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 ☒

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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

Not for distribution

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 15-1 **NSF 15-1** **11/02/15**	FOR NSF USE ONLY NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) **AST - ADVANCED TECHNOLOGIES & INSTRM, (continued)**	

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				806345617	

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

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE **University of Arizona**	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE **888 N Euclid Ave** **TUCSON, AZ 85721-0001**
AWARDEE ORGANIZATION CODE (IF KNOWN) **0010835000**	
NAME OF PRIMARY PLACE OF PERF **University of Arizona**	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE **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 ☐ MINORITY BUSINESS
☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS
☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Phase 2 Development of the HEAT Observatory at Ridge A, Antarctica**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **899,272**	**36** months	**10/01/16**	

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)
☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ________
PHS Animal Welfare Assurance Number ________
☒ FUNDING MECHANISM **Research - other than RAPID or EAGER**
☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number ________
Exemption Subsection ________ or IRB App. Date ________
☒ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
AY AS
☒ COLLABORATIVE STATUS
Not a collaborative proposal

PI/PD DEPARTMENT **Astronomy**	PI/PD POSTAL ADDRESS **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).

Certification Regarding Conflict of Interest

The AOR is required to complete certifications stating that the organization has implemented and is enforcing a written policy on conflicts of interest (COI), consistent with the provisions of AAG Chapter IV.A.; that, to the best of his/her knowledge, all financial disclosures required by the conflict of interest policy were made; and that conflicts of interest, if any, were, or prior to the organization's expenditure of any funds under the award, will be, satisfactorily managed, reduced or eliminated in accordance with the organization's conflict of interest policy. Conflicts that cannot be satisfactorily managed, reduced or eliminated and research that proceeds without the imposition of conditions or restrictions when a conflict of interest exists, must be disclosed to NSF via use of the Notifications and Requests Module in FastLane.

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		

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER

Not for distribution

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) - continued from page 1
(Indicate the most specific unit known, i.e. program, division, etc.)

PLR - Antarctic Astrophys&Geosp Sci
AST - ASTRNMY & ASTRPHYS RES GRANTS

PROJECT SUMMARY

Overview:

Based on the successful deployment and operation of the facility starting in 2012, we propose the second development phase for the High Elevation Antarctic Terahertz (HEAT) telescope system, a robotic, 0.6-meter THz observatory at the summit of the Antarctic plateau. HEAT observes the brightest and most diagnostic spectral lines from the Galaxy. The 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 already made the most sensitive large-scale maps in the 370 micron line of neutral carbon and performed landmark observations at 200 microns, unveiling a population of "CO dark" molecular clouds and new regions where molecular clouds may be forming. With an established facility, we propose here the next level of instrument development, namely the augmentation of a hot electron bolometer (HEB) receiver operating at 4K, whose increased sensitivity will allow the facility to map the Galaxy >10 times faster. This effort is the second phase of development for this novel robotic facility. This proposal requires fieldwork in the Antarctic.

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, in which the most crucial astrophysical spectral diagnostics of the formation of galaxies, stars, planets, and life are found. HEAT is 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. The proposed upgrades of mixer, local oscillator, low-noise amplifier, cryogenic, and DSP technologies will play essential roles in future Terahertz observatories. This pioneering mission paves the way for future astronomical investigations from the high plateau and beyond.

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. Already, comprehensive science products from the survey and its collaborations are being freely 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, the local copy of the HEAT telescope transforms into an outstanding educational and outreach tool. Furthermore, 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.

1 Results from Prior NSF Support

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

In 2010, the PI initiated an NSF-funded (ANT-0944335, 10/2010-9/2014, $1.486M) 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.

1.1.1 Broader Impacts: 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 the 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. 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 3-mirror off-axis Gregorian telescope, cryogenic receiver system and frozen PI are visible in this image. (right) Enclosed in a fiberglass shell and teflon film “window” that is transparent to THz radiation, the HEAT telescope is ready for observations (January 2014).

For orientation, the facility is shown in Figures 1 and 2. It is comprised of several components: PLATO-R’s yellow **instrument module** houses 20 kW hr of LiFePO4 batteries, power distribution electronics, supervisor computers, and Iridium modems and antennas. A 4-panel **Solar Cube** provides up to 800 W of solar power to the instrument module during the summer months. PLATO-R’s green **engine module** 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, providing up to 1500W of power to the instrument module during winter. Finally, 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, like SPT. 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 810 and 492 GHz receivers for atomic carbon and was swapped for 810 GHz and 1460-1500 GHz receivers starting in January 2014.

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 an extreme environment, 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 a total power budget of less than 200W.
3. Developed and deployed an advanced telescope scheduling system that can autonomously execute an observing plan with little human involvement, with a 2 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 CO J=13-12 and [NII] at 200 μm installed in 2014, and ultimately ionized carbon at 158 μm (this proposal). By exploring molecular clouds and their environments in tracer species *other* than CO, HEAT will probe the entire carbon trail & 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.

1.1.2 Intellectual Merit: 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 131 days in 2015 in which the daily mean opacity at 200 μm (1.5 THz) was below 1.5. In comparison, the APEX radiometer for 2015 indicated only 3 such days for the Chajnantor plain, and the best estimates for Cerro Chajnantor (CCAT) indicate 10 days. Ridge A is especially remarkable in that 51 days of the 2015 yielded usable atmospheric transmission in the 150 micron window, containing the pivotal 158 μm ionized carbon line!

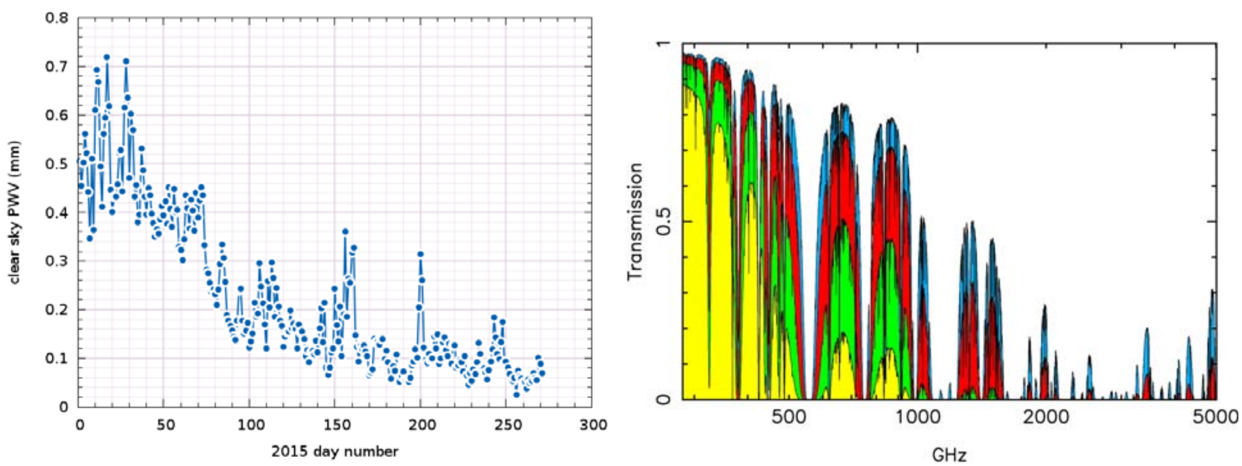

Figure 3: (left) Daily mean PWV in 2015 shows an incredibly stable, transparent atmosphere, with a median winter PWV of 105 microns and a best quartile of 65 microns! Such dry air conservatively leads to the upper-two (blue and red) transmission plots shown at right. The bottom two (green and yellow) curves represent the ALMA site and Mauna Kea, respectively. Ridge A opens entirely new atmospheric windows to routine observations from the ground.

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.

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 diode mixer receivers, HEAT's sensitivity to each spectral line is already extremely competitive.

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
Ridge A, 4040m	0.07	0.11	79%	50%	30%
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 2012-15 HEAT data for Ridge A, 2012-15 radiosonde data for South Pole, and Chajnantor from 2012-15 APEX radiometer data, Mauna Kea from literature values (Delgado et al., 1999; Hogg, 1992).*

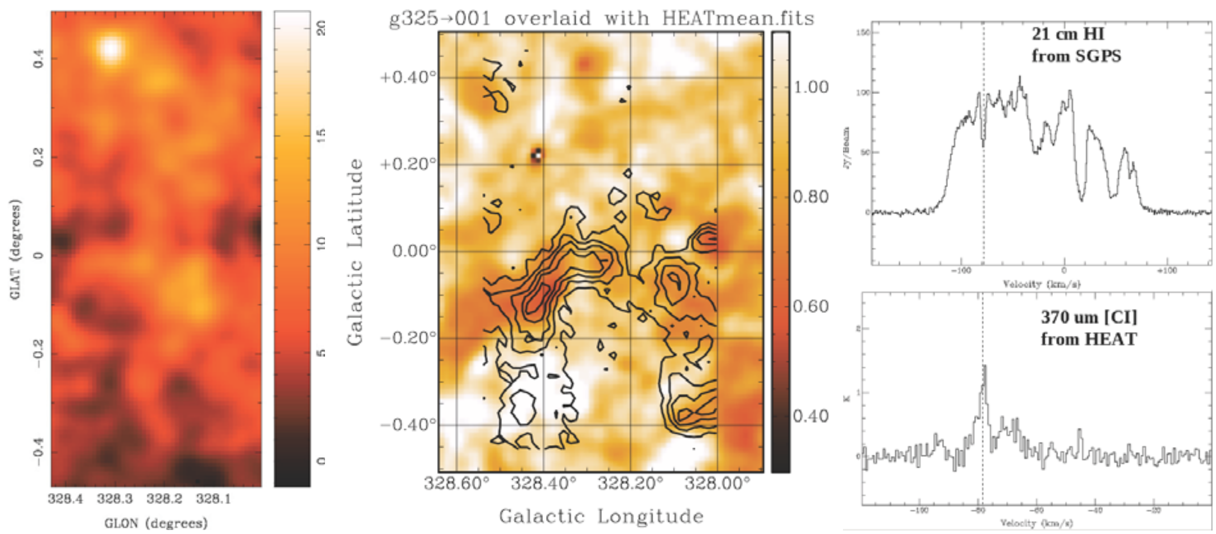

Figure 4: (left) Integrated intensity map of [CI] line emission toward l=328^o shows that diffuse atomic carbon emission fills the Galaxy and is nearly as abundant as CO. (center) The molecular gas shown by HEAT's detected line emission at -78 km/s V_{lsr} (contours) appears to be associated with self-absorption 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.

1.1.3 Intellectual Merit: 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 as well as a high priority $1^o \times 1^o$ maps that are now publically available. With a 3-sigma rms noise level of 100 mK and almost 10 square degrees released, these are the largest, most sensitive maps in the atomic carbon line to date.

Early 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-dark gas" (Grenier et al., 2005; Wolfire et al., 2010). HEAT has already produced in its 2014 season maps of CO J=13-12 data at 1497 GHz and to-be-downlinked results at [NII] 1461 GHz (Figure 5).

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 (Burton et al. 2014).

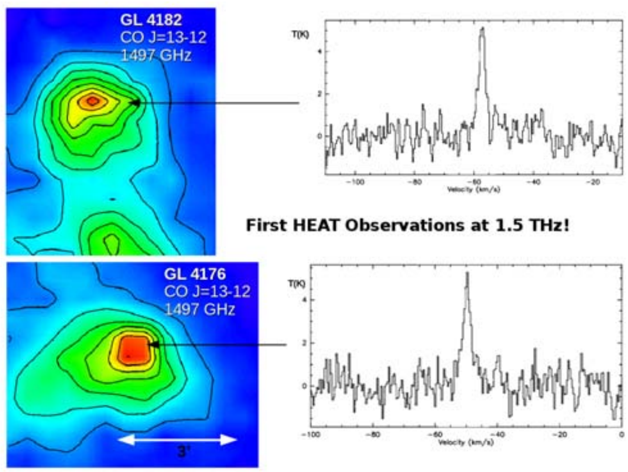

Figure 5: Commissioning observations of CO J=13-12 toward two high mass star forming regions performed by HEAT in 2014. In total, HEAT's 2014 observations at 200 microns nearly quadruple the amount of THz measurements made from the ground!

1.1.4 Publications and Research Products

The first major data releases (DR1 and DR2) from the HEAT telescope are online and comprise data acquired during the 2012 and 2013 seasons at Ridge A. Preliminary 2014 data are now available in DR2. The following papers have been published or are currently in press at the time of review. **Please visit soral.as.arizona.edu/heat/ for data and updates on publications and results!**

1. Kulesa, C., "Terahertz Spectroscopy for Astronomy: From Comets to Cosmology", IEEE Transactions on Terahertz Science and Technology, 2011, 1, 232.
2. C. Kulesa, C. Walker, A. Young, J. Storey, and M. Ashley, "HEAT: The High Elevation Antarctic Terahertz Telescope", 22nd International Symposium on Space Terahertz Technology, (2011), 9.
3. Craig A. Kulesa, Michael C.B. Ashley, Yael Augarten, Colin S. Bonner, Michael G. Burton, Luke Bycroft, Jon Lawrence, David H. Lesser, John Loomis, Daniel M. Luong-Van, Christopher L. Martin, Campbell McLaren, Shawntel Stapleton, John W.V. Storey, Brandon J. Swift, Nicholas F.H. Tothill, Christopher K. Walker and Abram G. Young, "Opportunities for Terahertz Facilities on the High Plateau", IAU Symposium 288, 2012, 256.
4. Burton, M. G., Braiding, C., Glueck, C., Kulesa, C. et al. 2013, "The Mopra Southern Galactic Plane CO Survey", PASA, 30, 44.
5. Burton, M. G., Ashley, M. C. B., Braiding, C., Storey, J.W.V., Kulesa, C., Hollenbach, D., Wolfire, M., Glueck, C., Rowell, G., "The Carbon Inventory in a Quiescent, Filamentary Molecular Cloud in G328", 2014, ApJ, 782, 72.

6. Kulesa, C. A., Honniball, C., Lesser, D., Swift, B. J., Walker, C.K., Young, A.G., "The High Elevation Antarctic Terahertz (HEAT) telescopes on Ridge A, Antarctica", IEEE Transactions on Terahertz Science and Technology, 2015, in review.
7. Kulesa, C. A, Ashley, M., C. B., Braiding, C., Storey, J.W.V., Lesser, D., Hollenbach, D., Wolfire, M., "An Antarctic [CI] and CO Survey of the Milky Way", 2015, ApJ, in review.
8. Kulesa, C.A., Ashley, M. C. B., Storey, J.W.V., Honniball, C., Lesser, D., Walker, C.K., Young, A.G., "New Far-Infrared and Terahertz Astronomical Capabilities over the High Antarctic Plateau", 2015, ApJ, in review.

1.1.5 Relation to Current Proposal

Much of the effort to date has focused on the technological development of this pathfinding observatory and achieving its first results. The current 2-year AAG program maintains the current facility and provides for the publishing of these first results. While the choice of Schottky diode mixer receivers at an operating temperature of 50K was done for robustness, the state of the art in detector sensitivity is achieved using superconducting devices at temperatures of ~4K. Now that basic operation of HEAT and PLATO-R has been proven, augmentation of a superconducting receiver system would improve the mapping speed and scientific capability of the system by an order of magnitude. **The goal of this proposal is to develop a superconducting receiver system using existing best-of-breed Hot Electron Bolometer (HEB) mixers from 1.4-1.9 THz to augment the existing cryogenic Schottky diode mixers from 0.8 to 1.5 THz. This augmentation will bring world-class instrument sensitivity to the very best site on Earth for astronomy at terahertz frequencies.** This represents the next development phase for the observatory.

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. 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~70K) atomic clouds and the warm (T~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 and is available now!

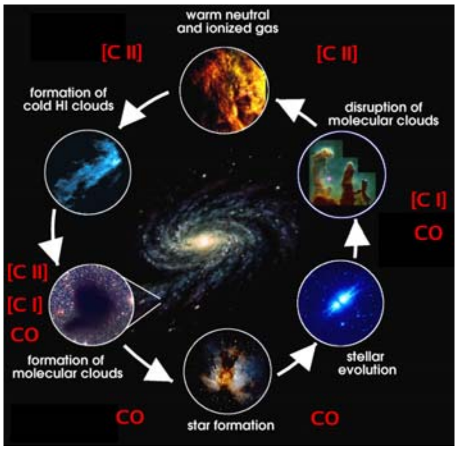

Figure 6: The HEAT telescopes will observe the fine structure lines of [N II], [C II], [C I], and CO that probe the entire life cycle of interstellar clouds. In particular, HEAT will witness the transformation of neutral atomic clouds into star-forming clouds, the interaction of the interstellar medium (ISM) with the young stars that are born from it, and the return of enriched stellar material to the ISM by stellar death.

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. HEAT can distinguish between the mechanisms proposed to form clouds 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 probes 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] are 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. 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 APEX, and the ALMA and SMA interferometers (in addition to current studies using Herschel data). How will the HEAT telescope address the scientific goals that have been illustrated?

2.4.1 A Robotic Superconducting HEB Mixer Receiver at 4 Kelvin

The main technical advance of this proposal is to integrate a highly-sensitive receiver capability to the autonomous HEAT telescope. The current deployment of Schottky diode mixers are robust, operate at ambient temperatures, and improve substantially when cooled. Nevertheless, they are a factor of $\sim$3 less sensitive than superconducting Hot Electron Bolometer (HEB) mixers. This sensitivity is most critical for the very highest frequencies (e.g. 1.9 THz) where the good weather opportunities are limited. In order to maximize the science return at the highest frequencies, state-of-the-art mixers must be deployed.

Technical Readiness: Mixers and LOs The team is well prepared to deliver an exemplary 1.5 and 1.9 THz HEB mixer receiver system at 4K to augment the 50K Schottky system. J.R. Gao in the Division of Sensor Research and Technology at SRON in the Netherlands has delivered among the most sensitive HEB mixers in the world (e.g. Kloosterman et al. 2013). Indeed, recent lab results delivering a noise temperature of 650K DSB at 1.9 THz have been achieved (Gao, private communication), and the HEAT team has pumped these SRON mixers in 2015 for the STO-2 project (Section 2.4.4) in the Arizona laboratory with an available Virginia Diodes 1.9 THz LO module that provides a suitable 10 uW of LO power. The noise temperature measured in Arizona with a slightly thicker LO diplexer (mylar beamsplitter) than used at SRON was 750K, an excellent result at this frequency. By comparison, Herschel/HIFI delivered a noise temperature of $\sim$1300K DSB at the [CII] line. Gao's team at SRON will provide two new HEB mixers at 1.5 and 1.9 THz for use with HEAT. The existing, proven 1.9 THz VDI LO will be used; a new 1.5 THz LO will be purchased from Virginia Diodes to observe the [NII] line and CO 13-12 at 1497 GHz. The University of Arizona will fabricate the coupling optics, electronics and packaging to integrate with the existing HEAT telescope optics as was done for the Schottky mixers. The existing IF amplifier and Berkeley ROACH(2)-based FFT spectrometer system will be used, providing two independent 2 GHz-wide digitized spectral bandpasses, providing 320 km/s instantaneous bandwidth at the [CII] line and 700 km/s at the [CI] J=2-1 and CO J=7-6 lines.

Technical Readiness: Cryogenic System

To house the SRON mixers, we will develop a hybrid cryostat that leverages the very successful design currently used on HEAT (Figure 2). The proposed cryostat has a radiation shield cooled to 50K by the current Sunpower Cryotel CT stirling engine, which also cools the existing Schottky diode mixers and maintains an excellent vacuum year-round through cryopumping. When the weather is especially good, a second cold work surface is cooled even further to 4-6K using a Sumitomo RDK-101 cold head attached to a matching CNA-11 helium compressor in a specially-insulated vessel, modified to operate from PLATO-R's 120 VDC bus with 800W of input power. Helium compressor lines are short, insulated, with seals replaced with fluorosilicone rings rated to -60C and temperature-regulated. The compressor will be integrated to the HEAT telescope and PLATO-R system using an industrial, cold-rated, simplified VFD (variable frequency drive). The system will be environmentally tested to -60C using a large dry ice chamber. This hybrid system provides year-round observations with Schottky diode mixers at 810 GHz or 1460 GHz at a low total power consumption of 150-200W, and superconducting operation at 4-6 Kelvin with a total power consumption of 1000W during the days of best weather, when precipitable water vapor drops to 100 microns (0.1 mm) or lower. PLATO-R can already provide this power capability. Table 2 shows the measured noise temperatures of the HEAT receivers at different operating temperatures, demonstrating the marked improvement possible with the 4K system.

HEAT Receiver	**T_{rec} at 290K**	**T_{rec} at 50K**	**T_{rec} at 4.5K**
0.8 THz Schottky	5000K	1500K	–
1.5 THz Schottky	10000K	3500K	–
1.5, 1.9 THz HEB	–	–	750K

Table 2: Double-sideband receiver noise temperatures for HEAT receivers at different temperatures. Mapping speed is inversely-proportional to receiver noise temperature squared; so a 2x reduction in noise temperature generally results in a 4-fold increase in mapping speed.

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 7 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. In particular, 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. 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.

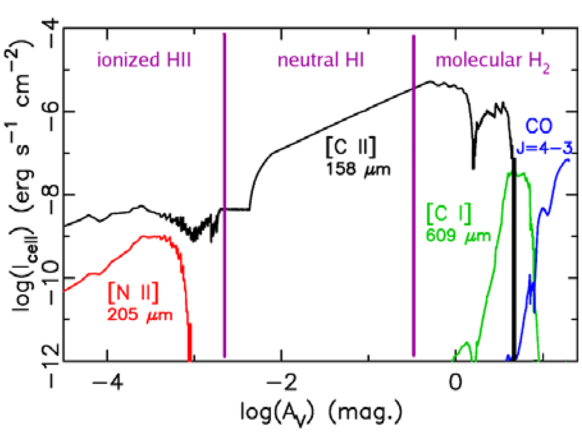

Figure 7: **The uniqueness of HEAT's [CI], [CII] and [NII] surveys.** A model depiction of the intensity of diagnostic lines of carbon and nitrogen species as viewed through a UV-illuminated cloud from depths of A_V=0 to 20 mag. Vertical purple lines overlay the HII-to-HI-to-H_2 boundaries found at the edges of dense interstellar clouds. This figure demonstrates that [CII] and [CI] probe H_2 clouds with little CO, and that adding [NII] disentangles the [CII] emission stemming from ionized gas.

This proposal brings the crucial [CII] mapping capability to HEAT, with the high sensitivity needed to perform a statistically meaningful survey of Galactic emission. This is a unique capability that cannot be done from the ground. There are no space observatories that can provide these data, and the only suborbital platforms (SOFIA & balloons) can only fly for limitied missions. HEAT will uniquely 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 Broad Mapping Coverage of the Galactic Plane

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 ($0 > l > -100^o$) in [CI] and [NII], with smaller regions mapped in [CII]. The survey 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 the Herschel "GOTC+" open time key program (Langer et al., 2010). The target line sensitivity is set to identify all ionized, atomic, and molecular (CO) carbon to a column density corresponding to a visual extinction of 1 magnitude (1.8×10^{21} cm^{-2}) or less.

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 using the On-The-Fly (OTF), or "drift scanning" technique. HEAT can reach the requisite sensitivity of 1σ=0.15 K km s^{-1} per beam at 810 GHz over a fully sampled square degree in 10 days, assuming median winter conditions of τ_{810} ~0.5. 20 square degrees distributed from $0 > l > -20^o$ and $-45 > l > -100^o$ will be mapped in ≈300 days. The superconducting [NII] channel will map a square degree in 3-7 days during typical winter weather, and the superconducting [CII] channel will map a square degree in 15 days during the best weather, when the opacity at 1900 GHz drops to 2. It is expected that 2-3 square degrees can be mapped per season in [CII] to the nominal sensitivity (3σ rms noise of 1K or less) and an additional 2 square degrees to shallow sensitivity (3σ rms noise of 2K or less) toward regions with anticipated bright [CII] emission. In two seasons, 10 square degrees in [CII] will be observed towards carefully selected Galactic regions including spiral arm and inter-arm regions, bright PDRs and diffuse clouds.

2.4.4 Broader Impact: Synergies with Other Observatories

HEAT is timely. The Spitzer 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 interstellar dust, and constrains extinction laws as a function of galactocentric radius. HEAT provides the best corresponding spectroscopic survey that will provide key 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 results provided by SOFIA and Herschel. The higher angular resolution afforded by larger telescopes necessarily reduces their field of view and mapping speed. 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 500 times the areal coverage of "GOTC$^+$" during this proposal period, and will exceed the Herschel coverage in [CII] by a factor of 200 in a single season. Given the expiration of Herschel and SOFIA's limited flying hours, the terahertz astronomy provided by the HEAT telescope has become even more critical!

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 very effectively performed by single-dish telescopes like HEAT. Indeed, HEAT's Southern survey in atomic carbon, [NII], [CII] 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.

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 2016 and will last for $\sim$2 weeks. Such flights can be repeated on 2-3 year timescales. HEAT plays an important role with respect to STO-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. HEAT will map 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-2 observations will be carefully coordinated to provide maximum science return.

2.4.5 Broader Impact: Site testing of the coldest place on Earth

Analysis of 1 km land surface temperatures from the MODIS instruments on NASA's Aqua and Terra satellites shows surface skin temperatures that exceed the record low temperature of -89.2C measured at Vostok in 1983. One such site to have experienced temperatures as low as -92C twice in the last 3 seasons, is a mere 26 km from HEAT and PLATO-R, which lie at a comparatively "warm" location. One hypothesis suggests that the local topography drives the cold air drainage rate; when winds are calm, local minima act as "sinks" for cold air and represent places where record cold temperatures are achieved. In contrast, HEAT & PLATO-R lie along the ridge where the coldest air easily drains downhill and the turbulent boundary layer becomes vanishingly small. Indeed, during such periods of calm, HEAT typically witnesses a sharp rise in air temperatures (from -75C to -55C), not a drop as is common at downstream sites such as Vostok or South Pole Station. In collaboration with lead NSIDC researcher Ted Scambos, remote weather monitoring systems will be installed both at Ridge A and at a neighboring "cold" site as a part of the fieldwork that services HEAT and PLATO-R. These weather monitoring systems, already funded separately and ready to deploy, will address critical questions for aeronomy and glaciology:

1. What is controlling the record minimum skin temperature level, which is consistently -91.5 to -93C in several widely-spaced locations?
2. Does air drainage rate, related to local topography, control the inversion layer temperature gradient? What weather patterns favor record low temperature events?
3. Can increasing CO_2, CH_4, etc. levels in the atmosphere, or changing H_2O or SO_2 in the stratosphere, affect the minimum temperature levels over time?

2.4.6 Science Products and Dissemination

Access to HEAT data products to the greater scientific community will be provided through a web browser interface that will interface with a SQL database that accesses and the FITS data cubes that HEAT generates. 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. Early access of data downlinked from the experiment in the current season will be released each Fall. A more formal annual data release will be made each Spring after the annual collection of raw data products from HEAT. This annual data 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/`

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 3 provides a listing of the roles of each member in the organization.

Participant	Affiliation	Participation Activity
Michael Ashley	UNSW	PLATO-R lead; site testing
Michael Burton	UNSW	Lead: Companion CO Survey from the Mopra 22m
J.R. Gao	SRON	Provides HEB mixers for 1.5-1.9 THz channels
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
Ted Scambos	NSIDC	"Coldest Place on Earth" site testing campaign
Christopher Walker	Univ. Arizona	Co-PI, leads student advising
Mark Wolfire	U. Maryland	Advisor: PDR modeling
Abram Young	Univ. Arizona	Systems lead: leads cryostat design

Table 3: Activities of the HEAT Instrument and Science Team

Collectively the HEAT team members represent many years of instrument building, observing experience, and theoretical expertise. As related by Table 3, the main components of the organization are the PI, who has overall responsibility for the project and coordinates the activities of

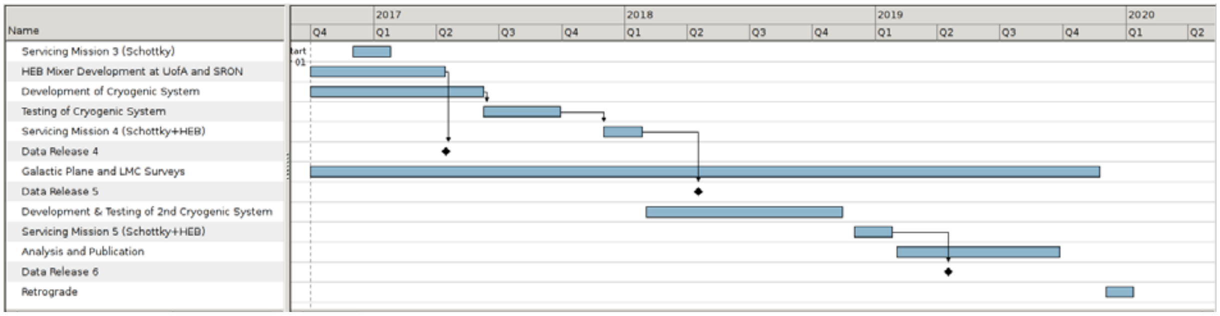

Figure 8: High level project timeline

the participants; Co-PI Walker who shares in these responsibilities and leads 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 8. 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.

A schedule of key project milestones and tasks is provided in Figure 8. A maintenance servicing of the Ridge A robotic facility will be undertaken in 2016-17 to resupply the site with the 810 GHz and 1.5 THz Schottky mixers. In 2016-17, an aggressive receiver development effort will be coordinated between Arizona and SRON to develop a cold-rated HEB receiver system for deployment in the the 2017-18 field season. Each year, a readiness review will be performed prior to shipping to assess the following system requirements: 1) fully remote operation, 2) low power dissipation 3) receiver sensitivity, and 4) receiver stability. A second HEB receiver system will be constructed in 2018 to exchange with the first, minimizing time and risk in the deep field. 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 (see Supplementary Documents).

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

4 Broader Impact: Education

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 THz 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 THz 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 notable is an 3-14 um infrared sky brightness monitor for HEAT designed and built by undergraduate Casey Honniball as part of her independent study research.** In the proposed budget for HEAT, partial funding for one undergraduate and 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 effectively “an ALMA dish 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

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. The overall HEAT 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 fail to 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 “pay it back” by collecting the videographic and photographic materials needed to produce a short science video highlight for the program. Initial interest in this development at NOVA was highly favorable and would be explored for the 2016-17 or 2017-18 deployment to Ridge A.

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Craig A. Kulesa

Steward Observatory
University of Arizona
Tucson, AZ 85721

Telephone: (520) 621-6540
FAX: (520) 621-1532
Email: ckulesa@email.arizona.edu

Professional Preparation

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

Recent Appointments

2012-	Associate Astronomer University of Arizona
2006-	Assistant Astronomer University of Arizona
2003-2006	Assistant Staff Scientist 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. "The Carbon Inventory in a Quiescent, Filamentary Molecular Cloud in G328", M.G. Burton, M.C.B. Ashley, C. Braiding, J.W.V. Storey, C. Kulesa, D. Hollenbach, M. Wolfire, C. Glueck, G. Rowell, 2014, ApJ, 782, 72.
5. "Abundances of H_2, H_3^+ & CO in Dark Molecular Clouds", Kulesa, C. A. & Black, J. H. 2015, ApJ, submitted

Selected Related Papers

1. "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.
2. "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.
3. "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.

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 studies of life cycle of interstellar matter in 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 driest 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, scheduled to fly in December 2015.
3. Deputy-PI of *Supercam*, a 64-beam, 345 GHz heterodyne receiver to be deployed at the 10-meter HHT telescope in Arizona and the 12m APEX telescope in Chile. Responsibilities focus on the I&T of IF processor and spectrometer, system level testing, telescope integration & data system.
4. With PI-Mccarthy, implemented *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, 2013-2015:

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	4.00	0.00	0.00	19,377	
2. Christopher K Walker - Professor	0.00	0.00	0.50	5,813	
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)	4.00	0.00	0.50	25,190	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (3) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	6.00	0.00	0.00	34,422	
3. (1) GRADUATE STUDENTS				20,608	
4. (1) UNDERGRADUATE STUDENTS				2,400	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				82,620	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				22,866	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				105,486	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
4K dual closed-cycle cryostat	$ 45,000				
Diamond-turned THz mirrors for existing 2nd telescope	34,000				
PLATO-R annual replacement modules	30,000				
Others (See Budget Comments Page...)	37,460				
TOTAL EQUIPMENT				146,460	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				2,100	
2. FOREIGN				1,300	
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				10,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,640	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				8,450	
TOTAL OTHER DIRECT COSTS				21,090	
H. TOTAL DIRECT COSTS (A THROUGH G)				276,436	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC Base, IDC at 53.5% (Rate: 53.5000, Base: 124456)					
TOTAL INDIRECT COSTS (F&A)				66,584	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				343,020	
K. SMALL BUSINESS FEE				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				343,020	

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*	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

** D- Equipment
ROACH2 FFT spectrometer (Amount: $ 7460)
Two HEB mixers from SRON (Amount: $ 30000)

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	6,005	
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	36,029	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (3) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	8.00	0.00	0.00	48,093	
3. (1) GRADUATE STUDENTS				21,548	
4. (1) UNDERGRADUATE STUDENTS				2,479	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				108,149	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				31,443	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				139,592	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
1.5 THz LO source, Virginia Viodes			$ 80,000		
4K dual closed-cycle cryostat			45,000		
PLATO-R annual replacement modules			30,000		
TOTAL EQUIPMENT				155,000	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				2,169	
2. FOREIGN				1,343	
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				10,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,727	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				5,965	
TOTAL OTHER DIRECT COSTS				18,692	
H. TOTAL DIRECT COSTS (A THROUGH G)				316,796	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC Base, IDC at 53.5% (Rate: 53.5000, Base: 155834)					
TOTAL INDIRECT COSTS (F&A)				83,371	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				400,167	
K. SMALL BUSINESS FEE				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				400,167	

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*	Date Checked / Date Of Rate Sheet / Initials - ORG	

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 3

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	31,015	
2. Christopher K Walker - Professor	0.00	0.00	0.50	6,203	
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	37,218	
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.)	2.00	0.00	0.00	12,949	
3. (1) GRADUATE STUDENTS				22,540	
4. (1) UNDERGRADUATE STUDENTS				2,561	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				75,268	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				19,735	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				95,003	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				2,241	
2. FOREIGN				1,387	
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				500	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,817	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				1,980	
TOTAL OTHER DIRECT COSTS				5,297	
H. TOTAL DIRECT COSTS (A THROUGH G)				103,928	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC Base, IDC at 53.5% (Rate: 53.5000, Base: 97489)					
TOTAL INDIRECT COSTS (F&A)				52,157	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				156,085	
K. SMALL BUSINESS FEE				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				156,085	
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*	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**	16.00	0.00	0.00	**80,416**	
2. **Christopher K Walker - Professor**	0.00	0.00	1.50	**18,021**	
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)	16.00	0.00	1.50	**98,437**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	**0**	
2. (**7**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	16.00	0.00	0.00	**95,464**	
3. (**3**) GRADUATE STUDENTS				**64,696**	
4. (**3**) UNDERGRADUATE STUDENTS				**7,440**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**266,037**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**74,044**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**340,081**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **$ 301,460**					
TOTAL EQUIPMENT				**301,460**	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				**6,510**	
2. FOREIGN				**4,030**	
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				**20,500**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**8,184**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**16,395**	
TOTAL OTHER DIRECT COSTS				**45,079**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**697,160**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**202,112**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**899,272**	
K. SMALL BUSINESS FEE				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**899,272**	
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*	Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

BUDGET JUSTIFICATION

A. SENIOR PERSONNEL

4.0 calendar months of salary is requested for PI Craig Kulesa in Year 1, and 6.0 months per year in Years 2 and 3. His base salary is $58,131 per 12-month fiscal year.

0.5 summer months of salary is requested for Co-PI Christopher Walker in Years 1-3. His base salary is $100,914 per 9-month academic year.

4.0, 6.0, and 2.0 calendar months of salary in years 1, 2 and 3 respectively is requested for Systems Engineering Lead, Abram Young. His base salary is $72,800 per 12-month fiscal year.

B. OTHER PERSONNEL

Partial funding for 3 years is requested for one graduate student (base salary $36,177) engaged in Ph.D. thesis research under this project. One semester of academic year support, plus 50% (1.5 months) summer salary is requested. University-designated tuition remission for this student at the level of $5,520 per semester is requested.

During development of the new cryogenic receiver systems in Years 1 and 2, one month of an electrical engineer and one month of a mechanical engineer is requested. The costing is based on the average salary of a departmental electrical and mechanical engineer ($60,000 and 70,000 per 12-month fiscal year, respectively).

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 and Classified Staff: 34.7%
- Graduate Students: 13.9%
- Undergraduate Students: 3.5%

D. CAPITAL EQUIPMENT

Based on the successful design and construction of the 50-Kelvin HEAT cryostat, Universal Cryogenics will be consigned to construct the two next-generation 4K instrument cryostats. Their quotation for a dual-cryocooler cryostat is $45,000 per system, commensurate with the $26,000 for the current single-stage version. One system will be delivered in year 1, with a second identical system in year 2. They will recycle the Sunpower CT cryocoolers from the prototypes.

A 1.5 THz Local Oscillator source will be purchased in year 2 from Virginia Diodes Inc. to operate the Hot Electron Bolometer mixer receivers. They are the only commercial supplier of such THz systems. Their quotation for a single unit is $80,000.

SRON will provide two quasi-optical Hot Electron Bolometer mixers to the HEAT project for a total of 25,000 EUR, or 30,000 USD at the mean current exchange rate.

A ROACH2-based spectrometer system, identical to one purchased in the prototype system, will be purchased from Digicom in year 1. Their quote is for $7,500 for the ROACH2 FPGA board, ADC boards, and 10 Gbit ethernet boards. Digicom is the only commercial supplier of the ROACH2 systems.

We will purchase replacement engine modules for PLATO-R from the University of New South Wales (UNSW), the designer and manufacturer of PLATO-R. The total cost for two complete engine modules ready to be installed into PLATO-R is $30,000 and is based on a breakdown of the current actual costs for the individual components. We will purchase one replacement set of 2 engines in each of years 1 and 2.

Finally, only one of the two HEAT telescopes has precision-machined diamond-turned aluminum mirrors. We will task NiPro Optics, the manufacturer of the first precision set for the currently- deployed telescope, to construct a duplicate mirror set for the second telescope. The quoted cost for diamond turning and lightweighting all three mirrors is $34,000.

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, but are not limited to, disk drives, poster printer costs, and design and analysis software.

Funds are requested for operational repairs to the HEAT telescope and its cryogenic, receiver, electronics, and optomechanical systems. Costing is based on 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 years 1 and 2 for augmenting the HEAT electronics control boards used to operate the more advanced receiver system proposed here. The costs listed are based on the actual costs incurred during the previous design and prototyping efforts.

Funds are requested for two domestic 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 $3,000 USD annually, based directly on the average shipping cost incurred during the last two years of operation. Shipping costs in year 3 are estimated at $1,500 for the return of the experiment.

G. INDIRECT COSTS

The university-mandated indirect cost rate (IDC) was applied to all costs except capital equipment and graduate student tuition remission. This rate is 53.5% effective 7/1/2016.

*A cost inflation rate of 3.3% per year is applied to all eligible costs for years 2 and 3, save graduate student tuition remission which follows the University-recommended 8% annual rate.

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

CURRENT AWARDS as Principal Investigator

Project Title:	Continuing operation of the HEAT telescope at Ridge A, Antarctica
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

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:	$4,180,531 (UA Portion: $1,081,269)
Start and End Date: (MM/DD/YY)	1/01/2014 – 12/31/2016
Months Committed to the Project:	3 months per year

PENDING AWARDS as Principal Investigator

Project Title:	Phase 2 Development of the HEAT Observatory at Ridge A, Antarctica (THIS PROPOSAL)
Source of Support:	NSF ATI
Project Location:	The University of Arizona
Total Award Amount:	$899K
Start and End Date: (MM/DD/YY)	10/1/2016 – 09/30/2019
Months Committed to the Project:	5 months per year (average)

PENDING AWARDS as Co-Investigator

Project Title:	GUSTO: Galactic ULDB Stratospheric Terahertz Observatory
Source of Support:	NASA Explorer Mission of Opportunity (Explorer/MO)
Project Location:	The University of Arizona
Total Award Amount:	$17.7M
Start and End Date: (MM/DD/YY)	6/1/2015 – 09/30/2021
Months Committed to the Project:	5 months per year (average)

CURRENT AND PENDING SUPPORT

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) Phase II
Source of Support:	NASA
Project Location:	The University of Arizona
Total Award Amount:	$149,974
Start and End Date: (MM/DD/YY)	9/9/14-12/31/15
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:	Continuing Operation of the High Elevation Antarctic Terahertz (HEAT) Telescope at Ridge A, Antarctica (PI: C. Kulesa)
Source of Support:	NSF 1410896
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:	.5 summer month per year

PENDING AWARDS as Principal Investigator

Project Title:	Advancing 4k-class mechanical cryocoolers for future ULDB missions and low-cost space missions
Source of Support:	JPL
Project Location:	The University of Arizona
Total Award Amount:	$69,079
Start and End Date: (MM/DD/YY)	1/1//2016-12/31/2017
Months Committed to the Project:	.5 summer month per year

CURRENT AND PENDING SUPPORT

Project Title:	GUSTO:Gal/Xgal U/LDB Spectroscopic/Stratospheric Terahertz Observatory
Source of Support:	NASA
Project Location:	The University of Arizona
Total Award Amount:	$17,714,074
Start and End Date: (MM/DD/YY)	6/1/2015-9/30/2021
Months Committed to the Project:	3 summer months in years 1, 3 and 4; 1 academic month in year 3

Project Title:	Innovative Deployable Reflector Antenna for RF Communication on Small Satellites
Source of Support:	ONR
Project Location:	The University of Arizona
Total Award Amount:	$827,058
Start and End Date: (MM/DD/YY)	1/1/2016-12/31/17
Months Committed to the Project:	1 summer month per year

Project Title:	Innovative Spherical Reflectors for Space-based Applications
Source of Support:	DARPA
Project Location:	The University of Arizona
Total Award Amount:	$4,418,709
Start and End Date: (MM/DD/YY)	10/1/2015-9/30/2017
Months Committed to the Project:	2.6 summer month year 1; 3 summer months and 4.8 academic months in year 2

PENDING AWARDS as Co-Investigator

Project Title:	Phase 2 Development for the HEAT Observatory at Ridge A, Antarctica (PI Craig Kulesa)
Source of Support:	NSF
Project Location:	The University of Arizona
Total Award Amount:	$899,271
Start and End Date: (MM/DD/YY)	10/1/16 – 9/30/19
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.

A number of Local Oscillator (LO) units are available for HEAT's HEB receivers. Two units from Virginia Diodes (VDI) at 810 GHz (for [CI]) and 1900 GHz (for [CII]) are available from other concluded efforts and both are capable of pumping broadband spiral-antenna-fed HEB modules.

Two suitable mixers from the STO-2 project could be made available for HEAT as backup mixer modules. These mixers already have the performance needed by this project and have proven themselves in the lab and after STO-2's flight in January 2016, will be maintained for possible future flights.

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:

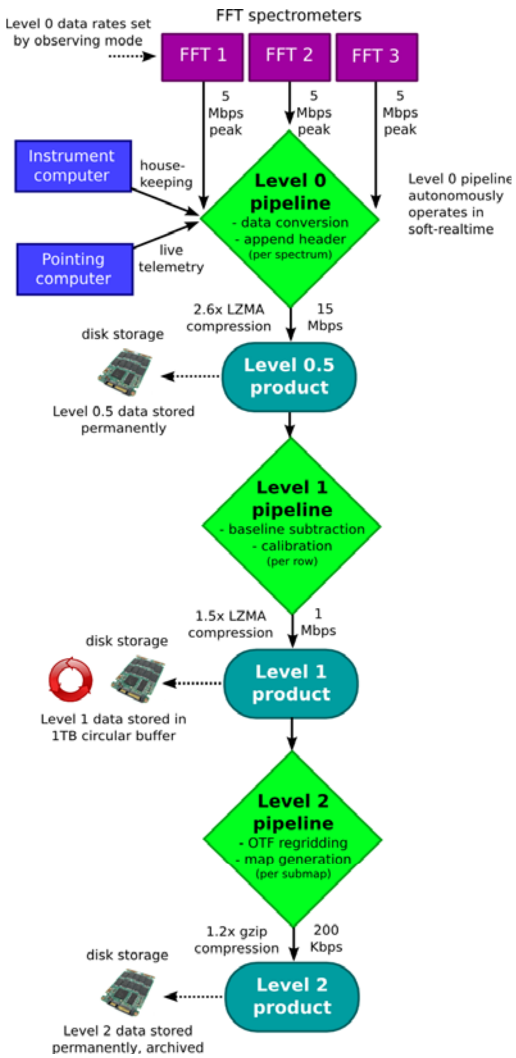

Figure 1: HEAT's demonstrated data pipeline

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.

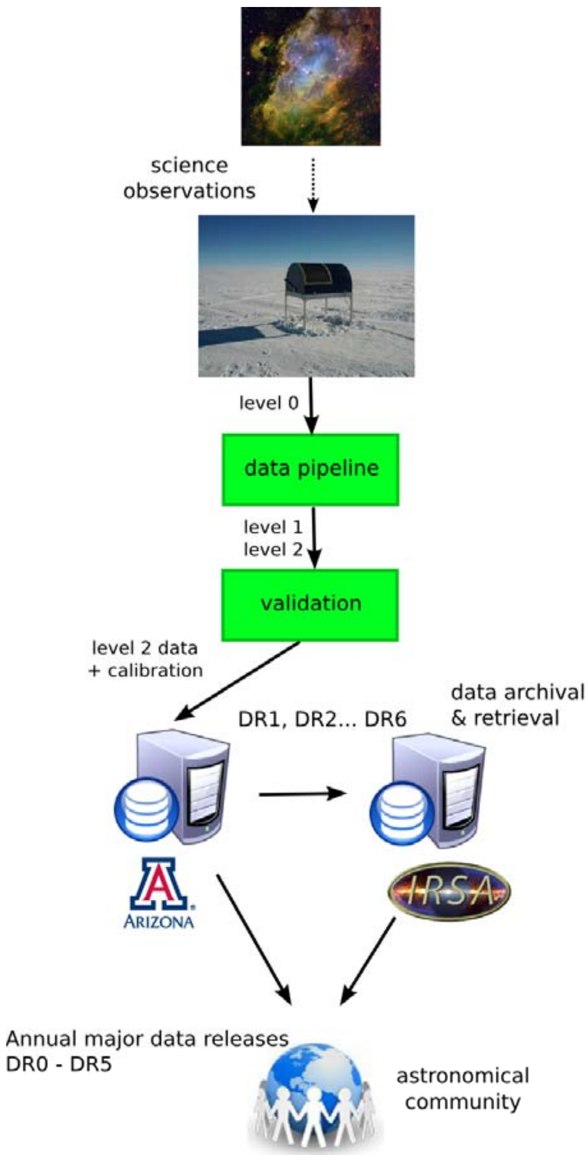

Figure 2: Archival data flow.

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). Major data releases will be released annually in April, with preliminary "early" releases of very recent data each August, from 4/2013 to 4/2018 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.

Logistical Requirements and Field Plan

Number of fieldwork seasons	Four (2016-17, 2017-18, 2018-19, retro in 2019-20)
Deploying participants per season	5-6 in 2016-17 and 4 in subsequent years
BFC/FSTP mountaineer	1 requested per season (2-4 weeks)
Science Cargo: Weight of equipment N/B & S/B per season	2000-3500 lb each way (highest in 2016-17 and retro in late 2019). COMSUR and Vessel, selected direct-shipped to CHC
Estimated AN8 fuel requirement	Eight 55 gal drums for science experiment (3 seasons; typically cached via airdrop at AGAP-S)
Number of Twin Otter days	5 in 2016-17, 4 per season in subsequent years
Number of days in the deep field	5-7 per season typical
Site Name and Location	Ridge A: 81:40:25 S, 72:42:55 E (4040 m elevation) AMIGOS: 81:54:47 S, 73:12:14 E (3999 m elevation) Distance from South Pole: 500 nautical miles
Number of days at South Pole	7-14 per season (acclimitization and testing)
Number of days at McMurdo	7-14 per season (field camp checkout/training, camp closeout)
Communications requirement	3 active Iridium SIM cards for data downlink (SBD, direct-IP) 2 Iridium phones, 1 HF radio only during field deployment
Facility construction/alteration	None.

Table 1: Operational Requirements at a Glance

Annual servicing of the experiment requires the swapping of the HEAT telescope/receiver module, PLATO-R engines, refueling (8x55 gal drums, for mean power consumption of 500W) and system-level testing. The servicing is typically carried out by 4 grantees at Ridge A in combination with one BFC/FSTP mountaineer. By swapping entire modules versus implementing field repairs, the time spent in the deep field is minimized: 4 days per deployment is requested based on previous servicings in 2013-14. In 2016-17, the one-time additional installation of AWS and AMIGOS-II monitoring equipment at Ridge A and a neighboring “cold sink” site 26 km away is requested in collaboration with Ted Scambos' team at NSIDC. Close support via Twin Otter with 3 hours ground time is requested at the AMIGOS cold site.

A typical deployment might be scheduled as follows:

- Science cargo shipped from Point of Origin to Port Hueneme (October 1)
- Point of Origin to Christchurch to McMurdo (10-14 December)
- Berg Field Camp checkout and Training (15-21 December)
- Arrival at South Pole, Acclimitization and testing (23 December – 2 January)
- Deep field deployment to Ridge A (3-8 January)
- South Pole: Science Cargo retrograde (9-11 January)
- McMurdo return, camp closeout (12-18 January)
- McMurdo to Christchurch to PoO (19-22 January)

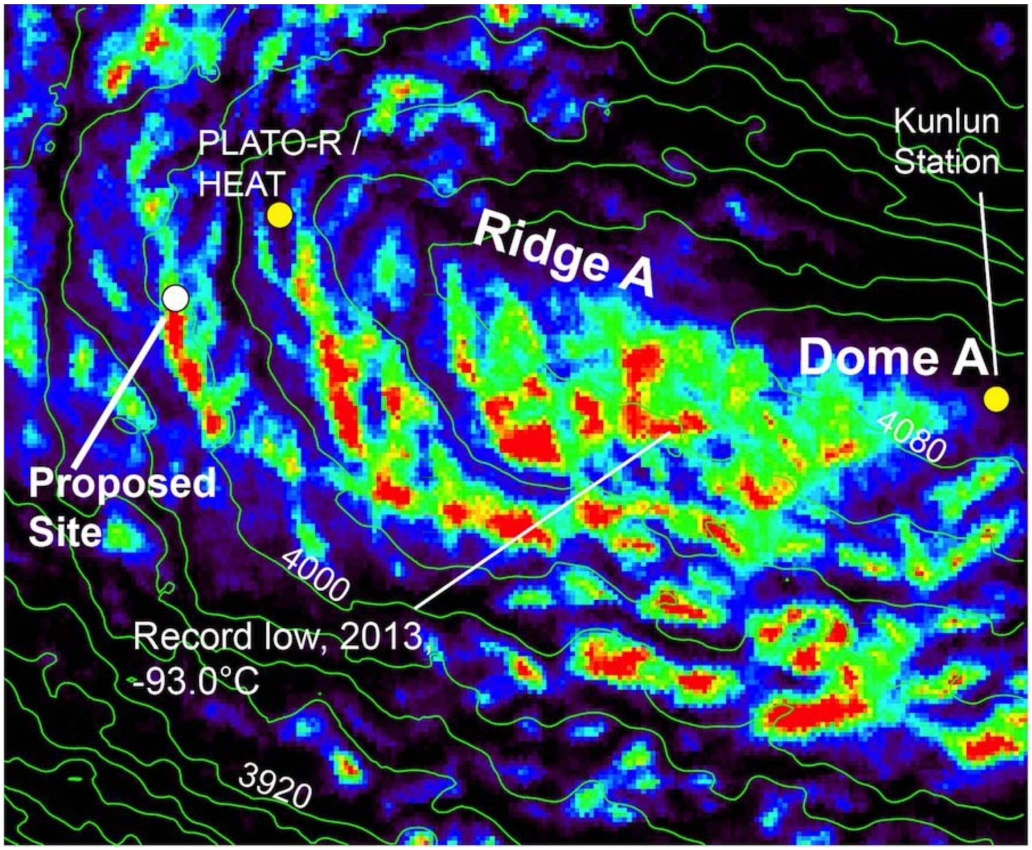

Figure 1: Close up of the proposed AMIGOS "cold sink" site in relation to the HEAT and PLATO-R installation and Dome A. The color scale represents the increasing occurrence rate of surface temperatures below -88C as determined by Land Surface Temperatures from the MODIS instruments on board NASA's Terra and Aqua satellites. Image courtesy of Ted Scambos.

UNSW

MICHAEL C. B. ASHLEY
PROFESSOR
Department of Astrophysics and Optics
School of Physics

25 Oct 2015

Dr. Craig Kulesa
The University of Arizona
Tucson, AZ 85721 USA

Dear Craig,

I acknowledge that I am identified by name as a collaborator on the investigation entitled 'Phase 2 Development of the HEAT Observatory at Ridge A' that is being submitted by Dr. Craig Kulesa in response to NSF Program Solicitation 15-1 (Advanced Technologies & Inst.), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

The development of the PLATO-R observatory supporting the HEAT telescope at Ridge A was funded by the Australian Federal Government with a $500k grant to my research group. UNSW, Astronomy Australia Limited, and the Australian Antarctic Division, have since contributed in excess of $300k directly and in-kind. We have provided 2-3 scientists and engineers to assist with the work at Ridge A each year, and we also remotely operate the PLATO-R observatory.

The HEAT project—operating a state-of-the-art THz telescope at a deep field site 950km from South Pole—is an extraordinary achievement. The quality of the data returned has demonstrated the exceptional qualities of the Ridge A site. This new NSF proposal represents an exciting jump in capabilities for HEAT, and I am pleased to reaffirm the commitment of my research group to working on the project.

Yours sincerely,

M. Ashley

Prof. Michael Ashley

THE UNIVERSITY OF NEW SOUTH WALES
UNSW SYDNEY NSW 2052 AUSTRALIA
Telephone: +61 2 9385 5465
Facsimile: +61 2 9385 6060
Email: m.ashley@unsw.edu.au

UNSW

PROFESSOR
MICHAEL BURTON
BA (Hons), MA, MMaths, PhD, FASA, FAIP
Department of Astrophysics and Optics
School of Physics

26 October 2015

Dr Craig Kulesa
The University of Arizona
Tucson, AZ 85721, USA

Dear Craig

I acknowledge that I am identified by name as a collaborator on the investigation entitled “Continued Development of the HEAT telescope at Ridge A” that is being submitted by Dr. Craig Kulesa in response to NSF Program Solicitation AST/ATI: Advanced Tech. & Instr., and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

I am supported by the Australian Research Council with a $300K grant for a complementary project using the 22m Mopra telescope in Australia which will obtain the CO J=1-0 data at similar spatial and spectral resolution as the data being obtained by the HEAT telescope. The University of New South Wales is further supporting the project with an award of a further 300K to purchase the necessary observing time on the Mopra telescope to conduct this southern Galactic plane CO survey. These two facilities (HEAT and Mopra) work together towards the science objectives in this proposal, as evident through our two recent publications (Burton et al., 2013 & 2014) referred to in this proposal.

Yours sincerely,

Prof. Michael Burton

THE UNIVERSITY OF NEW SOUTH WALES
UNSW SYDNEY NSW 2052 AUSTRALIA
Telephone: +61 2 9385 5618
Facsimile: +61 2 9385 6060
Email: m.burton@unsw.edu.au
Web: www.phys.unsw.edu.au
ABN 57 195 873 179
CRICOS Provider Number: 00098G

SRON

Netherlands Institute for Space Research

Dr. Craig Kulesa
University of Arizona
Tucson, AZ 85721 USA
United States of America

SRON Utrecht
Sorbonnelaan 2, 3584 CA Utrecht,
The Netherlands
T +31 (0)88 777 5600, F +31 (0)88 777 5601
www.sron.nl
Your reference:
Our reference:
Direct dialling: +31(0)15-2781370
E-mail; j.r.gao@tudelft,nl
Date: Oct 15, 2015

Re: Letter of commitment for HEAT

Dear Dr. Kulesa

I acknowledge that I am identified by name as a collaborator on the investigation entitled 'Continued Development of the HEAT telescope at Ridge A' that is being submitted by Dr. Craig Kulesa in response to NSF Program Solicitation GPG 15-1 (Advanced Tech Instr. ATI), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

SRON's track record includes the Principal Investigator role of the HIFI instrument on Herschel, and contributions to the receivers for Band 9 of the Atacama Large Millimeter Array. SRON still maintains a research and development program dedicated to SuperTeraHertz technology and towards heterodyne receivers. If HEAT is selected, SRON is committed to provide technical expertise in HEB mixer and to build two HEB mixers for HEAT.

I wish you and your team all success and look forward to a fruitful collaboration.

Sincerely yours.

Dr. Jian-Rong Gao
Project leader ofthe super-THz technology at SRON and TU Delft
Senior Instrument Scientist in SRON Netherlands Institute for Space Research
Part time senior researcher in Delft University of Technology

NSIDC
National Snow and Ice Data Center
World Data Center for Glaciology, Boulder

449 UCB
University of Colorado
Boulder, CO 80309-0449
Phone: +1.303.492.6199
Fax: +1.303.492.2468
Email: nsidc@nsidc.org
http://nsidc.org

29 October 2015

Dr. Craig Kulesa
University of Arizona
Tucson, AZ 85721 USA

Dear Craig;
I acknowledge that I am identified by name as a collaborator on the investigation entitled 'Phase 2 Development of the HEAT Observatory at Ridge A' that is being submitted by Dr. Craig Kulesa in Response to NSF Program Solicitation (Adv. Tech. & Instr.) and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Craig, the proposal looks excellent, and definitely a forerunner to greater radio astronomy science to come from the site. But of course my main interest is the unique climate and atmosphere-snow interactions that occur in the area. Our interests overlap: the extremely dry air, high altitude, and exceptionally thin inversion layer make for some remarkable climate properties. Radiative cooling to space is extremely efficient, creating surface skin temperatures as low as -90°C and lower. As you know, my group and I seek to install modified weather stations and a small tower profiler of the lower atmosphere and upper snow temperature to attempt to record these conditions. As a complimentary study to the atmospheric monitoring you are conducting on the Ridge, we seek to see how the ultra-cold inversion layer pools in adjacent topographic lows, permitting still greater cooling of the surface snow and perhaps creating a 2m thick or thicker layer of <90°C air. Our selected site is just ~26 km from PLATO-R / HEAT, and almost directly between the Ridge A instruments and South Pole.

Our group has submitted a RAPID proposal to NASA to fund the modification and preparation of the sensor group we will aim to install, but we require NSF-PLR logistical support to reach Ridge A, and the exceptional sites of ultra-cold austral winter conditions. We are striving to create the lightest, fastest-installing set of weather an snow sensors we can design at reasonable cost.

Collaboration between our studies offers a real chance to explore a true ‘edge of the Earth’, with atmospheric conditions fully 20°C colder than any in Greenland, and several degrees colder than past record air temperature measurements. Your data on tranmissivity, precipitable water, and the record you have of weather conditions will extend our planned results greatly. More important than records, however, is a complimentary understanding of air movement and energy balance between the cold Ridge A and the adjacent local lows, where the near-surface air layer pools.

I think it is clear that there is a unique science opportunity here, combining NASA and NSF resources, and an interest in a unique area of the atmosphere and ice sheet from two different perspectives.

Sincerely,

Dr. Ted Scambos
Senior Research Scientist, and Lead Scientist, National Snow and Ice Data Center

QUOTE from Universal Cryogenics

JOB CODE	Date	Quote #
UACL20K	10/2/2015	514

UNIVERSAL CRYOGENICS
1815 W. Gardner Ln.
Tucson, AZ. 85705
520-622-6277 ph
520-623-3167 fx
www.ucryo.com
kirby@ucryo.com

	Ship To
QUOTE VALID FOR 30 DAYS.	The University of Arizona Central Receiving 1145 South Warren Ave. Tucson, AZ 85721-0458 Attn Craig Kulesa
SHIPPING WILL BE ADDED TO FINAL INVOICE.	
PROGRESS PAYMENTS MAY APPLY WITH PO.	

Customer Name / Address
The University of Arizona

Customer Contact	Customer Contact Ph	Rep	Project
CRAIG KULESA			

Line	Item	Description	Qty	Rate	Total
1	Dewar	Southpole Dewar based on Closed Cycle System. -12-inch case section -Dewar stand and handles located around cold head for handling. -External case holes TBD for interface with customers system. -Case split at critical location for ease of dewar assembly with array. -Cold plate details to allow install of customers instrument. -System assembly and Stack up.	1	8,500.00	8,500.00
2	Cryo-Cooler	Existing Sunpower CryoTel CT Series cooler. - Sumitomo RDK-101 -Electronics contol box mounted in rack mount enclosure with cooling fan. -KF50 welded bellows interface mount. -SunPower cooling tube with heat exchange fins and high flow cooling fan to allow in lab testing. -Gold plated thermal bus bar interface from cold tip to cold plate. -Thermal radiation shield. -System design and integration.	1	29,000.00	29,000.00
3	Rad-Shield	Radiation shield attached to cold plate. -Allows flange mount at both ends.	1	1,000.00	1,000.00
4	Rigid-Supp-A	Internal Rigid Support System fixed between cold work regions.	1	650.00	650.00

UNIVERSAL CRYOGENICS TERMS AND CONDITIONS 2015 APPLY, THANK YOU FROM UNIVERSAL CRYOGENICS!	**Total**

QUOTE from Universal Cryogenics

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UACL20K	10/2/2015	514

UNIVERSAL CRYOGENICS
1815 W. Gardner Ln.
Tucson, AZ. 85705
520-622-6277 ph
520-623-3167 fx
www.ucryo.com
kirby@ucryo.com

	Ship To
QUOTE VALID FOR 30 DAYS.	The University of Arizona Central Receiving 1145 South Warren Ave. Tucson, AZ 85721-0458 Attn CRAIG KULESA
SHIPPING WILL BE ADDED TO FINAL INVOICE.	
PROGRESS PAYMENTS MAY APPLY WITH PO.	

Customer Name / Address

The University of Arizona

Customer Contact	Customer Contact Ph	Rep	Project
CRAIG KULESA			

Line	Item	Description	Qty	Rate	Total
13	baffle-filter-hldr	Baffle with filter holding on radiation shield cover.	1	375.00	375.00
14	Blank-Flange-A	Blank mounting Flange mounted to dewar. -Location TBD based on design. -Allows access to array install to match customers instrument design.	1	1,000.00	1,000.00
15	Design	Dewar Mechanical Design of system. -Design meetings and presentation at UofA.	1	1,000.00	1,000.00
16	Dewar-Test-A	Dewar Leak Checking, Vacuum and Cryogenic Testing of Dewar with Documentation.		1,000.00	1,000.00
17	DELIVERY TERMS	DELIVERY OF SYSTEM IS 16 - 18 WEEKS ARO.			

UNIVERSAL CRYOGENICS TERMS AND CONDITIONS 2015 APPLY, THANK YOU FROM UNIVERSAL CRYOGENICS!	**Total**	$45,000.00

NiPro Optics

QUOTATION NO.: 130917-3

DATE: October 17, 2015
QUOTE VALID THROUGH: March 17, 2016

7 Marconi
Irvine, CA 92618
Phone: (949) 215-1151

PREPARED BY: Laszlo Tamas
E-mail: Laszlo@NiProOptics.com

Company University of Arizona
Street 1401 E University Blvd Tucson, AZ 85721
City, state,zip Tucson, AZ, 85721
Phone:
Attention: *Craig Kulesa*

CUSTOMER RFQ NO.:

ITEM No.	DESCRIPTION	QUANTITY	UNIT PRICE	EXTENDED PRICE
1	M1 flat mirror, after cutting the first section, tool post will be moved to complete the full surface.	1	$9,500.00	$9,500.00
2	M2 30-degree off axis paraboloid mirror. 610 x 630 elliptical shape, 55 mm thick.	1	$14,000.00	$14,000.00
3	M3 on axis ellipsoidal mirror. OD 230 mm x 55 mm thick	1	$5,500.00	$5,500.00
4	Tooling	1	$5,000.00	$5,000.00
	Total			~~$34,000.00~~
	Notes:			
	1 - Mataerial is Al 6061 2 - Surface finish RMS < 10 micron			
	3 - Surface form will not be measured. Best practice will be used for mounting mirrors on fixturing to minimize distortion.			
	Deposit: 50% of total order.			
	Delivery: 8 weeks from receipt of deposit.			

Shipment: UPS ground shipping

FOB: Irvine, Ca.

VIRGINIA Diodes Inc.

QUOTATION: QTC111015UAz

TO: Craig Kulesa
University of Arizona
e-mail: ckulesa@as.arizona.edu

October 10, 2015
Total Pages = 1

We are pleased to offer the following budgetary quotation for Schottky diode multipliers.

Item	Description Unit	Price	Delivery
1	**1.45 THz Local Oscillator**	**$80,000**	**16 Weeks**

Output Power: >20 uW from 1.4 to 1.5 THz
Expected System Configuration: {PLO} + {Amplifier} + {D60 Doubler} + {D120 Doubler} + {D250 Doubler} + {T750 tripler} + {WR-0.65SHM}
RF Input Port: WR-0.65 Diagonal Feedhorn, 25 dB gain typical
DC Requirements: 12V @3A

NOTES:
All VDI components offered use planar diode technology and have no mechanical tuners.
This quote is valid for sixty days beyond date given above.
Delivery: Delivery dates shown are the expected maximum, VDI will add cost of shipping and insurance to invoice. Please include shipping instructions with the PO.
Terms: Net 30 days, VDI Terms and conditions apply.

Authorization:

Thomas W. Crowe, President
Virginia Diodes, Inc.

Roach 2 current status as of Sept. 2014
Updated Aug. 2014

Below are current estimated cost for each of the items that will be available.
The DRAM modules is required for a functional Roach2 board and it is a plug in module. You may also need either a CX4 or the SFP+ cards which are used in pairs to give 8 port output. Even though the power supply is listed separately, for a complete chassis assembly, it is already included. ADC cards suitable for Roach1 are also compatible for Roach2 cards.

Roach2 board assembly, unit price $3,650.00 Xilinx chip to be issued by customer.

DRAM modules Kingston, unit cost $45.00 (one unit per Roach board needed)

ATX power supply, unit cost $65.00, included in complete chassis price.

Complete chassis, power supply, fans, led board, power switch, and associated wiring; $550.0

SFP+ Card Mezzanine, unit cost $450.0
CX-4 card Mezzanine, unit cost $148.0
New ADC card 16 I/P 8 bit . $1500 ea

TOTAL of 1 x ROACH2 + 1 x DRAM + ATX + chassis + 2 x SFP + 2 x ADC5: $7460

PLATO-R budget estimate (cost USD)

Item	Description	Unit Cost	Qty	Total Cost
Engine	Hatz 1B30	4400	2	8800
Alternator	e-cyle	3500	2	7000
Engine Mounts	vibration damping	500	2	1000
Fuel lines				2000
Fuel filters		250	4	1000
Oil tanks and lines		250	4	1000
Air filters		200	4	800
Exhaust system		800	2	1600
Thermal Control				2000
Power distribution PCB		1400	2	2800
Wiring/cabling				2000
TOTAL				**$30,000**