02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

Submit only ONE copy of this form **for each PI/PD and co-PI/PD** identified on the proposal. The form(s) should be attached to the original proposal as specified in GPG Section II.C.a. Submission of this information is voluntary and is not a precondition of award. This information will not be disclosed to external peer reviewers. ***DO NOT INCLUDE THIS FORM WITH ANY OF THE OTHER COPIES OF YOUR PROPOSAL AS THIS MAY COMPROMISE THE CONFIDENTIALITY OF THE INFORMATION.***

PI/PD Name: Craig A Kulesa

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☐ Not Hispanic or Latino

Race:
(Select one or more)

- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Disability Status:
(Select one or more)

- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☐

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
Race Definitions:
American Indian or Alaska Native. A person having origins in any of the original peoples of North and South America (including Central America), and who maintains tribal affiliation or community attachment.
Asian. A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam.
Black or African American. A person having origins in any of the black racial groups of Africa.
Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.
White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.

WHY THIS INFORMATION IS BEING REQUESTED:

The Federal Government has a continuing commitment to monitor the operation of its review and award processes to identify and address any inequities based on gender, race, ethnicity, or disability of its proposed PIs/PDs. To gather information needed for this important task, the proposer should submit a single copy of this form for each identified PI/PD with each proposal. Submission of the requested information is voluntary and will not affect the organization's eligibility for an award. However, information not submitted will seriously undermine the statistical validity, and therefore the usefulness, of information recieved from others. Any individual not wishing to submit some or all the information should check the box provided for this purpose. (The exceptions are the PI/PD name and the information about prior Federal support, the last question above.)

Collection of this information is authorized by the NSF Act of 1950, as amended, 42 U.S.C. 1861, et seq. Demographic data allows NSF to gauge whether our programs and other opportunities in science and technology are fairly reaching and benefiting everyone regardless of demographic category; to ensure that those in under-represented groups have the same knowledge of and access to programs and other research and educational oppurtunities; and to assess involvement of international investigators in work supported by NSF. The information may be disclosed to government contractors, experts, volunteers and researchers to complete assigned work; and to other government agencies in order to coordinate and assess programs. The information may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records", 63 Federal Register 267 (January 5, 1998), and NSF-51, "Reviewer/Proposal File and Associated Records", 63 Federal Register 268 (January 5, 1998).

02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

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PI/PD Name: Christopher K Walker

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☐ White

Disability Status:
(Select one or more)
☐ Hearing Impairment
☐ Visual Impairment
☐ Mobility/Orthopedic Impairment
☐ Other
☐ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
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Black or African American. A person having origins in any of the black racial groups of Africa.
Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.
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Collection of this information is authorized by the NSF Act of 1950, as amended, 42 U.S.C. 1861, et seq. Demographic data allows NSF to gauge whether our programs and other opportunities in science and technology are fairly reaching and benefiting everyone regardless of demographic category; to ensure that those in under-represented groups have the same knowledge of and access to programs and other research and educational oppurtunities; and to assess involvement of international investigators in work supported by NSF. The information may be disclosed to government contractors, experts, volunteers and researchers to complete assigned work; and to other government agencies in order to coordinate and assess programs. The information may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records", 63 Federal Register 267 (January 5, 1998), and NSF-51, "Reviewer/Proposal File and Associated Records", 63 Federal Register 268 (January 5, 1998).

List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 13-1		FOR NSF USE ONLY
NSF 12-589	11/15/13	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) AST - ASTRNMY & ASTRPHYS RES GRANTS		1410896

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
11/13/2013	1	03020000 AST	1678	806345617	11/13/2013 4:01pm

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☒ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)
742652689	0944335	

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
University of Arizona	TUCSON, AZ 857210001 US
AWARDEE ORGANIZATION CODE (IF KNOWN) 0010835000	

NAME OF PRIMARY PLACE OF PERF	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE
University of Arizona	University of Arizona 933 N. Cherry Ave Tucson ,AZ ,857210001 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)	☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION	☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS	☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Continuing operation of the HEAT telescope at Ridge A, Antarctica**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 273,715	24 months	10/01/14	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG I.G.2)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ________ PHS Animal Welfare Assurance Number ________
- ☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number ________ Exemption Subsection ________ or IRB App. Date ________
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) ________

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Astronomy	933 N. Cherry Ave Tucson, AZ 85721 United States
PI/PD FAX NUMBER 520-621-1532	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME Craig A Kulesa	PhD	2002	520-621-6540	ckulesa@email.arizona.edu
CO-PI/PD Christopher K Walker	PhD	1988	520-621-8783	cwalker@as.arizona.edu
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent) or Individual Applicant

By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding conflict of interest (when applicable), drug-free workplace, debarment and suspension, lobbying activities (see below), nondiscrimination, flood hazard insurance (when applicable), responsible conduct of research, organizational support, Federal tax obligations, unpaid Federal tax liability, and criminal convictions as set forth in the NSF Proposal & Award Policies & Procedures Guide,Part I: the Grant Proposal Guide (GPG). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

Conflict of Interest Certification

When the proposing organization employs more than fifty persons, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Conflict of Interest:
By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the organization has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Section IV.A;
that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the organization's expenditure of any funds under the award, in accordance with the organization's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent), is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:
(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.
(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certification Regarding Nondiscrimination

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:
(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:
(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

Certification Regarding Responsible Conduct of Research (RCR)
(This certification is not applicable to proposals for conferences, symposia, and workshops.)

By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research.
The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

CERTIFICATION PAGE - CONTINUED

Certification Regarding Organizational Support

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Federal Tax Obligations

When the proposal exceeds $5,000,000, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal tax obligations. By electronically signing the Certification pages, the Authorized Organizational Representative is certifying that, to the best of their knowledge and belief, the proposing organization:
(1) has filed all Federal tax returns required during the three years preceding this certification;
(2) has not been convicted of a criminal offense under the Internal Revenue Code of 1986; and
(3) has not, more than 90 days prior to this certification, been notified of any unpaid Federal tax assessment for which the liability remains unsatisfied, unless the assessment is the subject of an installment agreement or offer in compromise that has been approved by the Internal Revenue Service and is not in default, or the assessment is the subject of a non-frivolous administrative or judicial proceeding.

Certification Regarding Unpaid Federal Tax Liability

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal Tax Liability:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has no unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

Certification Regarding Criminal Convictions

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Criminal Convictions:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has not been convicted of a felony criminal violation under any Federal law within the 24 months preceding the date on which the certification is signed.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Mary Gerrow**	**Electronic Signature**	**Nov 13 2013 3:56PM**

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER
520-626-6433	**maryg@u.arizona.edu**	**520-626-4130**

* EAGER - EArly-concept Grants for Exploratory Research
** RAPID - Grants for Rapid Response Research

PROJECT SUMMARY

Overview:

Based on the results of an NSF-funded design study in 2006 and successful deployment in 2012, we propose to continue operating a robotic, 0.6-meter THz observatory at the summit of the Antarctic plateau with the dual purpose of performing site testing and leading-edge terahertz astronomy. The High Elevation Antarctic Terahertz (HEAT) telescope operates from 158 to 609 microns, and observes the brightest, most diagnostic spectral lines from the Galaxy. The (first) telescope was deployed in 2012 with the University of New South Wales' PLATeau Observatory (PLATO-R) to Ridge A, the driest, calmest and clearest point on the summit. The facility operates with no direct human contact for a year at a time between servicing missions, with commands and data being transfered to and from the experiment via satellite daily. The site is truly exceptional, and HEAT has made the most sensitive large-scale maps in the 370 micron line of neutral carbon, unveiling a substantial number of 'CO dark' molecular clouds and candidate regions in which molecular clouds may be forming. With an established facility and forward momentum, we propose here to operate the current instrument suite for one additional year, with a followup year devoted to data analysis, data dissemination, and publication. This effort is part of a longer term plan for the facility & site.

Intellectual Merit :

The HEAT telescope forges entirely new capabilities for ground based infrared and submillimeter astronomy which otherwise would be unachievable except via expensive airborne or space-based platforms. HEAT and PLATO-R represent a new generation of polar instrumentation that permits the excellent conditions available from remote sites like Ridge A to be harnessed without the costs and hazards associated with manned operations. The unparalleled stability, exceptional dryness, low wind and extreme cold make Ridge A a site without equal for astronomy at infrared and submillimeter wavelengths. HEAT operates in the atmospheric windows between 158 and 609 microns, in which the most crucial astrophysical spectral diagnostics of the formation of galaxies, stars, planets, and life are found. HEAT is in the process of addressing timely and fundamental questions about the evolution of the interstellar medium and star formation. In particular, through large-scale Galactic surveys, the measurement and impact of the Galactic environment on the life cycles of interstellar clouds and their relation to star formation are gradually being realized. Future upgrades of mixer, local oscillator, low-noise amplifier, cryogenic, and DSP technologies are planned and will play essential roles in future Terahertz observatories. This pioneering mission paves the way for future astronomical investigations from the high plateau.

Broader Impacts :

HEAT's key project is to map, with great sensitivity and precision, portions of the Southern Galactic Plane in the spectral light of the dominant coolants of the interstellar medium. Definitive and comprehensive science products from the survey and its synergistic collaborations are being made available to the astronomy & aeronomy community with no proprietary period. These survey products enhance the value of numerous contemporary surveys. Beneficiaries include Legacy programs from the Spitzer Space Telescope, Key Projects from Herschel, the most recent HI and CO surveys of the Galactic Plane, and the 2MASS & UKIDSS infrared sky surveys. The wide-field terahertz surveys provided by HEAT place Herschel, ALMA, SOFIA and balloon-borne observations in a broader, richer context. Thus, HEAT will serve both as a scientific and technological pathfinder for contemporary and future suborbital and space-based missions. As a portable, accessible terahertz observatory, HEAT transforms into an outstanding educational and outreach tool. The HEAT project uniquely captures the kind of high adventure spirit that attracts many to science in the first place, and we aim to provide video and photographic documentation of our experience for everyone, via PBS's NOVA program. Finally, the design and fabrication of HEAT has been an interdisciplinary team effort involving students from astronomy, optical sciences, and electrical engineering. Astronomical instrumentation is becoming ever more complex, requiring the talents of many individuals to bring them to fruition. Providing students with both technical training and team-work experience increases their probability of success, both in science and in society.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Project Description

1 Results from Prior NSF Support

1.1 High Elevation Antarctic Terahertz (HEAT) telescopes for Ridge A

1.1.1 Summary

In 2010, the PI initiated an NSF-funded (ANT-0944335, 10/2010-9/2014) program to build two 60 cm terahertz telescopes for robotic operation at the summit of the Antarctic high plateau with the dual purpose of site testing and performing leading edge terahertz astronomy. These High Elevation Antarctic Terahertz (HEAT) telescopes operate from 150 to 600 microns wavelength and observe the brightest and most diagnostic far-infrared lines in the Galaxy. An international collaboration with Australia's University of New South Wales provided the PLATeau Observatory for Ridge A (PLATO-R), a platform for power and satellite communication. In January 2012, PLATO-R and the first HEAT prototype were successfully deployed to Ridge A and have performed admirably. A servicing mission to Ridge A in which the second-generation HEAT telescope will be installed is scheduled for January 2014. HEAT is the world's first robotic THz telescope. It has the first cryogenic receiver system in the deep field that operates for a full year between servicing missions. HEAT is showing that the Ridge A site is the best site on the planet from which to perform terahertz observations, with $10\times$ more observing days suitable for 200 μm observations than Chajnantor (e.g. ALMA). Already, a preliminary public data release of 809 GHz (370 μm) data of atomic carbon J=2-1 line emission returned via Iridium satellite has been made available at `http://soral.as.arizona.edu/heat/`. Incremental followup data releases are expected 2 times per year for the duration of the program.

1.1.2 Activities

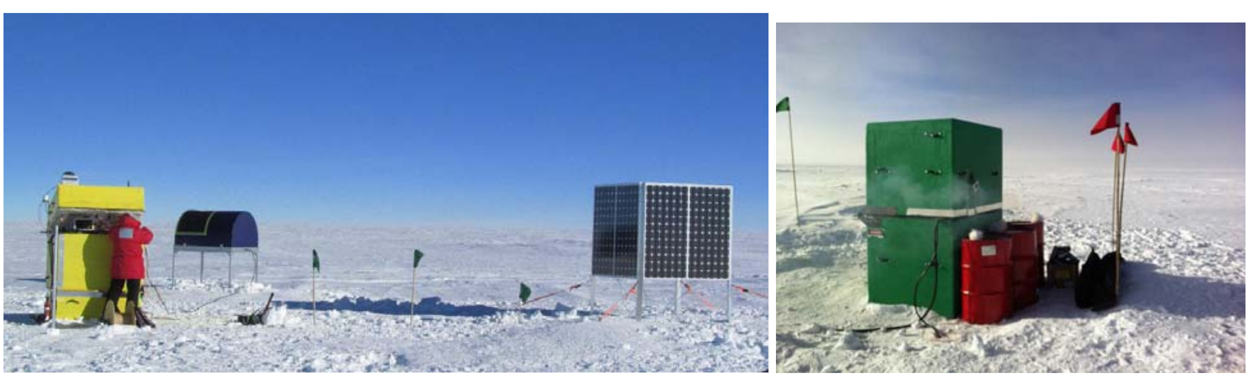

Figure 1: (left) A new far-infrared astronomical observatory was established on Ridge A, the inland summit of the polar plateau, as a joint collaboration between University of Arizona and the University of New South Wales in Australia in January 2012. Consisting of a (blue) High Elevation Antarctic Terahertz (HEAT) telescope and the (yellow and green) PLATeau Observatory (PLATO-R) instrument and engine modules, the observatory is designed to operate unattended for 12 months at a time.

The High Elevation Antarctic Terahertz (HEAT) telescope is forging 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. HEAT represents a true international pioneering effort between the US and Australia. The HEAT telescopes' key science project is a THz survey of the Galactic Plane observable from Antarctica in the CO J=7-6 and [CI] J=2-1 lines at 809 GHz, [NII] at 1461 GHz, and ultimately the [CII] line at 1900 GHz. Via spatially and spectrally-resolved 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**. These science goals are discussed further in Section 2. The initial proposal supports the HEAT telescopes through the first 2 full years of science operations at Ridge A, which lies about 110 miles inland from the Chinese Kunlun station at Dome A but at essentially the same elevation.

Figure 2: (left) The prototype 3-mirror off-axis Gregorian telescope, cryogenic receiver system and frozen PI are visible in this image. (right) Enclosed in a fiberglass shell and thin black HDPE "window" that is transparent to THz radiation, the HEAT telescope is ready for observations (January 2012).

For orientation, the facility is shown in Figures 1 and 2. It is comprised of:

- PLATO-R's yellow instrument module, which houses 20 kW hr of LiFePO4 batteries, power distribution electronics, supervisor computers, and Iridium modems and antennas. The roof of the instrument module has an all-sky camera and a 7-camera webcam system which streams hourly mosaics to the HEAT web page. The all-sky camera will be replaced in January 2014 with a thermal infrared sky monitor, designed and built by University of Arizona *undergraduate student* Casey Honniball for her independent study project.
- A 4-panel Solar Cube, which provides up to 800 W of solar power to the instrument module during the summer months.
- PLATO-R's green engine module, which houses 800 liters of AN8 fuel in an internal bladder and another 800 liters in external fuel barrels. Two diesel engines are housed inside the temperature-controlled module. One operates at a time to provide up to 1500 W of power to the instrument module during winter.
- The HEAT telescope is connected to the yellow instrument module by a 10-meter umbilical which supplies ethernet and power. HEAT is a 62 cm aperture off-axis Gregorian telescope.

Optically, it is comprised of 1) a 45-degree flat mirror which steers in elevation and represents the only moving part of the telescope, 2) an off-axis parabolic primary mirror, and 3) an elliptical camera mirror, which re-images the Gregorian focus to a small cryostat cooled to 50K by a Sunpower Cryotel CT Stirling cycle cryocooler. The initial deployment featured 809 and 492 GHz receivers for the fine structure lines of atomic carbon and will be swapped for 809 GHz and 1461 GHz receivers starting in January 2014.

- A 15-meter weather tower, instrumented with temperature and wind sensors.

Indeed, the design and philosophy behind HEAT and PLATO-R more closely resembles a space observatory than a typical ground based telescope. The program has been a remarkable success; since the beginning of the effort in October 2010, the team has:

1. Designed, constructed, and deployed an autonomous, robotic observatory for the most remote site on Earth, and among the most hostile and challenging environments, using a blend of solar and diesel power, to operate without physical human intervention for a year at a time.
2. Deployed cryocooled heterodyne receiver systems and telescopes at THz frequencies that operate for a year at a time between servicings, with an all-up power budget of less than 200 watts.
3. Developed and deployed an advanced telescope scheduling system that can autonomously execute an observing plan with little human involvement, with a 3 watt computing power budget using mobile phone ARM processors.
4. Developed and deployed a data processing system that can return fully-reduced spectroscopic maps of the 4th Galactic quadrant over the 'soda straw' bandwidth of an Iridium modem (2400 baud)... using the same mobile phone CPU.
5. Generated the deepest large-scale maps of the ISM in neutral carbon at 370 μm, with 205 μm ionized nitrogen arriving in 2014, and ultimately ionized carbon at 158 μm. By exploring molecular clouds and their environments in tracer species *other* than CO, HEAT will probe the entire carbon trail – and the full life cycle of interstellar clouds.
6. Provided the data products freely to the astronomical community after collection and calibration, with no proprietary period.

1.1.3 Site testing results

HEAT's sensitivity is owed 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. Figure 3 demonstrates the exceptionally **transparent** and **stable** conditions that are routinely available at Ridge A. To illustrate, HEAT measured 86 days in 2012 in which the daily mean opacity at 200 μm (1.5 THz) was below 1.5. In comparison, the APEX radiometer for 2012 indicated only 4 days for the Chajnantor Plain, and the best estimates for Cerro Chajnantor (CCAT) indicate 12 days. Ridge A is especially remarkable in that $>$10% of the year yields usable atmospheric transmission in the 150 micron window, containing the pivotal 158 μm ionized carbon line.

A tabular comparison of Ridge A to other well-known submillimeter sites is shown in Table 1. To the proposers' knowledge, the Ridge A results are the best measured anywhere from the ground. That such conditions are frequently realizable makes them even more remarkable.

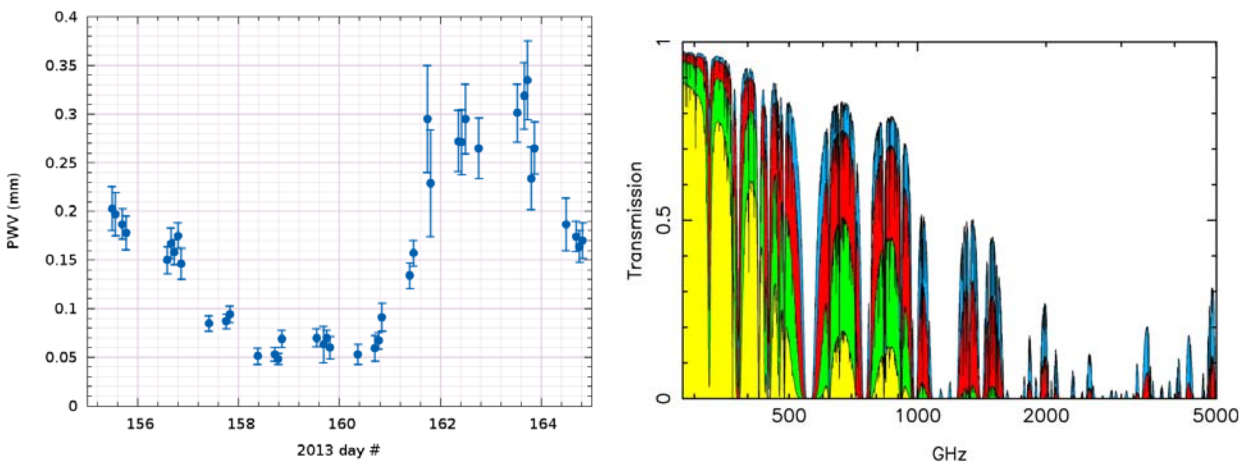

Figure 3: (left) A sample week of precipitable water vapor measurements from HEAT during winter 2013 shows an incredibly stable, transparent atmosphere, with a median winter PWV of 124 microns, and a best quartile of 87 microns! Such dry air leads to the upper-two (blue and red) transmission plots shown at right. The bottom two (green and yellow) curves represent the ALMA site and Mauna Kea, respectively. Ridge A opens entirely new atmospheric windows to routine observations from the ground.

Site	25%ile 50%ile winter PWV (mm)		Median winter transmission @660 GHz	Best 25% winter transmission @1500 GHz	Best 10% winter transmission @2000 GHz
	25%ile	50%ile			
Ridge A, 4040m	0.09	0.12	77%	41%	28%
South Pole, 2850m	0.23	0.32	52%	9%	1%
Plano Chajnantor, 5050m	0.35	0.60	47%	10%	2%
Mauna Kea, 4100m	1.0	1.5	15%	0%	0%

Table 1: *Comparison of Ridge A with other established submillimeter observing sites, based on 2012 HEAT data for Ridge A, 2012 radiosonde data for South Pole, and Chajnantor from 2012 APEX radiometer data, Mauna Kea from literature values (Delgado et al., 1999; Hogg, 1992).*

The high elevation, cold stable atmosphere and benign wind conditions at Ridge A **open the Terahertz windows to ground-based observatories and are unlikely to be matched anywhere else on Earth**. Thus, even with an initial deployment of cooled Schottky mixer receivers, HEAT's sensitivity to each spectral line is already scientifically competitive.

1.1.4 Astronomical Results

In the light of 370 μm (809 GHz) atomic carbon J=2-1 emission, HEAT has obtained high-fidelity strip maps of the Galactic Plane (Figure 4) as well as a high priority $1^o \times 0.6^o$ map at Galactic longitude 328^o (Figure 1) that are now publically available. With a 3-sigma rms noise level of 100 mK, these are the largest, most sensitive maps in the atomic carbon line to date.

Preliminary results of these data indicate that atomic carbon, while of lower surface brightness than CO, is more widespread and is only slightly less abundant on large scales. Since all [CI] emission stems from regions where hydrogen is molecular, this implies that a substantial fraction (at least 30%) of the molecular mass is not probed by CO emission, the so-called "CO-

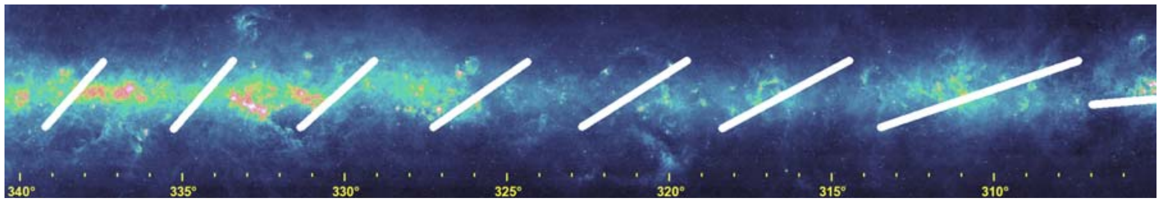

Figure 4: Eight of the fifteen Galactic strip maps observed by HEAT in 2012, atop a color-scale image of the MSX 8 micron infrared emission. To minimize telescope motion and maximize pointing accuracy, the maps are performed in drift scanning mode at constant azimuth and elevation, yielding strips of differing inclination when plotted atop the Galactic Plane.

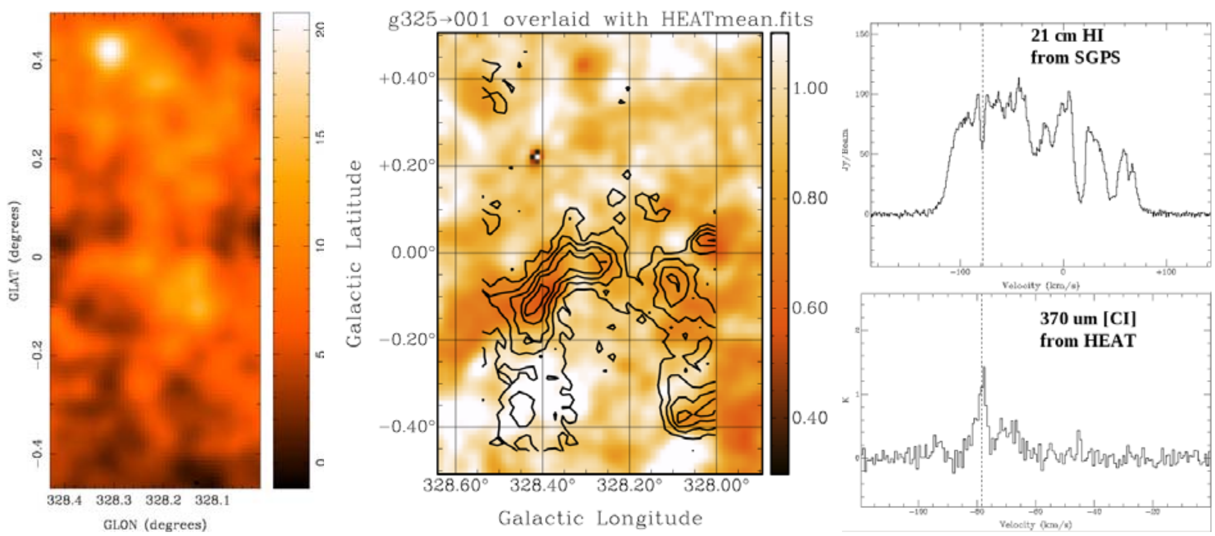

Figure 5: (left) Integrated intensity map of [CI] line emission toward l=328^o shows that diffuse atomic carbon emission fills the Galaxy and is nearly as abundant as CO. (center) The molecular gas shown by HEAT's detected line emission at -78 km/s V_{lsr} (contours) appears to be associated with self-absorption in the 21 cm HI line (color scale) at the same velocity. The high abundance of [CI] suggests that this molecular gas is chemically-young; it has not yet converted much of its elemental carbon to CO. Such a signature is indicative of a natal cloud. Establishing where these clouds are forming in a Galactic context is one of the primary goals of the HEAT telescope and one of the main motivations to extend its initial mission.

dark gas" (Grenier et al., 2005; Wolfire et al., 2010). (Kulesa et al. 2014, in preparation, see `soral.as.arizona.edu/heat` for latest publication updates).

Specific regions in the first square degree to be mapped by HEAT (at l=328^o) are already providing evidence of molecular cloud formation. [CI] appears to be well correlated with cold HI gas observed in absorption. A quiescent filament spanning 0.5 degrees on the sky is observed at -78 km/s V_{lsr} with high [CI] abundance relative to CO, suggestive of recent cloud formation. This work has been submitted to ApJ (Burton et al. 2014) and is currently being reviewed.

While excellent progress has been made, much of the effort to date has focused on the technological development of this pathfinding observatory, and only recently has shifted full-time to data product generation and scientific publication. **The goal of this proposal is to complete this transition: to maximize HEAT's scientific productivity by extending normal, stable operations for one year with no major instrument development, and providing for a follow-up year funded expressly for analysis and publication.**

2 Science Goals

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 6.

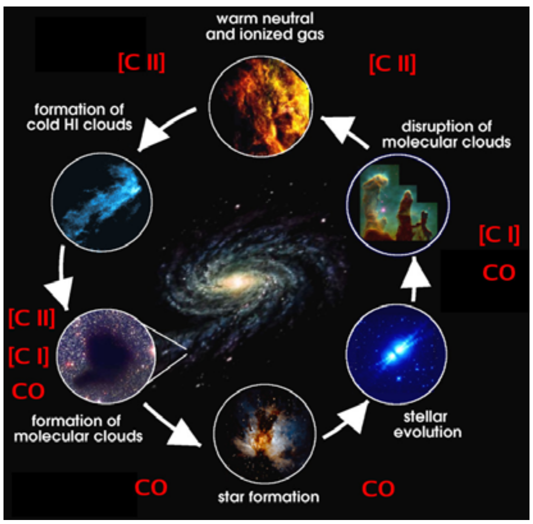

Figure 6: *The HEAT telescopes will ultimately observe the fine structure lines of [N II], [C II], [C I], and CO that probe the entire life cycle of interstellar clouds. In particular, HEAT will witness the transformation of neutral atomic clouds into star-forming clouds, the interaction of the interstellar 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. The most recent decadal survey, "Astro2010: New Worlds, New Horizons", specifically identifies the questions "*What controls the mass-energy-chemical cycles within galaxies*", "*how do stars form*", "*what determines the star formation rates and efficiencies in molecular clouds*", and "*what determines the properties of pre-stellar cloud cores and what is the origin of* the stellar mass function*" as among the key questions for radio and (sub)millimeter facilities in this decade. Further, the specific recommendation is made: **"A large-field mapper operating at millimeter and submillimeter wavelengths is required to pave the way for follow-up observations with ALMA"**. HEAT is a direct answer to this recommendation!

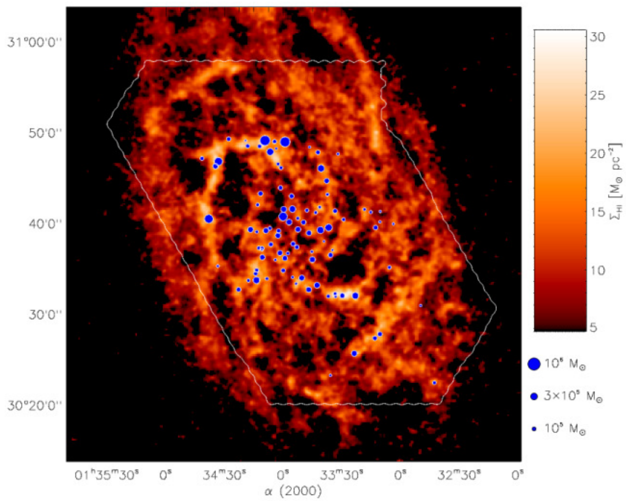

Figure 7: *The location of GMCs in the nearby spiral galaxy M33 are overlaid upon an integrated intensity map of the HI 21 cm line (Engargiola, Plambeck, Rosolowsky, & Blitz, 2003). These observations show that GMCs are formed from large structure of atomic gas, highlighting the detailed study of GMC formation that HEAT is providing in the Milky Way.*

2.2 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 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 7). 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.

2.3 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).

2.4 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 telescope address the scientific goals that have been illustrated?

2.4.1 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 SCUBA2 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.**

2.4.2 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 8 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 the cold neutral gas in the Galactic ISM is likely in this state (Wolfire et al., 2010), 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 [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.

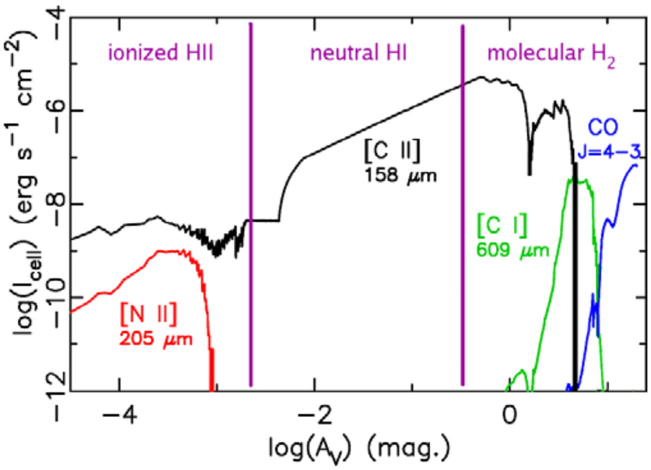

Figure 8: **The uniqueness of HEAT's [CI], [CII] and [NII] surveys.** *A model depiction of the intensity of diagnostic lines of carbon and nitrogen species as viewed through a UV-illuminated cloud from depths of A_V=0 to 20 mag. Vertical purple lines overlay the HII-to-HI-to-H_2 boundaries found at the edges of dense interstellar clouds. This figure demonstrates that [CII] and [CI] 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 ultimately provide a velocity-resolved large-scale mapping survey in all these species. For this proposal effort, the existing receiver systems at [CI], CO, and [NII] will be the main focus, with a 4K [CII] system arriving in the next instrumental development phase, beyond the proposed effort. HEAT will ultimately 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.

2.4.3 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 Ridge A ($0 > l > -100^o$); see Figure 9. However, for the initial implementation, using Schottky mixer receivers, an initial total of 40 square degrees is 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, and high luminosity portions of the LMC. 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" Spitzer Legacy program (Evans et al., 2003) and Herschel GOTC+ open time key program (Langer et al., 2010).

The remaining sky coverage in the Galactic Plane survey will be provided in the future by HEB mixers from SRON, using a cryocooled 4K system. This next-generation instrument development is beyond the scope of this proposal but planned for the 2016-19 timeline.

2.4.4 Synergies with Other Observatories

HEAT is timely. The Spitzer Space Telescope Legacy program GLIMPSE, and Herschel program Hi-Gal, provide 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 and cold 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 observed the [CII] line toward over 900 selected points in the Galactic Plane 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 400 times the areal coverage of "GOTC$^+$" during this proposal period, and could exceed the Herschel coverage in [CII] by a factor of 2-5 in a single season. 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. Multi-square-degree large-scale imaging with ALMA will be prohibitively time consuming but is a task effectively performed by single-dish telescopes like HEAT. Indeed, HEAT's Southern survey in atomic carbon, [NII] and high-J 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.

HEAT distinguishes itself from other small ground-based observatories such as 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 2.4.2). 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 with HEAT from Ridge A.

Finally, the reflight of the Stratospheric Terahertz Observatory (STO-2: 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], and [O I]. The STO-2 science flight will occur in late 2016 and will last for $\sim$2-4 weeks. Such flights can be repeated on 2-3 year timescales. HEAT plays an important role with respect to STO-2, which has a 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-2, which due to its trajectory has limitations in its sky coverage, HEAT is mapping the important southern Lupus, Carina, and Chamaeleon molecular cloud complexes, in addition to deeper, smaller scale maps of the Large Magellanic Cloud. HEAT and STO observations will therefore be coordinated to provide maximum science return (Figure 9).

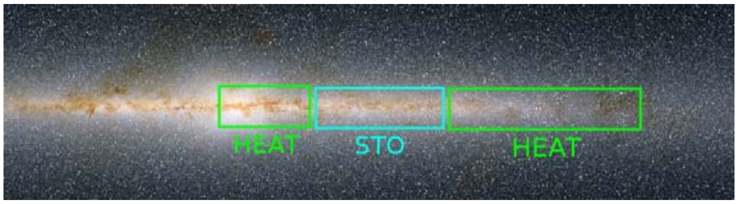

Figure 9: *Regions of the Galactic Plane from l=0 to l=-100, mappable by STO-2 and HEAT. The large scale HEAT survey will initially focus on [CI] and CO, with smaller maps performed in [NII] and eventually [CII].*

2.5 *Survey Activities*

2.5.1 *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 across a field while the backends are read-out at a sufficient rate to eliminate aliasing and beam smearing. This is the mode in which HEAT currently operates and no changes are planned.

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} $\sim$0.5. 25 square degrees distributed from $0 > l > -20^o$ and $-45 > l > -100^o$ will be mapped in $\approx$300 days.

2.5.2 *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. The most demanding storage requirements for the final 40 square degree maps, regridded to 45$''$ spacing, with 1024 spectral points per grid position, is less than 4 GB. This volume is 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 Austral summer release in November, and a final release of the previous season's data in March. 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/`

2.5.3 Roles of the Collaboration Participants

Participant	Affiliation	Participation Activity
Michael Ashley	UNSW	Advisor: PLATO-R operations and site testing
Michael Burton	UNSW	Advisor: Companion CO 1-0 Survey from the Mopra 22m
David Hollenbach	SETI	Advisor: ISM physics
Craig Kulesa	Univ. Arizona	PI, HEAT development and testing, ISM physics
Mark McCaughrean	ESA	Advisor: synergy with Planck and JWST
Christopher Walker	Univ. Arizona	Co-PI, leads student advising
Mark Wolfire	U. Maryland	Advisor: PDR modeling
Abram Young	Univ. Arizona	Lead: annual HEAT servicing mission

Table 2: Activities of the HEAT Science Team

Personnel initially using HEAT comprise the Science Team tabulated in Table 2. *Both graduate and undergraduate students are participating in both the instrument development and science study.*

3 Project Management

3.1 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 of each member in the organization.

A schedule of key project milestones and tasks is provided in Figure 10. In January 2015, the [CI] and [NII] receiver will be swapped in the field and HEAT will begin a second year of operations at these two frequencies. 2015 will feature publication and distribution of the 2014 data, and in turn, the 2015 data will be released and published in 2016.

Transitioning HEAT from an instrument development effort to a scientific workhorse is an exciting prospect that our team has been working towards for years. Collectively the HEAT team members represent many years of instrument building, observing experience, and theoretical expertise. As related by Table 2, the main components of the organization are the PI, who has overall responsibility for the project and coordinates the activities of the participants; Co-PI Walker who shares in these responsibilities and lead the student advising efforts; and the distributed members of the science team who act as an advisory council to the PI and Co-PIs to ensure that the project stays on course. A schedule of key project milestones and tasks is provided in Figure 10. Routine communications between project participants is essential. There will be monthly science team telecons to monitor progress and provide insight into solutions to emerging problems, and redefine priorities as needed. A HEAT wiki at Arizona will provide a resource for team communications and documentation.

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

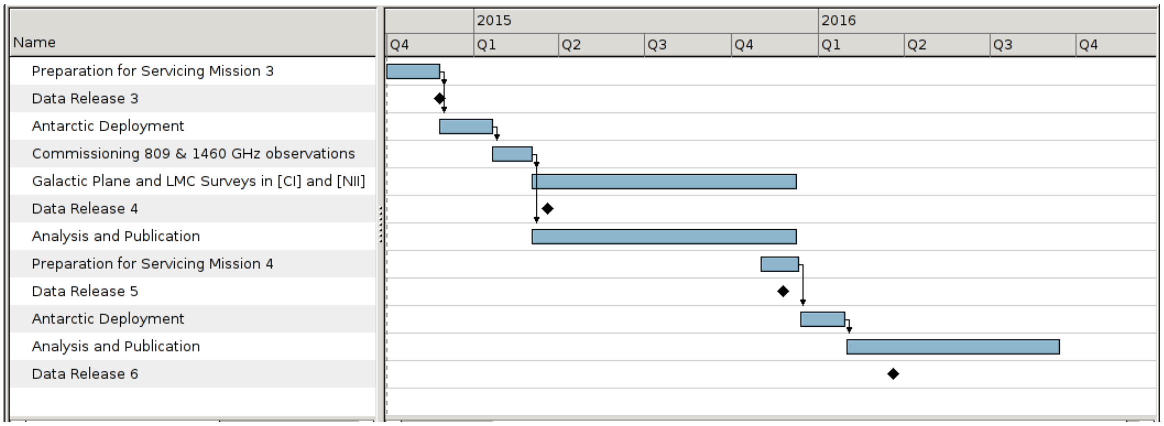

Figure 10: High level project timeline

Note that without an active NSF program, e.g. this proposed project, we cannot continue to operate HEAT and will have to disassemble and retrograde the experiment. We cannot service it without NSF and USAP logistical backing, nor are we allowed to "pause" and leave it on the plateau, by the Antarctic Treaty.

4 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.

4.1 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 9 Ph.D. dissertations. Numerous undergraduate research projects have also resulted; the most recent and relevant to this effort is an infrared sky brightness monitor (for site testing) designed and built by Casey Honniball as part of her independent study research. HEAT is a natural extension of these research efforts. In the proposed budget for HEAT, partial funding for one graduate student 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 team-work 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 and the US will be ongoing.

4.2 HEAT: A Portable, Accessible THz Telescope for Education

Two HEAT telescopes and receivers were constructed, so that one would be swapped with the other in the field, allowing one to be in operation at Ridge A while the other is refurbished at Arizona. The 'off duty' HEAT telescope remains a complete facility: with heterodyne receiver, IF processor, FFT spectrometer, and data system. However its portability and accessibility makes it particularly ideal for education: it is "ALMA in a box". We propose to use the 'off duty' telescope in support of education and public outreach activities. Roof-top astronomical observations in CO J=1-0 from campus, and 492 GHz [CI] observations during the best spring and fall weather on Mt. Lemmon (9157' elevation) would be undertaken by undergraduate and graduate students to gain expertise in terahertz astronomy and astronomical spectroscopy. Unlike optical telescopes, HEAT can be used day and night, on-site or remote, making it ideal for classroom instruction. 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. We will exploit the 'off duty' telescope as a hands-on demonstrative laboratory with the goal of providing students with an intuitive understanding of underlying physical concepts.

4.3 Development of a NOVA ScienceNow video

Reception of public blogs during HEAT's annual deployments is positive and popular. Indeed, the overall experiment and particularly the human story of deployment to Ridge A captures the kind of 'high adventure' spirit that drives many young individuals to science in the first place – but which many scientific programs do not advance. Many of us gained our scientific awareness and creative excitement through programs like PBS's NOVA, and it would seem only appropriate for us to work to collect the videographic and photographic materials needed to produce a short science video highlight for the program. Initial interest in this development at PBS was highly favorable and would be explored for the 2014-15 deployment to Ridge A.

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Professional Preparation

Ph.D., Astronomy	December 2002	The University of Arizona
B.S., Physics	June 1993	Miami University (Ohio)

Appointments

2012-	Associate Astronomer University of Arizona
2006-	Assistant Astronomer University of Arizona
2003-2006	Assistant Staff Scientist University of Arizona
1998-2002	Research Assistant (Science and Instrumentation) University of Arizona
1994-1996	Research Assistant (Science) University of Arizona

Selected Papers

1. "Large Scale CO and [CI] Emission in the Rho Ophiuchi Molecular Cloud", Kulesa, C.A., Hungerford, A.L., Walker, C.K., Zhang X., & Lane, A., 2005, ApJ, 625, 194
2. "Warm, Dense Molecular Gas in the ISM of Starbursts, LIRGs, and ULIRGs", Narayanan, D., Groppi, C. E., Kulesa, C. A., & Walker, C. K. 2005, ApJ, 630, 269.
3. "Millimeter and Submillimeter Survey of the R Coronae Australis Region", Groppi, C. E., Kulesa, C., Walker, C., & Martin, C. L. 2004, ApJ, 612, 946
4. "Exceptional Terahertz Transparency and Stability Above Dome A, Antarctica", Yang, H. & Kulesa, C. A., et al. 2010, PASP, 122, 490
5. "Abundances of H_2, H_3^+ & CO in Dark Molecular Clouds", Kulesa, C. A. & Black, J. H. 2012, ApJ, submitted

Selected Related Papers

1. "Pre-HEAT: Submillimeter Site Testing and Astronomical Spectra from Dome A, Antarctica", Kulesa, C.A, et al., Proc SPIE 7012, 545 (2008).
2. "Deep Near-Infrared Observations of L 1014: Revealing the Nature of the Core and its Embedded Source", Tracy L. Huard et al., 2006, ApJ, 649, 391.

3. “The Youngest T Tauri Star - the Sudden Appearance of Mcneil’s Nebula”, Rettig, T. & S. Brittain, E. Gibb, T. Simon & C. Kulesa, 2005, ApJ, 626, 245.

4. “CO Line Emission and Absorption from the HL Tau Disk - Where is all the dust?”, Brittain, S., T. Rettig, T. Simon & C. Kulesa, 2004. ApJ, 2005, 626, 283.

5. “SuperCam: a 64-pixel heterodyne imaging array for the 870-micron atmospheric window”, Groppi, C., Walker, C., Kulesa, C., Puetz, P., Golish, D., Gensheimer, P., Hedden, A., Bussmann, S., Weinreb, S., Kuiper, T., Kooi, J., Jones, G., Bardin, J., Mani, H., Lichtenberger, A., Narayanan, G., 2006, Proc. SPIE, vol 6275, 62750O.

Synergistic Activities:

- Dissemination of research results to the wider public by lectures and presentations, e.g. through Steward Observatory programs, student organizations, and primary/secondary schools.
- Development of new techniques for molecular cloud modeling of physical structure, chemistry, radiative transfer and dynamics.
- Development of infrared and submillimeter survey data and science products for ecological studies of the Milky Way

Instrumentation Experience Relevant to this Proposal:

1. PI of *HEAT*, an automated 0.6-meter terahertz telescope with 0.5-2 THz heterodyne receivers deployed in January 2012 to Ridge A, Antarctica, the best site on Earth for far-IR astronomy.
2. Deputy-PI of the *Stratospheric Terahertz Observatory* (STO), a balloon borne experiment to explore the life cycle of the ISM.
3. Deputy-PI of *Supercam*, a 64-beam, 345 GHz heterodyne receiver to be deployed at the 10-meter HHT telescope in Arizona. Responsibilities focus on the I&T of IF processor and spectrometer, system level testing, telescope integration, data system.
4. Constructed *ARIES*, the Arizona Infrared Imager and Echelle Spectrometer, for the adaptive optics secondary at the 6.5-meter MMT. Aside from NIRSPEC at Keck, ARIES is the only cross-dispersed NIR echelle spectrometer in the northern hemisphere.

Collaborations, 2010-2012:

J. Bieging (Arizona)	S. Brittain (Clemson)	D. Chuss (NASA/GSFC)
C. Groppi (Arizona)	D. Hollenbach (NASA-Ames)	T. Huard (CfA)
A. Lane (Harvard/CfA)	D. McCarthy (Arizona)	G. Narayanan (UMass/Amherst)
G. Novak (Northwestern)	T. Rettig (Notre Dame)	T. Simon (Hawaii)
A. Stark (Harvard/CfA)	C. Walker (Arizona)	M. Wolfire (Maryland)

Ph.D. Advisors:

Christopher K. Walker (Arizona)
John H. Black (Onsala Space Observatory)

Ph.D. Advisees:

Abigail Hedden (2007, Univ. of Arizona)
Desika Narayanan (2007, Univ. of Arizona)

Christopher K. Walker
Steward Observatory, University of Arizona, Tucson, AZ 85721

Education

B.S.: Electrical Engineering, Clemson University, 1980
Graduated with Honors
M.S.: Electrical Engineering, Ohio State University, 1981
Advisor: John D. Kraus
Thesis: "Upgrading the Ohio State Radio Observatory"
Ph.D.: Astronomy, University of Arizona, 1988
Advisor: Charles J. Lada
Thesis: "Observational Studies of Star Forming Regions"

Experience

- Professor of Astronomy and Optical Sciences, Associate Professor of Electrical Engineering, University of Arizona, 2003-
- Associate Professor of Astronomy, Optical Sciences, and Electrical Engineering, University of Arizona, 2002-2003
- Associate Professor of Astronomy & Optical Sciences, University of Arizona, 2000-2002
- Associate Professor, Steward Observatory, University of Arizona, 1997-2000
- Assistant Professor, Steward Observatory, University of Arizona, 1991-1997
- Millikan Research Fellow in Physics, Caltech, 1988-1991
- Graduate Research Assistant, Steward Observatory, 1983-1991
- Research and Development Engineer, Jet Propulsion Laboratory, 1983
- Electrical Engineer, TRW Aerospace Division, 1981-1983

Publications

5- Recent Closely Related Publications

Bussmann, R. S., Wong, T. W., Hedden, A., Kulesa, C., and Walker, C. K., 2007, *A CO (J=3-2) Outflow Survey of the Elias 29 Region, Ap.J.,* 657, Issue 1, pp. L33-L36.
Hedden, A. S., Walker, C. K., Groppi, C. E., and Butner, H. A., 2006, Star *Formation in the Northern Cloud Complex of NGC 2264*, *Ap.J.*, **645**, p.345.
Kulesa, C., Hungerford, a., Walker, C., Zhang, X., and Lane, A., 2005, *Large-Scale CO and [CI] Emission in the Rho Ohiuchi Molecular Cloud, Ap. J.,* **625**, 194.
Stark, A., Martin, C., Walsh, W., Xiao, K., Lane, A., and Walker, C., 2004, "*Gas Density, Stability, and Starbursts near the Inner Lindblad Resonance of the Milky Way*", *Ap.J.*, **614**, Issue 1, pp. L41-L44.
Martin, C., Walsh, W., Xiao, K., Lane, A., and Stark, A., 2004, *The AST/RO Survey of the Galactic Center Region. I. The Inner 3 Degrees, Ap.J.S.,* **150**, 239.

5- Additional Publications

Narayanan, D., Kulesa, C., Boss, A., and Walker, C. K., 2006, *Molecular Line Emission from Gravitationally Unstable Protoplanetary Disks, Ap.J.*, **647**, Issue 2, pp. 1426-1436
Narayanan, D., Cox, T., Robertson, B., Dave', R., Di Matteo, T., Hernquist, L., Hopkins, P., Kulesa, C., and Walker, C. K., 2006, *Molecular Outflows in Galaxy Merger Simulations with Embedded Active Galactic Nuclei*, *Ap.J.*., 642, Issue 2, pp. L107-L110.
Groppi, C., Kulesa, C., Walker, C., and Martin, C., 2004, *Millimeter and Submillimeter Survey of the R Coronae Australis Region*, *Ap. J.,* **612**, 946.
Narayanan, G., Moriarty-Schieven, G., Walker, C.K., and Butner, H.M. 2002, *Detection of Infall Signatures Towards SMM4, Ap.J.*, **565**, 319.
Melia, F., Bromley, B., Liu, S., and Walker, C.K. 2001, *Measuring the Black Hole Spin in Sag A**, *Ap. J. Letters*, **554**, 37.

Synergistic Activities

1) Prof. Walker's lab the led efforts to construct the world's first 810 and 345 GHz heterodyne array receivers and helped developed one of the first 1.5 THz HEB receiver systems for radio astronomy.
2) Instruments developed by Prof. Walker's team have served as primary facility instruments at the Heinrich Hertz Telescope and the AST/RO telescope at the South Pole for over a decade.
3) Funded by the NSF, Prof. Walker has led the effort to design and build the world's largest (64 pixels) submillimeter-wave heterodyne array receiver (SuperCam).
4) He is PI of the NASA funded long duration balloon project ``The Stratospheric THz Observatory (STO)''.
5) Prof. Walker has served as dissertation director for nine Ph.D. students (7-Astronomy and 2-Optical Sciences).

Recent Collaborators (48 Months)

Pietro Bernasconi (JHAPL), Christopher Groppi (ASU), Karl Jacobs (U. Cologne), Craig Kulesa (UofA), Arthur Lichtenberger (UVa), Carey Lisse (JHAPL), David Neufeld (JHU), Gordon Stacey (Cornell), Paul Goldsmith (JPL), William Langer (JPL), David Hollenbach (SETI Institute), John Kawamura (JPL), Christopher Martin (Oberlin College), Antony Stark (SAO), Jeffrey Stern (JPL), Juergen Stutzki (U. Cologne), Sander Weinreb (CIT/JPL), Mark Wolfire (U. Maryland), Harold Yorke (JPL), Eric Young (USRA).

M.S.E.E. Graduate Advisor: John D. Kraus, OSU
Ph.D. Advisor: Charles J. Lada, SAO
Postdoctoral Advisor (Millikan Fellowship in Physics): Thomas G. Phillips, CIT

Ph.D. Advisees: Grace Wolf (Hansen Planetarium), Jason Glenn (UC Boulder), Gopal Narayanan (U. Mass), Craig Kulesa (UofA), Christian d'Aubigny (Teravision Inc.), Christopher Groppi (UofA), Desika Narayanan (CfA), Abigail Hedden (SAO), Dathon Golish (Teravision Inc.)

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION **University of Arizona**			FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Craig Kulesa**			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Craig A Kulesa - Associate Astronomer**	6.00	0.00	0.00	**29,065**	
2. **Christopher K Walker - Professor**	0.00	0.00	0.50	**5,333**	
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**2**) TOTAL SENIOR PERSONNEL (1 - 6)	6.00	0.00	0.50	**34,398**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	**0**	
2. (**1**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1.00	0.00	0.00	**5,579**	
3. (**1**) GRADUATE STUDENTS				**15,087**	
4. (**2**) UNDERGRADUATE STUDENTS				**2,400**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**57,464**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**21,054**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**78,518**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**2,300**	
2. FOREIGN				**1,500**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**620**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**2,640**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**8,700**	
TOTAL OTHER DIRECT COSTS				**11,960**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**94,278**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC base (Rate: 51.5000, Base: 86735)**					
TOTAL INDIRECT COSTS (F&A)				**44,669**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**138,947**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**138,947**	
M. COST SHARING PROPOSED LEVEL $ **0**	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME **Craig Kulesa**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Mary Gerrow**	Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION **University of Arizona**			FOR NSF USE ONLY		
			PROPOSAL NO.	DURATION (months)	
				Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Craig Kulesa**			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Craig A Kulesa - Associate Astronomer**	6.00	0.00	0.00	**30,024**	
2. **Christopher K Walker - Professor**	0.00	0.00	0.50	**5,509**	
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**2**) TOTAL SENIOR PERSONNEL (1 - 6)	6.00	0.00	0.50	**35,533**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	**0**	
2. (**1**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1.00	0.00	0.00	**5,763**	
3. (**1**) GRADUATE STUDENTS				**15,585**	
4. (**2**) UNDERGRADUATE STUDENTS				**2,479**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**59,360**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**21,749**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**81,109**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**2,376**	
2. FOREIGN				**1,550**	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ **0** 2. TRAVEL **0** 3. SUBSISTENCE **0** 4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**120**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**2,727**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**3,723**	
TOTAL OTHER DIRECT COSTS				**6,570**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**91,605**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC base (Rate: 51.5000, Base: 83812)**					
TOTAL INDIRECT COSTS (F&A)				**43,163**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**134,768**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**134,768**	
M. COST SHARING PROPOSED LEVEL $ **0**	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME **Craig Kulesa**	FOR NSF USE ONLY		
	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Mary Gerrow**	Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION: University of Arizona				FOR NSF USE ONLY — PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Craig Kulesa				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. Craig A Kulesa - Associate Astronomer	12.00	0.00	0.00	59,089		
2. Christopher K Walker - Professor	0.00	0.00	1.00	10,842		
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0		
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	12.00	0.00	1.00	69,931		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0		
2. (2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	2.00	0.00	0.00	11,342		
3. (2) GRADUATE STUDENTS				30,672		
4. (4) UNDERGRADUATE STUDENTS				4,879		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				116,824		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				42,803		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				159,627		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				0		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				4,676		
2. FOREIGN				3,050		
F. PARTICIPANT SUPPORT COSTS						
1. STIPENDS $ 0						
2. TRAVEL 0						
3. SUBSISTENCE 0						
4. OTHER 0						
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				740		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				5,367		
3. CONSULTANT SERVICES				0		
4. COMPUTER SERVICES				0		
5. SUBAWARDS				0		
6. OTHER				12,423		
TOTAL OTHER DIRECT COSTS				18,530		
H. TOTAL DIRECT COSTS (A THROUGH G)				185,883		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)						
TOTAL INDIRECT COSTS (F&A)				87,832		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				273,715		
K. RESIDUAL FUNDS				0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				273,715		
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					

PI/PD NAME: Craig Kulesa	FOR NSF USE ONLY		
	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*: Mary Gerrow	Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

BUDGET JUSTIFICATION

A. SENIOR PERSONNEL

6.0 calendar month of salary per year is requested for PI Craig Kulesa. His base salary is $58,131 per 12-month fiscal year.

0.5 summer month of salary per year is requested for Co-PI Christopher Walker. His base salary is $92,582 per 9-month academic year.

1.0 calendar month of salary per year is requested for Servicing Mission Lead, Abram Young. His base salary is $72,800 per 12-month fiscal year.

B. OTHER PERSONNEL

Partial funding for 2 years is requested for one graduate student (base salary $30,175) engaged in Ph.D. thesis research under this project. One semester of academic year support, plus 50% summer salary is requested.

200 hours of undergraduate student research support is requested each year (base rate $12/hour).

C. FRINGE BENEFITS

The following university-approved fringe benefit rates were applied to each labor category:

- Faculty/Appointed Personnel: 30.0%
- Graduate Students: 59.5% composed of:
  - 9.5% for health/dental/life insurance
  - 50.0% for tuition remission (exempt from indirect cost charges)
- Undergraduate Students: 3.5%

D. CAPITAL EQUIPMENT

None requested.

E. TRAVEL

Domestic

Funds are requested for one domestic conference (typically AAS, SPIE, or SCAR) for two personnel (typ. one graduate student and one mentor) for five days each year. Travel funds requested include roundtrip airfare (@ $400/trip), lodging (@ $100/night), and per diem (@ $50/day). Conference registration fees are detailed under 'Other Direct Costs' in accordance with University of Arizona cost classification practices.

International

To support the annual servicing mission to Antarctica, travel funding support for per diem (@$50 USD/day) and lodging (@$100 USD/day) is requested for 2 personnel for 5 days in Christchurch, New Zealand.

F. OTHER DIRECT COSTS

Funds are requested in each year for research supplies and work-flow/data capture and telecommunications expenses required for the conduction of this investigation. These operational items represent the material costs of creating, replicating, archiving, distributing and presenting all project related data, documentation, reporting, and analysis that are directly related to this project. Such material costs include external disk drives, poster printer costs, and analysis and presentation software.

Funds are requested for minor electronics repairs to the HEAT telescope. Costing is estimated from the replacement costs of repairs during the first two years of operating HEAT at Ridge A, including replacement of instrument control computers, solid state storage, and power supplies.

Funds are requested in year 1 for possible refurbishment and/or repair of one of HEAT's two receiver systems at Virginia Diodes, Inc. The costs listed are averaged on actual costs incurred over the last two years of operation. Repair of the 810 GHz receiver is $3800 and the 1460 GHz receiver is $6000.

Funds are requested for two conference registrations per year, typically one student and one mentor.

Funds are requested for publication of findings in professional journals each year; estimated at 3 papers of 8 pages per year @ $110/page (Astrophysical Journal).

Shipping charges for equipment to/from Antarctica (commercial surface shipping to Port Hueneme, CA or air freight to Christchurch, New Zealand) is estimated at $3000 USD annually, based directly on the average shipping cost incurred during the last two years of operation.

G. INDIRECT COSTS

The university-mandated indirect cost rate of 51.5% was applied to all costs except capital equipment and 50.0% of the graduate student fringe benefit rate, which is for tuition remission and exempt from IDC.

*A cost inflation rate of 3.3% per year is applied to all eligible costs for year 2.

CRAIG A KULESA, PI
The University of Arizona, Steward Observatory

CURRENT AWARDS as Principal Investigator

Project Title:	High Elevation Antarctic Terahertz (HEAT) Telescopes for Dome A and Ridge A
Source of Support:	NSF 0944335
Project Location:	The University of Arizona
Total Award Amount:	$1,480,000
Start and End Date: (MM/DD/YY)	10/01/2010 – 09/30/2014
Months Committed to the Project:	6 months per year

CURRENT AWARDS as Co-Investigator

Project Title:	Reflight of the Stratospheric Terahertz Observatory (STO-2)
Source of Support:	NASA APRA
Project Location:	The University of Arizona
Total Award Amount:	$4,400,000
Start and End Date: (MM/DD/YY)	1/01/2014 – 12/31/2017
Months Committed to the Project:	3 months per year

PENDING AWARDS as Principal Investigator

Project Title:	A Submillimeter-Wave Spectroscopic Galactic Plane Survey using Supercam at the HHT
Source of Support:	NSF AAG
Project Location:	The University of Arizona
Total Award Amount:	$339,569
Start and End Date: (MM/DD/YY)	9/01/2014 – 08/31/2017
Months Committed to the Project:	0.5 months per year

Project Title:	Continuing operation of the HEAT telescope at Ridge A, Antarctica (THIS PROPOSAL)
Source of Support:	NSF AAG
Project Location:	The University of Arizona
Total Award Amount:	$273,715
Start and End Date: (MM/DD/YY)	10/01/2014 – 09/30/2016
Months Committed to the Project:	6 months per year

CHRISTOPHER K. WALKER, Co-PI
The University of Arizona, Steward Observatory

CURRENT AWARDS as Principal Investigator

Project Title:	10 meter Sub-Orbital Large Balloon Reflector (LBR)
Source of Support:	NASA
Project Location:	The University of Arizona
Total Award Amount:	$99,898
Start and End Date: (MM/DD/YY)	8/12/13 – 5/11/14
Months Committed to the Project:	1 summer month

Project Title:	Reflight of the Stratospheric TeraHertz Observatory: STO-2
Source of Support:	NASA
Project Location:	The University of Arizona
Total Award Amount:	$4,180,531 (UA Portion: $1,081,269)
Start and End Date: (MM/DD/YY)	1/1/14 – 12/31/16
Months Committed to the Project:	1 summer month per year

CURRENT AWARDS as Co-Investigator

Project Title:	High Elevation Antarctic Terahertz (HEAT) Telescopes for Dome A and Ridge A (PI: C. Kulesa)
Source of Support:	NSF 0944335
Project Location:	The University of Arizona
Total Award Amount:	$1,511,020
Start and End Date: (MM/DD/YY)	10/01/2010 – 09/30/2014
Months Committed to the Project:	1 summer month per year

PENDING AWARDS as Principal Investigator

Project Title:	Investigation of the Meissner Effect Transistor
Source of Support:	NSF
Project Location:	The University of Arizona
Total Award Amount:	$350,535
Start and End Date: (MM/DD/YY)	5/1/14 – 4/30/17
Months Committed to the Project:	1 summer month per year

PENDING AWARDS as Co-Investigator

Project Title:	A Submillimeter-Wave Spectroscopic Galactic Plane Survey using Supercam at the HHT (PI Craig Kulesa)
Source of Support:	NSF
Project Location:	The University of Arizona
Total Award Amount:	$339,569
Start and End Date: (MM/DD/YY)	9/1/14 – 8/31/17
Months Committed to the Project:	0.5 summer month per year

Project Title:	Continuing Operation of the HEAT telescope at Ridge A, Antarctica (PI Craig Kulesa) – THIS PROPOSAL
Source of Support:	NSF
Project Location:	The University of Arizona
Total Award Amount:	$273,715
Start and End Date: (MM/DD/YY)	10/1/14 – 9/30/16
Months Committed to the Project:	0.5 summer month per year

FACILITIES, EQUIPMENT & OTHER RESOURCES

University of Arizona: Steward Observatory

Steward Observatory (SO) has a large technical staff with many years of experience in the design and construction of state-of-the-art telescopes and instrumentation for use from optical (e.g. MMT, Magellan, and Large Binocular Telescope) to millimeter/submillimeter wavelengths, such as the Heinrich Hertz Telescope (HHT). This expertise will be augmented by Instrument Team members with extensive experience in the development and deployment of terahertz instrumentation during the science operations of HEAT at Ridge A. Given that HEAT is already successfully operating at Ridge A and a successful servicing misson is under our belt, no difficultities in integration and operation are expected.

In 1992, Co-PI Walker established a laboratory (the Steward Observatory Radio Astronomy Laboratory, SORAL) for the development of state-of-the-art submillimeter-wave receiver systems. The PI-Kulesa, was trained in this group. SORAL possess all the equipment (spectrum analyzers, network analyzer's, vacuum pumps, cryogenic support facilities, etc.) needed to maintain HEAT. In addition, the Arizona Radio Observatory utilizes similar equipment both at the 10-meter HHT and in the university ARO laboratory. We also have ^{4}He, ^{3}He, and closed-cycle cryostats, a full receiver testbed, local oscillator sources (including a Coherent/DEOS FIR laser), and an antenna test range which allows us to characterize a wide range of receiver systems. A Kern micromilling machine with 5 micron machining accuracy was purchased for Supercam and is available for precision machining work.

SORAL has licenses for CST Microwave Studio, Solidworks, and Altium Designer, should they be necessary for the support of HEAT. These programs are used to accurately model and optimize mixers and other crucial receiver components, produce solid models of mechanical structures, and design and simulate electronic circuits. In addition, we have licenses for optical design packages such as Zemax. All of these were used in the design and construction of HEAT and can be brought to bear on optimizing HEAT's science operations, as needed.

Data Management Plan

HEAT's extensive 3D FITS spectral line data cubes of the Galactic Plane, and targeted deep surveys will be acquired, reduced, analyzed, and distributed to the broader astronomical community via publications and permanent data archives.

Data Pipeline

The rate at which raw (Level 0) data is collected from the spectrometer is substantial in OTF mode (see Project Description, Section 2.3 for a description of the mapping strategy) and not in the form desired for scientific distribution; therefore data processing is performed on the HEAT instrument control computer. The data flow is depicted in Figure 1 and can be operated autonomously after basic verification. The steps undertaken in each data processing level are described as follows:

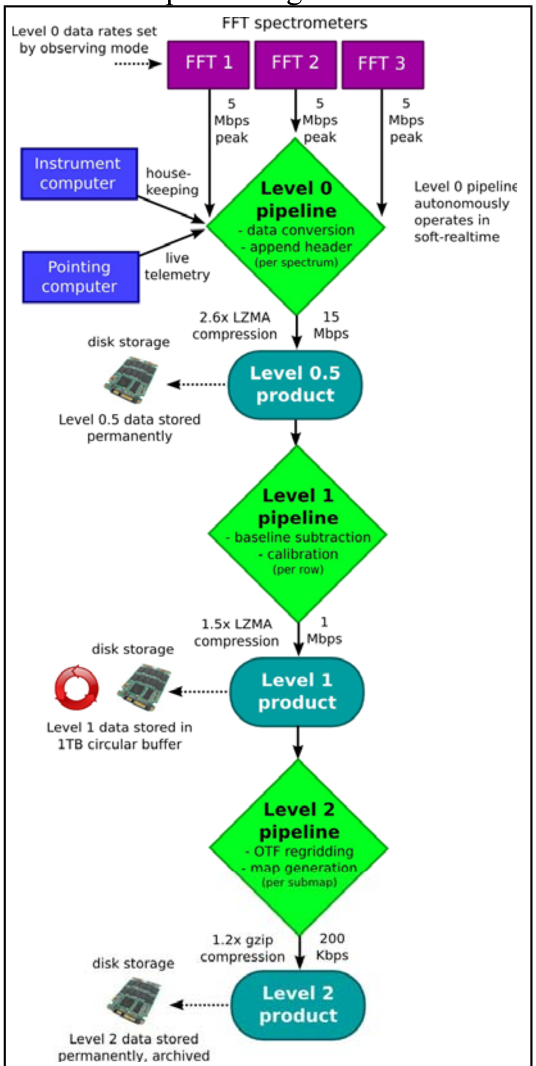

Figure 1: HEAT's demonstrated data pipeline

Level 0.5 (**data conversion, header tagging**) Each of the spectrometer data files is time-tagged upon being written to a RAM disk on the HEAT control computer. A data header is synthesized from streamed data from the HEAT tracker, which delivers telescope telemetry, and instrument housekeeping data. The data payload is rescaled from 64-bit words to 32-bit integers and written as a single-dish FITS file. The archival disk storage holds the LZMA-compressed (.xz) file, while a 'scratch' disk maintains the uncompressed file for follow up processing for a limited time. After validation, the 'raw' level 0 files are removed from memory.

Level 1 (baseline subtraction and calibration): After the conclusion of a single OTF scan, the map data can be preliminarily processed. The reference scan is subtracted from the source scans acquired during drift mode. If poor results are obtained, the best adjacent reference scan is used instead. Residual artifacts are masked from the resulting spectrum, and the data are flux calibrated using the ambient temperature chopper wheel method. Based on the antenna pointing and the time, the spectra are frequency calibrated onto a V_{LSR} velocity scale.

Level 2 (OTF regridding & map production): Once a submap has been repeated a sufficient number of times that the desired sensitivity has been achieved, the highly oversampled data are regridded and convolved to 90" resolution with 45" pixels. Optionally, spectral smoothing and additional spatial smoothing can be applied at this stage. The numerical methods used during regridding follow that used by the 32-beam

Sequoia array used at FCRAO to deliver outstanding high fidelity maps of CO emission in the first Galactic quadrant. These level 2 FITS cubes represent the baseline science products that HEAT uploads over Iridium modem. Thus, the highest priority for the observer is to continuously validate the level 2 processing using sparse quicklook versions of the level 0.5 and level 1 data that are streamed using available bandwidth.

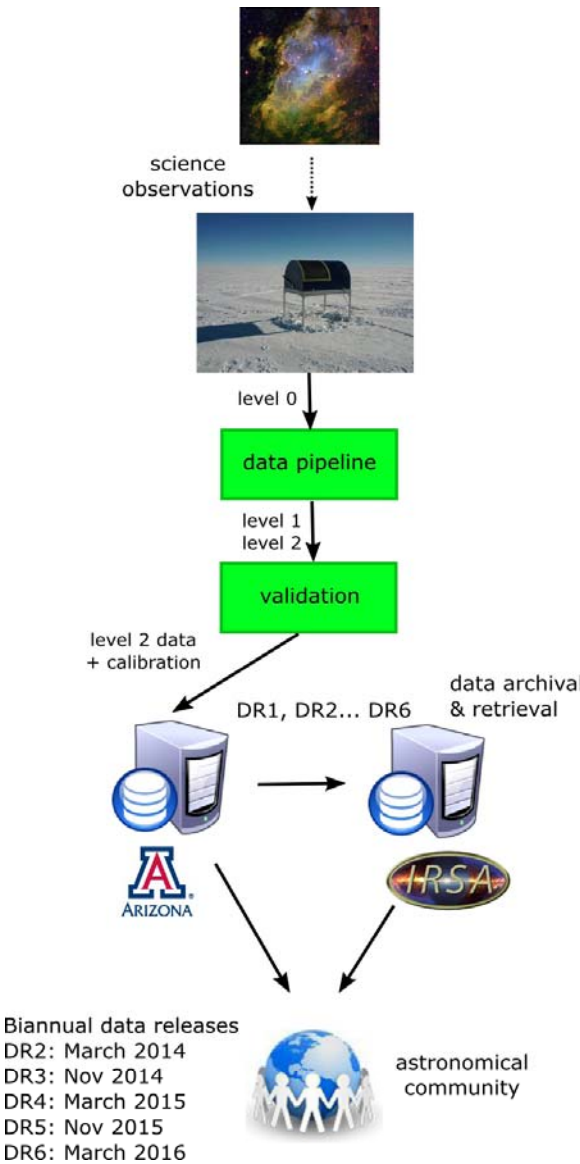

Figure 2: Archival data flow.

Data Archive

The HEAT data products will be in the form of FITS data cubes provided to the community from the University of Arizona and registered to the National Virtual Observatory (NVO). The data will be released biannually in March and November from 3/2013 to 3/2016 as Data Releases 0, 1, … 6. (DR0, DR1,... DR6) as soon as calibration and formatting is complete, with **no proprietary period**. The archival data flow is diagramed in Figure 2. The maximum data volume is expected to be 5 GB in total, including all calibration datasets. The large FITS cubes will be developed within the HEAT team and hosted both at the University of Arizona and at the Infrared Science Archives (IRSA) at the Infrared Processing and Analysis Center (IPAC), as was done with the BGPS survey. The FITS headers will be stored in a SQL database to make a web-based relational queries of HEAT data and extraction of data subsets easy from the astronomer's perspective. PI Kulesa will lead the development of the web interface to the data.

Postdoctoral Mentoring Plan

Not applicable: no postdoctoral researchers are supported under this proposal.