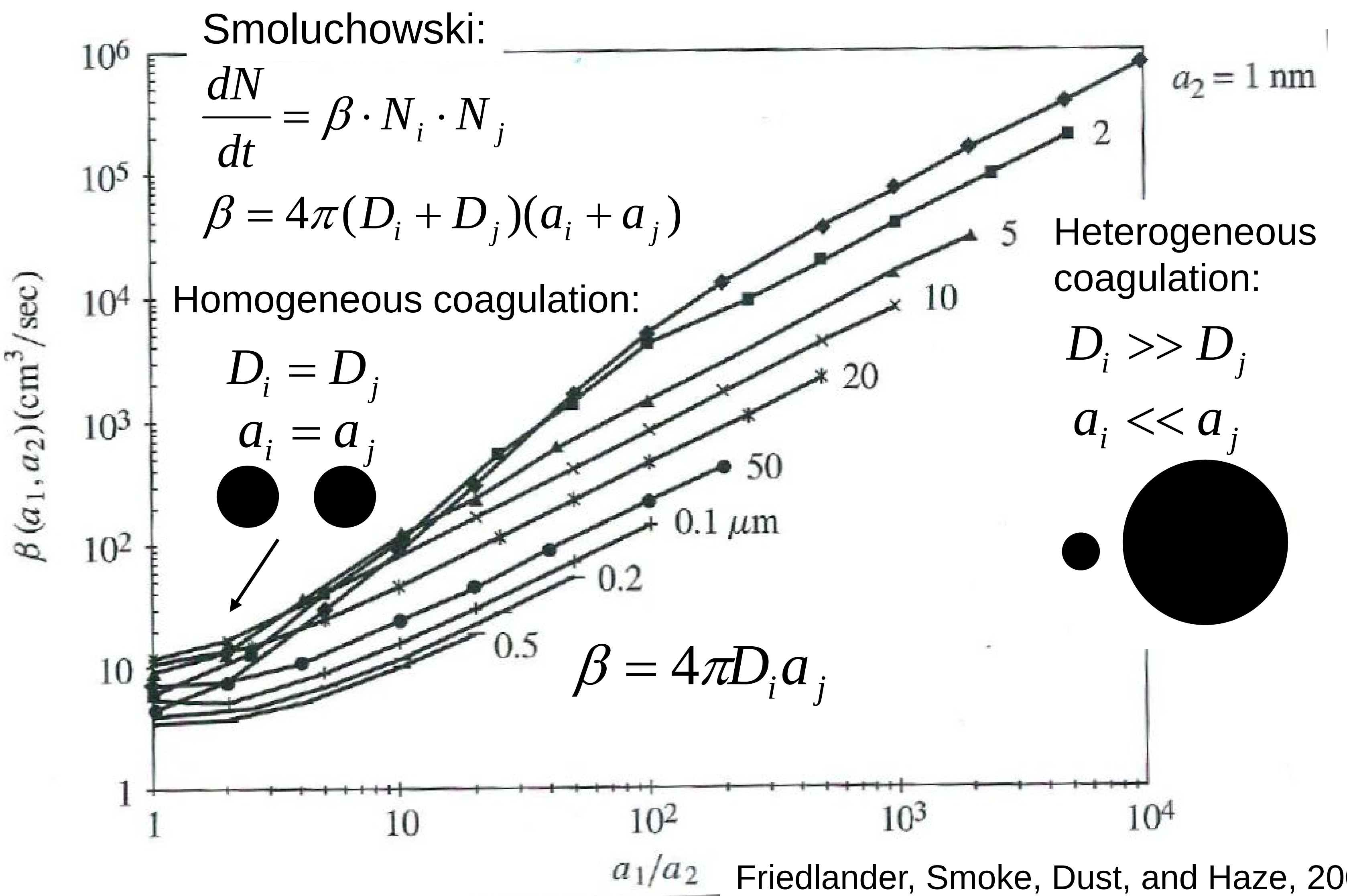
$$a_i = a_j$$

Heterogeneous coagulation:

$$D_i >> D_j$$

$$a_i << a_j$$

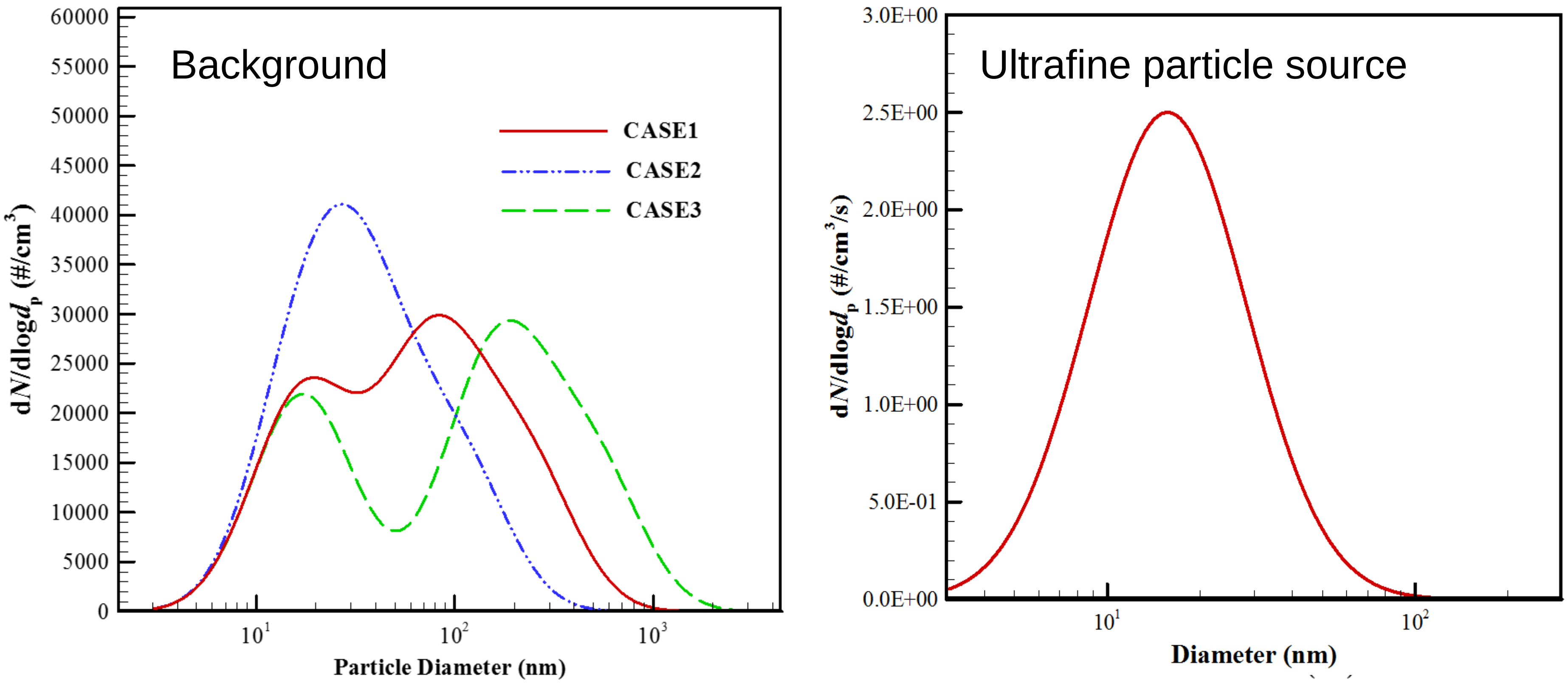
$$\beta = 4\pi D_i a_j$$



Friedlander, Smoke, Dust, and Haze, 2000

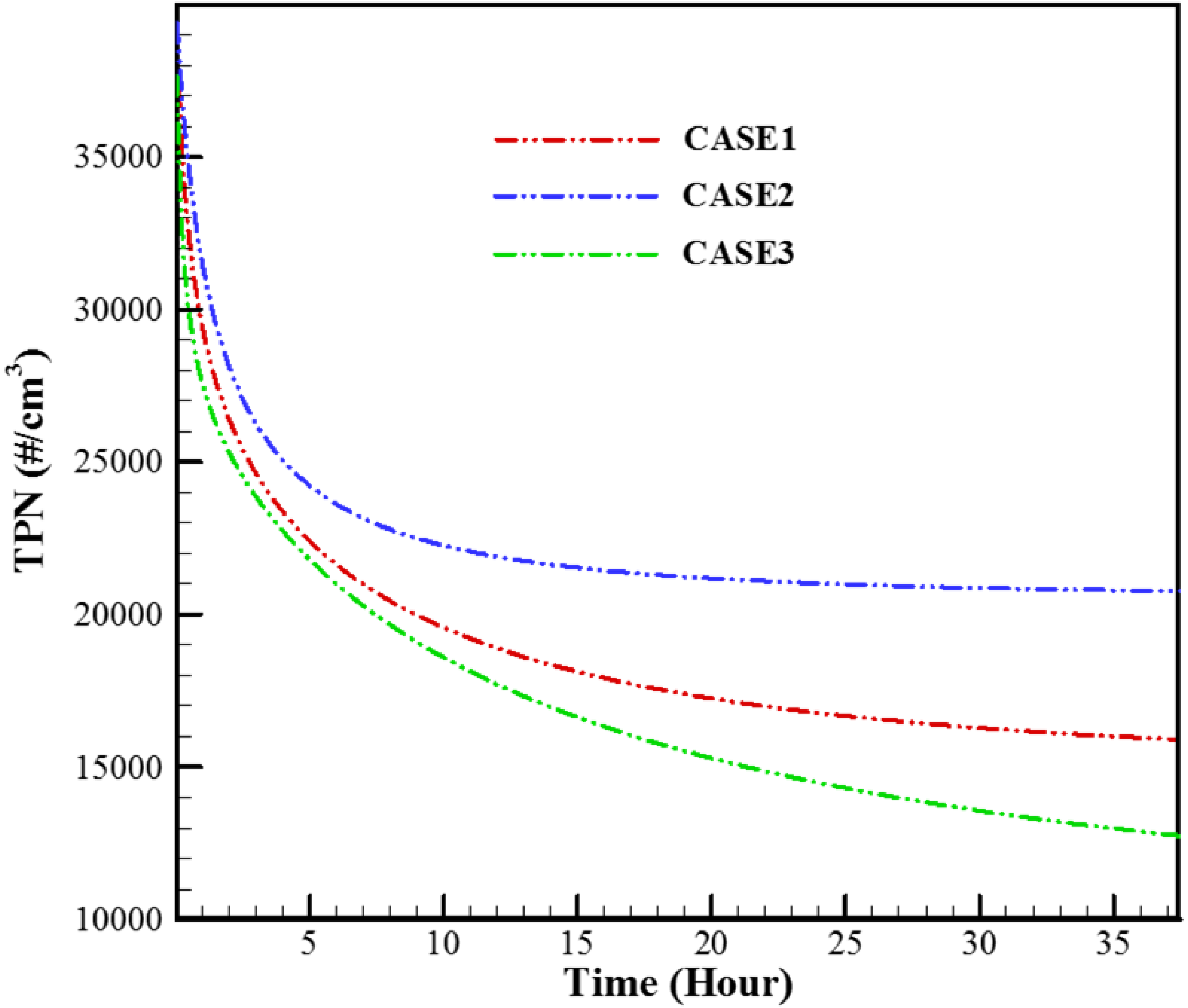
More theory: an aerosol model

- A model was developed to describe the interaction of a background aersosol and a continuous ultrafine particle source



Case 1: size distribution from the polluted case presented in Yue et al..
Cases 2 and 3 are fictional but with identical number concentration as C1

Temporal evolution of the total particle number concentration



Approx. a factor of two difference in number concentrations

Non-polluted case

Heavily polluted case

Conclusions

- Measured data gives evidence for a disconnect between mass based assessment of fine particles and number concentrations
- Laboratory experiment and modelling results suggest binary coagulation between the ultrafine and coarser modes of the size distribution as likely explanation.
- PM 2.5 does not appear to be a monitoring metric for heavily polluted atmospheres
- Separate limit values needed for PN and PM
  - emissions -> Euro 5B / Euro VI -> in force
  - ambient -> ...?

More theory: an aerosol model

$$\frac{\partial n(v,t)}{\partial t} = \underbrace{\frac{1}{2}\int_0^v \beta(v-v',v')n(v-v',t)n(v',t)dv' - n(v,t)\int_0^\infty \beta(v,v')n(v',t)dv'}_{\text{coagualtion within SP mode}}$$

$$\underbrace{-n(v,t)\int_0^\infty \gamma(v,v')p(v',t)dv'}_{\text{SP mode attached to BP mode}} \underbrace{-\frac{F_{out}}{V}n(v,t)}_{\text{ventilation}} + \underbrace{\frac{f(v,t)F_{in}}{V}}_{\text{injection}}$$

$$\frac{\partial p(v,t)}{\partial t} = \underbrace{\frac{1}{2}\int_0^v \beta(v-v',v')p(v-v',t)p(v',t)dv' - p(v,t)\int_0^\infty \beta(v,v')p(v',t)dv'}_{\text{coagulation within BP mode}}$$

$$\underbrace{+\int_0^v \gamma(v-v',v')n(v-v',t)p(v',t)dv' - p(v,t)\int_0^\infty \gamma(v,v')n(v',t)dv'}_{\text{interaction between SP and BP mode}} \underbrace{-\frac{F_{out}}{V}p(v,t)}_{\text{ventilation}}$$

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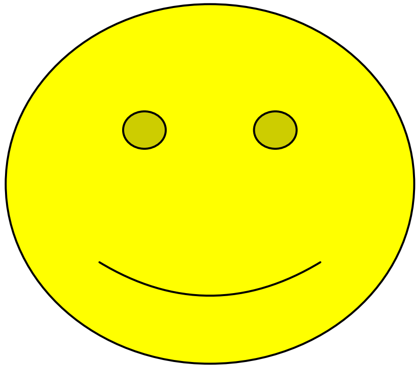

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