CASIMIR: A high performance submm spectrometer

Caltech Airborne Submillimeter Interstellar Medium Investigations Receiver

CASIMIR is a multiband, far infrared and submillimeter, high resolution, heterodyne spectrometer. It is a first generation, PI class instrument, designed for detailed, high sensitivity observations of warm (100 K) interstellar gas, both in galactic sources, including molecular clouds, circumstellar envelopes, and protostellar cores, and in external galaxies.

CASIMIR will be extremely sensitive, combining the 2.5-meter SOFIA mirror with state-of-the-art superconducting mixers. Five bands are under development: 550 GHz, 750 GHz, 1000 GHz, 1250 GHz, and 1400 GHz. Observing time is maximized by having four bands available on each flight. For example, searches for weak lines from rare species in bright sources can be carried out on the same flight with observations of abundant species in faint or distant objects.

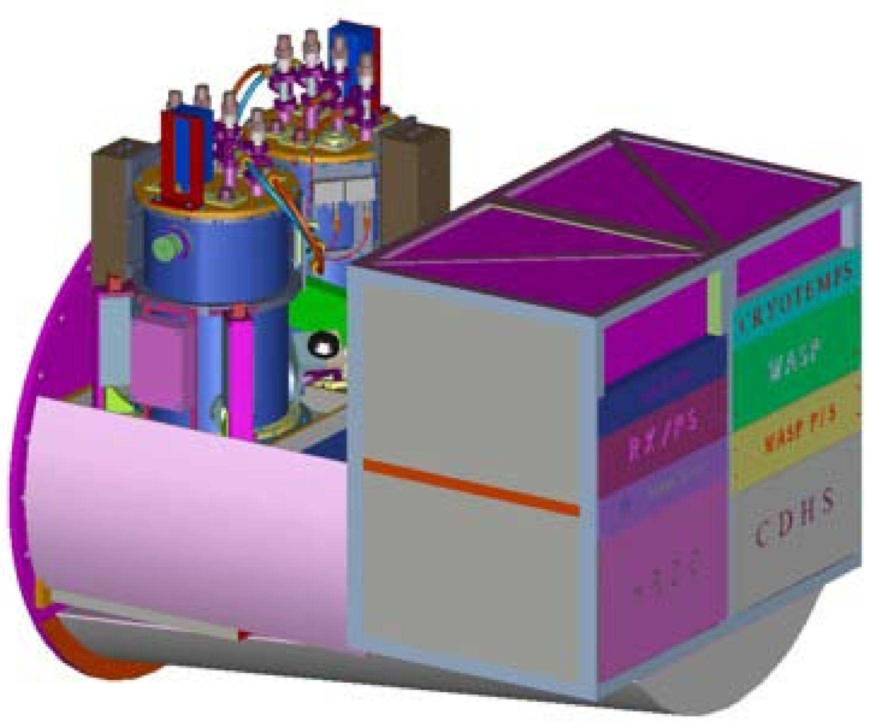
Instrument Configuration

The instrument is mounted to the telescope via the round flange at extreme left of the figure. This flange forms the pressure interface between the telescope cavity and the aircraft's cabin. The portion of the instrument shown is located in the cabin, with the observers.

The telescope beam enters the instrument through the center of this round flange, about 150 mm below the bases of the cryostats. The instrument structure is constructed almost exclusively of aluminum. It is approximately 1.5 m long by 1m square. The total weight is approximately 550 kg.

Two cryostats are mounted side by side on the Optics Box, which contains the relay optics. These optics direct the telescope beam to one of the detectors mounted in the cryostats. The beam is directed through the baseplate of the cryostat by an elliptical mirror, mounted directly to the base of the cryostat., see below.

Two 19-inch racks are mounted directly forward to the Optics Box, i.e. in the right of the figure. All the critical electronics equipment is mounted in these racks, eg. the LO drive electronics and microwave spectrometer. This ensures very short cable runs to the cryostat and prevents any differential rotation. All electronic systems for the instrument are packaged as 19-inch bins, which will allow easy replacement of any unit and the standard format will allow easy upgrades of any of the individual electronic components.



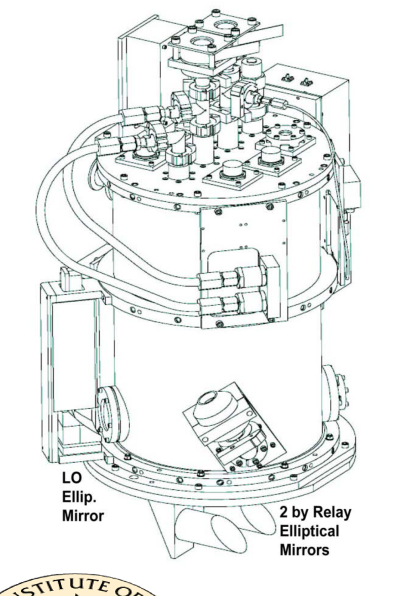
Cryostats

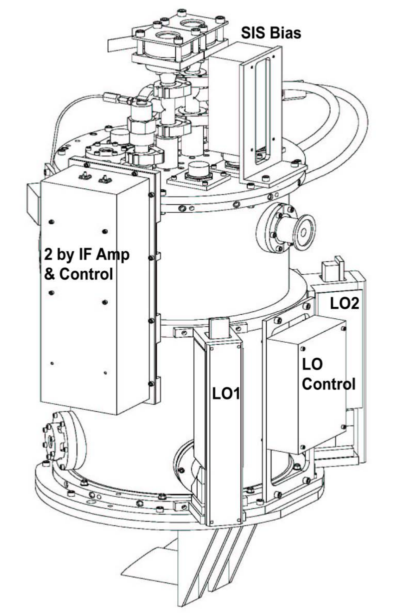
The cryostats are of conventional LN_2 and LHe design with 5 l of each cryogen.

Up to 2 cryostats per flight, with 2 bands per cryostat., therefore, up to 4 bands per flight.

All LOs, IF, relay optics and all band specific components are integrated directly onto the cryostat itself. This allows easy swapping of cryostats between flights and any band improvements can be implemented independent of the rest of the instrument.

Initially, there will be 3 cryostats. More of same design can be manufactured with minimal airworthiness concerns. Small design changes to the jacket, e.g. different window sizes or configurations, may be accommodated with only a reasonable engineering effort required for airworthiness certification.





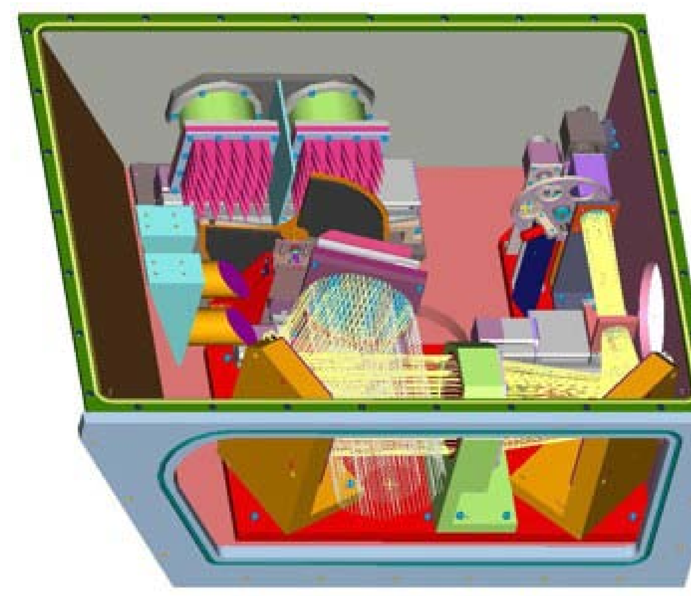
http://www.submm.caltech/casimir

Optics Box

The Optics Box, is the mount for the cryostats and contains all the optics common to all frequency bands. There are no frequency specific components. The image shows the box with its lid removed. All of the optical components are controlled remotely by stepper motors.

The central feature is a plane mirror, which can be commanded to rotate through +/-180° in the plane of the telescope and up to +/-5° in tilt. This rotating mirror directs the telescope beam to one of the four elliptical mirrors mounted on the two cryostats, selecting the frequency band. These mirrors direct the beam through the cryostat base. Two of these mirrors are shown in the left part of the figure. This mirror can also direct the telescope beam to an optical boresight camera assembly, shown in the front and right of the figure, which is the case shown.

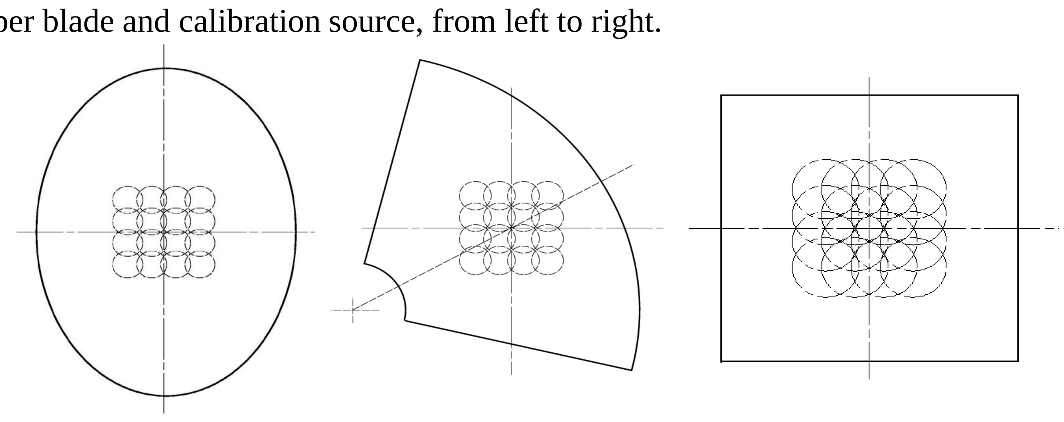
The calibration system consists of a chopper wheel at ambient temperature plus hot and ambient temperature loads, at the rear of the image. Moving the rotating mirror by 180°, allows any of the frequency bands to be first illuminated with the sky signal and then the signal from a known temperature calibration load.



Possible Arrays

The optical components in the Optics Box were designed to be oversized, so they could accommodate the full 8' field of view of the telescope. As a result, they are large enough to support moderate sized arrays, without any modifications and only minor adjustment of the telescope focus position,

The figures below show the beam footprints of a proposed 2 THz, eg. C^+ line, 4x4 array of 1 cm spacing on the cryostat cold work surface. The dashed line diameters in the figure represent 5 times the beam waist for a f/# 20.7 beam at the existing rotating mirror, chopper blade and calibration source, from left to right.



Microwave Spectrometer

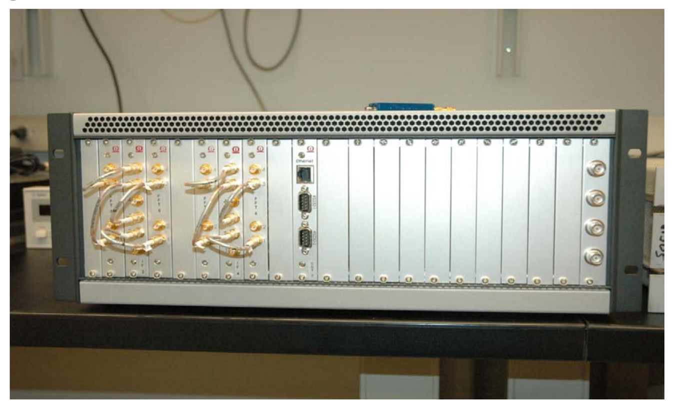
The microwave, or backend, spectrometer is a FPGA based FFT, built by Omnisys Instruments, consisting of independent 4 GHz IF bandwidth modules.

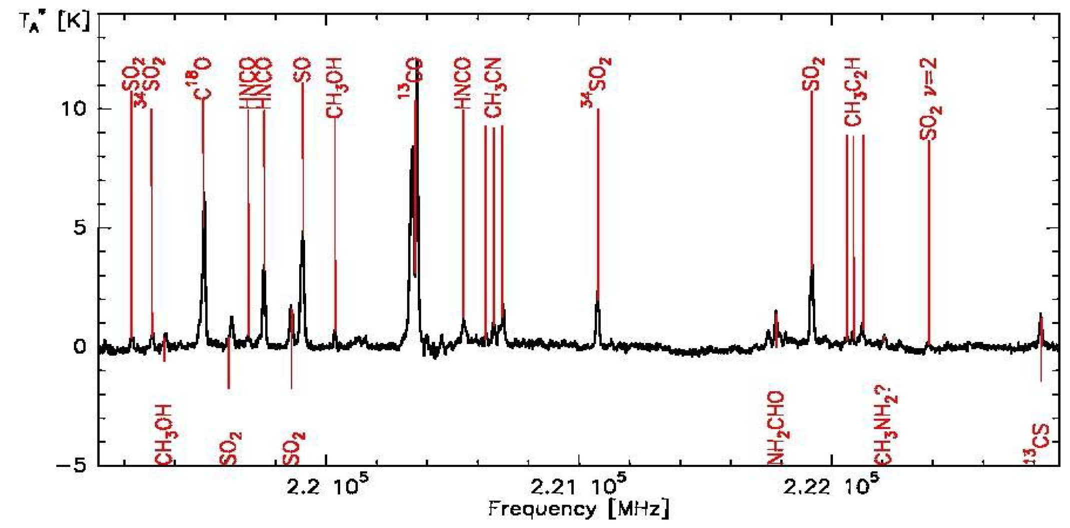
3.8 GHz useful B/W, due to some overlap in side bands.
270 kHz Resolution, R> 3×10^6 or 800 m/s @ 1 THz.

Independent 4 GHz modules makes them easily scalable to much higher bandwidth coverage by adding modules, or whole crates.

2 x 4 GHz IF Modules in spectrometer crate, i.e. 8 GHz bandwidth

16 GHz IF bandwidth when entire crate is full





Galactic Center observed with 230 GHz Wide Band Receiver, at the CSO, obtained with a single 4 GHz IF Module of the Omnisys Spectrometer.. The spectrum is 3.8 GHz wide, centered on 211GHz

Initial Frequency Bands

Initially, there will be 5 frequency bands

All bands will use. Nb/AlN/NbTiN Quasi-optically Coupled Twin Slot SIS Mixers, see separate poster in this session.

All bands will have 4 GHz of IF bandwidth.

All bands will use Tunerless Solid State LOs., developed at JPL or Virginia Diodes Inc. (VDI).

The figures below shown the bandpasses, as defined by the LOs, for the 5 initial bands. All but the 550 GHz band, are flight LOs, although the 750 GHz LO might need repackaging for flight. In these cases the output power is shown as the red and green curves, representing the lower and upper sideband tunings, respectively. These curves are super imposed over the atmospheric absorption at 12.5 km altitude and frequency lines for the species in that band.

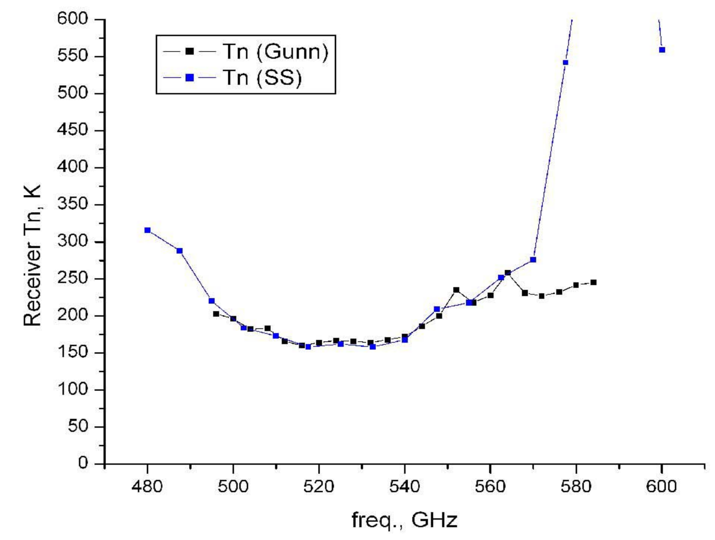
500-600 GHz

LO: VDI x5 Stage

•Replace with x2x3 VDI Stage

- Lines of Interest

H_2O^{18} (547),
CH (532,536),
NH_3 (572),
CO (576)



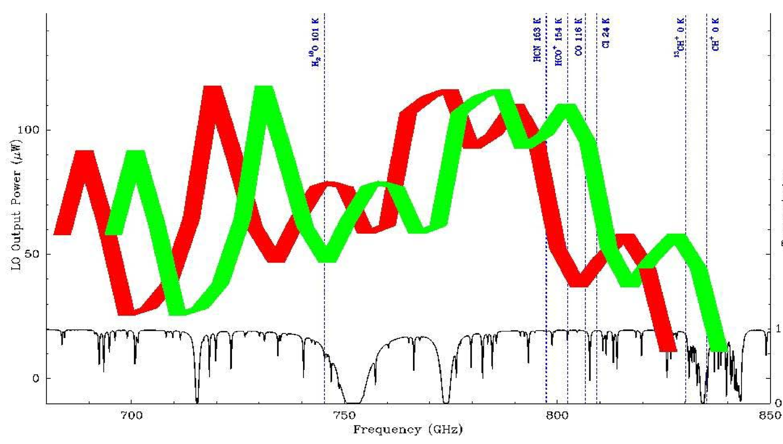
690-840 GHz

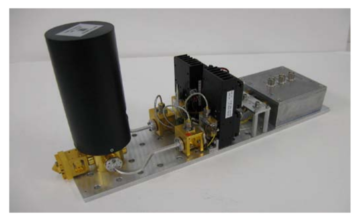
LO :VDI

40-100 uW Output

Significant Line:

H_2O^{18} 745 GHz





800-1050 GHz

LO: JPL

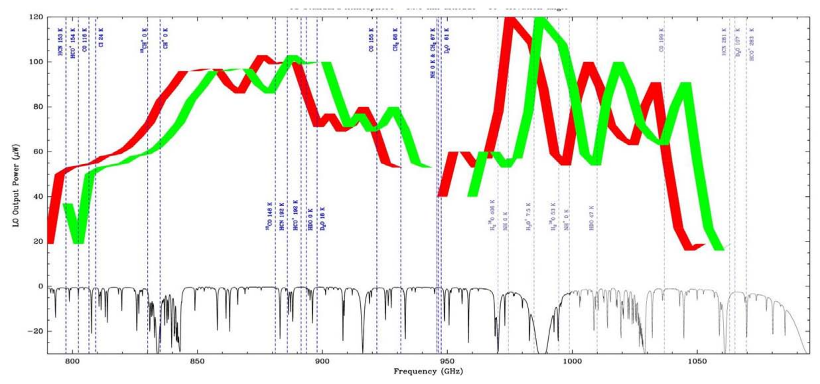
Large Fractional B/W

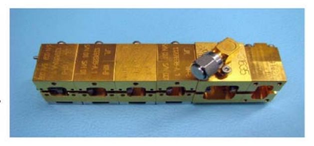
2 Separate Chains

40-120 uW Output

Lines of Most Interest:

H_3O^+ (985), CH_2 (946), NH (975), H_2O^{18} (995), CO(1037)





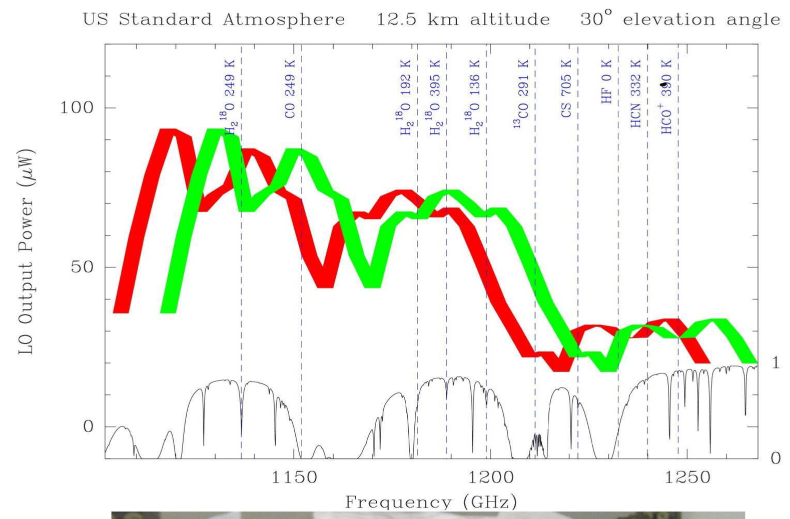
1050-1250 GHz

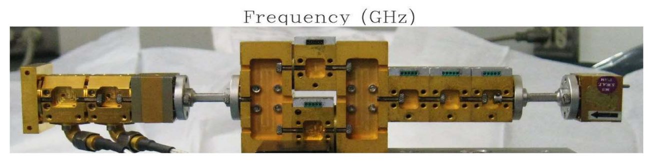
LO: JPL

30-100 uW Output

- Lines of Most Interest

H_2O^{18}, HF





1.4 THz

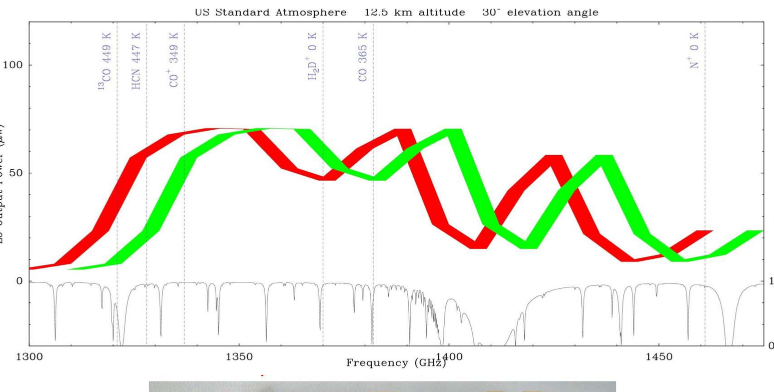
LO: JPL

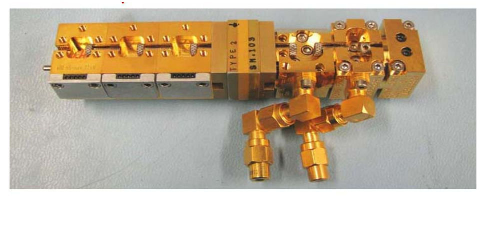
40 to 70uW Output

Lines of Most Interest

H_2D^+, 1.37 THz

Possibly: N^+, 1.46 THz





Scientific Objectives

CASIMIR will enable the study of fundamental rotational transitions of many astronomically significant hydrides and other molecules, unobservable from the ground, see the chart below.

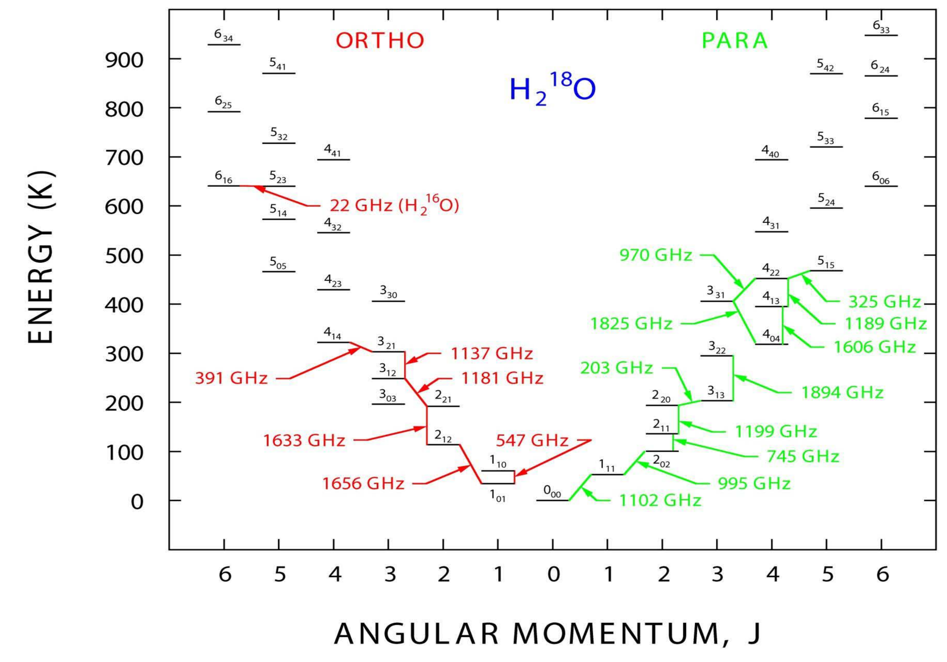
Species	Transition	Frequency (GHz)	E_{lower} (K)	Atmospheric Transmission 1 mm H_20	SOFIA
CH	$F_1 \to F_2;\ J = 3/2^- \to 1/2^+$	536.76	0.0	0 %	97 %
$H_2{}^{18}O$	$1_{10} \to 1_{01}$	547.68	34.2	0 %	81 %
NH_3	$1_0 \to 0_0$	572.50	0.0	0 %	94 %
$H_2{}^{18}O$	$2_{11} \to 2_{02}$	745.32	100.6	0 %	82 %
NH	$N = 1 \to 0;\ J = 2 \to 1$	974.48	0.0	0 %	96 %
H_3O^+	$0_0^- \to 1_0^+$	984.66	7.5	0 %	65 %
NH^+	$3/2^+ \to 1/2^-$	998.90	0.0	0 %	95 %
HF	$1 \to 0$	1232.48	0.0	0 %	30 %
H_2D^+	$1_{01} \to 0_{00}$	1370.09	0.0	0 %	94 %
N^+	$^3P\ J = 1 \to 0$	1461.13	0.0	0 %	92 %
^{16}OH	$^2\Pi_{1/2}\ J = 3/2^+ \to 1/2^-$	1837.82	181.9	0 %	94 %
C^+	$^2P\ J = 3/2 \to 1/2$	1900.54	0.0	0 %	88 %
CH_2	$1_{10} \to 1_{01}$	1917.66	22.4	0 %	99 %
CO	$18 \to 17$	1956.02	751.7	0 %	90 %

▪Water vapor plays an important role in the energy balance of molecular clouds by mediating radiative heating and cooling through its rotational transitions in the far infrared and submillimeter.

•CASIMIR will allow the study of the abundance and distribution of interstellar water with exceptional sensitivity and spatial and spectral resolution.

▪Even at the SOFIA operating altitude (above 12 km), there is too much terrestrial water to observe the common $H_2{}^{16}O$ isotopomer in astronomical sources.

•In its initial bands, CASIMIR can detect nine rotational transitions of the rare $H_2{}^{18}O$ isotopomer, including several lines near the ground state. Only two relatively high energy transitions can be observed from the ground (eg. CSO).



▪Oxygen is the third most abundant element, yet its chemistry in interstellar clouds is poorly understood. The atmosphere is opaque to many of its key species, such as O, O_2, H_2O, H_3O^+ and OH, limiting detailed ground observations.

▪The H_2D^+ ion is of particular interest, as it is the deuterated version of H_3^+, which is believed to be responsible for driving much of the chemistry of molecular clouds. Although the 372 GHz line of H_2D^+ now has been observed in several molecular clouds, the ground state line at 1371 GHz will be a better choice for studying the overall distribution of this important molecule. .

▪Another transition of major importance is the 1461 GHz transition of the nitrogen ion, N^+, which traces the warm, ionized interstellar medium. COBE has shown that, apart from the 1900 GHz C^+ line, the two fine-structure N^+ lines are the brightest emitted by our Galaxy.

▪The study of high J lines of CO, which typically trace shocked gas (studied extensively with the KAO with high-resolution, heterodyne spectroscopy), or may indicate heating by radiation from photo dominated regions (PDRs).

Conclusions

▪CASIMIR is a FAR/IR Submm, Heterodyne Spectrometer for SOFIA

▪Initially will Cover 500 to 1400 GHz and we expect to eventually cover up to 2 THz

▪Able to measure many significant lines unobservable from ground

▪Recent developments in mixer design will greatly improve sensitivity

▪ Flight LO chains are on hand for most of the bands

▪Continuous coverage of 3.8 GHz of IF bandwidth with extremely high resolution, > 10^6 , already demonstrated

-IF coverage can be readily expanded to much higher bandwidths with same high resolution

▪Instrument design extremely modular

-Able to continuously incorporate new hardware, to accommodate future improvements in mixer, LO and backend spectrometer technology, for some time to come.

-Moderate sized arrays can be incorporated into the existing instrument and cryostat designs with reasonable effort.