Modifying and Calibrating Low Cost Optical Particle Counters for Stratospheric Use

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Project Outline

- The goal of using optical particle counters with this project is to collect data for Dr. Candler, a professor studying the effects of particulates on hypersonic flows, and teams at the University of Colorado - Boulder and Embry Riddle Aeronautical University to get a better understanding of stratospheric turbulence and the impact that micron-sized particles may have on these regions of turbulence.

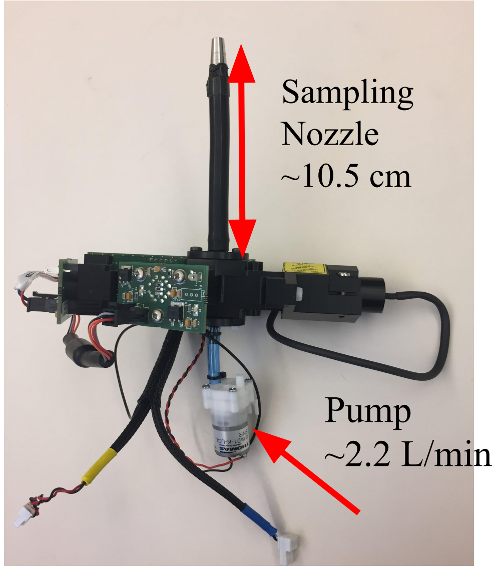
Background

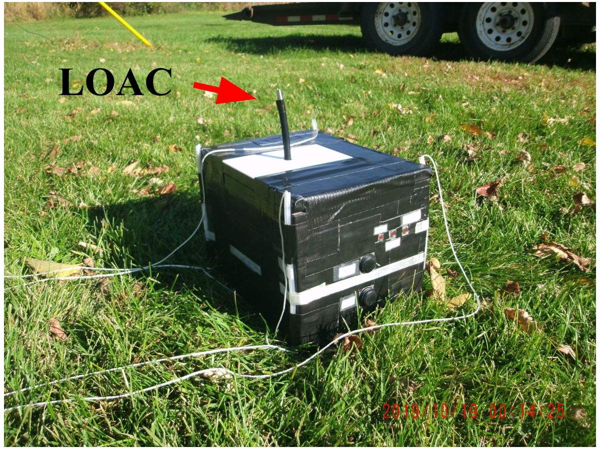
- Optical Particle Counters (OPCs) use laser light scattering to count small particulates on the order of one micron.
- Most OPCs are designed for ground based applications (e.g. indoor/outdoor air quality)

- **OPCs capable of stratospheric operation are expensive**, on the order of thousands of US dollars per commercial unit.

Background

- State-of-the-art for in-situ particulate measurements
- Designed/evaluated by Renard et. al. (2016)
- Calibrated at relevant pressure/temperature
- Over 130 flights in various measurement campaigns in Europe
- "High-cost" OPC (~$10k-$15k)
- **Most measurements show that particulates < 1 µm dominate size distribution at all altitudes**
- **UMN Goals for LOAC**:
  1. Use as an "in-flight reference" sensor for low-cost OPCs
  2. Gather quality data for particulate measurement database





Background

- Low-cost options for particulate sensors enable routine/multiple, potentially-non-recoverable balloon flights
  - No recovery requirements allow for flights over varying ground topology (e.g. mountains, oceans) where recovery would otherwise be difficult/impossible

Optical particle counters (OPCs) are capable of estimating particulate size distributions and are available at relatively low-cost (<$500)

Challenge: Low-cost OPCs are designed for ground based applications (e.g. indoor/outdoor air quality) but their evaluation under stratospheric conditions does not exist in the literature

Goal

For stratospheric ballooning capability:

1. Low-cost OPCs must be modified/recalibrated for stratospheric use
2. Quantitative study to characterize sensor output under the extreme conditions in the stratosphere (low-pressure, low-temperature)
3. Compare low-cost, commercial particulate sensors with available higher-cost atmospheric particulate sensors (e.g. LOAC - Light Optical Aerosol Counter)
    a. Are comparable quality measurements possible at a significantly lower cost?

Low Cost Optical Particle Counters Studied

- Low-cost OPCs
  - Alphasense OPC-N3 (~$500)
  - Alphasense R1 (~$150)
  - Sensirion SPS30 (~$50)
  - Plantower PMS5003 (~$30)
  - Honeywell HPM (~$30)
- Modifications made for stratospheric use:
  - Replaced fans with small rotary vane pumps (used to draw air samples) to maintain adequate volume flow rates in stratosphere
  - 3D printed sleeves to minimize disturbances near inlet and to connect inlet tubes and pumps to originally-fan-based sensors
- **Key notes so far:**
  - All sensors struggle to operate in stratosphere
  - Alphasense OPC-N3 has best ground calibration results
  - Sensirion SPS30 has been most promising during flights

Alphasense OPC-N3

Plantower PMS5003

Sensirion SPS30

Honeywell HPM

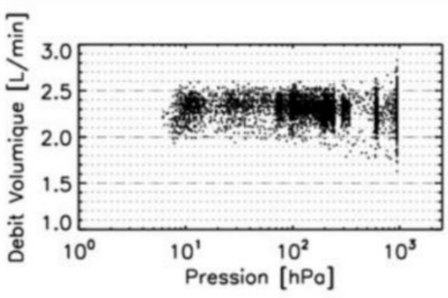
Alphasense OPC-R1

Low Cost Optical Particle Counters - SPS30

- **As of May 2020, the SPS30 was chosen as a main candidate based on its promising operation in the stratosphere**

- 3D printed casing for pump and sampling nozzle attachments (~$10)
- Thomas G.D. 6/01-K-LCL rotary vane pump (~$50)
- Silicon rubber anti-static tubing sampling nozzle (~$10/ft)

Data from Vignelles (2017) showing the Thomas G.D. pump maintaining constant volume flow at low-pressures

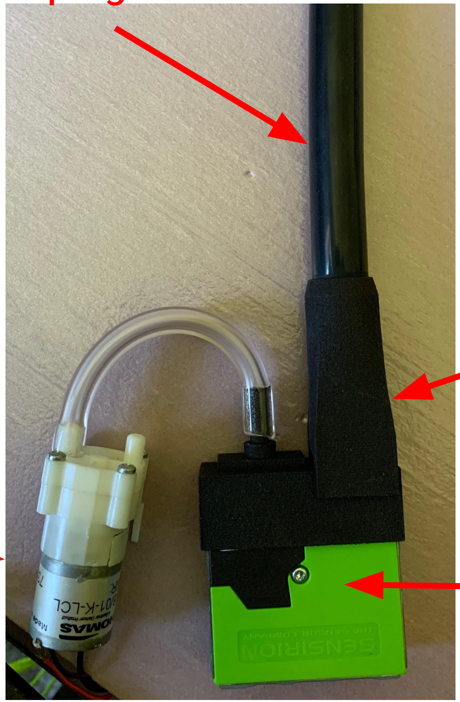


Sampling nozzle

3D printed casing

Thomas G.D. 6/01-K-LCL rotary vane pump

Sensirion SPS30 particle detector



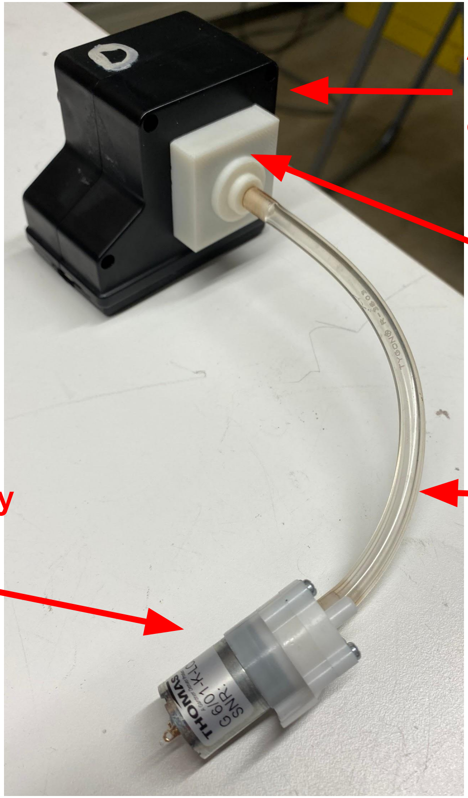
Low Cost Optical Particle Counters - Alphasense N3

- **The N3 is also under consideration for it's high quality standard condition calibration**

- 3D printed casing for pump and sampling nozzle attachments (~$10)
- Thomas G.D. 6/01-K-LCL rotary vane pump (~$50)
- Silicon rubber anti-static tubing sampling nozzle (~$10/ft)

Inlet Nozzle

Thomas G.D. 6/01-K-LCL rotary vane pump

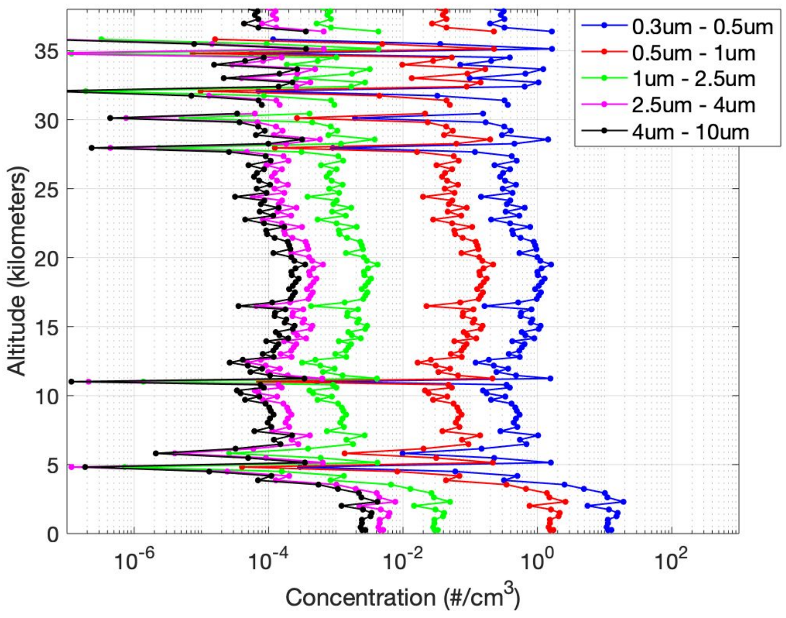


Alphasense N3 particle detector

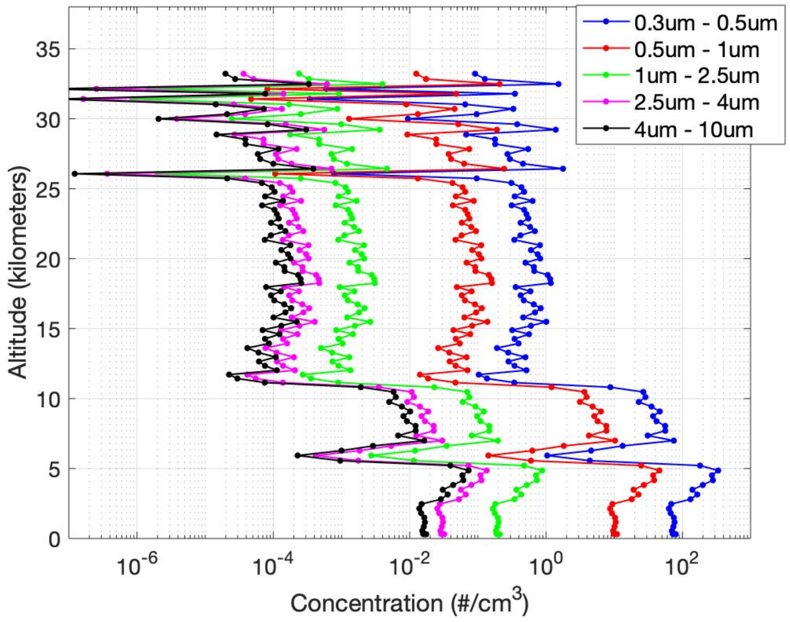
3D printed casing

Pump tubing

SPS30 Flight Data - August 17th, August 25th

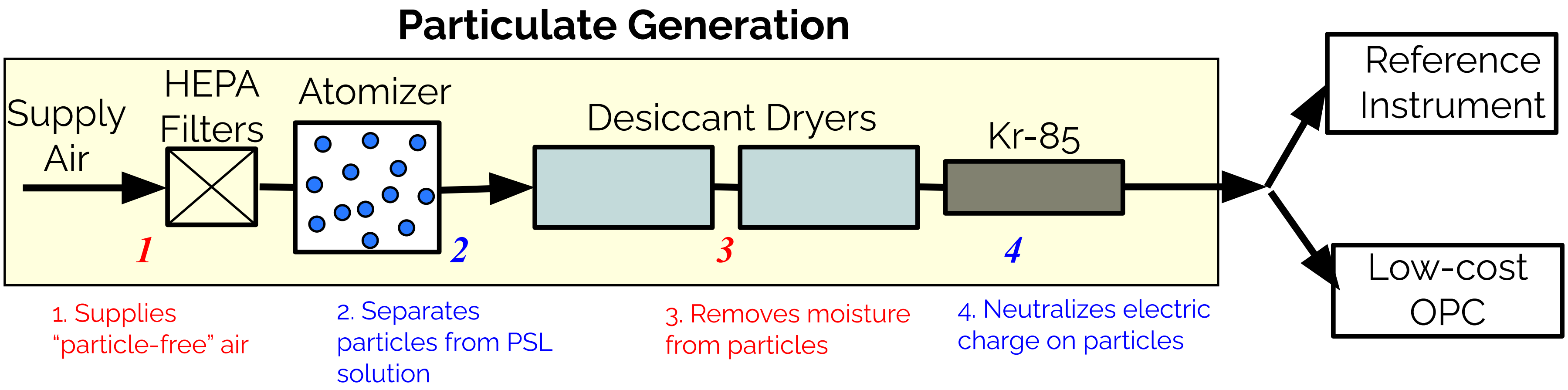


SPS30 1 Min Avg. Number Concentrations August 17th 2020



SPS30 1 Min Avg. Number Concentrations August 25th 2020

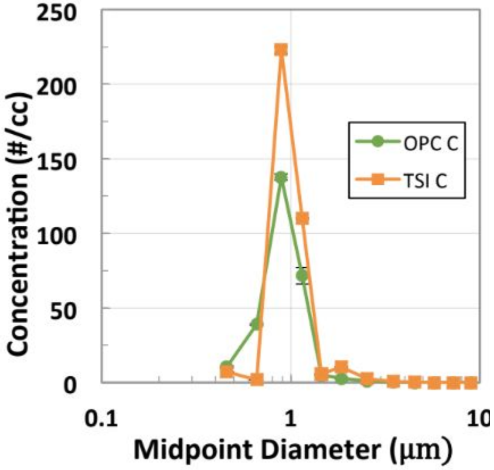
OPC Calibration: Standard Conditions



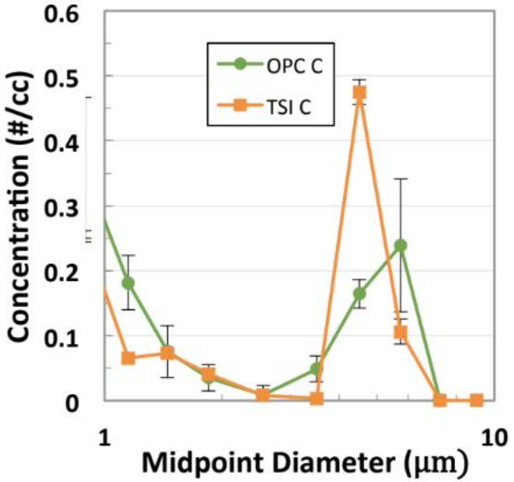
- Particulates of known sizes generated using NIST traceable Polystyrene Latex (PSL) spheres and supplied to OPCs under standard conditions (1 atm, room temperature)
- Generated size distribution verified using reference instrument, TSI 3321 Aerodynamic Particle Sizer Spectrometer (pre-calibrated)
- Low-cost OPC is then calibrated by comparing its measured size distribution to the reference instrument
- Setup serves as basis for calibration under stratospheric conditions

OPC Calibration: Standard Conditions

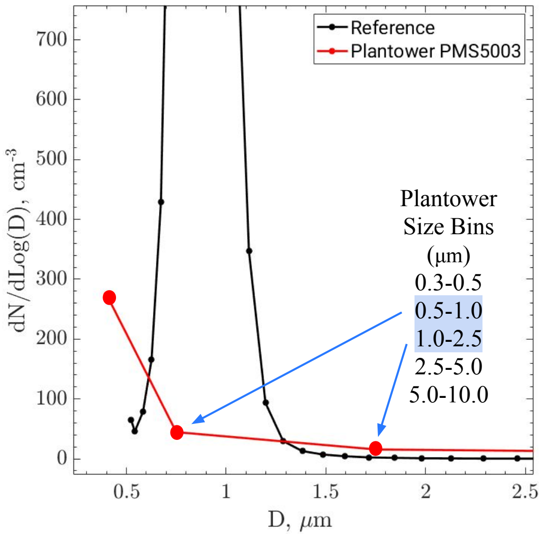
Alphasense OPC-N3: 1 µm PSL



Alphasense OPC-N3: 5 µm PSL



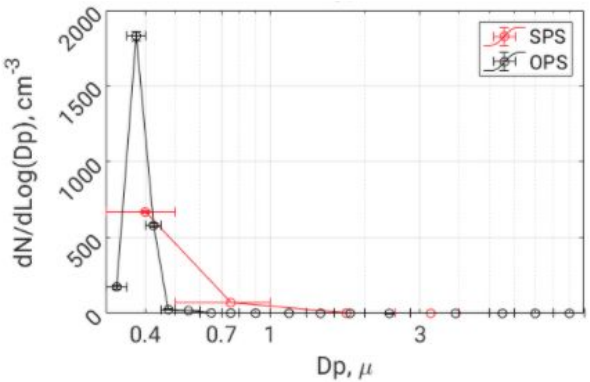
Plantower PMS5003: 1 µm PSL



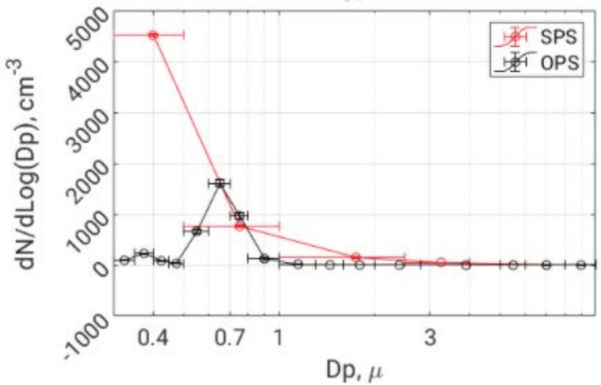
Arrows indicate size bins where particulates should have been detected

- **Alphasense OPC-N3** compares well with reference instrument (TSI C) for small and large particle sizes
  - But unreliable during balloon flights so far
- **Plantower PMS5003** compares poorly with reference instrument
  - Highlighted size bins indicate where particles should have been detected
  - Possible reason includes incorrect flow rates

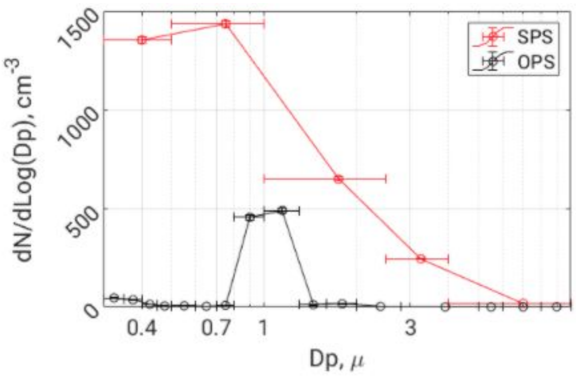
OPC Calibration: Standard Conditions



Sensirion SPS30: 0.4 μm PSL



Sensirion SPS30: 0.7 μm PSL



Sensirion SPS30: 1.0 μm PSL

- **Sensirion SPS30** performs better than Plantower
  - Response within an order of magnitude of the reference instrument
  - However, other bins experience spillover during calculations
  - Other SPS30s show very similar results

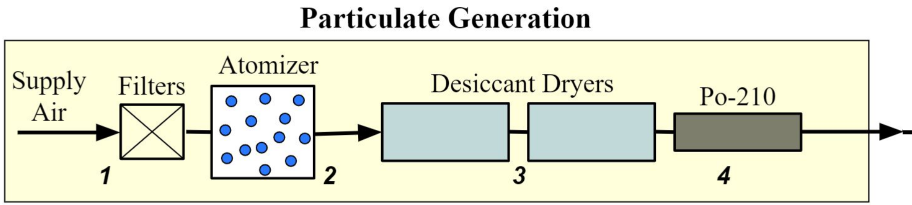
* Horizontal error bars represent bin width
* Vertical error bars are standard deviations
* SPS30 size bins: **0.3-0.5, 0.5-1.0, 1.0-2.5, 2.5-4.0, 4.0-10**

OPC Calibration: Stratospheric Conditions

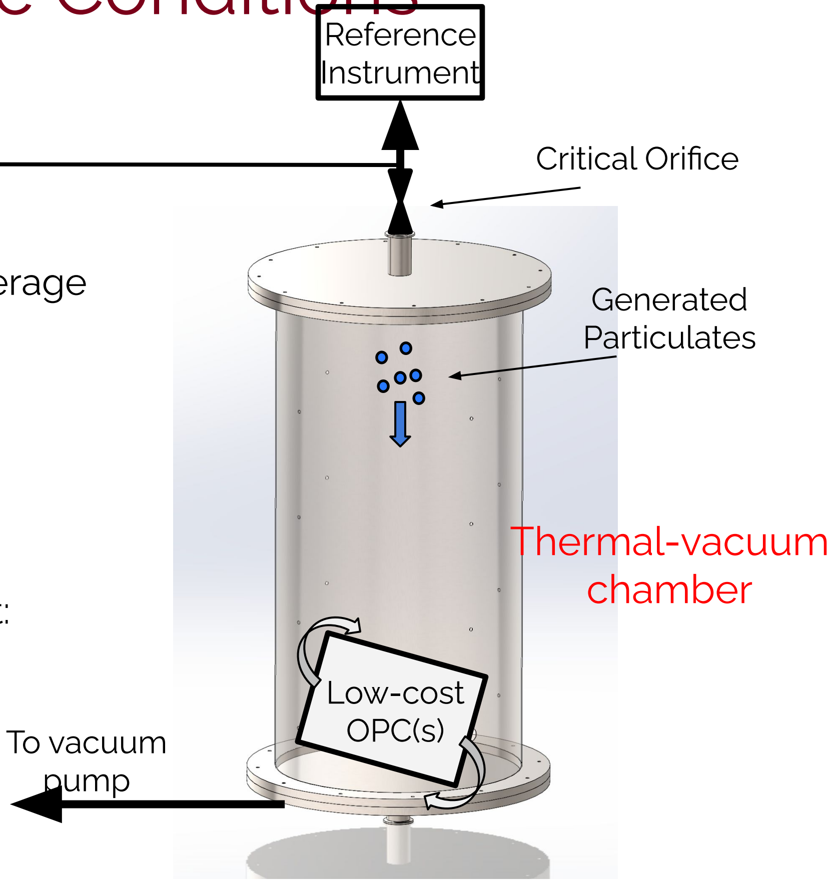
- Extreme conditions in stratosphere affect transmission efficiency of OPC
  - Transmission efficiency = measure of how efficiently particles travel from atmosphere to detection region of OPC
  - Particles with high inertia (large diameters) could avoid detection
- Need ground experiments to characterize effect of low-pressure and low-temperature on OPC transmission efficiency
  - Generate particles using existing experimental setup and introduce them to OPC inside thermal-vacuum chamber
- Machining of thermal-vacuum completed and installation in progress

Machined thermal-vacuum chamber for calibration

OPC Calibration: Stratospheric Conditions



- Flow rate through chamber adjustable to replicate average balloon ascent/descent rates
  - Experimentally estimate particle sampling loss based on ascent/descent rates
- Adjustable orientation of the OPC
  - Experimentally estimate particle sampling loss based on orientation of OPC on balloon gondola
- Access ports (x16) spaced around chamber to support:
  - Electrical feedthroughs
  - Pressure transducers
  - Hot-wires
  - Thermistors
- Large cross-section allows for multiple test OPCs



Conclusions

- Some low cost OPCs are able to function with modifications in the stratosphere.
- Calibration of low cost OPCs is underway in standard conditions.
  - Calibration in stratospheric conditions will begin soon.

Next Steps

- Conduct calibration tests in extreme stratospheric conditions.
- Continue OPC flights to gain more comparison data between high cost and low cost sensors.

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Questions?