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Gas Cell Experiment for the calibration of DESHIMA

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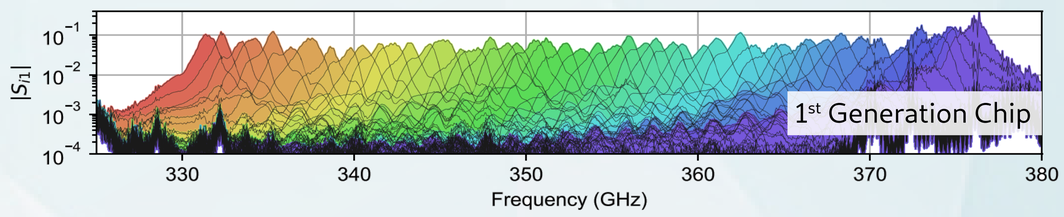
Motivation

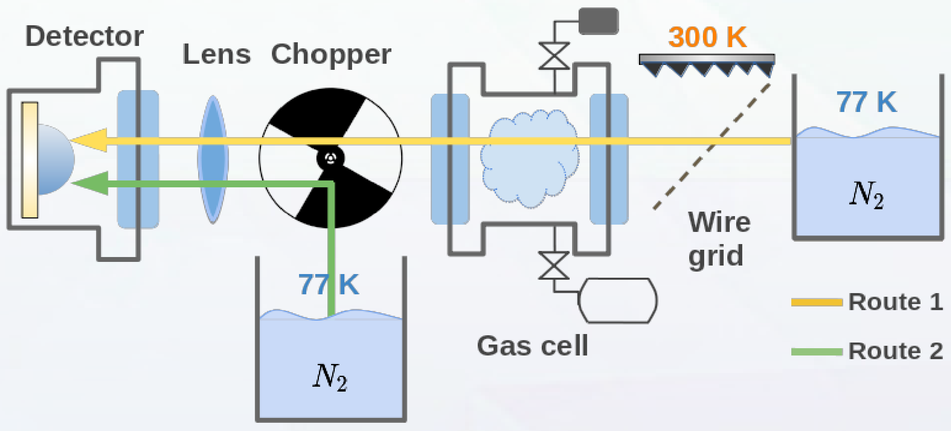
DESHIMA (Deep Spectroscopic High-redshift Mapper) is an ultra-wideband spectrometer with a dispersive filterbank and a microwave kinetic inductance detectors (MKIDs) sensor array integrated on a superconducting chip. The filterbank is characterized as the figure below [1] by a measurement using the frequency-domain continuous-wave terahertz source TOPTICA , which has a frequency accuracy < 2 GHz.

For the next DESHIMA campaign, we design a gas cell system to calibrate the absolute frequencies of the filterbank. Since the system is also designed to create a faint signal, we can characterize the DESHIMA sensitivity by performing a **long integration time test**, which is comparable to a real astronomical observation of a high-redshift object over several nights.



Design

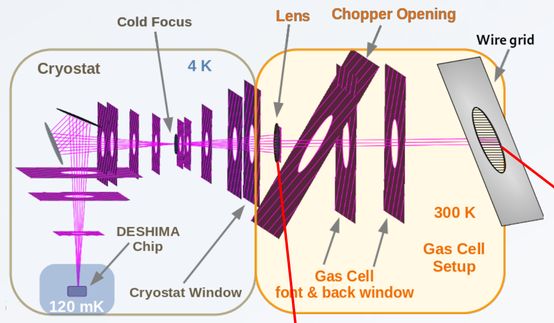
The experiment setup is consist of
- a thin lens
- a mechanical chopper with reflective surface
- a gas cell with a high vacuum system
- a wire grid polarizer
- a hot load at 300 K
- two liquid nitrogen cold load at 77 K



The absorption spectrum is formed in route 1, and route 2 acts as the cold load back-ground.

The gas cell is attached to a high vacuum system that can adjust the pressure and attenuate the strength of the absorption spectrum. The system can go down to 0.05 mbar and has pressure stability of 10%.

Optical Design



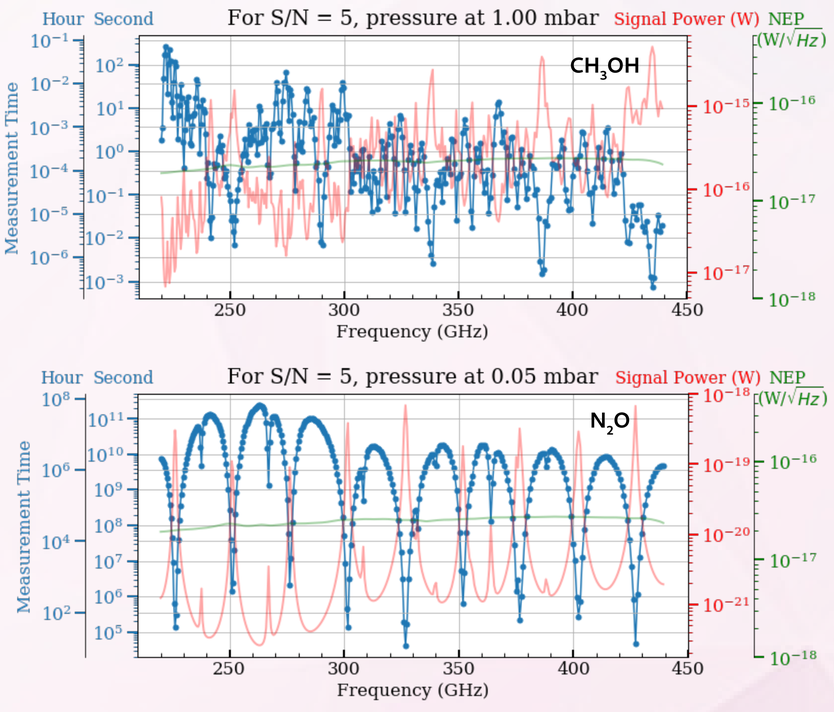
Antenna beam is traced through the setup in GRASP simulation.

Spillover efficiency is ~84%

Gas Choice

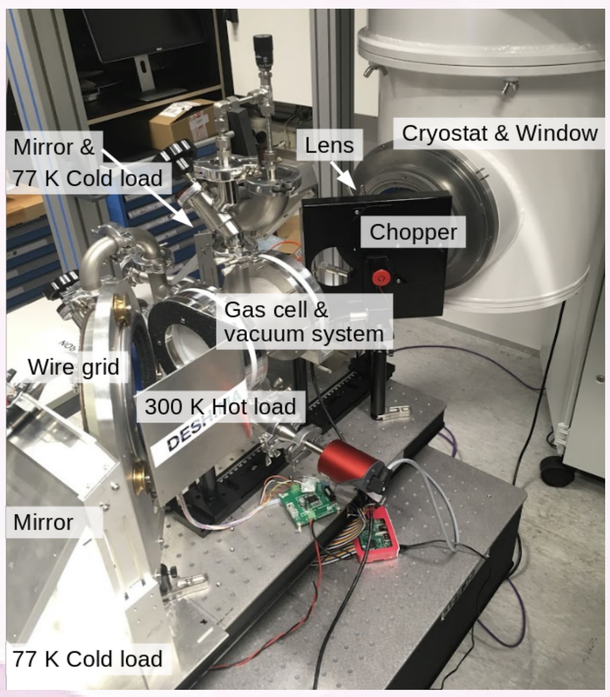
Methanol gas (CH_3OH) is chosen for absolute frequency calibration, whose peaks can be resolved instantaneously at 1 mbar. For the long integration test, nitrous oxide (N_2O) is a good candidate for its well-spaced and clean peak lines in low pressure, which can achieve signal-to-noise ratio (S/N) of 5 at 0.05 mbar in 60 hours of measurement time.

The integration time required for a given S/N is calculated from the convolution of the blackbody radiation, gas transmission rate and instrument efficiencies.



Experiment

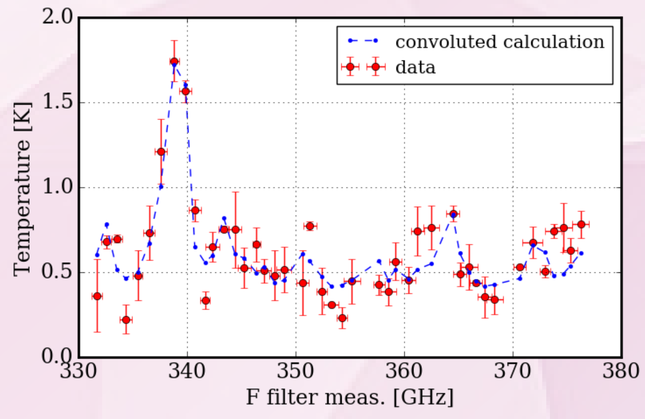
The gas cell setup is tested on the DESHIMA 1st generation chip, and two measurement are taken: **1)** for frequency calibration, methanol (CH_3OH) at 1 mbar for 100 sec, and **2)** for long integration time test, methanol at 0.05 mbar for 1000 sec, with chopper modulation frequency of 10 Hz.

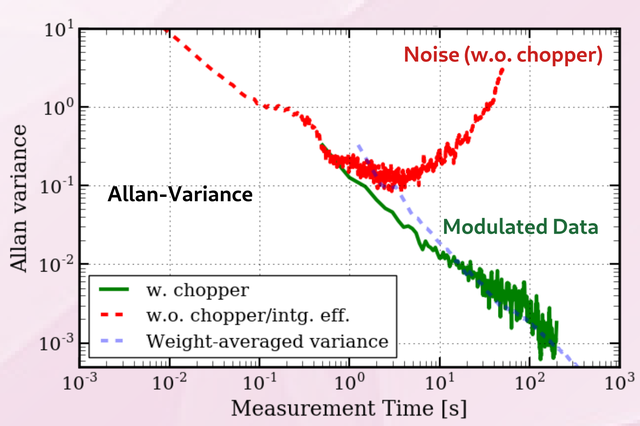


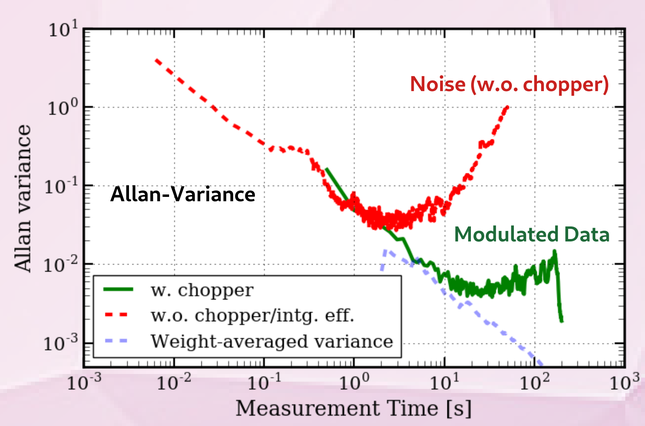
Results & Discussion

The largest peak around 338 GHz in the methanol spectrum is resolved in the 1 mbar measurement. By creating a convoluted model with different frequency shift and fitting it with our results, we determine a frequency shift of the TOPTICA source as -0.92 GHz.

The long integration time test 1000 sec methanol data cannot be resolved. The Allan-variances are analyzed and compared to the unmodulated noise data. The noise data shows a 1/f noise that is eliminated after chopper modulation (bottom left figure), but some filters show unknown systematic errors that prevent us to integrate longer than 20s (bottom right figure).







Reference

1. Akira Endo et al., Journal of Astronomical Telescopes, Instruments, and Systems, **5(3)**:1 – 12 – 12 (2019)

Summary & Outlook

We have designed and constructed a gas cell system for DESHIMA, and carried out experiments to determine the frequency shift of TOPTICA source. Unknown systematic errors are found that prevent us to perform long integration time test. Further design optimization and noise analysis are needed to eliminate and investigate the sources of the errors.

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