Project Description

1 Results from Prior NSF Support

Over the past few years, the PI's group at the University of Arizona has constructed two spectroscopic heterodyne array receivers; *PoleSTAR*, a 4 pixel 810 GHz receiver that operated at the 1.7 m AST/RO telescope at the South Pole, *DesertSTAR*and a 7 pixel 345 GHz array receiver for the 10-meter Heinrich Hertz Telescope (HHT) on Mt. Graham, Arizona. Both instruments are the very first of their kind. *PoleSTAR* was completed in 2000 and offers excellent ($T_{\rm rec}$=600-800K) receiver performance on all 4 pixels (Kulesa et al., 2005). *DesertSTAR* went into routine operation on the HHT with an initial complement of 3 pixels in October 2003 and has recently been expanded to the final hexagonal array of 7 pixels (Figure 1). Both instruments were funded by NSF programs; work on *PoleSTAR* was funded by the NSF Office of Polar Programs (A. Stark–PI: OPP-0126090), and *DesertSTAR* development has been a joint effort between the University of Arizona, the University of Massachusetts, and the University of Virginia with partial funding through the NSF ATI program (AST-9622569).

More recently, a multi-institutional team led by the PI was awarded an NSF MRI grant (AST-0421499) to construct *SuperCam*, a 64 pixel, heterodyne array for the Heinrich Hertz Telescope (Groppi et al 2006). *Supercam* represents the cutting edge of heterodyne array development technology in terms of integrated mixer and low noise amplifiers (Puetz et al 2006), and scalable IF processor and spectrometer technology. It represents the first steps towards cost-efficient scalability that will enable very large format heterodyne spectrometers arrays to be practical in the near future. *Supercam* will be completed in the PI's lab by the end of 2007 and commissioned at the HHT in 2008.

Finally, in 2006 funding was obtained through NSF/OPP (ANT-0538665) to develop a design study for HEAT. The following proposal is based upon the design study funded by this award.

The experience and heritage gained through these unique efforts will be instrumental in making HEAT a reality.

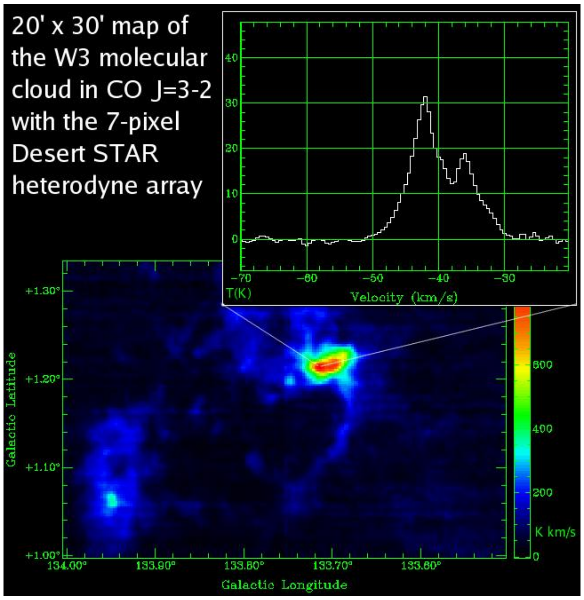


Figure 1: Large scale map of CO J=3-2 from the W3 star forming region taken by DesertSTAR, the PI's 345 GHz 7-beam array receiver at the Heinrich Hertz Telescope. The "cavity" seen in the center of the map represents the location of an OB association and its radiative feedback on its parent cloud, indicative of the phenomena that HEAT will reveal clearly. Furthermore, as shown in the inset, every imaged point in a heterodyne map also represents a high-resolution ($\lambda/\Delta\lambda \approx 10^6$) spectrum.

2 Research Activities

The proposed High Elevation Antarctic Terahertz Telescope (HEAT) will forge entirely new capabilities for ground based infrared and submillimeter astronomy, by providing a window on the Universe which otherwise would be unavailable except via airborne or space-based platforms. The pioneering surveys to be performed by HEAT will be made available to the entire astronomical community. HEAT represents a true international pioneering effort (US, Australia, China and the Netherlands) in keeping with the spirit of the International Polar Year (`www.ipy.org`: 2007-2009). Here, we outline HEAT's "key project", a THz survey of the Galactic Plane observable from Dome A, Antarctica. HEAT is the Dome A component of the multinational 'AstroPoles' program which has been offically endorsed by the Joint Committee for the upcoming IPY (see attached letter).

2.1 *Introduction*

From the Milky Way to high redshift protogalaxies, the internal evolution of galaxies is defined by processes closely related to their interstellar contents:

1. the transformation of neutral, molecular gas clouds into stars & clusters (star formation).
2. the interaction of the interstellar medium (ISM) with the young stars that are born from it, a regulator of further star formation.
3. the return of enriched stellar material to the ISM by stellar death, eventually to form future generations of stars.

The evolution of galaxies is therefore determined to a large extent by the life cycles of interstellar clouds: their creation, star-forming properties, and subsequent destruction by young (hot) stars.

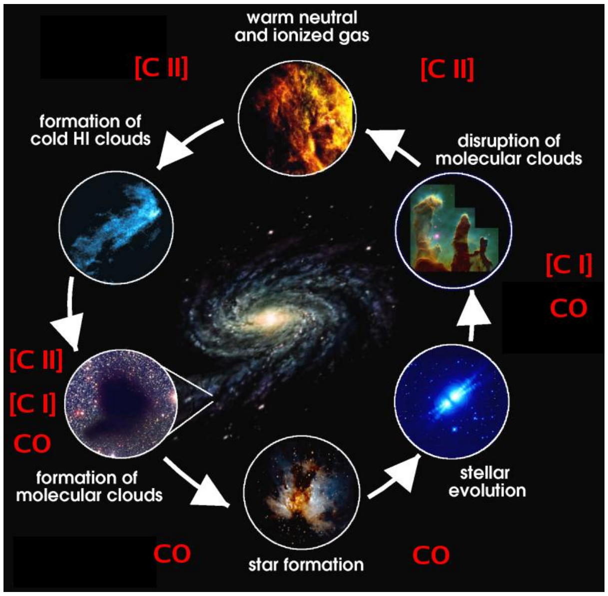


Figure 2: HEAT will observe the fine structure lines of N^+, C^+, C, and CO that probe the entire life cycle of interstellar clouds.

The life cycle of interstellar clouds is summarized pictorially in Figure 2. These clouds are largely comprised of atomic & molecular hydrogen and atomic helium. These species are notoriously difficult to detect under normal interstellar conditions. Atomic hydrogen is detectable via the 21 cm spin-flip transition and provides the observational basis for current models of a multiphase Galactic ISM. Its emission is insensitive to gas density and does not always discriminate between cold ($T\sim70K$) atomic clouds and the warm ($T\sim8000K$) neutral medium that is thought to pervade the Galaxy. Furthermore, neither atomic helium nor molecular hydrogen (H_2) have accessible emission line spectra in the prevailing physical conditions in cold interstellar clouds. Thus, it is important to probe the nature of the ISM via rarer trace elements. Carbon, for example, is found in ionized form (C^+) in neutral clouds, eventually becoming atomic (C), then molecular as carbon monoxide (CO) in dark molecular clouds.

Although we are now beginning to understand star formation, the formation, evolution and destruction of molecular clouds remains shrouded in uncertainty. The need to understand the evolution of interstellar clouds in the context of star formation has become a central theme of contemporary astrophysics. The National Research Council's most recent *Decadal Survey* has identified the study of star formation as one of the key recommendations for new initiatives in this decade.

A new, comprehensive survey of the Galaxy must address the following questions to make significant progress toward a complete and comprehensive view of Galactic star formation:

- How do molecular clouds form, evolve, and become disrupted? How do typical atoms and grains cycle through the ISM?
- How and under what conditions do molecular clouds form stars?
- How do the energetic byproducts of stellar birth, UV radiation fields and outflows regulate further star formation in clouds?
- How does the Galactic environment impact the formation of clouds and stars? What are the specific roles of spiral arms, central bars, infall and other influences from outside the Galaxy?

2.2 *HEAT Science Goals*

Via resolved C^+, C, CO, and N^+ line emission, HEAT uniquely probes the pivotal formative and disruptive stages in the **life cycles of interstellar clouds** and sheds crucial light on the **formation of stars** by providing new insight into the relationship between interstellar clouds and the stars that form in them; a central component of **galactic evolution**. A detailed study of the ISM of the Milky Way is used to construct a template to **interpret global star formation in other spiral galaxies**.

The **minimum science mission** of HEAT is to make significant contributions to achieving the three major science goals described below. Using the proposed instrument and observing methodology, the minimum mission is expected to be achievable in a single season of survey operation from Dome A. Note that funds for conducting the HEAT science program will be requested through a separate proposal to the Office of Polar Programs.

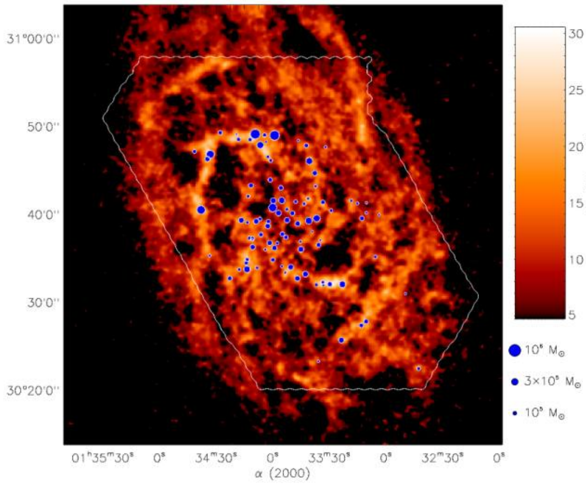


Figure 3: The location of GMCs in the nearby spiral galaxy M33 are overlaid upon an integrated intensity map of the HI 21 cm line (Engargiola, Plambeck, Rosolowsky, & Blitz, 2003). These observations show that GMCs are formed from large structure of atomic gas, foreshadowing the detailed study of GMC formation that HEAT will provide in the Milky Way.

Goal 1: Observing the Life Cycle of Interstellar Clouds

The formation of interstellar clouds is a prerequisite for star formation, yet the process has not yet been observed! HEAT is designed with the unique combination of sensitivity and resolution needed to observe atomic clouds in the process of becoming giant molecular clouds (GMCs) and their subsequent dissolution into diffuse gas via stellar feedback.

Theories of cloud formation are guided and constrained by observations of the atomic and molecular gas components. Based primarily on HI and CO observations, several mechanisms have been proposed to consolidate gas into GMC complexes (Figure 3). HEAT can distinguish these processes by:

1. Accounting for the entire H_2 mass (including H_2 clouds with little CO) when computing global measures of the interstellar medium.
2. Making a more complete & characterized catalog of interstellar clouds than CO or HI surveys alone.
3. Constructing spatial and kinematic comparisons of sufficient resolution, spatial coverage and dynamic range to probe a wide range of interstellar phases and environments.

Since the C^+ (and C^0) line emissivity barometrically selects clouds of atomic gas and H_2 clouds with little CO, regions of GMC formation may therefore be tracked by a large density of clouds per beam, or regions with individual clouds with higher than average columns or pressures. With HEAT's superlative spectral resolution, these regions can be identified with superrings or spiral arms or convergent parts of a turbulent medium. With guidance from 2MASS extinction mapping and existing CO and 21 cm HI surveys, HEAT will follow cold HI clouds and H_2 clouds as they transit the spiral potential, and will witness the process of cloud formation directly from the atomic substrate or small H_2 clouds. These clouds will be identified by C^+ and C line emission by HEAT. Similarly, N^+ observations of ionized gas survey the location and rate of star formation in the Galaxy. The rate of star formation is determined by using the N^+ luminosity to determine the ionizing luminosity of OB stars, a standard metric for the star formation rate.

HEAT's high spectral resolution enables crucial kinematic studies of the Galaxy to be made. HEAT will determine the kinematics and thermal pressures of most supershells, fossil superrings, and new molecular clouds condensing via gravitational instability of old superrings and supershells. HEAT can determine the role of OB association-driven supershells and superrings in the production of molecular clouds and the cycling of gas between the various phases of the ISM. Since N^+ measures the flux of ionizing photons, and C^+ measures their impact upon neighboring cloud surfaces, HEAT will measure the resolved photoevaporating atomic or ionized gas driven from clouds with UV-illuminated surfaces, thereby determining the rate of mass loss from all cataloged clouds, and their destruction timescales. HEAT's survey will correlate the star formation rate in a given OB association with the rate of destruction of any nearby (within 30 pc) natal GMC. Such measurements are crucial for models of star formation feedback and galactic evolution.

Goal 2: Measuring the Galactic Star Formation Rate

HEAT will probe the relation between the gas surface density on kpc scales and the N^+-derived star formation rate, so that we might be able to better understand the empirical Schmidt Law used to estimate the star forming properties of external galaxies.

Star formation within galaxies is commonly described by two empirical relationships: the variation of the star formation rate per unit area with the gas surface density (Schmidt, 1959; Kennicutt,

1998) and a surface density threshold below which star formation is suppressed (Martin & Kennicutt, 2001). The Schmidt Law has been evaluated from the radial profiles of HI & CO emission for tens of galaxies. The mean value of the Schmidt index, n, is 1.4 ± 0.15 (Kennicutt, 1998), valid for kpc scales. This empirical relationship is used in most models of galaxy evolution with surprising success given its simplicity. Oddly, there has been little effort to evaluate the Schmidt Law in the Milky Way owing to the difficulty in deriving the star formation rate as a function of radius within the plane.

The HEAT survey of CO, C, C^+ and N^+ emission provides the optimum set of data to calculate the Schmidt Law in the Galaxy. The N^+ line is an excellent tracer of the star formation rate as it measures ionizing luminosity with unmatched sensitivity, angular and spectral resolution, and is unaffected by extinction. The C^0 and C^+ lines, in conjunction with HI 21cm and CO line emission, provide the first coherent map of the neutral interstellar gas surface density and its variation with radius. HEAT's high spectral resolution allows one to assign a radial location of any emission feature assuming a rotation curve. The Schmidt Law is constructed from the radial profiles of the star formation rate derived from N^+ emission and the gas surface density. The column density threshold is inferred from the absence of star formation activity in the outer radii of galaxies where there is still a significant reservoir of gas (Kennicutt, 1998). Alternately, a threshold-less relation can be constructed by eliminating the HI gas that is inert to star formation (Blitz & Rosolowsky, 2006). Accounting for the H_2 clouds seen only in C^+ emission provides a far more detailed test of such a Schmidt Law formalism than do the CO clouds alone. The velocity-resolved star formation rate indicators provided by HEAT will be invaluable in interpreting more traditional indicators, like the far-infrared continuum. With its resolution and ability to gauge thermal ISM pressure, HEAT evaluates this critical, regulatory process in the Milky Way.

Goal 3: Constructing a Milky Way Template

C^+ and N^+ will be the premier diagnostic tools for submillimeter studies of external galaxies with large redshifts (e.g. with ALMA). In such spatially unresolved galaxies, however, only global properties can be measured. Detailed interstellar studies of the widely varying conditions in our own Milky Way Galaxy serve as a crucial diagnostic template or "Rosetta Stone" that can be used to translate the global properties of more distant galaxies into reliable estimators of star formation rate and state of the ISM. The HEAT mission covers a broad range of density and UV intensity, establishing the relationship between physical properties, C^+, C, CO, N^+, HI, FIR emission, and star formation. This relationship can be tested by application to nearby galaxies in the SINGS Spitzer Legacy Survey (Kennicutt et al., 2003), for which a large amount of ancillary optical, infrared and submm data exist.

2.3 *Properties of the Proposed Survey*

HEAT's science drivers represent a definitive survey that would not only provide the clearest view of interstellar clouds and their evolution in the Galaxy, but would also serve as the reference map for contemporary focused studies with Herschel, SOFIA, APEX, and the ALMA and SMA interferometers. The following properties define the science needs for HEAT.

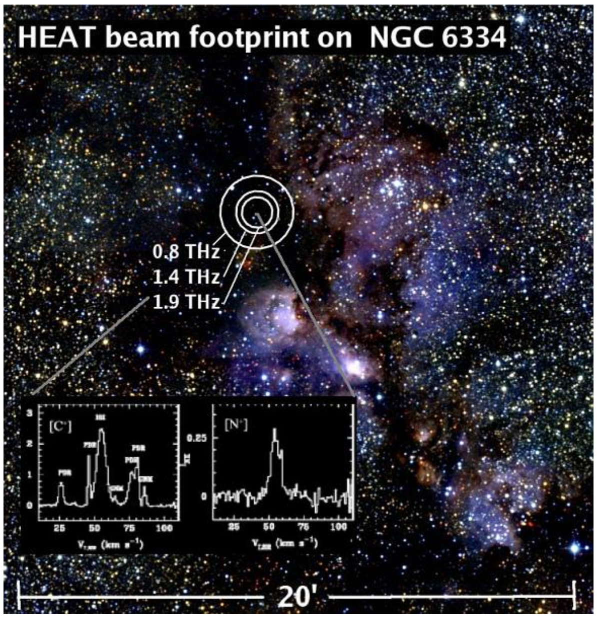


Figure 4: The power of HEAT: Each of the 3 heterodyne beams of HEAT are overlaid upon a 2MASS infrared image of NGC 6334. The beams will measure high-resolution spectra in the 0.81, 1.46, and 1.90 THz bands respectively, a small portion (25%) of each is shown as synthetic spectra of NGC 6334.

2.3.1 *High Resolution Spectroscopic Imaging*

Techniques commonly used to diagnose the molecular ISM include submillimeter continuum mapping of dust emission (Hildebrand, 1983) and dust extinction mapping at optical and near-infrared wavelengths (Lada, Lada, Clemens, & Bally, 1994). Large format detector arrays in the infrared are now commonplace, and with the advent of bolometer arrays like SCUBA at the JCMT and SHARC at the CSO, both techniques have performed degree-scale maps of molecular material. However, these techniques have limited applicability to the study of the large-scale evolution of molecular clouds due to the complete lack of kinematic information.

The confluence of many clouds along most Galactic lines of sight can only be disentangled with spectral line techniques. Fitting to a model of Galactic rotation is often the only way to determine each cloud's distance and location within the Galaxy. With resolution finer than 1 km s^{-1}, a cloud's kinematic location can be even distinguished from other phenomena that alter the lineshape, such as turbulence, rotation, and local effects such as protostellar outflows. These kinematic components play a vital role in the sculpting of interstellar clouds, and a survey that has the goal of understanding their evolution **must** be able to measure them. **HEAT will easily resolve the intrinsic profiles of Galactic interstellar lines, with a resolution of $<$0.4 km s^{-1} up to 370 km s^{-1} of spectrometer bandwidth, comparable to the Galactic rotational velocity.**

2.3.2 *A Terahertz Galactic Plane Survey*

Molecular line surveys have been performed over the entire sky in the light of the 2.6 mm J=1-0 line of ^{12}CO, and have been used to synthesize our best understanding of the molecular content of the Galaxy. Still, our understanding of the evolution of Galactic molecular clouds is woefully incomplete. The CO J=7→6 line measured by HEAT is a better probe of the energetic gas that plays a role in stellar/interstellar feedback mechanisms. It probes gas that 1) participates in molecular outflows, 2) senses radiation fields at the photodissociated surfaces of clouds, and 3) is warmed by star-formation in cloud cores. It will help us interpret even basic properties of clouds derived from existing mm-wave observations by constraining excitation conditions.

As already described in Section 2.2, the dominant spectral lines of the Galaxy are the fine structure far-infrared and submillimeter lines of C, CO, C^+ and N^+. They probe and regulate all aspects of the formation and destruction of star forming clouds. They will provide the first barometric maps of the Galaxy, and illuminate the properties of clouds and their life cycles in relation to their location in the Galaxy. They will highlight the delicate interplay between (massive) stars and the clouds which form them, a critical component of galactic evolution.

2.3.3 *Angular Resolution and Fully Sampled Maps*

Good angular resolution is a critical aspect of improvement for a new Galactic survey. Previous surveys of [N II] and [C II] were limited to very small regions (KAO, ISO) or had low angular resolution (COBE, BICE) (Bennett et al., 1994; Nakagawa et al., 1998). HEAT will fully sample both species over large regions of sky to their diffraction limited resolution of 1.7′ and 1.3′, respectively. Arcminute resolution with proper sampling is crucial to disentangling different clouds and cloud components over large distances in the Galaxy. For example, the Jeans length for star formation in a GMC is approximately 0.5 pc. This length scale is resolved by HEAT to a distance of 500 pc at CO J=7→6 & [C I], and 1200 pc at [C II]. Warm and cold HI clouds and GMCs can be resolved well past 10 kpc.

2.3.4 *High Sensitivity*

HEAT's high sensitivity is owed mostly to the superlative atmospheric conditions above Dome A, Antarctica. The extreme cold and exceptional dryness allow ground-based observations into the otherwise forbidden THz windows. A plot of the expected atmospheric transmission for excellent winter observing conditions at Dome A versus the comparable opacity at the South Pole is plotted in Figure 5. **The high elevation, cold atmosphere and benign wind conditions at Dome A definitively open the Terahertz windows to ground-based observatories and cannot be matched anywhere else on Earth.** The implications for the sensitivity to each spectral line is discussed below.

CO $J = 7 \rightarrow 6$

We aim to detect all CO to A_V=1.5, where most hydrogen has formed H_2 and CO is just forming. This extinction limit corresponds to N(^{12}CO)$\sim 5 \times 10^{15}$ cm^{-2}, or an integrated intensity ($T_k \sim$ 70K) of 3 K km s^{-1} in the J=7→6 transition at $n_H = 10^5$ cm^{-3}. This sensitivity limit is achievable (3σ) within 100 seconds of integration time at 806 GHz in *median* winter atmospheric conditions ($T_{sys} \sim$10,000K) on Dome A. Limits on J=7→6 in that time would constrain the gas density, based upon the line brightness of millimeter wave transitions.

Atomic carbon $J = 2 \rightarrow 1$

The same extinction limit (A_V=1.5 mag) set for CO will also be applied to the J=2→1 fine structure

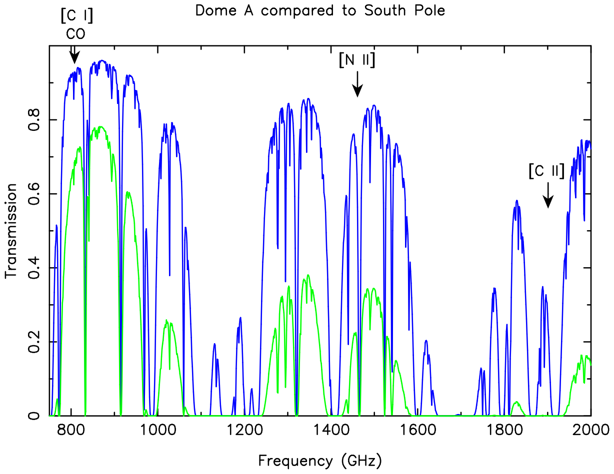


Figure 5: Terahertz atmospheric transmission for good (∼25th percentile) winter conditions for South Pole (bottom) and Dome A (top), derived from PWV measurements at Pole, atmospheric models from Lawrence (2004) and **actual Automatic Weather Station (AWS) data collected during 2005 from Dome A**. The PWV content for each model atmosphere is 220 and 70 microns respectively, Arrows indicate the wavelengths of the [N II], [C II], and CO/[C I] lines.

line of atomic carbon at 809 GHz. The corresponding column density of atomic carbon is $N(C) = 1.6 \times 10^{16}$ cm^{-2}, yielding a line intensity of 1.8 K km s^{-1} at $T_k = 50$K and $n_{\rm H} = 10^4$ cm^{-3}, achievable (3σ) in 5 minutes of integration time with HEAT during winter on Dome A.

N^+ and C^+

The fine structure lines of ionized carbon and nitrogen represent the dominant coolants of the interstellar medium of the Galaxy and starforming galaxies. Indeed, the integrated intensity of the 158 μm C$^+$ line alone represents 1% of the bolometric luminosity of the Galaxy! As such, these lines are relatively easy to detect in the ISM. Our most demanding requirements for detection of C$^+$ and N$^+$ lie in the search for the formation of giant molecular clouds (via C$^+$) and the measurement of the diffuse warm ionized medium in the Galaxy (via N$^+$). A flux limit of 2 K km s^{-1} will detect N$^+$ in warm HI as far away as the Molecular Ring, achievable in good winter weather in 3 minutes with velocity smoothing to 2 km s^{-1}, appropriate for hot ionized gas. Similarly, the accumulation of GMCs from many cold neutral clouds of atomic hydrogen occurs at low relative column densities of $\sim 5 \times 10^{20}$ cm^{-2}. Since essentially all carbon in such clouds is ionized, $N(C^+) \sim 10^{17}$ cm^{-2}. At the $T = 70$K common in cold atomic clouds and $n_{\rm H} = 10^3$ cm^{-3}, the expected C$^+$ line emission would be 2.5 K km s^{-1}, detectable in 10 minutes in excellent winter weather on Dome A. The 3σ limit achievable with deep integrations (2 hours) with HEAT would reach $n_{\rm H} = 10^2$ cm^{-3}. This *pressure* limit would readily determine whether interstellar material causing significant infrared extinction but without CO is gravitationally bound and likely to be a forming molecular cloud, or is simply a line of sight with numerous overlapping diffuse HI clouds.

2.3.5 *Mapping Coverage of the Galactic Plane*

From previous CO surveys it is known that the scale height of CO emission toward the inner Galaxy is less than one degree (Dame et al., 1987; Dame, Hartmann, & Thaddeus, 2001). The BICE experiment demonstrated that the C$^+$ distribution is more extended, but still is confined to $|b| < 1$. Interstellar pressure, abundances, and physical conditions vary strongly as a function of Galactocentric radius, so it is necessary to probe the inner Galaxy, the outer Galaxy, and both spiral arms and interarm regions, to obtain a statistically meaningful survey that encompasses the broad dynamic range of physical conditions in the Galaxy. We propose therefore to probe the entire Galactic plane as seen from Dome A ($0 > l > -120^o$). A *completely unbiased survey* will be undertaken, ultimately covering up to 240 square degrees ($-1^o < b < 1^o$); however 90 square degrees in 3 years will be targeted by the Schottky receiver system proposed here. Figure 6 demonstrates the sky coverage of HEAT's survey of the Inner Galaxy, with the first season coverage highlighted in yellow. It will probe three crucial components of the Galaxy; the Molecular Ring, the Crux spiral arm and the inter-arm region. The remaining sky coverage will be provided by a future, upgraded instrument package from SRON, featuring a cryocooled 4K SIS and HEB system (see SRON support letter). The "inner" Galaxy survey will coincide with GLIMPSE, a Spitzer Space Telescope (SST) Legacy Program (Benjamin et al., 2003). Above $l = 90^o$, most of the CO emission is located at higher Galactic latitude, so l and b "strip mapping" will locate the best regions to map, generally following the outskirts of CO J=1→0 distribution(Dame et al., 1987; Dame, Hartmann, & Thaddeus, 2001) and the best characterized star forming regions in the Galaxy – while maximizing synergies with the "Cores to Disks" SST Legacy program (Evans et al., 2003), and other SST GTO programs.

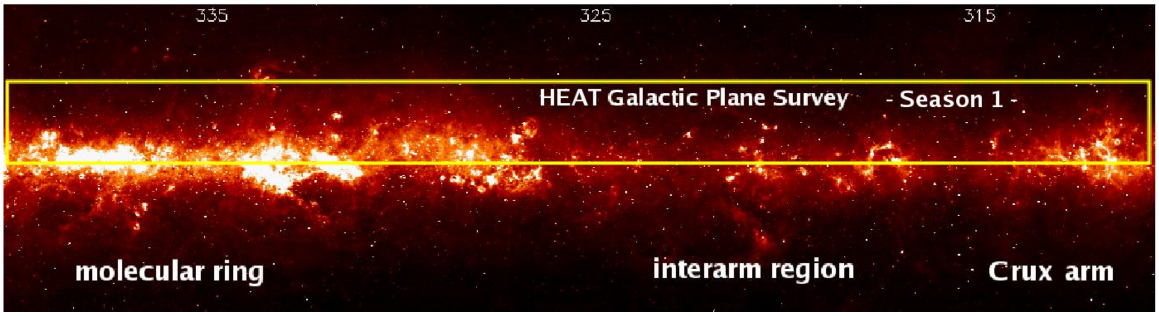


Figure 6: Midcourse Space Experiment (MSX) 8.3 μm map of the Galactic Plane from the Molecular Ring through the Scutum-Crux Spiral Arm ($-20^\circ > l > -55^\circ$). The yellow rectangle highlights the region to be explored by HEAT in its **first season** at Dome A. A definitive chemical and kinematic survey of star forming clouds in C^0 J=2-1, ^{12}CO J=7→6, and [N II] of 30 square degrees (~10 square degrees in [C II] emission) can be performed in a single season. No other site on Earth allows routine access to both far-infrared lines.

HEAT exceeds all of these needs and constitutes an exceptional Galactic survey instrument.

2.4 *Survey Activities*

2.4.1 *Mapping Strategy*

The most efficient mode of data collection which produces the highest fidelity images is On-the-Fly (OTF) mapping. In this mode, the telescope continuously scans back and forth across a field while the backends are read-out at a sufficient rate to eliminate aliasing and beam smearing.

The broad coverage of the HEAT survey and the circumpolar nature of the sky rotation over Antarctica lends itself naturally to efficient, 24-hr/day mapping. HEAT can reach the requisite sensitivity of 1σ=0.2 K km s^{-1} per beam at 810 GHz (1σ=0.9 K km s^{-1} at 1.4 THz) over a fully sampled square degree in 7 days, assuming median winter conditions of τ_{810} ~1. 30 square degrees from $-20 > l > -60^o$ will be mapped in ≈210 days. Mapping of the Inner Galaxy with $-1 < b < 0$ (30 sq degrees) will follow in Season 2, and targeted observations (30 sq. degrees) in the Outer Galaxy in Season 3 (with the SRON 4K HEB receiver upgrade if available). When the atmospheric opacity at 1.9 THz drops below ~1.5, focused surveys including C^+ will begin. Of the best 35 days of winter weather, 3-4 weeks will be devoted to a medium-sensitivity C^+ survey (1σ ~1.5 K km s^{-1}), with each square degree of mapping requiring about 2 days each, for a total of up to 10 square degrees of coverage per season. 10 days will be devoted to deep C^+ surveys of selected regions guided by 2MASS and GLIMPSE for the formation of molecular clouds – a total of 0.4 square degrees will be mapped to $1\sigma \sim 0.4$ K km s^{-1} per season.

HEAT's wide IF bandwidth, coupled with chopping OTF techniques, allows detection of the 158, 205, and 370 μm dust continuum emission. Thus, we will also simultaneously record total power scans and construct dust continuum maps.

2.4.2 *Science Products and Dissemination*

A primary challenge of OTF mapping is data management. We therefore plan to adopt a scheme akin to that developed at FCRAO, whereby coadded and regridded data is written as FITS & CLASS files, and headers for each scan are written into a MySQL relational database, which facilitates efficient logging and retrieval of the data. The most demanding storage requirements for the final 90 square degree maps, regridded to 50″ spacing, with 1024 spectral points per grid position, is <4 GB. This volume can be readily handled by embedded computers with disks of nonvolatile flash memory.

Access to these data products to the greater scientific community will be provided through a web browser interface that will interface with MySQL and the FITS data cubes. Preprocessed data cubes will be transferred over Iridium satellite. Raw data will be collected from the telescope annually during maintenance, and hopefully earlier with an occasional downlink from NASA's TDRSS-1 satellite using a portable field antenna. There will be biannual data products – a preliminary release midseason, and a final release in January. The final release will be fully calibrated and will include all science products.

All science tools, packaged reduction software, data products and science products will be made available from the HEAT web page.

Participant	Team	Affiliation	Participation Activity
Christopher Walker	I, S	Univ. Arizona	Project PI
James Burge	I	Univ. Arizona	Optical systems: opto-mechanics, testing and metrology
J. R. Gao	I	TU Delft/SRON	Future 4K mixer package upgrade of HEAT
Paul Goldsmith	I, S	JPL	THz instrumentation, space flight hardware, ISM physics
Jeffrey Hesler	I	Virginia Diodes, Inc.	Schottky mixer development and LO technology
Jon Lawrence	I	UNSW	Antarctic instrumentation, site testing & astronomy
Craig Kulesa	I, S	Univ. Arizona	Deputy PI, software+electronics integration, ISM physics
Chris Martin	I, S	Oberlin College	Antarctic Astronomy and Instrumentation
Michael Schein	I	Univ. Arizona	Optical systems design, pointing & tracking, cryocoolers
Peter Siegel	I	Caltech/JPL	THz Schottky mixer development
Gordon Stacey	I, S	Cornell	Far-infrared Instrumentation & spectroscopy
Antony Stark	I, S	SAO/CfA	Telescope Optics & Systems; Synergy w/ AST/RO
John Storey	I, S	UNSW	PLATO Systems, Site testing, Polar Operations
Sander Weinreb	I	JPL	IF amplifiers & processors, backend spectrometers

Table 1: Activities of the Science (**S**) and Instrumentation (**I**) Teams

2.4.3 Synergies with Spitzer, ALMA, SOFIA and Herschel

HEAT is timely. The Spitzer Space Telescope Legacy program GLIMPSE, headed by E. Churchwell, provides a thermal infrared survey of the Galactic plane that provides a complete census of star formation, the stellar structure of the molecular ring, will map the warm interstellar dust, constrain extinction laws as a function of galactocentric radius and will detect all young embedded O and B stars. HEAT will provide the best corresponding interstellar cloud survey that will account for the dense cloud material that forms stars, cloud interaction with formed stars, and kinematic disruption by mass ejection, outflow, and supernova remnants.

HEAT naturally complements the capabilities of heterodyne receivers on SOFIA and Herschel. The higher angular resolution afforded by larger telescopes necessarily reduces their field of view and mapping speed. **The HEAT survey would require many months of dedicated observing time on either Herschel or SOFIA, inconsistent with their use as general purpose observatories.** In contrast, HEAT is a dedicated mapping instrument with a focused mission and a lifetime that exceeds the grasp of long duration balloons. HEAT will provide ideal reference maps of THz line emission for more detailed followup with SOFIA and Herschel. Indeed, the HEAT data distribution and databasing system will be aligned as much as possible with that of Herschel/HIFI.

Similarly, the small field of view of the ALMA interferometer (8-25″) makes such large scale surveys untenable. However, HEAT's Southern survey in atomic carbon and CO emission will be an ideal survey for active star forming clouds and cores and represents an exceptional reference map for detailed followup with ALMA when it becomes available.

2.4.4 Roles of the Collaboration Participants

Personnel who will initially develop and use HEAT comprise the Science (S) and Instrument (I) Teams tabulated in Table 1. They are also represented in an organization chart, Figure 12 in Section 4. *At least 2 graduate students and 2 undergraduates will participate in the instrument development alone.*

3 Research Instrumentation and Needs

3.1 Overview

HEAT will be a fully automated, state-of-the-art THz observatory designed to operate autonomously from Dome A in Antarctica. The combination of high altitude (4,200 m), low precipitation, and extreme cold make the far-IR atmospheric transmission exceptionally good from this site. In Figure 5 we present a plot of the expected atmospheric transmission above Dome A as a function of wavelength (Lawrence, 2004), indicating that winter weather at Dome A approaches (to order of magnitude) the quality of that achieved by SOFIA. The wavelengths of several important astrophysical lines are indicated with arrows. HEAT is designed to take advantage of these unique atmospheric conditions and observe simultaneously in [C II](158 μm), [N II](205 μm), and CO J=7$\rightarrow$6 & [C I] (370 μm).

A conceptual drawing of HEAT is shown in Figure 7. For robustness and efficiency, the tele-

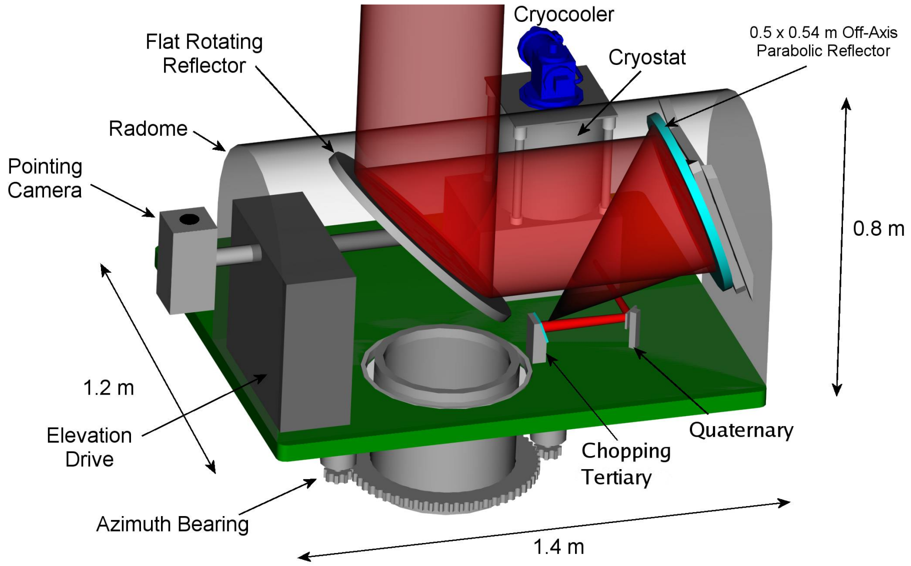


Figure 7: HEAT concept: The telescope has an effective collecting area of 0.5m. Elevation tracking is accomplished by rotating the 45° flat reflector. The entire telescope structure rotates for azimuth tracking and is warmed well above ambient by waste heat from the PLATO module below. The Schottky mixers used in the instrument package are efficiently cooled to $\sim$ 70 K using reliable off-the-shelf closed-cycle cryocoolers.

scope and instrument are integrated into a common optical support structure (OSS). HEAT will be mounted on top of a University of New South Wales Plateau Observatory (PLATO), a successor to the AASTINO (Automated Astrophysical Site-Testing InterNational Observatory) deployed to Dome C in 2003. The PLATO provides power and communications for the HEAT telescope and instrument. The total power budget for HEAT (including cryogenics, telescope drive system, and instrument control system is maximally 600 W, which is readily provided by efficient, high reliability generators within the PLATO. Data transfer and command and control of HEAT will be done via satellite and is described in more detail in Section 3.3.7. The University of New South Wales will construct a PLATO for HEAT and participate in all aspects of design, integration, deployment, and operation (see Support Letter from J. Storey). The HEAT/PLATO facility is functionally equivalent to a space-based observatory. A 3D rendering of HEAT mounted atop PLATO is shown in Figure 8.

3.2 *Telescope*

The telescope is designed to have maximum efficiency and the minimum number of optical components. Its design is similar to that of Kraus (1966) and utilizes an off-axis, Gregorian configuration. Incoming light is reflected horizontally off a 45°, 0.5×0.7 m flat reflector to an f/2.2 off-axis parabolic mirror. The converging beam is intercepted by a hyperbolic tertiary mirror that directs it to a flat quaternary and into the receiver. The tertiary mirror can chop the incoming beam between source and reference positions ($\Delta\mathrm{az} \sim 10'$) at a rate of 0 to 4 Hz. The mirrors are fabricated from aluminum on a numerical milling machine and have a surface roughness $\leq 3\,\mu$m rms. Elevation tracking is achieved by rotating the first flat reflector. Azimuth motion is achieved by rotating the OSS on a bearing attached to the roof of the PLATO. Mapping will be typically performed in drift-scanning ("on-the-fly") mode with the azimuth drive locked and tracking only in elevation. In fact, some of the Galactic Plane can be mapped purely with sidereal-rate scanning, using no tracking whatsoever! The absolute pointing accuracy will be 15″, 1/5 of the smallest diffraction-limited beam. The slew speed will be 1°/sec. The University of Arizona has a long history of building state-of-the-art telescopes and, with oversight from members of the Instrument Team, has the expertise required to optimize the telescope for operation in a Polar environment. The telescope cost estimate, which includes detailed design, fabrication, and testing of the telescope and drive system, is provided in the budget.

To prevent ice accumulation, the telescope is enclosed and warmed to -10°C by ducted waste heat forced up through the azimuth bearing from the PLATO. A small radome made of a low-loss dielectric (e.g. Goretex or polyethylene) encircles the first flat reflector. This optical configuration provides an unobstructed view of the sky. A near-IR camera (provided by UNSW) is mounted just outside the radome on an extension of the elevation axis. The camera will provide pointing and site testing data.

3.3 Receiver

3.3.1 Design Approach

Heterodyne receivers are needed to achieve the sensitive, high spectral resolution ($R = \lambda/\Delta\lambda > 10^6$) observations of [N II], [C II], and CO/[C I] required for the proposed Galactic plane survey. The key components of a submillimeter-wave heterodyne receiver are the mixer and local oscillator (LO). There are 3 types of mixers in common use; the Schottky diode mixer, the SIS mixer, and, more recently, the Hot Electron Bolometer (HEB) mixer. The Schottky diode mixer is somewhat less sensitive than either SIS or HEB mixers and requires more LO power, but is exceptionally stable in operation and **can operate at ambient temperature**. In contrast, SIS and HEB receivers require cooling to LHe temperatures (4K). HEAT's aggressive development schedule combined with the critical need for robust technologies that will work at low power and in a harsh environment leads us to select Schottky mixer systems for the initial deployment of HEAT. Virginia Diodes, Inc. has a long history of delivering submm-wave Schottky mixer systems and has demonstrated sub-harmonically pumped Schottky mixers using lower frequency LO sources (see Support Letter from J. Hesler). Virginia Diodes will deliver one such mixer at 1.9 THz and another at 1.46 THz. Two sub-harmonically pumped 810 GHz mixers (one for each polarization) will be provided to increase sensitivity and redundancy. Though the system will function well at ambient temperatures, we plan to improve HEAT's sensitivity to within a factor of ∼3 of demonstrated THz HEB systems by cooling the mixer blocks to ∼70K using economical, low power, commercial Stirling-cycle cryocoolers such as those sold by Qdrive and Sunpower, Inc. In this manner we will achieve a solid blend of good sensitivity and experimental robustness. A future 4K cryocooled SIS and HEB receiver system for HEAT is now in development at the Space Research Organization of the Netherlands (SRON, see K. F. Wakker, Director, support letter), with an initial 600,000 Euros of institutional support.

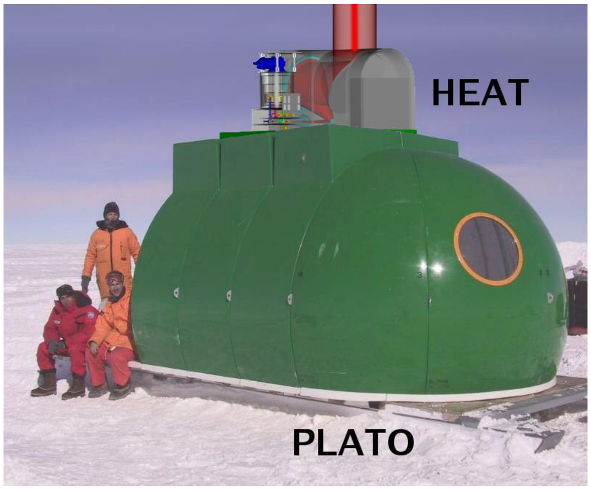


Figure 8: Rendering of HEAT atop a UNSW Plateau Observatory (PLATO)

3.3.2 Receiver Optics and Cryostat

A close-up of the receiver optics is shown in Figure 9. The incoming beam from the quartenary encounters two bandpass filters, the first centered on the [N II] (1.459 THz) line and the second on the [C II] (1.9 THz) line.

Outside of their nominal passband, the filters are highly reflective. Therefore, when the incoming beam encounters the first filter, all but a narrow range of frequencies around the [C II] line are reflected to the [N II] filter. The light reflected off the [N II] filter contains the CO J=7→6 and [C I] lines. The three emerging beams are collimated and directed into the instrument cryostat.

Sub-harmonic LO pumping of the Schottky mixers eliminates the quasi-optical injection of the LO signal and simplifies the optical layout of the cryostat. Wire grids direct the horizontal and vertical polarization components of the incoming light into the two 0.8 THz mixers.

The vacuum vessel and cryocooler integration will be consigned to Universal Cryogenics of Tucson, Arizona (see attached quote), who delivered a cryostat with a 4K cryocooler for the PI's Supercam heterodyne array, and has recently delivered a 70K cryocooled vacuum vessel to another Steward Observatory project. The 10" diameter, 5" tall vacuum vessel, complete with Antarctic coldproofing and its integration with a 70K cryocooler will be a straightforward application for Universal Cryogenics.

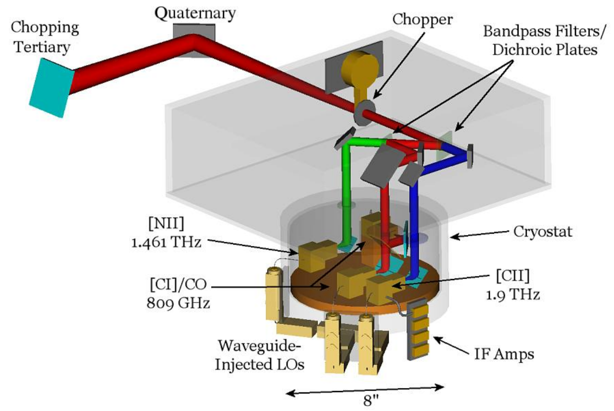


Figure 9: Optical subsystem for HEAT's Schottky mixers.

3.3.3 *Mixer Performance*

Virginia Diodes will provide Schottky mixers subharmonically-pumped using integrated, synthesizer-driven LO chains with competitive receiver noise performance even when warm (see attached quote from VDI and Support Letter from J. Hesler). With 5 watts of thermal load, both Qdrive and Sunpower cryocoolers will deliver a detector temperature of 70 K, sufficient to increase the sensitivity of the Schottky mixers by a factor of 2 (Hesler et al., 1997). We anticipate delivered cooled DSB receiver noise temperatures in the vicinity of 1500K at 0.8 THz, 3000K at 1.4 THz and 5000K at 1.9 THz. These receiver noise figures were used in defining the scope of the science program discussed in Section 2.3.

3.3.4 *IF Processors*

The entire IF processing and spectrometer system will be leveraged from the successful design currently implemented in the 64-beam Supercam 345 GHz array receiver in final development in the PI's lab. Funds will only be needed to fabricate additional amplifiers, IF processor modules, and spectrometer boards for HEAT. The 5 GHz-centered IF output of the THz mixers is first amplified by a low-noise MMIC amplifier designed by Sander Weinreb's group at Caltech for the Supercam project. In order to simultaneously detect the CO J=7→6 line in the lower sideband and the [C I] line in the upper sideband, the 0.8 THz mixer will have an IF center frequency of 1.5 GHz, be initially amplified by a commercial Miteq amplifier, and then upconverted outside the cryostat to 5 GHz in order to match the other channels for subsequent IF processing.

The 5 GHz IF signal emerging from the cryostat must be filtered, downconverted to baseband (0-1 GHz) and amplified to 0 dBm to be properly conditioned for the input of the digital spectrometer system. We will use the same IF processor boards designed by Sander Weinreb and his students at Caltech for the Supercam project to fulfill the IF processing needs for HEAT. The IF processor board provides each IF with an initial 48 dB of gain, a variable digital attenuator, a 1 GHz bandpass filter, a mixer conversion to baseband, a low pass filter and then 50 dB of baseband gain. An additional circuit provides total-power measurements of the IF power for telescope pointing and continuum measurements. A picture of a rack-mountable 8-channel IF processor module and a sample 0.5 GHz bandpass (from Supercam) is shown in Figure 10.

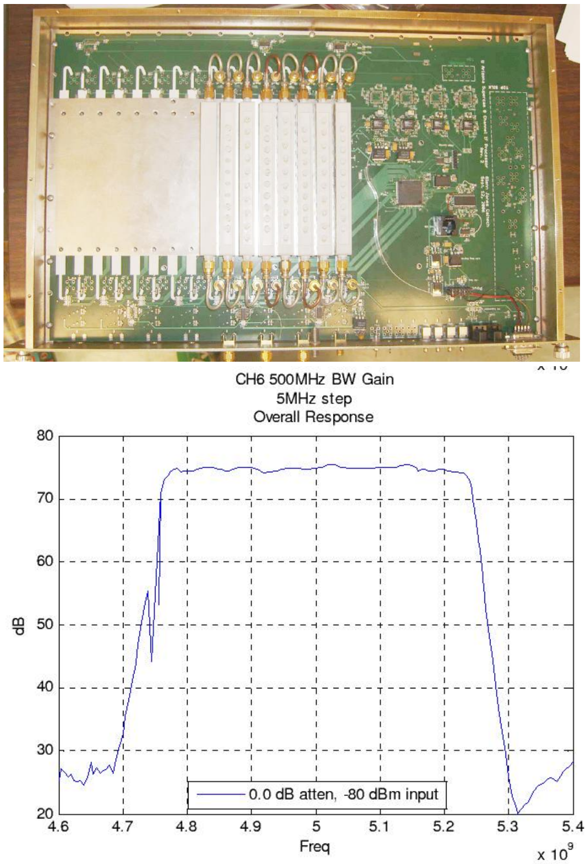


Figure 10: 8-channel Supercam IF processor module and sample 0.5 GHz bandpass

3.3.5 *FFT-in-FPGA Spectrometer*

Science drivers for the HEAT spectrometer stipulate two principal requirements. Sufficient kinematic resolution of molecular cloud components in

C^+C/CO emission will only be achieved with frequency resolution of finer than 2 MHz per channel, with 1 MHz preferred. The divergence of the velocity field of the inner Galaxy requires a bandwidth of 1 GHz or greater. **Recent gains in high-speed ADCs and FPGAs have made such a wide bandwidth direct-digitization spectrometer economically feasible.** The baseband output of the IF processors is fed into two direct digitization spectrometer boards each featuring 2-IF inputs each with 1 GHz of bandwidth (Figure 11). These spectrometer units perform 8-bit digitization of the input signal using dual 1 Gs ADCs in combination with a Xilinx Virtex4 FPGA which performs a real-time FFT power spectrum which is stored on the instrument computer(s). The spectrometers will each have 1 GHz of instantaneous bandwidth and 1 MHz resolution. They provide velocity coverage up to 370 km/s at a resolution ≤ 0.4 km/s, enabling all three lines to be resolved and observed throughout the Milky Way while only needing to Doppler-track in frequency. Omnisys Inc. has already been consigned to design and deliver 8 of these boards for the Supercam 64-beam array receiver being completed in the PI's lab. The prototype was delivered in mid-2006 and performs admirably. Allan variance (stability) times are 650 seconds using a 5 GHz noise source, downconverted through the Caltech IF processor board! Funds are requested in this proposal to consign Omnisys to fabricate and test three additional boards for HEAT (2 for deployment, 1 as a spare; see quote from Omnisys).

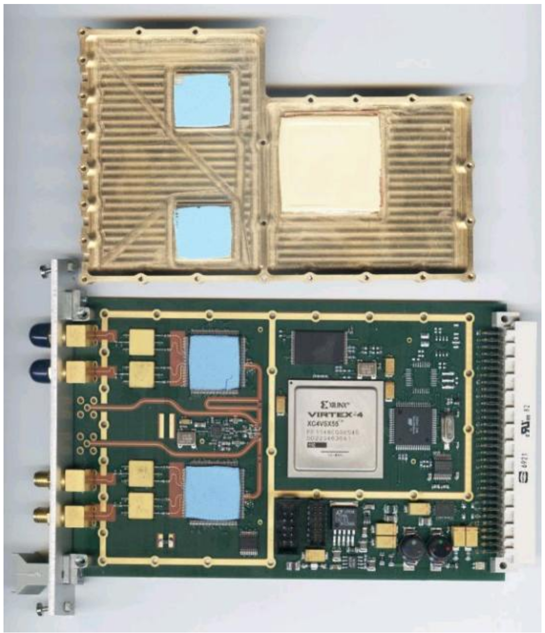


Figure 11: SuperCam spectrometer card as constructed by Omnisys Inc. The board features 2 GHz of bandwidth.

3.3.6 Calibration

HEAT will be able to calibrate observations through several means. 1) A vane with an ambient temperature absorbing load will be located at the cryostat entrance window, allowing standard chopper wheel calibration to be performed. 2) HEAT will routinely perform sky-dips to compute the atmospheric optical depth in each of its three wavelength bands. 3) HEAT will regularly observe a standard list of calibration sources. 4) The PLATO will host a submillimeter tipper that will measure atmospheric transmission throughout the FIR. These measurements will be coordinated with HEAT spectral line observations to provide cross calibration.

3.3.7 Control System and Communication

The HEAT control system will consist of a distributed computer control system where the telescope drive system, receiver frontend (*e.g.* mixers, LOs, and cryostat) computer, backend (spectrometer) computer, and the PLATO communicate via Ethernet. The prototype system is based on Technologic Systems TS-ARM embedded computers that draw less than 2 watts of power, runs Linux or NetBSD, and have been field-tested to survive the cold. These systems provide digital I/O, analog-to-digital conversion, serial I/O, and CAN, SPI and I2C bus interfaces for control of the various electronic subsystems in HEAT. These single-board computers are slave to a UNSW-designed "supervisor" power control board that contains a watchdog circuit that will reset the system in case of a software or hardware malfunction and cycle tasks to the next available embedded computer. HEAT will be designed to work autonomously for up to a week at a time, performing pre-programmed observational programs and storing astronomical and housekeeping data on non-volatile memory. Preprocessed sample data will be uploaded to control centers at the Universities of Arizona and New South Wales via dedicated Iridium satellite channels located on each "supervisor" board. Raw data will be recovered from HEAT each year during maintenance and processed into the released data products. We aim to also integrate a portable field antenna for NASA's TDRSS-1 satellite for routine downlink of raw data well in advance of annual maintenance, however financial support for this capability is not included in this MRI request.

3.4 *Integration and Testing*

The use of developed or commercial subsystems in HEAT allows for a significant and necessary program of integration and testing even on the abbreviated timescale for the delivery of the observatory. A testing schedule is provided for in Figure 13.

1. **Cold component testing** will be used to determine limiting temperatures for reliable operation of constituent components in each subsystem – for example, drive motors of the telescope, nonvolatile (flash) memory for storage, or the flexibility of interconnects and cabling at -60^{o}C. These component tests will define a process by which the telescope can be nominally operated in a range of highest reliability, or safely resurrected from an idle state in which all components have been thoroughly cold-soaked.
2. **Subsystem testing** will demonstrate the proper functionality of large components of the HEAT system, such as the assembled telescope drive system or the Schottky instrument package and control electronics, or the spectrometer and data system.
3. **Integrated system testing** involves the interplay of subsystems in the actual collection of data, such as performing on-the-fly mapping observations with active receivers, spectrometers, data system, while monitored over a Iridium satellite connection; i.e. normal astronomical operation at Dome A.
4. **Failure Mode testing** involves the intentional disabling of a component to observe the fault handling and interplay of the hardware and software systems. A Failure Mode Effects Criticality Analysis (FMECA) will be generated to determine system robustness to component failure. System reliability will then be enhanced through application of redundancy, increased reliability rated components, and improved operational design where indicated.

3.5 *Survivability and Robustness*

The applicability of Murphy's Law to remote observatories means that one must design an experiment to survive despite component failures or unexpected conditions. The adoption of Schottky diode receivers with dual polarization at 810 GHz, redundant and interchangable instrument and telescope computers and Iridium links on robust watchdog circuits, diesel power generation with solar panel backup, eliminating the need for the telescope drives to track for most observations, and adopting a largely fixed, stable, and simple optical system – all contribute to a highly redundant and robust system. For example, in the extreme instance of a PLATO power failure during the winter, HEAT will be designed to auto-boot using solar panels when the Sun reappears in September. Remote access to the instrument allows a wide range of system modification even in the event of a major failure; even a complete software reprogramming is possible should the need arise. **HEAT represents an exceptionally robust experiment optimized for remote operation under the environmental conditions of Dome A.**

4 Project Management

4.1 *Organization*

HEAT is an exciting, challenging project that requires the coordinated participation of scientists and engineers from several academic institutions and leading-edge companies to succeed. We have developed an organizational structure (shown in Figure 12) to meet this task. Collectively the HEAT team members represent many years of successful telescope and instrument development in Antarctica. The organizational structure of the HEAT project provides effective control of the project while allowing the delegation of authority to be made at the proper level within the organization. The main components of the organization are (1) the PI, who has overall responsibility for the project and coordinates the activities of the participants, (2) the DP-I (Kulesa) who assists the PI and is responsible for instrument control, system integration, and data products, (3) Co-I Burge who is responsible for the HEAT telescope design, fabrication, and testing (4) the Project Manager (PM-McMahon) who oversees the fiscal realities of the project, and (5) the Science and Instrument Teams who will provide scientific and technical guidance throughout the course of the project. Table 1 provides a listing of the roles and responsibilities of each member in the organization. Endorsement letters from members of the Science and Instrumentation committees are provided in the Supplementary Documentation section.

A schedule of key project milestones and tasks is provided in Figure 13. Based upon the 2006 design study funded by NSF-OPP the project will begin with a design review by the instrument and science teams. Procurement of key components will begin

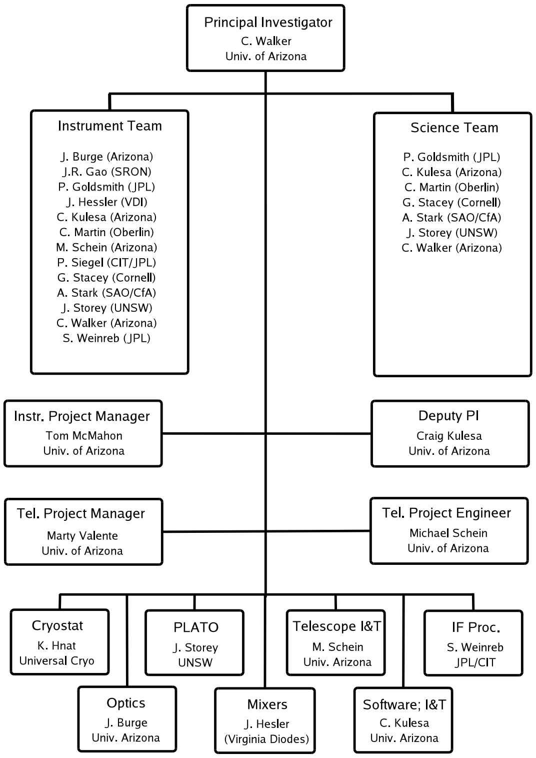


Figure 12: HEAT Organizational Chart

soon after following the spending profile outlined in the budget. Integration and test of the receiver system will take place at the Univ. of Arizona in the PI's lab in March 2008. Acceptance tests of the telescope will take place in June 2008. The receiver and telescope will then be shipped to the University of New South Wales, where an extended period of integration and testing with the PLATO module will occur, including system evaluation in a -80°C environmental chamber (see Support Letter from J. Storey). HEAT will then ship in October 2008, with deployment on Dome A in January 2009.

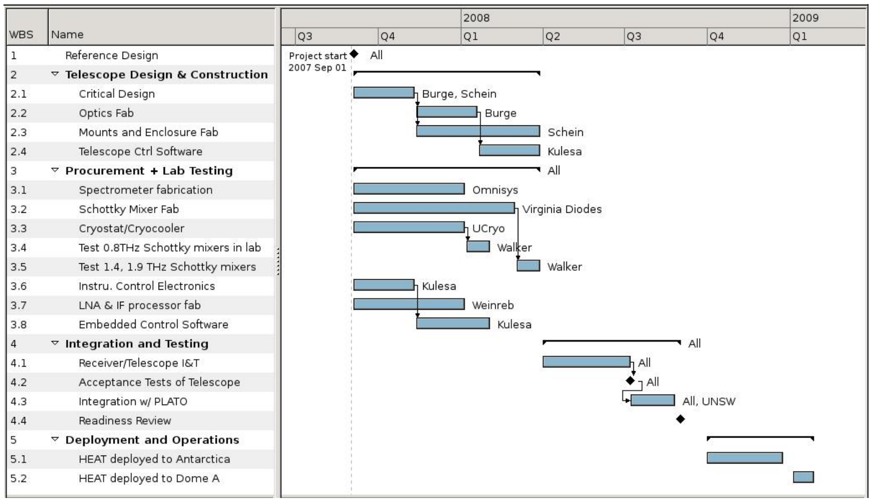
Routine communications between project participants is essential. There will be quarterly telecons between Science and Instrument team members to monitor progress, provide insight into solutions to emerging problems, and redefine priorities as needed. There will be weekly telecons and quarterly meeting (primarily through teleconferencing) between the PI, D-PI, Co-I, PM, and Technical Leads (Storey - PLATO, Burge - Telescope, Hesler - Mixers, Weinreb -IF amplifiers and processors, and Kulesa - spectrometers, data system, software).

The ability to meet the proposed schedule is made possible by the heavy leveraging of IF processor and spectrometer technology funded through NSF-ATI for Supercam, the PI's 64-beam heterodyne array receiver, in combination with commercially-available mixer and cryogenic hardware. The simplicity of the telescope design and operation in combination with the expertise of the Optical Sciences College at the University of Arizona in developing optical systems for ground and space is a solid match. *Indeed, the HEAT instrument team officially formed over a year ago and has been optimizing component technologies and system designs for HEAT since.*

4.2 Logistics: Deployment to Dome A

Although no logistical support is requested in this instrument proposal, it is nonetheless important to highlight how HEAT will be deployed to Dome A. The Antarctic science has reached a level of maturity where several options exist for fielding instruments on remote sites. For Dome A, these include:

1. **(Chinese) Traverse from Zhongshan to Dome A**: UNSW has recently signed a Memorandum of Understanding (provided in the Supplementary Documentation) with the Polar Research Institute of China and the National Astronomical Observatories of China for Chinese deployment of a UNSW PLATO to Dome A in 2007-8. An attractive option would be to simply install HEAT atop this PLATO unit in 2008-9. It could be installed as part of a 2008-9 Chinese traverse or combined with alternative transport options described below.
2. **CASA 212** (Australian Antarctic Division): J. Storey (see Support Letter) will be requesting one CASA 212 cargo flight directly from South Pole to Dome A for transport of the HEAT experiment, with subsequent flights to support fuel and personnel for the HEAT installation.
3. **LC-130 or Twin Otters from South Pole**: Raytheon Polar has developed a flight plan to deploy the HEAT experiment on Dome A using an LC-130 flight from McMurdo (put-in) and Twin Otter flights from Pole (personnel). If a Chinese traverse brings PLATO and HEAT to Dome A, Twin Otter air support would allow personnel to be flown in from South Pole to participate in the HEAT installation.
4. **IPY Traverse from Dome C** (Multinational): There is considerable interest amongst the international community in exploring the astronomical potential of Dome A by deploying a set of experiments to monitor site conditions there. HEAT is included in the international IPY proposal for the Dome A traverse.



WBS	Name
1	Reference Design
2	**Telescope Design & Construction**
2.1	Critical Design
2.2	Optics Fab
2.3	Mounts and Enclosure Fab
2.4	Telescope Ctrl Software
3	**Procurement + Lab Testing**
3.1	Spectrometer fabrication
3.2	Schottky Mixer Fab
3.3	Cryostat/Cryocooler
3.4	Test 0.8THz Schottky mixers in lab
3.5	Test 1.4, 1.9 THz Schottky mixers
3.6	Instru. Control Electronics
3.7	LNA & IF processor fab
3.8	Embedded Control Software
4	**Integration and Testing**
4.1	Receiver/Telescope I&T
4.2	Acceptance Tests of Telescope
4.3	Integration w/ PLATO
4.4	Readiness Review
5	**Deployment and Operations**
5.1	HEAT deployed to Antarctica
5.2	HEAT deployed to Dome A

Figure 13: Timeline: two years of development, integration and testing (through the proposed MRI grant) is followed by three years of survey work at Dome A (funded separately through the OPP grants program). Leverage of technologies both from commercially available mixers and IF technologies from the PI's SuperCam instrument development makes this timeline achievable.

5. **Traverse from Pole**: By the IPY it is expected that the overland route from McMurdo to the South Pole will be well established, and the necessary infrastructure such as tractors and sleds will be routinely available at South Pole. A single overland expedition from Pole to Dome A could bring in all the equipment and supplies needed for the HEAT experiment.

The HEAT team will continue to work closely with the NSF, Raytheon Polar, and the International Community to implement an optimal plan for deployment to Dome A during the IPY.

5 Educational Impact

The development and establishment of the first astrophysical observatory on Dome A offers many opportunities to tap into the imagination of students of all ages. Below we highlight two examples.

Instrument Development Experience

The training of students in the development of state-of-the-art instrumentation is essential to the future of science. This is particularly true in mm/submm astronomy where technological advances are happening so rapidly. Ironically, there are only a handful of laboratories in the world where students gain hands-on experience in the design, fabrication, and fielding of radio astronomy instrumentation. In the PI's lab we have had a number of students (both graduate and undergraduate) participate in the development of submm-wave instrumentation for Antarctica (i.e. AST/RO) and the Heinrich Hertz Telescope (HHT) on Mt. Graham, Arizona. This work, and the astronomy that has come from it, has been a major component of 5 Ph.D. dissertations and numerous undergraduate research projects. HEAT is a natural extension of these research efforts. In the proposed budget for HEAT, funds for two graduate students are requested. However, as is customary in the PI's lab, many other students will also participate in making the program a success. Indeed, one of the most important aspects of training students in instrument development is experience in working in teams. Astronomical instrumentation is becoming ever more complex, and requires the talents of many individuals. Providing students with both technical training and team-work experience increases their probability of success.

K-12 Outreach: A Student Radio Telescope

In support of education and public outreach activities the PI and his students have constructed a remotely operable, steerable, 3.5 m Student Radio Telescope (SRT) for observing the HI line in the Milky Way. The SRT has been used as a instructional tool in undergraduate courses (both major and non-major). Students from on and off campus will soon be able to monitor and control observations with the SRT. Unlike optical telescopes, the SRT can be used day and night, making it ideal for classroom instruction. Like HEAT, the SRT is a spectroscopic Galactic Plane survey telescope. During the course of developing and operating HEAT we will develop instructional modules for various age groups that focus on the science and technology of HEAT and use the SRT as a "hands-on" laboratory with the goal of providing students with an intuitive understanding of underlying physical concepts.

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