POPS User Manual

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Software License

Laser safety

All varients of the POPS (LWP2, COPS, and MOPS) are Class 1 Laser Products with a 405 nm, 70 mW laser. Under normal operation there is no exposure to laser radiation. During service procedures the operator can be exposed to Class 3B laser radiation and therefore only trained personnel with appropriate protective equipment should perform service and/or maintenance procedures described in this manual.

WARNING: The use of controls, adjustments or procedures other than those specified in this manual may result in exposure to hazardous laser radiation.

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1 Introduction

The Printed Optical Particle Spectrometer (POPS) was designed to be a low-weight, high performance optical particle counter. It counts and measures the optical size of sampled particles using single-particle light scattering between approximately 140 nm and 3 µm. The POPS comes in several packages depending on the intended application. The Light-Weight Particle Profiler (LW2P) model includes a lightweight enclosure and hardware for autonomous airborne operation intended for use with unmanned balloon systems. The Compact Optical Particle Spectrometer (COPS) model includes a hardened weatherproof enclosure and other hardware for outdoors and bench top applications. The Modular Optical Particle Spectrometer (MOPS) model does not come with a standard enclosure, has various options depending on application requirements, and is intended to be a flexible measurement package that can be installed in a variety of sensor platforms.

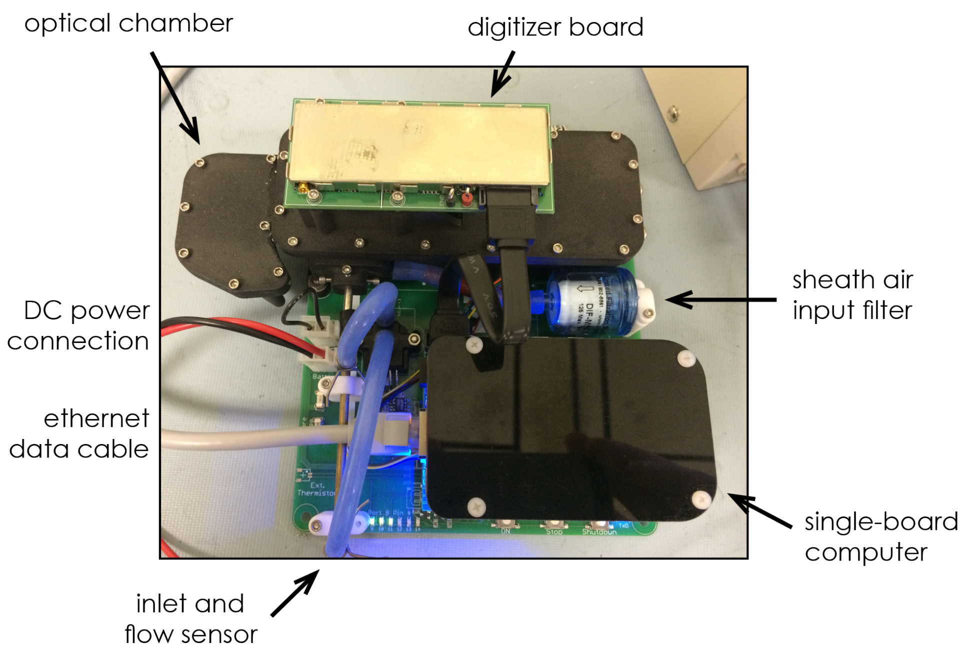


Figure 1. Overview of the core POPS components, with data system and optical chamber mounted to baseplate.

The POPS was originally developed by the Chemical Sciences Division of the US National Oceanic and Atmospheric Administration (NOAA) and is licensed to Handix Scientific LLC.

2 Unpacking and Setup

Carefully inspect the shipping container for any signs of damage and verify all major components of the instrument package are included and match the description provided on the packing slip. LW2P and COPS versions of the instrument will come pre-assembled and the MOPS version may include separate components.

2.1 POPS Component Overview

Major components include:

- POPS optical particle detection chamber
- Data acquisition and instrument control hardware
- Vacuum pump, sample and exhaust tubing
- AC/DC universal input power supply and/or battery packs (user supplied)
- RJ45 ethernet cable (optional)

POPS optical particle detection chamber

The optical chamber consists of the main sampling enclosure, which houses the laser diode, focusing optics, light collection mirror, laser beam dump, photo detector and inlet and exhaust ports. The laser beam produced by an ~70 mW 405 nm laser diode is aligned to the horizontal center of the optical chamber, shown in Figure 2. The vertical position of the laser beam is adjusted so that the center of the profile is aligned with the inlet nozzle tip. The laser alignment is adjusted using three screws located on the rear of the laser diode assembly and comes pre-aligned.

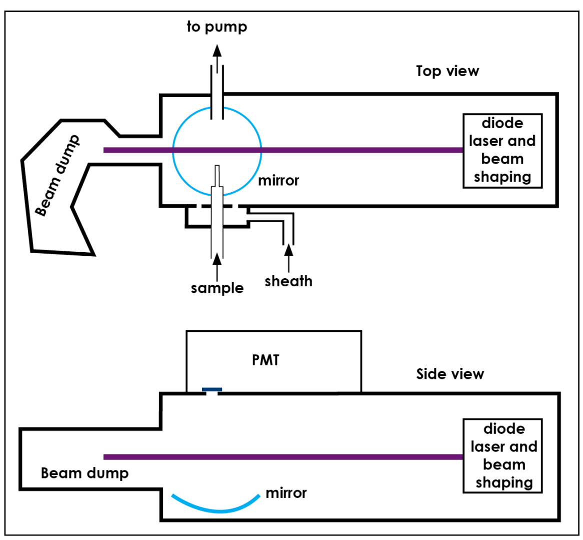


Figure 2. Schematic showing top and side views of the POPS optical particle detection chamber and main components.

The inlet is a 1/8-inch outer diameter, 0.069-inch inner diameter stainless steel tube housing an inlet nozzle 0.4-inch long 1/16-inch outer diameter, 0.032-inch inner diameter stainless steel tube that is inserted 0.1-inches inside the 1/8-inch outer diameter inlet tube. The nozzle tip is positioned within 0.5

cm of the laser beam. The exhaust is positioned approximately 1 cm from the exhaust beam. The sample jet/detection region is focused onto the sensing area of a photomultiplier tube located at the top of the optical chamber by a spherical mirror.

A series of four pairs of slits prevents stray light from entering the detection area and introducing background light. Each pair of slits is adjusted using two setscrews that are accessed from the top and side of the optical chamber.

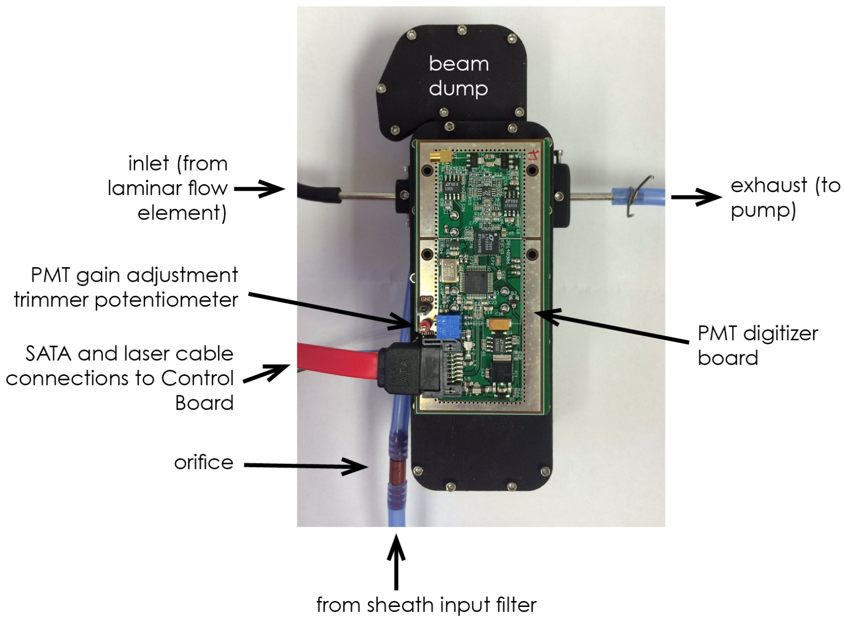


Figure 3. Top view of the POPS optical chamber. Note: Other versions of the chamber have an integrated outlet port rather than the stainless steel tubing shown in the picture.

The circuit board mounted to the top of the optical chamber is the signal processing and digitizer for the raw light scattering signals measured by the photo detector, shown in Figure 3. It is connected to the instrument support hardware through a SATA cable. It also has a trimmer potentiometer (trimpot) for adjusting the gain on the photomultiplier tube signal amplification circuit. The gain is set at the factory to produce a raw signal of ~3160 analog-to-digital counts for a 500 nm polystyrene latex sphere calibration particle, which has been found to produce the best signal-to-noise over the detectable size range (Gao et al., 2016).

Data acquisition and control package

The data acquisition and control package consists of a Beaglebone Black Industrial single-board computer running Linux (referred to in this manual as the POPS Computer), custom POPS support board (referred to as the POPS Cape), and custom POPS baseplate board (referred to as the POPS Baseplate). More details on the Beaglebone Black (BBB) device may be found at https://beagleboard.org/black. The POPS uses an "Industrial" version of the board rated for temperatures between -40 to +85 C. A 32 GB micro-SD memory card is supplied and pre-installed with the POPS Computer for data storage and the instrument also ships with an Ethernet cable and USB cable for connecting to the POPS Computer with a remote client.

The POPS Cape is an interface between the individual component systems (detector board, laser, pump, flow sensor, user controls) and the POPS Computer. It has many functions, including providing a current source for the POPS laser diode, passing digitized raw particle signals from the photo detector board to the computer, controlling the pump voltage and sample flow.

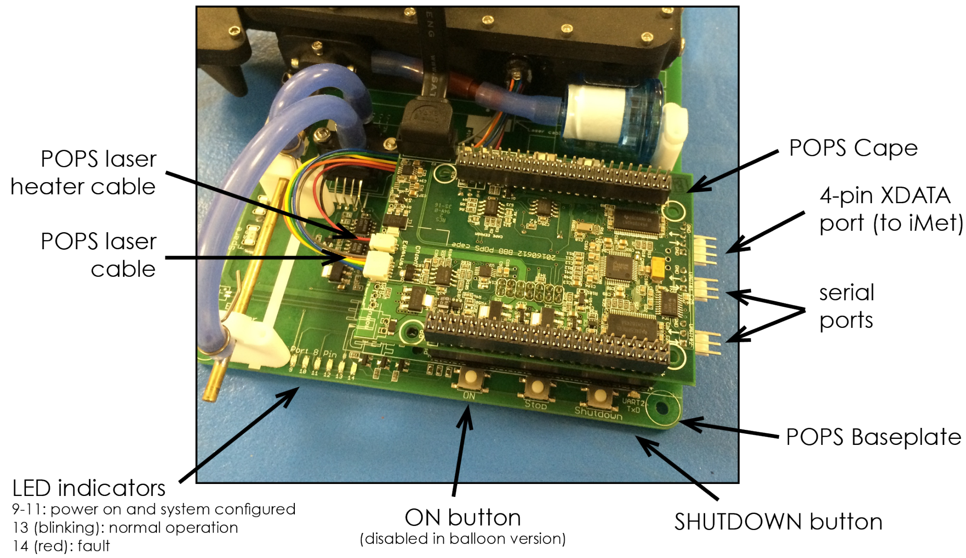


Figure 4. Top view of the POPS, highlighting the location of the POPS Cape (bottom right) and connections for the laser and laser heater cables and data input/output.

The baseplate is the main chassis for the other instrument components and has several input and output features for basic operation and troubleshooting. The baseplate has a series of LEDs located along the edge closest to the inlet and laminar flow element that illuminate when the system has been powered on (LEDs labeled 9 and 10), the software has been loaded (LED 11) and the system is operating normally (LED 13 will blink every second). Any faults, typically associated with an over-voltage on one the analog input signals, will cause LED to illuminate, which is red. This error will not necessarily prevent the system from acquiring data but persistent problems, such as a faulty sample pump or large leak, will cause the repeated illumination of the error LED and users should contact Handix Scientific for assistance.

The baseplate also has connections for the input DC power and a second connector that can be used as an external power switch for the instrument. The system will only operate if DC power has been supplied and there is an electrical connection between the two pins of the power switch connector. Instruments intended for balloon applications will come with a length of wire with connectors on each end that can be used to short the connections on the baseplate. In this configuration the "ON" button on the baseplate has no function and will have been bypassed using a jumper wire. Non-balloon instruments will have a connector that will short the external power switch and for these configurations the "ON" button is used to turn the device on.

The "STOP" and "SHUTDOWN" buttons on the baseplate are both used to turn the instrument off safely. Do not disconnect the system from power until a safe shutdown has been performed to avoid corrupting the POPS computer. In current versions of the instrument there is no difference in functionality between the "STOP" and "SHUTDOWN" buttons. Each sends an interrupt signal to the acquisition program and triggers a shutdown of the POPS computer. The shutdown operation can take several seconds. If the system fails to shut down try pressing the button again or pressing and holding the button until the system shuts down. When the system has shutdown safely the LEDs will no longer be illuminated. In some cases balloon based instruments will continue to supply power to the pump until the external power switch is disconnected. When shutting down these instruments wait until the LEDs on the baseplate stop blinking and disconnect the connectors at the end of the external power switch loop. It is now safe to remove the battery connection, if desired.

Vacuum pump, sample and exhaust tubing

The complete POPS flow schematic is shown in Figure 5. The POPS uses a miniature rotary vane pump to produce a small pressure drop in the optical chamber and pull sample and sheath flow into the cavity. The pump speed is controlled through a feedback loop running and is automatically adjusted to maintain a near-constant sample flow rate through the laminar flow element connected to the POPS inlet. The sheath flow is proportional to the pressure drop in the optical chamber and is passively controlled through an orifice. The sheath air is taken from the ambient air, drawn through a filter and orifice before being passing through six holes located around the sample inlet nozzle.

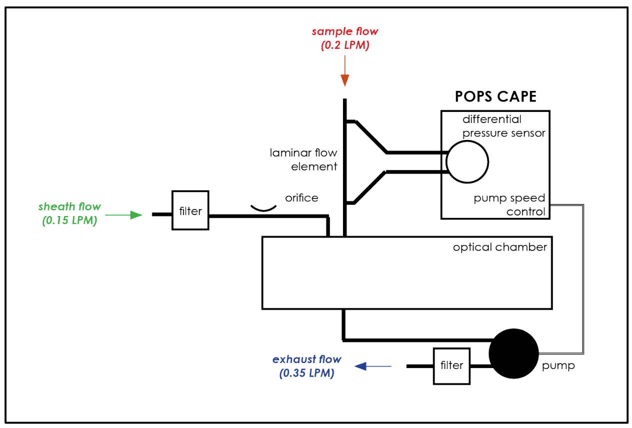


Figure 5. POPS sample, sheath and exhaust flow schematic. The filter on the exhaust pump is optional.

Power

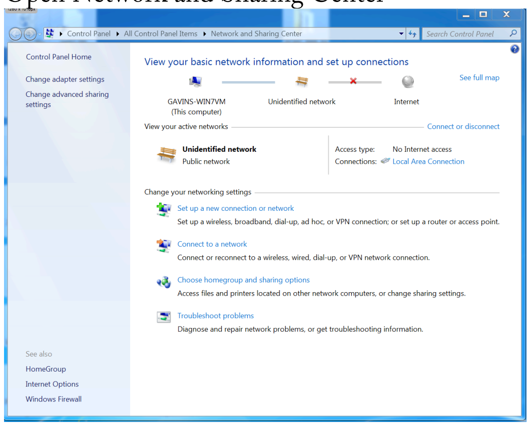
The POPS requires 11-15 VDC input power, supplied either by a DC power supply (e.g., a wall block AC-DC power supply) or an external battery module. Contact Handix Scientific for recommendations for the choice of battery and vendors.

2.2 Software setup

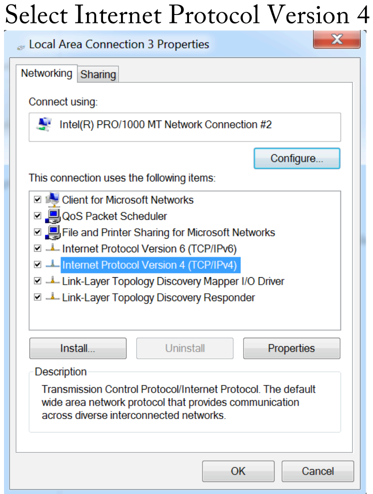
Connecting to the POPS Beaglebone Black single-board computer

The POPS computer comes with the POPS data acquisition software pre-installed and will automatically begin operating the instrument and collecting data when the system is powered on. Users wishing to view data in real-time or edit the instrument configuration will need to access the POPS Computer using an external PC. The instrument configuration can also be directly edited on the micro-SD card using a card reader and basic text editor, though this is not recommended as in some cases the formatting of the file can be altered depending on the text editor used to make the configuration changes. The external PC should be connected to the POPS Computer using a standard ethernet patch cable with RJ45. The POPS Computer will only accept incoming connections and provide real-time data to a specific network address, so you must edit the IP settings on the external PC as follows (for Windows 7):

1. Open Network and Sharing Center



2. Select “Change adapter settings” on the left side of the window
3. Right-click on the Local Area Connection associated with the POPS and select Properties. Removing and re-connecting the Ethernet cable can help identify the appropriate connection if more than one are listed.
4. Select Internet Protocol Version 4 and click Properties.



5. Select “Use the following IP address” and change the IP address to 10.11.97.100 and the subnet mask to 255.255.255.0. Press OK to accept the changes and update the adapter settings.

6. You can test the connection to the POPS Computer by opening the command prompt in Windows and entering the command “ping 10.11.97.50” and verifying the external PC gets a reply from the POPS.

Once the POPS Computer is powered on and you have changed the IP address on the external PC the file system on the POPS can be accessed directly through a terminal program, such as PuTTY, using ssh. By default the POPS Computer username is “root” and there is no password. Alternatively, you can access data files and the configuration file directly on the micro-SD card using a card reader. **NEVER REMOVE THE SD CARD WHILE THE INSTRUMENT IS RUNNING!** Always perform a safe shut down of the system before removing the SD card. Do not change any of the files or organization of the directory structure without first consulting Handix Scientific, with the exception of the configuration file as described below.

Users comfortable with the linux command line can edit the file directly on the SD card while the instrument is running by connecting to the instrument with ssh, then using a text editor such as nano or vi on the POPS Computer to modify the file directly. For example, using nano the command would be "nano /media/uSD/POPS_BBB.cfg".

Editing the configuration file

The configuration file is called "POPS_BBB.cfg" and is located on the root (also known as the "main", "parent" or "top") level directory on the micro-SD card. Always keep a copy of the configuration file backed up before making any changes to the file on the micro-SD card. The file is read by the acquisition software and used to set a number of parameters when operating the instrument. Configuration settings are described in detail in the "POPS Data Acquisition Software" section of the manual. If editing the file externally save changes and copy the file back to the SD card, overwriting the previous version.

Viewing data in real-time

To view POPS data in real-time via UDP bi-directional communications you must first change the IP address on the external PC as described above. You must also install the POPS BBB Data Viewer UI Labview executable (contact Handix Scientific to receive the latest version of the installer) to the external PC. Windows may also require you to permit the UDP traffic to pass through the firewall the first time you run the software.

Once you have completed these steps you should be able to power on the POPS (described in the next section), connect the PC to the POPS Computer with an Ethernet cable, and start the Data Viewer UI software. Communication has been established when the green LED indicator in the Labview program begins blinking. It may take the POPS as long as one minute to begin acquiring data. Contact Handix Scientific if you have problems connecting to the POPS.

POPS Configuration file and default settings

Parameter	Default Value(s)	Description
gBaseAddr	/media/uSD/Data/F	Default directory and file name prefix for data files. Do not change.
BBB_SN	-	Serial number for the Beaglebone Black single-board computer in the instrument.
POPS_SN	-	Serial number for the instrument.
Flow	offset = X.X divisor = X.X	Coefficients used to convert the differential pressure sensor raw reading to flow rate in vccm.
gBins	Nbins = 16 logmin = 1.6 logmax = 4.817	Number of log-spaced bins for particle size distributions power of 10 for lowest bin boundary (~25 raw counts from digitizer) power of 10 for upper bin boundary (~65k raw counts from digitizer)
AI	Multiple	No user-editable values.
AO	Name = "Laser Current" set_V = 2.867 maxV = 4.096 minV = 0 Ki = 1 use_pid = false	Analog ouput control settings for laser current. Default is to hold laser current to constant value by applying a set voltage, which converts to approximately 70 mA and corresponds to a laser power of about 70 mW at the laser output and approximately 30 mW in the particle detection region. Contact Handix Scientific before changing.
AO	Name = "Flow_Set" set_V = 2.35 maxV = 4.096 minV = 0	Raw pump voltage to apply to obtain desired sample flow set point. Instruments are pre-configured to achieve a target sample flow rate of ~180 cm^3 / minute, volumetric. Increasing the set_V value will give a higher sample flow rate and reducing the set_V will give a lower sample flow rate.

	`Ki = 1` `use_pid = false`	
`Serial_Port`	`Multiple`	No user-editable values.
`Skip`	`Skip_Save = 0`	Reduces number of particles saved to the particle-by-particle peak information file. Default is to save all particles, but can generate large amounts of data. Replace "0" with integer with number of particles to skip. For example, "Skip_Save=4" will save 1 of every 5 detected particles to the file and "Skip_Save=9" will save 1 of every 10.
`Peak`	`MinPeakPts=5` `MaxPeakPts=255`	Number of digitized points in the raw detector signal that must be above baseline to be considered a valid particle. Do not change without first consulting Handix Scientific.
`Baseline`	`BL_Start = 30000` `TH_Mult = 3.0`	BL_Start should not be changed. The value of TH_Mult determines the minimum raw signal peak height that must be measured in order for a signal to be counted as a valid particle. The signal must be greater than the average baseline plus TH_Mult standard deviations. For example, if the baseline is 1000 raw A/D counts with standard deviation of +/- 5, the default TH_Mult value (3.0) gives a signal threshold of 1015 raw A/D counts.
`Raw`	`Multiple`	Option to record raw digitized data to the uSD card. Set the "save" value to false in order to preserve uSD card space for longer duration operation.
`Status`	`Status_Type="UAV"`	Sets the operating mode of the instrument. Currently two modes are supported: UAV or iMet. UAV mode allows any number of bins (max recommended is 200) and preserves information when sent via UDP or serial to an external computer. "iMet" mode forces the system to use and transmit 8 bins, but this can be modified based on bandwidth availability.
`UDP`	`IP`	IP address used for UDP data transfer.
	`port`	port number used for UDP data transfer
	`type`	S = simplified UDP data format; F = full UDP data format. The Labview data viewer is configured to read these formats automatically and display data. Contact Handix Scientific if you wish to know more details about the data streamed via UDP.
	`use`	Set to false to disable UDP data transfer if you do not wish to use this feature.

3 POPS Operation and Real-Time Data Viewer

3.1 Operating the POPS

Non-balloon versions: To begin sampling, first verify the POPS inlet is not obstructed and the micro-SD card is fully inserted into the POPS Computer, then plug in the instrument or connect the battery terminals. Press and hold the "ON" button (see Figure 6) on the POPS Baseplate for about 1-2 seconds, or until the LEDs on the Baseplate illuminate. The pump should begin operating within a minute and quickly settle on a steady operating speed to maintain a constant sample flow rate. After another minute the POPS data acquisition software will automatically load the current configuration, begin acquiring and saving particle data to file and send housekeeping and binned data via UDP and various serial protocols to any connected external systems.

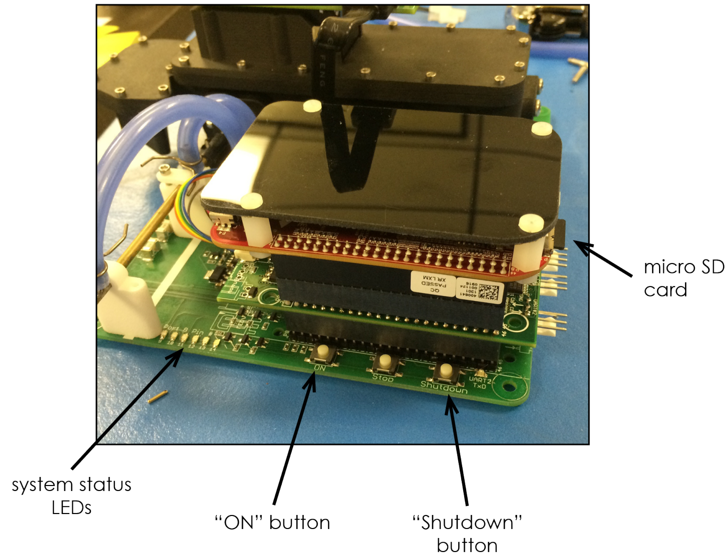


Figure 6. Locations of the micro SD card (inserted into slot on POPS Computer (red board), power on and shutdown buttons, and system status LEDs.

Balloon versions:
Setup: Balloon-configured instruments are shipped in a foam enclosure with a pass-through for the sample inlet tubing. The instrument is supplied with a short brass 1/8" outer diameter tube that should be inserted firmly into the inlet housing if not already installed. It is easiest to do this by opening the foam box and pushing the inlet against the housing while holding the instrument assembly with your other hand. Install the battery pack and connect to the battery connection on the instrument baseplate to the external battery connector port, as shown in Figure 7.

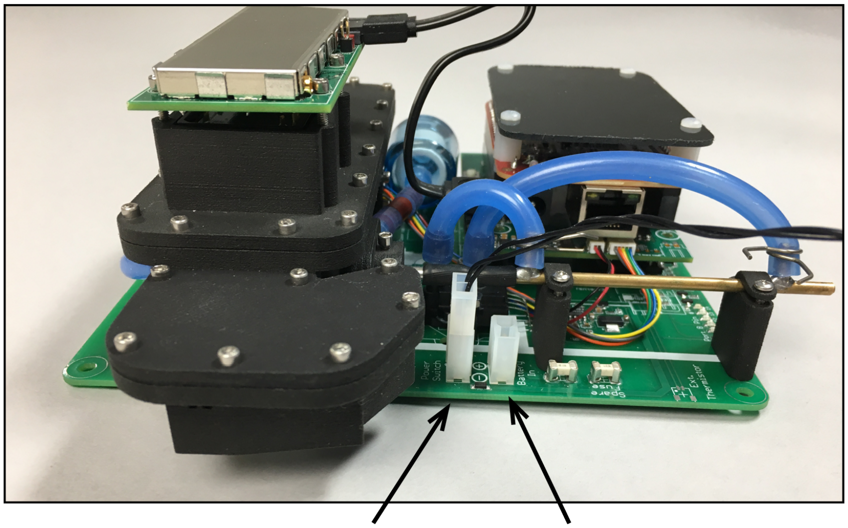


Figure 7. Locations of the external power cable connector location (left; shown with cable connected) and the external battery connector (right; not connected). Newer instruments will also have a dedicated "ground power" DC input to be used with a DC power supply.

Verify that the micro-SD card for the POPS computer is installed. At this point you can test the system by matting the open connection on the external power cable. The instrument should power up and LED 13 should begin blinking after about two minutes. You should also be able to hear the pump operating once the LED begins to blink. Confirm the system is working and then press the shutdown button to power down safely (use a small screwdriver to access the button if the instrument is installed in the foam box.

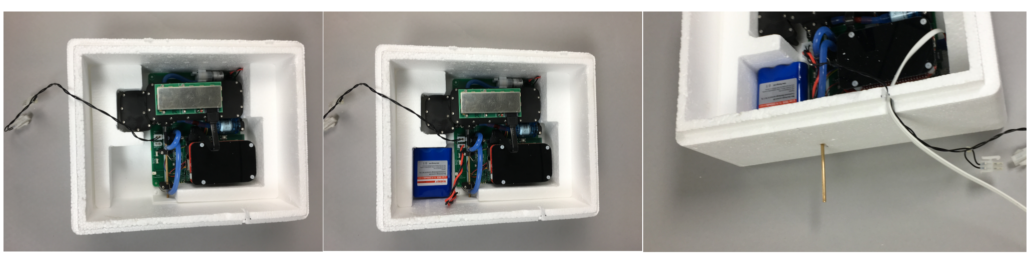


Figure 8. Installation of the battery pack (left and center) and inlet tube (right) into the foam enclosure. Note the XDATA and power cables running out of the box through a notch located above and to the right of the inlet in the right-most picture.

Once the inlet and battery pack are installed the foam box can be closed, taped shut, and inserted into the provided anti-static bag, which provides additional shielding against electro-magnetic interference. The bag comes pre-punched with holes for the inlet and data/power cables. Be sure to line up the holes with the inlet and cables as you insert the box into the bag. Seal the open end of the anti-static bag with packing tape. The system is now ready to be connected to the rest of the balloon payload, powered on, and launched. Figure 9 shows the foam enclosure with and without the anti-static bag.

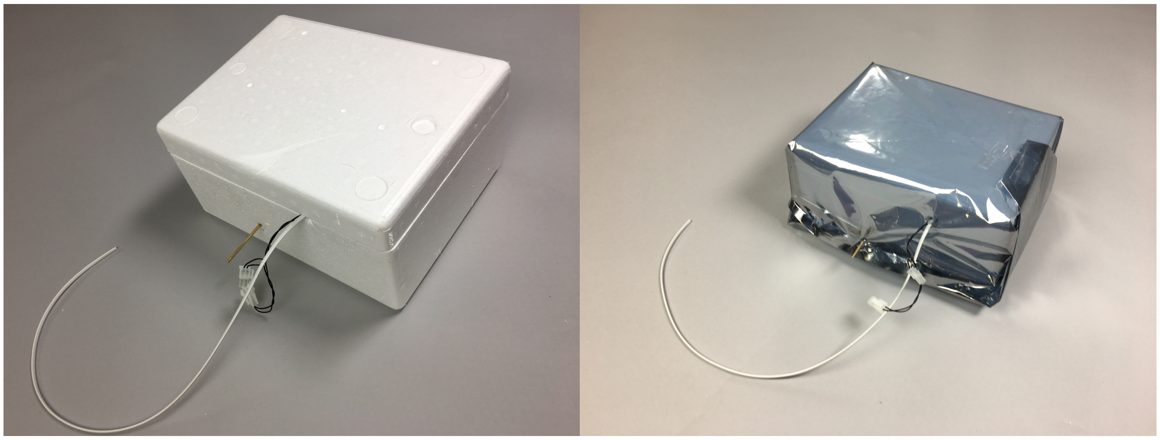


Figure 9. Pictures showing balloon-configured instrument in foam enclosure with (right) and without (left) anti-static shielding bag.

Operation: Operation is similar to that described above for non-balloon versions, except the "ON" button functionality is disabled and instead the external power switch cable is used to turn the system on prior to launch. Mating the connectors at the end of the power switch cable will turn on the instrument. The POPS may come with 4-position XDATA cable for connecting to either an iMet RSB radiosonde or another XDATA type instrument. If present, this cable should be connected to either the radiosonde or next instrument in the payload series.

Data transferred via the radiosonde has some configuration options, but the current standard is to provide the sample flow rate, total particle concentration, and particle count data binned over 8 or 12 size channels, every second. The POPS has been implemented into NOAA's publically available SkySonde software, which records the real-time data received from the radiosonde, POPS and other instruments into the payload (additional hardware is required to receive data transmitted from the radiosonde; contact Handix Scientific for more information).

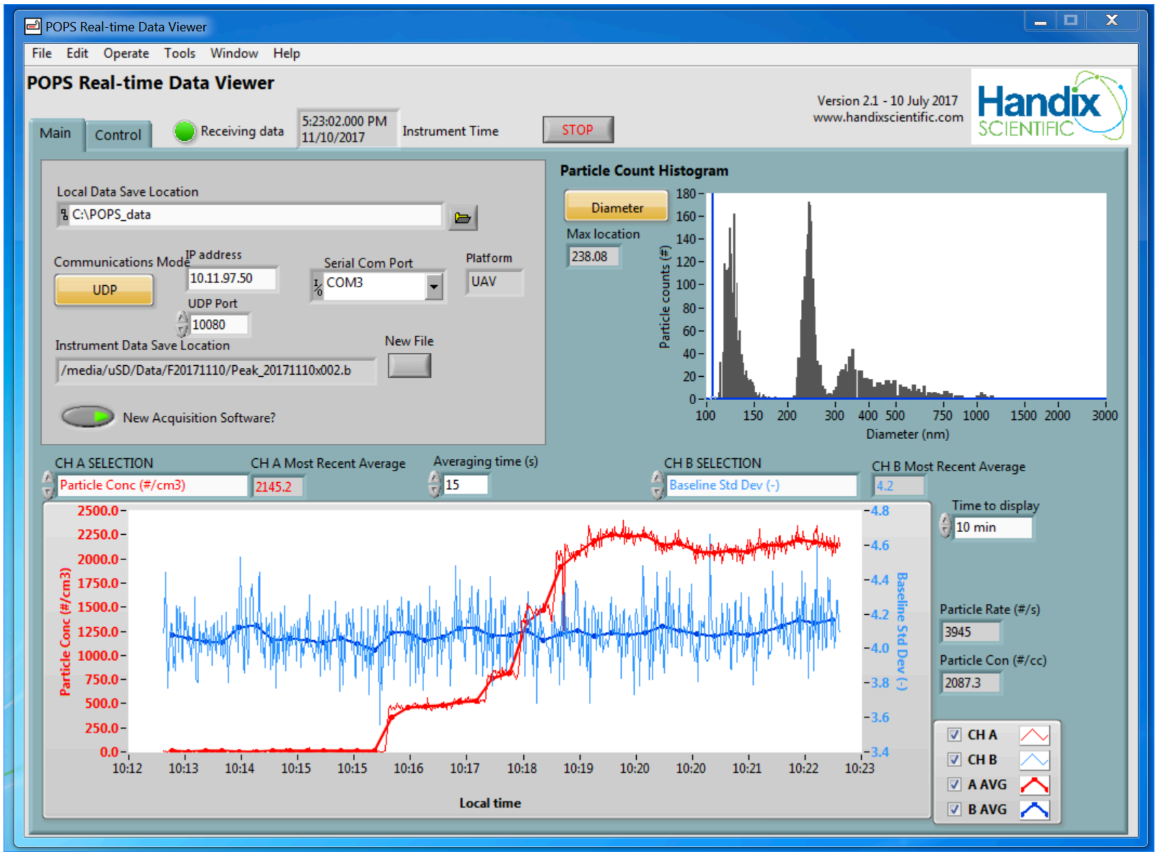
3.2 Shutting down the POPS

Never disconnect power from the instrument before first safely shutting down the system or the POPS Computer can become corrupted. To shut down the system safely press and hold the "Shutdown" button (shown in Figure 6) until the system powers down. It can take the system several seconds to recognize the shutdown command. When the system has shut down the pump will turn off and the system status LEDs will no longer be illuminated. It is now safe to remove the AC-DC power supply and/or battery module connections.

3.3 Viewing POPS data in real-time

The POPS includes a Labview run-time executable program, the POPS Data Viewer UI, which automatically interprets the UDP or serial data output stream from the instrument and allows for temporary modification of the POPS operating parameters, such as number of bins in the output histograms, depending on operating mode.

POPS Main tab

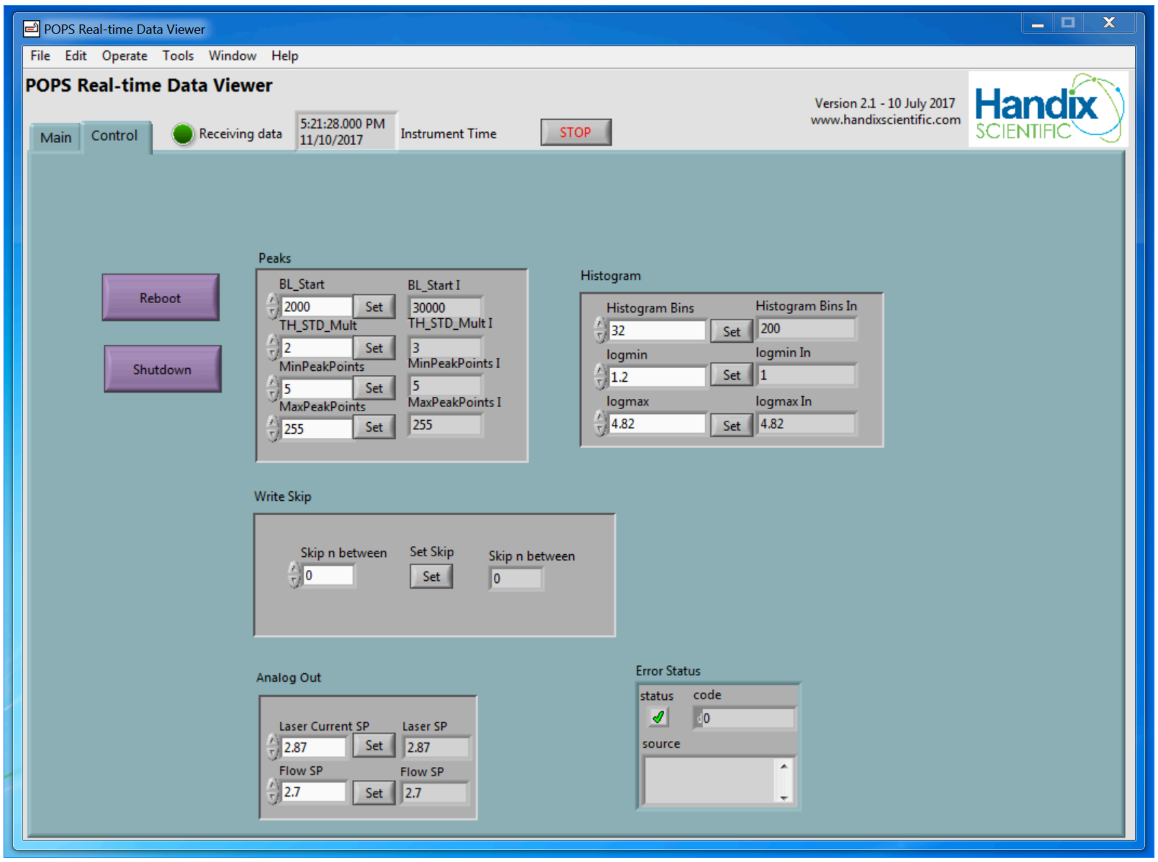


The POPS main tab is the main user interface to display information about the running instrument, including communication status, name of current file being written to on instrument and on the data viewing computer, instrument timestamp (UTC), particle count rate and concentration, the histogram of particle counts, and diagnostic information such as the current baseline and baseline standard deviation.

Panel Item	Description
Instrument time	Current UTC time and date reported by POPS
Local Data Save Loc.	Directory where local text file containing basic POPS data will be saved (in addition to data saved on instrument)
Communications mode	UDP [default] or serial (not currently supported in viewing software)
IP address	IP address of the POPS computer
UDP Port	UDP port number
Serial Com Port	Serial port number on local computer connected to POPS
Platform	Classification for platform type – UAV default and best for most applications
Instrument Save Loc.	Directory where POPS data currently being saved on POPS computer
New File	Manually initiate a new file on the POPS data system
New Acquis. Software?	Option to support older versions of the instrument
Particle Count Hist.	Display for current (1-second) particle counts, shown against either diameter or raw signal intensity depending on user selection
CH A Selection	Data parameter to display in red against left-axis in the time series plot
CH A Most Rec. Avg.	Average of last n seconds of data where n is value of "Average time (s)"
CH B Selection	Data parameter to display in blue against right-axis in the time series plot

CH B Most Rec. Avg.	Average of the last n seconds of data where n is the value of "Average time (s)"
Time to display	Length of x-axis in time series plot
Particle rate (#/s)	Last measured particle count rate (for all particles above threshold)
Particle conc. (#/cm3)	Concentration of particles measured in last second (all particles above threshold)
Receiving data	Should blink when UDP communication to POPS is established.
Graph option panel	Allows user to display or hide time series plots (1-second and/or averaged)

POPS Control tab



Provides access to temporary control settings for configuration parameters used by the POPS. Changes made here will not be saved between power cycles on the POPS. The POPS will reset back to the values saved in the configuration file. To modify settings permanently change the values in the configuration file in the POPS configuration file on the microSD card supplied with the instrument. All settings have two components: a box where a new value can be set and another that displays the current setting. To change a value simply type or enter the desired value, press the button labeled "set" to its right, and the output variable should update within a few seconds.

BL_Start sets the initial baseline applied when the acquisition software first loads and should always be set to a value much higher than the expected baseline. The default value is 30,000 A/D counts and **should not be modified unless instructed**. TH_STD_Mult applies a constant multiplier to the measured standard deviation in the detector baseline signal and is used to set the trigger point for recording valid particle pulse data. Reducing the value will lead to higher data recording rates and potentially triggers on false particles or electronic and/or background light "noise", while larger values will prevent the system from acquiring data for real particles measured at the lower range of the instrument detection window. MinPeakPoints and

MaxPeakPoints set the limits for the number of digitized raw signal points allowed when classifying a raw signal pulse as a valid particle count.

Histogram settings allow customization of the histograms generated at 1-second time resolution by the instrument in real-time. Histogram_bins changes number of bins, while minlog and maxlog are powers of 10 values that control the minimum and maximum limits in raw signal intensity space for histograms. Write_skip sets number of particles to skip for recording peak intensity data in the binary files and can be increased to save storage space. Analog out settings are used to adjust the laser current set point (to reduce or increase laser intensity) and the current sample flow rate. Both are set in volts and should not be adjusted without prior discussion with Handix Scientific.

3.4 POPS Data Files

The POPS automatically generates directories on the micro SD card based on the file information prefix in the configuration file. By default, the instrument creates a directory for each calendar day in the "Data" directory (e.g., F20161016) containing data files and a copy of the current configuration file for that date. Files are saved depending on configuration settings. Normally it records a "housekeeping" or "HK" file containing the most commonly needed parameters and data. If desired, the system will record high time resolution raw signal data to help evaluate system performance, including laser beam profiles and baseline stability, parameterized raw peak data for individual particles such as maximum peak signal amplitude and peak width, and a log file to help diagnose any instrument problems.

Housekeeping files

Most commonly needed data are saved in comma-delimited housekeeping files, which are named "HK_YYYYMMDDxnnn.csv" where YYYY is the year, MM and DD are the month and day and nnn is a file index. Multiple files are usually collected per day if raw peak data is also being saved. The following parameters/data are saved in the HK file at 1-second time resolution:

Parameter	Description
`DateTime`	Date and time in seconds from midnight, 1 January 1970.
`Status`	1 = run
`PartCt`	Particle counts (# / s)
`PartCon`	Particle concentration (# / cm^3; volumetric)
`BL`	Current baseline of the detector (raw analog-to-digital counts)
`BLTH`	Current threshold for particle counting; equals BL + STD x TH_Mult
`STD`	Current standard deviation of baseline
`P`	Ambient pressure measured on POPS Cape (hPa)
`TofP`	On-board temperature measured on POPS Cape (C)
`POPS_Flow`	Current sample flow rate measured by the laminar flow element and differential pressure sensor (cm^3 / s)
`PumpFB`	Feedback value used when controlling pump speed using PID control.
`LDTemp`	Temperature of laser diode control board (C)
`LaserFB`	Feedback value used when controlling laser power using PID control.
`LD_Mon`	Laser diode output power monitor
`Temp`	External thermistor value (not used)

`BatV`	Battery or input DC power voltage (V)
`Laser_Current`	Laser diode current (constant if not using PID control; from config)
`Flow_Set`	Pump voltage set point (constant if not using PID control; from config)
`BL_Start`	Starting point for baseline value determination
`TH_Mult`	Threshold multiplier for determining valid particle counts (from config)
`Nbins`	Number of bins for particle raw peak signal distributions (from config)
`Logmin`	Power of 10 for lowest particle signal bin (from config)
`Logmax`	Power of 10 for largest particle signal bin (from config)
`Skip_save`	Value of the "skip_save" parameter set in configuration file (see above)
`MinPeakPts`	Minimum number of peak points above threshold to be considered valid particle count (from config)
`MaxPeakPts`	Maximum number of peak points above threshold to be considered valid particle count (from config)
`RawPts`	Number of points saved for any raw data recorded
`[HISTOGRAM] or [b0]`	Nbins columns where Nbins is the number of histogram bins. Each column contains counts recorded in last second within a logarithmically spaced size bin. See "Determining sizing bin boundaries" in Appendix 2.

Peak files

Peak files contain several parameters describing the raw particle peak signals recorded by the photodetector. The data can be useful if you need to re-bin to different size bins or work with > 1 Hz data. Contact Handix Scientific if you would like to work with peak data files.

RawBL and RawPeak files

RawBL and RawPeak files contain high-speed raw signals recorded during particle and baseline periods. They are typically used for diagnosing problems with the instrument. Contact Handix Scientific if you would like to work with raw data files.

Data Storage Management

The 32 GB microSD card supplied with the POPS has sufficient storage space for up to three weeks of continuous data collection with full data writing options selected (including peak-by-peak, baseline and raw data being saved), though the exact capacity will depend on particle concentrations. Reducing the save rate for peak-by-peak data or disabling raw/baseline data saving will increase storage capacity. **The POPS will no longer save newly acquired data once there is no longer space on the microSD card!** To avoid data loss, periodically move files from the microSD card to another storage device.

If the microSD card becomes full it will need to be re-formatted for the POPS to operate normally. To reformat the microSD card first copy all data, including configuration files, contents of the "Data" directory, and the pump life data file to another storage device or computer. A microSD to SD or microSD USB reader is useful for this step. If using Windows, after copying data, reformat the microSD card by right-clicking on the card in Windows Explorer and selecting "Format…" from the menu. Select the FAT32 file system and then click "Start" to format the SD card (all data will be lost at this point, so be sure data have been backed up first!). If using OSX, start Disk Utility, select the microSD card, then press the "Erase" button, again selecting the FAT32 file system. After formatting the microSD card copy the POPS_Configuration.ini and pump file (if present) back to the card, and also create a directory/folder on the card called "Data". Eject the card and insert back into the microSD card slot on the Beaglebone Black attached to the POPS. The POPS should now operate normally again.

4 Maintenance, Alignment and Calibration

4.1 Routine maintenance

WARNING: Perform a safe shutdown, turn off the POPS and disconnect from any power source or battery before performing any maintenance operations unless otherwise instructed.

Cleaning and replacing the mirror

Over time the spherical mirror used to collect and focus scattered light onto the photodetector can become dirty. A dirty mirror causes the amount of light reflected to the detector to decrease, resulting in a drop in measured pulse amplitude for particles of the same size. The rate at which the mirror will become dirty will vary with instrument flow rates and ambient particle concentrations, with higher particle concentrations leading to more rapid contamination of the mirror.

In most cases the photomultiplier tube used to detect the scattered light is sufficiently sensitive that simply performing calibrations with particles of known size will account for changes in the mirror reflectivity. The signal-to-noise ratio will drop for extremely dirty mirrors to the point where the lower size limit of the instrument begins to increase above an acceptable value. At that point the mirror should be cleaned or replaced.

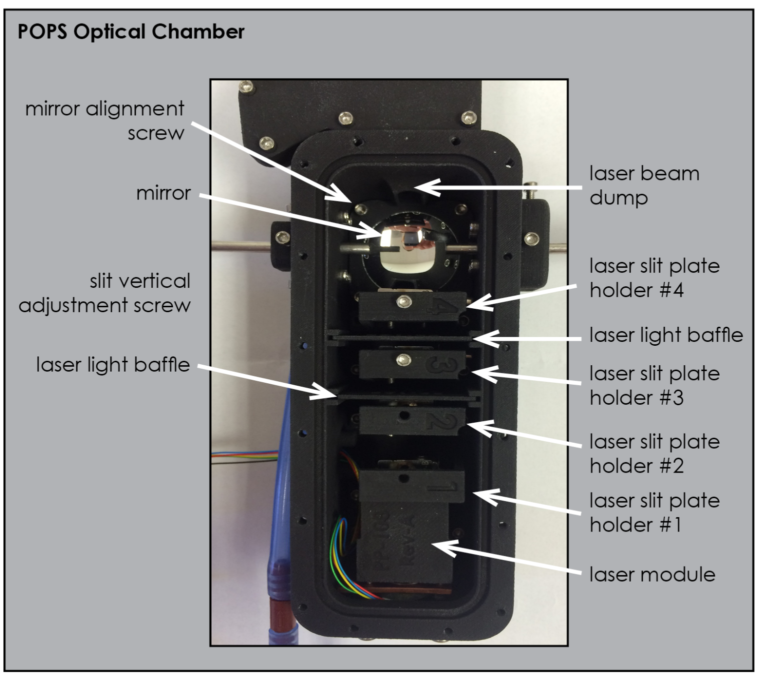


Figure 10. Top view of the interior of the POPS optical chamber, with key components identified.

Cleaning the mirror

1. If necessary remove the POPS optical chamber from the enclosure so that its top cover can be completely removed. In most situations the POPS cover can be removed without removing the

baseplate from the enclosure. You may need to remove the inlet and exhaust tubing, unplug the laser power cable and SATA cable connected to the PMT digitizer board in order to remove the chamber from the enclosure.
2. Using a 5/64" socket driver remove the screws securing the POPS optical chamber cover to the POPS chamber.
3. Moisten optical cleaning wipes or swabs with optical grade methanol or a solvent mix of your choice.
4. Gently cleanse the surface of the mirror using the wipes or swab, being careful not to move the inlet nozzle or exhaust tubing.
5. Ensure the O-ring is in place before replacing the POPS optical chamber cover and tightening the socket head screws.
6. Replace inlet and exhaust tubing, laser power cable, SATA cable (if removed) and put POPS optical chamber back in the enclosure (if applicable).

Replacing the mirror

1. If necessary remove the POPS optical chamber from the enclosure so that its top cover can be completely removed. You may need to remove the inlet and exhaust tubing, unplug the laser power cable and SATA cable connected to the PMT digitizer board in order to remove the chamber from the enclosure.
2. Using a 5/64" socket driver remove the screws securing the POPS optical chamber cover to the POPS chamber.
3. Using a 5/64" socket driver remove the two screws securing the POPS laser slit holder #4 and POPS laser slit holder #3. Lift each slit holder vertically out of the POPS optical chamber and set to the side.
4. If necessary pull up firmly on the POPS laser light baffle to remove it from the optical chamber.
5. Using a 5/64" socket head driver remove loosen the four mirror alignment screws until the mirror assembly is free from the base of the optical chamber.
6. Using tweezers slide the mirror towards the laser module and remaining slit plates until you can lift it and remove from the optical chamber without hitting the inlet nozzle or exhaust tube.
7. Transfer the alignment screws, springs and O-rings from the old mirror assembly to the replacement mirror assembly.
8. Reversing the procedure described in step 6 insert the new mirror assembly into the base of the POPS chamber, being sure to orient the mirror so that the notch in the mirror frame is oriented towards the laser beam dump.
9. Using a 5/64" socket head driver tighten the four alignment screws into the base of the POPS optical chamber.
10. Replace the POPS laser slit holders removed in Step 3 being sure to tighten securely to the base of the optical chamber. Replace the laser light baffle if removed by pushing down until it is snug to the bottom of the chamber.
11. Align the mirror following the Mirror Alignment Procedure described below.
12. Replace the POPS optical chamber cover being careful to replace the O-ring, reattach tubing and cables and replace in enclosure (if applicable).

Replacing particle filters

1. Loosen the screw holding the filter into the filter-mounting block. You should be able to push the filter out of the holding clamp so that it can be removed.
2. Pull flexible tubing away from filter inlet. If necessary you may need to cut the tubing at the inlet to remove.
3. Insert inlet of new filter into the flexible tubing.

4. Push the filter back into the filter-mounting block and slightly tighten the screw to secure in place.

Replacing the pump

1. Unplug the pump power cable from the POPS Baseplate.
2. Remove pump exhaust tube and set to the side.
3. Remove tube running from the pump to the POPS optical chamber at the pump inlet port.
4. Remove the pump from mount (will vary depending on POPS enclosure style).
5. Install new pump into the mount (will vary depending on POPS enclosure style).
6. Reattach tube running from pump to the POPS optical chamber on the vacuum side of the pump.
7. Reattach tube running to pump exhaust filter.
8. Plug pump power cable into the POPS Control Board.

Inlet inspection and cleaning

1. If necessary, remove the POPS optical chamber from its enclosure, removing any cables and/or tubing as needed.
2. If not already done so remove the inlet and exhaust tubing.
3. Hold the optical chamber up to a light source so that you can look through the exhaust tube and through the inlet to the light source.
4. Inspect the nozzle for any signs of debris or blockage. When clean you should see clearly through the round inlet nozzle.
5. If the nozzle is blocked or obstructed first attempt to clear the blockage by pushing a small wire filament through the inlet nozzle from the exhaust port to remove the debris. You will likely need to remove the POPS optical chamber cover as described in the “Cleaning and replacing the mirror” section in order to feed the filament into the inlet nozzle.
6. If you are unable to remove the blockage remove the inlet nozzle by loosening the four screws securing it in place on the outside of the optical chamber. Pull the inlet nozzle out from the POPS chamber (it will be quite firm due to the pressure from an O-ring sealing the nozzle. If the nozzle is stuck you may need to loosen the four screws securing the inlet nozzle mounting block to the side of the POPS chamber before attempting to pull it out.
7. Clean the nozzle by soaking in water to remove any soluble material or running water and/or solvent of your choice through the inlet nozzle interior. If the nozzle remains obstructed contact Handix Scientific for a replacement.
8. If you removed the nozzle to clean it push it back into the optical chamber to approximately the same position. Follow the laser adjustment procedure described below after replacing the nozzle to re-align the optical system to the new nozzle position.
9. If the nozzle was not removed during cleaning simply replace the optical chamber cover if removed, replace inlet and exhaust tubing, cables and return to the enclosure (if applicable).

4.2 Optical alignment

WARNING: With the cover removed for service the POPS is a Class 3B laser product. Protective eyewear is required when performing any of the procedures described in the following sections.

All procedures in this section assume that the POPS optical chamber has been removed from any enclosure, any tubing removed, cables/wiring disconnected and cover has been removed.

Laser position alignment

1. Using a 5/64" ball socket driver, remove the three slit position holders from the base of the optical chamber and remove any laser light baffles.
2. Using a 5/64" ball socket driver, remove the laser assembly from the optical chamber. Be careful not to stress the laser power cable connected to the laser control board on the rear of the laser assembly.

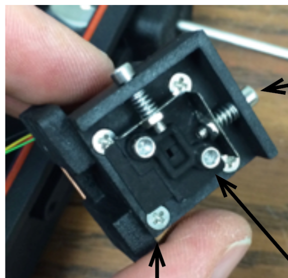


Figure 11. Detail view of the POPS laser assembly after removal from the optical chamber, showing slit plates, adjustment screws and plate clamp.

3. Using a 5/64" ball socket driver, remove the slit clamp screws from the front of split plate holder #1 attached to the face of the laser assembly.
4. Using a 5/64" ball socket driver, remove the slit adjustment screws located on the top and side fo the plate holder. Do not lose the small springs located between the holder and the metal slit plate when removing the screws. Set the plates, spring and adjustment screws to the side.
5. Put the laser assembly back in the optical chamber and secure with the mounting screws using a 5/64" ball socket driver.
6. Remove the three Philips head sealing screws from the rear of the optical chamber. Remove the four Philips head sealing screws form the exhaust side of the POPS optical chamber.
7. Disconnect the pump power cord from the POPS Control Board. Connect the laser cable to the POPS Control Board.
8. Put on laser safety glasses!
9. Connect the POPS to a power source to turn on the laser.
10. Using a 5/64" right-angle driver adjust the three laser alignment screws to center the laser beam horizontally on the beam dump. Use a small scrap of white paper to produce an image of the beam to help with the alignment. You will most likely need to adjust the upper two alignment screws, as the bottom alignment screw does not have much effect on the horizontal position.
11. The distance from the laser beam to the inlet nozzle should be approximately 1/8" inch and light from the laser should not be striking the inlet nozzle. If the nozzle is too far or too close to the laser beam loosen the laser set screws and push in or out as necessary.
12. Insert the laser alignment filament into the exhaust tube in the optical chamber and feed through into the inlet nozzle using tweezers to adjust the filament position. Continue to feed through the inlet nozzle until the filament remains in position without being held.
13. Adjust the laser alignment screws to center the beam on the filament running through the inlet. The filament should approximately split the beam in half when centered properly.

Figure 12. Example of a well-aligned laser beam, with alignment filament passing from the exhaust tube (right) to the inlet nozzle (left).

14. Adjust horizontal position again if it has shifted due to the vertical alignment, trying to keep the vertical alignment unchanged. It may take several iterations to center the beam both vertically and horizontally.
15. Disconnect the POPS from the power source to turn off the laser.
16. Remove the laser assembly from the POPS optical chamber.
17. Replace the vertical and horizontal slit plates in the slit plate holder by first threading the alignment screws into the holder, sliding the spring over the screw, then inserting the screw into the slit plate. Put the slit clamp holder in place but do not fully tighten the clamp screws.
18. Replace the laser assembly in the POPS optical chamber.
19. Perform the slit adjustment procedure described in the following section, skipping step 1.

Laser slit plate alignment

1. If present, use a 5/64" ball socket driver to remove the laser slit plate holders #2-4 from the optical chamber, remove any laser light baffles in the chamber, and slightly loosen the two slit clamp screws on the front face of the slit holder. Insert the laser adjustment filament into the exhaust tube on the chamber and insert into the inlet nozzle to provide a target for alignment.
2. Connect the POPS to the power source to turn on the laser.
3. Adjust the vertical and horizontal alignment screws to move the slits until the laser beam is as bright as possible and still centered vertically on the filament and horizontally on the beam dump.
4. Using a 5/64" ball socket driver tighten the two slit clamp screws. Be careful not to over-tighten and strip the plastic in the slit holder. Stop tightening the clamp screws as soon as you feel resistance.
5. Insert slit plate holder #2 into the optical chamber and repeat the slit adjustment described in the previous two steps.
6. Insert slit plate holder #3 into the optical chamber and repeat the slit adjustment procedure.
7. Insert slit plate holder #4 into the optical chamber and repeat the slit adjustment procedure.
8. Insert the laser light baffles into their original positions.
9. At this point you should have a bright laser beam centered horizontally on the laser beam dump and vertically on the laser alignment filament. If not, repeat the procedure until you have a satisfactory beam.
10. Remove the laser filament form the inlet and darken the room as much as possible. You should see no stray laser light when viewing the inlet region of the optical chamber. If there is a large amount of stray light you may need to adjust the laser light baffles, laser alignment, or replace the slit plates. Contact Handix Scientific for instructions.
11. Disconnect the POPS from the power source and perform the mirror alignment procedure described in the following section.

Mirror alignment

1. Insert the laser filament into the inlet nozzle, first threading it through the exhaust tube on the side of the POPS optical chamber.
2. Ensuring the cover O-ring is in place, put the POPS mirror alignment cover plate on the top of the POPS optical chamber and secure with 3 or 4 screws evenly spaced around the cover plate.
3. Connect the POPS to the power source to turn the laser on. You should see an image of the filament on the target of the cover plate, which simulates the position of the POPS photodetector.
4. Using a 5/64" ball socket driver adjust the four mirror adjustment screws to focus the image on the plane of the target (adjusting the z-position of the mirror) while also centering the image on the target (the tilt of the mirror, which affects the x- and y-position of the image).

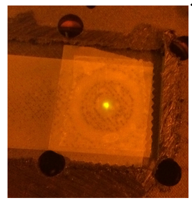


Figure 13. Image of the filament centered on the alignment cover plate target (early version).

5. Once you are satisfied with the position of the image disconnect the POPS from the power source and remove the mirror alignment cover plate.
6. Ensuring the O-ring is in position, replace the optical chamber cover and fasten securely. Re-attach inlet and exhaust tubing, cables and replace in enclosure, if applicable.
7. Perform a PSL alignment check and calibration as described below.

4.3 Performance checks and calibration

The POPS alignment and performance is most easily verified by providing it with monodisperse particles of a known size and distribution, such as polystyrene latex spheres. It is recommended that at minimum weekly single-size PSL checks are performed for the POPS, as the raw signal response will decrease as the collection mirror becomes dirty and the amount of light focused onto the detector decreases.

If available, a differential mobility analyzer or alternative particle classifier can be used to provide a known input distribution of particles of a known composition. Note that because the optical sizing is sensitive to the refractive index of the sampled particles the POPS reported optical size reflects the choice of calibration material.

PSL alignment check and calibration

1. Connect the POPS to the output of a particle generator of your choice. It is useful to have a dilution and/or drying system in place before the POPS to remove any water remaining on the nebulized or atomized output droplets as well as to provide an appropriate output concentration of test particles.
2. Turn on the POPS and connect to a computer that can operate the real-time data viewer run-time executable program. Run the data viewer program and verify it is communicating with the POPS.
3. Set the number of histogram bins to 200 in the POPS data viewer "Control" tab or edit the configuration file so that the number of bins defaults to 200.
4. Turn on the particle generator and adjust the output concentration until approximately 500-1000 particles per cm^3 are measured by the POPS. The test particle size, distribution and cleanliness of

the particle generation system will affect how many particles are detected by the POPS. The critical point here is to avoid excessive concentrations that lead to coincidence errors.

5. Inspect the POPS raw signal histograms to examine the shape and width of the measured distribution. You may see a secondary peak to the right of the main histogram peak, which is made up of coagulated or "clumped" PSL particles. If using a DMA or size classifier that is sensitive to particle charging you will likely see peaks for +2, +3, and higher charged particles. Depending on PSL size the main histogram peak should be a sharp (2-5 bins wide) and symmetrical, near Gaussian distribution. It is helpful to keep a long-term record of the PSL output distributions so that you can easily compare and evaluate the POPS output distributions over time and following changes in laser alignment or components.
6. If the distribution is satisfactory and you wish to perform a full calibration, repeat steps 4-5 for various PSL or test particle sizes, ideally covering the full size range of the POPS (~0.13 – 3.0 um diameter). Collect data for approximately 30 seconds at each size to ensure adequate counting statistics when processing calibration data to obtain a calibration response curve.
7. Disconnect the POPS from the calibration source and safely shut down the POPS and particle generator.
8. Transfer the data from the micro SD card using either a terminal-based transfer protocol (e.g., scp) or read data directly from the micro SD card using a card reader, first removing the SD card from the POPS Computer.
9. Using the data analysis program of your choice, load the housekeeping files generated by the POPS acquisition software and plot the histograms for each test particle size. Perform a fit to determine the center of the histogram.
10. Plot the center histogram signals against the true diameters of the test particles to generate a response curve and apply when processing raw POPS data as appropriate.

Appendix 1: Theory of Operation

Airborne particles interact with incident light depending on the particle's size, shape and composition. Light encountering an airborne particle can diffract or refract, referred to as light scattering, or be absorbed (light absorption). The amount and directional dependence of light scattering is described by Raleigh Theory for particles small relative to the wavelength of the incident light and by Lorenz-Mie Theory for spherical particles with similar sizes compared to the wavelength of the incident light. Both theories predict a strong size-dependence on the magnitude of the scattered light, meaning the light scattering signal can be converted to a physical diameter under certain assumptions. The POPS, like other optical particle counters, relies on the relationship between particle diameter and scattered light intensity to count and size individual particles.

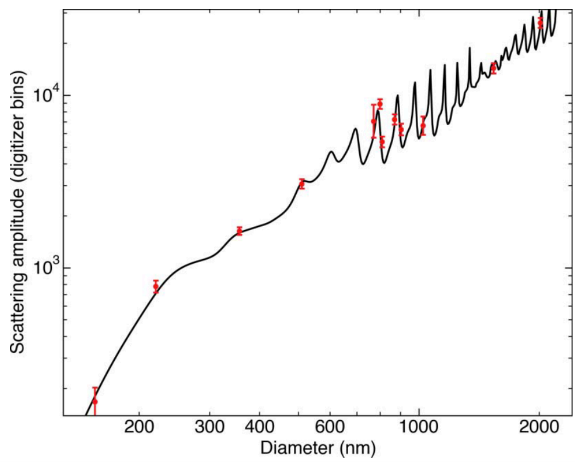


Figure 14. Scaled scattering intensities predicted by Mie theory for the POPS geometry for PSL particles (RI = 1.59). Red points show individual PSL calibration measurements. Figure courtesy NOAA and Aerosol Science and Technology.

Figure 13 shows an example theoretical response curve predicted by Mie theory for particles with the same refractive index (RI) as polystyrene latex spheres (1.588). The curve initially follows the diameter to the sixth power relationship predicted by Rayleigh scattering theory while the particle diameter is small compared to the POPS laser wavelength (405 nm). Oscillations in the curve become more pronounced and the size dependence becomes weaker for particle diameters near to and larger than the laser wavelength. The oscillations cause a reduced size resolution for particles at the upper range of the POPS.

Mie theory predicts a decrease in scattering intensity for as the particle refractive index decreases and/or the particle becomes more strongly light absorbing (or an increase in the complex component of the refractive index). Two particles with the same size and shape but different compositions may be sized differently depending on their size and refractive index.

During operation the POPS samples particles from the ambient air through an inlet with a laminar flow element to monitor the volumetric sample flow rate. A software controlled miniature rotary vane vacuum pump pulls air out of the optical chamber to draw flow through the inlet jet. Filtered sheath air is also pulled into the chamber by the pump, but restricted by an orifice. The pump speed is adjusted to maintain a constant volumetric flow rate through the sample inlet, as measured by the laminar flow element. Sheath air is introduced to the sample cavity through six small jets surrounding the inlet nozzle, which helps confine the sample jet and prevent contamination of optical surfaces inside the optical chamber.

Sampled particles are focused through the center of a vertically elongated laser beam with a Gaussian beam profile. Light scattering by particles as they transit through the beam is collected by a spherical mirror located at the base of the cavity and focused onto the sensing element of a photodiode located on the opposite side of the optical chamber. After transiting the laser beam sampled particles are exhausted through a tube connected to the vacuum pump and filtered.

Appendix 2: Data Processing

Determining size bin boundaries

The POPS bins particles based on their raw signal peak amplitudes. The bin boundaries are logarithmically spaced and determined based on the number of bins and logmin and logmax parameters set in the instrument configuration file. For example, for the default iMet configuration the number of bins, nbins = 8, logmin = 1.4 and logmax = 4.817. The log delta is:

$$\text{logdelta} = \frac{logmax - logmin}{nbins} = \frac{4.817 - 1.4}{8} = 0.427$$

so the bin boundaries are:

Bin #	1	2	3	4	5	6	7	8
Lower	$10^{1.4}$	$10^{1.4+0.427}$	…	…	…	…	…	$10^{4.817-0.427}$
Upper	$10^{1.4+0.427}$	$10^{1.4+2x0.427}$	…	…	…	…	…	$10^{4.817}$

or

Bin #	1	2	3	4	5	6	7	8
Lower	25	68	…	…	…	…	…	24540
Upper	67	180	…	…	…	…	…	65514

To convert from raw signal space to calibrated optical diameter, multiply by the calibration coefficients for the particular instrument. For a standard setup the bin boundaries for an 8-bin setup are typically ~130 nm, 150 nm, 200 nm, 340 nm, 550 nm, 1 um, 2 um and ~ 3.5 um.

Contact Handix Scientific if you have questions about determining the sizing bin boundaries and mapping raw signal values to optical diameters.