New eye on the sky: SPÉIR, a millimetre-wave radiometer for high Arctic research

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1. Overview

SPÉIR is a millimetre-wave radiometer currently being developed at the University of Toronto. It will be deployed at PEARL in the high Arctic to determine altitude profiles of atmospheric composition focusing on four species: ozone (O₃), nitric acid (HONO), nitrous oxide (N₂O), and chlorine monoxide (ClO).

The radiometer will measure radiation emitted from rotational transitions of the target species in the 265-280 GHz range. SPÉIR, a superconductor-insulator-superconductor (SIS) mixer which down-converts an intermediate signal by heterodyning with a local oscillator. A Fast Fourier Transform Spectrometer (FTS) with a 1 GHz bandwidth and 1 MHz spectral resolution converts the intermediate signal to the spectral domain.

2. Target Species

Nitric acid
Ozone
Nitrous oxide
Chlorine monoxide

3. Design Considerations

SPÉIR is designed to operate autonomously (no operator present at PEARL) and continuously (day and night). Three key design characteristics are:

- Flexible: The instrument will operate according to a measurement schedule defined in a control file. The file can be modified remotely to change measurement parameters (e.g., species to measure, local oscillator frequency, integration time).
- Robust: The instrument will operate safely in a wide variety of weather conditions in the high Arctic. Temperature and voltage will be monitored continuously to ensure safe and consistent operation. If conditions are not conducive to data acquisition, the instrument will cease operations until conditions are favourable.
- Efficient: The amount of usable data will be maximized by reducing setup time between measurements, ideally, operations are done in parallel where possible.

4. User Interface

The user interface is integrated with the control system via LabVIEW code to provide critical operational information to the remote user.

5. Measurement System

Two-body brightness calibration

Problem: FPTS returns data as volts per channel. To determine altitude profiles, one needs to relate counts to brightness temperature. [1]

Solution: Calibrate FPTS output with signal from two blackbodies at 77 K and ambient temperature (-293 K). By interpolating, it is possible to determine brightness temperature for any voltage output [2].

Total power and balanced measurement modes

Problem: O₃ and N₂O have relatively high abundances in the atmosphere, leading to strongly-defined spectral lines, while HNO₃ and ClO are less abundant and exhibit spectral lines that tend to be more difficult to discern due to systematic variations in the spectrometer channels. [3]

Solution: The instrument will operate in two modes: total power and balanced.

In total power mode, it is sufficient to calibrate periodically with the two blackbodies. In balanced mode (Fig. 6), it is necessary to also frequently calibrate with a reference signal formed by blending signals from the cold and ambient loads [4]. This reduces systematic variation originating due to channel nonlinearity and gain drift [5].

6. Instrument Operation

Step 1: Acquire atmospheric signal

Step 2: Calibrate

Step 3: Cycle between atmospheric & calibration signals

Fig. 9: (a) An additional rotation stage rotates a parasitic mirror to switch between the calibration/reference and atmospheric signals which are directed to the mixer & FTS; (b) Newport LUR 150 CC belt-driven rotation stage is used here.

References


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