Forecast for **HEAT** on Dome A, Antarctica
The **H**igh **E**levation **A**ntarctic **T**erahertz Telescope

We propose to develop a prototype 0.5-meter far-infrared telescope and heterodyne receiver/spectrometer system for fully-automated remote operation at the summit of Dome A, the highest point on the Antarctic plateau. The unparalleled stability, exceptional dryness, low wind and bitter cold make Dome A a ground-based site without equal for astronomy at infrared and submillimeter wavelengths. HEAT, the High Elevation Antarctic Terahertz Telescope, will operate in the atmospheric windows between 150 and 400 μm, in which the most crucial astrophysical spectral diagnostics of the formation of galaxies, stars, planets, and life are found. At these wavelengths, HEAT will have high aperture efficiency and excellent atmospheric transmission most of the year. The proposed superheterodyne receiver system will be comprised of 0.8 THz, 1.4 THz and 1.9 THz channels which will observe the pivotal J=7→6 line of CO, the J=2→1 line of atomic carbon, and the far-infrared fine structure lines of N^+ and C^+, the brightest emission lines in the entire Milky Way Galaxy. When combined with the HEAT telescope, the receiver system represents the most powerful instrument for reconstructing the history of star formation in our Galaxy, with application to the distant Universe. The receiver system itself serves as a valuable testbed for heterodyne Terahertz components, using leading-edge mixer, local oscillator, low-noise amplifier, cryogenic, and digital signal processing technologies that will play essential roles in future Terahertz observatories. The proposed study will pave the way for future astronomical investigations from Dome A.

1 Scientific Justification

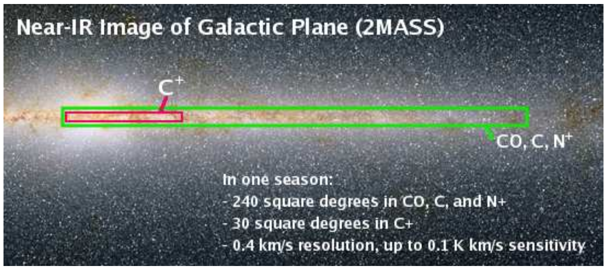

Figure 1: The power of HEAT: a definitive survey of the interstellar medium and star-forming clouds over 240 square degrees of the sky can be performed in 6 months in the spectral lines of atomic carbon and N^+. Over 30 square degrees of sky can be mapped in two months of the best winter weather in the pivotal 158 μm C^+ line. No other ground-based site is capable of routine observations at these highest frequencies.

Although great progress in understanding aspects of star and planet formation have resulted from the technological advent of sensitive (sub)millimeter wave detectors and the fabrication of large-format near-infrared detector arrays, many fundamental aspects of the formation and evolution of galaxies, stars, planets, and life remain shrouded in uncertainty. The common element of these mysteries is the evolution of interstellar clouds of dust and gas, from which stars and planets are born, and to which stars return enriched material at the end of their lives. These clouds sculpt the evolution of entire galaxies. The far-infrared (FIR) contains the brightest and most diagnostic spectral lines of the entire electromagnetic spectrum; in particular the pivotal fine structure lines of C, N^+ and C^+ at 0.8, 1.4 and 1.9 THz (370, 205 and 158 μm), respectively. Only on the high Antarctic plateau is the atmosphere dry, cold and stable enough to permit survey observations at all three wavelengths. In performing a Galactic Plane survey of these spectral lines, fundamental new insights into Galactic evolution, and star formation will be pioneered (Figure 1). In particular, HEAT will:

1. **Directly witness the formation of interstellar molecular clouds for the first time**, and answer where and how cloud formation takes place in the context of the Galaxy as a whole, with direct impact on star formation and Galaxy evolution. Natal molecular clouds are mostly comprised of spectroscopically elusive H_2, but the principal forms of carbon in forming will be C^+ and C – not CO, as found in developed clouds. 2MASS J-H/H-K extinction maps, in comparison with existing CO surveys, will guide the selection of fields for mapping.

2. **Derive a definitive star formation rate as a function of radius in the plane of the Milky**

Way, providing an optimum set of data to calculate the Schmidt Law in the Galaxy. N^+ emission at 1.4 THz provides a measure of the ionizing luminosity with unmatched sensitivity, angular and spectral resolution, and is unaffected by extinction.

3. **Provide the first map of warm dense molecular gas** via CO emission in the CO J=7→6 line at 0.8 THz, which can be observed simultaneously with the J=2→1 fine structure line of neutral carbon. Measurement of this energetic gas probes the pivotal feedback of stars with their parent interstellar clouds. It is energetic molecular gas that participates in molecular outflows, is the best probe of radiation fields at the surfaces of clouds, and is warmed by star formation in cloud cores.

The adoption of heterodyne receivers for HEAT naturally provides the high spectral resolution (<0.4 km s^{-1}) needed to disentangle kinematically the many cloud components along any particular line of sight through the Galactic Plane. The angular resolution provided by the 0.5-meter clear aperture (Figure 2) is optimized for resolving individual cloud components throughout the Galaxy while providing adequate mapping speed to perform a substantial survey of the Galaxy in a single observing season. The entire Galactic Plane visible from Dome A ($+10^o < l < -120^o$) will be mapped in 6 months to $1.5'$ resolution and RMS sensitivity of $\sim$0.1 K at CO and C, and $<$1 K at N^+, assuming that observations are being performed 75% of the time. A total of $\sim$30 square degrees can be mapped in C^+ during the coldest two months (typically August–September) to a resolution of $0.7'$ and a sensitivity of $\sim$1 K RMS (Figure 1).

2 Instrument Description

HEAT will be a fully automated, state-of-the-art THz observatory. It will have the unique capability of being able to observe simultaneously in the 0.8, 1.4, and 1.9 THz atmospheric windows. The telescope and instrument are designed for robustness, long-life, and efficiency. HEAT will be mounted on top of a University of New South Wales AASTINO. The HEAT/AASTINO facility is functionally equivalent to a space-based observatory.

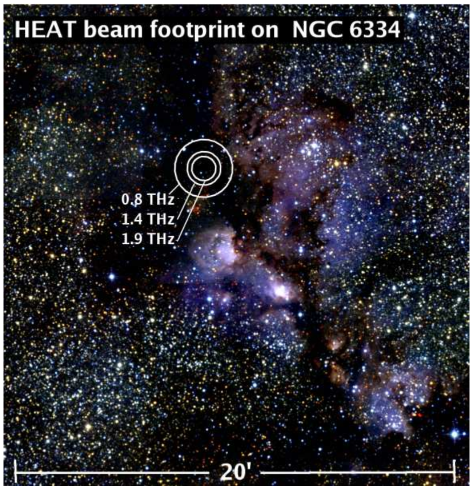

Figure 2: The 3 beams of HEAT overlaid upon a 2MASS image of NGC 6334. The size of the cospatial 0.8, 1.4, and 1.9 THz beams is 3, 1.7, and 1.3 arcminutes, respectively.

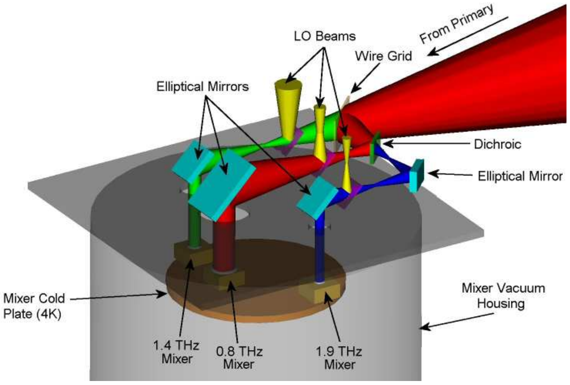

Figure 4: Optical subsystem and LO injection for HEAT's HEB and SIS mixers.

A conceptual drawing of HEAT is shown in Figure 3. The telescope is designed to have maximum efficiency and the minimum number of optical components. Its design follows that of Kraus (1966). Incoming light is reflected horizontally off a 0.5 x 0.7 m tiltable flat reflector to an f/5 off-axis parabolic (OAP) mirror. The converging beam is intercepted by a flat tertiary mirror that directs it into the receiver. The tertiary mirror can chop the incoming beam from 0 to 5 Hz. All three mirrors are of optical quality. Infrared and CCD cameras are mounted on the perimeter of the OAP for site testing and pointing. A close-up of the receiver optics is shown in Figure 4. The incoming beam first encounters a wire grid that splits it into horizontal and vertical components. The horizontally polarized beam

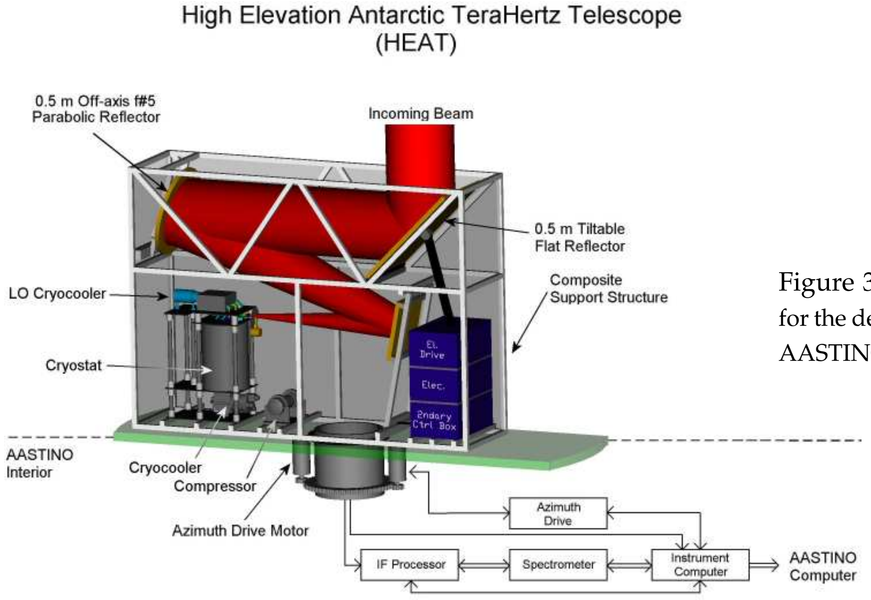

Figure 3: 3D overview and block diagram for the design of HEAT and integration with AASTINO.

is directed to the [N II] (1.459 THz) HEB mixer. A dichroic further splits the vertically polarized beam into high (>1.4 THz) and low (<1.4 THz) frequency components. The low frequency component is directed to an SIS mixer optimized for observing the CO J=7→6 and [^{12}C I] and [^{13}C I] 2→1 lines simultaneously. The high frequency beam proceeds to the [C II] (1.9 THz) HEB mixer. HEAT will use solid-state local oscillators (LOs) originally built by the Jet Propulsion Laboratory for the Herschel Space Observatory. The LO signals will be injected into the signal path using Mylar (for the 810 GHz mixer) and silicon (for the 1.45 and 1.9 THz mixers) beam splitters. The mixers are themselves copies of Herschel flight mixers. The HEB mixers have noise temperatures ≤ 900 K. The SIS mixer noise temperature is $\sim$350 K. The IF output of the HEB mixers is centered at 5 GHz; the SIS mixer 1.5 GHz. The IF output of each mixer is amplified and downconverted to baseband for processing by three, 1 GHz wide, 2048 lag correlators. The closed-cycle, low microphonic, 4 K cryogenic system for HEAT will be fabricated by Ball Aerospace and have an estimated, maintenance-free lifetime of $\sim$2 years. The telescope and instrument are controlled by a dedicated PC that communicates to the AASTINO via Ethernet. Astronomical data will be stored on disk and uploaded to the control centers at the Universities of Arizona and New South Wales via Iridium satellite or TDRSS-1 each day.

With the implementation of HEAT, the astronomical community will have a new, powerful capability for exploring the origin of stars, galaxies, and planetary systems like our own. It will serve as a model for future Antarctic observatories and the first step toward realizing the research potential of Dome A. We look forward both to the exciting science that will come from HEAT and the challenge of making it a reality.

3 Plan & Budget

The design and construction of HEAT will take place over a 2.0 year period (11/04 – 11/06). From 11/06 to 4/07 the instrument will be field tested at the Heinrich Hertz Telescope on Mt. Graham Arizona. For field testing purposes a functional mock-up of an AASTINO will be constructed on the HHT site. In 5/07, HEAT will be transported to UNSW for integration and test on an AASTINO module. Both the AASTINO module and HEAT will be transported to Dome A via CASA 212 jet or traverse in 11/07. After a month long check-out, HEAT will begin its survey of the Galactic Plane.

We request funding for 3 three years, with the possibility of continued funding for an additional two years of operation. The requested levels of funding for the first 3 years is $819K, $788K, and $290K, with a cumulative total of $1.9M. Funding levels for each of the additional two years is estimated to be $270K.