The Stratospheric THz Observatory (STO): Preparations for Science Flight

C. Walker[1], C. Kulesa[1], J. Kloosterman[1], T. Cottam[1], C. Groppi[2], P. Bernasconi[3], H. Eaton[3], N. Rolander[3], B. Carkhuff[3], S. Hechtman[3] , J. Gottlieb[3], D. Neufeld[3], C. Lisse[3], A. Stark[4], D. Hollenbach[5] , J. Kawamura[6], P. Goldsmith[6], W. Langer[6], H. Yorke[6], J. Sterne[6], A. Skalare[6], I. Mehdi[6], S. Weinreb[7], J. Kooi[7] , J. Stutzski[8], U. Graf[8], C. Honingh[8], P. Puetz [8], C. Martin[9], D. Lesser[9], Mark Wolfire[10]

[1]*Steward Observatory, University of Arizona, Tucson, AZ 85721 USA*
[2]*School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287 USA*
[3]*Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723 USA*
[4]*Smithsonian Astrophysical Observatory, Cambridge, MA 02138 USA*
[5]*SETI Institute, Mountain View, CA 94043 USA.*
[6]*Jet Propulsion Laboratory, Pasadena, CA 91109 USA*
[7]*California Institute of Technology, Pasadena, CA 91125 USA*
[8]*University of Cologne, Cologne, D-50937 Germany*
[9]*Oberlin College, Oberlin, OH 44074 USA.*
[10]*University of Maryland, College Park, MD 20740 USA*
*Contact: cwalker@as.arizona.edu, +01-520-621-8783

***Abstract*— The Stratospheric TeraHertz Observatory (STO) is a NASA funded, Long Duration Balloon (LDB) experiment designed to address a key problem in modern astrophysics: understanding the Life Cycle of the Interstellar Medium (ISM). STO will survey a section of the Galactic plane in the dominant interstellar cooling line [C II] (1.9 THz) and the important star formation tracer [N II] (1.46 THz) at ~1 arc minute angular resolution, sufficient to spatially resolve atomic, ionic and molecular clouds at 10 kpc. The science flight instrument package hosts four [CII] and four [NII] HEB receivers. There is also one 492 GHz Schottky receiver for observing the [CI] line. In this paper we discuss preparations for the scheduled Antarctic science flight in December 2011.**

I. INTRODUCTION

STO is a Long Duration Balloon (LDB) experiment designed to address a key problem in modern astrophysics: understanding the Life Cycle of the Interstellar Medium (ISM). During its upcoming science flight STO will survey a section of the Galactic plane in the dominant interstellar cooling line [C II] (1.9 THz), the important star formation tracer [N II] (1.46 THz) and the column density tracer [CI] (0.49 THz) at arcminute angular resolution. On Oct. 15, 2009 STO had its test flight from Ft. Sumner, NM. During its 12 hours at float altitude (~126,000 ft) key components of STO were tested to help ensure the system would meet the objectives of the upcoming ~28 day science flight. STO is the first balloon payload to fly a cryogenic, THz heterodyne receiver system. The science flight will serve as a pathfinder for future 100 day, ultra-long duration (ULDB) NASA missions (e.g. GUSSTO).

2. SCIENCE FLIGHT INSTRUMENT

STO itself has three main components; 1) an 80 cm optical telescope, 2) a THz instrument package, and 3) a gondola [1] (see Figure 1). Both the telescope and gondola have flown on previous experiments [2,3]. They have been re-optimized for the current mission to include a 3-axis inertial guidance system and wide and narrow field star cameras. Additional solar panels were also added to provide ~1kW of payload power. During the test flight the telescope was able to point and track well within its 15” design specifications. Figure 1 shows STO in its flight configuration.

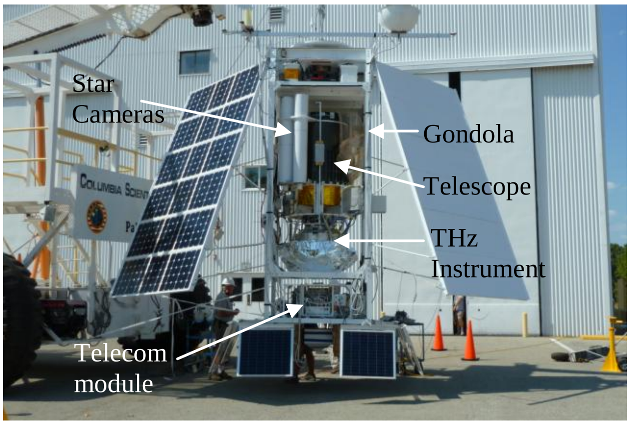

Figure 1: STO during its August 15, 2011 hang test in Palestine, TX.

STO is scheduled to have its first LDB science flight from McMurdo, Antarctica in December 2011. To achieve the goals of the science flight STO is designed to host two 4-pixel arrays of heterodyne receivers operating at 1.9 THz and 1.46 THz, as well as a room temperature 492 GHz Schottky diode receiver. Niobium superconducting hot electron mixers (similar to those used on *Herschel* – HiFi) provide state-of-the-art noise performance at THz frequencies. These mixers

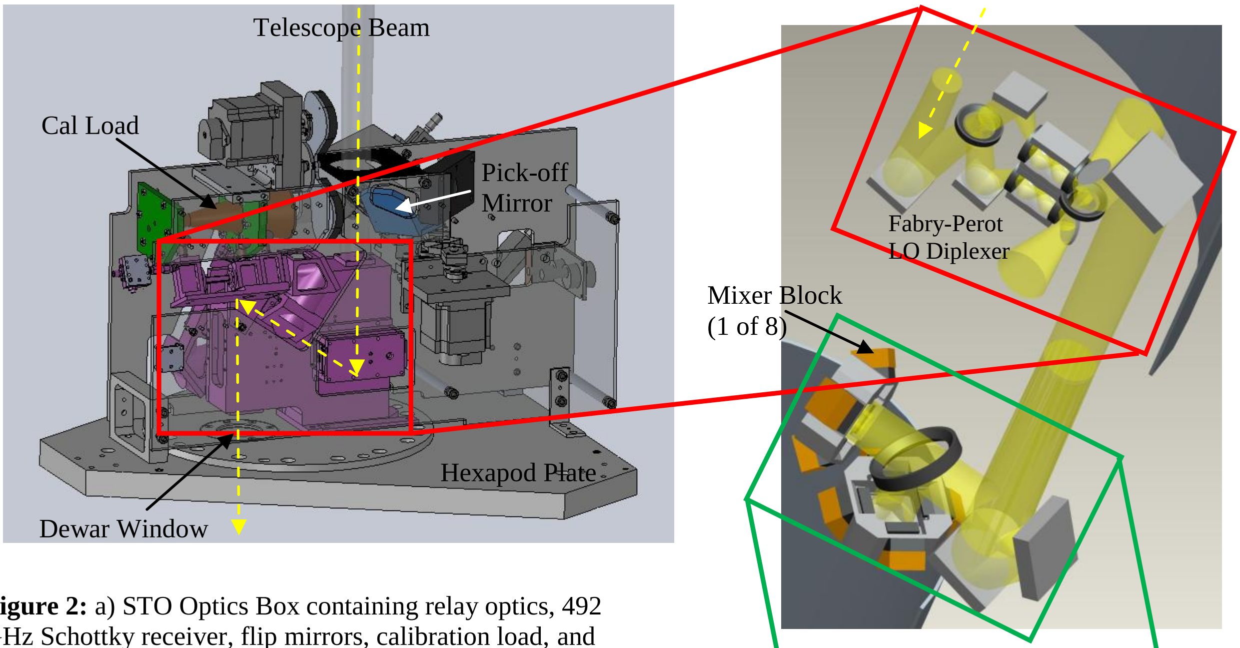

Figure 2: a) STO Optics Box containing relay optics, 492 GHz Schottky receiver, flip mirrors, calibration load, and Fabry-Perot ring diplexer. b) Optical assembly of Fabry-Perot

operate just below the transition temperature of niobium at 9K. Therefore, a key component of STO is a cryogenic system designed to maintain the mixers at their operating temperature during flight. For the science flight, a 90 liter liquid helium dewar with a hold time of ~14 days will be used for this purpose.

Between the telescope and the dewar is an Optics Box (see Figure 2a) containing flip mirrors for directing the *f*/17.5 telescope beam to either a Schottky receiver, calibration load, or Fabry-Perot ring diplexer designed to inject the local oscillator (LO) signal into the telescope beam (see Figure 2b). The Optics Box is mounted to a hexapod plate. The LO beams originate from two solid-state sources (not-shown; one at 1.9 and the other at 1.46 THz) whose output are divided into 4 equal power beams by a Fourier grating. From the diplexer, the combined telescope+LO beams enter the dewar through a 130 mm diameter window and continue to a wire grid located on the 4K cold plate. The grid splits the beams into horizontal and vertical polarizations. The horizontal polarized components proceed to the 1.9 THz mixer array and the vertical components to the 1.46 THz mixer array. Off-axis mirrors convert the telescope beam to match that expected by each mixer's feedhorn. As shown in the figure, each 2x2 mixer array is formed by bolting individual mixers to a common ring. The hot electron bolometer (HEB) mixers for the [NII] arrays are being provided by JPL and the HEB mixers for the [CII] arrays by the University of Cologne. Waveguide technology is being used by both groups to meet the instrument noise and optical coupling requirements. Laboratory measurements indicate the receiver noise temperatures are ≤1500K DSB.

The mixers and cold optics are mounted in a dewar insert (Figure 3). The top of the insert bolts directly to the bottom of the room temperature.Fabry-Perot diplexer and forms the

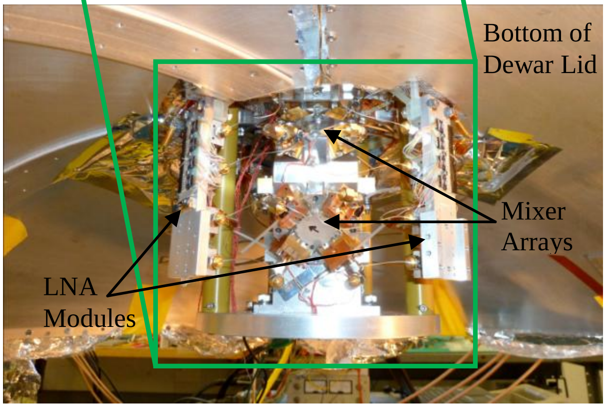

Figure 3: STO dewar insert. The telescope beam coming from above is split into orthogonal polarizations by a wire grid and directed into two, 4 pixel mixer arrays. The mixer mounts and cold plate are made from high purity aluminium and thermally strapped to the helium tank (not shown) with flexible S-links.

vacuum seal to the underlying dewar lid. The combined signal+LO beam enters the top of the insert through a resonant, polyethylene vacuum window. Optical alignment between cold and warm optics is maintained by a system of low thermal conductivity, Torlon tubes.

The IF signal for STO has a bandwidth of 1 GHz and is centered at 1.5 GHz, appropriate for low noise operation of our HEBs. The IF output of each mixer is conveyed through 4 cm long, 0.035" diameter coaxial cable to low-noise (~7K), low-power (~5mW) SiGe amplifiers operating at a physical temperature of ~17K. These amplifiers (see Figure 3) were designed and fabricated by Co-I Weinreb at Caltech specifically for STO. After being amplified ~30 dB, the IF signals are brought out of the dewar via coaxial cable to the IF Processor bolted on the frame of the telescope. The IF Processor Box further amplifies the signal from each HEB mixer and provides a DC signal proportional to each pixel's total power. An Electronics Box, also bolted to the telescope frame, contains a bias card and computer for the receiver frontend. From the IF processor eight coaxial cables (one for each focal plane mixer) carry the amplified IFs up to the pressurized vessel containing the spectrometer (see Figure 4) located at the mezzanine level of the gondola. The pressure vessel contains a single board computer and spectrometer that digitizes and performs FFTs on each of the eight, 1 GHz wide, input signals. The resulting power spectra are read out at ~ 1Hz, stored in non-volatile flash memory, and made available to the gondola computer via ethernet. From the gondola computer the data is relayed to ground stations on Earth via the TDRSS-1 satellite.

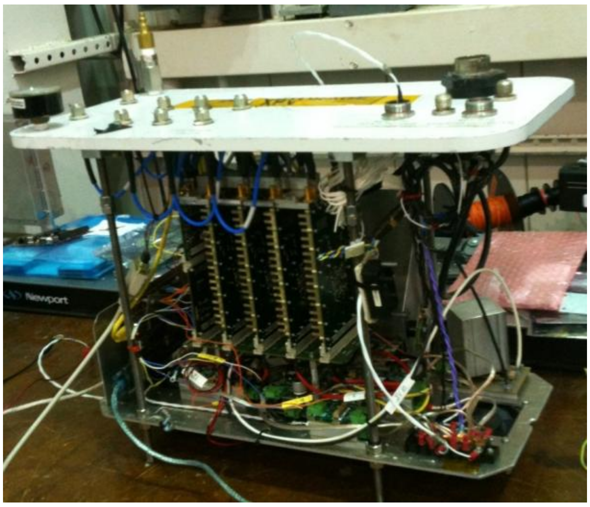

Figure 4: Pressure vessel containing STO flight spectrometer.

3. OBSERVING STRATEGY

STO is capable of performing either Absolute Position Switched (APS) or On-the-Fly (OTF) mapping observations. Pointed observations will be used for calibration, while OTF will be the default observing mode for Galactic Plane Surveys. During a typical OTF scan, STO will begin by taking a reference spectrum well off the Galaxy where the chance of significant emission in the reference (or OFF) position is minimal. The spectrometer is read out continuously as the STO beams cuts through the Galactic Plane. Every ~10 sec the Optics Box pick off mirror will swing in for ~5 sec. In this position the back of the mirror directs light from an ambient temperature calibration load down into the mixer arrays, while the front of the mirror directs the telescope beam into the 492 GHz Schottky receiver. When the mirror is swung out, the telescope beam passes through to the diplexer while the Schottky receiver sees the calibration load. By routinely observing the ambient load, the calibration of each observed spectrum can (in principle) be boot strapped to a reference position. Depending on stratospheric wind patterns and payload health, STO could be in flight for up to ~28 days.

4. CONCLUSION

STO is the first balloon-borne payload designed to perform high resolution spectroscopy at THz frequencies. It will observe the astrophysically important interstellar lines of [CII] (1.9THz), [NII] (1.46THz), and [CI] (0.49THz). The instrumentation used on STO has heritage from Herschel, ODIN, SWAS, and a number of ground-based observatories. We hope the upcoming STO flight will serve as a scientific and technical pathfinder for many other THz missions to come.

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