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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 ☒

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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.

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PI/PD Name: John H Bieging

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

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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:
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- ☐ None

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

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 04-23 **NSF 05-608** **11/15/06**	**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 - GALACTIC ASTRONOMY PROGRAM**	**0709194**

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
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EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN) **866004791**	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

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 PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

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

TITLE OF PROPOSED PROJECT **Identifying Molecular Cloud Formation in the Galaxy**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 224,175	36 months	07/01/07	

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

- ☐ BEGINNING INVESTIGATOR (GPG I.A)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date ________
- ☐ HUMAN SUBJECTS (GPG II.D.6) Exemption Subsection ________ or IRB App. Date ________
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) ________
- ☒ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

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	Electronic Mail Address
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CO-PI/PD **Christopher K Walker**	PhD	1988	520-621-8783	cwalker@as.arizona.edu
CO-PI/PD				
CO-PI/PD				

Electronic Signature

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution 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 debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 04-23. 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).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix C 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 NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Appendix D 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.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME Mary Gerrow	Electronic Signature	Nov 15 2006 5:14PM

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
520-626-6433	maryg@u.arizona.edu	520-626-4130

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PROJECT SUMMARY

Identifying Molecular Cloud Formation in the Galaxy

What is the intellectual merit of the proposed activity?

The **origin of Galactic molecular clouds** ranks among the most poorly understood aspects of the interstellar life cycle, star formation and galactic evolution – to date, the formation of a molecular cloud has never been positively identified! However, the combination of publically available Galactic Plane infrared imaging surveys (e.g. IRAS, GLIMPSE and 2MASS), millimeter-wave CO surveys (e.g. FCRAO's Galactic Ring and Outer Galacy Surveys), and HI radio surveys (e.g. the VLA/Canadian/Southern Galactic Plane Surveys) now allow for the comprehensive **identification of regions in the Galaxy where molecular cloud formation may be occuring**. Such "proto-molecular clouds", where the hydrogenic gas may be fully molecular (H_2), but not yet observable in CO line emission, may be an important and unrealized component of the cold ISM. Understanding where and how molecular clouds form in the Galaxy will constrain theoretical models of this pivotal component of galaxy evolution and provide a better understanding of the **life cycle of the interstellar medium**.

Innovative new astronomical instrumentation developed (in part) by this team at infrared and submillimeter wavelengths will allow these identified regions to be characterized in detail. These new data products are carefully chosen either to "glue" disparate archival survey data together (ex. infrared absorption line spectroscopy will directly connect dust extinction to the abundance of CO and H_2) or to improve the interpretation of the existing survey data (ex. submillimeter, multi-line carbon and CO maps of subarcminute resolution). In total, this study will provide a **pathfinding finderchart for far-infrared observations** for future ground, stratospheric, and space-based observatories.

What are the broader impacts of the proposed activity?

All comprehensive science products from this study will be made available to the astronomical community via the Web. These survey products will include (1) extinction maps over much of the Galactic Plane derived from 2MASS and GLIMPSE as related to the atomic and molecular gas content derived from radio surveys, (2) measurement of the H_2 and CO abundance in relation to extinction throughout the Galaxy, and (3) identification of regions predicted (or observed) to be sites of molecular cloud formation.

The broadest impact however may be drawn from the use of these surveys as educational and outreach tools. The visage of the dusty lanes of the Milky Way has inspired artistic and scientific imaginations for generations. This inherent fascination is a powerful tool to attract "students" of all ages and callings to a better, more literate appreciation of the sciences. Thus, spreading enthusiasm for science and training the next generation of scientists is a significant component of this research program. Specifically, this proposal will target (1) web-based and local (ex. grade school) public outreach, (2) guiding and training undergraduate and graduate students, and (3) presentation of research results to the general public and astronomical community.

TABLE OF CONTENTS

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

Appendix Items:

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

Project Description

We propose to use a combination of archival and new observations at infrared, radio, and millimeter/submillimeter wavelengths to identify and characterize "proto-molecular clouds" in the Galaxy. Such a study would have a significant impact on our understanding of the initial conditions of star formation, galactic evolution and the interstellar medium of external galaxies. The proposed work will:

1. Produce a catalog of regions in the Galaxy where molecular cloud formation may be ocurring, using archival infrared, CO and HI data.
2. Directly measure the abundance and excitation of H_2, C and CO relative to infrared dust extinction & far-IR dust emission for each candidate "protocloud".
3. Aim to provide initial statistics to determine which mechanism of cloud formation is most prevalent in the Galaxy.
4. Present a "finder chart" of cloud formation for future submm/THz/far-infrared observatories such as SOFIA, ALMA, and Herschel.
5. Provide unique opportunities for public outreach and education, with regard to interactive online content, to programs for local schools, summer camps and (under)graduate student research projects.

1 Introduction

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

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

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

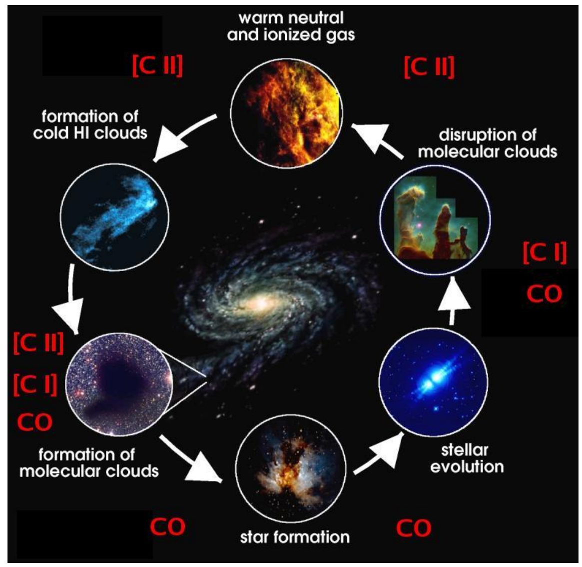

Figure 1: Life Cycles of the ISM

The life cycle of interstellar clouds is summarized pictorially in Figure 1. These clouds are largely comprised of atomic & molecular hydrogen and atomic helium. These species are notoriously difficult to detect under normal interstellar conditions. Atomic hydrogen is detectable via the 21 cm spin-flip transition and provides the observational basis for current models of a multi-phase Galactic ISM (Kulkarni & Heiles, 1987). Its emission is insensitive to gas pressure and does not always discriminate between cold (T$\sim$70K) atomic clouds and the warm (T$\sim$8000K) neutral medium that is thought to pervade the Galaxy. Furthermore, neither atomic helium nor molecular hydrogen (H_2) have accessible emission line spectra in the prevailing physical conditions in cold interstellar clouds. Thus, it is important to probe the nature of the ISM via rarer trace elements. Carbon, for example, is found in ionized form (C^+) in neutral clouds, eventually becoming atomic (C), then molecular as carbon monoxide (CO) in dark molecular clouds (Figure 2).

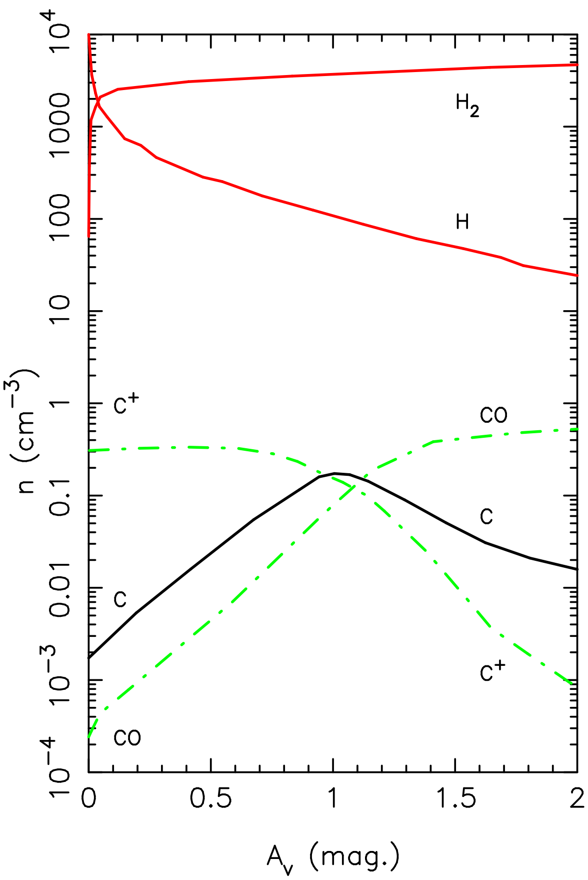

Figure 2: Steady state depth dependence of hydrogen and carbon species abundances in a typical molecular cloud exposed to the local interstellar radiation field. The HI–H_2 interface occurs long before the C^+–C–CO interface, leaving diffuse and translucent material whose hydrogen is fully molecular, but whose carbon is locked up in C^+. The depth difference between the hydrogen and carbon fronts INCREASES with the external radiation field strength and with decreasing cloud age.

The latter of these, the CO molecule, is the most prevalent gas-phase tracer of molecular clouds. Since its first measurement via millimeter-wave spectroscopy ∼35 years ago, numerous CO surveys now provide nearly all-sky coverage and are responsible for most of what is known about the distribution, physical structure and kinematics of molecular clouds in the Galaxy.

However, because the abundance of CO stabilizes only at significant cloud depths where hydrogen is already molecular (Figure 2), it makes an ineffective probe of the formative and disruptive stages of a cloud's life cycle. **Thus, despite great efforts and millions of CO spectra, the conclusive birth of a molecular cloud has never been identified!** Indeed, although we are now beginning to understand the formation of stars, the formation, evolution and destruction of their parent molecular clouds still remains (literally) shrouded in uncertainty.

The need to understand the evolution of interstellar clouds in the context of the initial conditions of star formation has become acute – driven by the advent of detailed infrared studies of external galaxies, the expectation of soon detecting the "first light" from primordial star-forming galaxies at high redshift, and the ever-increasing numerical resolution of galaxy simulations requiring better constraints on ISM physics. The National Research Council's most recent *Decadal Survey* has identified the study of star formation as one of the key recommendations for new initiatives in this decade. Similarly, understanding the processes that give rise to star and planet formation represent the central theme of NASA's ongoing Origins program.

1.1 Signposts of Molecular Cloud Formation

Theories of cloud formation are guided and constrained by observations of the atomic and molecular gas components. Based primarily on HI and CO observations, several mechanisms have been proposed to consolidate gas into GMC complexes (Figure 3): (1) gravitational-magnetothermal instabilities within the diffuse gas component, (2) collisional agglomeration of small atomic or molecular clouds, (3) accumulation of material within high pressure environments such as rings and shells generated by OB associations, and (4) compression in the randomly converging parts of a turbulent medium.

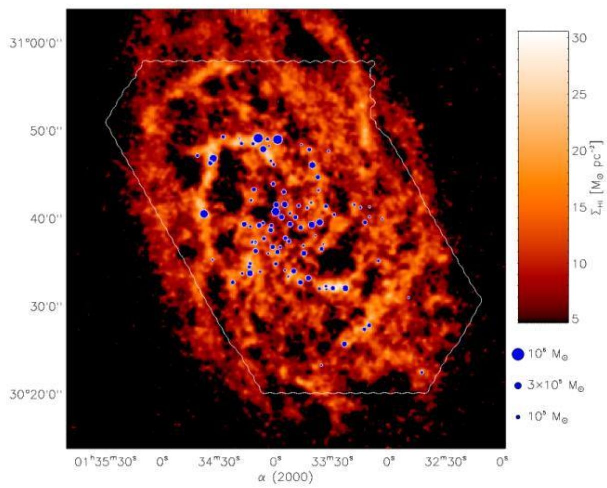

Figure 3: The location of GMCs in the nearby spiral galaxy M33 are overlaid upon an integrated intensity map of the HI 21 cm line (Engargiola, Plambeck, Rosolowsky, & Blitz, 2003). These observations show that GMCs are formed from large structures of atomic gas, foreshadowing the detailed study of GMC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

How might these mechanisms be differentiated? Clearly, a statistically-meaningful assessment of the formation of molecular clouds requires a survey of the Galactic Plane. Then, simply characterizing the Galactic environments of regions identified to be cloud-forming would be sufficient to disentangle the four principal mechanisms for Galactic cloud formation. However, identifying the environmental context of cloud formation requires a high resolution spectroscopic tracer. The role of turbulent flows, spiral arms, winds and shells, and cloud collisions are all kinematic phenomena which cannot be disentangled using continuum emission, but can be distinguished with spectroscopic imaging with ~ 1 km/s resolution.

What would a newly formed molecular cloud look like? Currently the association of diffuse gas (HI) with molecular gas (CO) is difficult owing to the large differences of emitting volumes of the HI and CO lines; that is, HI emission does not differentiate easily between cool atomic clouds and the warm diffuse ISM. However, Figure 2 shows that over a significant depth (which is larger still for newborn clouds), C and C^+ are the dominant carbon species and best spectroscopic probes of H_2 clouds with little CO. Indeed, dust lanes along the inner edges of spiral arms often show neither HI nor CO emission and are therefore likely to be in an intermediate phase; sufficiently dense and self-shielded to harbor H_2, but not CO (Wiklind et al., 1990). **This intermediate phase has received comparatively little recognition, but may play a crucial role in the sculpting of star forming clouds and thus entire galaxies!**

Future THz observatories will be able to survey the pivotal 158μm fine structure line of C^+ that will barometrically distinguish natal molecular clouds not seen in CO from diffuse atomic gas. Joined with CO, HI and infrared surveys, a dedicated THz survey telescope could advance our knowledge of star formation in the Galaxy in the following crucial ways – it would:

1. Map as a function of Galactic position the size and mass distribution and internal velocity dispersion of interstellar clouds in the Galaxy.
2. Construct the first barometric map in the Galactic Plane, the first map of the gas heating rate, and a detailed map of the star formation rate.
3. Probe the relation between the mass surface density (on kpc scales) and the star formation rate, so that we may be able to understand the empirical Schmidt Law used to estimate the star formation rate in external galaxies.
4. Reveal clouds clustering and forming in spiral arms and supershells, and fol-

low the growth of clouds to eventually shield molecules and become gravitationally bound.

5. Answer how the Galactic environment impacts the formation of clouds and stars. What are the specific roles of spiral arms, central bars, infall and other influences from outside the Galaxy?
6. Observe the formation and destruction of clouds throughout the Galaxy, and directly observe the feedback caused by supernovae and the ultraviolet radiation from massive stars.
7. Ultimately construct a Milky Way template connecting the line emission from C^+, N^+, C, CO, and dust continuum to star formation properties and state of the ISM. This template could be applied to nearby star-forming galaxies.

The importance of these fundamental measurements to a comprehensive picture of the cold ISM as it relates to star formation cannot be overstated! However the first generation of THz heterodyne instrumentation will have very limited mapping capabilities. For example – although SOFIA and Herschel will be capable of measuring 158μm [C II] spectra, they will possess heterodyne instruments with single diffraction-limited beams of 10-15$''$diameter, making large-scale mapping untenable. Two of the PI's (Walker & Kulesa) are currently performing a detailed design study under the auspices of NSF/OPP for HEAT, the High Elevation Antarctic Terahertz Telescope. A 0.5-meter telescope to be placed on Dome A (the summit of the Antarctic plateau) as early as 2009, HEAT will be dedicated to submm/THz CO, [C I] and [C II] surveys of the Southern Galactic Plane, but will still have a single 1-3$'$ spectroscopic beams at each frequency.

Clearly, in order to make significant progress forward on the topic of molecular cloud formation, it is necessary to focus the first THz observatories on specific regions of the Galaxy where cloud formation may be taking place. These "finder charts" would be based on the wealth of publically-available surveys from ground and space, in concert with new and unique ground-based instrumentation at infrared and (sub)millimeter wavelengths. It is the creation of these findercharts that is the focus of this proposed study.

2 Proposed Research Activity

2.1 *Generating Findercharts for Cloud Formation from Archival Data*

2.1.1 *Molecular Clouds at High Galactic Latitude*

This study will first hone its techniques by searching for molecular material in the diffuse ISM, a rich laboratory of molecule formation and destruction, and the putative medium from which dense molecular clouds are sculpted. The most visually stunning representations of the diffuse ISM are the far-infrared dust continuum maps of interstellar cirrus as first produced by IRAS (Low et al., 1984). Indeed, at high Galactic latitude, IRAS maps of the sky represent the most effective way to compute the combined column density of atomic and molecular hydrogen, $N_H = N(H) + 2N(H_2)$, once corrections for dust temperature, emissivity, and contamination by zodiacal dust have been applied. Such maps currently represent the best method of computing the foreground (Galactic) extinction toward extragalactic sources (Schlegel et al., 1998). After the IRAS mission, several studies aimed to assess the molecular component of high latitude clouds by accounting for the amount of infrared emission attributable to atomic gas via contemporary HI surveys. By subtracting the estimated contribution of HI gas (i.e. its associated dust) to the infrared continuum, molecular material would manifest itself as so-called "infrared excess clouds" (Desert et al., 1988; Reach et al., 1994, 1998). Several studies dis-

Survey	Product	Location	Resolution
FCRAO Galactic Ring Survey	^{13}CO J=1-0	Galactic Plane, 1st quadrant	$45''$
FCRAO Outer Galaxy Survey	^{12}CO J=1-0	Galactic Plane, 2nd quadrant	$45''$
Bell Labs 7m GPS	^{13}CO J=1-0	Galactic Plane, 1st/2nd quadrants	$3'$
CfA/Columbia CO survey	^{12}CO J=1-0	Galactic Plane, high-z	$>10'$
HI Parkes All Sky Survey	HI 21 cm	Galactic Plane, high-z	$15'$
Southern Galactic Plane Survey	HI 21cm	Galactic Plane, 4th quadrant	$1'$
Canadian Galactic Plane Survey	HI 21 cm	Galactic Plane, 1st/2nd quadrants	$1'$
VLA Galactic Plane Survey	HI 21 cm	Galactic Plane, 1st/2nd quadrants	$1'$
Leiden-Dwingeloo HI Survey	HI 21 cm	northern sky	$30'$
GLIMPSE	3.6-8 μm IR	Galactic Plane	1-5$''$
2MASS	1-2.4 μm IR	All Sky	$3''$

Table 1: Publically-available archival surveys which will be used during the course of this study.

covered that infrared excess clouds were frequently devoid of CO (Blitz et al., 1990; Reach et al., 1994; Meyerdierks & Heithausen, 1996; Lee et al., 1999; Onishi et al., 2001) and were interpreted as diffuse H_2 clouds. Indeed, this is also precisely the signature one would expect from natal molecular material!

Thus, we will extend the "infrared excess cloud" analysis of the aforementioned studies. From master maps of IRAS far-infrared emission (and Spitzer, when available), we will subtract the contribution of HI gas and the H_2 gas traced by ^{12}CO J=1-0 where both survey products are available (Table 1). Significant residual infrared excess represents H_2 gas with a comparatively weak or nonexistent CO counterpart – **a necessary signature of a newly-formed molecular cloud** that is either insufficiently UV-shielded or too chemically young to have yet formed much CO. Such residual H_2 clouds will be subdivided into two categories by the relative amplitude of the residual emission. Small excesses are likely to represent diffuse molecular clouds in which the volume and column densities are too low to support significant CO abundance and/or line excitation. Large excesses however, in which the residuals are comparable to the subtracted CO and HI emission, are more indicative of formative and transitional clouds en route to "traditional" CO-rich dark molecular clouds – and are of the greatest interest to this study.

A preliminary study was performed on the Polaris flare, a spur of infrared, CO and HI emission in the near vicinity of the North Celestial Pole. The analysis was compared to that of Meyerdierks & Heithausen (1996), and the results depicted in Figure 4. At left is plotted the CO J=1-0 emission from Dame et al. (2001), at center is the reference hydrogenic column density map of Schlegel et al. (1998), and at right is the column density map after subtraction of both the Meyerdierks & Heithausen (1996) HI map contents and CO. The northernmost clumps of emission are scarcely seen in CO, do not stand out at all above the ambient HI emission plateau, but are strongly visible in the IRAS maps (at 25, 60 and 100 μm). Thus, they remain in the subtracted plot as H_2-only clouds. The northern portion of the cloud, seen at top, has the appearance of being compressed by an old supernova remnant.

2.2 *Molecular Clouds in the Galactic Plane*

The advent of sensitive, large-scale CO J=1-0 observations to complement single-dish and interferometric HI surveys has enabled the all-sky mapping of molecular clouds and constitutes most of what is known about the overall physical structure and distribution of molecular gas in the Galaxy (Dame et al., 2001; Heyer

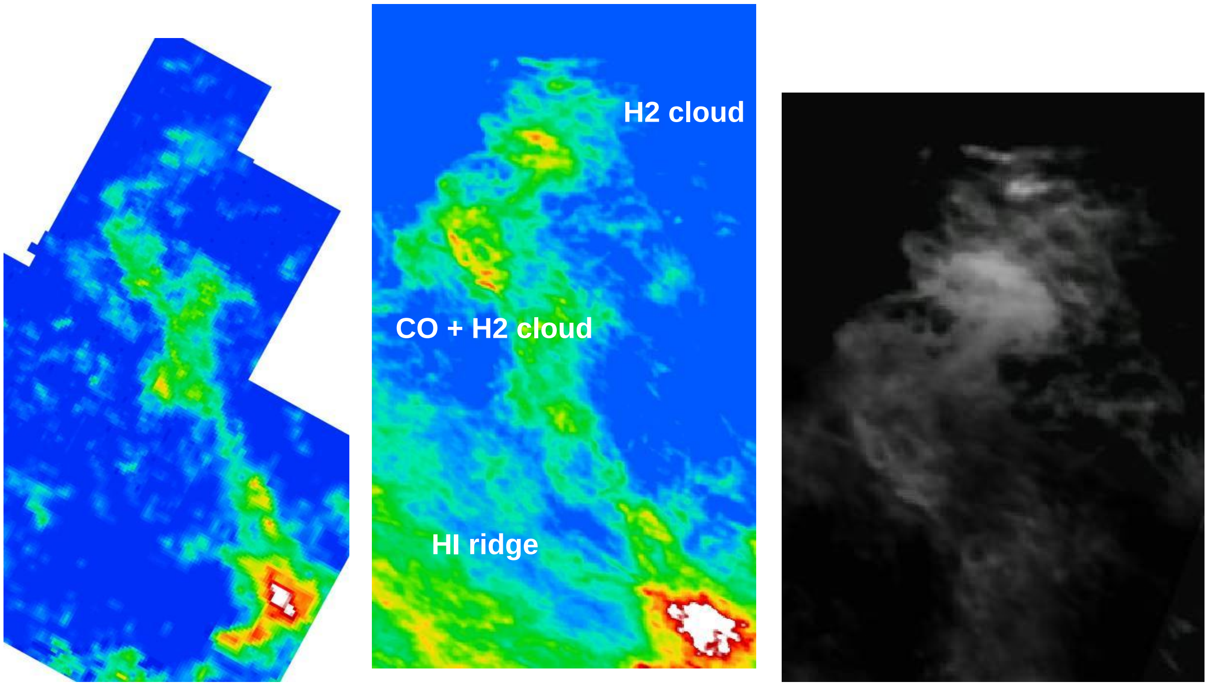

Figure 4: [LEFT] CO J=1-0 map of the Polaris Flare from the Milky Way survey of Dame et al. (2001). [CENTER] Column density map derived from the IRAS 100 μm survey (Schlegel et al., 1998), with results of preliminary analysis annotated; the peak intensity corresponds to $A_v = 7$. [RIGHT] Subtraction of HI and CO components from the column density map; leaving a residual of H_2 gas ($A_v \sim 2$) with little CO – the signature of molecular cloud formation that we will pursue in less diffuse environments elsewhere in the Galaxy.

et al., 1998; Lee et al., 2001; Jackson et al., 2006). Yet, understanding how dense molecular clouds are formed from a more diffuse atomic substrate is not observationally clear, despite millions of CO spectra! Figure 2 suggests that the answer lies in the low-visual extinction (A_v) molecular component not traced by CO, since it is in an intermediate state between diffuse atomic gas and dark clouds. Thus, we will search for H_2 clouds using a similar strategy as that adopted for high latitude clouds, above. However, we will need to start with a "master hydrogen map" optimized for studies in the Galactic Plane. Although far-infrared continuum emission from IRAS and Spitzer is still applicable, systematic uncertainties in emissivity and dust temperature make the translation to gas column density problematic. However, the GLIMPSE imaging survey of the Galactic Plane from Spitzer (Benjamin et al., 2003) and the 2MASS all-sky near-infrared survey (Skrutskie et al., 2006) allows infrared extinction maps using the NICE(R) algorithm (Lada et al., 1994; Alves et al., 2001) to be directly computed and translated to gas column density via canonical extinction laws (Rieke & Lebofsky, 1985). Once derived, the highest resolution Galactic Plane survey data of HI and CO can then be applied to and subtracted from these column density maps and a residual computed. In principle, this will lead to identification of regions where both CO and HI under-represent the state of the cold ISM and the existence of H_2 clouds with little CO can be verified. However, the plane of the Galaxy is kinematically complex – it is difficult enough to correlate CO and HI emission profiles, much less reference both quantities to an infrared-derived extinction that blindly measures the *total* absorbing column of all clouds along a given line of sight.

How will we bridge the fundamental differences between these survey data-types? First, interpreting color-color diagrams for the purpose of extinction measurements is much cleaner than at visible wavelengths, since the locus of points spanning unobscured stars is much more restricted. This makes differentiation of *intrinsic color* versus *color excess* more straightforward (Lada et al., 1994). This is particularly true when one adds the thermal infrared bands from GLIMPSE/Spitzer to the traditional J/H/K bands from 2MASS. Thus, lines of sight passing through multiple distinct spiral arms with dusty obscuration will lead to a color-color diagram with potentially distinguishable stellar loci that may be referenced kinematically to CO and HI emission. Secondly, we will accept that many regions along the Galactic Plane will be hopelessly confused and will not attempt to interpret them – the tangent arms at $l \sim 100^o$ and near the Galactic Center are likely to rank highest among these regions. We will concentrate on specific cloud complexes in the Outer Galaxy in coordination with Co-PI Bieging's ongoing CO surveys being performed at the HHT, and on regions of the Inner Galaxy with $30^o < |l| < 70^o$ and $|b| < 2^o$ where we can sample both "northern" and "southern" spiral arms and interarm regions, to help evaluate the role of the Galactic environment on potential sites of cloud formation. Finally, we will definitively differentiate gas and dust properties along complex lines of sight using ground-based high resolution infrared absorption line spectroscopy; discussion will follow in Section 2.3.1.

2.3 *Ground-Based Studies of Candidate Cloud Formation Regions*

Pathfinding studies using archival data surveys of CO and HI line emission coupled with near- and far-infrared continuum maps will provide a sample of regions suggestive of molecular cloud formation. Future THz observatories will be able to observe [C II] line emission toward these regions and, with knowledge of the contribution of hot ionized gas to the [C II] line intensity, will directly measure the interstellar pressure of H_2 clouds with little CO. These measurements will yield not only diffuse clouds with H_2 but will also yield the direct observation of bound molecular clouds forming from an atomic substrate.

However, the archival catalog of "protoclouds" can be improved in quality with selected ground-based observations that supplement and calibrate the rather disparate archival survey products, and provide fundamental new constraints on molecular cloud structure. We aim to do this in two diverse ways using unique instrumentation developed (in part) by this team of proposers at the University of Arizona:

1. Infrared absorption line spectroscopy will relate dust extinction to a directly-measured abundance of CO and H_2 for lines of sight spanning diffuse, translucent, and dense clouds throughout the Galaxy.
2. (Sub)millimeter wave mapping of higher excitation CO lines at the Arizona 10-meter Heinrich Hertz Telescope (HHT) will provide a complete excitation analysis that will dramatically enhance the interpretation of CO line emission and will improve upon the archival datas' angular resolution by up to an order of magnitude in many cases.
3. Measurement of carbon recombination lines at both infrared and submillimeter wavelengths will allow the fine structure level populations of C^+ to be measured – yielding *in advance of THz observations* the expected brightness and abundance of C^+ emission toward the most favorable lines of sight.

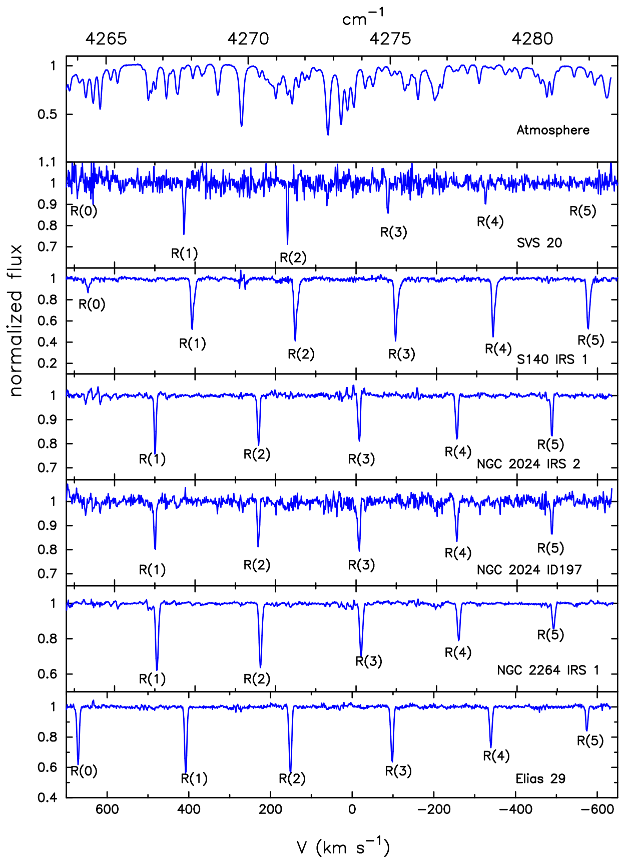

Figure 5: Spectra of ^{12}CO in the (2,0) R-band; R(0) through R(5). The uppermost spectrum is a typical comparison spectrum of the B2V star β_1 Sco that depicts the atmospheric transmission. The spectra are the ratioed (corrected) spectra of obscured (young) stellar objects that demonstrate prominent ^{12}CO absorption. The observed velocity shifts are due to the orbital motion of the Earth along the line of sight. These data were taken with the NOAO Phoenix spectrometer on the KPNO 2.1-meter telescope.

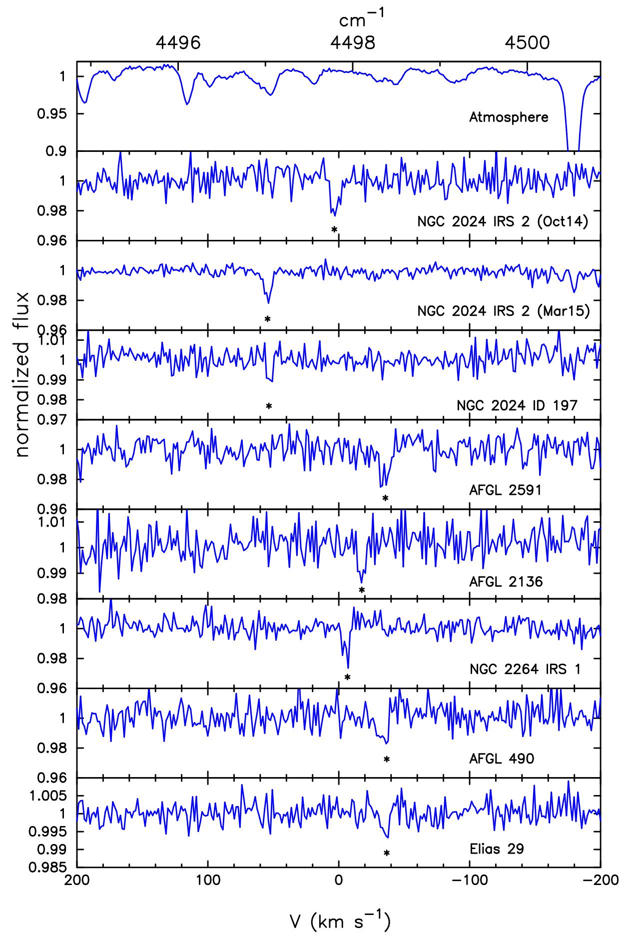

Figure 6: Direct measurements of H_2 line absorption in dark molecular clouds: the top plot represents the atmospheric transmission, ratioed astronomical spectra follow. The quality of the spectra obtained toward NGC 2024 IRS 2 at two different epochs can be compared to the landmark observations performed by Lacy et al. (1994). Asterisks show the V_{LSR} of CO absorption in each source.

2.3.1 Infrared Spectroscopy of Protoclouds

Although most interstellar molecules have been detected through millimeter-wave emission-line spectroscopy, this technique is inapplicable to non-polar molecules like H_2 (among others) which are central to our understanding of the structure and contents of molecular clouds and interstellar chemistry. **Thus high-resolution infrared spectroscopy plays an important but often unrecognized role in interstellar studies: significant non-polar molecules like H_2 can be directly observed alongside "common" molecules like CO, and their abundances and excitation conditions can be referred to the same "pencil-beam" absorbing column that gives rise to interstellar extinction.** With sufficient resolution and sensitivity, the long-sought relation connecting extinction, H_2, ^{12}CO and

^{13}CO can be conclusively and *directly* measured in dense clouds (Scoville et al., 1983; Black et al., 1990; Lacy et al., 1994; Kulesa & Black, 2002, 2006) as it has been in diffuse clouds (Bohlin, Drake & Savage, 1978). Figures 6 and 5 demonstrate the absorption line measurements of H_2 and ^{12}CO that this study will undertake.

ARIES, the Arizona Infrared Imager and Echelle Spectometer, is nearing completion as an adaptive optics instrument for the Arizona/SAO 6.5-meter MMT (McCarthy et al., 1998) and has the unique blend of high resolution ($\lambda/\Delta\lambda = 30,000 - 60,000$) and broad (cross-dispersed) simultaneous wavelength coverage needed for this project. The PI of this effort is on the ARIES instrument team. ARIES will be used at the 6.5-meter MMT to perform 1-5 μm absorption line spectroscopy of a sample of lines of sight through diffuse, translucent and dense lines of sight through the Galaxy. In the Galactic Plane, extinction measurements through complex lines of sight will be kinematically distinguished in H_2 and ^{12}CO line absorption at 2.1-2.3 μm with 5 km s^{-1} resolution, and directly comparable with radio measurements of CO and HI emission. Toward more diffuse lines of sight where the intrinsically weak H_2 lines cannot be measured, ^{12}CO can still be observed in its fundamental ro-vibrational bands at 4.6 μm and compared with its radio counterpart (Mitchell et al., 1989).

2.3.2 *Submillimeter Spectroscopy of Protoclouds*

Molecular line surveys have been performed over the entire sky in the light of the 2.6 millimeter J=1-0 lines of ^{12}CO and ^{13}CO and have been used to synthesize our best understanding of the molecular content of the Galaxy. Still, our understanding of Galactic molecular clouds is incomplete, since the J=1-0 lines are much less sensitive to warm, low-opacity, high velocity gas such as produced by outflows, photodissociation regions (PDRs), and shocks. This point is illustrated in Figure 8, with images of a synthetic model cloud constructed in the

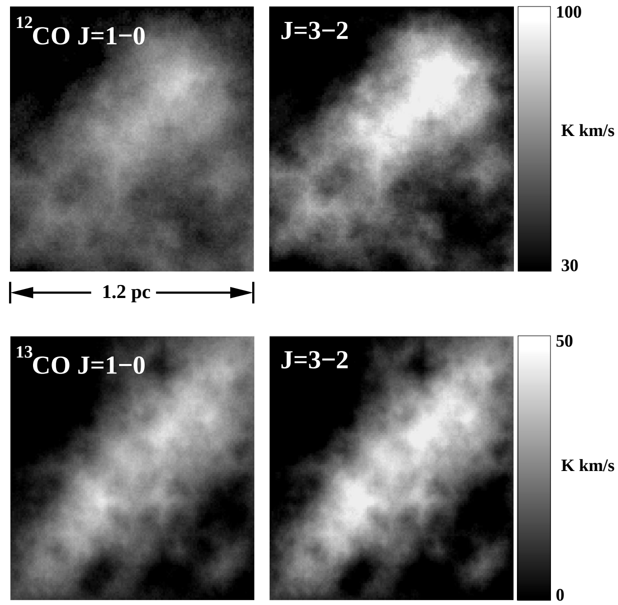

Figure 8: Simulated image of a fractal molecular cloud in several CO transitions shows the need for submillimeter CO lines. The energetic gas that interacts with stars is far better probed by the $3-2$ lines, however both $1-0$ and $3-2$ lines are needed together to extract a comprehensive understanding of cloud properties, dynamics & evolution.

integrated light of different spectral lines of CO. The model cloud is externally illuminated by a B star and cloud excitation, temperature and chemical abundances are determined self-consistently using Monte Carlo methods. The integrated spectral line images show that the heated portion of the cloud is largely missed by the J=1-0 lines, but captured by the J=3-2 lines. Reconstruction of the cloud based on observation of the ^{13}CO J=1-0 line alone recovers only 60% of the total cloud mass, whereas the combination of J=1-0 and J=3-2 lines recovers 90% of the H_2 mass.

A more comprehensive view of molecular clouds can therefore be gleaned from measurement of the submillimeter lines of CO and its isotopes, in combination with existing millimeter-wave observations. The gas probed by higher-J transitions is of greatest interest to our posed questions – it is the *energetic* gas

Figure 7: [LEFT] The purple imager and green spectrometer halves of the Arizona Infrared Imager and Echelle Spectrometer, slated for first light at the adaptive optics focus of the 6.5-meter MMT in December 2006. [RIGHT] Supercam, a 64-beam heterodyne receiver operating in the 345 GHz atmospheric window, slated for the HHT. Both instruments are unique and dovetail into the proposed science program.

that 1) participates in disruptive molecular outflows, 2) senses radiation fields at the photodissociated surfaces of clouds, and 3) is warmed by star-formation in cloud cores. Higher-J lines provide the dynamic range of excitation needed to interpret cloud properties from existing CO J=1-0 observations.

Unique new (sub)millimeter instrumentation offers new capabilities for mapping candidate regions. Walker and Kulesa are PI and Co-PI (respectively) of the *Supercam* instrument, a 64-beam heterodyne array for spectroscopic imaging in the 345 GHz atmospheric window (Groppi et al., 2006). When Supercam is completed in 2007, it will be the largest submillimeter heterodyne array in the world and will be capable of mapping CO J=3-2 with unprecedented speed and sensitivity (e.g. 3 hours per square degree of coverage). On the 10-meter Heinrich Hertz Telescope (HHT), Supercam will have angular resolution of $20''$ per diffraction-limited beam.

The HHT is now home to the world's most sensitive 230 GHz receiver. Equipped with prototype Band 6 ALMA mixers from NRAO, the facility receiver now offers simultaneous detection of the ^{12}CO and ^{13}CO J=2-1 lines with many times the sensitivity of the previous receiver system. System temperatures of 100K (SSB) have been measured in moderate weather conditions on Mt. Graham.

Using such unique instrumentation, we will map candidate cloud formation regions in ^{12}CO and ^{13}CO J=2-1 and 3-2 line emission much more sensitively, and with much higher angular resolution than provided by archival survey data. For high latitude clouds, these measurements of minute quantities of CO will directly measure the temperature and density of the cloud regions and confirm whether the molecular gas is likely to be diffuse and tenuous, or transitioning toward more dense and self-gravitating clouds. Toward the Galactic Plane, the higher excitation conditions of the (sub)millimeter lines will better diagnose the translucent surfaces of molecular clouds, reveal the full excitation and column density of CO and thereby better constrain its formative state.

Finally, toward regions that seem to possess all of the proper characteristics of newborn molecular clouds, we will attempt to ascertain the state of carbon in forms *other* than CO. We will measure the fine structure line of atomic carbon in its (^{3}P) J=1-0 transition at 492 GHz and measure multiple radio recombination lines of carbon from 70 GHz (using the Arizona 12-meter) to 230 GHz (using the HHT). Just as optical recombination lines of hydrogen (e.g. H-α) probe *hydrogen-ionized regions*, radio recombination lines of carbon can probe *carbon-ionized regions* in which the hydrogen may be fully molecular but the carbon has had insufficient time or UV-shielding to transform into CO. Although the radio recombination lines are at least one order of magnitude less sensitive than far-infrared spectroscopy of 158 μm [C II] emission, both line emission strengths are density-sensitive and will therefore be able to discern H_2 *clouds* from *diffuse* H_2 *gas*. Thus, it may be possible to ascertain the state of C^+ and the internal pressure of the cloud in advance of regular THz observations – at least toward the most favorable lines of sight. The PI has performed test observations of the technique toward the northernmost portion of the Orion Molecular Cloud using the Arizona 12-meter; the first millimeter-wave detection of carbon recombination lines is shown in Figure 9. The direct measurement of hydrogen recombination lines in the same bandpass allows the warm ionized gas component of the C^+ emission to be directly measured and corrected for.

3 Summary

This study aims to advance the observational study of cloud formation in the Galaxy in advance of the first focused THz observatories which, coupled with this work, should soon be able to address these questions even more directly and conclusively. The results of this study will be a finderchart of candidate "protoclouds" that will be well-characterized with fundamental and new observations of dust extinction, CO and H_2. These additions will dramatically advance our knowledge of the molecular ISM in their own right. This study bears important implications for the theoretical/numerical modeling of galaxy evolution and to unresolved cloud and star formation in distant galaxies, highlighting its broad applicability to topics that are both fundamental and timely.

4 Educational Outreach and Broader Impact

The broadest impact of the proposed research however may be drawn from the use of these surveys as educational and outreach tools. The visage of the dusty lanes of the Milky Way has inspired artistic and scientific imaginations for generations. Indeed, a project that encompasses so much of the entire sky offers numerous opportunities to capture the imagination of students of all ages and persuasions. This inherent fascination is a powerful tool to attract "students" of all ages and callings to a better, more literate appreciation of the sciences. Thus, spreading enthusiasm for science and training the next generation of scientists is a significant component of this research program. Specifically, this proposal will target (1) web-based and local (ex. grade school) public outreach, (2) guiding undergraduate students toward a greater appreciation and hands-on understanding of science and its methods, and (3) training graduate students through innovative research, and presentation of research results to the general public and astronomical community. These notions are outlined below.

4.1 Web-based Outreach

More people rely on the Internet for news, information, and entertainment than ever before; a trend which is unlikely to change soon. Thus, providing online outreach tools that are accessible and interesting would be a useful,

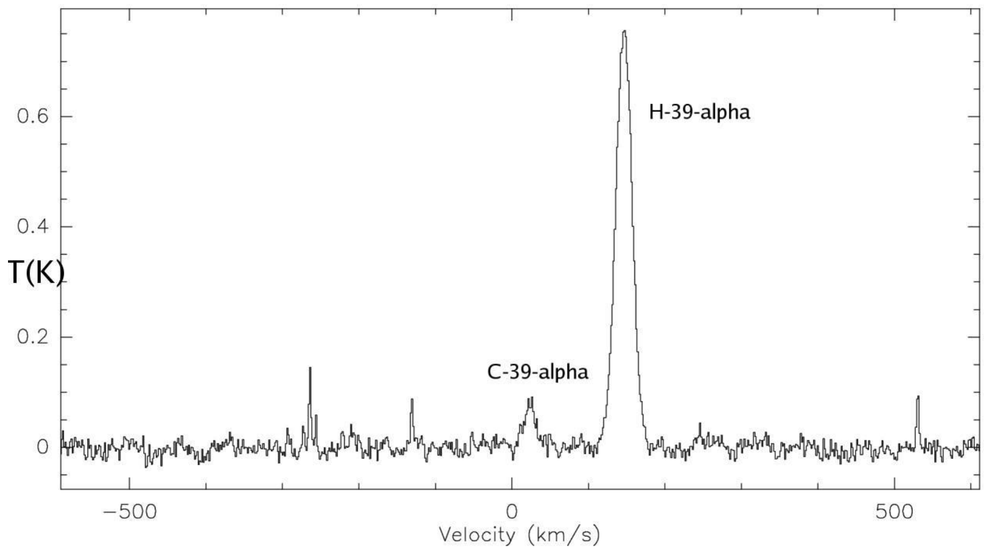

Figure 9: First detected carbon recombination line spectrum at mm-wavelengths, taken toward the northernmost edge of the Orion Molecular Cloud. The 39α lines of hydrogen and carbon are observed adjacent to each other in this spectrum at 106.8 GHz = 2.8 mm, taken at the Arizona (formerly NRAO) 12-meter. Analysis of multiple recombination lines allows reverse-construction of the C^+ level populations and 158 μm line intensity.

if indirect way of reaching the widest range of people. Distributed software should be operable on multiple platforms and be open source, so that others in the online community can embrace and extend what is provided in the confines of this study. A practical application would be, for example, to present a view onto the multiwavelength Universe using existing planetarium software. For example, Stellarium (`http://www.stellarium.org/`) is a visually stunning, 3D, open source planetarium package for Linux/BSD Unix/Macintosh/Windows (Figure 10. Writing a plugin to allow the user to put on different wavelength "glasses" to view the IRAS 100 μm sky in place of the visible one – or CO J=1-0 or HI 21 cm emission, is a tractable possibility and could be used to visualize the Galaxy in new ways with a minimum of distracting software efforts.

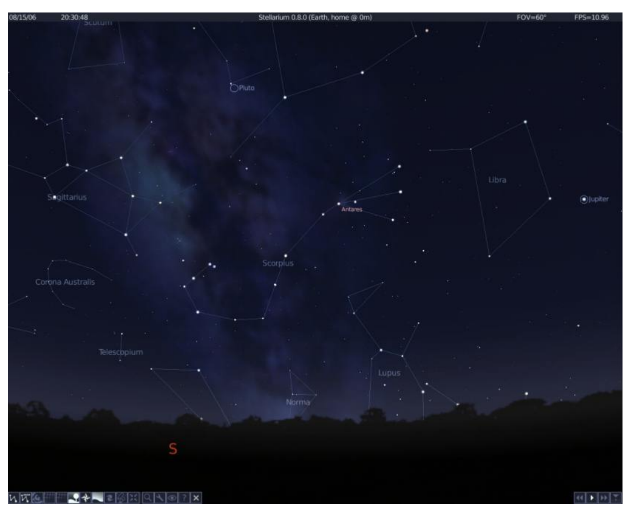

Figure 10: Open source planetarium software such as `stellarium` represent useful tools with which maps of the sky at other wavelengths can be rendered.

4.2 *Summer Outreach Programs for Teens*

The PI is a long-time counselor for the University of Arizona Alumni Association's Astronomy Camp for adults and teens (`http://www.astronomycamp.org/`). In particular, the advanced teen camps in the summer present a gender-balanced group of ∼30 motivated high school students with the opportunity of becoming real astronomers for a week; they live in astronomer's dorms at the summit of Mt. Lemmon Observatory, devise astronomical research programs, write telescope proposals, perform observations, reduce their data and present their results to the group. Many of them continue their research long after Camp concludes. Some of the earliest teen campers from the early 1990's have completed their Ph.D's in astronomy and other scientific fields! In concert with this study, we would integrate archival data of HI, CO and extinction into a uniform MySQL database that students could query and implement in their own projects – just as the investigators will do for the principal science program!

4.3 Undergraduate and Graduate Student Guidance and Training

The formal education of undergraduate students occurs through both the traditional classroom setting and through undergraduate research. However, the crucial role of creative inquiry in the development of a scientist is often better served outside the classroom. Since archival data is already pre-reduced, one can concentrate on more creative science-oriented problems; tasks particularly well suited for undergraduates or even first-year graduate students who are also new to astronomy. Similarly, advising graduate students is an essential role of University educators, because it is here where the next generation of professional scientists is prepared. This grant will support a portion of a graduate student's salary. Travel to scientific meetings is particularly important for graduate students – thus funding is requested to take a graduate student to at least one national meeting in the 2nd and 3rd years.

5 Prior NSF Support

This is the first proposal that PI Kulesa has authored to NSF/AST. He is a Co-PI on two ongoing instrumentation programs; *Supercam*, a 64-beam heterodyne array for the HHT (C. Walker, PI) funded through an NSF MRI grant (2004-2007), and the High Elevation Antarctic Terahertz Telescope (HEAT), a design study for an automated 0.5-meter THz telescope for Dome A, the apex of the Antarctic plateau, funded for 2006 through NSF's OPP program (2006 only). Both programs are ongoing and play an integral role in the definition of this proposed scientific endeavor.

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Onishi, T., Yoshikawa, N., Yamamoto, H., Kawamura, A., Mizuno, A., & Fukui, Y., "A Survey for High-Latitude Molecular Clouds toward Infrared-Excess Clouds with NANTEN", 2001, PASJ, 53, 1017

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Reach, W. T., Wall, W. F., & Odegard, N., "Infrared Excess and Molecular Clouds: A Comparison of New Surveys of Far-Infrared and HI 21cm Emission at High Galactic Latitudes", 1998, ApJ, 507, 507

Rieke, G. H., & Lebofsky, M. J., "The interstellar extinction law from 1 to 13 microns" 1985, ApJ, 288, 618

Schlegel, D. J., Finkbeiner, D. P., & Davis, M., "Maps of Dust Infrared Emission for Use in Estimation of Reddening and Cosmic Microwave Background Radiation Foregrounds", 1998, ApJ, 500, 525

Scoville, N., Kleinmann, S. G., Hall, D. N. B., & Ridgway, S. T., "The circumstellar and nebular environment of the Becklin-Neugebauer object - 2-5 micron wavelength spectroscopy", 1983, ApJ, 275, 201

Skrutskie, M. F., et al., "The Two Micron All Sky Survey (2MASS)", 2006, AJ, 131, 1163

Wiklind, T., Rydbeck, G., Hjalmarson, A., & Bergman, P., "Arm and interarm molecular clouds in M 83", 1990, A&A, 232, L11

Craig A. Kulesa

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Telephone: (520) 621-6540
FAX: (520) 621-1532
Email: ckulesa@as.arizona.edu
http://loke.as.arizona.edu/∼ckulesa/

Professional Preparation

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

Appointments

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

Selected Papers

1. "Large Scale CO and [CI] Emission in the Rho Ophiuchi Molecular Cloud", Kulesa, C.A., Hungerford, A.L., Walker, C.K., Zhang X., & Lane, A., 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. "CO Emission from Disks around AB Aurigae and HD 141569: Implications for Disk Structure and Planet Formation Timescales", Brittain, S. D., Rettig, T. W., Simon, T., Kulesa, C., DiSanti, M. A., & Dello Russo, N. 2003, ApJ, 588, 535
5. "Abundances of H_2, H_3^+ & CO in Molecular Clouds and Pre-planetary Disks", Kulesa, C. A. & Black, J. H. 2002, Chemistry as a Diagnostic of Star Formation, 60

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, in press (accepted Sept 12 2005)
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.

4. “Scientific results from the MMT Natural Guide Star Adaptive Optics System”, Kenworthy, M. et al., 2004, SPIE, 5490, 351.

5. “Infrared H_3^+ line absorption toward LkHα101”, Brittain, S., T. Simon, C. Kulesa & T. Rettig, 2004. ApJ, 606, 911.

Synergistic Activities:

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

Collaborations, 2004-2006:

J. Black (Onsala)
S. Brittain (Clemson)
M. DiSanti (Goddard)
N. Dello Russo (Goddard)
E. Gibb (Missouri)
C. Groppi (Arizona)
D. Hollenbach (NASA-Ames)
T. Huard (CfA)
A. Lane (Harvard/CfA)
P. Myers (CfA)
G. Narayanan (UMass/Amherst)
T. Rettig (Notre Dame)
T. Simon (Hawaii)
A. Stark (Harvard/CfA)
C. Walker (Arizona)
M. Wolfire (Maryland)
X. Zhang (NRL)

Ph.D. Advisors:

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

Ph.D. Advisees:

Sean Brittain (2003, Univ. of Notre Dame)
Abigail Hedden (estd. 2007, Univ. of Arizona)
Desika Narayanan (estd. 2007, Univ. of Arizona)

BIOGRAPHICAL SKETCH

Name: John Harold Bieging
Address: Steward Observatory, University of Arizona, Tucson, AZ 85721
Education:

Institution	Degree	Date	Field
Dartmouth College	A.B.	1968	Physics
California Institute of Technology	Ph.D.	1974	Astronomy

Employment History:

July 2003 to present: Professor of Astronomy, University of Arizona, and Astronomer, Steward Observatory

Aug. 1990 to June 2003: Associate Professor of Astronomy, University of Arizona, and Associate Astronomer, Steward Observatory.

Sept. 1978 to July 1990: Member of the research staff of the Radio Astronomy Laboratory at the University of California, Berkeley; Adjunct Associate Professor in the Berkeley Astronomy Department.

Oct. 1977 to Aug. 1978: Senior physicist in the Advanced Programs Laboratory of 3M Company's Central Research Laboratories, St. Paul, Minnesota.

Jan. 1974 to Sept. 1977: Postdoctoral fellow and member of the scientific staff of the Max Planck Institute for Radio Astronomy in Bonn, Germany.

Academic and Professional Societies: American Astronomical Society; International Astronomical Union; International Union of Radio Science; Phi Beta Kappa

Selected Publications:

1) *Related to this proposal*

V. Pankonin, E. Churchwell, C. Watson, and J.H. Bieging 2001, "A Methyl Cyanide Search for the Earliest Stages of Massive Protostars", *Astrophysical Journal*, 558, 194-203.

J.H. Bieging and C.D. Wilson 2001, "High Resolution Images of CO J=2-1 Emission from the Carbon Star V Cyg", *Astronomical Journal*, 122, 979-990.

J.H. Bieging 2001, "Discovery of Two New HCN Maser Lines in Five Carbon Stars", *Astrophysical Journal*, 549, L125-L129.

J.H. Bieging, S. Shaked, and P. Gensheimer 2000, "Submm- and mm-wavelength Observations of SiO and HCN in Circumstellar Envelopes of AGB Stars", *Astrophysical Journal*, 543, 897-921.

J.H. Bieging, "Radio Observations of the Isotopic Composition of the Galaxy", 1997, in *The Astrophysical Implications of the Laboratory Study of Presolar Materials*, eds. T.J. Bernatowicz and E. Zinner, (New York: AIP Press), pp. 265 - 283.

2) *Other significant publications*

B.J. Hrivnak and J.H. Bieging 2005, "CO J=2-1 and 4-3 Observations of Proto-planetary Nebulae: Time-variable Mass Loss", *Astrophysical Journal*, 624, 331

B.D. Oppenheimer, J.H. Bieging, G.D. Schmidt, K.D. Gordon, K.A. Misselt, & P.S. Smith 2005, " Spectropolarimetry and Radiative Transfer Modelling of Three Proto-planetary Nebulae", *Astrophysical Journal*, 624, 957

J.H. Bieging, M.J. Rieke, and G.H. Rieke 2002, "CO 1st Overtone Spectra of Cool Evolved Stars: Diagnostics for Hydrodynamic Atmosphere Models", *Astronomy and Astrophysics*, 384, 965-981.

J.H. Bieging and W.L. Latter, "A Molecular Line Survey of S Stars for Mass Loss and Chemistry", 1994, *Astrophysical Journal*, 422, 765-782.

J.H. Bieging and M. Tafalla, "The Distribution of Molecules in the Circumstellar Envelope of IRC+10216: HC_3N, C_3N, and SiS", 1993, *Astronomical Journal*, 105, 576-594.

Synergistic Activities:

-dissemination of research results to the wider public by lectures and presentations, e.g, through Steward Observatory programs, student clubs and other organizations, and public schools.

-teaching of introductory astronomy classes to non-science students at the University of Arizona. Typical enrollments are 150-200 per class, offering a large audience the possibility to appreciate the results of current research and implications for society.

-advising and mentoring graduate and undergraduate students in research projects, supported by grant funds, to do research and to travel to meetings to present the results to professional astronomers and other students.

Collaborators and other affiliations:

(1) Collaborators (last 4 years)
E. Churchwell (Univ. Wisconsin)
A. Dayal (KLA Tencor)
P. Gensheimer (Univ. Arizona)
W. Hoffmann (Univ. Arizona)
B. Hrivnak (Valparaiso Univ.)
R. Lucas (IRAM, France)
W. Latter (IPAC/Caltech)
D. Muders (MPIfR, Bonn)
H. Olofsson (Onsala Obs.)
V. Pankonin (NSF)
G. Rieke (Univ. Arizona)
M. Rieke (Univ. Arizona)
J. Saucedo Morales (Univ. Hermosillo)
F. Schoier (Stockholm Univ.)
A. Tielens (Univ. Groningen)
T. Wilson (Univ. Arizona & MPIfR-Bonn)
L. Ziurys (Univ. Arizona)

(2) Graduate and postdoctoral advisors
Graduate advisor: A.T. Moffett (Caltech)

Postdoctoral advisors (with current affiliation):
P.G. Mezger (MPIfR, Bonn; emeritus)
T.L. Wilson (ESO, Garching, Germany)
D. Downes (IRAM, Grenoble, France)

(3) Graduate student advisees (past 5 years):
Julio Saucedo Morales (Univ. Hermosillo)
Casey Meakin (Univ. Arizona)
Ben D. Oppenheimer (Univ. Arizona)
Amelia Stutz (Univ. of Arizona)

No. of graduate student advisees: 6

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: "Observations Studies of Star Forming Regions".
Postdoctoral Position: Millikan Fellow in Physics, Caltech, 1988-1991.

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

Five Selected Publications (Refereed Journal)

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.

Groppi, C., Kulesa, C., Walker, C., and Martin, C., 2004, *Millimeter and Submillimeter Survey of the R Coronae Australis Region*, *Ap. J.,* **612**, 946.

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.,* **150**, 239.

Melia, F., Bromley, B., Liu, S., and Walker, C.K. 2001, *Measuring the Black Hole Spin in Sag A* *, *Ap. Letters*, **554**, 37.

Tieftrunk, A., Jacobs, K., Martin, C., Siebetz, O., Stark, A., Stutzki, J., Walker, C., and Wright, G. 2001, ^{13}*CI in High-mass Star-forming Clouds*, *A. & A.*, **375L**, 23.

Five Selected Publications (Conference Proceedings)

Groppi, C., Walker, C.K., D. d'Aubigny, C., Kulesa, C., Hedden, A., Prober, D., Siddiqi, I., Kooi, J., Lichtenberger, A., and Chin, G. 2002, *Integrated Heterodyne Arrays for FIR Spectroscopy, Proceedings of Far-IR, Sub-MM and MM Detector Technology Workshop*, April 01-03, Monterey, CA.

Walker, C.K., Groppi, C., D. d'Aubigny, C., Kulesa, C., Hungerford, A., Jacobs, K., Graf, U., Schieder, R., and Martin, C. 2001, *PoleSTAR: A 4-Pixel 810 GHz Array Receiver for AST/RO, Proceedings of the* 12^{th} *International Symposium on Space TeraHertz Technology*, San Diego, CA, eds. Mehdi & McGrath, JPL.

Walker, C.K., Groppi, C., D. d'Aubigny, Chin, G., Schieder, R., Narayanan, G., Lichtenberger, A., and

Siegel, P. 2000, *Far-Infrared Array Receiver for SOFIA, Proc. SPIE*, **4014**, 125.
Groppi, C., Walker, C., Hungerford, A., and Narayanan, G., 2000, *345 GHz Array Receiver for the Heinrich Hertz Telescope, Proc. SPIE*, **4015**, 253.
Drouet d-aubigny, C., Walker, C., Groppi, C. Hill, J., Bieging, J., and Pompea, S. 2000, *Submillimeter-wave Receiver System for the Large Binocular Telescope, Proc. SPIE*, **4015**, 268.

Synergistic Activities

The training of students in the development of state-of-the-art instrumentation is essential to the future of science. This is particularly true in mm/submm astronomy where technological advances are happening so rapidly. Ironically, there are only a handful of laboratories in the world where students gain hands-on experience in the design, fabrication, and fielding of radio astronomy instrumentation. In the PI's lab we have been fortunate to have had a number of talented students pursue their research. Over the past 10 years the lab has produced 6 Ph.D.'s and numerous undergraduate senior projects. All the former Ph.D. students are still pursuing astronomical research and a number of the undergraduates have gone on to receive Ph.D.'s at other institutions. In recent years research in the lab has drawn an increasing number of students from other departments, particularly optical sciences and electrical engineering. Many students in science and technology have an interest in astronomy. It is this interest and the interdisciplinary nature of the research that attracts them to the PI's lab. In an effort to reach this population of students, the PI and fellow faculty members in other departments are seeking to establish an interdisciplinary program in astronomical instrumentation. Two of the PI's past Ph.D. students have received majors and minors in different departments. The PI currently has 7 graduate and 5 undergraduate students participating in interdisciplinary studies.

Collaborators and Other Affiliations

Gordon Chin (GSFC), Neal Erickson (U.Mass), Eyal Gerecht (NIST), Dave Glaister (Ball Aerospace), Martin Harwitt (SAO), Carl Heiles (UC Berkeley), Mark Heyer (U.Mass), David Hollenbach (NASA ARC), Jonathan Kawamura (JPL), Jacob Kooi (Caltech), John Kraus (OSU), Adair Lane (CfA), William Langer (JPL), Christopher Martin (CfA), Imran Mehdi (JPL), Arthur Lichtenberger (U.Va), Gopal Narayanan (U.Mass), Gordon Stacey (Cornell), Antony Stark (CfA), Mark Swain (JPL), Rodger Thompson (UofA), Sander Weinreb (JPL/Caltech), Erick Young (UofA), Sigfrid Yngvesson (U.Mass) Harold Yorke (JPL)

Graduate/Postdoctoral Advisors

John D. Kraus (OSU) for MSEE, Charles J. Lada (Harvard) for Ph.D., T.G. Phillips (Caltech) for postdoc

Thesis Advisor/ Post Graduate Sponsor

Past Ph.D. Advisees: Christian Drouet d'Aubigny (U AZ), Jason Glenn (UC Bolder), Craig Kulesa (U AZ), Gopal Narayanan (U. Mass), Grace Wolf-Chase (Adler Planetarium), Chris Groppi (NRAO)

Total Number of Graduate Students Supervised: 6 current, 7 past
Number of Postdoctoral Sponsorships: 3 current

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: University of Arizona

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Craig A Kulesa

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 - Asst. Astronomer	5.00	0.00	0.00	$ 22,845	$
2. John H Bieging - Professor	0.00	0.00	0.00	0	
3. Christopher K Walker - none	0.00	0.00	0.00	0	
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)	5.00	0.00	0.00	22,845	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				8,527	
4. (1) UNDERGRADUATE STUDENTS				2,898	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				34,270	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				9,490	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				43,760	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				700	
2. FOREIGN				0	
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				2,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,250	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				900	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				5,150	
H. TOTAL DIRECT COSTS (A THROUGH G)				49,610	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 51% of MTDC (Rate: 51.0000, Base: 47274)					
TOTAL INDIRECT COSTS (F&A)				24,110	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				73,720	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 73,720	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME: Craig A Kulesa

ORG. REP. NAME*: Mary Gerrow

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION University of Arizona	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Craig A 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 - Asst. Astronomer	5.00	0.00	0.00	$ 23,302	$
2. John H Bieging - Professor	0.00	0.00	0.00	0	
3. Christopher K Walker - none	0.00	0.00	0.00	0	
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)	5.00	0.00	0.00	23,302	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				8,698	
4. (1) UNDERGRADUATE STUDENTS				2,956	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				34,956	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				9,680	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				44,636	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,200	
2. FOREIGN				0	
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				200	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,250	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				900	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				3,350	
H. TOTAL DIRECT COSTS (A THROUGH G)				50,186	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 51% of MTDC (Rate: 51.0000, Base: 47803)					
TOTAL INDIRECT COSTS (F&A)				24,380	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				74,566	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 74,566	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

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

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION University of Arizona	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Craig A 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 - Asst. Astronomer	5.00	0.00	0.00	$ 23,768	$
2. John H Bieging - Professor	0.00	0.00	0.00	0	
3. Christopher K Walker - none	0.00	0.00	0.00	0	
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)	5.00	0.00	0.00	23,768	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				8,872	
4. (1) UNDERGRADUATE STUDENTS				3,015	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				35,655	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				9,874	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				45,529	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,200	
2. FOREIGN				0	
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				200	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,250	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				900	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				3,350	
H. TOTAL DIRECT COSTS (A THROUGH G)				51,079	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 51% of MTDC (Rate: 51.0000, Base: 48648)					
TOTAL INDIRECT COSTS (F&A)				24,810	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				75,889	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 75,889	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

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

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION: University of Arizona				FOR NSF USE ONLY	
				PROPOSAL NO.	DURATION (months): Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Craig A 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 - Asst. Astronomer	15.00	0.00	0.00	$ 69,915	$
2. John H Bieging - Professor	0.00	0.00	0.00	0	
3. Christopher K Walker - none	0.00	0.00	0.00	0	
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)	15.00	0.00	0.00	69,915	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (3) GRADUATE STUDENTS				26,097	
4. (3) UNDERGRADUATE STUDENTS				8,869	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				104,881	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				29,044	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				133,925	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				5,100	
2. FOREIGN				0	
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				2,400	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				6,750	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				2,700	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				11,850	
H. TOTAL DIRECT COSTS (A THROUGH G)				150,875	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				73,300	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				224,175	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 224,175	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

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

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

Budget Justification

A. Senior Personnel

5 months of calendar year salary for PI Kulesa is requested, with a 2% annual increase for inflation in the 2nd and 3rd calendar years.

B. Other personnel

1. Graduate students: support for one semester of one graduate student is requested each year, with a 2% annual increase for inflation in the 2nd and 3rd calendar years.

2. Undergraduate students: support for a research assistant for approximately 350 hours per academic year (~10 hr/week). If a strong candidate is found, we will request supplemental support for a summer appointment from the NSF REU program as a separate request.

C. Fringe benefits:

Rate for A and B.2 is 26.7% of salaries.

Rate for B.3 is 38.6% of wages, of which 11.2% is overhead bearing and 27.4% of which is for tuition remission and is overhead exempt).

Rate for B.4 is 3.4% of wages.

E. Travel:

This item support for one scientific meeting per year for 1-2 people to present results from the project at a rate of $700 per trip per person. Observation runs supporting this study require vehicular transportation to the telescope ($400 per run) for both infrared and submillimeter runs. Support for 2-3 runs per year in the 2nd and 3rd years are requested. Remote observing at the Arizona radio telescopes will be employed to minimize the number of trips required to the telescopes.

G. Other Direct Costs

1. Materials: A $2000 request for a data reduction workstation is made in year 1. This machine will be dedicated to the completion of the proposed work. This computer will store and provide Web access to the study's data products long past the performance period of the proposal.
2. Publication costs: support for page charges to refereed journals
3. Computer services: charges for 3 workstations on the Steward Observatory network, including the PI's existing data reduction machine and server for Internet access to the study's data products

I. Indirect costs

This project will be charged at the rate of 51% excepting graduate student fringe benefits, of which 11.2% is overhead bearing and 27.4% is overhead exempt (tuition remission). This is accounted for in the IDC calculated base.

Craig Kulesa

Current & Pending Support

Title ***Program Name***	***Agency***	***Performance Period*** ***Budget***	***Total Commitment*** (calendar months)
Development of a Submillimeter-wave Superheterodyne Camera (SuperCam) for the Heinrich Hertz Telescope	NSF/MRI	09/2004 - 08/2007 $1,742,356	6
HEAT: The High Elevation Antarctic Terahertz Telescope	NSF/OPP	07/2006 – 06/2007 $80,000	5
PENDING: Mapping the connections between molecular clouds, star formation, and stellar feedback	NSF/AST	07/2007 – 6/2010 $282,553	1
PENDING: Identifying molecular cloud formation in the Galaxy [THIS PROPOSAL]	NSF/AST	7/2007 – 6/2010 $224,175	5

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **John Bieging**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Probing mass loss mechanisms in AGB and post-AGB stars**

Source of Support: **NSF**

Total Award Amount: $ **153,976** Total Award Period Covered: **06/01/03 - 05/31/07**

Location of Project: **University of Arizona**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **1.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Mapping the connections between molecular clouds, star formation, and stellar feedback**

Source of Support: **NSF**

Total Award Amount: $ **282,553** Total Award Period Covered: **07/01/07 - 06/30/10**

Location of Project: **University of Arizona**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **1.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Identifying molecular cloud formation in the Galaxy (this proposal)**

Source of Support: **NSF**

Total Award Amount: $ **224,175** Total Award Period Covered: **07/01/07 - 06/30/10**

Location of Project: **University of Arizona**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Research Support
Investigator: Christopher K. Walker

CURRENT SUPPORT:

Project title: Development of a Submillimeter-wave Superheterodyne Camera (SuperCam) for the Heinrich Hertz Telescope
Source of Support: NSF MRI Program AST-0421499
Total Award Amount: $1,742,356 Total Award Period Covered: 09/01/04 - 08/31/07
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 1.0

Project title: Coherent THz Sources Using Carbon Nanotubes - PI: C. d'Aubigny
Source of Support: NSF - 05-557 SBIR/STTR Phase I
Total Award Amount: *$34,220 Total Award Period Covered: 01/01/06 - 12/31/06
*UA awarded amount
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: .50 Sumr:

Project title: A High Elevation Antarctic TeraHertz Telescope -HEAT-

Source of Support: NSF- OPP Antarctic Aeronomy & Astrophysics
Total Award Amount: $80,000 Total Award Period Covered: 07/01/06 – 06/31/07
Location of Project: The University of Arizona

Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 1.0

PENDING SUPPORT:

Project title: Identifying Molecular Cloud Formation in the Galaxy [PI: C. Kulesa] -- THIS PROPOSAL
Source of Support: NSF/AAG 05-608 Astronomy and Astrophysics Research
Total Award Amount: $224,175 Total Award Period Covered: 07/01/07 – 06/31/10
Location of Project: The University of Arizona

Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 0

Project title: Computing a Universe of Galaxies
Source of Support: NSF 05-627 DMS Infrastructure Program
Total Award Amount: $99,681 Total Award Period Covered: 08/01/06 - 07/31/07
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 0

Facilities and resources at Steward Observatory

As indicated in section 2 of the Project Description, one goal of the proposed research is to take advantage of the 10-meter Submillimeter Telescope (SMT), which went into operation on Mt Graham in southeastern Arizona in 1993. The current complement of receivers includes SIS–mixer systems for the 200-500 GHz atmospheric windows. Of particular relevence is the new 7-beam DesertSTAR receiver for 345 GHz operation, the Supercam 64-beam receiver that will replace it in 2008, and the upgraded 230 GHz balanced mixer receiver with ALMA Band 6 mixers.

Steward Observatory also shares in the operation of the 6.5-meter Multiple Mirror Telescope (MMT) on Mt Hopkins, operates a 2.3-meter telescope on Kitt Peak, and a 1.5-meter telescope on Mt Bigelow. A variety of instruments is available on these telescopes – of special note is the adaptive optics f/15 secondary which will be used with ARIES as described in the Project Description.

Steward Observatory maintains a local computer network, built around a number of PC workstations, and provides access to national/international networks.