2021 AMS User Meeting

PM_1 and $PM_{2.5}$ lens in AMS ground/aircraft applications: Insights from laboratory characterizations

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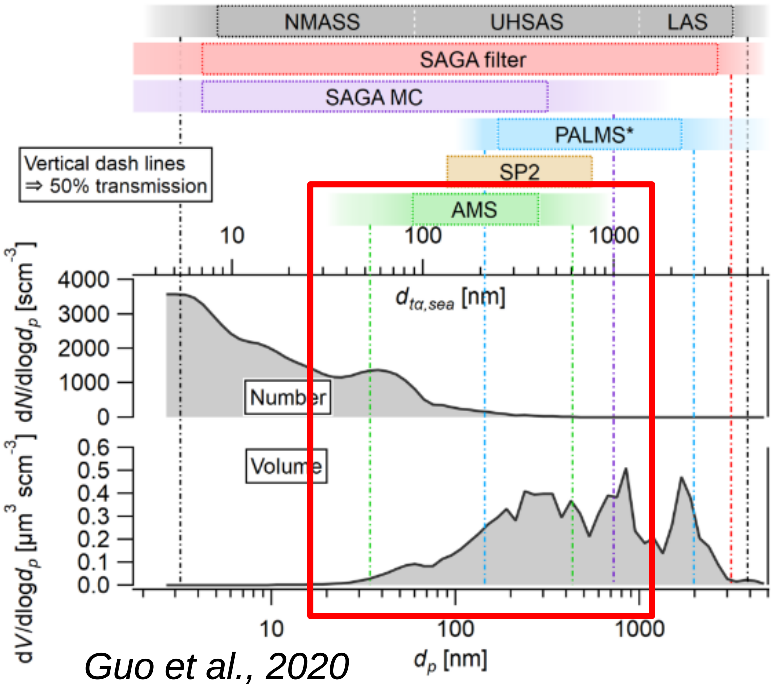
Da Yang, Mark Kanaparthi, Suresh Dhaniyala,
and Jose L. Jimenez

21 JAN 2021

dongwook.kim@colorado.edu

Introduction

For more info on aerosol intercomparisons, see Hongyu's slides presented on 20 JAN 2021 10:00 EST



Guo et al., 2020

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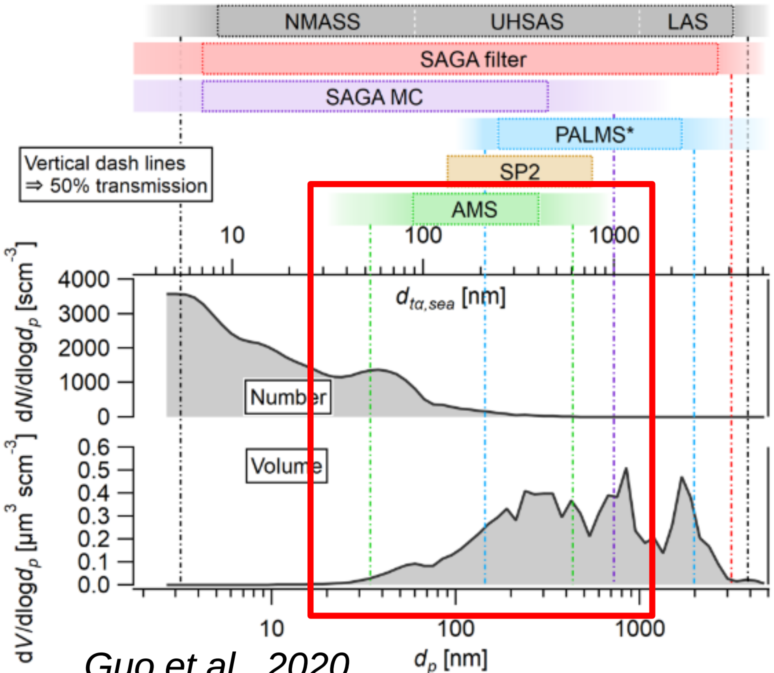
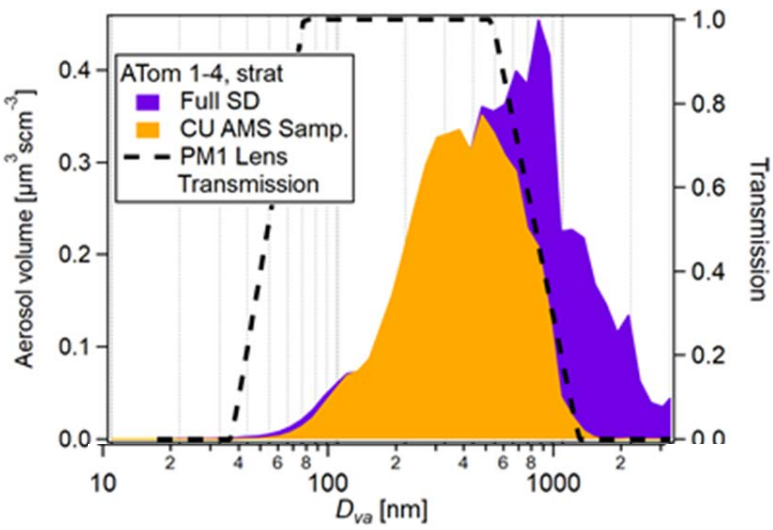


Guo et al., 2020

ATom 1-4 Stratosphere



- Size needs to be considered when comparing instruments (Guo et al., 2020)
- To better sample stratospheric aerosols, need better transmission for large particles w/o sacrificing small ones.

Introduction

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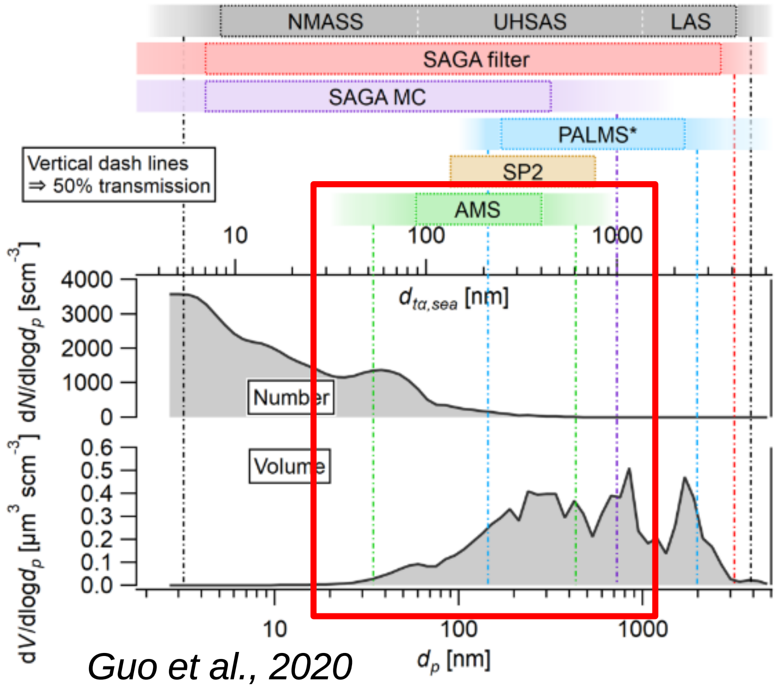

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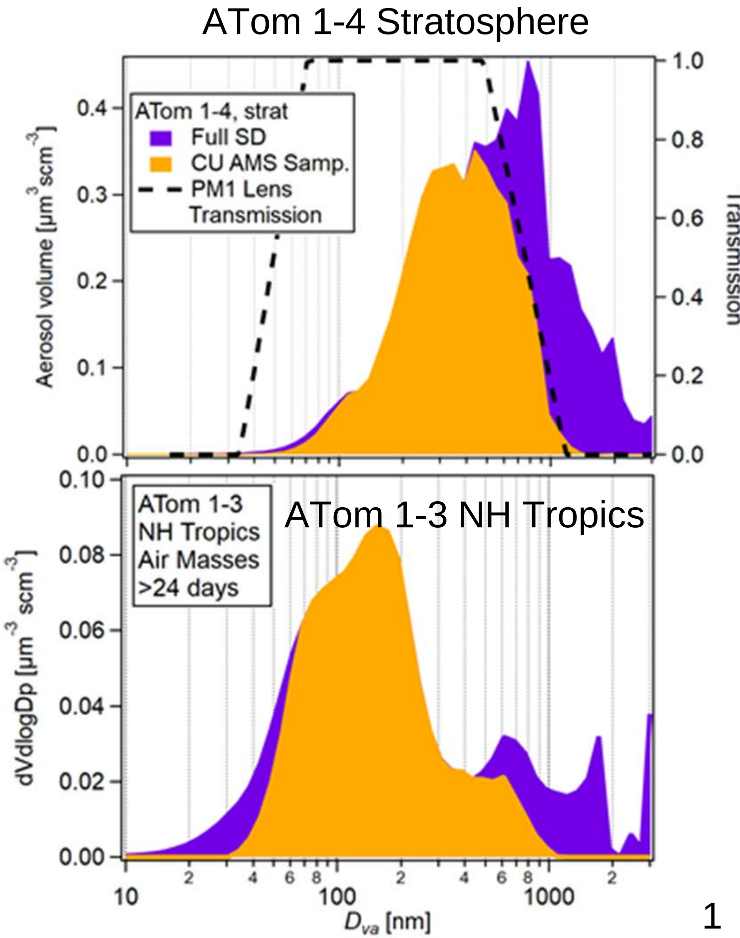

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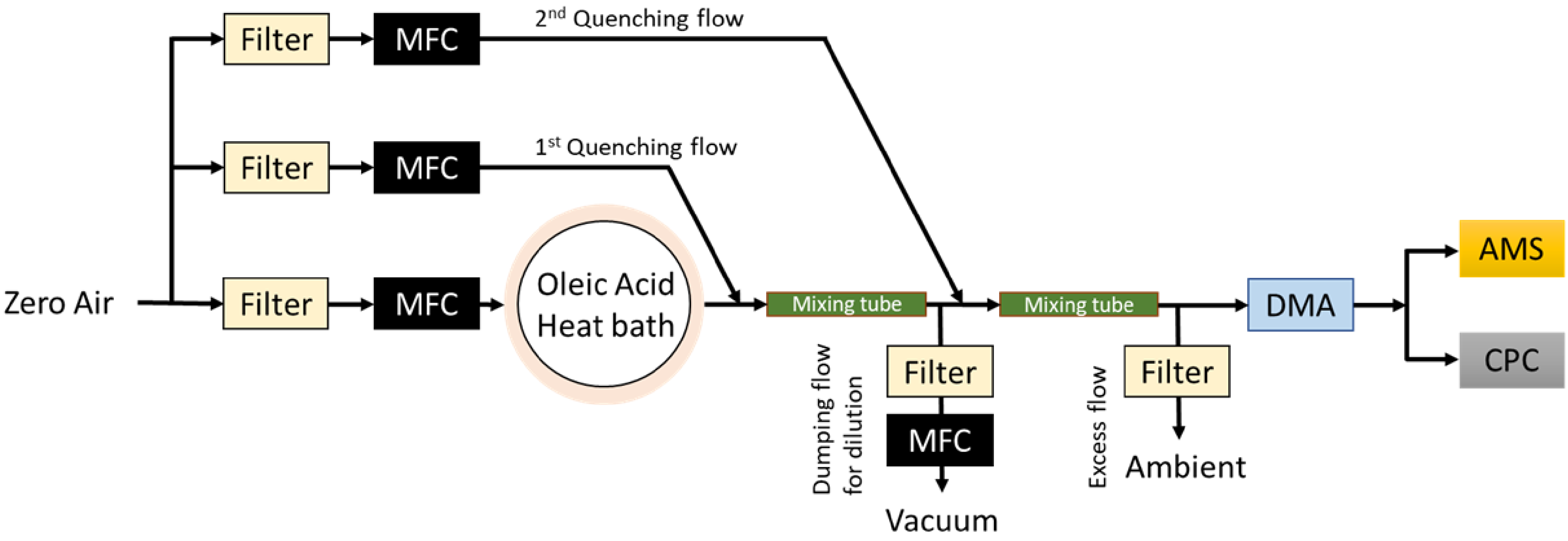
Small Particle Generator



- Objective is to generate monodisperse small particles (< 300 nm) w/o double charges.
- Evaporated oleic acids are condensed by quenching flow forming monomodal aerosols
- Tip: select larger size than the peak diameter to avoid doubly charged particles!
- Transmission efficiency was calculated comparing CPC and AMS mass.

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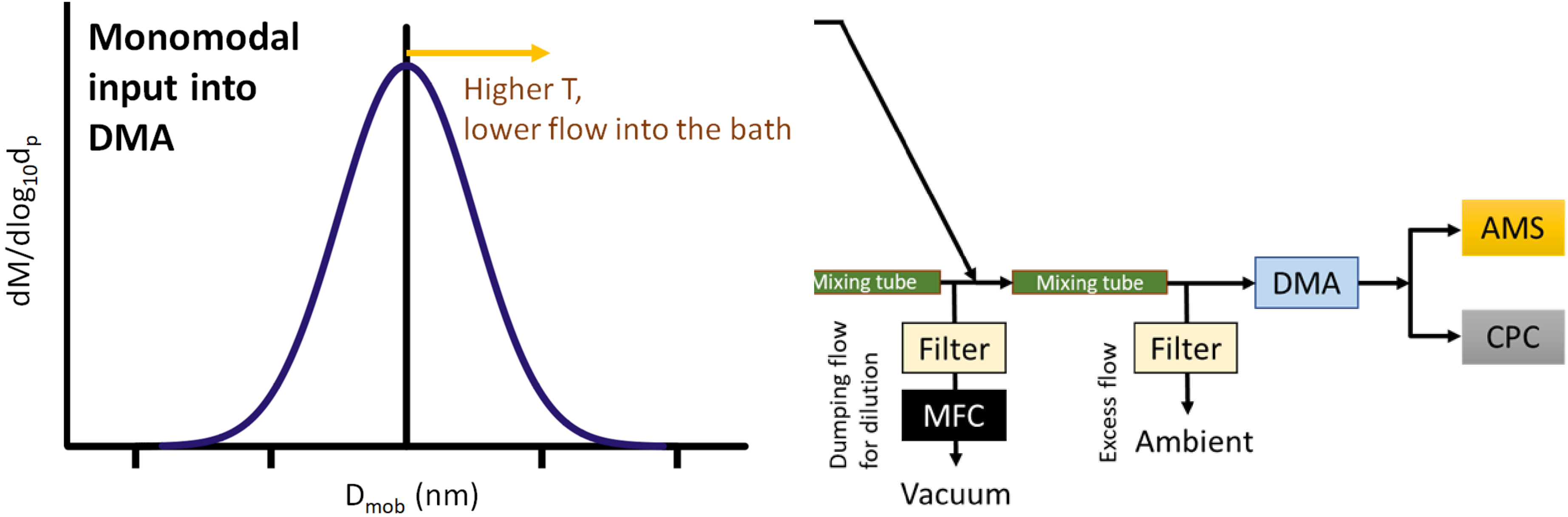

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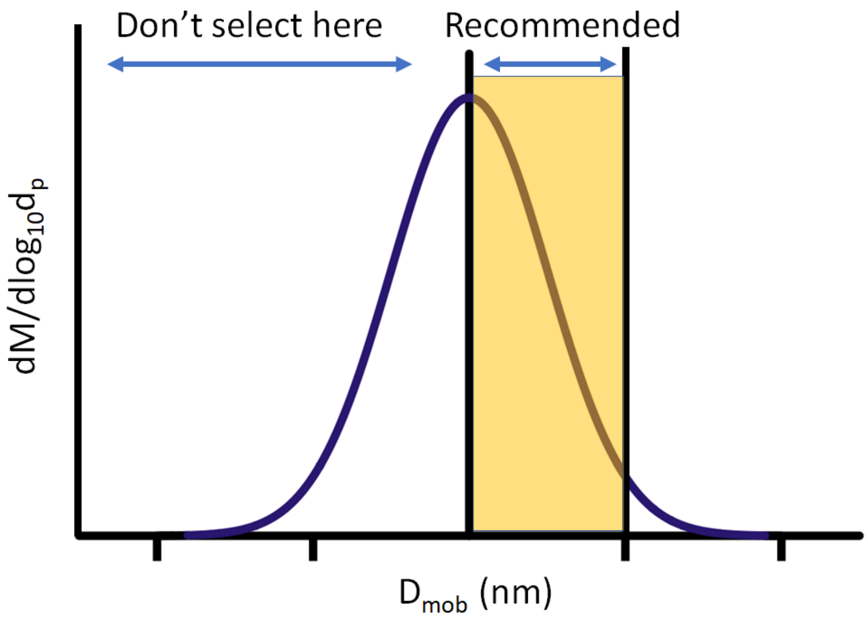

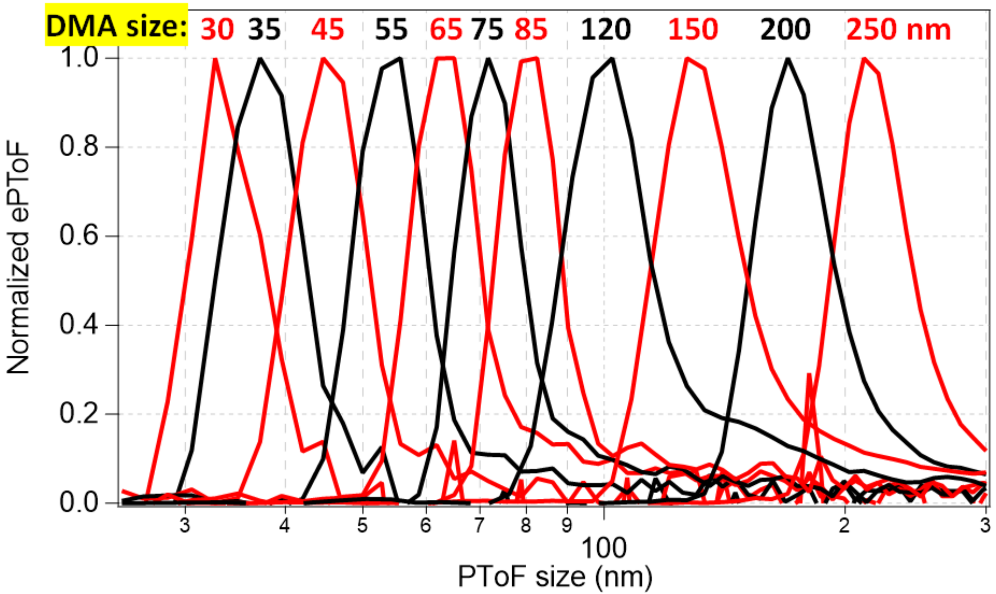

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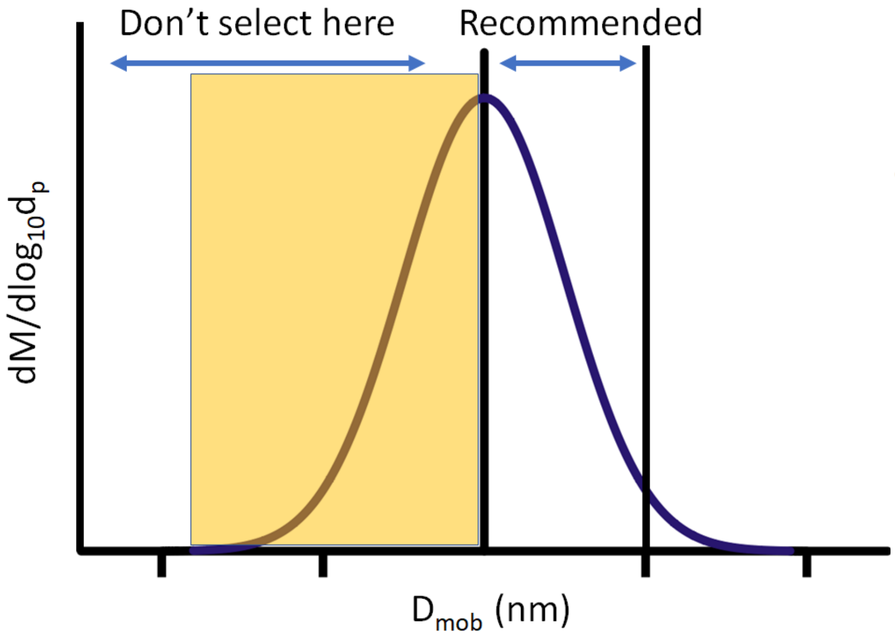

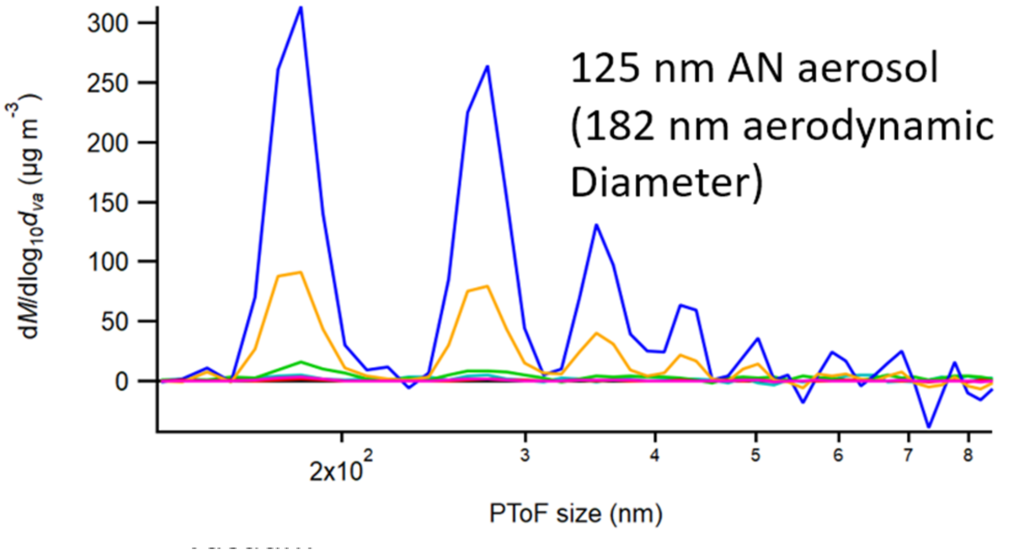

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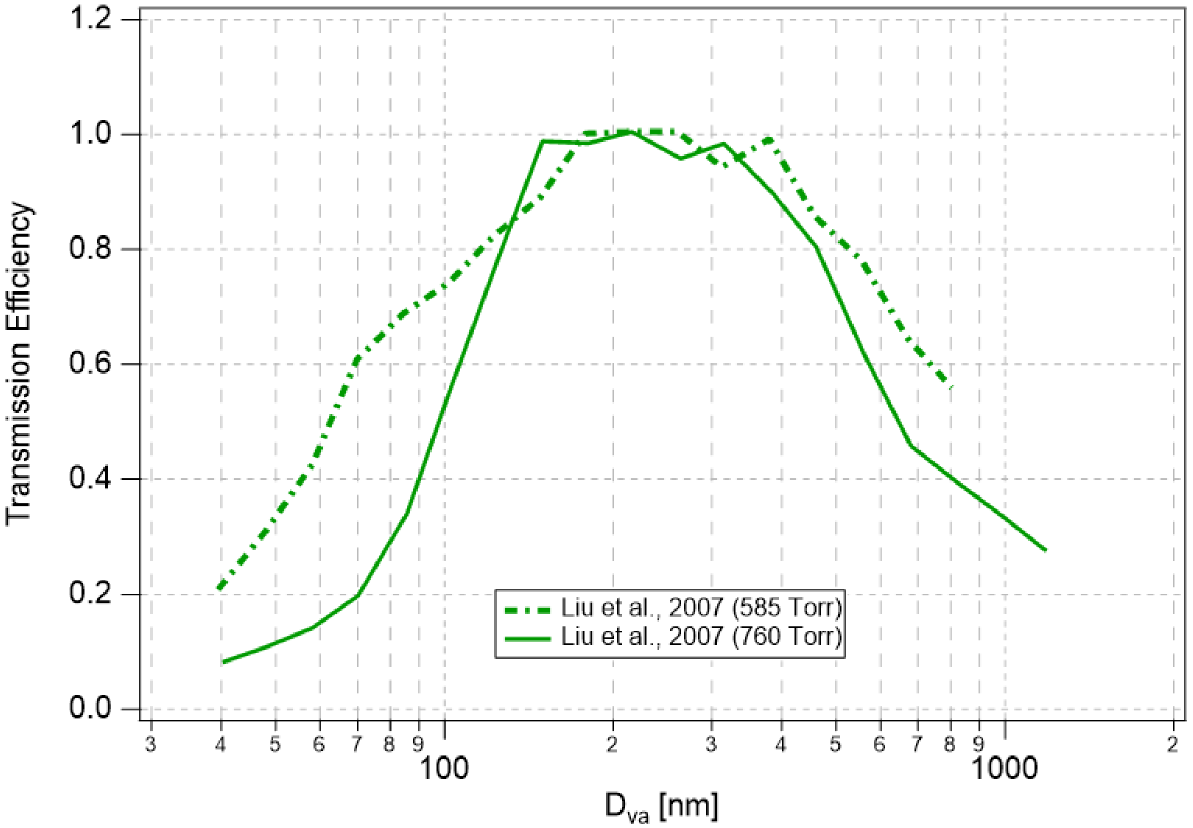
PM$_1$ Lens Transmission Efficiency (E_L)



- PM1 curve is slightly better at lower ambient pressure (Liu et al., 2007)

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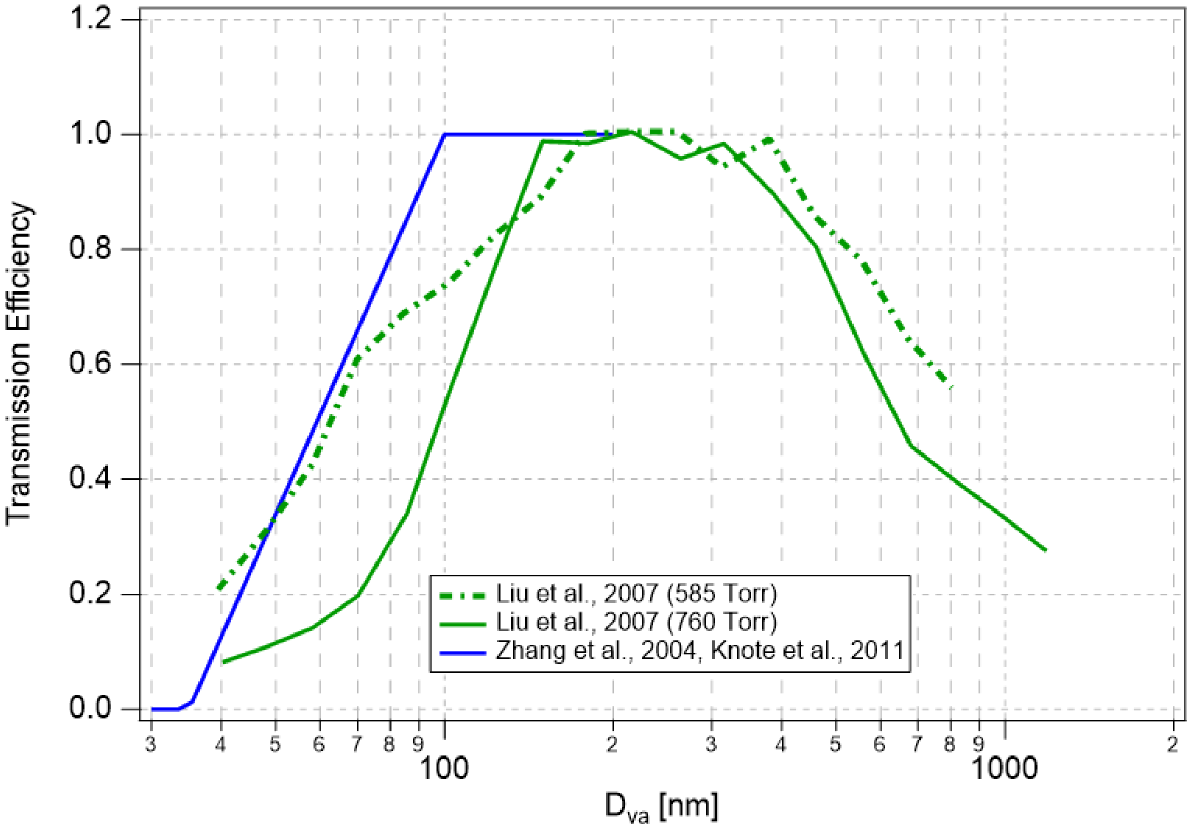

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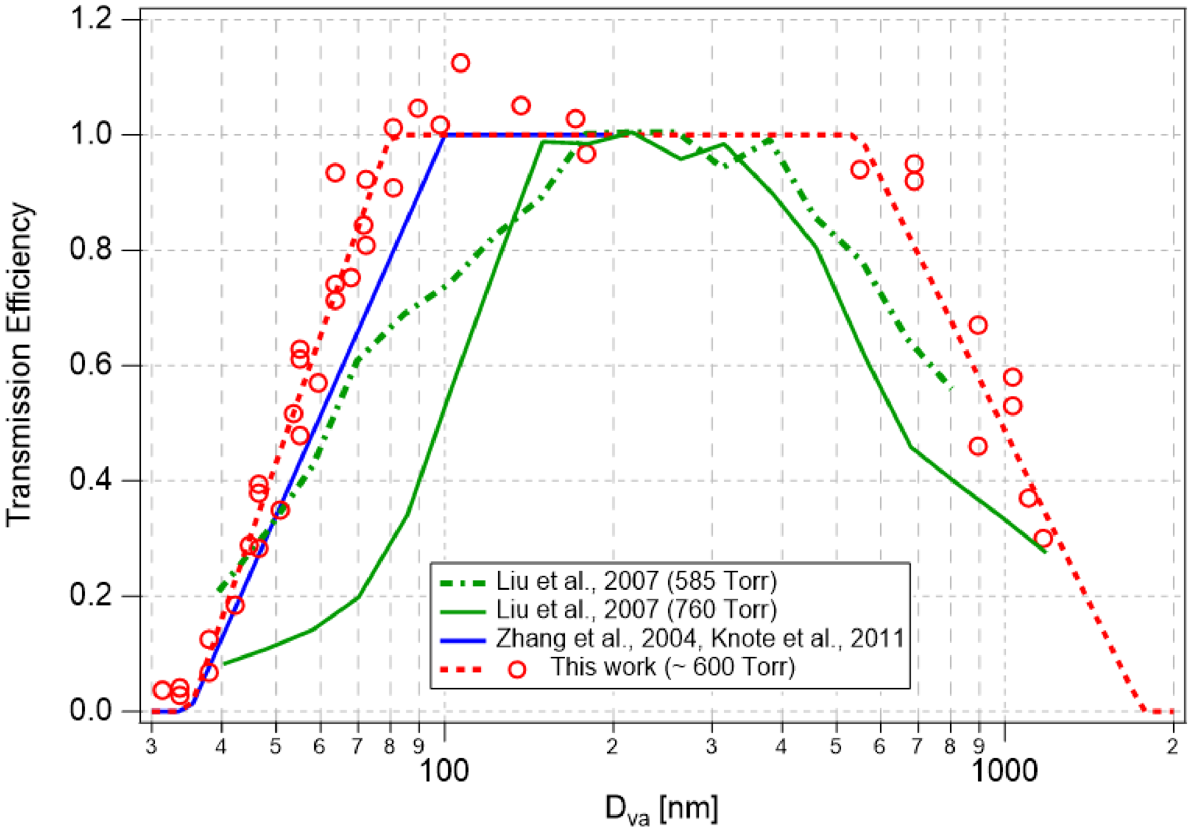
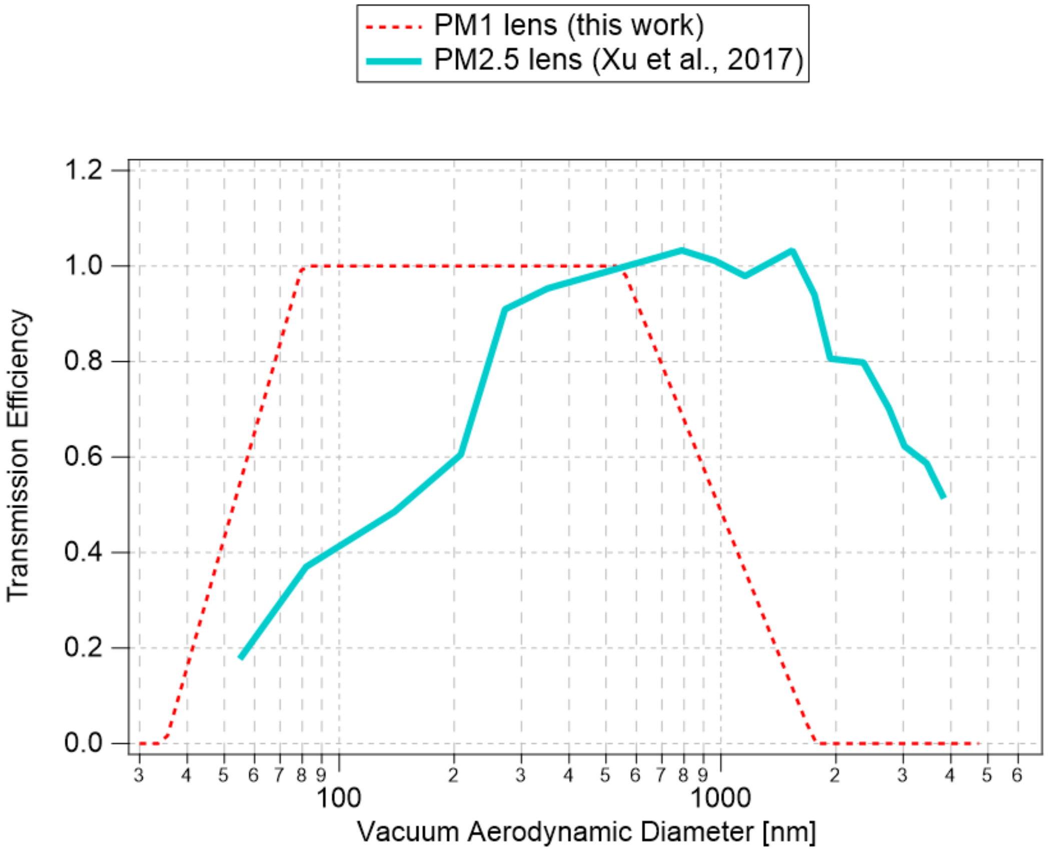


- PM1 curve is slightly better at lower ambient pressure (Liu et al., 2007)
- Zhang et al., 2004 determined low end TE during new particle formation event in Pittsburgh which shows higher TE.
- Our results are consistent with or slightly better than Zhang et al., 2004
- Oleic acid RIE = 3.5

$PM_{2.5}$ Lens Transmission Efficiency



- Xu et al. reported E_L curve for the new $PM_{2.5}$ lens showing much better transmission for large particles but much less transmission for small particles.

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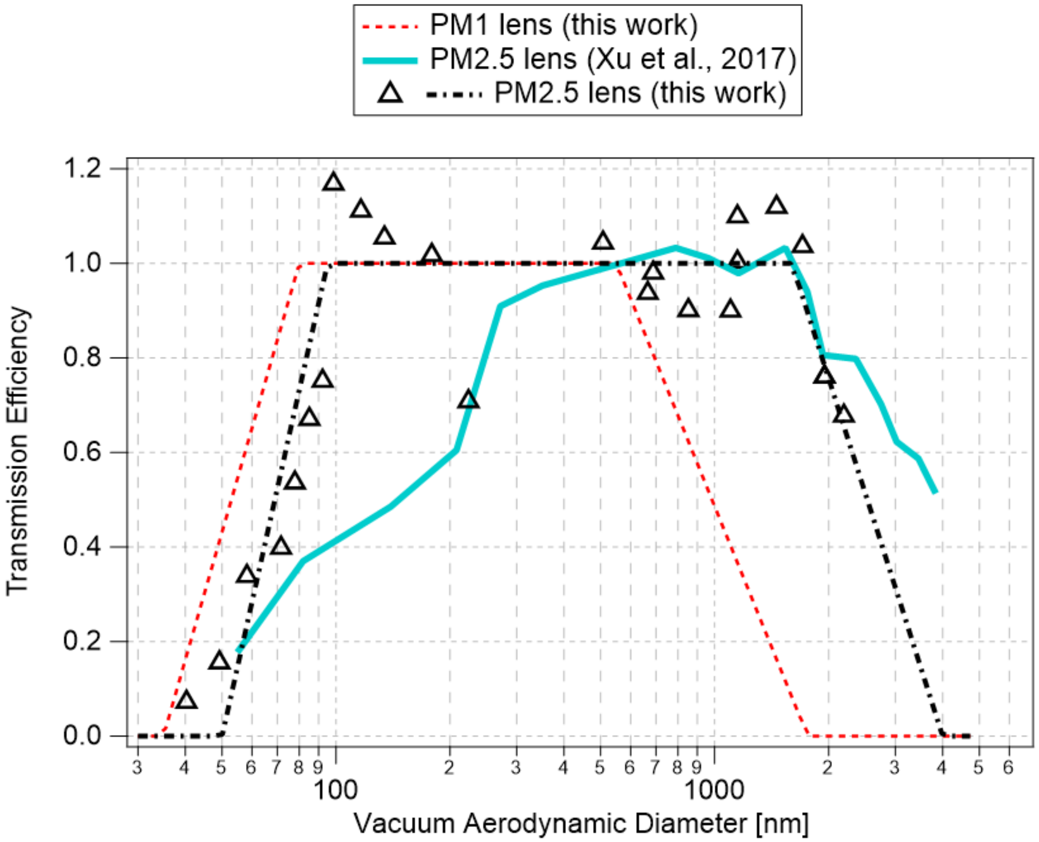

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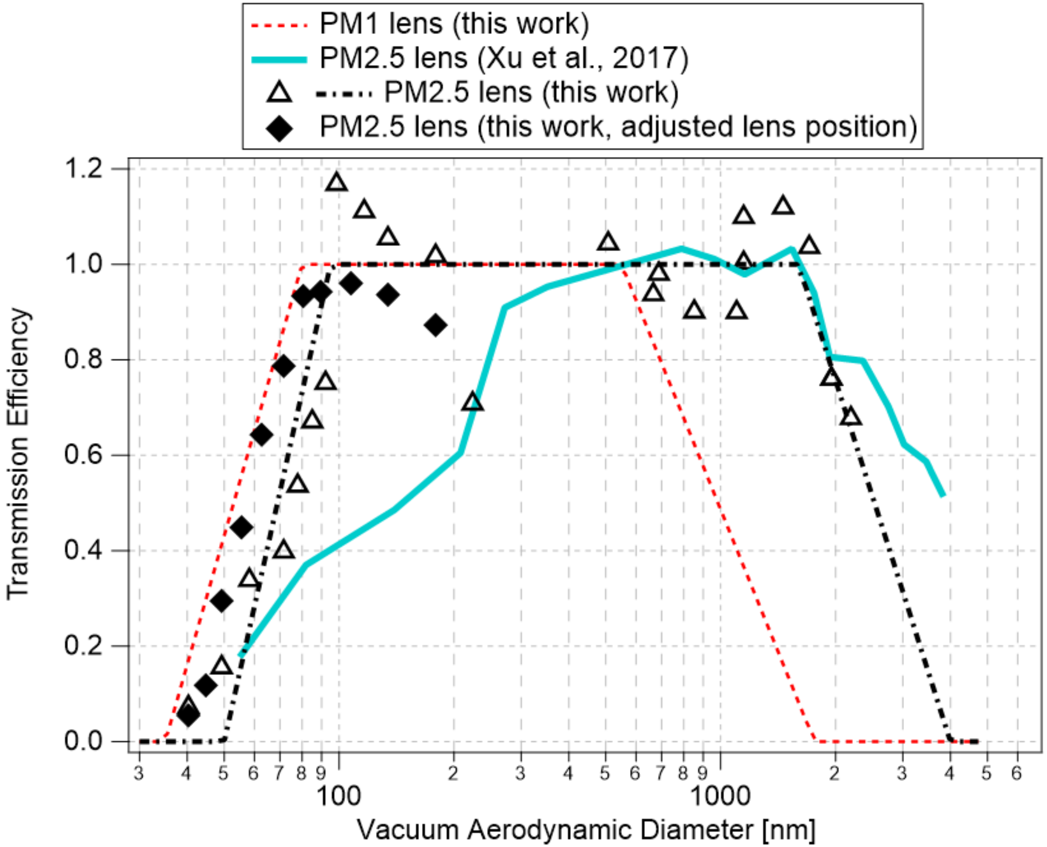

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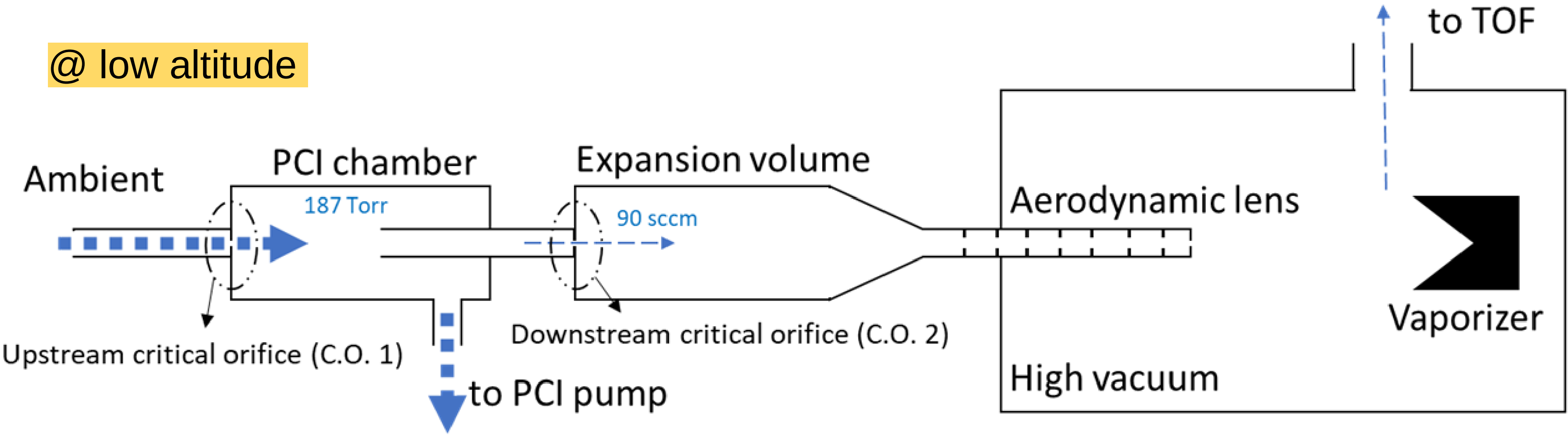
- Differences in setting: (1) Ambient pressure in Boulder is ~ 150 Torr lower (2) aircraft plumbing (3) Xu et al. used capture vaporizer and we used standard vaporizer.
- By adjusting the lens position, we could get even better transmission small particles.

For more info on lens stage, see Pedro's slides presented on 20 JAN 2021 11:00 EST

Pressure-controlled inlet (PCI) for aircraft platforms

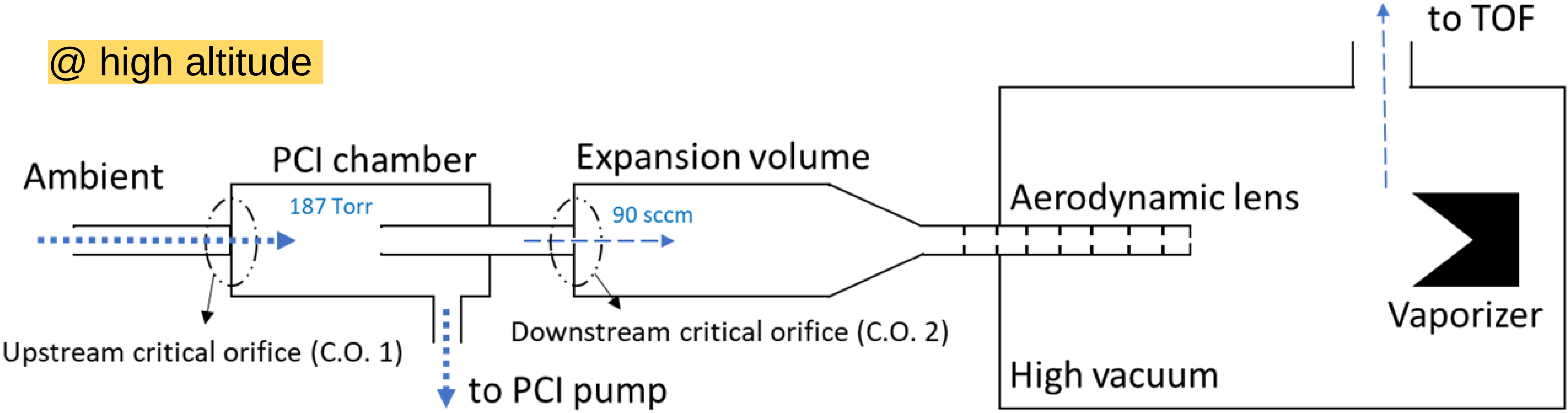
@ low altitude



- In aircraft platform, the ambient pressure keeps changing.
- PCI pump maintain constant pressure in the PCI chamber to keep the same AMS flow rate and lens pressure (Bahreini et al., 2008)
- Current version uses larger top/bottom C.O. (350/220 um) and expansion volume after PCI
- Current system can cover the typical DC-8 flight range (up to 13 km, Guo et al., 2020)

Pressure-controlled inlet (PCI) for aircraft platforms

@ high altitude



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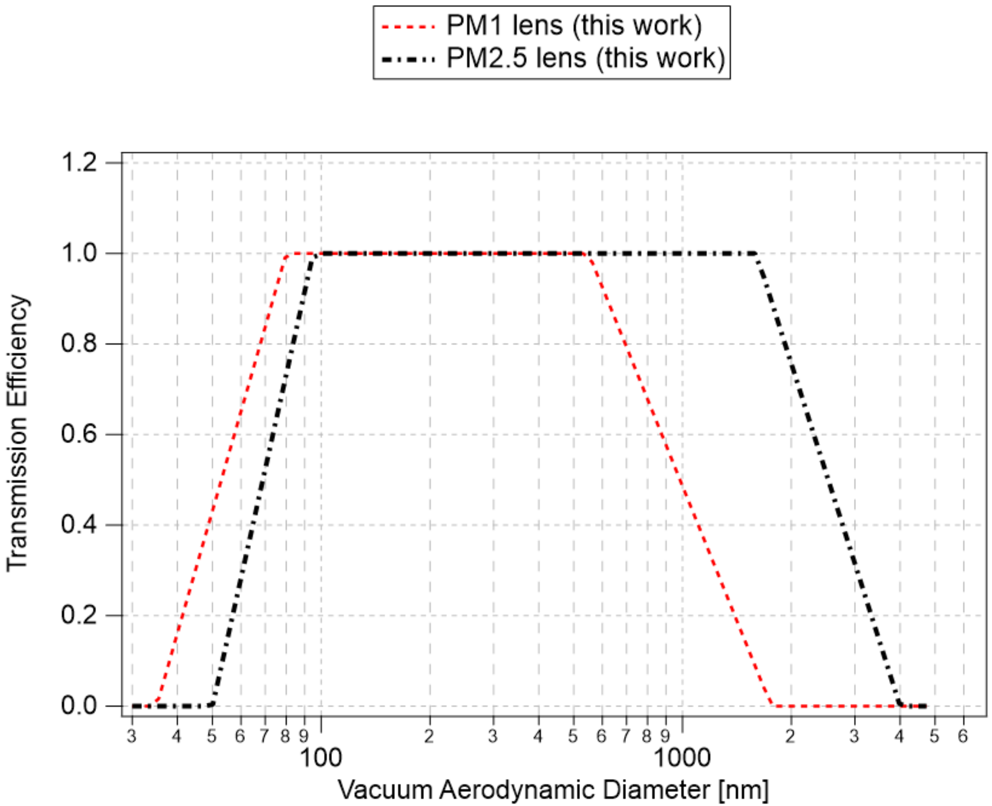
- Current system can cover the typical DC-8 flight range (up to 13 km, Guo et al., 2020)
- We aim to improve the system to work for PM2.5 lens up to 16 km with similar of better transmission range

Transmission Efficiency of $PM_{2.5}$ + PCI system



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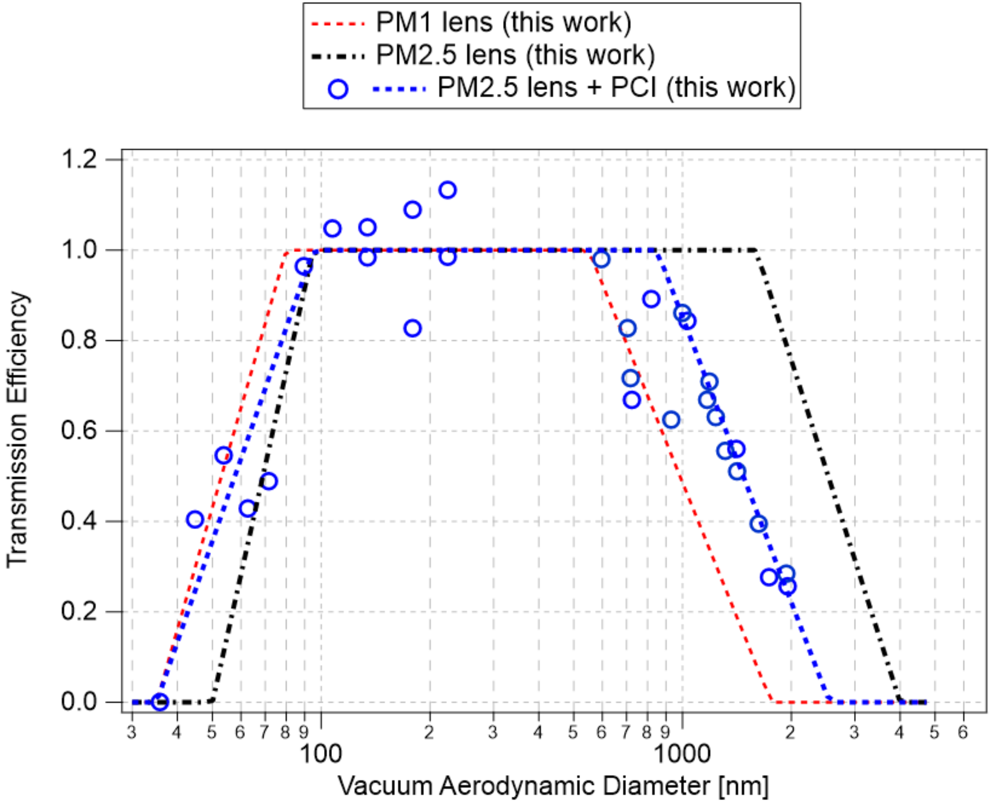

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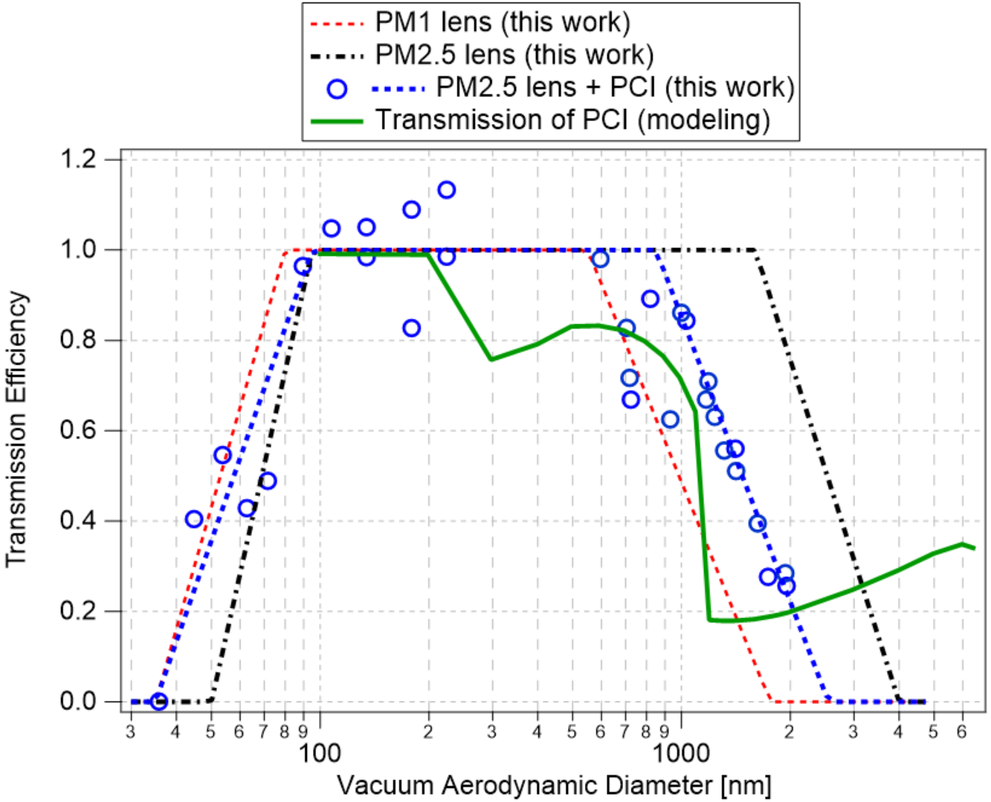

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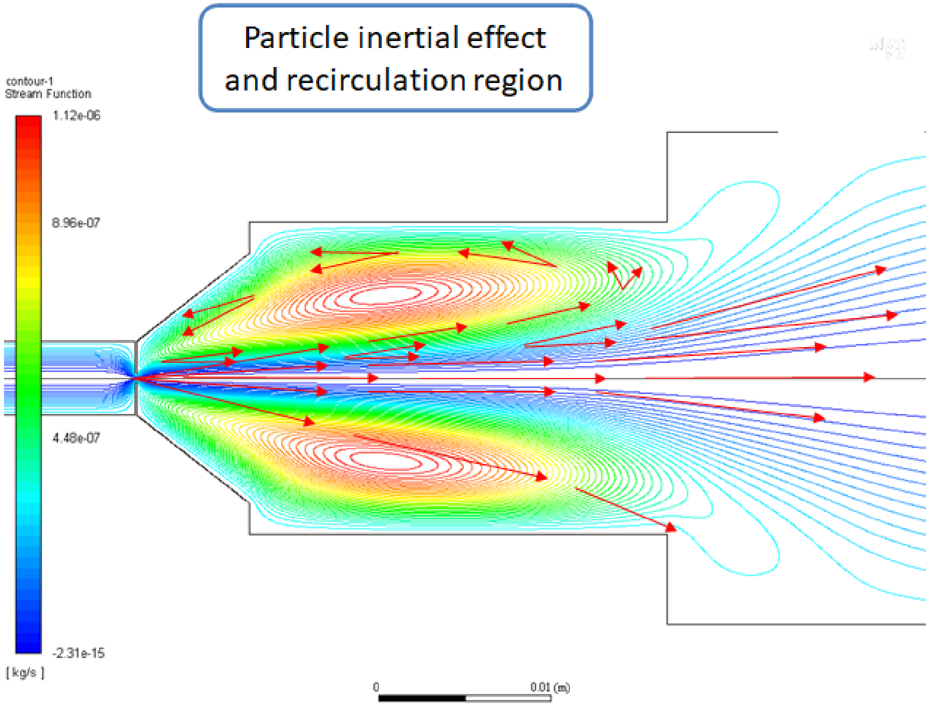
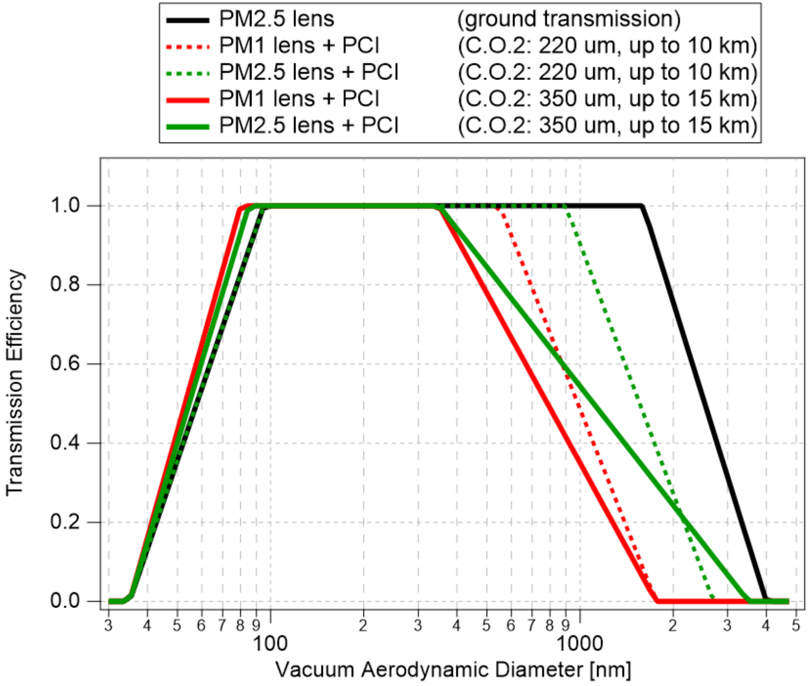


- Coupling with PCI worsen the transmission in the high end but still better than PM1 lens but slightly improve the low end.
- Fluid dynamic model captures some noisy feature of E_L.
- Large particle transmission is mostly limited by impaction loss followed by recirculation in the expansion volume due to higher lens pressure used for $PM_{2.5}$ lens.
- Better design of expansion volume for $PM_{2.5}$ lens may improve E_L in the high end.

Performance of Current PCI + $PM_{2.5}$ Lens System



- PCI setup with larger second C.O. (350 um), at ~15 km altitude, we achieved better transmission curve than PM1 lens.
- This be improved further redesigning PCI and expansion volume.

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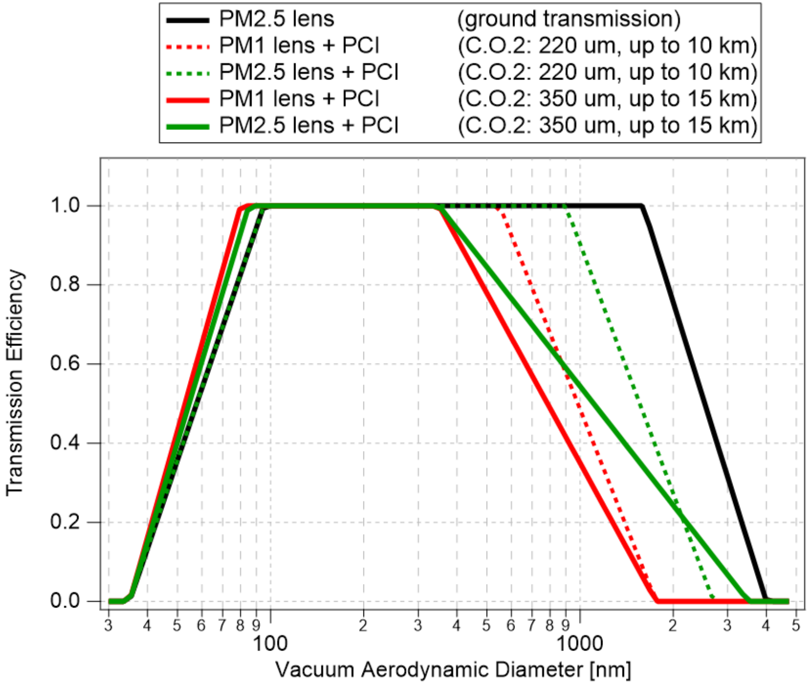

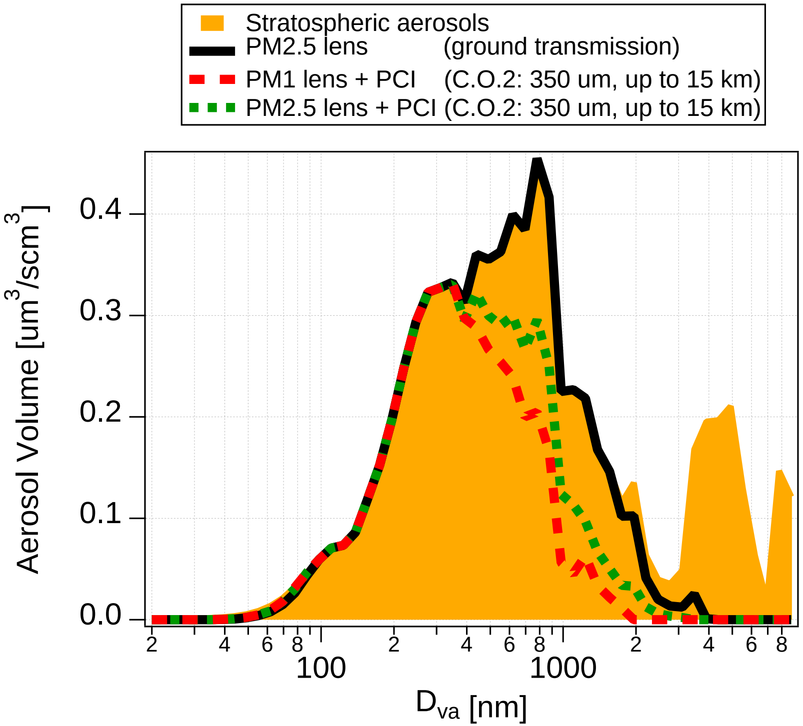

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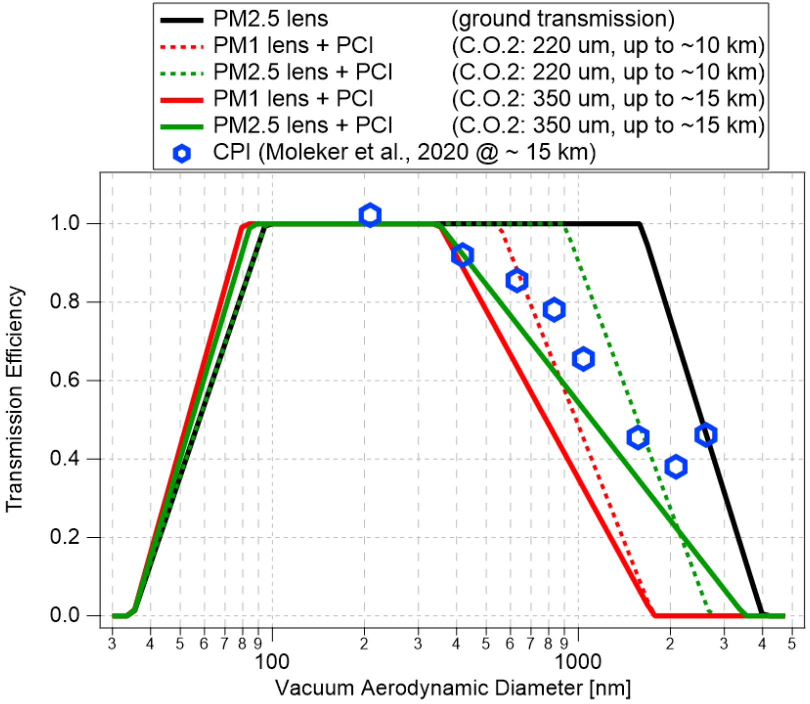

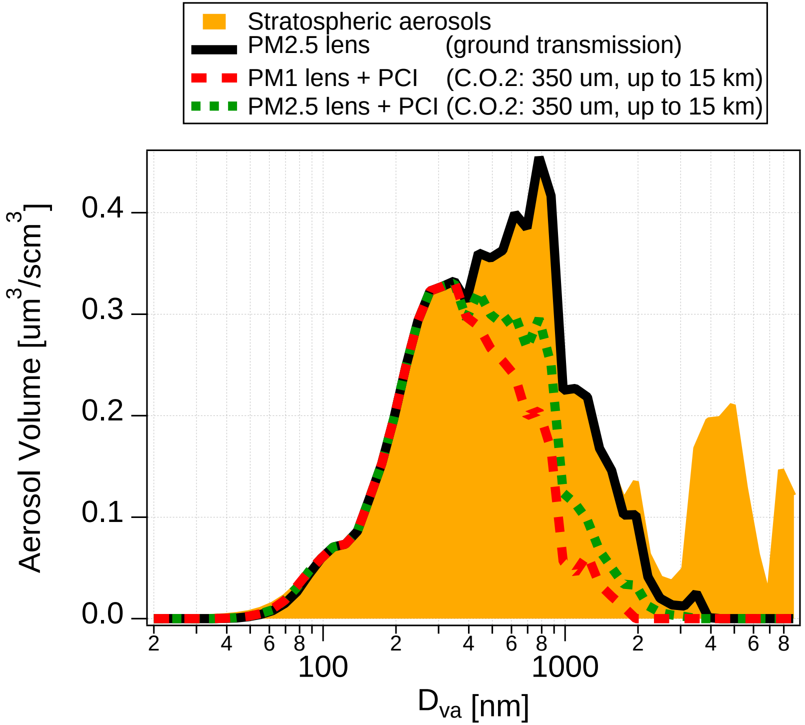

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Summary

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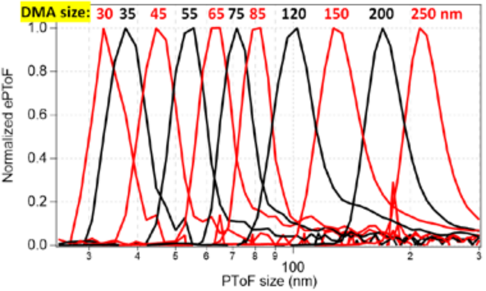
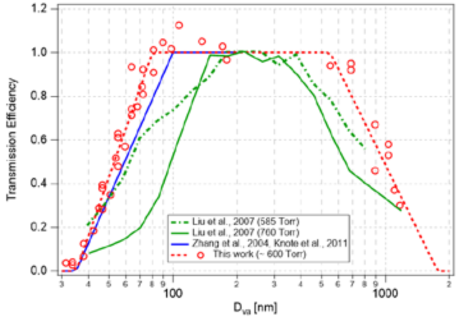
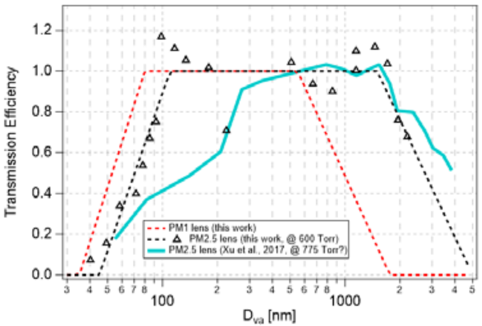


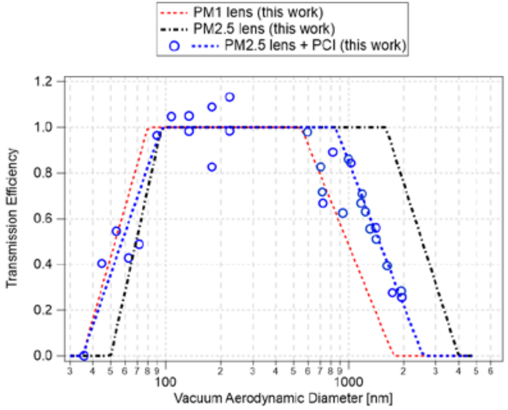
Can generate monodisperse aerosols (30-300 nm) without doubly charged particles.



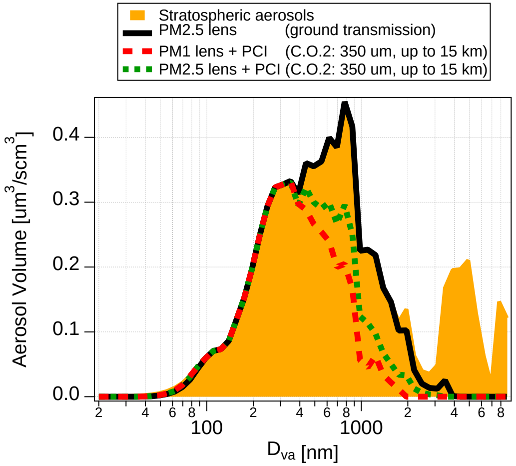
Observed better E_L of PM_1 lens than Liu in both low and high ends.



E_L of $PM_{2.5}$ lens may be better for small particle sampling than previously thought.



PM2.5 lens transmission is mainly limited by expansion volume.

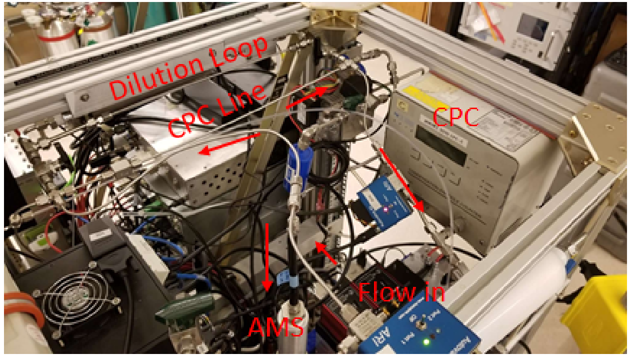


Current PCI with large C.O.2 can achieve better E_L than PM1 lens at ~15 km alt.

Backup slides

Basic Setup

Green: no PCI case
Purple: PCI installed



25x dilution line

Filter

CPC

1/8“ line

1/8“ line
1 lpm

0.1 lpm
1 lpm

1/4“ line

Ambient p
250 mbar

Straight tube
(1 orifice)
PCI (2 orifices)

1.1 lpm (no PCI)
2 lpm (w PCI)

3081
DMA
(w/ impactor)

Size select

Pneumatic
Nebulizer
(for salts)

Vapor
Supersaturation
particle
generator
(for organics)

Aerosol
Lens (2 mbar)

Particle Beam Chopper, for
clocking particle speed

AMS (High
vacuum)

Particle
Vaporizer

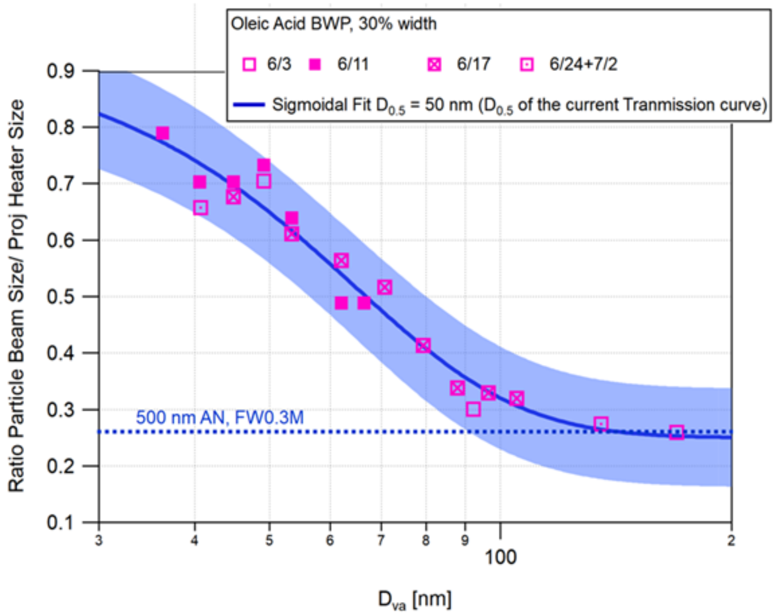
Three AMS measurements:

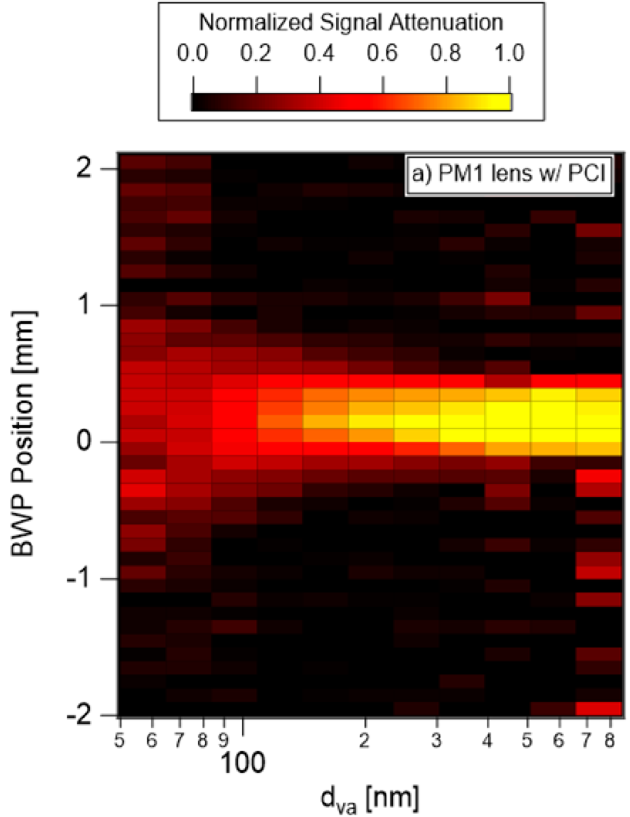
- Evaporation transient of single particles provides
  a) particles/cc
  b) Signal/particle (sensitivity cal)
  c) Size of particles from time correlated measurements

  Only works for large, volatile particles (>350 nm)
- Bulk (averaged) time correlated measurements provides size
- Bulk (averaged) total signal measurements provides mass

- Use all three AMS measurements for large particles
- Can only use only bulk size/mass for smaller particle
- Both AMS and DMA calibrated with PSLs
- Still use AMS measurement of size in case of evaporative losses (don’t happen in the lab with current setup)
- To prevent CPC saturation we use simple diluter for small particles (so we can measure up to 2e6/cc at e.g. 20 nm with a std TSI CPC)

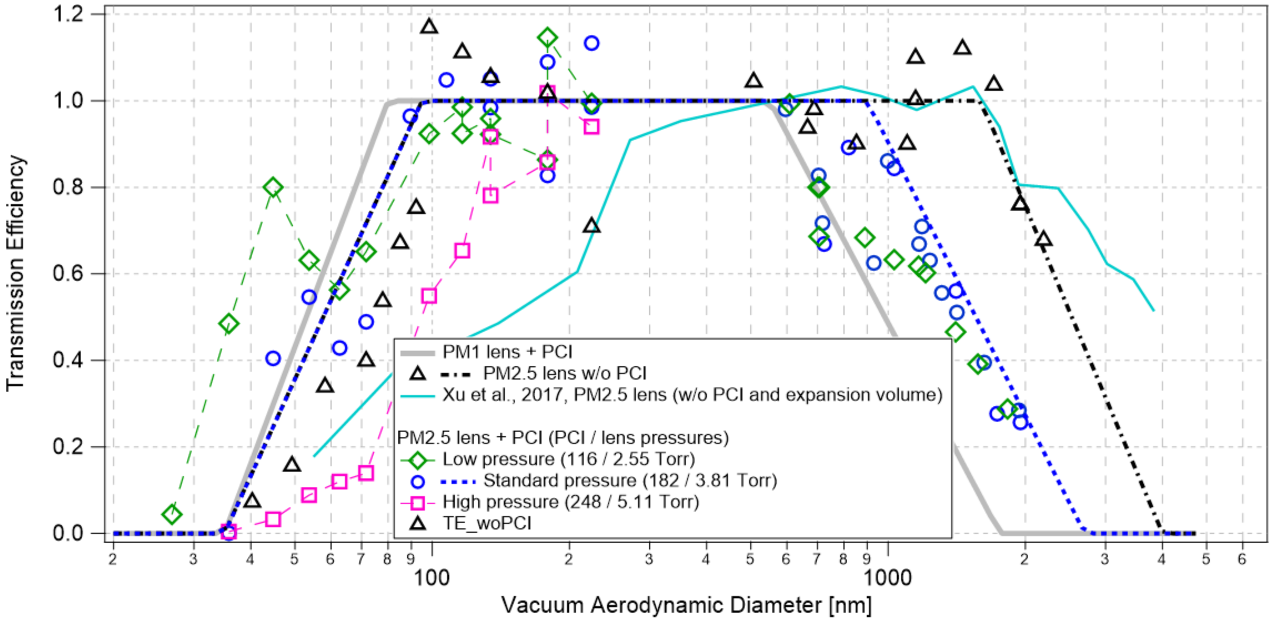
Small Particle Transmission



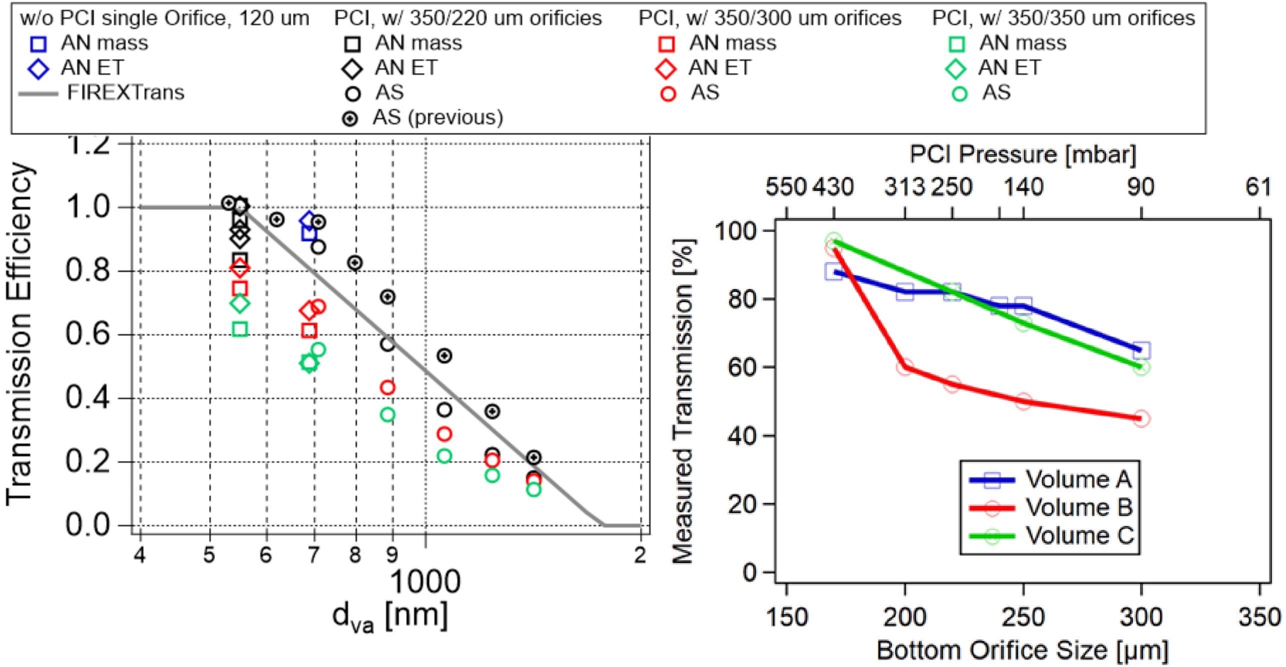


- Small particle TE decrease mainly due to the dispersion after the nozzle at the end of the aerodynamic lens
- The dispersion (beam width) was measured by 1-D and 2-D beam width probe (BWP) technique
- 2D BWP: ePToF & polydisperse aerosols
- The actual beam width may be smaller than shown above considering the width of BWP (0.5 mm).

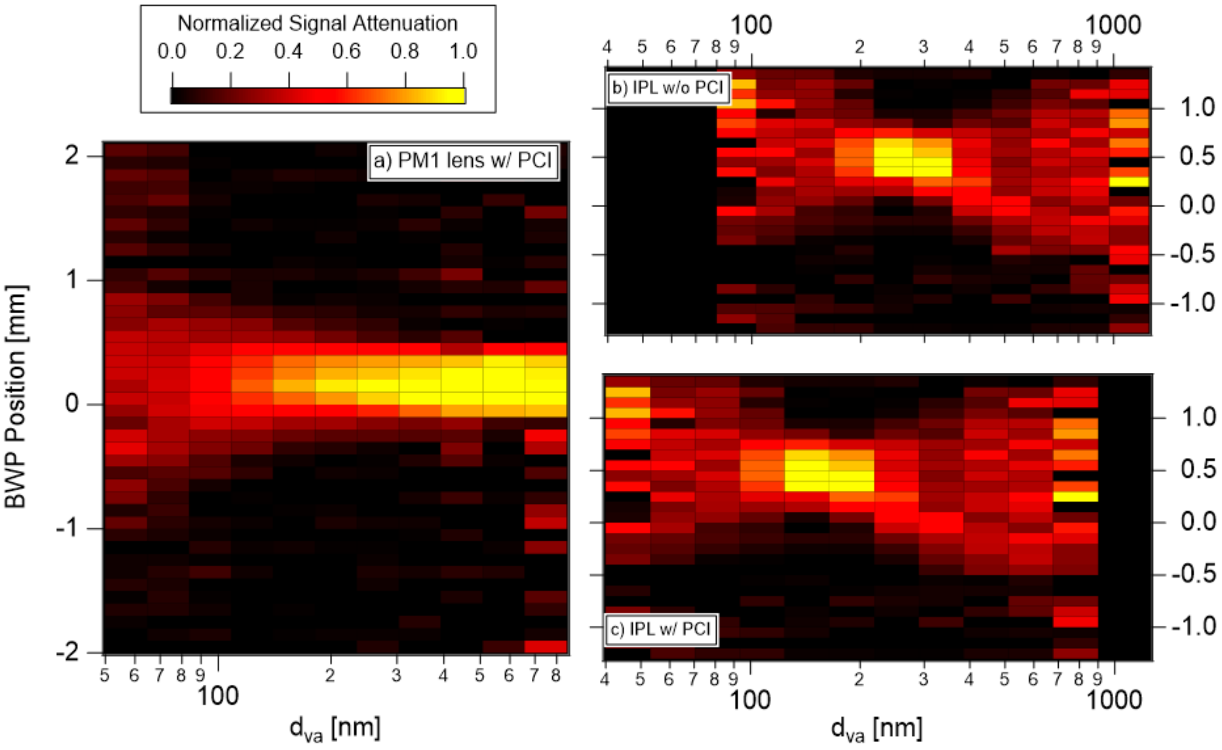
Lens Pressure and Small Particle Transmission



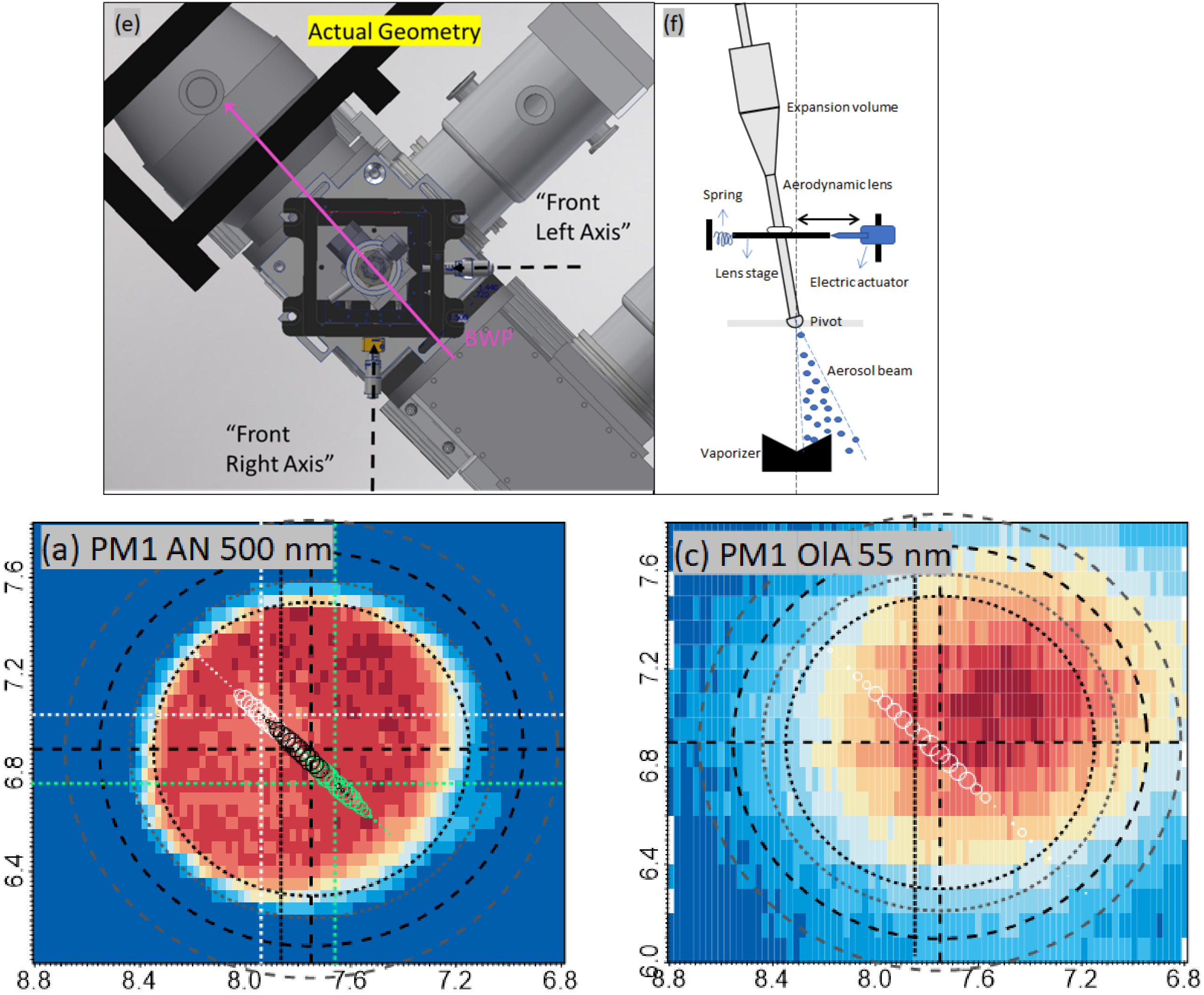
- IPL was designed to operate at ~ 3.8 Torr lens pressure
- But when airplane ascend beyond PCI’s limit, lens pressure starts to decrease
- Fortunately, ~ 33% lower lens pressure (green) shows better TE in low end and similar TE at high end
- ~ 33% higher lens pressure (magenta) shows much worse performance in the low end.



- With 350/220, standard lens P can be maintained up to 9.75 km
- Need lower PCI pressure (larger bottom C.O.) for operation in higher altitude
- Large particle TE degrades at lower PCI pressure so not suitable for TI3GER
- Thus trying PCI + PM2.5 lens

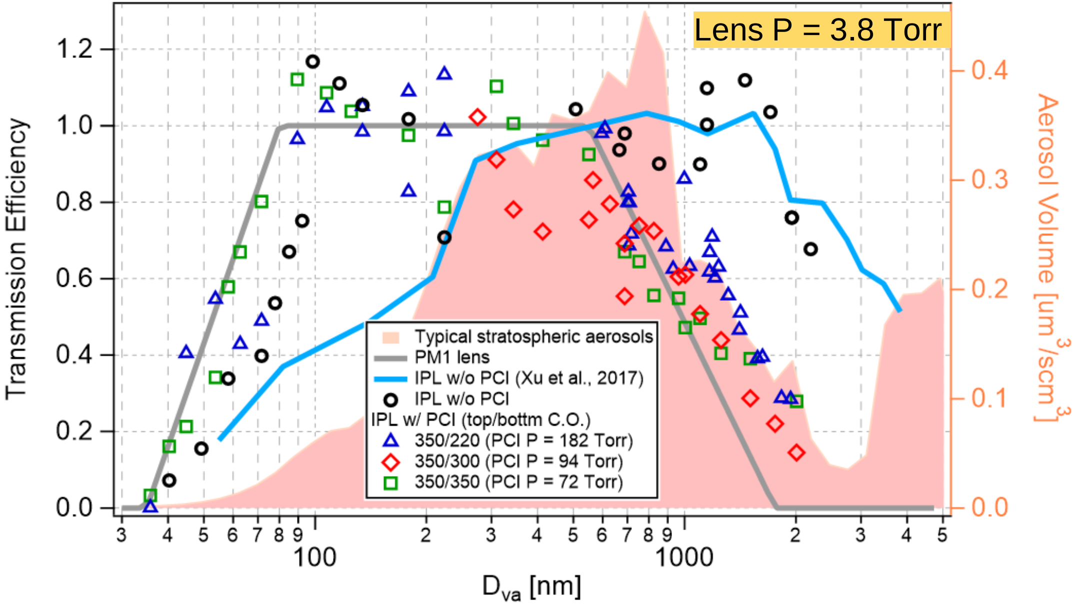


- Unlike PM1 lens, IPL focuses ~ 200 nm particle the most resulting in more broader sampling of aerosols.
- IPL lose both small and large particles due to dispersion at the nozzle at the end of the lens.
- Addition of the PCI shifts the beam focusing toward left which explains slightly better TE at low end.



(e)
Actual Geometry
"Front Left Axis"
BWP
"Front Right Axis"
(f)
Expansion volume
Aerodynamic lens
Spring
Lens stage
Electric actuator
Pivot
Aerosol beam
Vaporizer
(a) PM1 AN 500 nm
7.6
7.2
6.8
6.4
8.8
8.4
8.0
7.6
7.2
6.8
(c) PM1 OlA 55 nm
7.6
7.2
6.8
6.4
6.0
8.8
8.4
8.0
7.6
7.2
6.8

IPL+PCI: PCI pressure dependance of TE

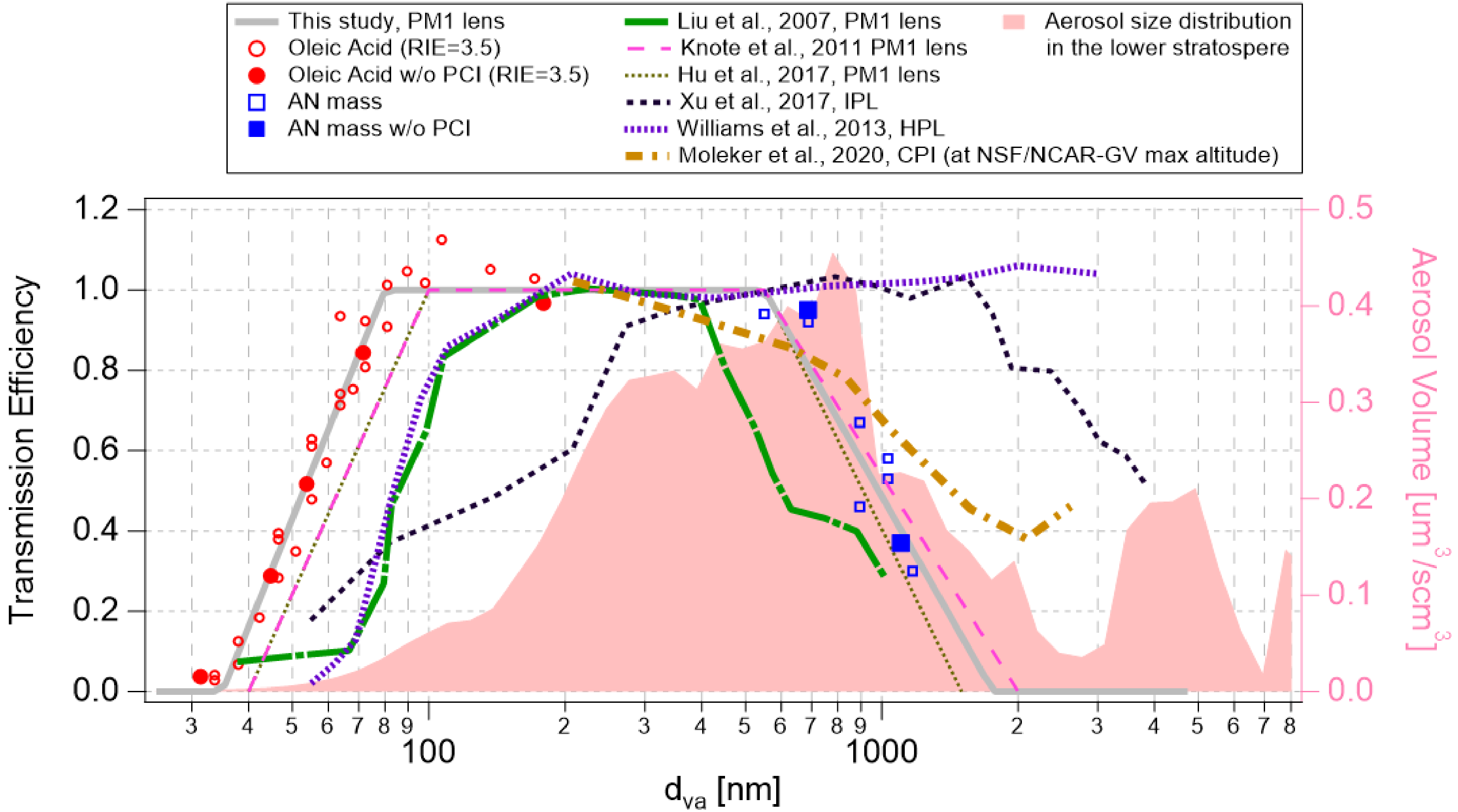


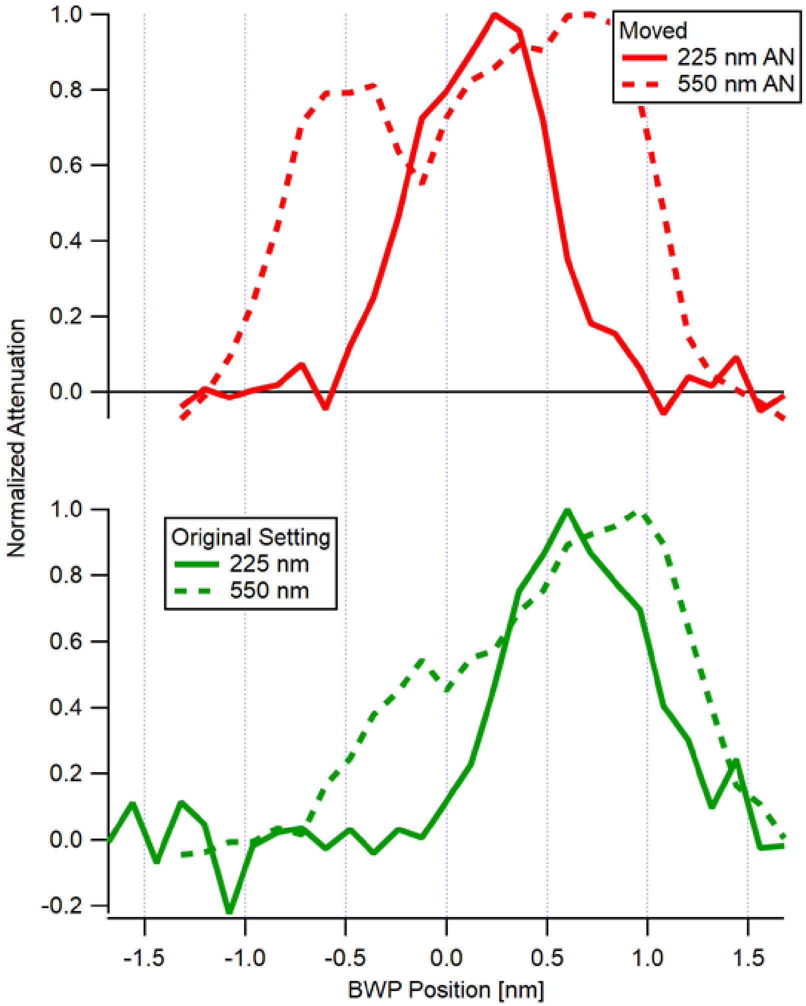
Ambient pressure
~ 137 Torr @ 12.5 km
~ 83.6 Torr @ 15.24 km

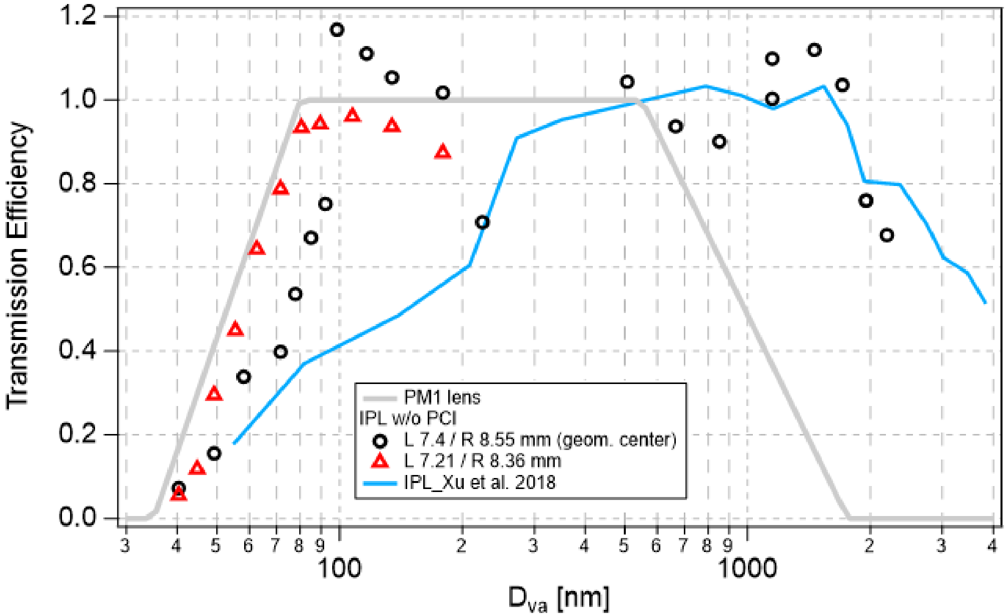
**In order to operate PCI without change of the lens pressure, PCI pressure needs to be lower than ambient pressure

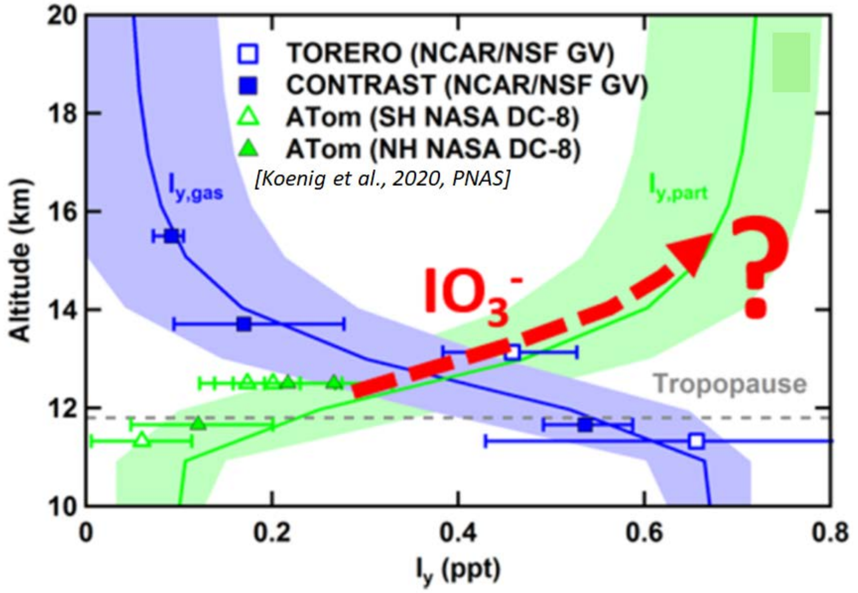
- 350/350 C.O. set up can tolerate ~ 72 Torr line pressure (~ 15 km alt.) with PM1 lens performance
- Even at higher alt. (thus lower lens pressure than 3.8 Torr), TE may stay similar but need further tests.
- We will test even larger bottom orifice (400 um).

PM1 Lens Transmission Efficiency




Moved
225 nm AN
550 nm AN
Original Setting
225 nm
550 nm
Normalized Attenuation
BWP Position [nm]
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5


PM1 lens
IPL w/o PCI
L 7.4 / R 8.55 mm (geom. center)
L 7.21 / R 8.36 mm
IPL_Xu et al. 2018
Transmission Efficiency
D_{va} [nm]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
100
1000



Technological Innovation into Iodine and GV Environmental Research (TI3GER) campaign : upto ~ 16 km