Caltech Airborne Submillimeter Interstellar Medium Investigations Receiver (CASIMIR) characterization at 1.2 THz and future development

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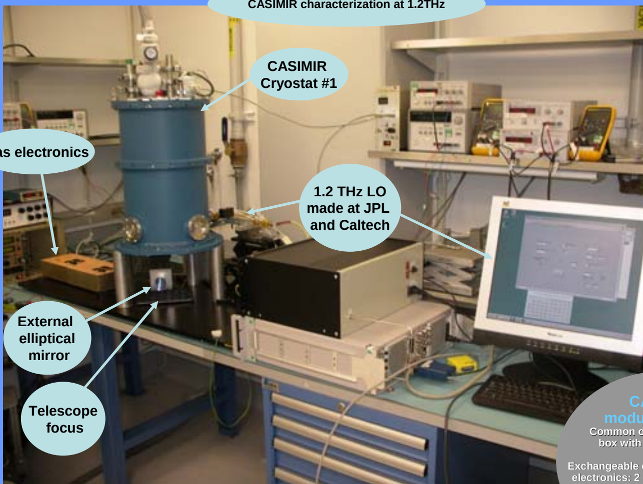
CASIMIR characterization at 1.2THz



Abstract:

The completion of the heterodyne receivers program for the Herschel space observatory is marking an important milestone in the development of the instrumentation for astrophysics. Caltech and JPL contribution to the development and to technology of the THz frequency mixers for the Bands 5, 4 and 3 of the HIFI instrument allowed the creation of the most sensitive THz heterodyne receiver up to date. Nevertheless their sensitivity in THz range is still 10-20 times above the quantum limit, and may be improved.

The SIS mixer technology is proven to give a unique opportunity to build the quantum limited sensitivity heterodyne receivers at the sub millimeter wavelengths. In this work we are extending this and similar technologies in the THz range.

We report the development of 0.5 - 1.4 THz SIS mixers for a heterodyne spectrometer CASIMIR aimed for the stratospheric observatory SOFIA. One of goals of this work is to supply a low noise spectrometer for the studies of the H2D+ 1_{01} - 0_{00} line around 1370 GHz.

In more details we present characterization of performance of CASIMIR around 1.2 THz and the plans of a further development.

Caltech Airborne Submillimeter Interstellar Medium Investigations Receiver (CASIMIR) overview:

- High resolution heterodyne spectrometer 500 – 1500 GHz, Modular design, 5 bands: 550 GHz, 750 GHz, 1.0 THz, 1.2 THz, 1.4 THz
-Single pixel, single polarization per band. Four bands available per flight
- Advanced SIS mixers: DSB Trx < {3-6} hv/k for 0.5-1.4 THz 4–8 GHz IF bandwidth
- Target initial flights in 2013. The initial flights with two bands: 1.2 THz and 1.0 THz

For more details on CASIMIR please see poster presentation by Michael Edgar

SIS mixer:
Quasi-optical design with silicon lens diameter 5 mm

•NbTiN/AlN/Nb junction with Vg~3.5 mV (2fg= 1700 GHz)

•Nb / Normal metal tuning circuit

CASIMIR modular design:
Common optical multiplexing box with calibration loads

Exchangeable cryostats with receiver electronics: 2 channels per cryostat

A cryostat may be dedicated to a multi beam receiver array for an upgrade of CASIMIR

CASIMIR characterization at 1.2THz

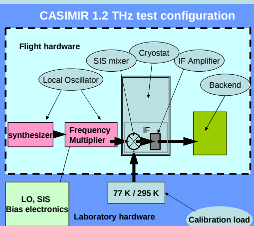
We performed electrical and optical end to end test of the 1.2 THz channel using a complete set of the flight components. Electrical test proved that all the receiver electronics performs properly and we can operate and monitor all the receiver components

•Receiver optical test proves that CASIMIR can perform properly in entire 1120-1250 GHz band. The receiver noise is close to the expectations taking into account the signal loss in the cryostat window

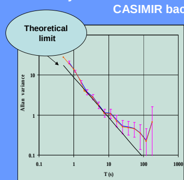
•Receiver operation is stable and the Allan variance is close to the theoretical minimum up to 30 second integration time

• Receiver beam test confirms the proper performance of the optics and that it is suitable for efficient coupling of the receiver to the telescope beam.

CASIMIR 1.2 THz test configuration



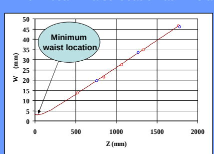
Stability test: Allan variance measured using CASIMIR backend



Allan variance improves up to 30 second integration time.
The error bars give the 2 sigma error

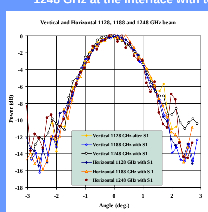
This level of receiver stability should be sufficient for
Most of the observing modes at CASIMIR

Minimum beam waist location at 1128 and 1180 GHz



-Minimum waist location found at within 3 mm off the design requirement.

Beam Vertical and Horizontal scans at 1128, 1188 and 1248 GHz at the interface with telescope

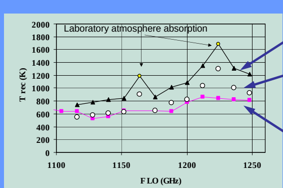


-The beam f/d design requirement is 20.7

-The beam direction is frequency independent

-The beam width is nearly frequency independent with f/d of about 18.4

CASIMIR 1.2 THz Channel measured DSB noise IF band 4-8 GHz



DSB receiver noise Measured with CASIMIR

DSB receiver noise in CASIMIR corrected for 20% loss in cryostat Window

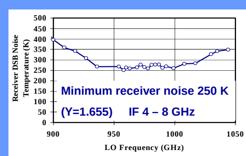
Best DSB receiver noise Measured in the test Cryostat with 12 um Mylar window With the same SIS mixer

Next steps

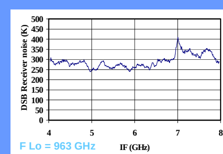
1. Short term. Demonstration of the two channel operation after integration of the 1 THz band mixer in the CASIMIR cryostat #1

Performance of the 1 THz channel in the test cryostat is encouraging with the minimum receiver noise about 250 K or only 5 hv/k, the lowest reported to date at 1 THz. We may expect similar sensitivity in the flight cryostat.

Measured test receiver noise 900 – 1050 GHz

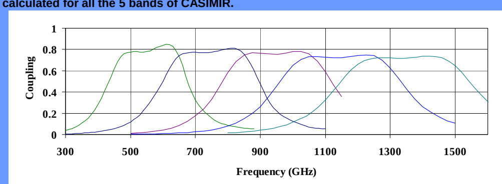


Test SIS receiver performance is uniform across 4-8 GHz Intermediate Frequency band



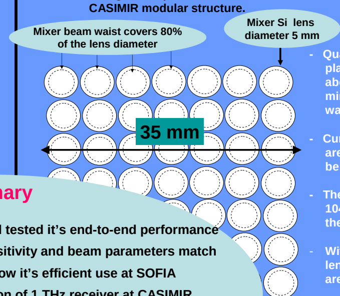
2. Medium term. Improvement of the receiver sensitivity up to the target levels

An updated version of the SIS mixer chip design is currently in production. The expected reduction of the mixer circuit loss should allow to demonstrate receiver noise temperature close to 3 hv/k below 0.8 THz and 6 hv/k above 1 THz. Below is the design prediction of SIS mixer with SiO2 dielectric. The on-chip mixer coupling to the signal is calculated for all the 5 bands of CASIMIR.



3. CASIMIR upgrade: Development of multi beam SIS mixer focal plane module

A large focal plane area available at SOFIA is suitable to build a large array of THz heterodyne receivers using CASIMIR modular structure.



- Quasi-optical SIS mixer design allows to create a densely packed focal plane array receiver. The beam waist diameter at the lens aperture is about 80% of the lens diameter. This makes possible to have a minimum spacing between the beams in the focal plane of only 1.2 waist diameter.
- Current design of the multiplexing optics at CASIMIR allows to use an area of about 54 X 54 millimeters. An array receiver fitting this area may be coupled to the telescope and to the calibration loads of CASIMIR.
- The focal plane area of the telescope usable for an array is bigger, about 104 mm wide. In order to use this entire area one may need to redesign the multiplexing optics of CASIMIR.
- With currently existing optics and the mixer chip at 5 mm diameter Si lens we may envision a 10 X 10 = 100 pixel array in the already available area of 54 x 54 mm.
- An example of a smaller - 49 SIS mixer lens arrangement is presented at the left. It is using a 35 X 35 mm area.

Summary

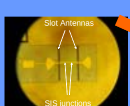
-We built CASIMIR 1.2 THz receiver and tested it's end-to-end performance

- At 1.2 THz the CASIMIR stability, sensitivity and beam parameters match the design requirements and allow it's efficient use at SOFIA

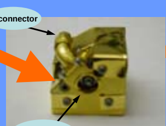
- The next step will be the integration of 1 THz receiver at CASIMIR

-Developed SIS mixer technology is suitable to build a compact focal plane array for CASIMIR. CASIMIR optics allows accommodate a large size receiver array with up to 100 elements at 1-2 THz

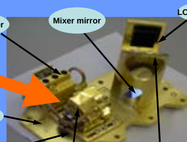
1.2 THz SIS Mixer chip



1.2 THz Quasi-optical SIS mixer



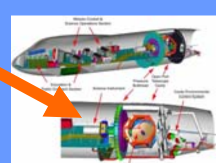
CASIMIR 1.2 THz Channel Cryogenic Front–End



CASIMIR cryostat #1

CASIMIR instrument

CASIMIR at SOFIA



SOFIA Workshop: Scientific Opportunities For new Instrumentation, Asilomar, CA June 5-8, 2010

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