Development and Flight of an Imaging Fabry-Perot Spectrometer for Atmospheric Observations

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Climate Change

- Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.
- In the United Nations Framework Convention on Climate Change (UNFCCC), climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere.

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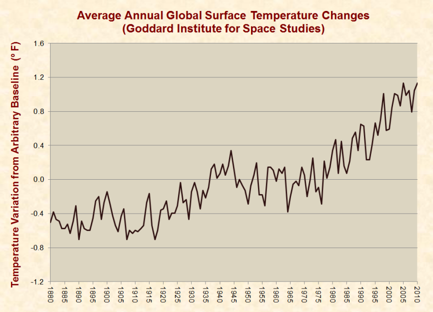
Climate Change

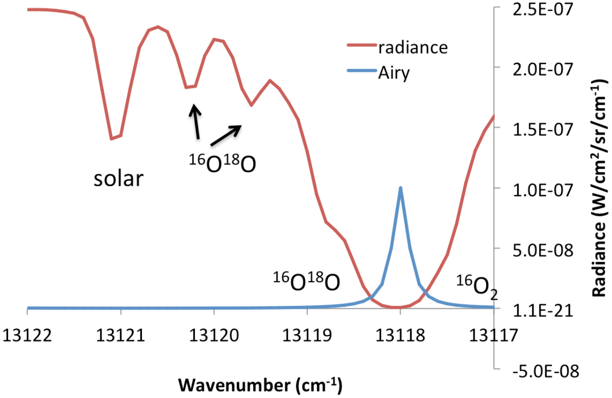


Earth's average temperature warmed by 0.8°C between the 1880s and 2000s, mostly during 1907-1944 and 1976-2014.

Climate Change

- To study climate change, many ground-based and space-based instruments have been developed to observe Earth’s land, air, water and ice.
- Together, these observations are important for knowing the past and present state of Earth’s climate. They are important for understanding how Earth’s climate works.
- The greenhouse effect is a warming effect caused by certain gases that retain heat from sunlight. Without such gases, the average surface temperature of the Earth would be below freezing.

- In 2014-2017, under two FAST grants from the Canadian Space Agency (CSA), SDCNLab designed and developed an imaging Fabry-Perot Spectrometer (IFPS) for climate change research by observing surface pressure, aerosol information and surface albedo at O_2 A band (760 nm).
- The instrument, IFPS, has been validated through two successful stratospheric balloon flights: one in Sweden in 2016 and the other in Australia in 2017.

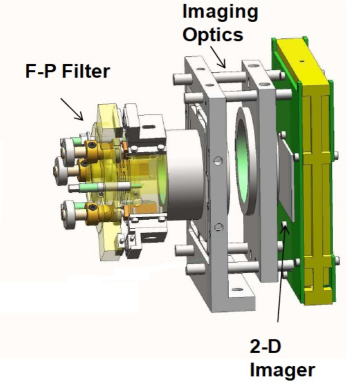

radiance
Airy
solar
$^{16}O^{18}O$
$^{16}O^{18}O$
$^{16}O_2$
2.5E-07
2.0E-07
1.5E-07
1.0E-07
5.0E-08
1.1E-21
-5.0E-08
Radiance (W/cm²/sr/cm⁻¹)
13122
13121
13120
13119
13118
13117
Wavenumber (cm⁻¹)

Scientific Goals

- Air vertical column density (VCD, molec/cm^2): $\pm 0.5\%$
- Aerosol information (AOD or layer height).
- Three parameters must be retrieved:
  - Surface albedo: from the continuum.
  - Surface pressure: from the wings of the $^{16}O_2$ line.
  - Aerosol information: from the core of this line.

Imaging Fabry-Perot Spectrometer (IFPS)

The key element of this spectrometer is a Fabry-Perot (or etalon), which has two lenses and its gap spacing is tuned by three parallel piezoelectric actuators.



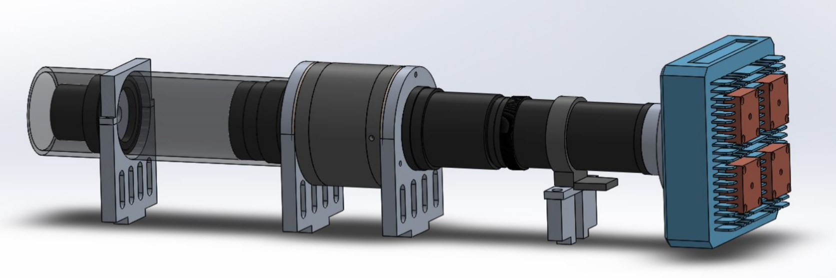
What is Fabry-Perot?

- A basic Fabry-Perot is a pair of parallel, highly reflecting surfaces separated by a gap distance.
- Varying the gap spacing changes the interference condition at which the light can go through the system, therefore changing the transmitted wavelength. By varying the gap spacing, we can therefore obtain a spectrum.
- A Fabry-Perot transmits light not only at a specific wavelength, but at multiples wavelengths, separated by the free spectral range (FSR).

Challenges

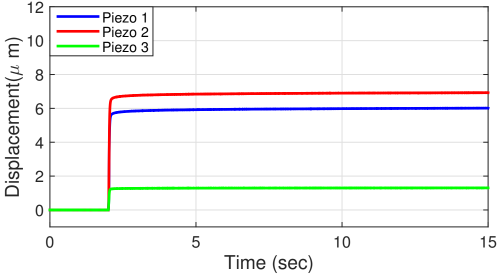
- During the operation, the PEAs will be controlled to perform step trajectories and hold for measurements.
- There are multiple steps and each step is nanometer level.
- The objective is to stabilize as quickly as possible so that the instrument can take pictures and move on.
- Therefore, high-precision control of PEAs and motion synchronization between three PEAs are required for parallelism.
- However, nonlinearities...

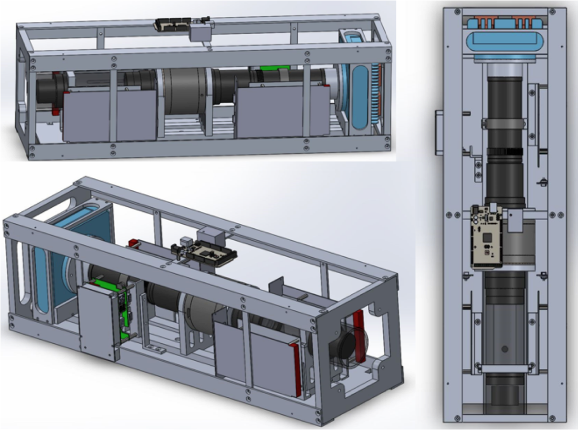
Fabry-Perot Spectrometer



Piezoelectric Actuators

For design reasons, the applied preloads of three PEAs are not the same. Thus, the synchronized motion of three PEAs cannot be guaranteed, causing non-parallel movement of the actuated instrument.





Thermal Control

The operational temperature of Fabry-Perot spectrometer should be at room temperature, i.e. 25-30°C since all the optics tests are done in laboratory. At 30 km the average temperature ranges from -20°C to -40°C. According to thermal simulations, the temperature inside the optical tube will range from -2°C to 16°C. Therefore, thermal control system is required.

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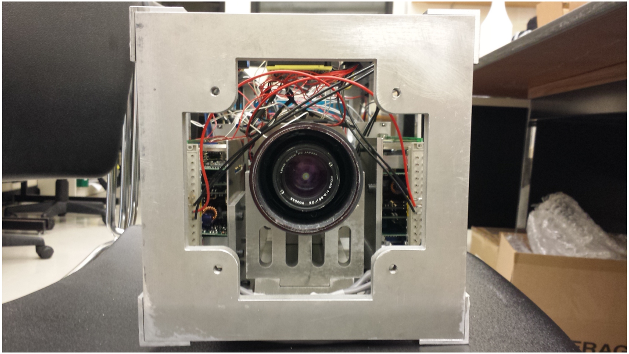
- Localized heating and insulation around the spectrometer.
- From thermal simulations we found three 10" heater strips evenly spread around the spectrometer gave the best heating results.
- Using FR4 to isolate the spectrometer from rest of the system.
- Paint exterior surfaces white to prevent overheating.



Kiruna, Sweden, 09/03/2016

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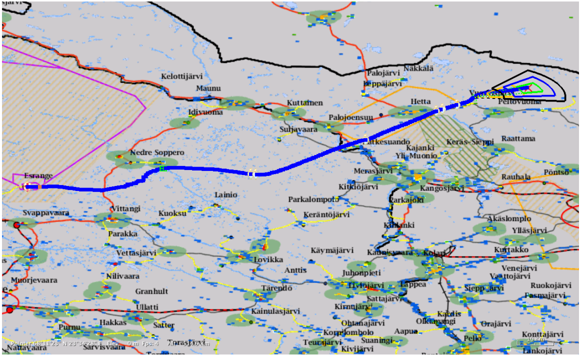

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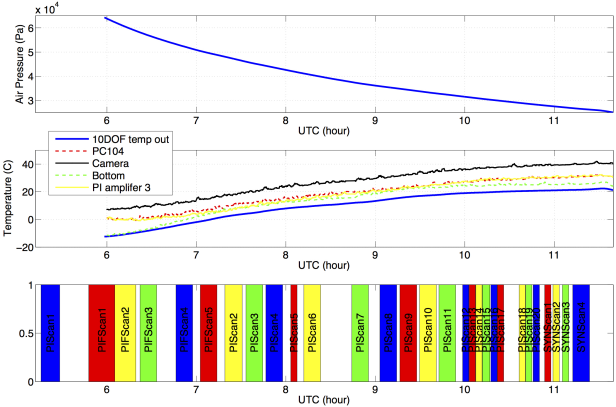

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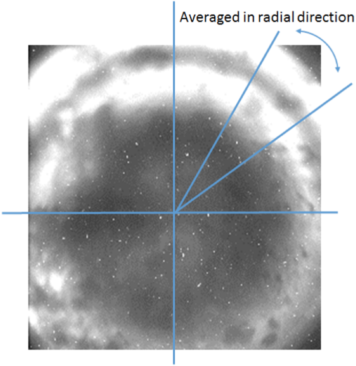

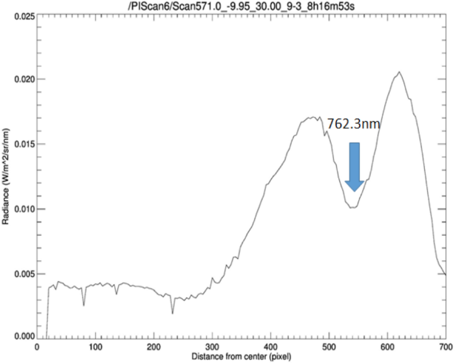

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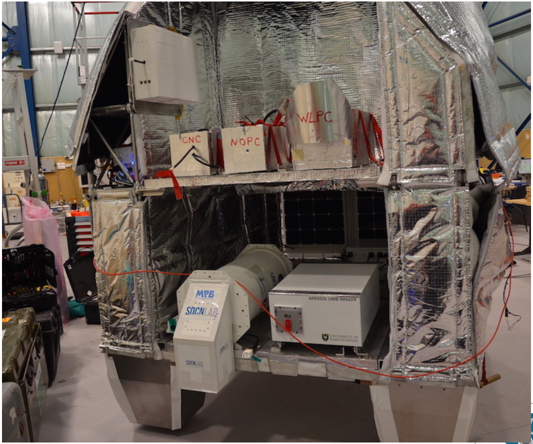
Alice Springs, Australia, 04/09/2017



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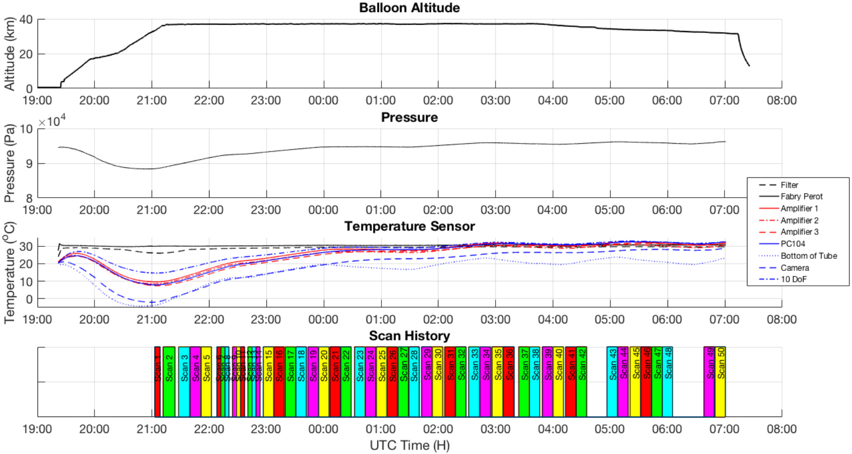

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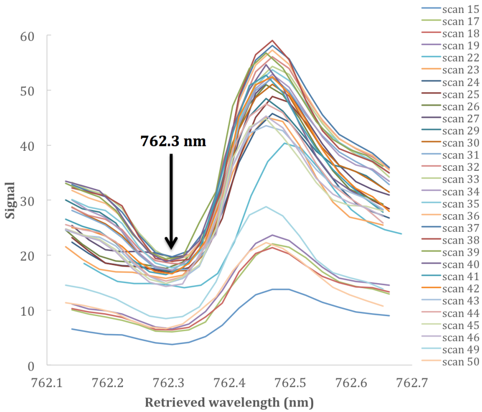

- An imaging Fabry-Perot spectrometer (IFPS) has been developed at SDCNLab supported by Canada Space Agency (CSA) in 2014-2017 for measuring surface pressure, aerosol, and surface albedo from a balloon platform.
- Two balloon flights have been completed and all scientific objectives have been achieved.
- Recently, we received another FAST grant to develop a miniature instrument (<10 kg) with high finesse for future satellite applications.

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CRSNG

MPB
mpb-space.com

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