Project Description

1 Results from Prior NSF Support

The investigators of this proposal have committed to developing submillimeter astronomy at Dome A, the summit of the Antarctic plateau. This effort stems largely from the experience of developing heterodyne receivers for the 1.7 m AST/RO telescope at the South Pole, particularly *PoleSTAR*, a 4 pixel 810 GHz receiver which was funded by the NSF Office of Polar Programs (A. Stark–PI: OPP-0126090).

In 2006 funding was obtained through NSF/OPP (ANT-0538665: Walker-PI, Kulesa-CoPI) to perform a design study for HEAT. This proposal is based upon that design study. In 2007 an NSF-SGER proposal was funded (ANT-0735854: Walker-PI, Kulesa-CoPI) to construct `Pre-HEAT`, a 20 cm telescope with a 450 μm heterodyne spectrometer. `Pre-HEAT` was constructed and successfully deployed to Dome A with the University of New South Wales' PLATeau Observatory (`PLATO`) in January 2008. The effort was an international collaboration between the US, China, UK and Australia. The overland traverse and installation of `PLATO` at Dome A was led by the Polar Research Institute of China and the Chinese Academy of Sciences. As of the writing of this proposal, `Pre-HEAT` took data for 204 days in 2008, and is still taking data in 2009, albeit with reduced functionality. Its principal science products are submillimeter atmospheric transmission data and Galactic spectra of the ^{13}CO J=6-5 line. **The Pre-HEAT results show that the Dome A site is unparalled for submillimeter atmospheric transmission and stability** (see Section 2.3.3). One instrumentation paper has already been published (Kulesa et al. 2008), and the first major scientific paper discussing the site testing results has been submitted to Nature (Kulesa et al. 2009). Two additional papers; one discussing the Dome A site in the context of other submillimeter sites, and another presenting the ^{13}CO J=6-5 data, are in preparation. The proposed HEAT telescope will use the same optics, receiver, and spectrometer technologies as Pre-HEAT. Furthermore, the same international collaboration that successfully fielded Pre-HEAT will take the proposed HEAT observatories to Dome A and Ridge A.

Figure 1: *The* `Pre-HEAT` *telescope, installed at Dome A with the PLATeau Observatory (PLATO). A technological prototype for the proposed HEAT telescopes,* `Pre-HEAT` *has a 20 cm clear aperture combined with a 660 GHz Schotty diode receiver and a digital FFT spectrometer. It was deployed to Dome A on an overland traverse led by the Polar Research Institute of China. Its measurements of the submillimeter opacity at Dome A are the basis for the expected performance of HEAT described in this proposal.*

Finally, a multi-institutional team led by Co-PI Walker and assisted 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 technology in terms of integrated mixers (Puetz et al 2006) and IF processor/spectrometer technology. The prototype IF processor and spectrometer for *SuperCam* were used as receiver subsystems for Pre-HEAT, and will be baselined for HEAT. *Supercam* will be commissioned at the HHT in the fall of 2009. The experience and heritage gained through each of these unique efforts will be instrumental in making the HEAT telescopes a reality.

2 Research Activities

The proposed High Elevation Antarctic Terahertz (HEAT) telescopes will forge new capabilities for ground-based infrared and submillimeter astronomy, by providing a window on the Universe which otherwise would be unavailable except via suborbital 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, UK, Australia, and China), continuing the spirit of the International

Polar Year. Here, we outline the HEAT telescopes' key science project, a THz survey of the Galactic Plane observable from Antarctica. This proposal supports the development of the HEAT telescopes through the first two years of science operations at Dome A and the first year at Ridge A.

2.1 *Introduction*

From the Milky Way to high redshift protogalaxies, the internal evolution of galaxies is determined to a large extent by the life cycles of interstellar clouds, as shown in Figure 2.

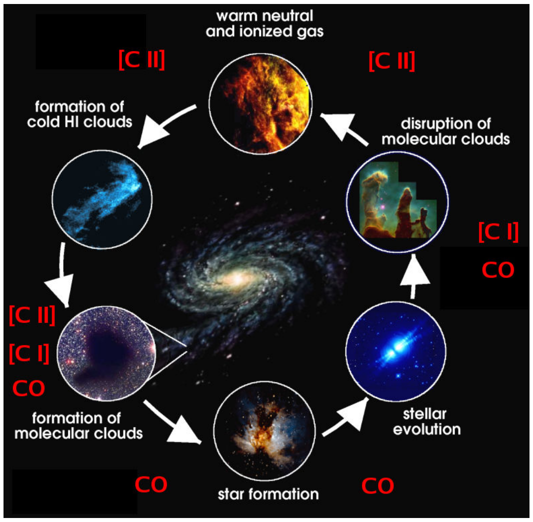

Figure 2: *The HEAT telescopes will observe the fine structure lines of [N II], [C II], [C I], and CO that probe the entire life cycle of interstellar clouds. In particular, HEAT will witness the transformation of neutral atomic clouds into star-forming clouds, the interaction of the interstellar medium (ISM) with the young stars that are born from it, and the return of enriched stellar material to the ISM by stellar death.*

These clouds are largely comprised of atomic & molecular hydrogen and atomic helium, which 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$\sim$70K) atomic clouds and the warm (T$\sim$8000K) 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. Indeed, 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. HEAT is designed with the goal of providing insights into the gaps in our knowledge of the Life Cycle of the ISM.

2.2 *HEAT Science Goals*

Via resolved [C II], [C I], CO, and [N II] 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 needed to construct a template to **interpret global star formation in other spiral galaxies**.

The **science mission** of HEAT is to make significant contributions to achieving the two major science goals described below. Using the proposed instrument and observing methodology, the minimum mission is expected to be achievable in two seasons of survey operation from Dome A and Ridge A.

Goal 1: Observing the Life Cycle of Interstellar Clouds

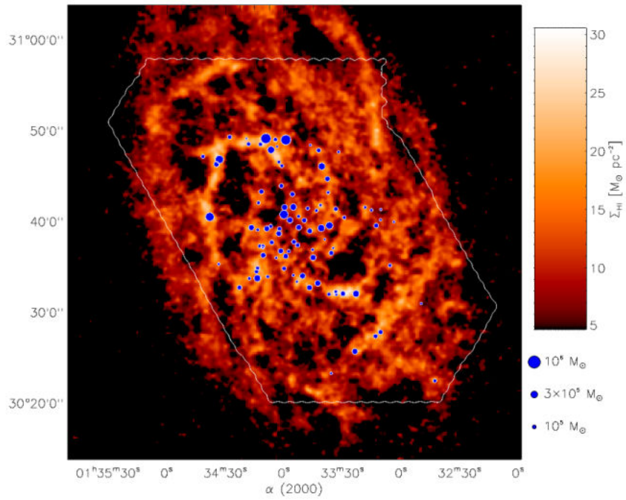

Figure 3: *The location of GMCs in the nearby spiral galaxy M33 are overlaid upon an integrated intensity map of the HI 21 cm line (Engargiola, Plambeck, Rosolowsky, & Blitz, 2003). These observations show that GMCs are formed from large structure of atomic gas, foreshadowing the detailed study of GMC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

The formation of interstellar clouds is a prerequisite for star formation, yet the process has not yet been identified observationally! HEAT is designed with the unique combination of mapping speed, 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, and 2) constructing spatial and kinematic comparisons of sufficient resolution, spatial coverage and dynamic range to probe a wide range of interstellar phases and environments. Within its survey region, HEAT will generate a better characterized catalog of interstellar clouds than CO or HI surveys alone.

Since the [C II] (and [C I]) line emissivity 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 high 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. Similarly, the [N II] luminosity determines the ionizing luminosity of OB stars, a standard metric for the star formation rate. Therefore, [N II] observations of ionized gas provide an extinction-free, low-density measurement of the location and rate of star formation in the Galaxy.

HEAT's high spectral resolution enables crucial kinematic studies of the Galaxy to be made. HEAT will determine the kinematics and thermal pressures of supershells, fossil superrings, and new molecular clouds condensing out of old superrings and supershells via gravitational instability. 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 II] measures the flux of ionizing photons, and [C II] 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: Constructing a Milky Way Template for Star Formation

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.

[C II] and [N II] will be the premier diagnostic tools for far-infrared studies of external galaxies with large redshifts (e.g. with Herschel & 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 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 II], [C I], CO, [N II], 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.

For example: 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. Furthermore the SFR-dense gas relation established in nearby galaxies is a linear one (Gao & Solomon 2004) and this has been extended to the Milky Way dense cores (Wu, Evans, Gao et al. 2005), and possibly high-z galaxies and QSOs as well (Gao et al. 2007), implying that the same physics drives the active massive star formation in both GMC dense cores and galaxies near and far.

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 I], [C II] and [N II] emission provides an initial set of data to calculate the Schmidt Law in the Galaxy. The [N II] 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 I] and [C II] 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. A preliminary Schmidt Law will be constructed from the radial profiles of the star formation rate derived from [N II] 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).

2.3 *Implementation of Science Objectives*

HEAT's science drivers highlight a survey that would not only provide the first comprehensive view of interstellar clouds and their evolution in the Galaxy, but would also serve as a reference for contemporary focused studies with Herschel, SOFIA, APEX, and the ALMA and SMA interferometers. How will the HEAT telescopes answer the scientific goals that have been illustrated?

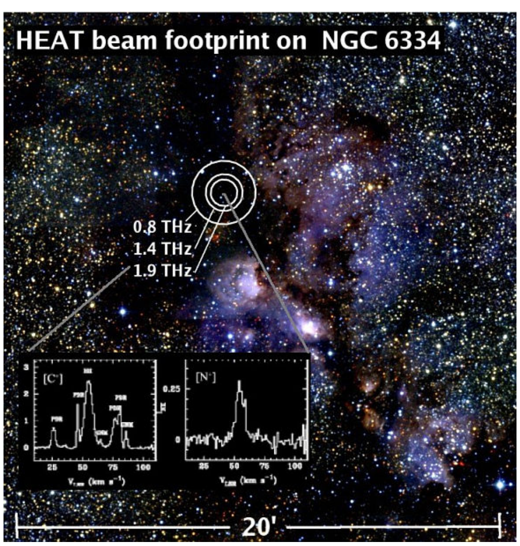

Figure 4: *The power of HEAT: Each of the 3 heterodyne beams of HEAT are overlaid upon a 2MASS infrared image of NGC 6334, a massive Southern star forming region, and representative of the kinds of regions that HEAT will survey. The beams will measure high-resolution spectra in the 0.8, 1.5, and 1.9 THz bands respectively. The (inset) synthetic spectra of NGC 6334 depict a small fraction of the spectral coverage achieved with each of HEAT's receiver channels.*

2.3.1 *Velocity-Resolved Imaging Spectroscopy*

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 structure of the Galactic ISM 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 *Uniqueness of a [CI], [CII], [NII] and CO 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! Figure 5 depicts a plane-parallel cross-sectional representation of an interstellar cloud which highlights several ways that HEAT's THz surveys can shed new light on our understanding of the life cycles of clouds:

1. A significant column of "hidden" gas exists between where the atomic to molecular transition of H to H_2 takes place, and where CO finally becomes the dominant form of gas-phase carbon. A significant volume of cold neutral gas in the Galactic ISM is likely in this state, and all molecular clouds should be dominated by this material at certain points in their evolution. CO is, at best, a faithful tracer of well-established, shielded molecular material.
2. This translucent material is best probed by [CII] and, to a lesser extent, [CI]. Both lines are therefore more revealing than CO of the formative and destructive states in the evolution of a molecular cloud. They will reveal natal molecular (H_2) regions that are weak or absent in CO emission.
3. In regions of significant UV radiation, [NII] can be used to disentangle the fraction of [CII] emission that stems from ionized gas, versus neutral clouds.
4. The [CII] emissivity is proportional to pressure, $n \cdot T$; thus it selects *clouds* versus diffuse neutral gas prominently seen in 21 cm HI emission.

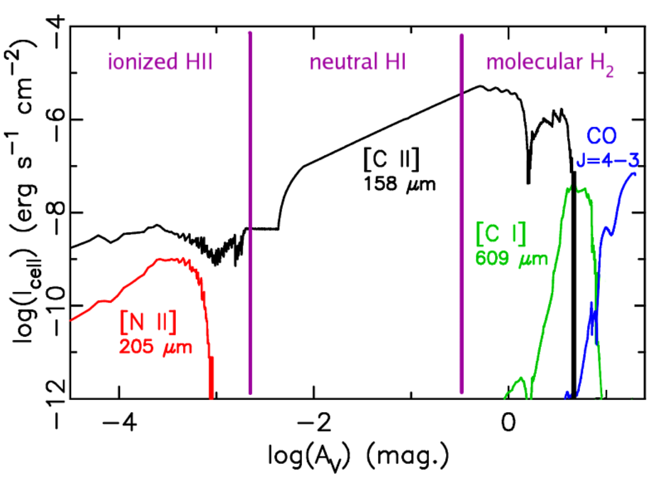

Figure 5: **The uniqueness of HEAT's [CII] and [NII] surveys.** *A model depiction of the intensity of diagnostic lines of carbon and nitrogen species as viewed through a UV-illuminated cloud from depths of A_V=0 to 20 mag. Vertical purple lines overlay the HII-to-HI-to-H_2 boundaries found at the edges of dense interstellar clouds. This figure demonstrates that [CII] will probe H_2 clouds with little CO, and depicts the need to use [NII] to disentangle the portion of [CII] emission stemming from ionized gas.*

HEAT will provide the first velocity-resolved large-scale mapping survey of these species. It will measure all three principal forms of carbon in the gas phase: ionized, neutral, and molecular. In combination with existing infrared, HI and CO surveys, the potential to identify the formation and destruction of molecular clouds and GMCs observationally may finally be realized! This survey 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 *Dome A: An Exceptional Observing Site*

HEAT's sensitivity is owed principally to the superlative atmospheric conditions above the summit of the Antarctic plateau. The extreme cold and exceptional dryness allow ground-based observations into the otherwise forbidden THz windows, as demonstrated by the `Pre-HEAT` experiment. The solid line in Figure 6L shows the measured sky transparency at 660 GHz (450 microns) for 5 months of fully automated Pre-HEAT data. Translation of the 660 GHz opacity to estimates of the precipitable water vapor (PWV) column are made through application of the (AM) atmospheric model (Paine, S., 2004) which has provided excellent fits to submillimeter Fourier Transform Spectrometer measurements of the sky above the Chajnantor plain in Chile (Paine et al., 2000) and the South Pole (Chamberlin et al., 2000). Comparison with other (MOLIERE-5, ATM and LLRTM) atmospheric models shows less than 20% inter-model variance in the precipitable water vapor estimate at 660 GHz.

An independent, year-long assessment of the water vapor content above Dome A can be derived from 183 GHz passive radiometry from the Microwave Humidity Sounder (MHS) on NOAA-18 (Miao et al., 2001). In Figure 6L, the solutions for precipitable water vapor measured by NOAA-18/MHS in 2008 are zero-point calibrated with and overlaid atop the Pre-HEAT measurements of submillimeter opacity, which are converted to water vapor column. The match of these datasets is striking, except during storms: the satellite-based measurements are insensitive to ice particle scattering and therefore underestimate the water content when low-level ice clouds are present; an effect corrected for in the site statistics.

Figure 6R shows the cumulative distribution of precipitable water vapor and 450 micron atmospheric transmission over the Austral winter and the whole year, combining the calibrated satellite measurements with the direct measurements of transmission provided by the Pre-HEAT telescope. The best quartile of winter weather yields 100 microns of precipitable water vapor ; the best 20 days (10%) of winter weather, about 70 microns. Ten days averaged 60 microns of water vapor column or less, with the lowest daily average reaching 25 microns. A tabular comparison of Dome A and Ridge A to other well-known submillimeter sites is shown in Table 1. To the proposers' knowledge, these are the driest values measured anywhere from the ground; that such conditions are frequently realizable makes them even more remarkable.

Site	**25%ile**	**50%ile winter PWV (mm)**	**Median winter transmission @660 GHz**	**Best 25% winter transmission @1460 GHz**	**Best 10% winter transmission @1900 GHz**
Dome A, 4100m	0.1	0.14	74%	28%	4%
Ridge A, 4050m	0.08	0.12	77%	33%	10%
Dome C, 3250m	0.15	0.24	60%	13%	<1%
South Pole, 2850m	0.23	0.32	52%	6%	0%
Chajnantor, 5050m	0.35	0.60	47%	7%	0%
Mauna Kea, 4100m	1.0	1.5	15%	0%	0%

Table 1: *Comparison of Dome A and Ridge A with other established submillimeter observing sites, based on 2008 NOAA-18 data for Domes A, C and Ridge A. 2008 radiosonde data was used for South Pole, and Chajnantor and Mauna Kea are based on literature values (Delgado et al., 1999; Hogg, 1992).*

The high elevation, cold atmosphere and benign wind conditions at Dome A **open the Terahertz windows to ground-based observatories and are unlikely to be matched anywhere else on Earth**. Thus, even with moderately-cooled Schottky receivers, HEAT's sensitivity to each spectral line is scientifically useful:

CO J=7-6 and *[C I] J=2-1*

We aim to detect all CO and C^0 to A_V=1-2, where most hydrogen has formed H_2 and CO is just forming. This extinction limit corresponds to N(CO)$\sim 5 \times 10^{15}$ cm^{-2} and $N(C) = 1.6 \times 10^{16}$ cm^{-2}, for integrated

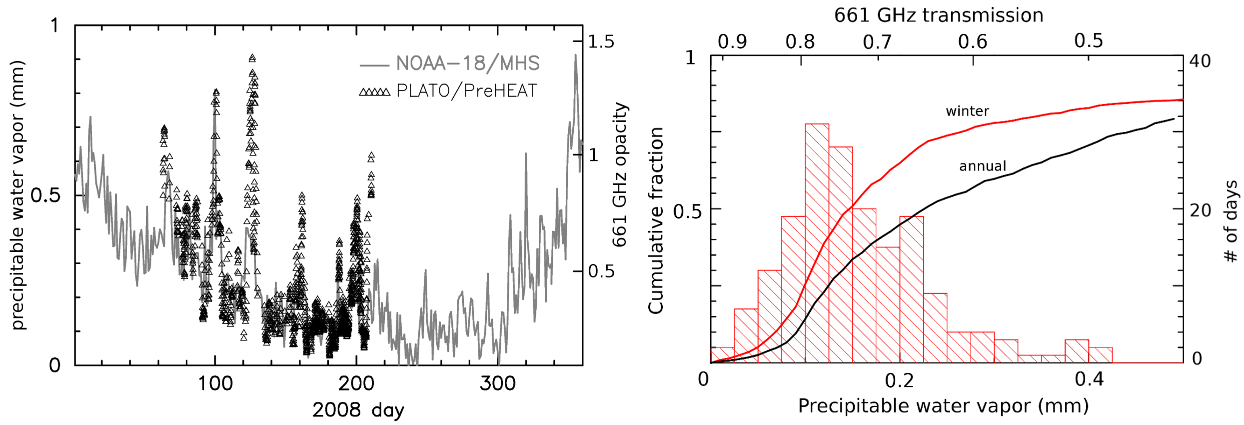

Figure 6: *(L) 661 GHz transmission data from Pre-HEAT (solid line) plotted atop passive soundings of Dome A from the MHS instrument on board NOAA-18 shows unprecedented conditions at the Dome A site. (R) Cumulative and histogram distributions of the wintertime and annual transmission at 660 GHz and the corresponding modeled precipitable water vapor show that terahertz observing conditions are prevalent for 25% of the winter.*

intensities of 3 K km s^{-1} in CO J=7-6 and 1.8 K km s^{-1} in [C I]. These sensitivity limits are achievable (3σ) within 1.6 and 5 minutes, respectively, of integration time at 810 GHz in *median* winter atmospheric conditions (T_{sys}=8,000K) on Dome A, with a Schottky receiver! The atomic carbon emission will correspond well to diffuse gas, whereas the CO J=7-6 emission (or upper limits) diagnose warm, dense regions and should be properly referenced to existing and ongoing lower-J CO surveys from e.g. the NANTEN, Mopra and AST/RO telescopes.

[N II] and [C II]

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 II] line alone represents close to 1% of the bolometric luminosity of the Galaxy! In an absolute sense, these lines are relatively easy to detect in the ISM. Our most demanding requirements for detection of [C II] and [N II] lie in the search for the formation of giant molecular clouds via [C II], and the measurement of the diffuse warm ionized medium in the Galaxy, via [N II]. A flux limit of 1 K km s^{-1} will detect [N II] in warm diffuse ionized gas as far away as the Molecular Ring, achievable in good winter weather in 9 minutes with appropriate velocity smoothing to 5 km s^{-1}. In the least favorable case where the [N II] emission seen by COBE is weakly and uniformly distributed throughout the Galactic plane, HEAT's spatial resolution can be traded for sensitivity, and the Galactic plane maps smoothed to angular scales of 10-30′ as needed.

Similarly, the accumulation of GMCs from many cold neutral clouds of atomic hydrogen occurs at low relative column densities of $\sim 5\times10^{20}$ cm^{-2}. Since essentially all carbon in such clouds is ionized, $N(C^+) \sim 10^{17}$ cm^{-2}. At the T = 70K common in cold atomic clouds and PDRs, 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.

2.3.4 Diverse 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 both the inner and 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.

Ultimately, we propose to probe the entire Galactic plane as seen from Dome A ($0 > l > -100^o$); see Figure 7. However, for the two year survey period of this proposal, using a Schottky mixer receiver system, an initial total of 40 square degrees will be targeted. It will probe three crucial components of the Galaxy; the Scutum-Crux spiral arm, an inter-arm region, and portions of the Carina, Lupus, and Chamaeleon II cloud complexes. The Galaxy survey will coincide with GLIMPSE, a Spitzer Space Telescope (SST) Legacy Program (Benjamin et al., 2003) and will be designed to maximize coverage with the "Cores to Disks" SST Legacy program (Evans et al., 2003).

The remaining sky coverage in the Galactic Plane survey will be provided by a future instrument package from SRON, featuring a cryocooled 4K HEB receiver system – beyond the scope of this proposal.

2.3.5 Synergies with Other Observatories

HEAT is timely. The Spitzer Space Telescope Legacy program GLIMPSE, provides a thermal infrared survey of the Galactic plane that provides a complete census of OB stars, the stellar structure of the molecular ring, maps the warm interstellar dust, and constrains extinction laws as a function of galactocentric radius. HEAT will provide the best corresponding interstellar cloud survey that will provide the kinematic information that can associate star formation with specific clouds of molecular gas. HEAT can measure the dense cloud material that forms stars, cloud interactions with formed stars, and kinematic disruptions 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.** For example, the most intensive [CII]-related key project for Herschel is "GOTC$^+$" (PI: W. Langer), which will observe the [CII] line toward over 900 selected points in the Galactic Plane, in 223 hours of observing time with the HIFI instrument. HEAT, by virtue of being a dedicated mapping instrument with a focused mission and a long mission lifetime, will map almost 50 times the areal coverage of "GOTC$^+$" in its deep survey sensitivity mode alone during this proposal period! The same situation applies to the handful of [CII] data taken during the era of the Kuiper Airborne Observatory (KAO). Indeed, HEAT will provide ideal reference maps of THz line emission for more detailed followup with SOFIA and Herschel, and the HEAT data distribution and databasing system will be aligned as much as possible with the `HIPE` software to be used with Herschel data products.

Similarly, the small field of view of the ALMA interferometer (7-30″) means that many tens of thousands of pointings will be needed to map a single square degree. Even with ALMA's planned mosaicing capability, such large scale surveys are unlikely to be scheduled. Furthermore, ALMA will not have even 0.8 THz receivers for some time. Fortunately, 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 follow-up with ALMA when it becomes available.

HEAT distinguishes itself from other small ground-based observatories such as AST/RO, NANTEN and the RLT in that (1) HEAT is a dedicated observatory with an autonomous and efficient year-round observing schedule, and (2) it is at the only ground based site that can stably and reliably observe the terahertz lines warranted by these scientific goals (Section 2.3.2). In combination with the surveys produced by these other telescopes, HEAT will be able to address questions which other surveys alone could not.

It should be noted that both AST/RO and the RLT have made pioneering, targeted observations of [N II] (Oberst et al. 2006, Marrone et al. 2005). These observations have been helpful in optimizing the larger scale survey possible with HEAT from Dome A.

Finally, the Stratospheric Terahertz Observatory (STO: PI-Walker, DPI-Kulesa) is a funded long duration balloon (LDB) project which complements the Galactic plane survey capabilities of HEAT. It has a 0.8m aperture and is designed to observe high lying THz lines including [C II], [N II], [O I], and HD. The first STO science flight will occur in late 2010 and will last for $\sim$2 weeks. Such flights can be repeated on 2-3 year timescales. HEAT plays an important role with respect to STO, which has a severely restricted view of the Galactic Plane (from l=-20 to l=-50) owing to Solar angle restrictions and the occulting of the sky by the helium balloon itself. Unlike STO, which due to its trajectory has limitations in its sky coverage, HEAT *will* be able to map the important southern Lupus, Carina, and Chamaeleon molecular cloud complexes, in addition to deeper, smaller scale maps of the Magellanic Clouds. HEAT and STO observations will therefore be coordinated to provide maximum science return (Figure 7).

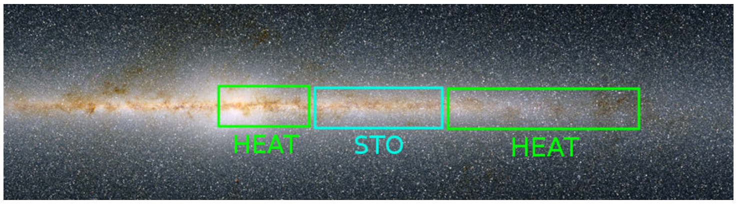

Figure 7: *Regions of the Galactic Plane from l=0 to l=-100, mappable by STO and HEAT. The large scale HEAT survey will initially focus on [CI] and CO, with small maps performed in [NII] and [CII].*

2.4 *Survey Activities*

2.4.1 *Why Ridge A, and two telescopes?*

The use of passive microwave sounding data, calibrated to the daily South Pole radiosonde launches and Pre-HEAT's submillimeter tipping measurements, can be used to ask the question "are even better weather conditions prevalent elsewhere on the Plateau?" Indeed, the MHS data from NOAA-18 suggest that the minimum PWV lies along the inland ridge 150 km south-west of Dome A (Kulesa et al. 2009) called Ridge A (Saunders et al., 2009) near 82S and 73E. **At the highest frequencies, the estimated difference in transparency would lead to a four-fold reduction in observing time or more (Table 1)!** Furthermore, passive satellite measurements of wintertime cloud cover suggest that the cloud minimum similarly lies south-west of Dome A (Figure 8) and in the vicinity of Ridge A. The null, or origin of the katabatic winds appears to be offset in this direction as well. Given that even small changes in the wintertime PWV can lead to very significant changes in the terahertz transmission, it would seem wise to understand which site is better for astronomy before committing resources to a future larger, telescope with sizeable logistical needs.

The addition of Ridge A to the deployment plan only requires that the telescope, enclosure and a small subset of PLATO systems be duplicated, which is a comparatively small portion of the budget and work effort. Indeed, redundancy of the receiver system is already a near-requirement on the high plateau, since (unlike at South Pole) the likelihood of making a repair on-site is very low, particularly via (Chinese) proxy. It is far easier to simply swap parts, thus having a secondary receiver and telescope system maximizes the scientific availability of the system.

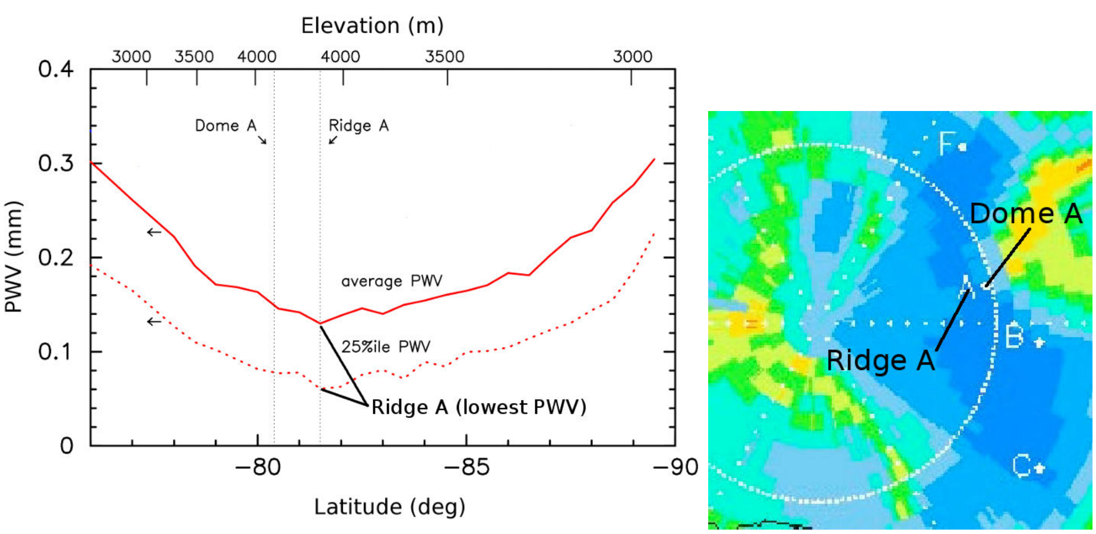

Figure 8: *(L) Average and 25%-ile midwinter PWV measured by MHS/NOAA-18 as a function of latitude, crossing through Dome A, Ridge A, and South Pole. The PWV minimum appears to be over Ridge A. (R) Wintertime MODIS/CERES satellite cloud cover data suggests that the cloud cover minimum is centered on Ridge A.*

As will be described in the Logistics section, at the conclusion of this proposal, there should be sufficient Ridge A and Dome A data by the end of 2012 to make a site selection to focus future efforts.

2.4.2 *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 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=0.15 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 10 days, assuming median winter conditions of τ_{810} ~0.5. 25 square degrees distributed from $0 > l > -20^o$ and $-45 > l > -100^o$ will be mapped in ≈300 days. Some overlap in mapping coverage between the two survey years is expected. When the atmospheric opacity at 1.9 THz drops below ~3, focused surveys including C^+ will begin. Of the best 40 days of winter weather, half will be devoted to a shallow-sensitivity C^+ survey (1σ ~1.5 K km s^{-1}), with each square degree of mapping requiring about 5 days each, for a total of up to 4 square degrees of coverage per season. The other half will be devoted to deeper C^+ surveys of selected regions guided by 2MASS and GLIMPSE extinction maps for the formation of molecular clouds – a total of 0.5 square degrees will be mapped to $1\sigma \sim 0.3$ K km s^{-1} per season.

Participant	Team	Affiliation	Participation Activity
Michael Ashley	I	UNSW	PLATO systems, Antarctic astronomical instrumentation
Yu Gao	S	PMO	Extragalactic submm astronomy; Milky Way template lead
Jeffrey Hesler	I	Virginia Diodes, Inc.	Schottky mixer development and LO technology
Craig Kulesa	I, S	Univ. Arizona	PI, HEAT development and testing, ISM physics
Chris Martin	I, S	Oberlin College	Antarctic Astronomy and Instrumentation
Mark McCaughrean	S	Exeter	Antarctic astronomy, star formation, synergy with JWST
Michael Schein	I	Univ. Arizona	Telescope design and contruction
Antony Stark	I, S	SAO/CfA	Telescope Optics & Systems; Synergy with AST/RO
John Storey	I, S	UNSW	PLATO Systems, Site testing, Polar Operations
Nick Tothill	I, S	Exeter	Antarctic submillimeter astronomy
Christopher Walker	I, S	Univ. Arizona	Co-PI, receiver development and testing
Wilfred Walsh	I,S	Newcastle	Antarctic astronomy, data processing
Lifan Wang	S	Texas A&M	CCAA lead – Coordinate US and Chinese efforts
Ji Yang	S	PMO	Submillimeter science lead at PMO

Table 2: Activities of the Science (**S**) and Instrumentation (**I**) Teams

2.4.3 *Science Products and Dissemination*

A 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. This software is being developed as part of the PIs' efforts on SuperCam, and will be completed before the proposed effort on HEAT begins. The most demanding storage requirements for the final 40 square degree maps, regridded to 50″ spacing, with 1024 spectral points per grid position, is less than 4 GB. This volume can be 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. Standard Virtual Observatory (VO) services will be enabled in this interface. Preprocessed data cubes will be transferred from HEAT over Iridium satellite, while raw data will be collected from the telescope annually during maintenance. Thus, there will be biannual data products – a preliminary release midseason (August of 2011 and 2012), and a final release of the previous season's data in February of 2012 and 2013. 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 freely available from the HEAT web page: `http://soral.as.arizona.edu/heat/`

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 2. *Both graduate and undergraduate students will participate in the instrument development and science study.*

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. Its design is heavily leveraged from the successful Pre-HEAT experiment (Kulesa et al. 2009). The combination of high pressure altitude (4,700 m), low precipitation, and extreme cold make the far-IR atmospheric transmission exceptionally good from this site (Table 1, Figure 6). HEAT is designed to take advantage of these unique atmospheric conditions and, between the two telescopes, observe simultaneously in [C II](158 μm), [N II](205 μm), and CO J=7$\rightarrow$6 & [C I] (370 μm).

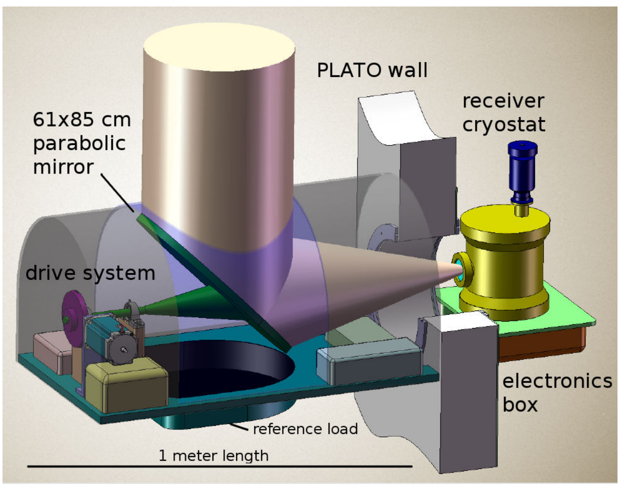

Figure 9: HEAT concept, shown here attached to the Dome A PLATO observatory. The telescope has an effective collecting area of 0.6m. Elevation tracking is accomplished by rotating the off-axis parabola. The Schottky mixers used in the instrument package are efficiently cooled to $\sim$80 K using a reliable off-the-shelf closed-cycle cryocooler.

A conceptual drawing of HEAT is shown in Figure 9. For robustness and efficiency, the telescope and instrument are integrated into a common optical support structure. One HEAT telescope will replace `Pre-HEAT` on the side-port of the University of New South Wales Plateau Observatory (PLATO) at Dome A, and will therefore be mounted in exactly the same manner as shown in Figure 1. PLATO provides power and communications for the HEAT telescope and instrument. The total power budget for HEAT is maximally 500 W, which is readily provided by efficient, high reliability generators within PLATO. The second HEAT telescope on Ridge A will stand alone on stilts, with a built-in reduced set of PLATO electronics modules: power distribution, solar panels, Iridium communication, optical cameras, and supervisor control modules. A trade study to select a very minimal power generator for low power (100W) midwinter operation will be performed at Arizona and UNSW in Years 1 and 2, respectively. Data transfer and control of HEAT will be done via satellite and is described in more detail in Section 3.3.5. UNSW will participate fully in HEAT's design, integration, deployment, and operation.

3.2 *Telescope*

The telescope is designed to have maximum simplicity and the minimum number of optical components. The design draws heritage from the successful `Pre-HEAT` telescope currently at Dome A. Incoming light is reflected horizontally off a 45°, 0.6×0.85 m f/1.9 off-axis parabolic mirror. The converging beam passes through an HDPE lens to match the Gaussian beam propagating from the Schottky receiver feedhorns. The primary mirror will be fabricated from aluminum on a numerical milling machine and will achieve a surface roughness $\leq 3\,\mu$m rms. Elevation slewing is achieved by rotating the primary. From Dome A, the Galactic Plane can be mapped purely with sidereal-rate scanning. The absolute pointing accuracy will be better than 30″, about 1/3 of the smallest diffraction-limited beam. The telescope cost estimate includes fabrication, testing of the telescope and drive system, and is provided in the budget.

To prevent ice accumulation, the telescope window can be warmed to 5°C above ambient by resistive heaters controlled by PLATO. A small fan inside the HEAT enclosure prevents frost from accumulating on the inside of the window. Additional passive and active resistive heating inside the PLATO instrument module keeps the HEAT receiver module and electronics at -40°C or warmer. A small radome made of a low-loss dielectric (HDPE) film encircles the primary mirror. This optical configuration provides an unobstructed view of the sky.

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 stable in operation and **can operate at ambient temperature**. In contrast, SIS and HEB receivers require cooling to near LHe temperatures (4K). HEAT's critical need for robust technologies that will work at low power and in a **harsh environment that is unattended for at least a year at a time** 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 two at 810 GHz. The 1.5 THz Schottky receiver system will come from JPL via an internally-funded program. 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 ∼80K using economical, low power, commercial Stirling-cycle cryocoolers such as those sold by Sunpower, Inc. In this manner we will achieve a solid blend of good sensitivity and experimental robustness. We anticipate delivered cooled DSB receiver noise temperatures in the vicinity of 2000K at 0.8 THz, 4000K at 1.4 THz and 6000K at 1.9 THz. A future 4K cryocooled SIS and HEB receiver system for HEAT is in development at the Space Research Organization of the Netherlands (SRON). A wire grid, wound at the University of Arizona, will direct the horizontal and vertical polarization components of the incoming telescope beam from the primary mirror into the 0.8 THz and (either 1.5 THz or 1.9 THz) mixers.

3.3.2 IF Processor

The entire IF processing and spectrometer system will be leveraged from the successful design being implemented in SuperCam (the PI's 64-pixel, 345 GHz array receiver). Funds will only be needed to rework the 8-channel prototype IF processor from SuperCam for operation with 1 GHz of output bandwidth. In order to simultaneously detect the CO J=7→6 and [C I] lines in separate sidebands, the 0.8 THz mixer will have an IF center frequency of 1.5 GHz and then be upconverted to 5 GHz to match the other channels for subsequent IF processing. Low-noise 5 and 1.5 GHz IF amplifiers are readily available. An additional circuit provides total-power measurements of the IF power for telescope pointing and continuum measurements.

3.3.3 FFT-in-FPGA Spectrometer

The HEAT Galactic Plane surveys require both fine kinematic resolution (1 MHz) to disentangle cloud components and wide instantaneous bandwidth (≥ 1 GHz) to span the velocity dispersion of the Galaxy. **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 board with 2-IF inputs. For each IF input the spectrometer board provides 1 GHz of instantaneous bandwidth at 1 MHz resolution. The resulting velocity coverage (up to 370 km/s at a resolution ≤ 0.4 km/s) enables all three lines to be resolved and observed throughout the Milky Way. Omnisys Inc. has already designed and delivered 8 of these boards for the PI's Supercam array project, which perform admirably. The measured Allan variance (stability) time is 650 seconds when using a 5 GHz noise source that has been downconverted through the Caltech IF processor board. Funds are requested to purchase two additional boards for the HEAT telescopes (see quote from Omnisys).

3.3.4 Calibration

HEAT will be able to calibrate observations through several means. 1) A two-temperature absorbing load will be located below (and accessible by) the primary mirror, 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) An FTS will be deployed to Dome A in 2009-10 by a collaboration between Purple Mountain Observatory (China) and the Smithsonian Center for Astrophysics (S. Paine), and will provide the best mechanism by which the opacities from 0.8-2 THz can be referenced to each other.

3.3.5 Control System and Communication

The HEAT control system consists of several subsystems; the telescope drive system, receiver frontend (*e.g.* mixers, LOs, and cryostat) computer, and backend (spectrometer) computer. The subsystems communicate via SPI, CAN and I^2C digital buses, whereas communication to the PLATO supervisor is done through TCP/IP over ethernet. The subsystem control is based on embedded computers with ARM processors that draw less than 2 watts of power, run the open-source NetBSD operating system, and have been field-tested to survive the cold. These systems provide full control over the various electronic subsystems in HEAT. Like Pre-HEAT, HEAT will be designed to work autonomously, performing programmed observational programs and storing astronomical and housekeeping data in 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 PLATO "supervisor" board. Raw data will be recovered from HEAT each year during maintenance and processed into the released data products.

3.4 Integration and Testing

The use of already-developed subsystems in HEAT allows system integration and testing to be performed in a timely manner. A testing schedule is provided in Figure 10. *Cold component testing* will be used to determine limiting temperatures for reliable operation of constituent components in each subsystem. *Subsystem testing* will demonstrate the proper functionality of large components of the HEAT system, whereas *Integrated system testing* involves the interplay of subsystems in the actual collection of data. Finally, *Failure Mode testing* involves the intentional disabling of a component to observe the fault handling and interplay of the hardware and software systems.

The combination of Schottky diode receivers, interchangable computer control subsystems, redundant Iridium communication links, watchdog reset systems, solar power generation with diesel generator backup, and largely fixed, stable, simple optics, all contribute to a highly **reliable and robust system**.

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. Collectively the HEAT team members represent many years of successful telescope and instrument development in Antarctica. Table 2 provides a listing of the roles and responsibilities of each member in the organization.

A schedule of key project milestones and tasks is provided in Figure 10. 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 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 PIs' (Walker/Kulesa) lab in spring 2010, starting with the 0.8 THz units, and finishing with the 1.5 and 1.9 THz receivers. The receiver module and telescope will then be shipped to the University of New South Wales, where an extended period of integration and testing with PLATO subsystems will occur. HEAT will then ship from Australia in October 2010, with deployment to Dome A in January 2011. The second HEAT telescope will be constructed on the very same annual schedule in 2011 and deployed to Ridge A at the end of that year.

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 bimonthly telecons and quarterly meetings (primarily through teleconferencing) between the PIs and Technical Leads (particularly Storey - PLATO and Hesler - Mixers). Annual meetings of the international collaboration (CCAA lead - L. Wang) will be scheduled to discuss requirements for Antarctic logistics before coordinating with respective agencies (i.e. USAP and PRIC). Student exchange between Arizona and Purple Mountain Observatory will be organized by the PIs and the science lead at PMO (J.Yang). This effort will give graduate students the opportunity to work at the partner institution, broadening their skill sets.

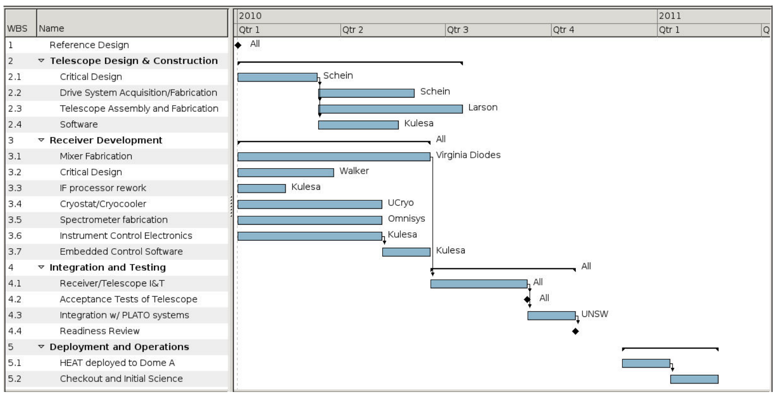

Figure 10: Example of first year timeline: one year of fabrication, integration and testing is followed by up to two years of survey work at Dome A. The second HEAT telescope will follow the same schedule in 2011, with a single year of survey work. Leverage of technologies from commercially available mixers and IF technologies from the Co-PI Walker's SuperCam instrument development makes this timeline achievable.

The ability to meet the proposed schedule is made possible by the heavy leveraging of IF processor and spectrometer technology funded through NSF/MRI for Supercam, the 64-beam heterodyne array receiver effort led by Co-PI Walker and assisted by PI-Kulesa. The aggressive schedule is also aided by the use of commercially-available mixer and cryogenic hardware. It should be noted that the same basic telescope and receiver subsystems were deployed to Dome A for the single-mixer `Pre-HEAT` telescope in 5 months from start-to-finish (June through October). Here, we are aiming for a 9 month deployment schedule, using the same basic designs, electronics, and software as Pre-HEAT. Furthermore, HEAT will be constructed by the same people who successfully constructed Pre-HEAT.

4.2 Logistics: Deployment to Dome A and Ridge A

Antarctic science has reached a level of maturity where several options exist for fielding instruments on remote sites. The successful deployment of PLATO and Pre-HEAT to Dome A is a clear demonstration of a working international collaboration. For Dome A and Ridge A, the best scenarios would respectively be:

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. HEAT could be installed to Dome A as part of the 2010-11 Chinese traverse or combined with air transport as described below (to be negotiated between USAP and CHINARE).
2. **Twin Otter Air Support**: HEAT has been designed to accomodate the limited cargo dimensions, weight, and volume of a Twin Otter aircraft. As Ridge A is an undeveloped site, we would depend on USAP Twin Otter flight(s) to Ridge A from South Pole Station or the nearby AGAP field camps to facilitate the HEAT installation and maintain the facility annually.

The nominal 1 year deployment of the second HEAT telescope to Ridge A should provide the first ground-truth comparisons between the two sites. The results of that comparison would then be used to determine upon which site future HEAT support efforts would be focused.

The HEAT team will work closely with the NSF, USAP, Raytheon Polar Services, and the International Community to implement an optimal plan for deployments to Dome A and Ridge A.

5 Educational Impact

The visage of the dusty lanes of the Milky Way has inspired artistic and scientific imaginations for generations. This inherent fascination is a powerful tool to attract "students" of all ages and callings to a better, more literate appreciation of the sciences. Thus, spreading enthusiasm for science and training the next generation of scientists is a significant component of this research program. Three examples of these efforts to be performed during the proposal performance period are outlined below.

5.1 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 Co-PI Walker'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 7 Ph.D. dissertations and numerous undergraduate research projects. HEAT is a natural extension of these research efforts. In the proposed budget for HEAT, funding for one graduate student in the summer is requested. However, as is customary in the 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 teamwork experience increases their probability of success. This is especially true for the HEAT project, where direct collaborations between students and faculty at universities in Australia, China, the UK, and the US will be ongoing.

5.2 Web-based Outreach

The broadest impact of the proposed research however may be drawn from the use of these surveys as educational and outreach tools. More people rely on the Internet for news, information, and entertainment than ever before; a trend which is unlikely to change soon. Thus, providing online outreach tools that are accessible and interesting is an excellent way of reaching a wide range of people. Distributed software should be operable on multiple platforms and be open source, so that others in the online community can embrace and extend what is provided within the confines of this study. A practical application would be to present a view onto the multi-wavelength Universe using existing planetarium software. For example, Stellarium (`http://www.stellarium.org/`) is a visually stunning, 3D, open source planetarium package for Unix/MacOSX/Windows. Writing a plugin to allow the user to put on different wavelength "glasses" to view the IRAS 100 μm sky instead – or spectroscopic images of CO J=1-0, [CII] or HI 21 cm emission, is an entirely tractable possibility and could be used to visualize the Galaxy in new ways. Such a tool would be very useful for instruction. Familiar with the Stellarium source code, PI-Kulesa would be responsible for implementing these visualization tools.

5.3 K-12 Outreach: A Student Radio Telescope

In support of education and public outreach activities, Co-PI Walker 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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