Development of a new high-altitude aircraft inlet coupled with a $PM_{2.5}$ lens for Aerosol Mass Spectrometer (AMS) measurements in the lower stratosphere

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Introduction and Background

1. Importance of particulate halogens in the stratosphere

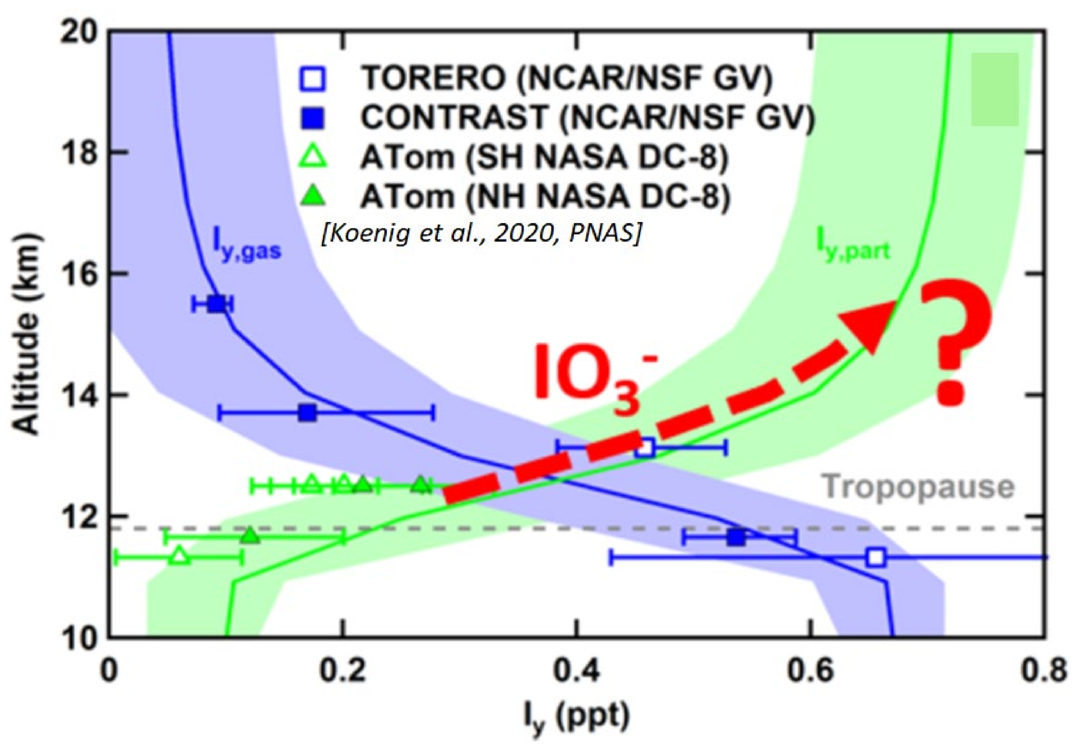

Figure 1. $I_{y,gas}$ (blue) dominates in the troposphere and decrease rapidly around the tropopause; $I_{y,part}$ (green) is taken as $I_{y,part}$ = 0.77 pptv – I_{ygas}. The figure was adapted from Koenig et al. [1]

- Stratospheric aerosols can lead to significant changes in Earth's radiative balance and play an important role in the destruction of the ozone layer. [2]
- Current gas phase measurements in the stratosphere can only constrain less than 10% of the total iodine budget which is 400-1000 times more effective at destroying ozone than chlorine. [1]
- Thus, we are aiming to measure aerosol chemical composition in the stratosphere to better understand the consistent ozone destruction in the lower stratosphere in the past 25 years. [3]

2. Pressure-controlled inlet

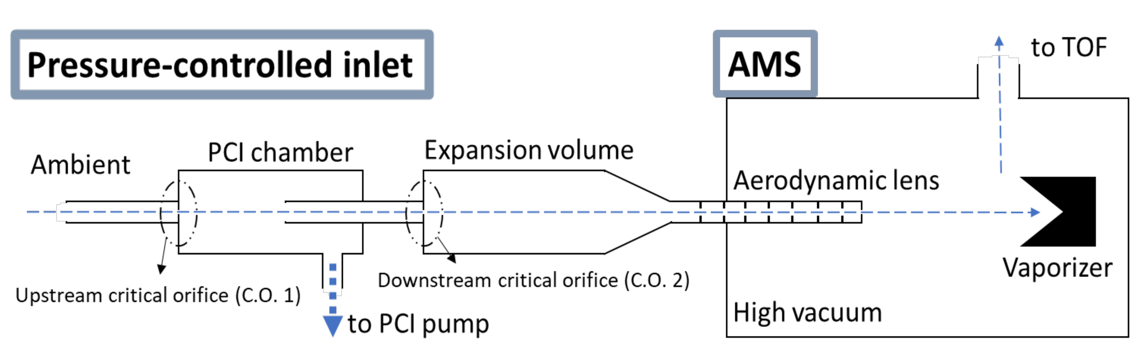

Figure 2. Schematic diagram of PCI and aerosol pathway (dotted line)

- AMS requires stable pressure upstream of aerodynamic lens which presents major challenge for its operation on airborne platforms, where the ambient pressure keeps changing depending on the altitude.
- In 2008, through a collaboration, the Jimenez group addressed this problem by building a PCI that maintains constant inlet pressure up to 7 km altitude. [4]
- PCI inlet consist of two critical orifices (C.O., top and bottom), pressure controlling pump in between the two C.O., and an expansion volume that minimize particle loss after bottom C.O.

3. Our goals in this work

- Current aerodynamic lens is capable of measuring aerosols smaller than 1 um (PM_1 lens). We aim to expand the measurable size range up to 2.5 um using a $PM_{2.5}$ aerodynamic lens, [5] to better quantify the larger accumulation mode aerosols in the stratosphere.
- Current version of PCI can be operated up to 13 km altitude. We are aiming to make it work up to 16 km altitude for sampling of aerosols in the lower stratosphere, with minimal aerosol loss by optimizing PCI design (i.e., C.O. size and expansion volume design).

Transmission Efficiency (TE) and Particle Loss in PCI

1. Standard PM_1 lens and $PM_{2.5}$ lens comparison

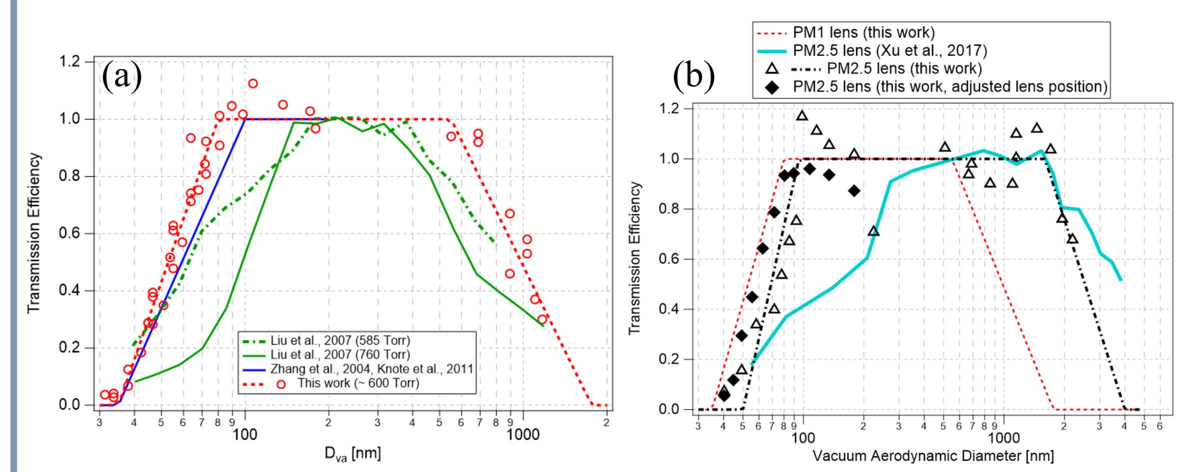

Figure 3. Measured transmission efficiencies of (a) PM_1 lens and (b) $PM_{2.5}$ lens and comparison with literatures

- Transmission efficiencies (TE) of PM_1 and $PM_{2.5}$ lenses were experimentally measured.
- Compared to previous literatures, our lenses showed better transmission. (Fig. 3a,b) Especially, $PM_{2.5}$ lens exhibits much better transmission for small particles (e.g., D_{va} < 200 nm) than Xu et al. [5] (Fig. 3b)
- Compared to PM_1 lens, our $PM_{2.5}$ lens shows similar transmission for small particle and much better transmission for large particles (e.g., D_{va} > 1 μm)

2. PM2.5 lens with and without PCI

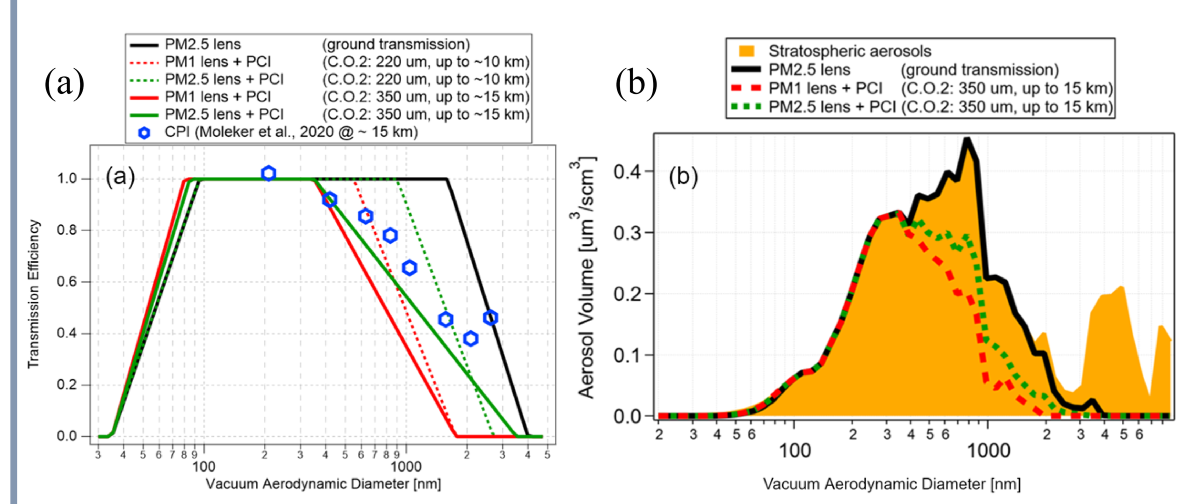

Figure 4. (a) TEs of PM_1 and $PM_{2.5}$ lens with PCI (solid and dotted lines) and performance of another type of aircraft inlet (marker) (b) measurable aerosols in the lower stratosphere with PM_1 lens and $PM_{2.5}$ lens.

- Current setup of PM2.5 lens + PCI system at ~ 15 km altitude has similar transmission to Molleker et al. [6] which used different type of aircraft inlet called CPI.
- However, the transmission is still worse than the ground transmission of $PM_{2.5}$ lens due to aerosol loss in the PCI.

3. Computational fluid dynamic modeling (CFD) results

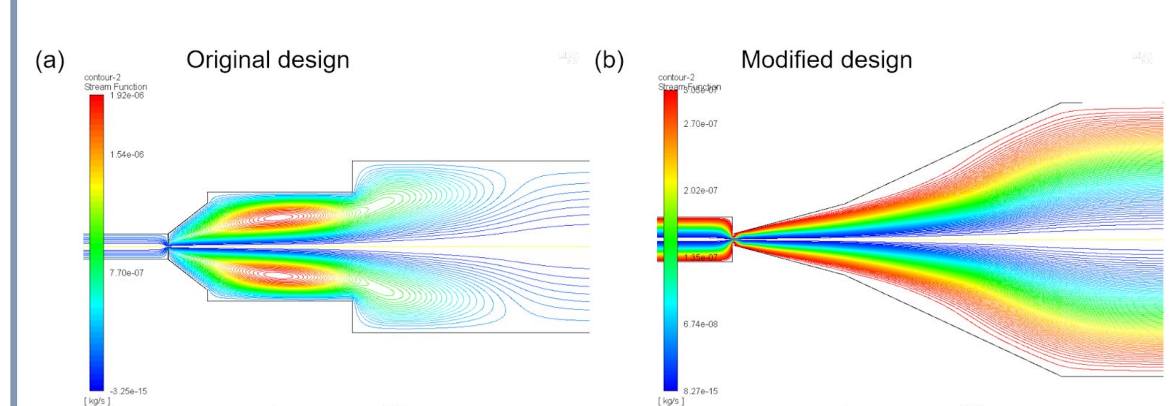

Figure 5. (a) current and (b) modified design of expansion volumes

- With $PM_{2.5}$ lens which operates at higher pressure than PM_1 lens, CFD model shows that current expansion volume generates recirculation of air after C.O.2 causing particle loss by impaction to wall.
- CFD model shows that the modified expansion volume significantly reduce recirculation implying it will improve overall aerosol transmission.

Techniques for Particle Beam Characterization

1. Beam Width Probe (BWP)

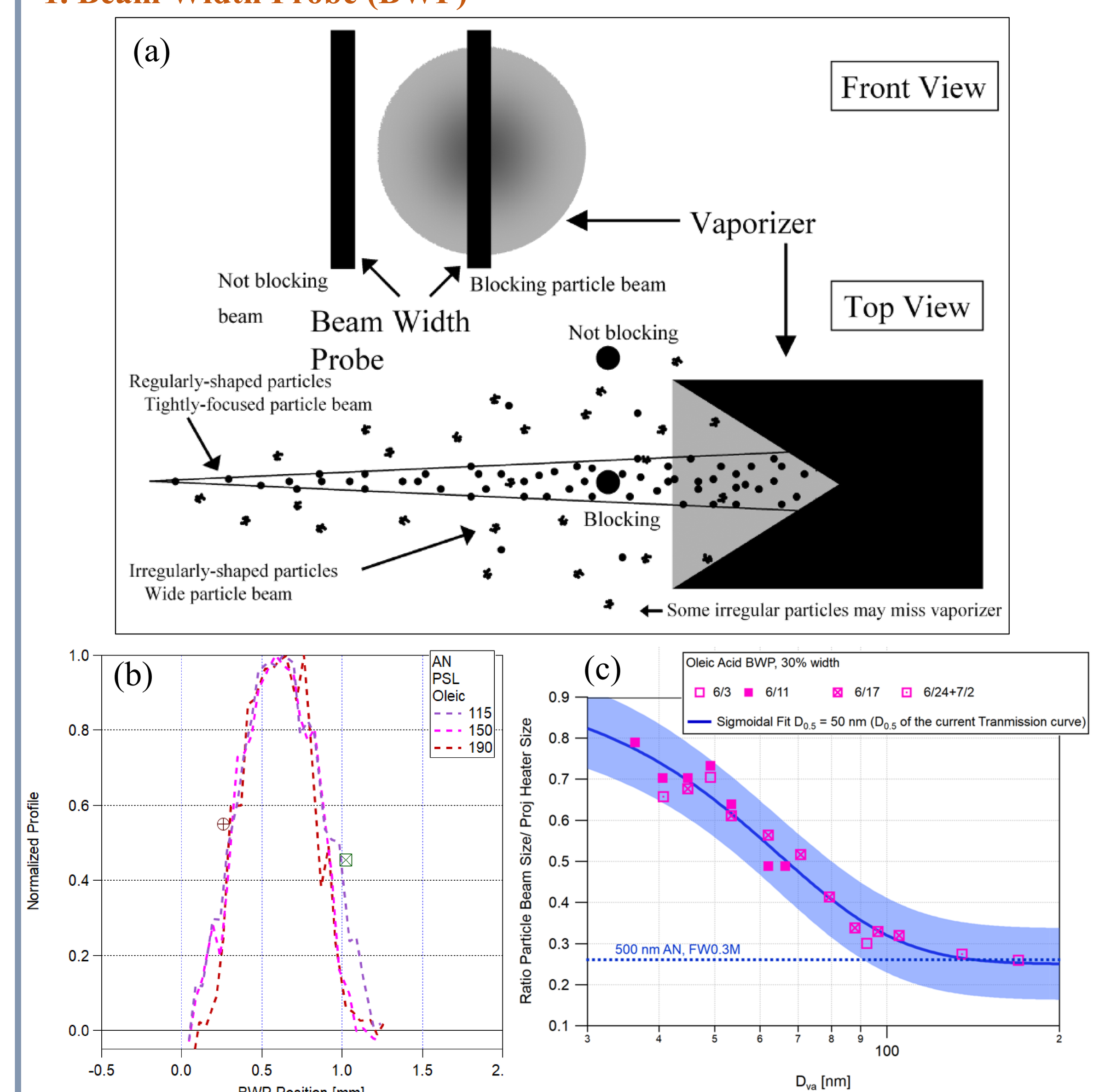

Figure 6. (a) Schematic diagram of BWP. Adapted from Huffman et al. [7] (b) Normalized signal attenuation profile for each BWP position (c) Estimated beam size of monodisperse aerosols.

- Characterizing aerosol beam is important in understanding the aerosol lens transmission. BWP provides direct diagnosis on how well an aerodynamic lens focuses aerosols.
- BWP measures aerosol beam width by scanning the cross section of the aerosol beam with a thin wire. (Fig. 6a) Beam signal attenuation at each BWP position is acquired to calculate the particle beam width. (Fig. 6b,c)

2. 2D Beam Width Probe (BWP) imaging

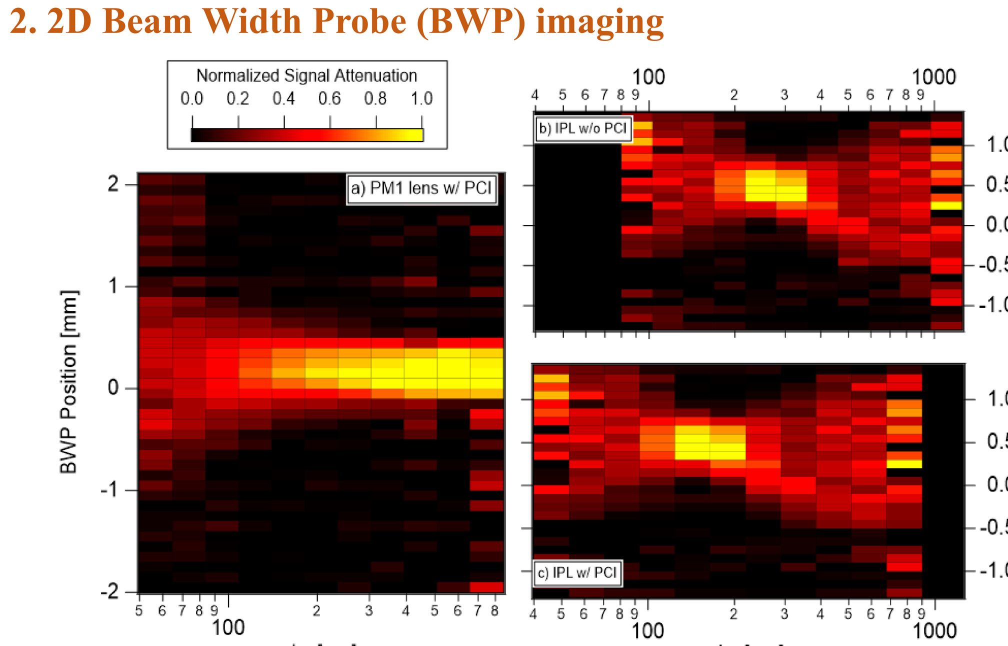

Figure 7. 2D BWP image of (a) PM_1 lens with PCI (b) $PM_{2.5}$ lens without PCI (c) $PM_{2.5}$ lens with PCI

- Size resolving capability of AMS, called PToF [8], enables signal attenuation measurement directly from polydisperse aerosols, (Fig. 7) when stable aerosol generation is provided.
- While PM2.5 lens has single focal point at ~ 200 nm D_{va}, PM1 lens has much broader focusing of large particles.
- Dispersion of small particles explain the lower TE while the TE of large particles are affected both by dispersion and loss inside aerodynamic lens.

Summary and Future Work

1. Summary

- Small particle TE of PM_1 lens and $PM_{2.5}$ lens measured in this work shows better transmission than previous literatures.
- Aerosol loss due to PCI is negligible in PM_1 lens + PCI system.
- PM2.5 lens produce broader beam width than PM1 lens but still the whole beam is captured by vaporizer resulting in TE ~ 1 up to 1.6 μm D_{va}.
- With $PM_{2.5}$ lens, large particles are mostly lost in the PCI (i.e., expansion volume) due to the recirculation air after C.O.2.

2. Future works

- Test TE with re-designed expansion volume.
- Test a high-pressure aerodynamic lens (HPL, Williams et al, [9]) with the new expansion volume.
- Characterize cross-sectional shape of beam (e.g., circular or elliptical) using rotation stage for BWP measurement.

Acknowledgements

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References

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