Overview of the Particle Size Magnifier (PSM)

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AIRMODUS

Airmodus Ltd.

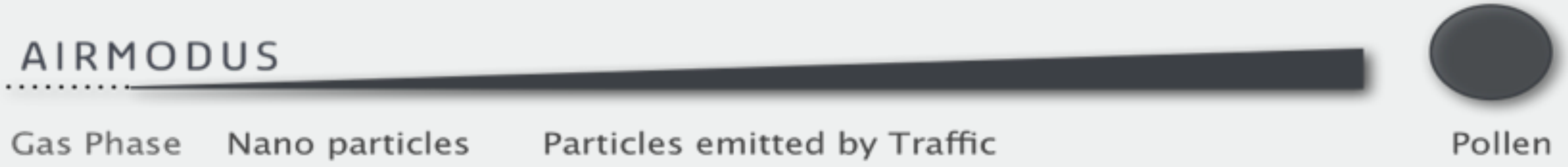
It's the small things that count

Founded in 2010

A spin-off from the University of Helsinki by a group of aerosol experts specialised in nanoparticle detection

Professor Markku Kulmala is one of the co-founders of the company

Located in Helsinki, Finland



Airmodus products

Nanoparticle measurements

A20 bCPC, Condensation Particle Counter

- Particle number concentration measurements

A23 bCPC, Condensation Particle Counter

- Vehicle exhaust measurements (PMP), number concentration

A10 PSM, Particle Size Magnifier

- Getting to the smallest sizes, down to 1 nm

A11 nCNC , nano Condensation Nucleus Counter (= A10 + A20)

- Total number concentration of aerosol particles from 1-4 nm up to 1000 nm
- Particle size distribution between 1-4 nm

A11 nano Condensation Nucleus Counter (nCNC)

A combination of A10 Particle Size Magnifier and A20 butanol Condensation Particle Counter. **The first instrument capable of measuring aerosol particle nucleation real time.**

BENEFITS:

Total aerosol number concentration down to **1 nm** in diameter

Size distribution measurement between **1-4 nm**

Designed for stand alone continuous use

Well characterised and utilised in over 50 peer reviewed publications

APPLICATIONS:

Atmospheric research, emission measurements, occupational health studies, synthetic nanoparticle research

PSM can be used with almost all CPCs
Online data inversion only with the Airmodus A20 bCPC

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A11 nano Condensation Nucleus Counter (nCNC)

Technology

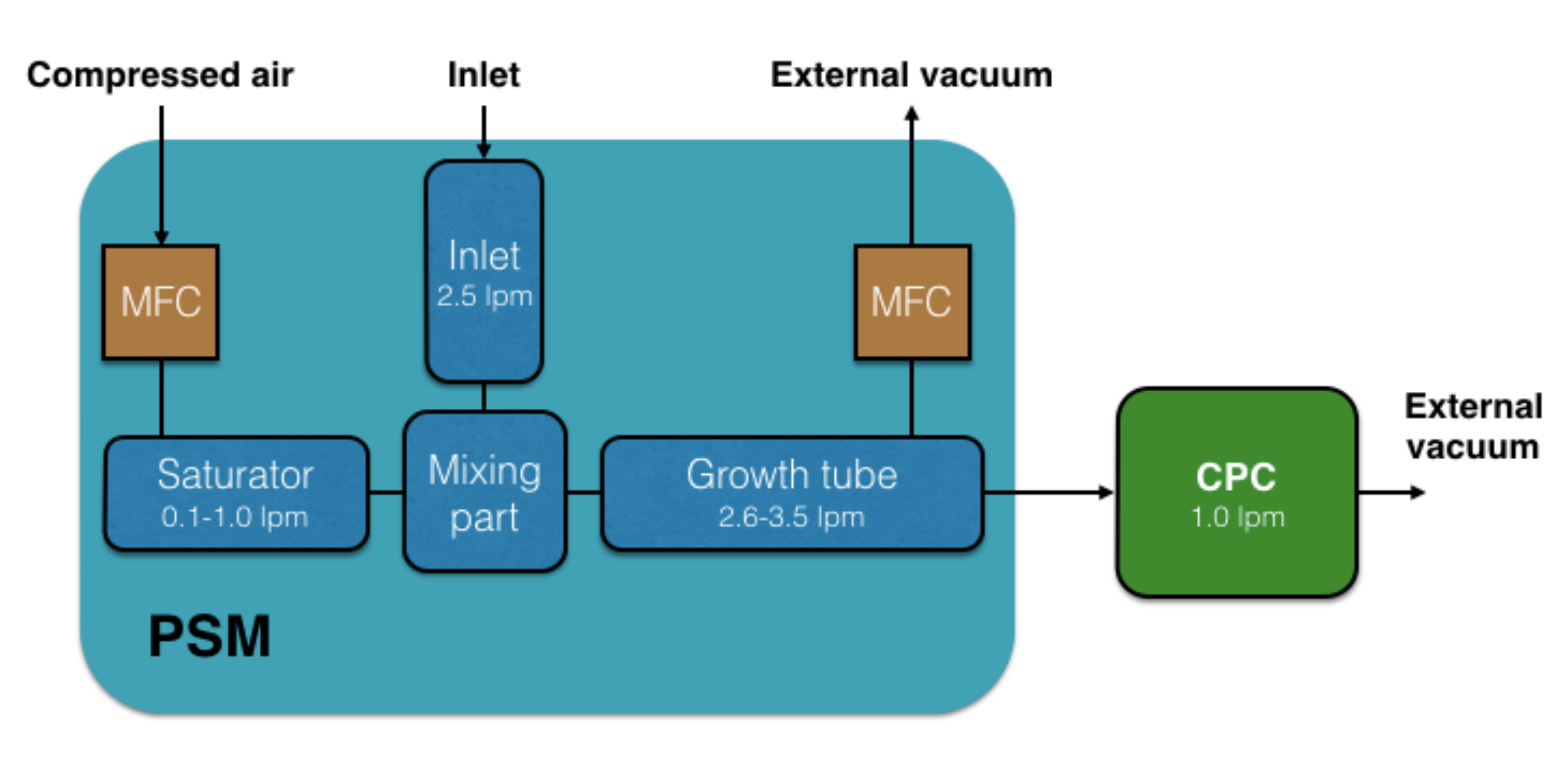
A combination of A10 Particle Size Magnifier and A20 butanol Condensation Particle Counter.

PSM is a mixing type device using diethylene glycol to grow particles as small as 1 nm up to about 90 nm in diameter. It allows rapid changes in mixing ratio giving the user the opportunity to scan activation size spectra from 1-4 nm.

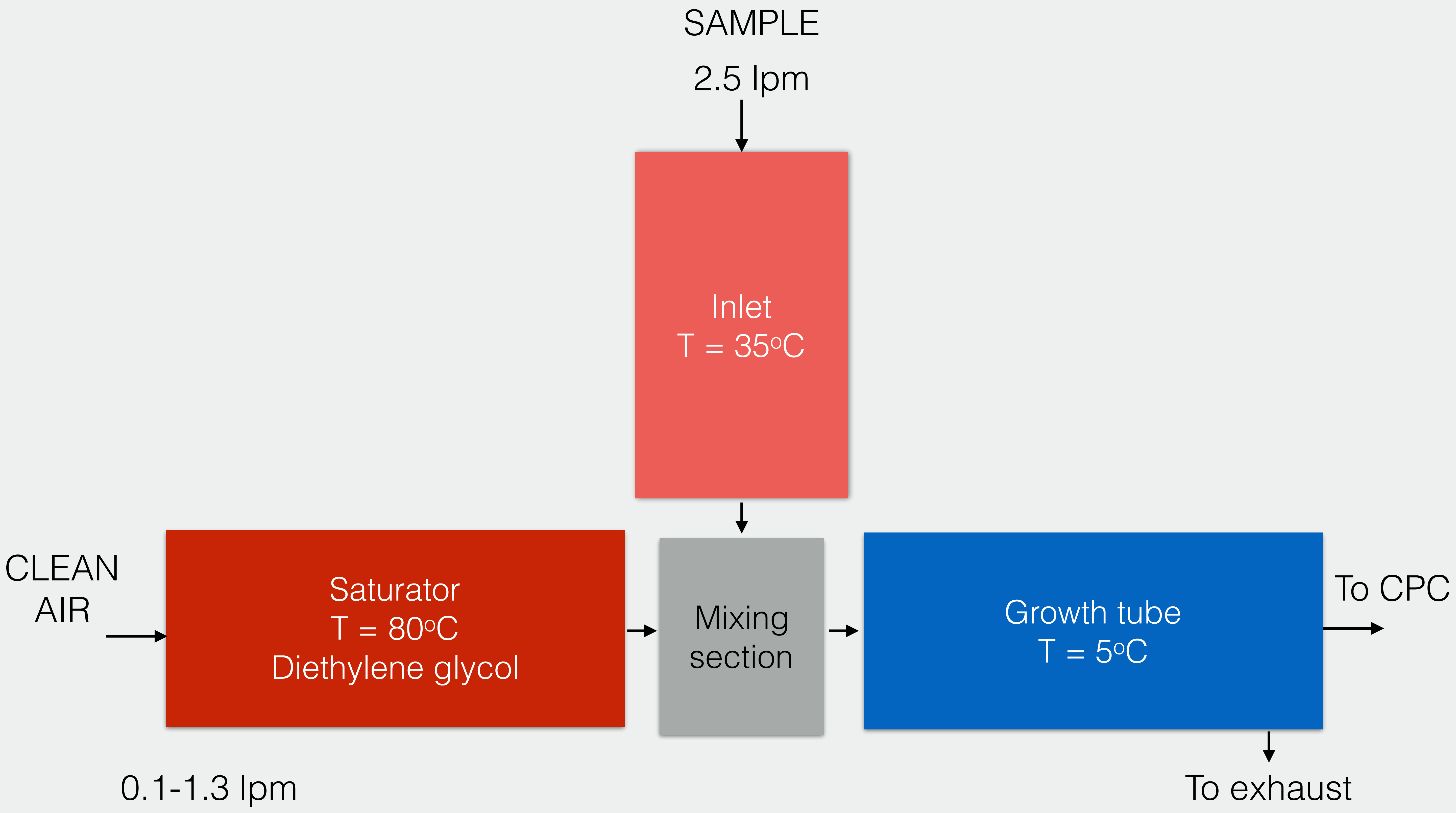
A butanol based condensation particle counter (CPC) is used to count the diethylene glycol droplets

2.5 lpm inlet flow rate to reduce diffusional wall losses

Aerosol particle size distribution through online data inversion



A10 Particle Size Magnifier (PSM)



Vanhanen J. et al. Particle Size Magnifier for Nano-CN Detection, Aerosol Science and Technology, 45:,533-542, 2011

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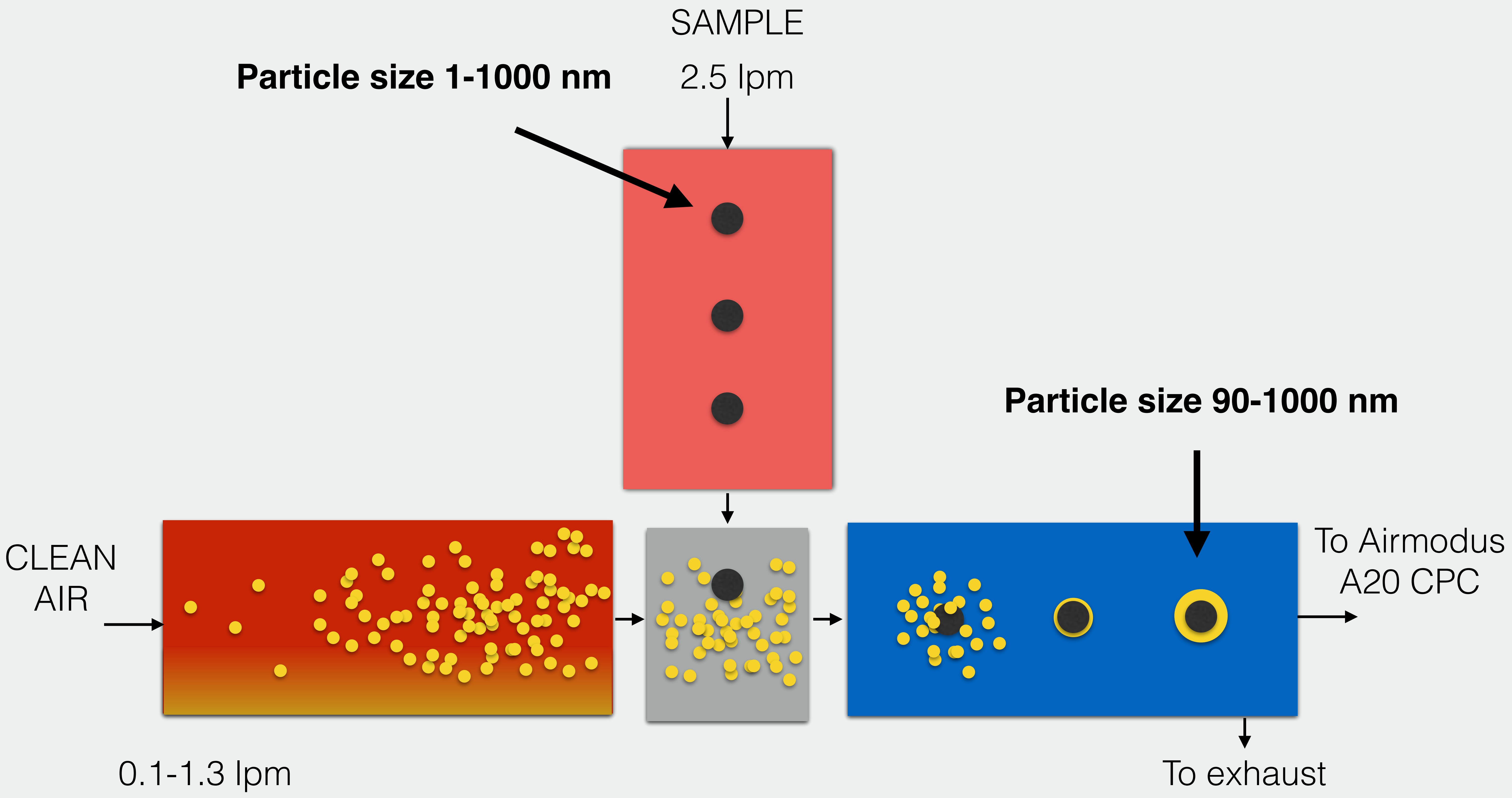
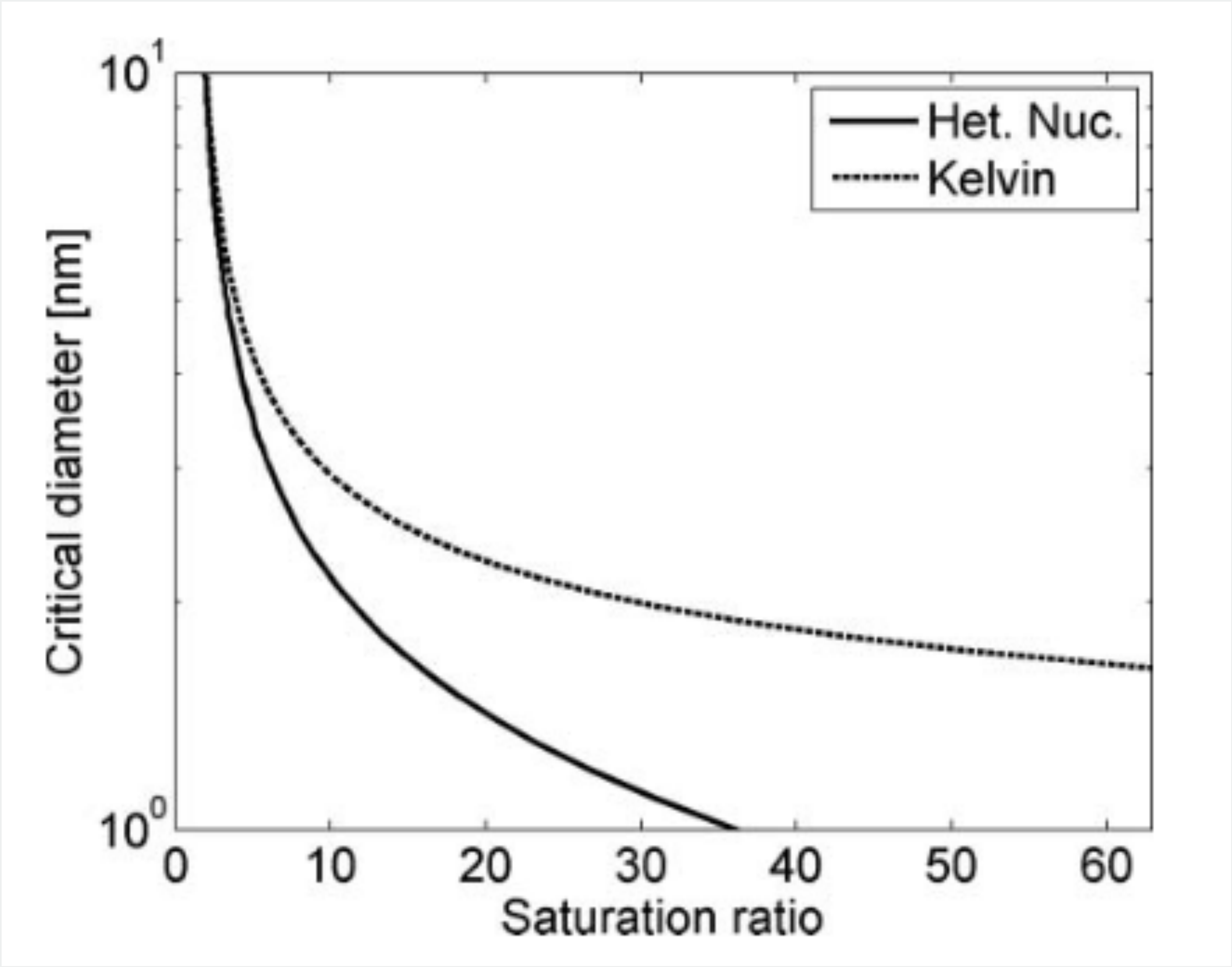


By changing the flow rates the user can change the saturation ratio

-> the smallest particle detected by the instrument is changed (critical diameter)



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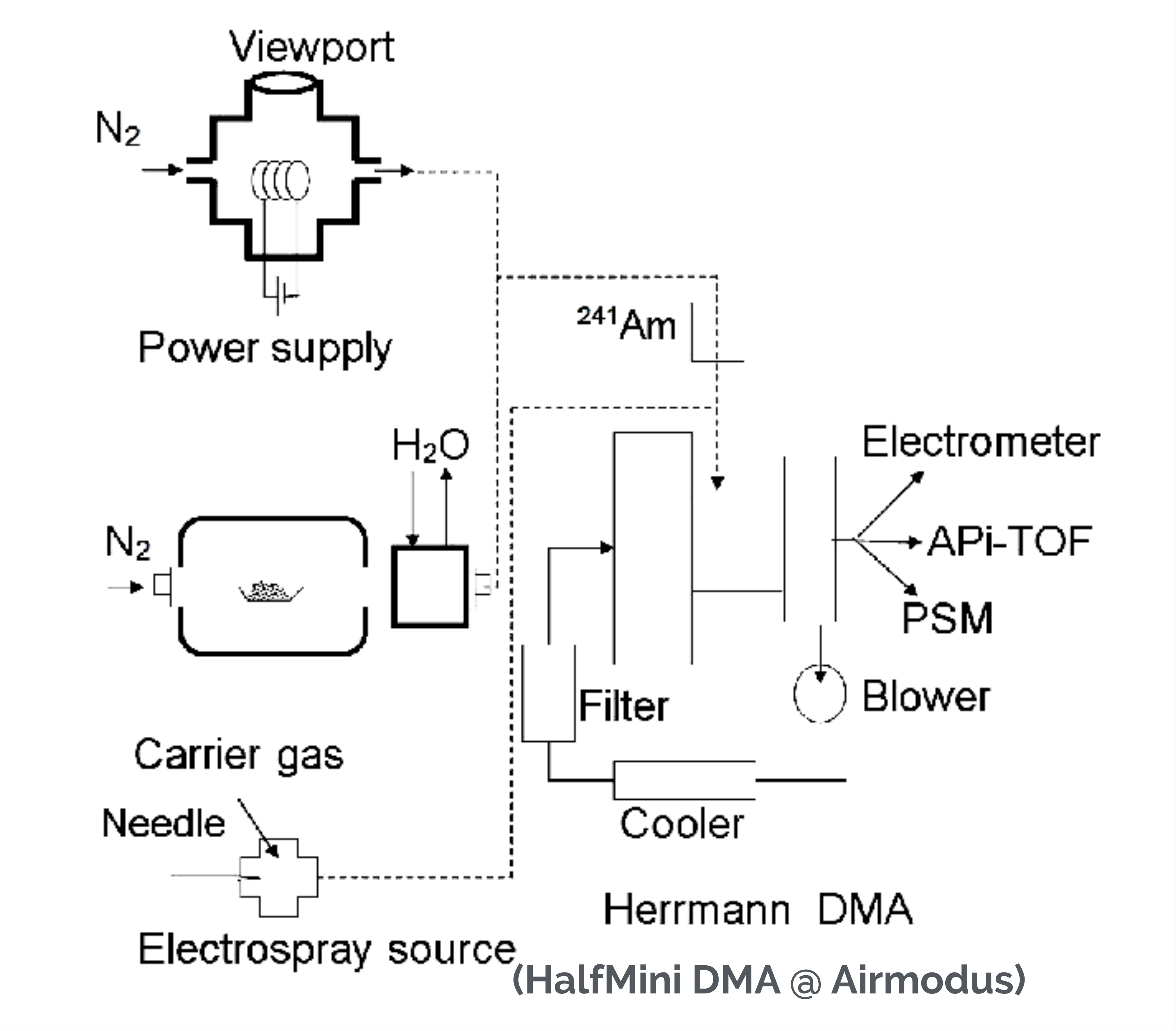
PSM

Calibration



Aerosol generators used:

- Hot wire generator (metal oxides)
- Tube furnace (evaporation condensation method)
- Electrospray for molecular mobility standards

High flow and high resolution DMAs (by Prof. de la Mora):

- Herrmann DMA
- HalfMini from SEADM

Reference instruments

- Aerosol electrometer for concentration
- API-TOF for chemical composition

Kangasluoma J. et al. Remarks on Ion Generation for CPC Detection Efficiency Studies in Sub-3-nm Size Range, Aerosol Science and Technology, 47:5, 556-563

PSM

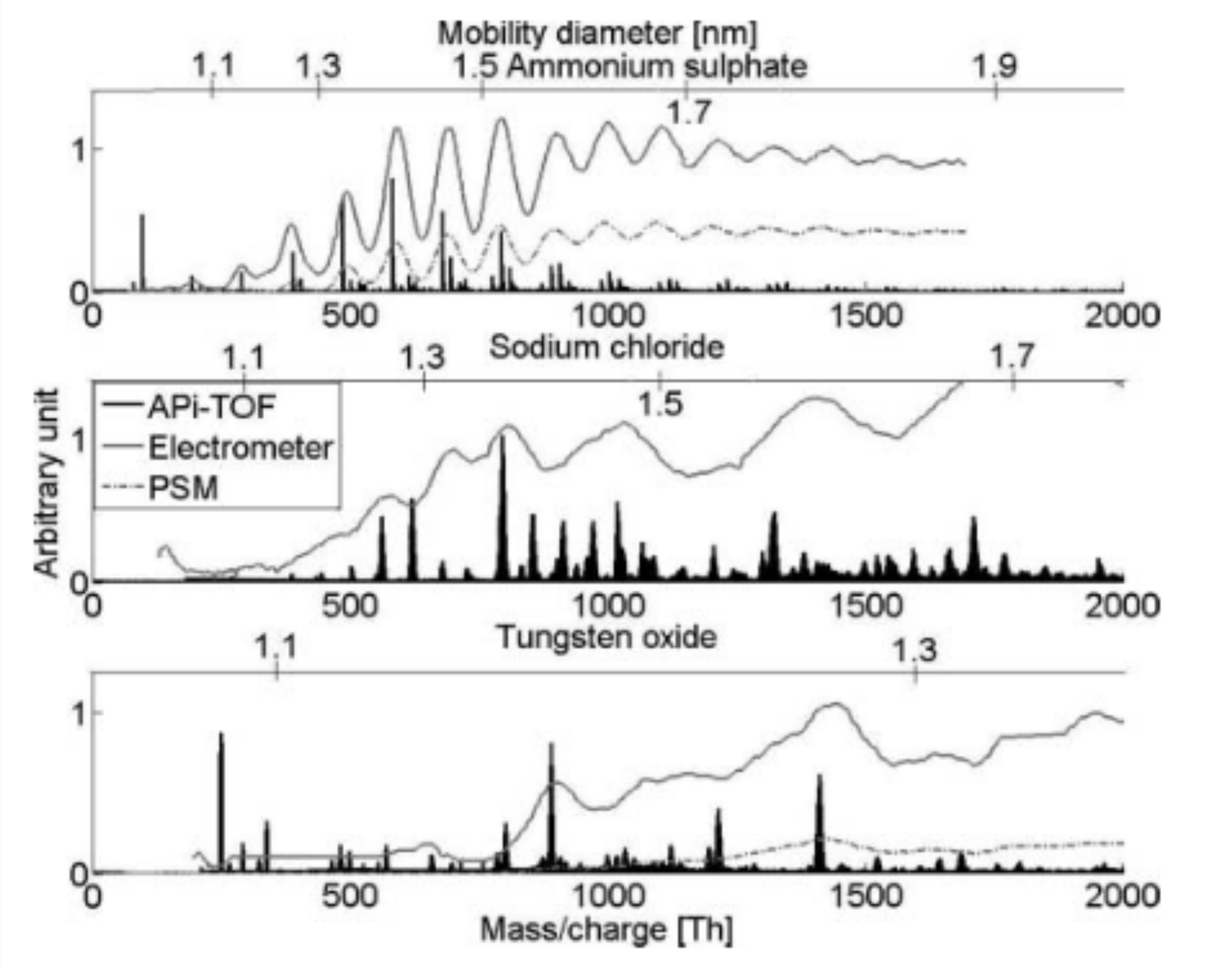
Calibration

Discrete peaks for different clusters up to continuous particle mode made from "bulk" material

Ammonium sulfate:

$(HSO_4)_x(NH_3)_ySO_5^-$

The chemical composition can be validated by using API-TOF-MS (Junninen *et al.* 2010)



Kangasluoma J. et al. Remarks on Ion Generation for CPC Detection Efficiency Studies in Sub-3-nm Size Range, Aerosol Science and Technology, 47:5, 556-563

Junninen, H. et al. A high-resolution mass spectrometer to measure atmospheric ion composition. *Atmos. Mean. Tech.*, 3, 1039-1053, 2010.

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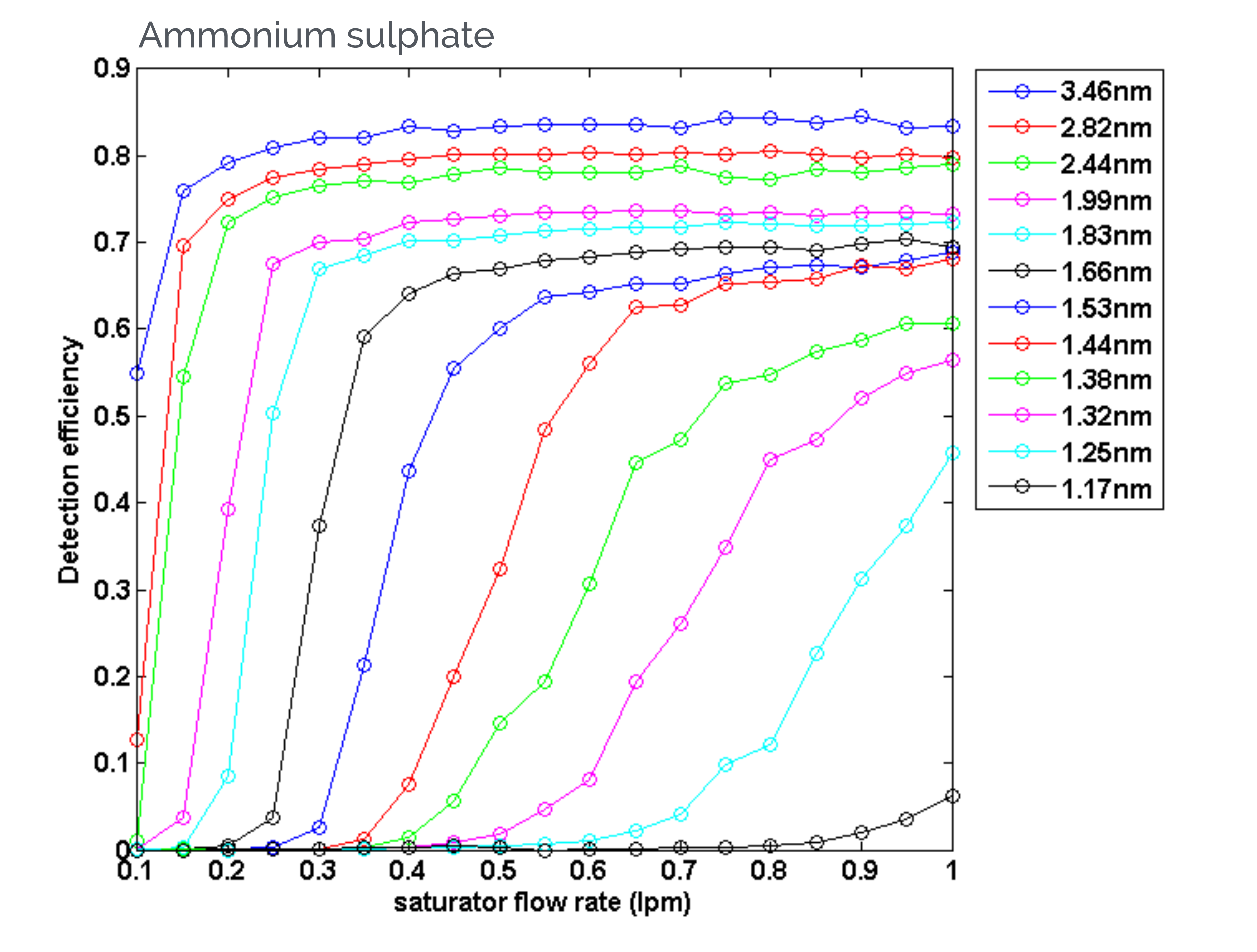
Detection efficiency in scanning mode

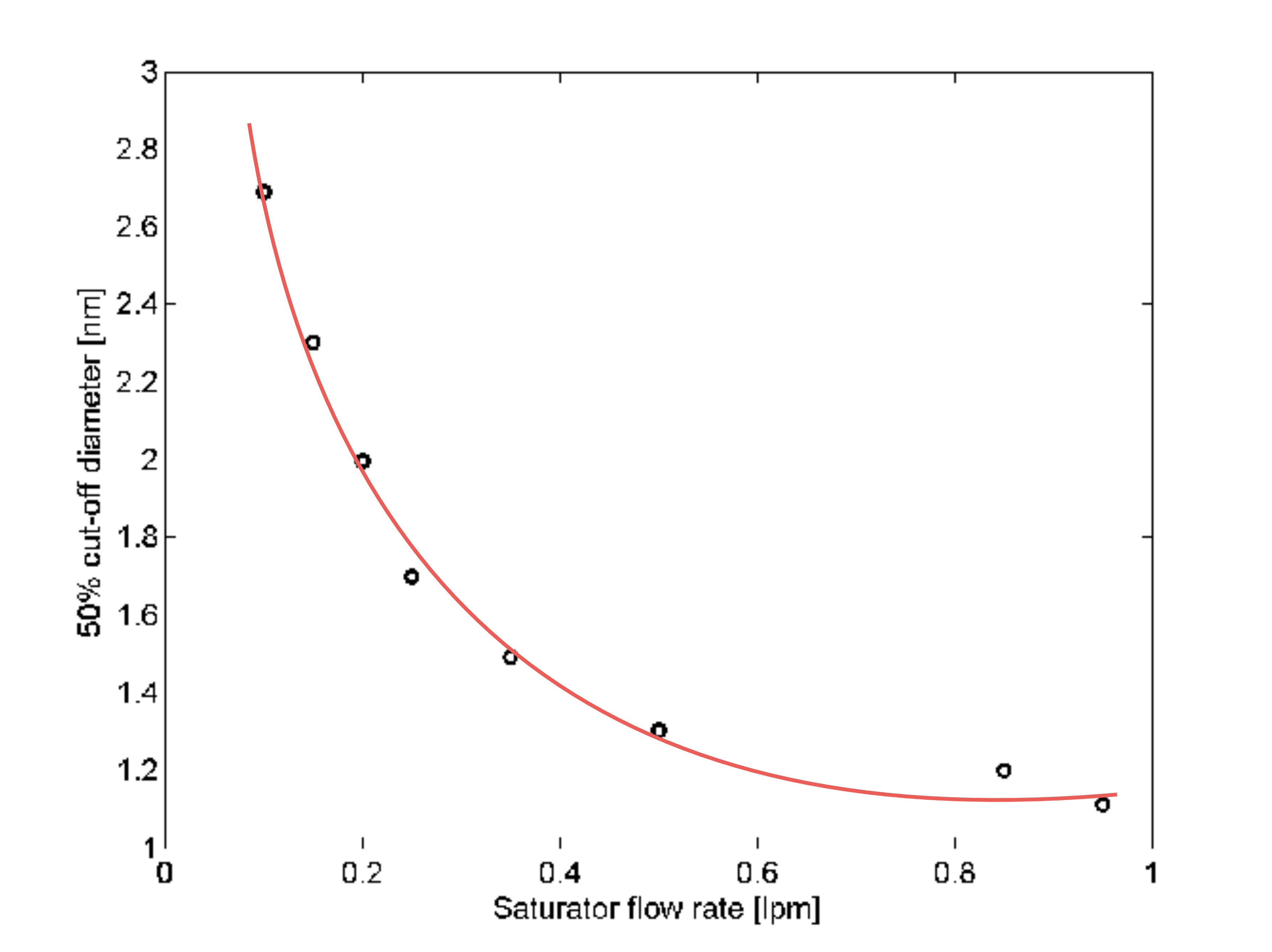
More about PSM calibrations:

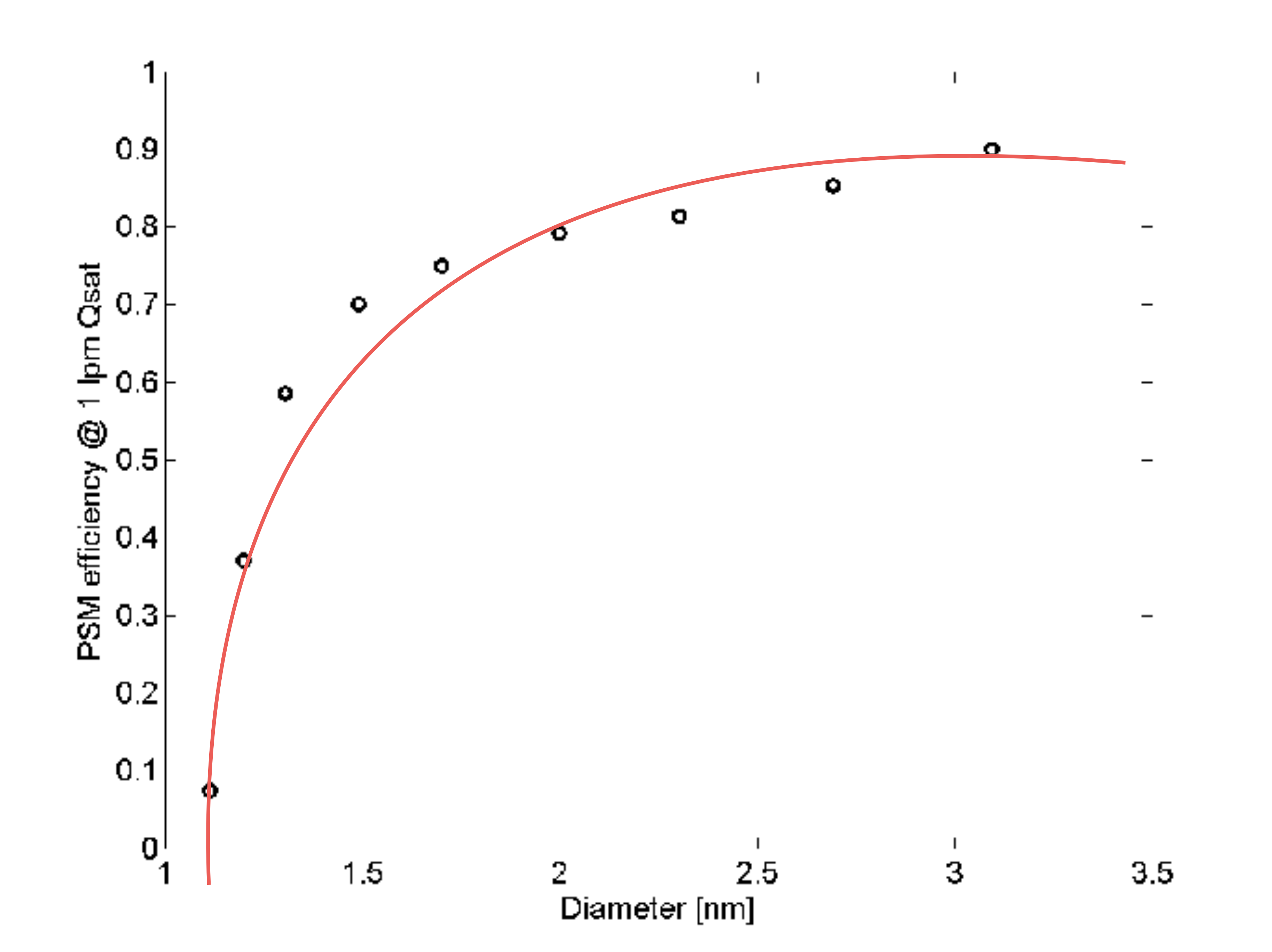
- Kangasluoma et al., 2013 Aerosol Science & Technology
- Wimmer et al., 2013 Atmospheric Measurement Techniques



Size distribution measurement

Calibration data





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Size distribution measurement

Example of inverted data

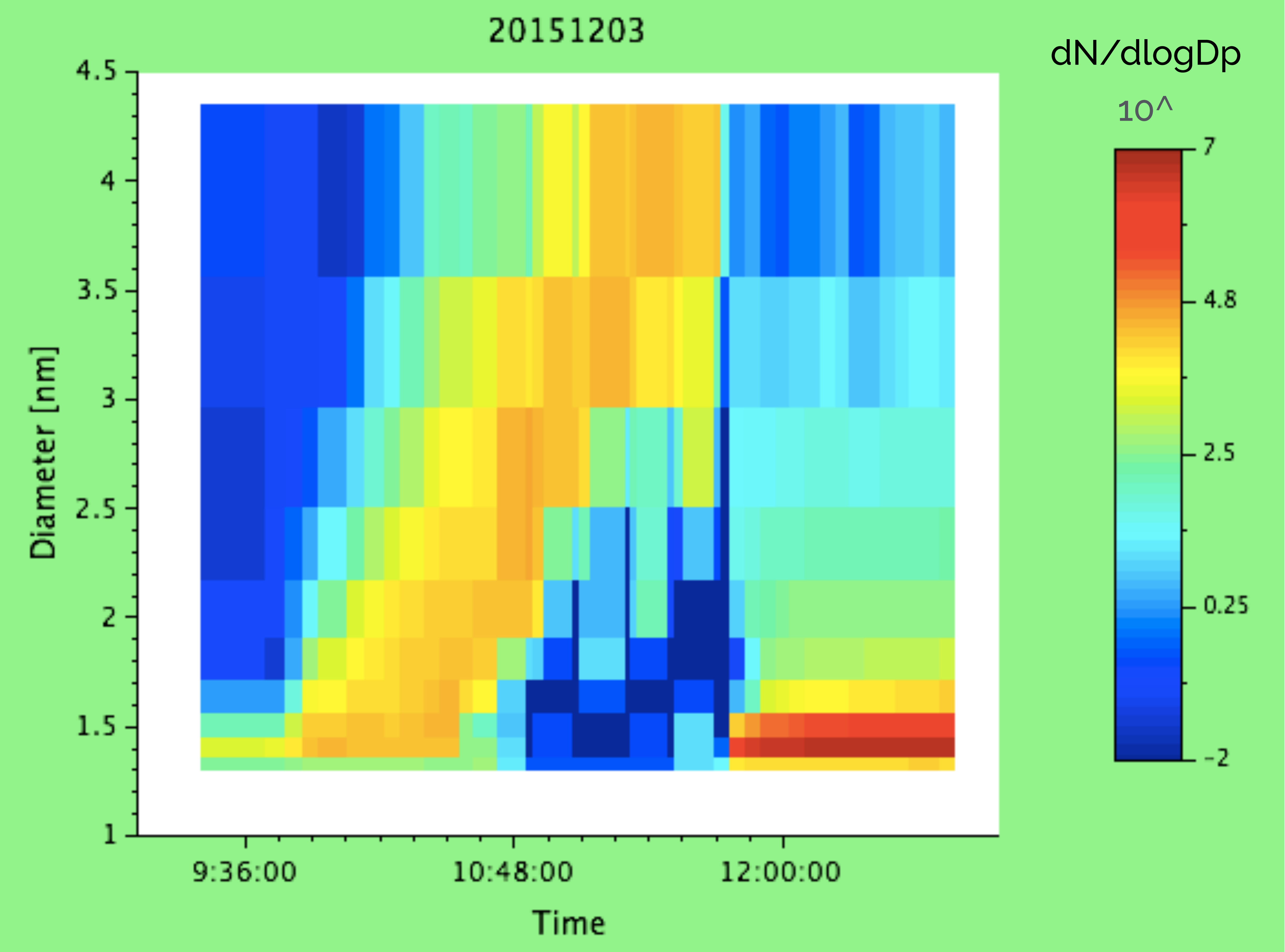
Example of a calibration with different size of mono disperse particles (hot NiCr wire)

At noon HEPA filtered air through Americium source

Size distribution is based on calibration made with a specific particle type (Currently metal oxides)

Post processing inversion code (Scilab) for raw data can be downloaded for free from:

https://github.com/Airmodus/A11_Scan



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Atmospheric nucleation / growth rates

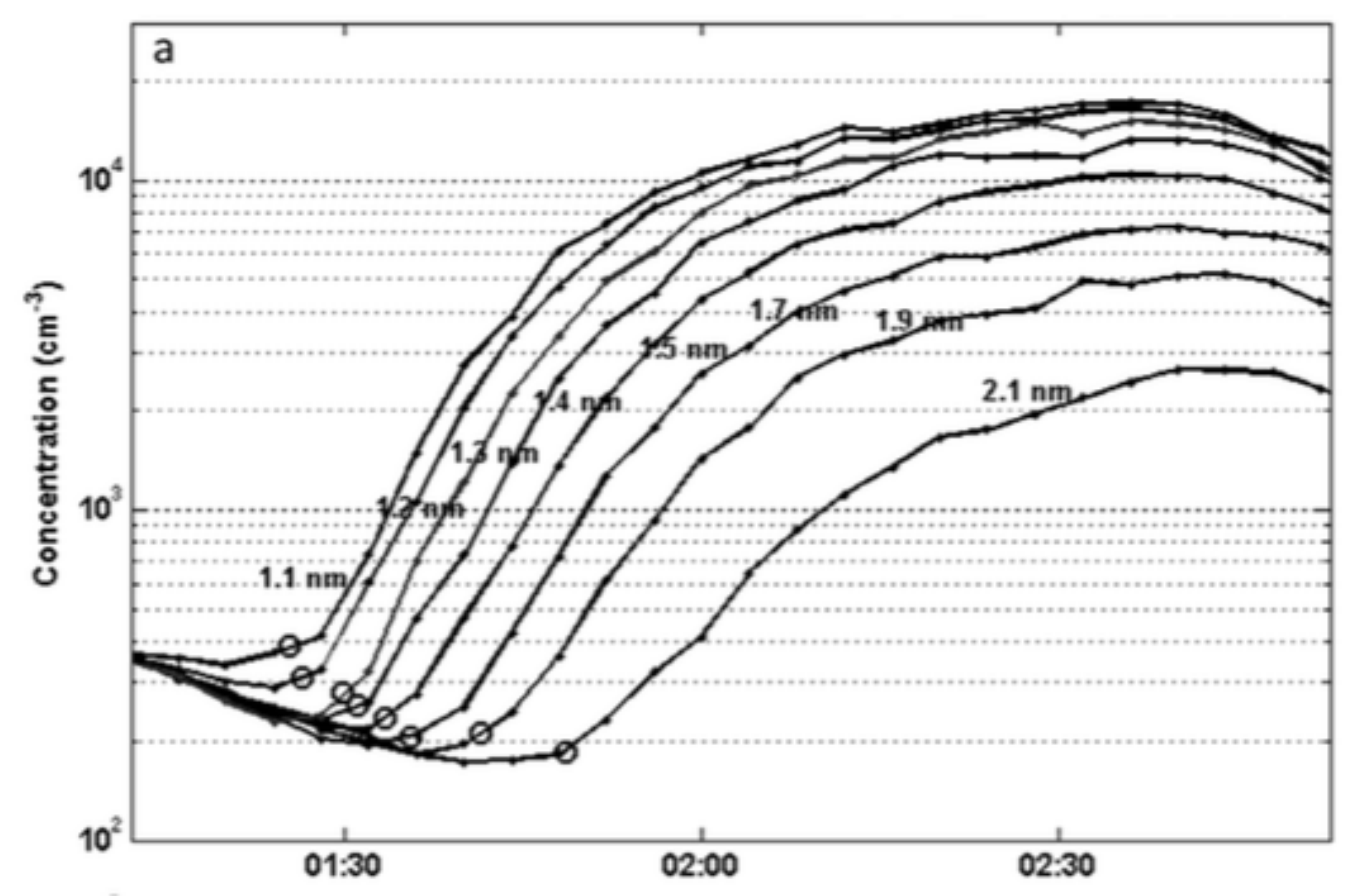
Measurements of atmospheric nucleation conducted in the CLOUD chamber at CERN

Well controlled and “clean” nucleation event (never in the real atmosphere !)

Growth rate of the particles can be calculated from concentration readings of different size bins of the PSM (increase of 5% and 50%)

Growth rates determined from the PSM, NAIS and from the API-TOF match nicely

- Both NAIS and API-TOF measured only ions



Lehtipalo K. et al. Methods for determining particle size distribution and growth rates between 1 and 3 nm using the Particle Size magnidier. Boreal Env. Res. vol 19, 2014

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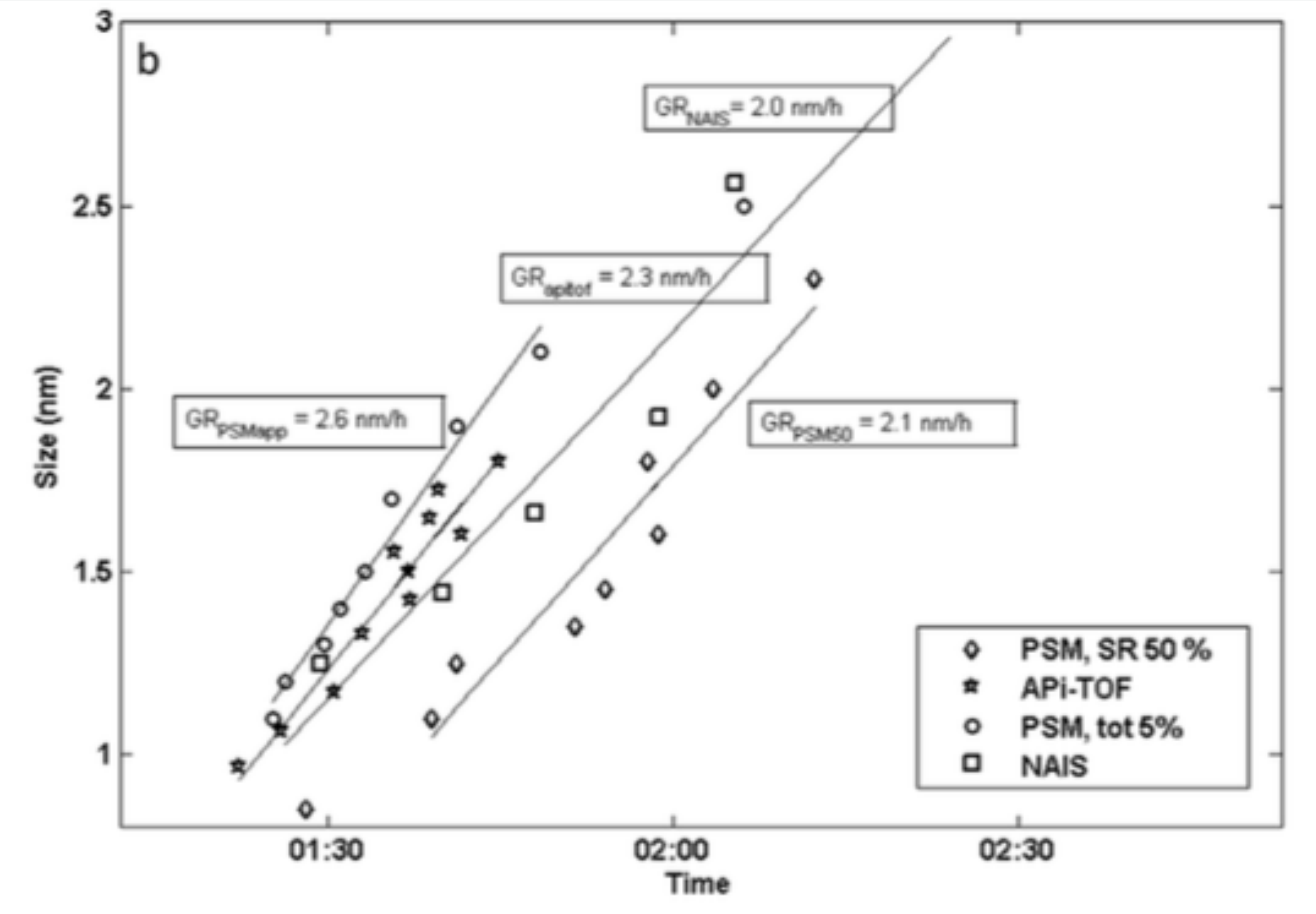

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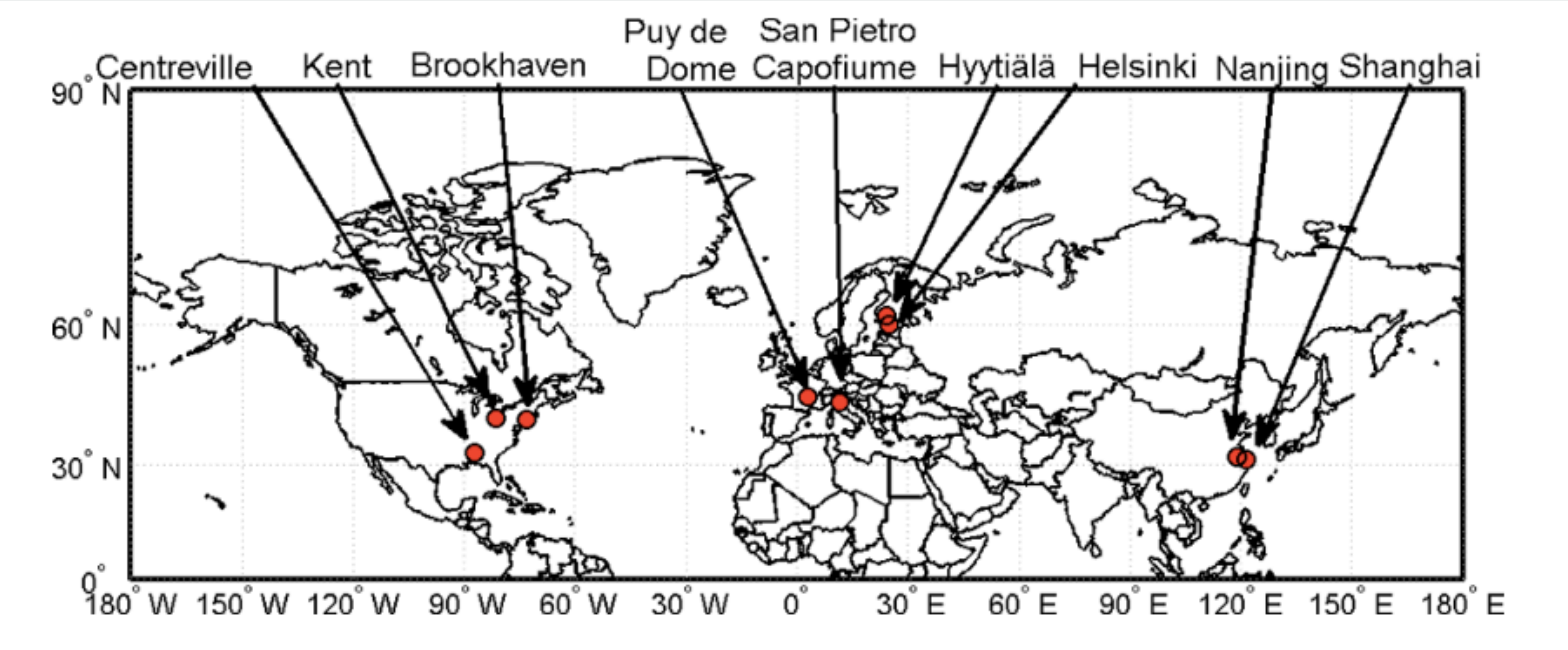
Atmospheric measurements with the Airmodus PSM

Long term PSM measurements have been conducted all over the world

Highest concentrations are measured at the sites with strong anthropogenic influence

Day time maxima has been measured in all the locations -> photochemistry



Kontkanen, J., Lehtipalo, K., Ahonen, L., Kangasluoma, J., Manninen, H. E., Hakala, J., Rose, C., Sellegri, K., Xiao, S., Wang, L., Qi, X., Nie, W., Ding, A., Yu, H., Lee, S., Kerminen, V.-M., Petäjä, T., and Kulmala, M.: Measurements of sub-3nm particles using a particle size magnifier in different environments: from clean mountain top to polluted megacities, Atmos. Chem. Phys., 17, 2163-2187, doi:10.5194/acp-17-2163-2017, 2017.

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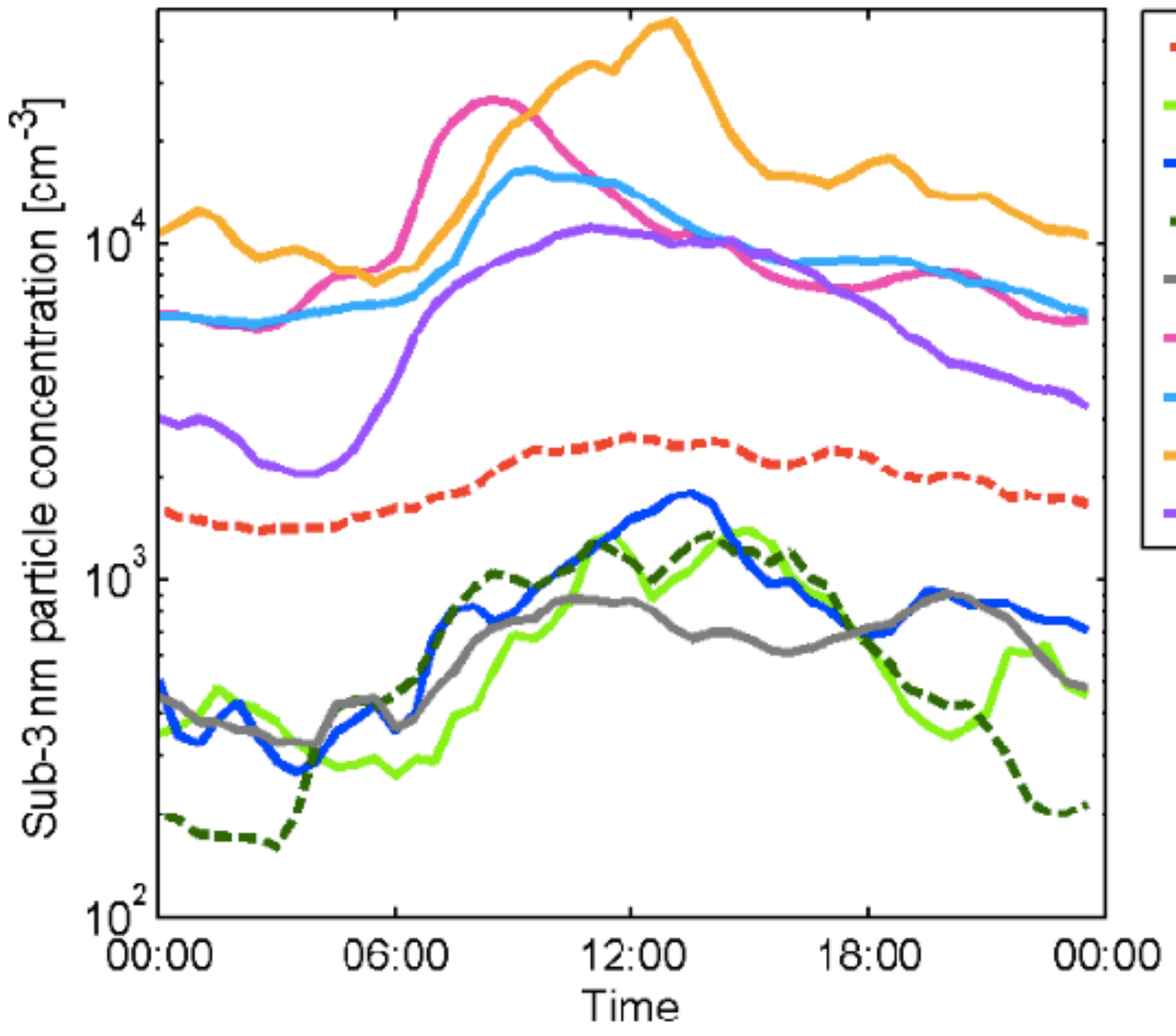

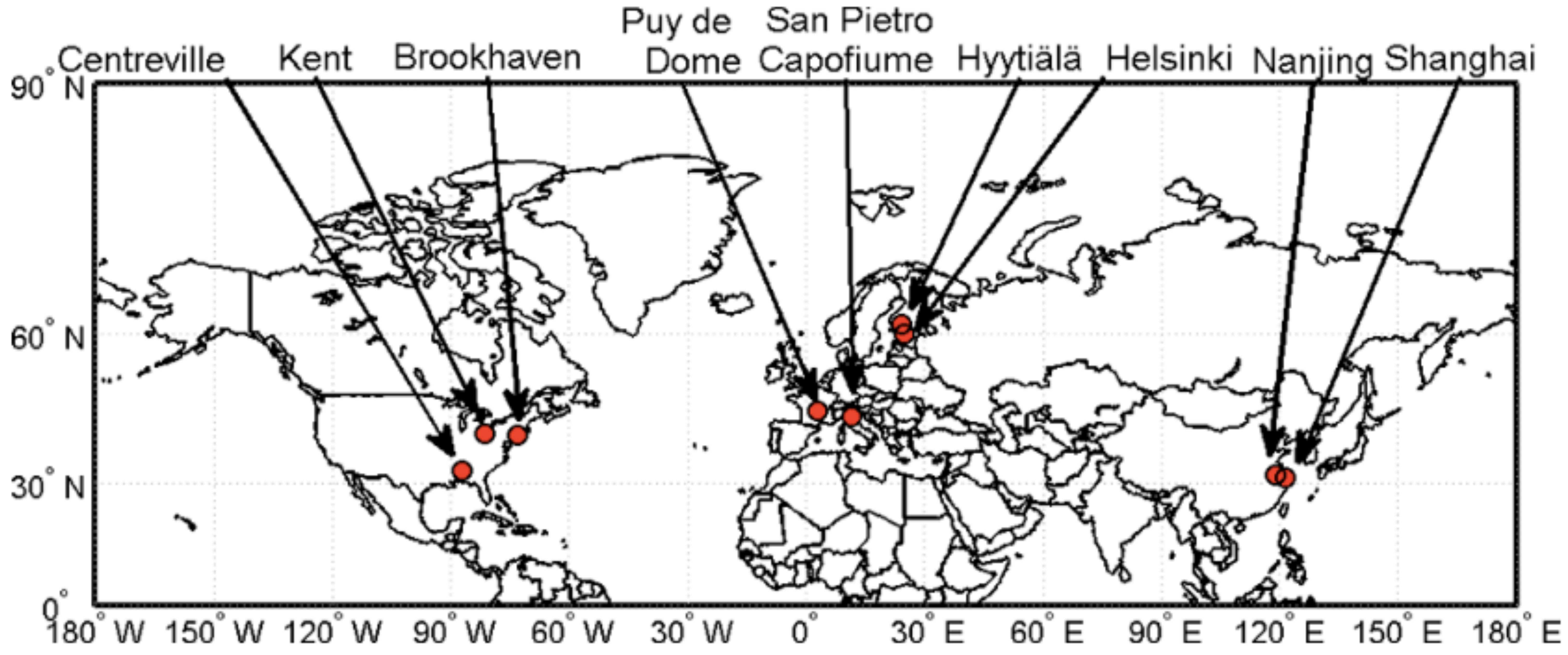

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Nucleation measurements in urban environment

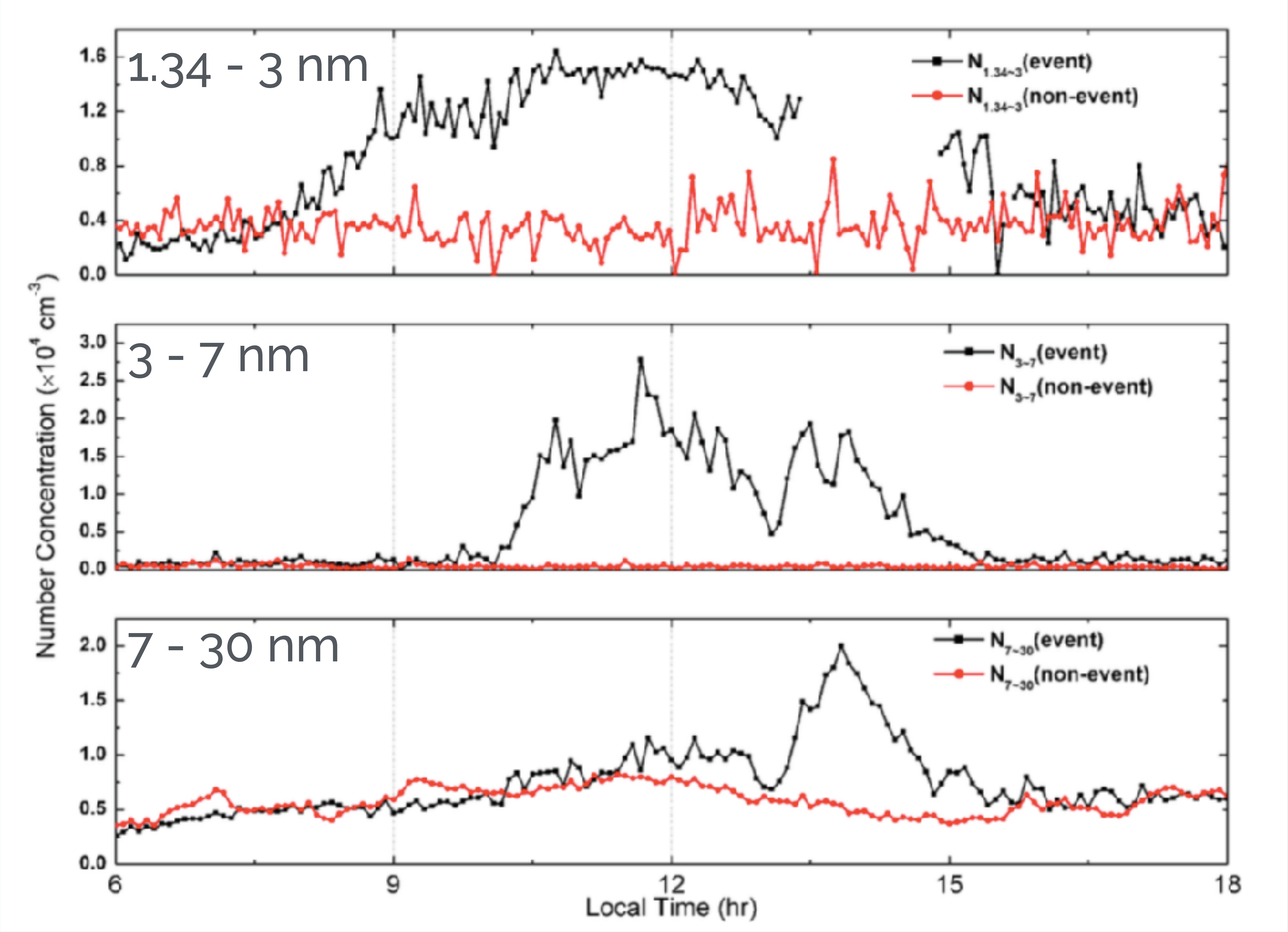
nCNC measurements during winter in Shanghai, China

Typical levels of 1.34-10 nm particles around 10^4 #/cc

Clear nucleation events even in such a polluted area; condensation sinks about 1 to 2 orders of magnitude higher compared to pristine atmosphere

In addition to sulphuric acid, ammonia seems to play a role in the observer nucleation events

Clear diurnal trend of sub 3 nm particles only during event days



Diurnal aerosol variation number concentrations for different size ranges during event and non-event days

Xiao, S. et al. Strong atmospheric new particle formation in the winter in urban Shanghai, China, Atmos. Them. Pays., 15, 1769-1781, 2015

Sub 5 nm particles in natural gas engine emissions

A passenger car that was modified to run with natural gas

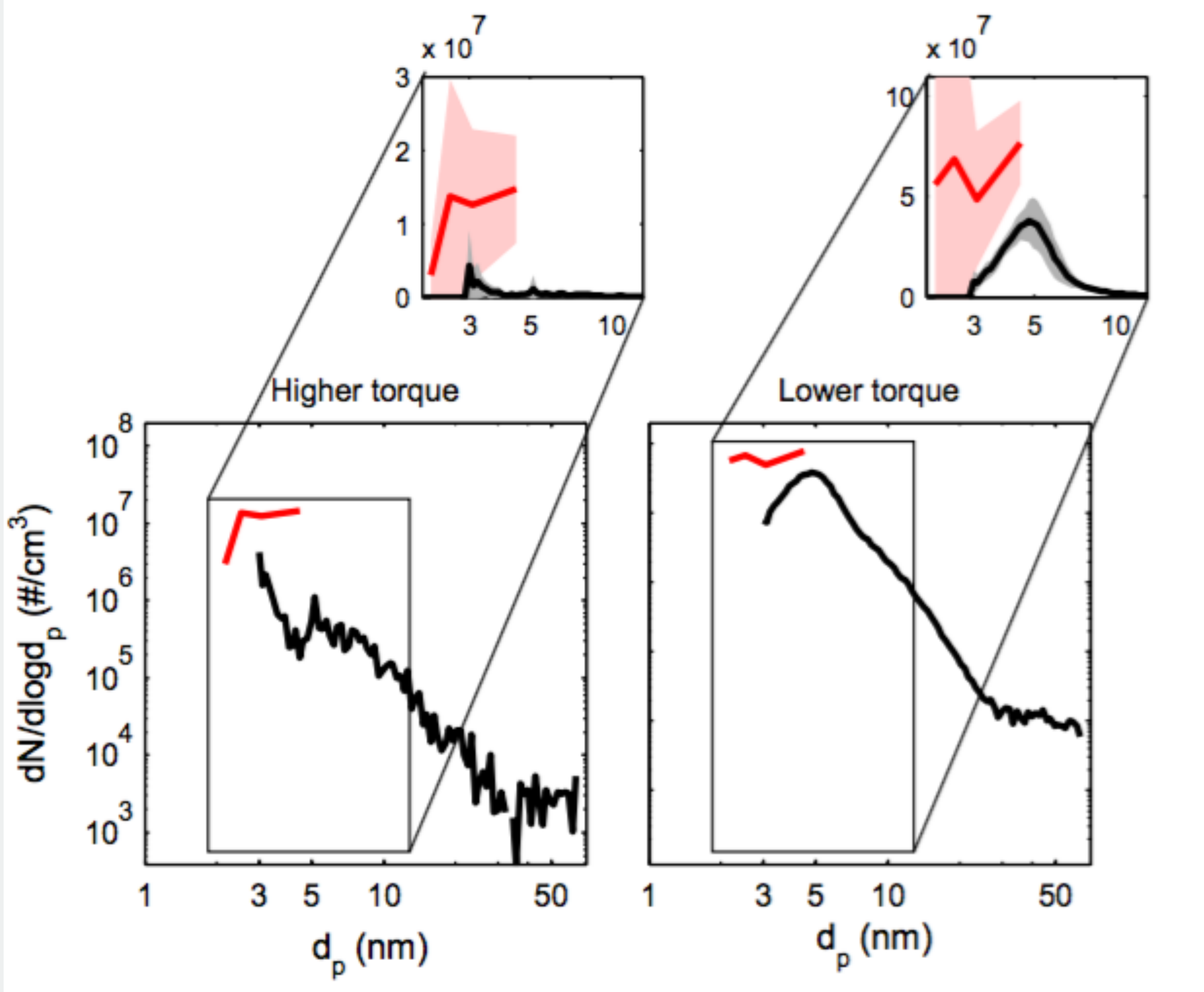
The peak in size distribution at size range of **2-5 nm**

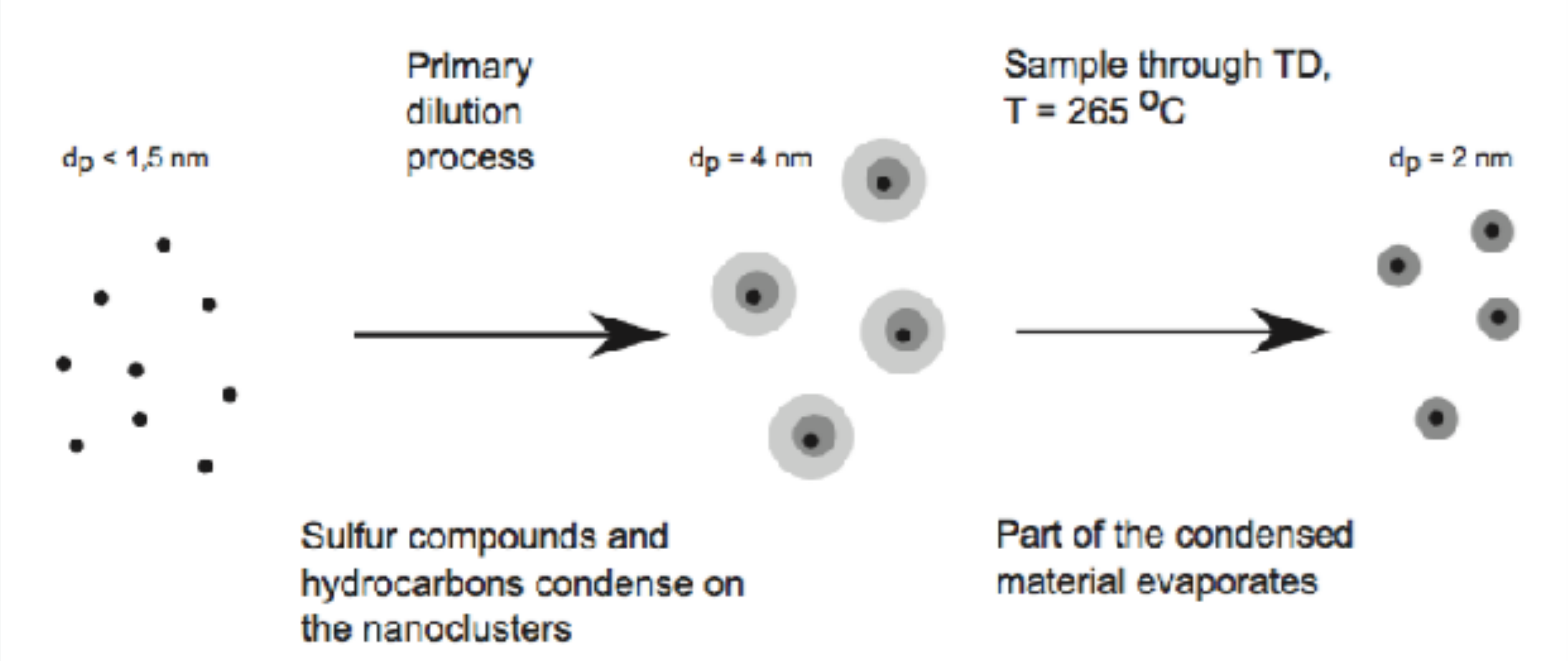
Total concentration of particles above the PMP (EU) limit of 23 nm was really low compared to particles below it

Also the particles in the sub 5 nm sizes had a **solid core**

The smallest cores formed inside the engine cylinders from lubrication oil?

Small core particles grow by condensation inside the sampling system





Alanen, J. et al. The formation and physical properties of the particle emissions from a natural gas engine. Fuel vol 162, 155-161, 2015.

Nanoparticles from brake materials

Different brake pad materials tested with a pin - disc - machine

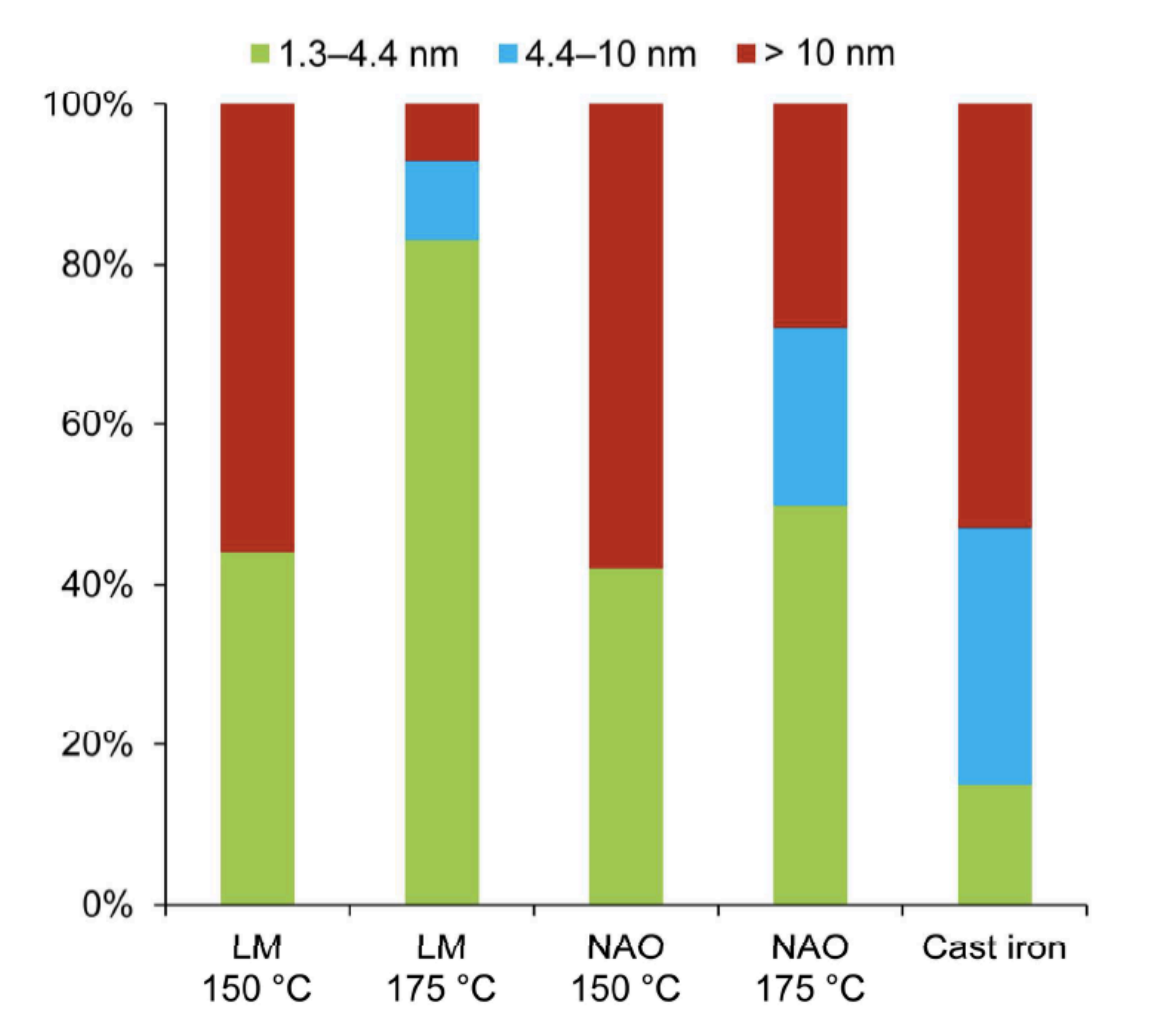
LM = low metallic

NAO = non-asbestos organic

All materials emit nanoparticles in the sub 10 nm size range

Critical temperature for nanoparticle production is in the range of 175 celsius

Highest emissions for 1.3 - 4,4 nm particles is for low metallic brake pad



Nosko et al. 2016, Emissions of 1.3-10 nm airborne particles from brake materials, Aerosol Science and Technology, Accepted.

Publications

www.airmodus.com/publications

Instrument characterization

Vanhanen, J., Mikkilä, J., Lehtipalo, K. , Sipilä, M. , Manninen, H. E. , Siivola, E. Petäjä, T. and Kulmala, M.: Particle Size Magnifier for Nano-CN Detection, Aerosol Sci. Technol., 45: 4, 533-542, 2011

Data analysis methods

Lehtipalo, K., Leppä, J., Kontkanen, J., Kangasluoma, J., Franchin, A., Wimmer, D., Schobesberger, S., Junninen, H., Petäjä, T., Sipilä, M., Mikkilä, J., Vanhanen, J., Worsnop, D. R. & Kulmala, M. 2014: Methods for determining particle size distribution and growth rates between 1 and 3 nm using the Particle Size Magnifier. *Boreal Env. Res.* 19 (suppl. B).

Peer-reviewed articles reporting measurements with Airmodus nCNC (PSM)

Kirkby et al. Ion-induced nucleation of pure biogenic particles. Nature, vol 533, pp. 521-526 2016

Tröstl et al. The role of low-volatility organic compounds in initial particle growth in the atmosphere. Nature vol. 533, pp. 527-531, 2016

Lehtipalo et al. The effect of acid-base clustering and ions on the growth of atmospheric nano- particles. Nature Communications 7, 11594, 2016

Sarnela N., Jokinen, T., Nieminen, T., Lehtipalo, K., Junninen, H., Kangasluoma, J., Hakala, J. Taipale, R., Schobesberger, S., Sipilä, M., Larnimaa, K., Westerholm, H., Heijari, J., Kerminen, V.-M., Petäjä, T., Kulmala, M. Sulphuric acid and aerosol particle production in the vicinity of an oil refinery. Atmos. Env. vol 119, 156-166, 2015.

Alanen, J., Saukko, E., Lehtoranta, K., Murtonen, T., Timonen, H., Hillamo, R., Karjalainen, P., Kuuluvainen, H. Harra, J., Keskinen, J., Rönkkö, T. The formation and physical properties of the particle emissions from a natural gas engine. Fuel, vol 162, 155-161, 2015. www.sciencedirect.com/science/article/pii/S0016236115008935

Kangasluoma, J., A. Franchin, J. Duplissy, L. Ahonen, F. Korhonen, M. Attoui, J. Mikkilä, K. Lehtipalo, J. Vanhanen, M. Kulmala, and T. Petäjä. Operation of the Airmodus A11 nanoCondensation Nucleus Counter at various inlet pressures, various operation temperatures and design of a new inlet system. Atmos. Meas. Tech., 9, 2977-2988, 2016 (Atmos. Meas. Tech. Discuss., 8, 8483–8508, 2015)

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