Cover Page for Proposal Submitted to the National Aeronautics and Space Administration

NASA Proposal Number

TBD on Submit

NASA PROCEDURE FOR HANDLING PROPOSALS

This proposal shall be used and disclosed for evaluation purposes only, and a copy of this Government notice shall be applied to any reproduction or abstract thereof. Any authorized restrictive notices that the submitter places on this proposal shall also be strictly complied with. Disclosure of this proposal for any reason outside the Government evaluation purposes shall be made only to the extent authorized by the Government.

SECTION I - Proposal Information

Principal Investigator	E-mail Address	Phone Number
Christopher Walker	cwalker@as.arizona.edu	520-621-8783

Street Address (1)	Street Address (2)
933 N Cherry Ave	

City	State / Province	Postal Code	Country Code
Tucson	AZ	85721-0009	US

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

Proposed Start Date	Proposed End Date	Total Budget	Year 1 Budget	Year 2 Budget	Year 3 Budget	Year 4 Budget	Year 5 Budget
01 / 01 / 2017	12 / 31 / 2017	244,891.00	244,891.00	0.00	0.00	0.00	0.00

SECTION II - Application Information

NASA Program Announcement Number	NASA Program Announcement Title
NNH15ZDA001N-APRA	Astrophysics Research and Analysis

For Consideration By NASA Organization *(the soliciting organization, or the organization to which an unsolicited proposal is submitted)*

NASA , Headquarters , Science Mission Directorate , Astrophysics

Date Submitted	Submission Method	Grants.gov Application Identifier	Applicant Proposal Identifier
	Electronic Submission Only		

Type of Application	Predecessor Award Number	Other Federal Agencies to Which Proposal Has Been Submitted
New	NNX14AD58G	

International Participation	Type of International Participation
Yes	Equipment

SECTION III - Submitting Organization Information

DUNS Number	CAGE Code	Employer Identification Number (EIN or TIN)	Organization Type
806345617	0LJH3		2A

Organization Name (Standard/Legal Name)	Company Division
University Of Arizona	

Organization DBA Name	Division Number

Street Address (1)	Street Address (2)
888 N EUCLID AVE	

City	State / Province	Postal Code	Country Code
TUCSON	AZ	85719	USA

SECTION IV - Proposal Point of Contact Information

Name	Email Address	Phone Number
Christopher Walker	cwalker@as.arizona.edu	520-621-8783

SECTION V - Certification and Authorization

Certification of Compliance with Applicable Executive Orders and U.S. Code

By submitting the proposal identified in the Cover Sheet/Proposal Summary in response to this Research Announcement, the Authorizing Official of the proposing organization (or the individual proposer if there is no proposing organization) as identified below:

- certifies that the statements made in this proposal are true and complete to the best of his/her knowledge;
- agrees to accept the obligations to comply with NASA award terms and conditions if an award is made as a result of this proposal; and
- confirms compliance with all provisions, rules, and stipulations set forth in this solicitation.

Willful provision of false information in this proposal and/or its supporting documents, or in reports required under an ensuing award, is a criminal offense (U.S. Code, Title 18, Section 1001).

Authorized Organizational Representative (AOR) Name	AOR E-mail Address	Phone Number

AOR Signature *(Must have AOR's original signature. Do not sign "for" AOR.)* Date

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION VI - Team Members

Team Member Role	Team Member Name	Contact Phone	E-mail Address
PI	**Christopher Walker**	**520-621-8783**	**cwalker@as.arizona.edu**
Organization/Business Relationship: **University Of Arizona**		Cage Code: **0LJH3**	DUNS#: **806345617**
International Participation: **No**	U.S. Government Agency:		Total Funds Requested: **0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I	**Matthew Ashby**	**617-496-7742**	**mashby@cfa.harvard.edu**
Organization/Business Relationship: **Smithsonian Institution/Smithsonian Astrophysical Observatory**		Cage Code: **1PPP1**	DUNS#: **003261823**
International Participation: **No**	U.S. Government Agency:		Total Funds Requested: **0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I	**Craig Kulesa**	**520-621-6540**	**ckulesa@as.arizona.edu**
Organization/Business Relationship: **University Of Arizona**		Cage Code: **0LJH3**	DUNS#: **806345617**
International Participation: **No**	U.S. Government Agency:		Total Funds Requested: **0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I	**William Langer**	**818-395-5034**	**William.Langer@jpl.nasa.gov**
Organization/Business Relationship: **Jet Propulsion Laboratory**		Cage Code: **23835**	DUNS#: **095633152**
International Participation: **No**	U.S. Government Agency:		Total Funds Requested: **0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I	**Gary Melnick**	**617-495-7388**	**gmelnick@cfa.harvard.edu**
Organization/Business Relationship: **Smithsonian Institution/Smithsonian Astrophysical Observatory**		Cage Code: **1PPP1**	DUNS#: **003261823**
International Participation: **No**	U.S. Government Agency: **Smithsonian Institution**		Total Funds Requested: **0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I	**Jorge Pineda**	**626-429-0299**	**Jorge.Pineda@jpl.nasa.gov**
Organization/Business Relationship: **Jet Propulsion Laboratory**		Cage Code: **23835**	DUNS#: **095633152**
International Participation: **No**	U.S. Government Agency:		Total Funds Requested: **0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I	**Volker Tolls**	**617-495-7432**	**vtolls@cfa.harvard.edu**
Organization/Business Relationship: **Smithsonian Institution/Smithsonian Astrophysical Observatory**		Cage Code: **1PPP1**	DUNS#: **003261823**
International Participation: **No**	U.S. Government Agency:		Total Funds Requested: **0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I	**Harold Yorke**	**818-354-5515**	**Harold.Yorke@jpl.nasa.gov**
Organization/Business Relationship		Cage Code	DUNS#
Jet Propulsion Laboratory		**23835**	**095633152**
International Participation	U.S. Government Agency		Total Funds Requested
No			**0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I/Institutional PI	**Pietro Bernasconi**	**443-778-8970**	**pietro.bernasconi@jhuapl.edu**
Organization/Business Relationship		Cage Code	DUNS#
Johns Hopkins University		**5L406**	**001910777**
International Participation	U.S. Government Agency		Total Funds Requested
No			**0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I/Institutional PI	**Christopher Groppi**	**480-965-6436**	**cgroppi@asu.edu**
Organization/Business Relationship		Cage Code	DUNS#
Arizona State University		**4B293**	**943360412**
International Participation	U.S. Government Agency		Total Funds Requested
No			**0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I/Institutional PI	**Jonathan Kawamura**	**818-393-4779**	**jonathan.h.kawamura@jpl.nasa.gov**
Organization/Business Relationship		Cage Code	DUNS#
Jet Propulsion Laboratory		**23835**	**095633152**
International Participation	U.S. Government Agency		Total Funds Requested
No			**0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I/Institutional PI	**Antony Stark**	**617-496-7648**	**aas@cfa.harvard.edu**
Organization/Business Relationship		Cage Code	DUNS#
Smithsonian Institution/Smithsonian Astrophysical Observatory		**1PPP1**	**003261823**
International Participation	U.S. Government Agency		Total Funds Requested
No			**0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I/Institutional PI	**Mark Wolfire**	**301-405-1538**	**mwolfire@astro.umd.edu**
Organization/Business Relationship		Cage Code	DUNS#
University of Maryland, College Park		**0UB92**	**790934285**
International Participation	U.S. Government Agency		Total Funds Requested
No			**0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I/Science PI	**Paul Goldsmith**	**818-393-0518**	**Paul.F.Goldsmith@jpl.nasa.gov**
Organization/Business Relationship		Cage Code	DUNS#
Jet Propulsion Laboratory		**23835**	**095633152**
International Participation	U.S. Government Agency		Total Funds Requested
No			**0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Consultant	**David Hollenbach**	**559-336-9525**	**dhollenbach@seti.org**
Organization/Business Relationship		Cage Code	DUNS#
SETI Institute		**1NVY9**	**137315552**

International Participation	U.S. Government Agency	Total Funds Requested
No		**0.00**

PI Name : **Christopher Walker**

Organization Name : **University Of Arizona**

NASA Proposal Number

TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION VII - Project Summary

The Stratospheric TeraHertz Observatory was ready for its second Antarctic flight (STO-2) in the 2015-2016 austral summer. However, due to the late establishment of the stratospheric anti-cyclone and poor surface conditions, STO-2 was unable to launch. The decision was made to winter-over the STO-2 payload in its hangar for launch during the 2016-2017 Antarctic campaign. Funds to cover preparations and deployment of key members of the instrument team in support of the campaign are being provided by NASA under the existing grant. However, these funds are only sufficient to cover expenses up to December 31st, 2016. Here, we request resources for calendar year 2017 to support mission operations, payload recovery, and science operations. These elements will enable the team to deliver fully on STO-2's science mission, and maximize NASA's demonstrated investment in STO-2's success.

STO-2 addresses a key problem in modern astrophysics: understanding the Life Cycle of the Interstellar Medium (ISM). STO-2 will survey approximately ¼ of the Southern Galactic Plane in the dominant interstellar cooling line [CII] (158 µm) and the important star formation tracer [NII] (205 µm). In addition, STO-2 will perform path finding observations of the 63 µm [OI] line toward selected regions. With 1 arcminute angular resolution, STO-2 will spatially resolve atomic, ionic and molecular clouds out to 10 kpc. The STO-2 survey will be conducted at unparalleled sensitivity levels. STO-2 will uniquely probe the pivotal formative and disruptive stages in the life cycle of interstellar clouds and the relationship between global star formation rates and the properties of the ISM. Combined with previous HI and CO surveys, STO-2 will create 3-dimensional maps of the structure, dynamics, turbulence, energy balance, and pressure of the Milky Way's ISM, as well as the star formation rate. Once we gain an understanding of the relationship between ISM properties and star formation in the Milky Way, we can better interpret observations of nearby galaxies and the distant universe. The mission goals for these surveys are to:

- **Determine the life cycle of Galactic interstellar gas.**
- **Study the creation and disruption of star-forming clouds in the Galaxy.**
- **Determine the parameters that affect the star formation rate in the galaxy.**
- **Provide templates for star formation and stellar/interstellar feedback in other galaxies.**

STO-2 reuses the 80cm telescope and many subsystems from STO-1. It also reuses the gondola developed by APL for the BOPPS and BRRISON comet missions. For the STO-2 flight, STO-1's high spectral resolution (<1 km/s) heterodyne receiver system was upgraded for extended cryogenic lifetime, enhanced sensitivity, and greater reliability. The flight receiver has five cryogenic HEB mixers; two optimized for the 158 µm [CII] line, two for the 205 µm [NII] line, and one for the 63 µm [OI] line. STO is capable of detecting every giant molecular cloud, every HII region of significance, and every diffuse HI cloud with (AV ≥ 0.4) within its survey region.

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION VIII - Other Project Information

Proprietary Information

Is proprietary/privileged information included in this application?
Yes

International Collaboration

Does this project involve activities outside the U.S. or partnership with International Collaborators?
Yes

Principal Investigator	Co-Investigator	Collaborator	Equipment	Facilities
No	**No**	**No**	**Yes**	**No**

Explanation :

The focal plane mixers for STO-2 were purchased from the Netherlands Institute for Space Physics.

NASA Civil Servant Project Personnel

Are NASA civil servant personnel participating as team members on this project (include funded and unfunded)?
Yes

Fiscal Year	Fiscal Year	Fiscal Year	Fiscal Year	Fiscal Year	Fiscal Year
2017					
Number of FTEs	Number of FTEs	Number of FTEs	Number of FTEs	Number of FTEs	Number of FTEs
0.1					

PI Name : **Christopher Walker**	NASA Proposal Number TBD on Submit
Organization Name : **University Of Arizona**	

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION VIII - Other Project Information

Environmental Impact

Does this project have an actual or potential impact on the environment?	Has an exemption been authorized or an environmental assessment (EA) or an environmental impact statement (EIS) been performed?
No	**No**

Environmental Impact Explanation:

Exemption/EA/EIS Explanation:

PI Name : **Christopher Walker**	NASA Proposal Number TBD on Submit
Organization Name : **University Of Arizona**	

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION VIII - Other Project Information

Historical Site/Object Impact

Does this project have the potential to affect historic, archeological, or traditional cultural sites (such as Native American burial or ceremonial grounds) or historic objects (such as an historic aircraft or spacecraft)?

No

Explanation:

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION IX - Program Specific Data

Question 1 : Short Title:

Answer: STO-2

Question 2 : Type of institution:

Answer: Educational Organization

Question 3 : Will any funding be provided to a federal government organization including NASA Centers, JPL, other Federal agencies, government laboratories, or Federally Funded Research and Development Centers (FFRDCs)?

Answer: Yes

Question 4 : Is this Federal government organization a different organization from the proposing (PI) organization?

Answer: Yes

Question 5 : Does this proposal include the use of NASA-provided high end computing?

Answer: No

Question 6 : Research Category:

Answer: 7) Suborbital rocket/balloon/airplane investigation

Question 7 : Data Management Plan (Part 1)

Answer:

All STO-2 science data will be provided to the public via designated websites in 3D FITS data cubes that can be viewed and analyzed using standard astronomical visualization and processing software. The websites will contain links to data analysis tools, as well as to ancillary science data. All STO-2 science data will be permanently archived on RAID arrays at the University of Arizona (soral.as.arizona.edu) and at the Harvard University Library's Astronomical Dataverse (dataverse.harvard.edu/dataverse/cfa). Additional details regarding the data management plan may be found in the main proposal description under Section 6.3.

Question 8 : Data Management Plan (Part 2)

Answer:

N/A

Question 9 : Team Members Missing From Cover Page:

Answer:

Question 10 : This proposal contains information and/or data that are subject to U.S. export control laws and regulations including Export Administration Regulations (EAR) and International Traffic in Arms Regulations (ITAR).

Answer: No

Question 11 : I have identified the export-controlled material in this proposal.

Answer: N/A

Question 12 : I acknowledge that the inclusion of such material in this proposal may complicate the government's ability to evaluate the proposal.

Answer: N/A

Question 13 : Does the proposed work include any involvement with collaborators in China or with Chinese organizations, or does the proposed work include activities in China?

Answer: No

Question 14 : Are you planning for undergraduate students to be involved in the conduct of the proposed investigation?

Answer: Yes

Question 15 : If yes, how many different undergraduate students?

Answer: 4

Question 16 : What is the total number of student-months of involvement for all undergraduate students over the life of the proposed investigation?

Answer: 12

Question 17 : Provide the names and current year (1,2,3,4) for any undergraduate students that have already been identified.

Answer:

Question 18 : Are you planning for graduate students to be involved in the conduct of the proposed investigation?

Answer: Yes

Question 19 : If yes, how many different graduate students?

Answer: 4

Question 20 : What is the total number of student-months of involvement for all graduate students over the life of the proposed investigation?

Answer: 48

Question 21 : Provide the names and current year (1,2,3,4, etc.) for any graduate students that have already been identified.

Answer:

David Lesser, 5 year Siddhartha Sirsi, 2 year Terrence Patt, 1 Year Stefan O'Dougherty, 3 year

Question 22 : Proposal Category:

Answer: Suborbital Investigation: Balloon

Question 23 : Proposal Type:

Answer: Sub-mm

Question 24 : If this is a Balloon payload, please select a category.

Answer: Science Investigations

If this is a proposal for a suborbital investigation, please answer all the relevant questions below.

Question 25 : Suborbital Proposal Type:

Answer: PI

Question 26 : Lead PI

Answer:

NOTE: The following Questions are for sounding rocket proposals only and should be answered only by the Lead PI.

Question 27 : Requested Launch Vehicle:

Answer:

39.57 MCF Zero Pressure Balloon

Question 28 : Launch Site:

Answer:

Antarctica

Question 29 : Launch date and window:

Answer:

December 2016 - January 2017

Question 30 : Apogee and/or observation time:

Answer:

120,000 ft Float Altitude

Question 31 : Special launch considerations:

Answer:

None

Question 32 : Pointing Accuracy:

Answer:

Provided by Science Payload

Question 33 : Telemetry rates, number of links:

Answer:

Iridium Pilot: 100 - 130 kbps Iridium dialup: 2 kpbs High Gain TDRSS: 90 kpbs

Question 34 : Special systems:

Answer:

none

Question 35 : Recovery:

Answer:

Priority Item(s) 1 (Mission Critical) XPV Pressure Vessel: contains science data 2 JPL LO Plate, SRON Box (with the sticker), Avionics Box, Mini-GRS 3 Instrument Cryostat, Telescope with cradle, IMU, star cameras, and slider 5 Instrument Electronics Boxes, PDU 7 Gondola Penthouse, Double H's (x2) 8 Solar Arrays, MPPT 9 Radiator 10 Remainder of Gondola Hardware: mostly

Question 36 : Hardware to be built by NSROC:

Answer:

None

Question 37 : Experiment section diameter:

Answer:

5 x 5 ft

Question 38 : Approximate experiment section weight:

Answer:

4,955 lbs

Question 39 : Approximate experiment section length:

Answer:

15 ft

Question 40 : Experiment section CG estimate:

Answer:

N/A

Question 41 : Approximate experiment section power:

Answer:

1,200 W

Question 42 : Experiment section contamination sensitivity:

Answer:

N/A

Question 43 : Experiment section cleanliness:

Answer:

N/A

Question 44 : Experiment section purge requirements:

Answer:

N/A

Question 45 : Experiment section deployments:

Answer:

N/A

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Cumulative Budget

Budget Cost Category	Funds Requested ($)					
	Year 1 ($)	Year 2 ($)	Year 3 ($)	Year 4 ($)	Year 5 ($)	Total Project ($)
A. Direct Labor - Key Personnel	25,593.00	0.00	0.00	0.00	0.00	25,593.00
B. Direct Labor - Other Personnel	77,302.00	0.00	0.00	0.00	0.00	77,302.00
Total Number Other Personnel	5	0	0	0	0	5
Total Direct Labor Costs (A+B)	102,895.00	0.00	0.00	0.00	0.00	102,895.00
C. Direct Costs - Equipment	0.00	0.00	0.00	0.00	0.00	0.00
D. Direct Costs - Travel	3,750.00	0.00	0.00	0.00	0.00	3,750.00
Domestic Travel	0.00	0.00	0.00	0.00	0.00	0.00
Foreign Travel	3,750.00	0.00	0.00	0.00	0.00	3,750.00
E. Direct Costs - Participant/Trainee Support Costs	11,040.00	0.00	0.00	0.00	0.00	11,040.00
Tuition/Fees/Health Insurance	11,040.00	0.00	0.00	0.00	0.00	11,040.00
Stipends	0.00	0.00	0.00	0.00	0.00	0.00
Travel	0.00	0.00	0.00	0.00	0.00	0.00
Subsistence	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00
Number of Participants/Trainees						0
F. Other Direct Costs	45,701.00	0.00	0.00	0.00	0.00	45,701.00
Materials and Supplies	1,000.00	0.00	0.00	0.00	0.00	1,000.00
Publication Costs	4,000.00	0.00	0.00	0.00	0.00	4,000.00
Consultant Services	35,201.00	0.00	0.00	0.00	0.00	35,201.00
ADP/Computer Services	500.00	0.00	0.00	0.00	0.00	500.00
Subawards/Consortium/Contractual Costs	0.00	0.00	0.00	0.00	0.00	0.00
Equipment or Facility Rental/User Fees	0.00	0.00	0.00	0.00	0.00	0.00
Alterations and Renovations	0.00	0.00	0.00	0.00	0.00	0.00
Other	5,000.00	0.00	0.00	0.00	0.00	5,000.00
G. Total Direct Costs (A+B+C+D+E+F)	163,386.00	0.00	0.00	0.00	0.00	163,386.00
H. Indirect Costs	81,505.00	0.00	0.00	0.00	0.00	81,505.00
I. Total Direct and Indirect Costs (G+H)	244,891.00	0.00	0.00	0.00	0.00	244,891.00
J. Fee	0.00	0.00	0.00	0.00	0.00	0.00
K. Total Cost (I+J)	244,891.00	0.00	0.00	0.00	0.00	244,891.00
Total Cumulative Budget						244,891.00

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2017	**12 / 31 / 2017**	**Project**	**1**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Kulesa, Craig	**CO-I**	**58,131.00**	**2**			**8,909.00**	**3,091.00**	**12,000.00**
Walker, Christopher	**PI**	**100,914.00**		**1**		**10,091.00**	**3,502.00**	**13,593.00**
							Total Key Personnel Costs	**25,593.00**

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
1	**Graduate Students**		**9**	**3**	**30,177.00**	**4,195.00**	**34,372.00**
1	**Undergraduate Students**			**1.5**	**2,400.00**	**84.00**	**2,484.00**
1	**Project Manager**	**2**			**13,027.00**	**4,520.00**	**17,547.00**
1	**Instrument Scientist**	**1**			**5,579.00**	**1,936.00**	**7,515.00**
1	**Software Engineer**	**2**			**11,421.00**	**3,963.00**	**15,384.00**
5	Total Number Other Personnel					Total Other Personnel Costs	**77,302.00**
						Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	**102,895.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2017	**12 / 31 / 2017**	**Project**	**1**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**0.00**
2. Foreign Travel	**3,750.00**
Total Travel Costs	**3,750.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**11,040.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	Total Participant/Trainee Support Costs	**11,040.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2017	**12 / 31 / 2017**	**Project**	**1**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**1,000.00**
2. Publication Costs	**4,000.00**
3. Consultant Services	**35,201.00**
4. ADP/Computer Services	**500.00**
5. Subawards/Consortium/Contractual Costs	**0.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
8 . Other: **Shipping Experiment to/from Antarctica**	**5,000.00**
Total Other Direct Costs	**45,701.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**163,386.00**

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MTDC base less capital, tuition remission	**53.50**	**152,346.00**	**81,505.00**
Cognizant Federal Agency: **None**		Total Indirect Costs	**81,505.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**244,891.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**244,891.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
		Project	**2**

A. Direct Labor - Key Personnel

Name	Project Role	**Base Salary ($)**	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	**Fringe Benefits ($)**	Funds Requested ($)
Walker, Christopher	**PI**	**0.00**				**0.00**	**0.00**	**0.00**
							Total Key Personnel Costs	**0.00**

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	Total Number Other Personnel					Total Other Personnel Costs	**0.00**
						Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type : **Project**	Budget Period : **2**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**0.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**0.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	Total Participant/Trainee Support Costs	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type : **Project**	Budget Period : **2**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**0.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**0.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
Total Other Direct Costs	**0.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**0.00**

H. Indirect Costs

	Indirect Cost Rate (%)	**Indirect Cost Base ($)**	Funds Requested ($)
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
Cognizant Federal Agency:		Total Indirect Costs	**0.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**0.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
		Project	**3**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Walker，Christopher	**PI**	**0.00**				**0.00**	**0.00**	**0.00**
							Total Key Personnel Costs	**0.00**

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	Total Number Other Personnel					Total Other Personnel Costs	**0.00**
						Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type : **Project**	Budget Period : **3**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**0.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**0.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	Total Participant/Trainee Support Costs	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
		Project	**3**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**0.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**0.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
Total Other Direct Costs	**0.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**0.00**

H. Indirect Costs

	Indirect Cost Rate (%)	**Indirect Cost Base ($)**	Funds Requested ($)
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
Cognizant Federal Agency:		Total Indirect Costs	**0.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**0.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit
Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**	

SECTION X - Budget

Start Date :	End Date :	Budget Type : **Project**	Budget Period : **4**

A. Direct Labor - Key Personnel

Name	Project Role	**Base Salary ($)**	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	**Fringe Benefits ($)**	Funds Requested ($)
Walker, Christopher	**PI**	**0.00**				**0.00**	**0.00**	**0.00**
							Total Key Personnel Costs	**0.00**

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	Total Number Other Personnel					Total Other Personnel Costs	**0.00**
						Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
		Project	**4**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**0.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**0.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	Total Participant/Trainee Support Costs	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
		Project	**4**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**0.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**0.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
Total Other Direct Costs	**0.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**0.00**

H. Indirect Costs

	Indirect Cost Rate (%)	**Indirect Cost Base ($)**	Funds Requested ($)
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
Cognizant Federal Agency:		Total Indirect Costs	**0.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**0.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit
Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**	

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
		Project	**5**

A. Direct Labor - Key Personnel

Name	Project Role	**Base Salary ($)**	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	**Fringe Benefits ($)**	Funds Requested ($)
Walker, Christopher	**PI**	**0.00**				**0.00**	**0.00**	**0.00**
							Total Key Personnel Costs	**0.00**

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	Total Number Other Personnel					Total Other Personnel Costs	**0.00**
						Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type : **Project**	Budget Period : **5**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**0.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**0.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	Total Participant/Trainee Support Costs	**0.00**

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **University Of Arizona**	TBD on Submit

Proposal Title : **STO-2: Support for 4th Year Operations, Recovery, and Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
		Project	**5**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**0.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**0.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
Total Other Direct Costs	**0.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**0.00**

H. Indirect Costs

	Indirect Cost Rate (%)	**Indirect Cost Base ($)**	Funds Requested ($)
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
	0.00	**0.00**	**0.00**
Cognizant Federal Agency:	Total Indirect Costs		**0.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**0.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**0.00**

TABLE OF CONTENTS

STO-2: Support for 4th year Operations, Recovery and Science

1 Executive Summary

The structure of the interstellar medium, the life cycle of interstellar clouds, and their relationship with star formation are processes crucial to deciphering the evolution of galaxies. High resolution spectral line imaging of key gas tracers not accessible from the ground is needed to supply major missing pieces of Galactic structure and witness the formation and dissipation of interstellar clouds. The reflight of the Stratospheric Terahertz Observatory (STO-2), a balloon-borne 0.8-meter telescope with an 5-beam far-infrared heterodyne spectrometer, will address these issues and significantly advance NASA's Strategic Goal of "discovering how the universe works" by exploring how structures in galaxies evolve and how galactic-scale star formation proceeds, using our Milky Way as a template.

In its long duration flight, STO-2 will survey part of the Galactic plane in [C II] line emission at 158 μm, the brightest spectral line in the Galaxy; [N II] line emission at 205 μm, a tracer of the formation rate of massive stars; and [O I] line emission at 63 μm, a probe of dense warm gas in PDRs, shocks, and hot cloud cores where massive stars are forming. With 1' angular resolution and <1 km/s velocity resolution, STO-2 will detect every interstellar cloud with $A_V \geq 0.4$ mag (hydrogen column density $\geq 4 \times 10^{20}$ cm^{-2}) in the surveyed region (Figure 1), and, through excitation and kinematic diagnostics provided by [C II] and [N II] line emission, will study how atomic and molecular clouds are formed and dispersed. STO-2 will make 3-dimensional maps of the structure, dynamics, turbulence, energy balance, and pressure of the Milky Way's Interstellar Medium (ISM), as well as the star formation rate.

STO-2 was selected for development in late 2013 and passed its hang test and mission readiness review on schedule in August 2015 at CSBF headquarters in Palestine, Texas. It featured cryocooler, mixer and local oscillator developments well above and beyond that proposed in the original proposal. In particular, the [OI] receiver development was a value-added contribution from the Space Research Organization of the Netherlands (SRON) that was integrated into the STO-2 flight system. STO-2 was shipped to Antarctica, was received in good shape in late October 2015, and was fully tested and readied for flight by 20 December 2015 when the stratospheric polar vortex had finally stabilized. However, surface weather conditions suitable for launching a mission of long duration never materialized despite numerous launch attempts. Finally, on 21 January 2016, NASA HQ made the decision to end the LDB season, store STO-2 on the Ice, and support a renewed launch attempt for a full flight in the 2016-17 season. Existing grant resources will support the team's mission operations through 31 December 2016. **Here, we request resources for 2017 to support STO-2 mission and science operations that will enable the team to deliver fully on the science return, and maximize NASA's demonstrated interest and investment in STO-2's success.**

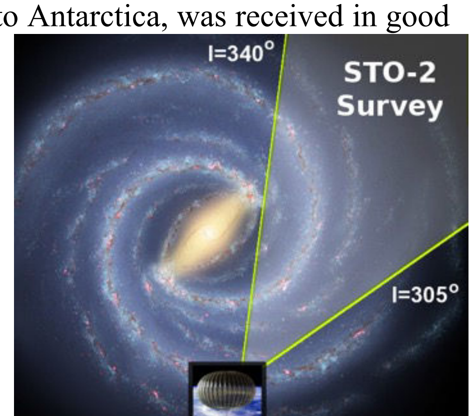

Figure 1: Overview of the region to be surveyed by STO-2. This 35° swath through the Galactic Plane includes spiral arm and interarm regions.

1.1 Summary: Science Goals and Objectives

STO-2 will help provide a comprehensive understanding of the inner workings of our Galaxy by exploring the connection between star formation and the life cycle of interstellar clouds. We will study the formation of molecular clouds, the feedback of high mass star formation heating and disrupting clouds, and the effect of these processes upon the global structure and evolution of the Galaxy. The detailed understanding of star formation and evolution of stars and gas in the Galaxy is directly relevant to star formation in other galaxies. The nature of the feedback mechanism of massive star formation is pivotal to the evolution of galaxies. STO-2 thus addresses NASA's goals and research objectives on galaxy evolution and star formation. STO-2 addresses the high priority goals:

1. ***Determine the life cycle of Galactic interstellar gas.***
2. ***Study the creation and disruption of star-forming clouds in the Galaxy.***
3. ***Determine the parameters that affect the star formation rate in a galaxy.***
4. ***Provide templates for star formation & stellar/interstellar feedback in external galaxies.***

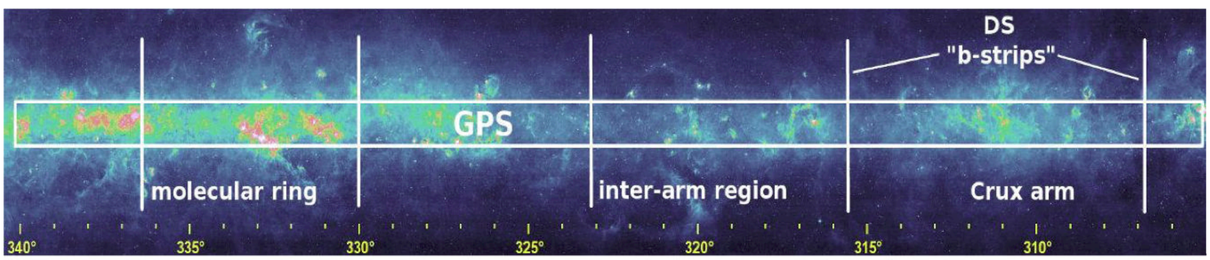

Figure 2: Midcourse Space Experiment (MSX) 8.3 μm map of the Galactic Plane from the Molecular Ring through the Scutum-Crux spiral arm. Annotations highlight regions to be explored by STO-2 in its Galactic Plane Survey (GPS) and the deeper survey *b* strips (DS).

1.2 Summary: Mission Approach

To achieve these timely scientific goals, STO-2 will map the pivotal [C II] 158 μm, [N II] 205 μm and [OI] 63 μm lines. **[C II] is extraordinarily versatile**; it probes ionized gas (HII), atomic clouds (HI), and the photo-illuminated surfaces of molecular clouds. **[C II] provides a unique measure of the interstellar medium that is not possible with HI or CO line emission alone**: it directly distinguishes *atomic clouds* from diffuse intercloud HI gas (unlike HI which is not density sensitive), identifies "CO-dark" molecular gas not associated with CO emission, and probes mass flows from molecular cloud surfaces. Thus, in combination with CO, HI and [NII], [C II] identifies and measures the formation and destruction of clouds in ways not possible with HI and CO images. The [N II] line, in addition to providing an extinction-free probe of ionizing radiation and star formation rate in the Galaxy, can be used to isolate the fraction of [C II] line emission that comes from ionized gas. In the highest excitation regions, such as hot cores, shock fronts, and PDRs with high UV flux, the [O I] line emerges as a dominant coolant and provides a powerful diagnostic capability in concert with [C II].

To map the these lines over a large portion of the southern Galactic Plane, STO-2 will utilize three heterodyne receiver bands to produce a total of five beams in the focal plane (two each of [CII] and [NII], and one [OI]). Each beam will provide 1024 spectral channels. In a long duration (14 to 30 day) flight STO-2 will map a 35^{o}x1^{o} area including the Galactic molecular ring (Figures 1 & 2) as well as 5 deeper strips in Galactic latitude b=±2° in selected arm and interarm regions. STO-2 achieves arcminute angular resolution and 3σ intensity limits of 7×10^{-6}

and 1×10^{-6} erg s^{-1} cm^{-2} sr^{-1} in the [C II] and [N II] lines, respectively, sufficient to resolve both spectrally and spatially all Giant Molecular Clouds (GMCs), all significant H II regions, and all cold neutral medium (CNM) clouds with $A_V \geq 0.4$ mag (potential building blocks of GMCs) in the surveyed region. [CII] and [NII] emission will be observed simultaneously. Because of its relative compactness, [OI] line emission will be mapped separately toward a sample of regions during the mission. STO-2's heterodyne receivers provide sufficient velocity resolution and coverage to detect and resolve line emission from all significant Galactic clouds along the line of sight. The deliverable data products include:

1) A high fidelity database of spatially and velocity resolved [C II] 158 μm, [N II] 205 μm and [O I] 63 μm fine-structure line emission in the Galaxy.

2) A combination of STO-2's data with existing line and continuum surveys to characterize the structure and dynamics of interstellar clouds and their relation to star formation.

The data are produced in large scale (Galactic Plane Survey) and selective (Deep Survey) modes:

- **GPS: Galactic Plane Survey:** $305^{\circ} < l < 340^{\circ}$; $-0.5^{\circ} < b < 0.5^{\circ}$. The GPS contains more than 10^5 spatial pixels and has 10^4 times higher sensitivity than FIRAS/COBE when convolved to the same resolution. STO-2 will catalogue all neutral clouds with $A_V \geq 0.4$ mag. and all ionized clouds with emission measure > 50 cm^{-6} pc, detecting all significant interstellar material in the Galaxy.
- **TDS: Targeted Deep Survey** of Galactic and LMC sources defined by ancillary observations from AST/RO and Mopra telescopes. In the Galaxy, $b = -2^{\circ}$ to $+2^{\circ}$ strips at $l = 315.97^{\circ}$, 323.13°, 330.00°, 336.42° and 342.54°, with $\Delta l=0.05^{\circ}$. Sensitivity will be >3 times higher than of **GPS**. A 20x20' region centered on 30 Dor in the LMC will be mapped. The **TDS** will also include a sample of ~12 sources for which small [OI] maps will be obtained.

2 Science Goals & Objectives

2.1 Background

Via spatially & spectroscopically resolved [CII], [NII] and [O I] line emission, STO-2 probes the formative and disruptive stages in the life cycles of interstellar clouds. It reveals the relationship between interstellar clouds and the stars that form from them, a central component of galactic evolution.

The current multi-phase model of the interstellar medium (ISM) is shown schematically in Figure 3. Neutral interstellar gas is the dominant mass component of the ISM and tends to exist as two phases in rough thermal pressure equilibrium: a diffuse warm neutral medium (WNM) with hydrogen densities at the solar circle of n~0.3 cm^{-3} and T~8000 K, and denser, colder "diffuse HI clouds" (cold neutral medium: CNM) with n~40 cm^{-3} and T~70 K (Heiles & Troland, 2003; Wolfire et al., 2003). Turbulence provides a broader spectrum of conditions (Mac Low et al., 2005; Gazol et al., 2005; Jenkins & Tripp, 2011; Kim et al. 2011), but thermal balance drives neutral gas toward these phases. With sufficient shielding column, $N > 10^{20} - 10^{21}$ cm^{-2} of hydrogen nuclei, the CNM

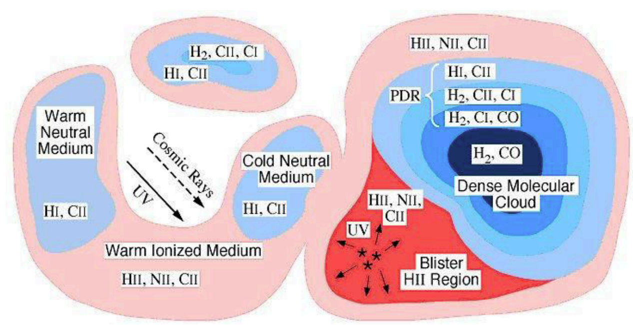

Figure 3: Schematic representation of ISM com-ponents. STO-2 detects and maps in the Galaxy the higher column density CNM component, the H_2/C^+ "CO-dark" component, the photodissociation region (PDR) surfaces of molecular clouds, the H II component, and (with H I) the WNM/CNM ratio.

clouds begin to harbor molecular interiors. These H_2/C^+ clouds are sometimes called "CO-dark clouds" because they cannot be detected in HI, H_2, or CO emission. This component has been indirectly inferred by γ ray (e.g., Grenier et al. 2005), submillimeter dust emission (Planck Collaboration et al. 2011), and IR dust extinction maps (Paradis et al. 2012), but direct observations of it and a determination of how it contributes to the ISM can only be achieved using the sensitive, large-scale [CII] and [NII] survey capabilities of STO-2. The CNM and CO-dark clouds are the building blocks of giant molecular clouds (GMCs).

WNM is converted into CNM clouds via thermal instability either if the ultraviolet radiation field (heating) diminishes (Parravano et al., 2003) or if the pressure increases because of the passage of a (e.g., supernova) shock wave (McKee & Ostriker, 1977). GMCs presumably form from a large assemblage of CNM clouds; the leading theoretical models invoke gravitational instabilities in huge regions 0.5-1 kpc in size along spiral arms (Ostriker & Kim, 2004). Other mechanisms have been invoked such as the convergence of flows in a turbulent medium (Hennebelle & Perault, 2000; Heitsch et al., 2006).

Figure 4 shows the [C II] and [N II] intensities of these cloud components with the nominal STO-2 survey mode sensitivities, while Figure 5 shows a Herschel/GOTC+ [C II] observation with complementary CO and H I spectra along a line of sight through the Galaxy. This pointed observation shows that many kinds of clouds are detectable with modern heterodyne receivers at THz frequencies. This single pointing with Herschel foreshadows the large scale mapping of these lines that will be possible with STO-2.

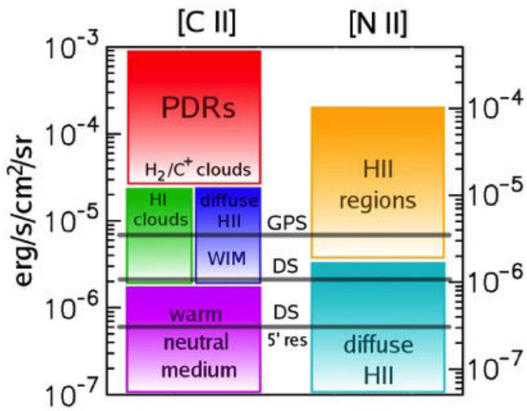

Figure 4: Comparison of STO-2's sensitivity with [C II] and [N II] integrated intensity for various ISM components. HI and H_2/C^+ clouds (CO-dark gas) constitute the building blocks for molecular clouds. HII regions and bright PDRs often include photoevaporating gas from molecular cloud destruction. The 3σ sensitivities of STO-2's two survey modes (see §1.2 for definitions*) are indicated by horizontal lines.*

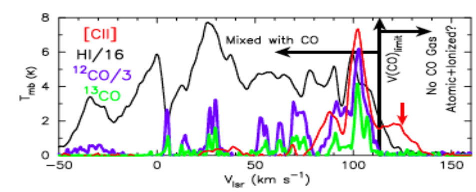

Figure 5: A Herschel HIFI [CII] spectrum from the GOT C+ program (Velusamy et al. 2012) in the Scutum-Crux spiral arm.

2.2 Goal 1: Map the Entire Life Cycle of Interstellar Gas

STO-2 will (1) map and catalog the size, mass distribution, and internal velocity dispersion of atomic, molecular and ionized clouds as a function of Galactic position. It will (2) identify the physical origin of [C II] emission, (3) allow construction of the first large-scale thermal pressure map of the ISM, (4) the first map of the gas heating rate, and (5) a more sensitive, detailed map (using [N II]) of the star formation rate.

(1) STO-2 will survey spiral arm/ interarm regions and a large portion of the molecular ring, where much of the star formation occurs in the Galaxy. Galactic rotation causes a distance-dependent velocity separation of the clouds along the line of sight, and STO-2's high spectral resolution allows us to then determine the distance to the clouds using standard methods. Therefore, *STO-2 will provide an unprecedented 3D global map of the distribution of clouds of*

ionized gas, atomic gas, and molecular clouds (via their [C II]-emitting surfaces) as a function of Galactocentric radius (R) and height (z) in the Galaxy. We can compute the density of clouds (*i.e.,* the number of clouds per kpc^3) and their size distribution as functions of R and z, and see how clouds are clumped together in spiral arms or supershells. In regions of cloud clustering, the superb velocity resolution of STO-2 will measure the random motions of clouds, and diagnose *large-scale turbulence*.

(2) Because [C II] line emission can come from ionized, atomic clouds, and from atomic and molecular surfaces of Giant molecular clouds (CO-dark H_2 material), its origin can be difficult to disentangle toward complicated lines of sight, particularly in the Inner Galaxy. For example, COBE FIRAS observations show that the ionized component of the ISM radiates strongly in both [C II] 158 μm and [N II] 205 μm (Wright et al., 1991). To distinguish the origin(s) of [C II] emission, velocity-resolved measurements of the distribution of the ionized gas must be made in [N II] and compared to the [C II] distribution, along with comparisons with H I and CO. *STO-2 will conclusively determine the origin of the [C II] emission*, by measuring the portion of the [C II] emission coming from each component.

(3) The ratio of CNM [C II] to H I intensity (which determines their column and mass) provides a measure of the [C II] emissivity per H atom which rises monotonically with gas density and thermal gas pressure. *The STO-2 survey of a large portion of the Galactic Plane enables the construction of the first barometric maps of the Galactic disk*, determining the ambient thermal pressure in different environments (*e.g.,* spiral arms vs. interarm regions, turbulent vs. quiescent regions). The STO-2 team's theoretical models are vital to determining the density, temperatures, and thermal pressures in the clouds. These can then be correlated with star formation rates to understand stellar/interstellar feedback mechanisms.

(4) The [C II] line dominates the cooling of CNM clouds. From its intensity we directly obtain the gas heating rate of clouds as a function of radius throughout the Galaxy. Besides the fundamental interest in tracing the energy flow in the Galaxy, the observations also can test our theoretical hypothesis that the heating is provided by the grain photoelectric heating mechanism in diffuse clouds.

2.3 Goal 2: Reveal the Formation & Destruction of Clouds

By observing the [C II] line, STO-2 will reveal clouds clustering and forming in spiral arms, super-shells, and filaments, and follow the growth of clouds to shield molecules and eventually to become gravitationally-bound GMCs. STO-2 will observe "CO-dark" clouds that cannot be seen in H I, H_2, or CO emission, and estimate their contribution to GMC formation. STO-2 will also directly measure the subsequent dissolution of GMCs into diffuse gas via stellar feedback.

Formation of diffuse H I clouds (CNM). Turbulence may play an important role in the formation and evolution of interstellar clouds. In a standard scenario where CNM clouds are formed from WNM gas by thermal instability, we can picture the role of turbulence in two ways: large scale instabilities, density waves and supernovae drive compressional motions that increase the thermal pressure and trigger the thermal instability (de Avillez & Breitschwerdt, 2005). Alternatively, regions undergoing thermal instability may generate turbulence, and convert the CNM into a complex network of pancakes and filaments (Kritsuk & Norman, 2002). STO-2 will perform the survey of both the spatial structure and kinematics of diffuse gas in transition between phases necessary to tell us the role of turbulence and dynamic pressure in the life-cycle of the ISM.

Formation of GMCs. The formation of GMCs is a prerequisite for massive star formation, yet the process has not yet been directly observed! STO-2 is designed with the unique combination of sensitivity and resolution needed to observe cold atomic and CO-dark clouds being assembled into GMCs (Figure 6). Four mechanisms have been proposed to consolidate gas into GMC complexes (Elmegreen 1996): (1) self-gravitating instabilities within the diffuse gas component, (2) random collisional agglomeration of clouds, (3) accumulation of material within high pressure environments, e.g. shells and rings generated by OB associations, and (4) compression in the randomly converging parts of a turbulent medium. STO-2 can distinguish these processes from each other and consider new cloud formation schemes by:

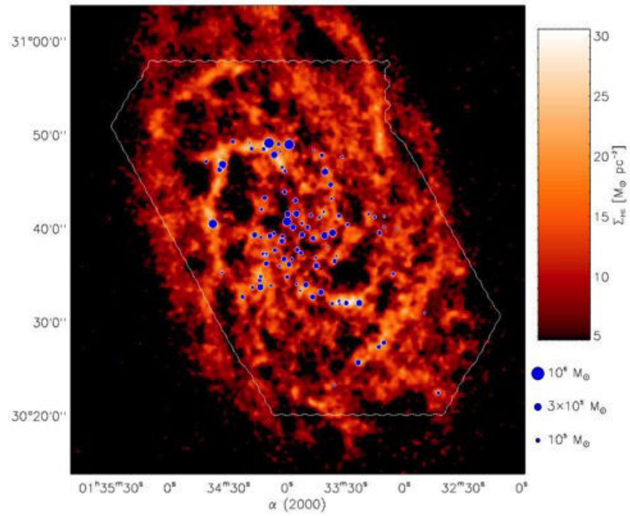

Figure 6: GMCs locations (blue dots) in the nearby spiral galaxy M33 are overlaid upon an integrated intensity map of the HI 21 cm line (Engargiola et al., 2003). These observations show that GMCs in M33 are formed from large structures of atomic gas, and foreshadow the detailed study that STO-2 will provide of GMC formation in the Milky Way.

- Accounting for all the molecular hydrogen mass (the H_2/C^+ CO-dark clouds as well as the H_2/CO clouds) when computing global measures of the interstellar medium.
- Clearly identifying CNM clouds via the density sensitivity of [CII] compared to HI 21 cm.
- Constructing spatial and *kinematic* comparisons with sufficient resolution, spatial coverage and dynamic range to discriminate the above 4 scenarios.

The high spectral resolution of STO-2 enables crucial kinematic studies of the Galaxy. STO-2 will determine the kinematics and thermal pressures of most supershells, fossil superrings, and molecular clouds just condensing via gravitational instability of old superrings. STO-2 will detect many of the CNM clouds formed out of WNM in the shells, and the larger column density clouds, which may harbor H_2. With these detections STO-2 will 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.

STO-2 reveals the disruption of clouds. [CII] and [NII] measure the photoevaporating atomic or ionized gas driven from molecular clouds with UV-illuminated surfaces, thereby converting the clouds to WNM, CNM, or to diffuse H II regions. Thus, STO-2 can directly determine the rate of mass loss from catalogued clouds, and their destruction timescales.

2.4 Goal 3: Map the Star Formation Rate in the Galaxy

STO-2 will probe the relation between the gas surface density on kpc scales and the [N II]-derived star formation rate, so that we can better understand the empirical Schmidt-Kennicutt Law used to estimate the star forming properties of external galaxies.

Star formation within galaxies is commonly described by two empirical relationships: the variation of the star formation rate per unit area with the gas surface density (atomic + molecular), Σ_{SFR} (Schmidt, 1959) and a surface density threshold below which star formation is suppressed (Kennicutt, 1989; Martin & Kennicutt, 2001). This empirical relationship is used in most models of galaxy evolution with surprising success given its simplicity. In practice, the relationship is derived by comparing a tracer of star formation to a tracer of interstellar gas; it has been evaluated from the radial profiles of Hα, H I, and molecular emission for tens of galaxies. The mean value of the Schmidt index, n, varies from 2 (Schmidt, 1959) for star formation vs. H I, to ~1 for star formation compared to tracers of high-density H_2 gas (Onodera et al. 2010).

STO-2 will help us understand the origin of the Schmidt Law. The [N II] line is a potentially excellent tracer of the star formation rate, measuring ionizing luminosity with high sensitivity, angular and spectral resolution, unaffected by extinction (Bennett et al. 1994). The [C II] line, in conjunction with H I (21cm) and CO line emission, provides the first coherent map of the neutral interstellar gas surface density and its variation with radius. STO-2 data will correlate the thermal pressures on the surfaces of GMCs (which may relate to the formation of cores inside) with surface densities of H I and CO. Extensive, velocity-resolved studies of our Galactic ISM with STO-2 will provide the detailed, complete picture of star formation that will enable us to understand the Schmidt law.

2.5 Goal 4: Construct a Milky Way Template

[C II] 158 μm and [OI] 63 μm, the strongest Galactic cooling lines, are the premier diagnostic tools for studying relatively nearby galaxies in the far-infrared (FIR) and more distant galaxies in the submillimeter (*e.g.* with the Atacama Large Millimeter Array). To interpret the measurement of extragalactic [C II] one must turn to the Milky Way for the spatial resolution needed to disentangle the various contributors to the total [C II] emission. At present, there is debate on the dominant origin of the [C II] emission in the Galaxy: diffuse H II regions, CNM clouds, or the surfaces of GMCs. ***STO-2 will solve this mystery.*** [C II] and [N II] maps, combined with ancillary CO and HI observations, identify each component of [C II] emission. In more extreme environments, [OI] takes over from [CII] as the dominant coolant; STO-2's survey in [OI] line emission will assess this transition and improve the interpretation of redshifted [OI] line emission with ALMA. The STO-2 surveys cover a broad range of density and UV intensity, thus establishing the relationship between physical properties, [C II], [N II], [OI], [CI], CO, H I, FIR emission, and star formation. This study provides a ***"Rosetta Stone"*** for translating the global properties of distant galaxies into reliable estimators of star formation rate and state of the ISM.

3 Science Requirements

The science goals outlined in Section 2 define a clear set of measurement requirements which the instrument and mission must be able to perform (Table 1). These requirements define the STO-2 surveys, which will span a maximum of 35 square degrees at moderate sensitivity. STO-2 will fully sample both [CII] and [NII] emission over large regions of sky with ~1' angular resolution and ~1 km/s velocity resolution. STO-2's Deep Survey (DS) will be sensitive to truly diffuse cloud column densities corresponding to A_V = 0.1 mag and spanning the full emission scale height of the Galaxy. The Deep Survey is comprised of one map of 30 Dor in the LMC and five 4-degree linear strips in Galactic latitude, spaced equally in Galactocentric radius, including the Molecular Ring, Scutum-Crux spiral arm, and inter-arm regions. Deep surveys allow us to detect faint [C II] and [N II] from diffuse ionized clouds, probe the formation of small molecular clouds, and help determine the origin of most of the [C II] emission in the Galaxy and low-metallicity regions like the LMC.

4 Complementarity to Existing Data Sets and with Other Missions

STO-2 will provide the community with a totally unique [C II], [N II] and [OI] survey, enabling quantitative extraction of many physical parameters of the interstellar medium in a 3D data cube.

4.1 Relationship to Existing Data Sets

CO: The Mopra telescope in Australia was upgraded for the STO project to make rapid carbon monoxide J = 1-0 surveys of the southern sky in three carbon monoxide isotopologues (^{12}CO, ^{13}CO, and C^{18}O). We have already obtained maps in each isotopologue from b = ±0.5° and l = 300° to 340°, at subarcminute angular resolution and 0.1 km/s spectral resolution. These data are now available online. The CO J=1-0 surveys will complement the STO-2 survey by helping to identify molecular clouds whose surfaces STO-2 detects and whose ionized gas seen in [N II] and warm neutral gas seen in [C II] may be expanding into the diffuse ISM (Onishi et al., 2005).

H I: The STO-2 surveys enhance substantially the interpretation of existing H I surveys McClure-Griffiths, 2005). The H I emission maps are sensitive only to column, whereas [C II] is sensitive to density times column. [C II] therefore picks out the cloud regions with density > 30 cm^{-3}, whereas the H I is often dominated by the WNM emission (see Figure 5).

Table 1: ***Flow of Requirements, from Science goals to Instrument Implementation***

Pertinent Science Goal(s)	Measurement Requirement	Instrument requirement
Life cycles (1), Formation of clouds (2)	Angular resolution to resolve ~3 pc clouds in the 5kpc Molecular Ring.	1 arcminute resolution requires 0.8m aperture at 1-2 THz.
Life Cycles (1), Formation of clouds (2), Galactic SFR (3), Milky Way template (4)	Spectral resolution to resolve spectral lines and measure cloud, shell and superbubble dynamics (km/s scale).	High-resolution heterodyne spectroscopy with 1 km/s spectral channels.
Life Cycles (1), Galactic SFR (3), Milky Way template (4)	Spectral bandwidth to span the Galactic rotation curve from *l*=305° to 340° .	V_{LSR} = -140 to +20 km/s requires max 1 GHz bandwidth at [CII].
Life Cycles (1), Galactic SFR (3), Milky Way template (4)	Mapping coverage to sample the inner Molecular Ring, interarm regions, and at least one major spiral arm.	Mapping longitudes from *l*=305° to 340° and coverage of the molecular scale height (-0.5° to 0.5°) in latitude.
Life cycles (1), Formation of clouds (2)	Sensitivity to sense CNM clouds aggregating into molecular clouds	3σ detectability of 1 K km/s = 7x10^{-6} erg/s/cm^2/sr in [CII].
Life cycles (1), Galactic SFR (3), Milky Way template (4)	Sensitivity to sense HII regions with emission measure of 50 cm^{-6} pc.	3σ detectability of 0.3 K km/s = 1x10^{-6} erg/s/cm^2/sr in [NII] w/ smoothing.
Life Cycles (1), Formation of clouds (2), Galactic SFR (3)	Sensitivity and mapping coverage to cover the full [CII] and [NII] scale heights to A_V = 0.1 mag.	Deep survey spanning -2° to +2° in latitude, with 3σ sensitivity 0.3 K km/s =2x10^{-6} erg/s/cm^2/sr in [CII].
Life Cycles (1), Formation of clouds (2), Galactic SFR (3), Milky Way template (4)	Sufficient mapping speed to span 35 square degrees of mapping within one LDB flight from Antarctica.	>1 sq.deg/day requires THz arrays of 2 pixels per frequency band at current sensitivities (T_{rec} = 1100K DSB).

[C I]: Moving from the CNM through the surfaces of molecular clouds to their cores, the predominant form of carbon changes from C^+ to CO, with atomic C abundant in the transition region. A southern Galactic Plane survey of the 609 and 370 micron [C I] lines (at ~2' angular and 1 km/s spectral resolution) is currently being performed by the High Elevation Antarctic Terahertz (HEAT) telescope now in operation at *Ridge A*, the summit of the high Antarctic plateau (Kulesa et al. 2011). These data are in the public domain with no proprietary period. Maps from STO-2 coupled with CO and [C I] data, will follow carbon in all its forms in position, velocity, cooling rate, temperature and pressure as the interstellar gas evolves.

Infrared Continuum Surveys: MSX, IRAS, and Spitzer GLIMPSE and MIPSGAL Galactic plane surveys permit locating CO-dark clouds, supershells, and star forming regions in the plane of the sky. With [CII] observations from STO-2, they can be located along the line of sight.

4.2 Complementarity with Other Missions

STO-2 builds upon the heritage of three pioneering surveys that provided coarse pictures of [C II] and [N II] emission in the Galaxy: COBE (spatial resolution 7°, velocity resolution >1000 km/s), BICE (spatial resolution $15'$, velocity resolution 175 km/s), and the Infrared Telescope in Space (IRTS, spatial resolution $10'$, velocity resolution 750 km/s). *STO-2 has sensitivity to accurately measure the [CII] along individual lines of sight, with orders of magnitude improvement in spatial and spectral resolution.* None of these missions had sufficient spectral or spatial resolution to locate clouds, or separate one cloud from another along a given line of sight, and thus could not draw specific conclusions about cloud properties or distributions, or even the origin of the [CII] or [NII] emission (Hollenbach & Tielens, 1999). The Spitzer Space Telescope had no spectroscopic capability at these wavelengths.

The high spectral resolution HIFI instrument on the Herschel Space Observatory has made a number of small maps of [C II] and [N II] emission from active star-forming cores and their adjacent cloud interfaces. Herschel's Galactic Observations of Terahertz C+ (GOT C+) project surveyed the Galactic disk in the [C II] line with HIFI's sub km/s resolution. GOT C+ measured 500 lines-of-sight (with a narrow 15 arcsec beam) separated typically by 0.5 to 1 degree. GOT C+ demonstrated the utility of velocity-resolved [C II] observations (together with complementary HI and CO surveys) to trace the different phases of the ISM. In particular, the GOT C+ survey found a significant number of CO-dark gas components (Langer et al. 2010, Velusamy et al. 2010) and detected CO-dark gas throughout the inner Galaxy (Pineda et al. 2013). STO-2 will map and measure the motions of these dark clouds. Due to its coarse sampling, the GOT C+ survey lacks a picture of the surroundings of individual lines-of-sight, and ***STO-2 will provide the full picture of clouds that are forming and dissipating.***

SOFIA with its present heterodyne instrument GREAT, and in particular with future array heterodyne receiver upgrades (e.g. upGREAT), will be efficient at mapping the detailed distribution and structure of ISM clouds at high spatial resolution over small areas, but ***will not*** have sufficient observing time to conduct large scale mapping. The STO-2 survey in the [C II] and [N II] lines will guide SOFIA's follow-up studies of small-scale structure in confined areas of interest. STO-2 will be unique in providing maps of large areas at moderate spatial but full spectral resolution, thus obtaining an unbiased sample of ISM clouds and their motions across the Milky Way. Because of significant atmospheric absorption (~50%) in the 63 um [OI] line at SOFIA altitudes, STO-2 has a significant mapping advantage, even with a single mixer!

The Gal/Xgal Ultra-Long Duration Balloon-borne Stratospheric THz Observatory (*GUSTO*) is a proposed Explorer Mission of Opportunity led by the University of Arizona in partnership with the Johns Hopkins University Applied Physics Laboratory (APL). *GUSTO* is a cryogenic balloon-borne, 0.9m telescope designed to stay aloft for >100 days using a super pressure balloon (SPB) developed by NASA. Scheduled for launch in 2020, *GUSTO* will survey ~150 square degrees of the inner Milky Way and all of the Large Magellanic Cloud (LMC) in three important interstellar lines: [CII], [OI], and [NII] at 158, 63, and 205 μm, respectively. The *GUSTO* project is completing a Phase A concept design study and will await a selection decision from NASA before February 2017. The *GUSTO* instrument is an expanded version of what is being flown in STO-2, and its timeline and science products only complement STO-2.

5 Science Implementation

The STO-2 gondola and instrument payload are "wintering over" in Antarctica currently and are essentially ready to fly. Advances in gondola systems and local oscillator technologies during the development period have allowed a more capable payload to be constructed, than originally proposed. STO-2 will be prepared for flight in November 2016 for a December launch.

5.1 Science Instrument Overview

A cross sectional view of the STO-2 science payload is shown in Figure 7. The observational goal of STO-2 is to make high spectral (<1 km/s) and angular resolution (60") maps of the Galactic plane in [C II] (1.9 THz), [N II] (1.46 THz) and [OI] (4.74 THz). A summary of key instrument parameters is provided in Table 2. To achieve the angular resolution requirement STO utilizes a telescope with an 80cm aperture. To achieve the target spectral resolution and sensitivity, STO utilizes a leading-edge, THz heterodyne receiver system. Our observing strategy for the main survey is to make adjacent On-the-Fly (OTF) strip maps of the Galactic plane. An ambient load/cold-sky calibration (CAL) is used at the beginning and end of each strip map. During each strip map (lasting typically ~3 minutes) the calibration load will be regularly observed. With this mode of operation, secondary chopping is not required.

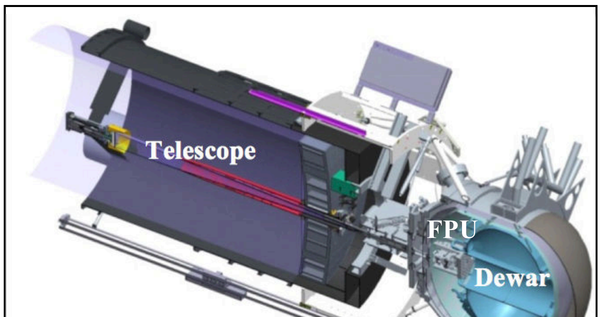

Figure 7: STO Science Payload

The STO instrument properties are summarized in Table 2. The STO-2 optical system consists of an 80 cm f/17.5 Cassegrain telescope, Calibration (Optics) Box, Local Oscillator (LO) Box, and simple reimaging optics. The converging light from the telescope's secondary passes through its focus just above the Optics Box. Just inside the box is a flip mirror. When in the beam path, the mirror redirects the light to the 63 um [OI] receiver. While the pick-off mirror is in the beam path the mirror's back-side directs the light from a blackbody calibration load down into the cryostat. The calibration load can be heated or kept at ambient temperature. With the flip mirror retracted, the telescope beam is reimaged onto two, 2-beam mixer arrays by an antireflection-coated silicon lens. A 10% reflective dielectric beam splitter mounted above the mixer arrays is used to inject the THz LO beams into the telescope beam. Making this simple LO diplexer scheme possible are recently-developed LO sources with ~10 times the power of those available for STO-1 in 2011. The new LO sources were designed by our Co-I's at JPL specifically for STO-2.

The 1.9 and 1.46 THz mixers are installed into a 2x2 mounting block, providing a pixel spacing that projects four 60" beams onto the sky. The Hot Electron Bolometer (HEB) mixers used on STO-2 are provided by SRON and are bolted to the dewar's 4K plate. The HEB mixers downconvert the high frequency sky signals to much lower, microwave frequencies. The downconverted sky signal is then conveyed by coax to a series of low-noise cryogenic and room temperature microwave amplifiers. The amplifiers boost signal levels to -10 dBm where they can be readily digitized. The first stage IF low-noise amplifiers (LNAs) will utilize the same high-performance, low-power technology developed for STO-1. Most IF signals will have a nominal center frequency of 1.65 GHz and a 1 GHz bandwidth; a special 0.5-4.5 GHz IF for the [OI] channel will also be available. Each STO-2 pixel has its own 1024 channel FFT spectrometer to produce a power spectrum of the input signal; the [OI] channel will also have a 512-channel, 4.5 GHz digital autocorrelator spectrometer to provide comparable bandwidth and resolution to the [CII] and [NII]. The power spectra from all pixels are read by the instrument's data computer and passed on to the gondola via Ethernet.

Table 2: STO-2 Instrument Properties

Property	**Description**
Telescope	0.8m Cassegrain
Target Frequencies	[CII]: 1.9 THz (2 beams) [NII]: 1.5 THz (2 beams) [OI]: 4.74 THz (1 beam)
Angular Resolution	60", all frequencies
Receiver Type	Hot Electron Bolometer mixers, T_{rec} = 700K DSB
System Noise Temp	< 2200K (SSB)
Spectrometers	FFTS, 6 x 1 GHz Autocorrelator, 1x4.5 GHz
Bandwidths	1 GHz=205 km/s at [NII] 1 GHz=160 km/s at [CII] 4 GHz=250 km/s at [OI]
Spectral Resolution (2 channel)	0.3 km/s at [CII] 1 km/s at [OI]
Cryogenic System	85 liter ^{4}He cryostat w/ Cryotel CT cryocooler
LHe Hold-time	25 days demonstrated

STO-2 uses the same high-efficiency liquid helium cryostat from STO-1 but with a small, robust, Stirling-cycle cryocooler that cools the outer vapor cooled radiation shield to <100K and extends the helium lifetime to ~25 days, roughly two "orbital passes" around Antarctica.

A major value-added contribution to the STO-2 mission is the 63 um [OI] receiver system built by the Space Research Organization of the Netherlands (SRON), and integrated by the STO-2 team in Palestine TX in August 2015. The HEB mixer for [OI] uses a wide-bandwidth spiral antenna that allows it to respond to light from 800 GHz to >5 THz, a fact that the STO-2 team has exploited for end-to-end system testing on the ground in Antarctica (Section 5.3). The LO source for the [OI] channel is a quantum cascade laser (QCL) from Sandia Labs and MIT which is cooled in a separate cryogenic vessel to 50K. STO-2 will be the first mission to operate an amplitude-stabilized, frequency-locked QCL in flight, though good science measurements will still be obtained if either stabilization loop is unavailable during the mission.

5.2 Gondola & Telescope

STO-2 reuses the telescope that was previously flown for STO-1 (Walker et al. 2010), but re-aluminized and with minor modifications. While the STO-2 gondola was also originally slated to draw from STO-1, intervening development of the BRRISON and BOPPS missions at APL led to the exciting prospect of using a new gondola system with updated avionics. STO-2 now

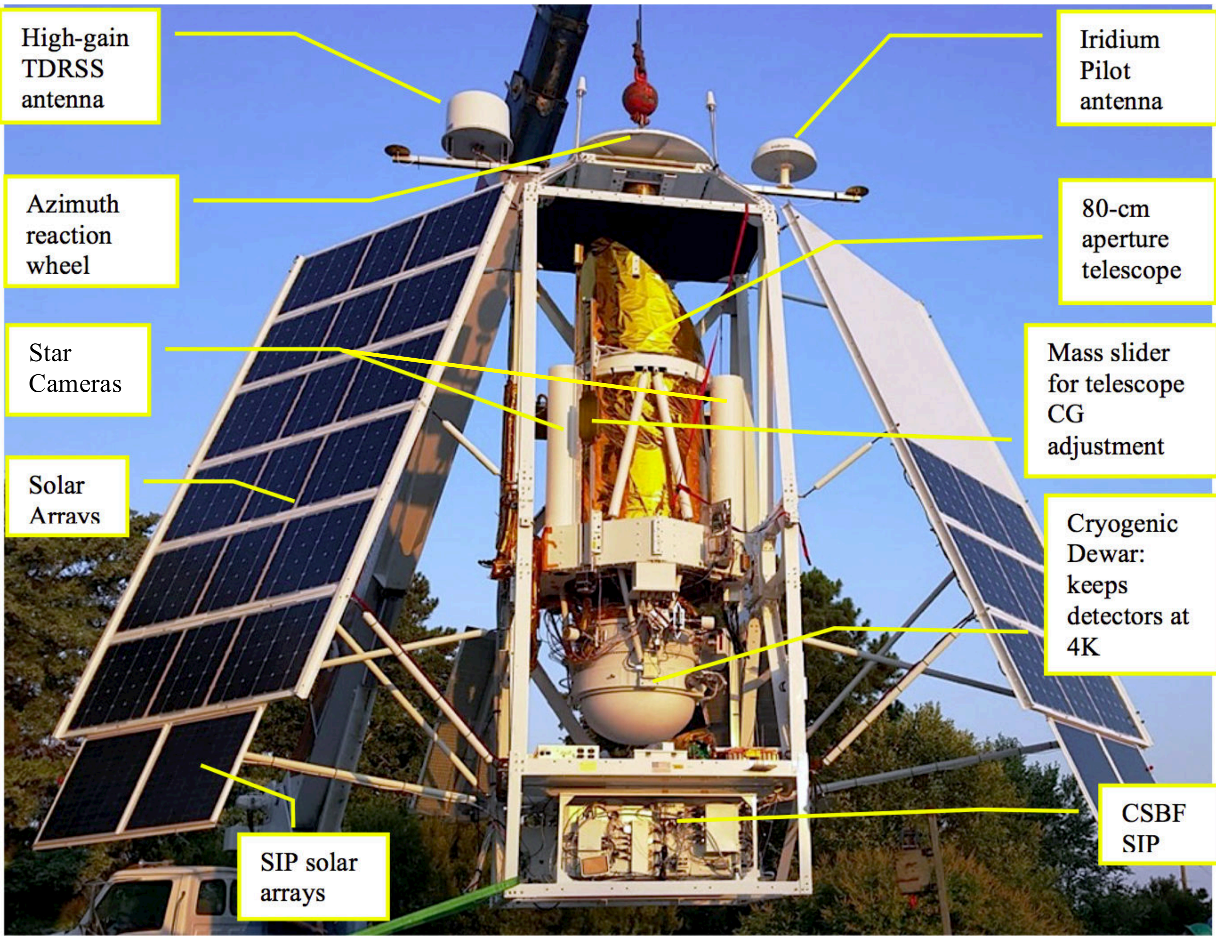

Figure 8: STO-2 flight system during the Compatibility Test at CSBF in Palestine (TX) on Aug. 15, 2015.

uses the BOPPS gondola. Figure 8 shows STO-2 in full flight configuration during the compatibility "hang" test at CSBF in Palestine, Texas.

The most significant observational capability of the new gondola system is a higher elevation limit; increased from 53 degrees elevation to 65 degrees, effectively limited by the projection of the balloon on the sky. This capability allows STO-2 better visibility of Galactic sources and allows observation of the Large Magellanic Cloud (LMC) for about 3 hours per day.

The STO-2 gondola system also provides an upgraded avionics system. The Avionics hardware used for STO-1 was obsolete, heavy, power hungry and cumbersome; it had to be flown inside two pressurized vessels. For BOPPS, APL developed a modern Avionics system specifically designed for balloon flights, which successfully flew in September 2014. The STO-2 avionics are based on the BOPPS design, with some improvements following lessons learned from the BOPPS 2014 flight.

In order to accommodate the increased thermal load of instrument cryoocolers and ambient-pressure avionics, STO-2 utilizes a cooling radiator and a liquid cooling loop. . The system is a replica of the liquid cooling system that APL also developed and successfully flew in the BRRISON and BOPPS missions. The liquid cooling fluid used is Fluorinert, a dense and inert liquid that has similar heat capacity as water, but a freezing temperature point of -75C. This distributed heat reject system serially extracts heat from cryocoolers, local oscillators, instrument and gondola electronics and dumps it onto a flat radiator surface (Figure 9) protected from direct sunlight for most mission operations, and capable of rejecting about 450W to the sky.

The STO-2 pointing system is well proven on STO-1 and BOPPS, with the new addition of jerk motion control that allows for smooth slews that do not introduce additional pendulation in the system. The science pointing requirements are: pointing range of 360° and 0 to 65° in elevation less a half cone of 20° in the direction of the Sun; stability < 15"; knowledge < 15"; source acquisition accuracy < 20". To aim the telescope at the desired target in the sky we use an elevation/azimuth mount. The telescope is attached to the gondola on its elevation axis and a torque motor attached to it rotates the telescope in elevation by pushing against the gondola frame. It is also equipped with a goniometer that measures the angle with respect to the gondola with a resolution of ~ 10 arc minutes. To point in azimuth the entire gondola rotates on the vertical axis via Momentum Transfer Unit (MTU). The fine gondola attitude is determined by an Inertial Measuring Unit (IMU) and two APL-built star cameras. The IMU is composed of three high-precision, low-drift fiber optic gyroscopes, the Optolink SRS-2000, already flown on STO-1. Initialization of azimuth and elevation for the IMU is done on the ground before launch. An addition to the STO-2 pointing control that APL developed for the BRRISON/BOPPS mission is a roll stabilization system. It is composed of a 15 kg wheel mounted vertically on the back of the gondola (Figure 9) and activated by a brushless motor. The wheel is controlled by the pointing control computer. The roll compensation system effectively eliminates most high frequency (up to about periods of 4 seconds) side-to-side gondola pendulation.

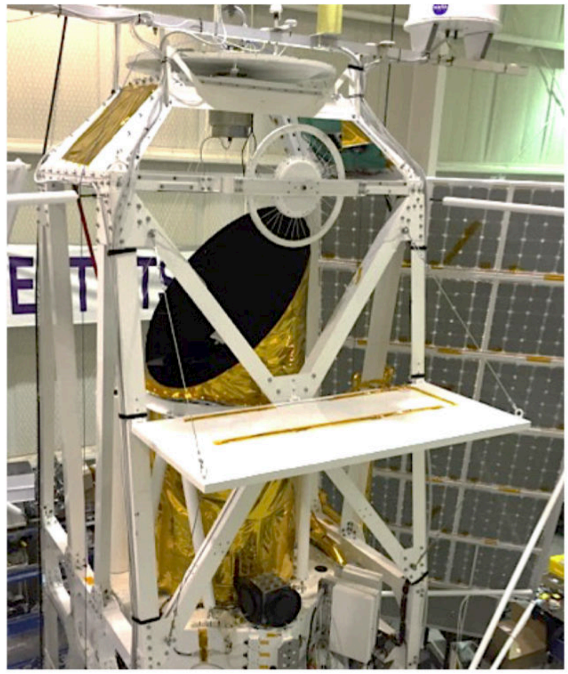

Figure 9: STO-2 Radiator and Roll Stabilization wheel.

The telecommunications system for STO-2 relies on the NASA-CSBF provided Support Instrument Package (SIP) for remote link between the gondola and the ground. The SIP has four available channels to/from the ground. For the first ~24 hours the gondola will be in Line-of-Sight (LOS) to the launch station in Antarctica and will use a UHF radio link at a data rate of 1 Mb/s. After loss of the LOS radio link, nominal gondola communications will be maintained via a 92-Kb/s TDRSS satellite relay. Lower rate 6-Kb/s TDRSS and 2.4 kbps Iridium links are also available as backup. A high-bandwidth Iridium Pilot system provides 130 kbps data transfers and is the nominal conduit for science data return. STO-2's mean science data rate is 70 kbps, so all of the raw science data acquired during the flight will be downlinked and will meet all scientific goals even in the (unlikely) event of payload loss. TDRSS and low-rate IRIDIUM signals will be received at CSBF's Operations Control Center (OCC) in Palestine (TX) and sent to a local STO ground support computer that redistributes the data packets to other STO ground stations at APL, the University of Arizona and to the team in Antarctica. Science data from the Iridium Pilot system returns directly to the science operations center at the University of Arizona.

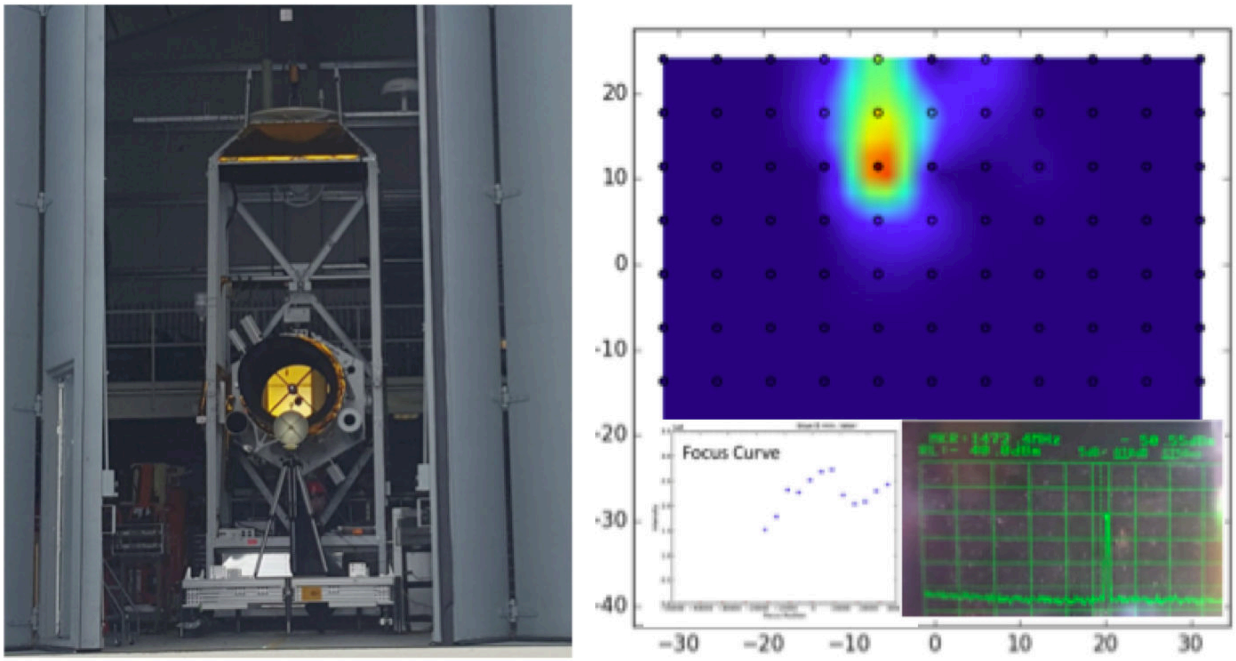

Figure 10: (left) STO-2 horizon-pointing, peering out of the LDB hangar toward a corner cube 500m distant. The co-located 868 GHz transmitter telescope can be seen as a small gray circle just below the STO-2 gold-coated primary. (right) On-The-Fly map of the transmitter as imaged spectroscopically through the full flight system, complete with focus curve and analog spectrum of the IF seen on a spectrum analyzer.

5.3 System Integration and Testing

The STO-2 flight system was prepared for launch in November/December 2015. After instrument and gondola integration and subsystem testing was complete, a full end-to-end ground testing program was developed and performed to provide maximum assurance of mission readiness. To accomplish this, the ultra-wide frequency response of the [OI] mixer (0.8-5 THz) was exploited. Two 870 GHz local oscillator units built at JPL were utilized for this test; one was used to pump the [OI] mixer and the second was used as a transmitter, directed to a 1.5m diameter corner-cube some 500 meters distant using a 20 cm Cassegrain telescope. At this distance, the alignment of APL's optical star cameras and the cryogenic THz receivers could then be measured and an approximate far-field THz focus could be obtained. Furthermore, data acquisition could be performed through the full telemetry system in precisely the same manner as in flight, and the data products could be downlinked and analyzed in the very same way as flight data. At the completion of these tests, the team was fully confident that the system was fully flight-ready. Images of the test setup in the LDB hangar are shown in Figure 10. The final configuration, "all dressed up and ready to go" is shown in Figure 11.

In preparation for a 2016-17 launch, the system currently disassembled and wintering-over in Antarctica will be re-integrated including minor fixes to address remaining known issues. The re-integration tasks in November 2016 will include opening and inspecting the cryostat, vacuum pump-out and cool-down, integration of electronics and local oscillators, followed by re-integration onto the gondola and system checkout. It is expected that the fully operational system will be ready to fly in the first week of December 2016.

Figure 11: STO-2 in Antarctica in December 2015, ready to fly.

6 Management

6.1 Roles and Responsibilities

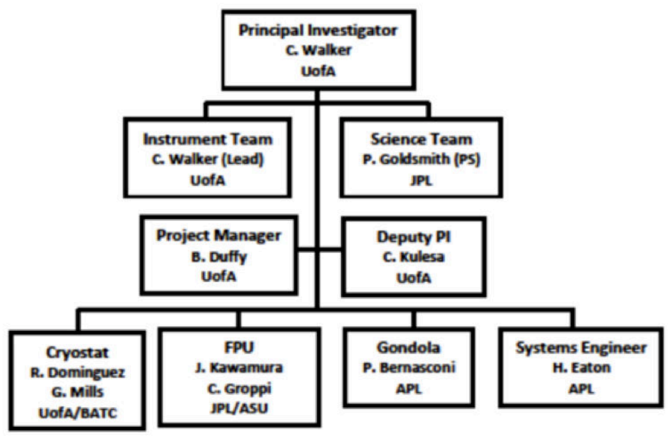

Figure 12. STO-2 Organization

The existing STO-2 organizational structure will be maintained throughout this effort (Figure 12). Dr. Walker (PI) is responsible for all aspects of the success and scientific integrity of STO-2. He is assisted at the University of Arizona by Dr. Craig Kulesa, who will serve as Deputy PI and Brian Duffy, Project Manager (PM). The STO science team is led by Dr. Paul Goldsmith, who will be STO Project Scientist (PS). The Instrument Team is led by the PI (Walker). Dr. Bernasconi (APL Institutional PI) oversees the STO gondola efforts at APL and STO-2 flight operations. Dr. Jonathan Kawamura oversees the LO integration and testing at JPL. The master schedule described below lists the project's major milestones and development activities. The instrument and science teams will make extensive use of electronic communication and management tools including e-mail, secure websites, on-line meetings and video communications to expedite accurate information dissemination. All management and control information will be posted on a secure STO website maintained by the UofA.

6.2 Work Efforts, Milestones & Schedule

The work effort begins on 1 January 2017, nominally 2 weeks after the launch of STO-2. The work breakdown structure follows 4 phases described below.

- **Mission operations** in Antarctica (January 2017)
  During flight, the 4-person Science Operations team will be taking turns monitoring the instrument and adjusting the mission observing profile as needed. Gondola and mission operations will largely be centered at APL where 3 operators will take turns in monitoring the gondola nearly continuously, and in assisting the science team in conducting the science operations. The science team will be examining the data immediately returned by the mission so that critical decisions regarding the mission profile may be made in a timely fashion. CSBF and the PI will coordinate the mission termination. *Milestones: STO-2 launch and termination (15 Dec 2016, 25 Jan 2017)*
- **Recovery Operations** (January - February 2017)
  After flight termination, the recovery team comprised of Arizona and APL participants will return the flight system (if possible) to the LDB field camp and pack and ship the system north. *Milestone: flight system recovered from field (1 Feb 2017)*
- **Data processing, release, archival** (January – April 2017) (Arizona and SAO)
  While preliminary maps will be constructed during the mission to assess the data quality and inform mission planning, the first integrated datasets will be constructed and released publicly during this time period, with no proprietary period. The data archive and web frontend will be developed and initially deployed during this time. Major milestones will be the first public data release (DR1) by 30 April 2017 followed by DR2 by 31 December 2017. DR2 will be considered the "final" data release with the best known calibration, full documentation and ancillary data. Both DR1 and DR2 will be permanently archived (see Section 6.3).
- **Publication** (April – December 2017) (Full science team)
  As the data products are released, different subsets of the science team will focus on answering different facets of the science questions posed in this proposal. Each working group will construct one or more papers on their topic; at a minimum, the Survey papers will be published by the end of this program's 1 year performance period. These working groups already exist and are:

  1. STO-2 Galactic Plane Survey (Walker lead)
  2. STO-2 Deep Surveys (Kulesa lead)
  3. Distribution of ionized, atomic & molecular gas in the Galaxy (Wolfire lead)
  4. The "CO dark" gas, e.g. hidden H_2 (Yorke lead)
  5. Origin of [CII] in the Galaxy (Wolfire lead)
  6. Heating of the ISM of the Galaxy (Wolfire lead)
  7. The formation of GMCs (Kulesa lead)
  8. The destruction of clouds (Hollenbach lead)
  9. Correlation of STO-2 data with Mopra, HEAT, Spitzer, Herschel, AST/RO
  10. The Milky Way Schmidt Law
  11. The Milky Way as a template for other galaxies
  12. The dynamics of gas in the Galaxy (Walker lead)
  13. Source-specific papers (eta Carina, LMC, etc.)

6.3 Data Management

STO-2'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 On-The-Fly mapping mode and not in the form desired for scientific distribution; therefore minimal data processing is performed on the STO-2 data computer; most processing happens on the ground. The data processing flow is described below and can be operated autonomously after basic verification. The steps undertaken in each data processing level are described as follows:

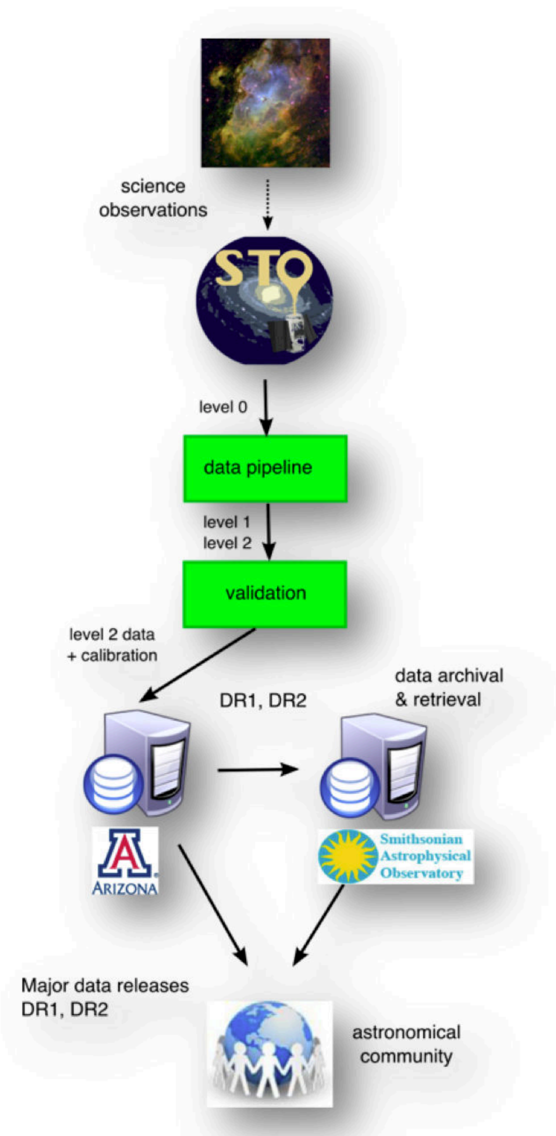

Figure 13: STO-2 data flow and archiving

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 data computer. A data header is synthesized from streamed data from the pointing control system and instrument housekeeping data. The data payload is rescaled and written as a single-dish FITS file. After validation, the 'stateless' 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 60" resolution with 20" pixels. Optionally, spectral smoothing and additional spatial smoothing can be applied at this stage. These level 2 FITS cubes represent the baseline data products that STO-2 will provide.

Data Archive

The STO-2 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 a preliminary releases of very recent data in April 2017 as Data Release 1 (DR1) as soon as calibration and formatting is complete, with **no proprietary period**. A final data release (DR2) will be made in December 2017. The archival data flow is diagramed in Figure 13. The maximum data volume is expected to be 25 GB in total, including all calibration datasets. The regridded level 2 maps should encompass no more than 1 GB. The FITS cubes will be developed within the STO-2 team and hosted on existing RAID arrays both at the University of Arizona and at the Harvard University Library's Astronomical Dataverse (see secondary proposal from SAO/CfA) for long term storage. The FITS headers will be stored in a SQL database to make web-based relational queries and extraction of data subsets easy from the end user's perspective.

References

Bennett, C. L., Fixsen, D.J., Hinshaw, G., et al. 1994, "Morphology of the Interstellar Cooling Lines detected by COBE", ApJ, 434, 587

de Avillez, M. A., & Breitschwerdt, D. 2005, "Testing Global ISM Models: A Detailed Comparison of O VI Column Densities with FUSE and Copernicus Data", ApJL, 634, L65

Elmegreen, B. G. 1996, "What Do We Really know About Cloud Formation" in Unsolved Problems of the Milky Way, 169, 551

Engargiola, G., Plambeck, R. L., Rosolowsky, E., & Blitz, L. 2003, "Giant Molecular Clouds in M33. I. BIMA All-Disk Survey", ApJS, 149, 343

Gazol, A., Vázquez-Semadeni, E., & Kim, J. 2005, "The Pressure Distribution in Thermally Bistable Tur-bulent Flows", ApJ, 630, 911

Grenier, I. A., Casandjian, J.-M., & Terrier, R. 2005, "Unveiling Extensive Clouds of Dark Gas in the Solar Neighborhood", Science, 307, 1292

Heiles, C., & Troland, T. H. 2003, "The Millennium Arecibo 21 Centimeter Absorption-Line Survey. II. Properties of the Warm and Cold Neutral Media", ApJ, 586, 1067

Hennebelle, P., & Pérault, M. 2000, "Dynamical condensation in a magnetized and thermally bistable flow. Application to interstellar cirrus", A&A, 359, 1124

Heitsch, F., Slyz, A. D., Devriendt, J. E. G., Hartmann, L. W., & Burkert, A., 2006, "The Birth of Molecular Clouds: Formation of Atomic Precursors in Colliding Flows", ApJ, 648, 1052

Hollenbach, D. J., Tielens, A. G. G. M. 1999, "Photodissociation Regions in the Interstellar Medium of Galaxies", RvMP, 71, 173

Jenkins, E. B., & Tripp, T. M. 2011,"The Distribution of Thermal Pressures in the Diffuse, Cold Neutral Medium of Our Galaxy. II. An Expanded Survey of Interstellar C I Fine-structure Excitations", ApJ, 734, 65

Kennicutt, R. C. Jr. 1989, "The Star Formation Law in Galactic Disks", ApJ, 344, 685

Kim, C.-G., Kim, W.-T., & Ostriker, E. C. 2011, "Regulation of Star Formation Rates in Multiphase Galactic Disks: Numerical Tests of the Thermal/Dynamical Equilibrium Model", ApJ, 743, 25

Kritsuk, A. G., & Norman, M. L. 2002, "Thermal Instability-induced Interstellar Turbulence", ApJL, 569, L127

Kulesa, C.A., Walker, C.K., Young, A.G., Ashley, M.C.B., & Storey, J.V.W. 2011, "HEAT: The High Elevation Antarctic Terahertz telescope". Proceedings of the 22nd International Symposium on Space Terahertz Technology, paper 9-3.

Langer, W. D., Velusamy, T., Pineda, J. L., et al. 2010, "C^+ Detection of Warm Dark Gas in Diffuse Clouds" ,A&A, 521, L17

Mac Low, M.-M., Balsara, D. S., Kim, J., & de Avillez, M. A. 2005, "The Distribution of Pressures in a Supernova-driven Interstellar Medium. I. Magnetized Medium", ApJ, 626, 864

Martin, C. L., Kennicutt, R. C. Jr 2001, "Star Formation Thresholds in Galactic Disks", ApJ, 555, 301

McClure-Griffiths, N. M. et al. 2005, "The Southern Galactic Plane Survey: H I Observations and Analysis", ApJS, 158, 178

McKee, C. F. 1989, "Photoionization-Regulated Star Formation and the Structure of Molecular Clouds", ApJ, 345, 782

McKee, C. F., Ostriker, J. P. 1977, "A Theory of the Interstellar Medium - Three Components Regulated by Supernova Explosions in an Inhomogeneous Substrate", ApJ, 218, 148

McKee, C. F. Williams, J. P. 1997, "The Luminosity Function of OB Associations in the Galaxy", ApJ, 476, 144

Nakagawa, T., Yui, Y. Y., Doi, Y., et al. 1998, "Far-Infrared [C II] Line Survey Observations of the Galactic Plane", ApJS, 115, 259

Onishi, T. et al., 2005, "New View of Molecular Gas Distribution of the Southern Sky: CO Surveys with NANTEN", in Protostars and Planets V, LPI Contribution No. 1286, p.8301

Onodera, S., Kuno, N., Tosaki, T., et al., 2010 "Breakdown of Kennicutt-Schmidt Law at Giant Molecular Cloud Scales in M33", ApJ, 722:L127

Ostriker, E. C., & Kim, W.-T. 2004, ASP Conf. Ser. 317: "Milky Way Surveys: The Structure and Evolution of our Galaxy", 317, 248

Ostriker, E. C., McKee, C. F., & Leroy, A.K. 2010, "Regulation of Star Formation Rates in Multiphase Galactic Disks: A Thermal/Dynamical Equilibrium Model", ApJ, 721, 975

Paradis, D., Dobashi, K., Shimoikura, T., et al. 2012, "Dark Gas in the Solar neighborhood from Extinction Data", A&A, 543, A103

Parravano, A., Hollenbach, D. J., McKee, C. F. 2003, "Time Dependence of the Ultraviolet Radiation Field in the Local Interstellar Medium" ApJ, 584, 797

Planck Collaboration, Ade, P. A. R., Aghanim, N., et al. 2011, "Planck Early Results. XIX. All-sky Temperature and Dust Optical Depth from Planck and IRAS. Constraints on the "Dark Gas" in our Galaxy", A&A, 536, A19

Schmidt, M. 1959, "The Rate of Star Formation", ApJ, 129, 243

Velusamy, T., Langer, W. D., Pineda, J. L., et al. 2010, "[C II] Observations of H_2 Molecular Layers in Transition clouds", A&A, 521, L18

Velusamy, T., Langer, W.D., Pineda, J.L., & Goldsmith, P.F. 2012, "[CII] 158 μm Line Detection of the Warm Ionized Medium in the Scutum-Crux Spiral Arm Tangency", A&A, 541, L10

Walker, C., Kulesa, C., Bernasconi, P., et al., 2010, "The Stratospheric THz Observatory (STO), in Ground based and Airborne Telescopes III", eds. Larry M. Stepp, Roberto Gilmozzi, Helen J. Hall, Proc. of SPIE Vol. 7733, 77330N (2010)

Williams, J. P., McKee, C. F. 1997, "The Galactic Distribution of OB Associations in Molecular Clouds", ApJ, 476, 166

Wolfire, M. G., McKee, C. F., Hollenbach, D., & Tielens, A. G. G. M. 2003, "Neutral Atomic Phases of the Interstellar Medium in the Galaxy", ApJ, 587, 278

Wright, E. L. et al 1991, "Preliminary Spectral Observations of the Galaxy with a 7 deg Beam by the Cosmic Background Explorer (COBE)", ApJ, 381, 200

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; Associate Professor of Optical Sciences and Electrical & Computer 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, 1983-1988
- Research and Development Engineer, Jet Propulsion Laboratory, 1983
- Electrical Engineer, TRW Aerospace Division, 1981-1983

Synergistic Activities

1) Prof. Walker has written the first textbook on "TeraHertz Astronomy", released in 2015 by Francis Taylor Publishing Group.
2) Prof. Walker was recently selected to be a NASA Innovative Advanced Concept (NIAC) Fellow based upon his research into the concept for a suborbital, 10 meter Large Balloon Reflector (LBR). LBR can be used for astronomy, remote sensing, and a host of telecommunications activities.
3) 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.
4) 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).
5) 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.
6) He is PI of the NASA funded long duration balloon project ``The Stratospheric THz Observatory (STO)''.

7) Prof. Walker has served as dissertation director for eleven Ph.D. students (7-Astronomy, 2-Optical Sciences, 1-Electrical Engineering).

Sample Publications (130+ authored/co-authored papers in literature)

Walker, C. K., 2015, **TeraHertz Astronomy**, CRC Press, Taylor & Francis Group, Boca Raton, FL.

Kloosterman, J. L., Hayton, D. J., Ren, Y., Kao, T. Y., Hovenier, J. N., Gao, J. R., Klapwijk, T. M., Hu, Q., Walker, C. K., and Reno, J. L., 2013, "Hot Electron Bolometer Heterodyne Receiver with a 4.7 THz Quantum Cascade Laser as a Local Oscillator", Appl. Phys. Lett., 102, 011123.

Walker, C., 2012, *STO, GUSSTO (EXPLORER): Recent Activities and Results,*
39th COSPAR Scientific Assembly, 14-22 July 2012, in Mysore, India, p. 2114

Walker, C., Kulesa, C. & GUSSTO Team, 2012, *GUSSTO (EXPLORER): Phase A Study Report*, delivered to NASA, 23 September 2012.

C. Walker, C. Kulesa, J. Kloosterman, T. Cottam, C. Groppi, P. Bernasconi, H. Eaton, N. Rolander, B. Carkhuff, S. Hechtman, J. Gottlieb, D. Neufeld, C. Lisse, A. Stark, D. Hollenbach, J. Kawamura, P. Goldsmith, W. Langer, H. Yorke, J. Sterne, A. Skalare, I. Mehdi, S. Weinreb, J. Kooi, J. Stutzski, U. Graf, C. Honingh, P. Puetz, C. Martin, D. Lesser, and M. Wolfire, 2011, *The Stratospheric THz Observatory (STO): Preparations for Science Flight*, Proceedings of 22nd International Symposium on Space Terahertz Technology, Tucson, 26-28 April 2011.

Craig Kulesa, Christopher Walker, Abram Young, John Storey, Michael Ashley, 2011, *HEAT: The High Elevation Antarctic Terahertz Telescope*, Proceedings of 22nd International Symposium on Space Terahertz Technology, Tucson, 26-28 April 2011.

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.

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

Past Ph.D. Advisees: Grace Wolf (Hansen Planetarium), Jason Glenn (UC Boulder), Gopal Narayanan (U. Mass), Craig Kulesa (UofA), Christian d'Aubigny (UofA), Christopher Groppi (ASU), Desika Narayanan (CfA), Abigail Hedden (ARL), Dathon Golish (UofA), Jenna Kloosterman (JPL)

CURRICULUM VITAE

Pietro Bernasconi, Principal Investigator, PM
JOHNS HOPKINS UNIVERSITY Applied Physics Laboratory
11100 Johns Hopkins Road, Laurel, MD 20723-6099, USA
Tel: +1-240-228-8970 Fax: +1-240-228-0386
e-mail: Pietro.Bernasconi@jhuapl.edu

Current Position

Principal Professional Staff, Solar Physics Section, Space Science Group, Space Exploration Sector

The Johns Hopkins University / Applied Physics Laboratory

Education

1992 Diploma in Physics (equivalent to American Master's Thesis), Swiss Federal Institute of Technology Zürich (ETH-Z)

1997 Ph.D. in Natural Science, Swiss Federal Institute of Technology Zürich (ETH-Z)

Professional Positions

1992-1997: Research Fellow, Institute for Astronomy of the ETH-Z, Solar Physics Group.

1997-1999: Post-Doc, JHU/APL

1999-2003: Research Associate, JHU/APL

2003-2014: Senior Professional Staff, JHU/APL

2014-Present: Principal Professional Staff, JHU/APL

Relevant Experience

1997-2004: Project Scientist Flare Genesis Experiment balloon program (FGE). Responsible for FGE vector magnetograph assembly and calibration; participate in I&T at APL and in Antarctic; 1999/2000 Antarctica Mission Operations and recovery lead; Responsible for post-flight data reduction and analysis.

2001-2007: Project Scientist, Solar Bolometric Imager balloon program (SBI). Responsible for SBI instrument assembly and calibration; participate in I&T operations at APL, in Fort Sumner for Flight 1 (2003) and in Antarctica for Flight 2 (2007); responsible for development command and control and autonomous observing program software; Fort Sumner and Antarctica Mission Operations lead; Responsible for post-flight data reduction and analysis.

2007-2008: PI, Solar Bolometric Imager balloon program (SBI2). In addition to responsibilities listed above for SBI, took over all PI and PM responsibilities; lead of the 2007 Fort Sumner flight campaign.

2008-2012: Institutional PI/Gondola PI, Stratospheric TeraHertz Observatory balloon program Flight 1 (STO1). PM and leader of the APL team tasked to develop the gondola and subsystems for STO; responsible for development and testing of command & control software, and autonomous operations software; lead of I&T at APL.

2013-2014: Gondola lead engineer, Balloon Rapid Response for ISON (BRRISON) and Balloon Observing Platform for Planetary Science (BOPPS). Lead of the technical team to develop, build and test the gondola; Lead of I&T at APL and at the launch site in Fort Sumner; Mission Operations Manager for September 2013 and 2014 flights.

2014 – present: Institutional PI/Gondola PI, Stratospheric TeraHertz Observatory balloon program Flight 2 (STO2). Same role and responsibilities as in STO1

CURRICULUM VITAE - *Christopher Emil Groppi*

School of Earth and Space Exploration, Arizona State University, PO Box 871404, Tempe, AZ 85287-1404

Tel: 480-965-6436, Fax: 480-965-8102 Email: cgroppi@asu.edu http://thz.asu.edu/cgroppi/

Professional Preparation:

B.A. with Honor in Astronomy, Cornell University, Ithaca, NY, 1997

Ph.D. in Astronomy with minor in Electrical and Computer Engineering, University of Arizona, Tucson, AZ 2003

Director's Postdoctoral Research Associate, National Radio Astronomy Observatory, Tucson, AZ 2003-2005

National Science Foundation Astronomy and Astrophysics Postdoctoral Fellow, University of Arizona, Tucson, AZ, 2006-2009

Appointments:

Assistant Professor, Arizona State University School of Earth and Space Exploration: 2009-present

Assistant Staff Astronomer, Steward Observatory, 2004-2009

Products:

Groppi, C.E., Wheeler, C.H., Mani, H., Weinreb, S., Russell, D., Kooi, J.W., Lichtenberger, A.W., Walker, C.K., The Kilopixel Array Pathfinder Project (KAPPa), a 16 Pixel Integrated Heterodyne Focal Plane Array, Millimeter and Submillimeter Detectors and Instrumentation for Astronomy VI, Edited by Holland, Wayne, Zmuidzinas, Jonas, Proc. SPIE 8452, 84520Y, pp. 1-9, 2012.

Groppi, C.E., Kawamura, J.H., Coherent Detector Arrays for Terahertz Astrophysics Applications, IEEE Trans. on Terahertz Science and Technology, v. 1, no. 1, 2011.

Groppi, C.E., Walker, C., Kulesa, C., Golish, D., Kloosterman, J., Weinreb, S., Jones, G., Barden, J., Mani, H., Kuiper, T., Kooi, J., Lichtenberger, A., Cecil, T., Puetz, P., Narayanan, G., Hedden, H., *Testing and Integration of Supercam, a 64-Pixel Array Receive for the 350 GHz Atmospheric Window*, Millimeter and Submillimeter Detectors and Instrumentation for Astronomy V, Edited by Duncan, William, Holland, Wayne, Withingtonm Stafford, Zmuidzinas, Jonas, Proc. SPIE 7741, 774110X, pp. 1-11, 2010.

Walker, C.,Kulesa, C., Bernasconi, P., Eaton, H., Rolander, N., **Groppi, C.**, Kloosterman, J., Cottam, T., Lesser, D., Martin, C., Stark, A., Neufeld, D., Lisse, C., Hollenbach, D., Kawamura, J., Goldsmith, P., Langer, W., Yorke, H., Stern, J., Skalare, A., Mehdi, I., Weinreb, S., Kooi, J., Stutzki, J., Graf, U., Brasse, M., Honingh, C., Simon, R., Akyilmaz, M., Puetz, P., Wolfire, M., *The Stratospheric Terahertz Observatory (STO),* Ground-based and Airborne Telescopes III, Edited by Larry M. Stepp; Roberto Gilmozzi; Helen J. Hall, Proc. SPIE 7733, 773330N, pp. 1-9, 2010.

Groppi, C.E., Walker, C.K., Kulesa, C., Golish, D., Hedden, A., Narayanan, G., Lichtenberger, A.W., Kooi, J.W., Graf, U.U., Heyminck, S. *First results from DesertSTAR: a 7-pixel 345-GHz heterodyne array receiver for the Heinrich Hertz Telescope*, Proc. SPIE, v. 5498, pp. 290-299, 2004.

Other Significant Publications:

Groppi, C.E., Hunter, T.R., Blundell, R., Sandell, G., *High Spatial Resolution Observations of Two Young Protostars in the R Corona Australis Region*, Ap.J., v. 670, pp. 489-498, 2007.

Groppi, C., Kulesa, C., Walker, C., Martin, C. *Millimeter and Submillimeter Survey of the R Corona Australis Region*, Ap.J., v. 612, pp. 946-955, 2004.

Groppi, C.E., Navarrini, A. & Chattopadhyay, G., *A waveguide orthomode transducer for 385-500 GHz*, Millimeter and Submillimeter Detectors and Instrumentation for Astronomy V, Edited by Duncan, William, Holland, Wayne, Withingtonm Stafford, Zmuidzinas, Jonas, Proc. SPIE 7741, 774112D, pp. 1-11, 2010.

Tan, B-K, Leech, J., Yassin, G., Kittara, P., Tacon, M., Wangsuya, S., **Groppi, C.,** *A High Performance 700 GHz Feed Horn*, Journal of IR, MM and THz Waves, v. 33, no. 1, pp. 1-5, 2012.

Tan, B-K., Yassin, G., Grimes, P., Leech, J., Jacobs, K., **Groppi, C.,** *A 650 GHz Unilateral Finline SIS Mixer fed by a Multiple Flare-Angle Smooth-Walled Horn*, IEEE Trans. on Terahertz Science and Technology, *v. 2,no. 1, pp. 40-49, 2012*.

Synergistic Activities:

Involvement in all facets of the design, construction, test and integration of five heterodyne array receivers (PoleSTAR, DesertSTAR, SuperCam, Stratospheric Terahertz Observatory, Kilopixel Array Pathfinder Project); Development of CNC micromachining techniques for THz circuit fabrication; Study of molecular gas content and star formation in nearby galaxies; Galactic star formation research using mm-wave and sub-mm wave telescopes, concentrating on the interaction of protostellar sources with the surrounding ISM, and the dynamics of protostellar accretion disks.

3 Biographical Sketch

3.1 Institutional Principal Investigator: Dr. Jonathan Kawamura

Jonathan H. Kawamura

Jet Propulsion Laboratory 168-314 tel: 818-393-4779
California Institute of Technology email: kawamura@jpl.nasa.gov
Pasadena CA 91109

Employment:

Senior Electronics Engineer, 2000–; Affiliate, 1998–2000, Jet Propulsion Laboratory
Postdoctoral Scholar in Physics, 1997–2000. California Institute of Technology.
Research Assistant, 1992–1997. Harvard College Observatory.

Education:

Ph. D., Astronomy, Harvard University, 1997; A. M., 1994.
B. S., Astronomy, California Institute of Technology, 1992.

Upon receiving his doctorate in 1997, Dr. Kawamura joined Caltech as a Postdoctoral Scholar in the Submillimeter Astronomy Group. He also became a JPL affiliate. Teaming with the JPL Microdevices Laboratory, he and his colleagues demonstrated a near-quantum noise limited SIS mixer above the gap frequency of Nb. Operating an SIS mixer at such a high-frequency was considered a serious barrier at the time for low-noise mixer operation above 0.7 THz. With colleagues from the Smithsonian Astrophysical Observatory, he built, deployed and performed observations with a HEB receiver. These were the first astronomical observations with this kind of receiver, and a detection of a celestial emission-line above 1 THz was made. These critical technologies were inserted into the HIFI instrument on the Herschel Space Observatory. Dr. Kawamura joined JPL in 2000. He has worked on Herschel HIFI and has been a PI on several research and development efforts to advance THz receiver technology and utilize them for astronomical research. For STO-2 he will be the Institutional PI for JPL and will assist in the I&T activities.

Selected relevant publications:

F. Boussaha, J. Kawamura, J. Stern, C. Jung, A. Skalare and V. White, "Terahertz-frequency waveguide HEB mixers for spectral lines astronomy," *Proc. SPIE* 845211 (2012)

F. Boussaha, J. Kawamura, J. Stern, A. Skalare, and V. White, "A low-noise 2.7 TH waveguide-based superconducting mixer," *IEEE Trans. Terahertz Sci. Tech*., 2, 284 (2012)

H.-B. Li, R. Blundell, A. Hedden, J. Kawamura, S. Paine, and E. Tong, "Evidence for dynamically important magnetic fields in molecular clouds," *Monthly Notices of the Royal Astronomical Society*, 411, 2067 (2011)

Th. de Graauw, et al., "The Herschel-Heterodyne Instrument for the Far-Infrared (HIFI)," *Astronomy and Astrophysics*, 518, 6D (2010)

C.-Y. E. Tong, J. Kawamura, D. Marrone, D. Loudkov, S. Paine, R. Blundell, C. Barrientos, and D. Luhr, "A 1.5 THz hot electron bolometer receiver for ground-based terahertz astronomy in northern Chile," *Proc. SPIE* 6373, 6373U (2006)

J. Kawamura, T. R. Hunter, C.-Y. E. Tong, R. Blundell, D. C. Papa, F. Patt, W. Peters, T. L. Wilson, C. Henkel, G. Gol'tsman, & E. M. Gershenzon, "Ground-based Terahertz CO Spectroscopy towards Orion," *Astronomy & Astrophysics*, **394**, 271-274 (2002)

3.2 Co-investigator, Dr. Jose Siles

Jose V. Siles
Member of Engineering Staff
Jet Propulsion Laboratory
4800 Oak Grove Drive • MS T1721-105
Pasadena, CA 91109
(818) 354-4006

Relevant Experience

Dr. Siles has more than 8 years of experience in the physics-based modeling of semiconductor devices employing numerical methods and in the design and test of frequency multipliers and mixers for terahertz applications. He has participated in several programs to develop terahertz technology, including frequency multiplied sources and receivers, for the French space agency (CNES), the European Space Agency (ESA), the European Commission and NASA/JPL. He is an experienced terahertz component and circuit designer, having designed and tested 200, 700, 1900 and 2700 GHz frequency multiplier circuit designs, and 340, 600 and 1200 GHz frequency mixer circuits, all them exhibiting world-record performances. He also has developed advanced physics based numerical drift-diffusion and Monte Carlo models for GaAs/GaN based terahertz circuits. His current research interests involve the design, development and test of solid-state power-combined multiplied local oscillator sources and receivers for high resolution multi-pixel heterodyne cameras at submillimeter-wave and terahertz frequencies for radio-astronomy, planetary science, cosmology and radar imaging applications. He was the recipient of a Fulbright Postdoctoral Research Award at NASA Jet Propulsion Laboratory for the period 2010-2012, sponsored by the U.S. Department of State and the J. Fulbright Program. He was the recipient of the 2012 NASA/JPL Outstanding Postdoctoral Research Award.

Education:

- Ph. D. Electrical Engineering, Technical University of Madrid, Spain, 2008.
- M.S., Telecommunication Engineering, Technical University of Madrid, Spain, 2003.

Professional Experience:

Current Positions:

2012–present Member of Engineering Staff – Submillimeter Wave Advanced Technology Group, NASA Jet Propulsion Laboratory, Pasadena, California

Previous Positions:

2010–2012: Fulbright Postdoctoral Scholar, NASA-JPL, Pasadena, CA
2008–2010: Postdoctoral Research Fellow, LERMA Dept., Observatory of Paris, France
2002–2008: Graduate Research Assistant – Technical University of Madrid, Spain
2004/2006: Visiting Graduate Researcher, “Tor Vergata” University of Rome, Italy

Professional Activities:

Vice-chair of IEEE MTT-S Joint San Fernando Valley/Metro LA Chapter

Refereed Publications

[1] E. Schlecht, **J. V. Siles**, C. Lee, et al., “Schottky Diode Based 1.2 THz Receivers Operating at Room- Temperature and Below for Planetary Atmospheric Sounding *IEEE Trans. on THz Sc. and Tech,,* Sep. 2014

[2] A. Maestrini, I. Mehdi, **J. V. Siles**, et al., “First demonstration of a tunable electronic source in the 2.5-2.7 THz range,” *IEEE Transactions on Terahertz Science and Technology*, Vol. 2, No. 3, pp. 177-185, Mar. 2012.

[3] **J. V. Siles** and J. Grajal, “Physics-based design and optimization of Schottky diode frequency multipliers for THz applications,” *IEEE Transactions on Microwave Theory and Techniques, Special Issue on "THz Technology: Bridging the Microwave-to-Photonics Gap",* Vol. 58, No. 7, pp. 1933-1942, July 2010.

3.3 Co-Investigator: Dr. William Langer

William D. Langer

Jet Propulsion Laboratory 183-600 tel: 818-354-5823
California Institute of Technology email: William.Langer@jpl.nasa.gov
Pasadena CA 91109

Current Position: Senior Research Scientist

Education: Ph.D., Physics, Yale University

Dr. William Langer is a Senior Research Scientist at the Jet Propulsion Laboratory. He has over thirty years experience in astrophysics and is author, or co-author, on over 160 research papers, the majority of them on topics related to the interstellar medium, star formation, and protostellar disks. Dr. Langer has been studying interstellar clouds and star formation both observationally and theoretically. His contributions include various time dependent chemical - dynamical codes for chemistry of clouds and protostellar cores and disks. He is involved in research on the thermal, chemical, and structural properties of the ISM. Currently he is the PI on a Herschel Open Time Key Program, "State of the Diffuse ISM: Galactic Observations of Terahertz CII Line" which will detect dark gas throughout the Galaxy. In addition, he is a member of two Herschel Guaranteed Time Programs and several Herschel Open Time 1 and 2 programs.

Representative Publications:

Molecular Cooling & Thermal Balance of Dense Interstellar Clouds, Goldsmith, P. F. & **Langer, W. D**., 1978, ApJ, 222, 881.

Stability of Interstellar Clouds Containing Magnetic Fields, 1978, Langer, W., ApJ, 225, 95.
Isotope Selective Photodestruction of CO, 1982, Bally, J. & **Langer, W. D**., ApJ, 255, 143.

The Relationship Between Carbon Monoxide Abundance and Visual Extinction in Interstellar Clouds, 1982, Frerking, M. A., **Langer, W. D**., & Wilson, R. W., ApJ, 262, 590.

Structure Function Scaling of a 2MASS Extinction Map of Taurus, Padoan, P., Cambresy, L., and **Langer, W. D**., 2002, ApJ Letters, 580, L57.
Molecular Hydrogen Emission from the Boundaries of the Taurus Molecular Cloud
P. F. Goldsmith, T. Velusamy, D. Li, **W. D. Langer**, 2010, Ap J., 715, 137.
C^+ Detection of Warm Dark Gas in Diffuse Clouds, **W. D. Langer,** T. Velusamy, J. L. Pineda, P. F. Goldsmith, D. Li, & H. W. Yorke, 2010, A&A, 521, L17.

[CII] Observations of H_2 Molecular Layers in Transition Clouds, T. Velusamy, **W. D. Langer,** J. L. Pineda, P. F. Goldsmith, D. Li, & H. W. Yorke, 2010, A&A, 521, L18.

A Sample of [CII] Clouds Tracing Dense Clouds in Weak FUV Fields Observed by Herschel, J. L. Pineda, T. Velusamy, **W. D. Langer,** P. F. Goldsmith, D. Li, & H. W. Yorke, 2010, A&A, 521, L19.

3.4 Co-Investigator: Dr. Jorge Pineda

Jorge L. Pineda
Scientist
Jet Propulsion Laboratory
4800 Oak Grove Drive • MS 169-237
Pasadena, CA 91109
(818) 354-3347

RELEVANT EXPERIENCE

Dr. Jorge L. Pineda has over 10 years of experience in radio astronomy and has specialized in the observations and interpretation of the millimeter-and submillimeter-wave line and continuum emission in the galaxy and extragalactic sources. He is a member of the Herschel Galactic Observations of Terahertz C+ (GOT C+) project devoted to study the [CII] 1.9 THz line in the Milky Way. He is also PI of several observations campaigns in the submillimeter wave spectrum using the Herschel Space Observatory. His role in this proposal will be to guide the performance objectives of the proposed work based on the scientific needs.

EDUCATION:

Ph. D., Astronomy, University of Bonn, Germany, 2007.
M.S., Astronomy, University of Chile, Chile, 2003.
B.S., Physics and Astronomy, University of Chile, 2002

PROFESSIONAL EXPERIENCE:

CURRENT POSITIONS:

2011–present: Scientist, Jet Propulsion Laboratory, California Institute of Technology

PREVIOUS POSITIONS:

2008–2011: Postdoc, Jet Propulsion Laboratory, California Institute of Technology
2007–2008: Postdoc, Angelander Institut fuer Astronomie, University of Bonn

SELECTED RELEVANT REFEREED PUBLICATIONS

1. **Pineda, J. L.,** Langer, W. D., Goldsmith. 2014, GOTC+ [CII] Galactic Plane Survey II: [CII] as a Tracer of Star Formation, A&A, 570, AA121.
2. **Pineda**, **J. L.**, Langer, W. D., Velusamy,T., Goldsmith. 2013, GOTC+ [CII] Galactic Plane Survey I: The Global Distribution of ISM Gas Components *A&A*, 554, A103.
3. **Pineda, J.L.**, Mizuno, N., Röllig, M., et al., Submillimeter line emission from LMC 30 Doradus: The impact of a starburst on a low-metallicity environment, 2012, *A&A*, 544, A84.
4. **Pineda**, **J. L.** Velusamy,T., Langer, W. D., Goldsmith, P. F., Li. D. & Yorke, H.W. 2010. A Sample of [CII] Clouds Tracing Dense Clouds in Weak FUV Fields. *A&A*, 521, L19.
5. **Pineda, J.L.**, Goldsmith, P.F., Chapman, N.L., Li, D., Snell, R., Cambr´esy, L. & Brunt, C. 2010. The Relation between Dust and Gas in the Taurus Molecular Cloud. *ApJ*, 721, 686

3.5 Co-Investigator: Dr. Paul Goldsmith

Paul F. Goldsmith, STO-2 Project Scientist
Senior Research Scientist and Chief Technologist
Jet Propulsion Laboratory
4800 Oak Grove Drive • MS 169-506
Pasadena, CA 91109
(818) 393-0518

RELEVANT EXPERIENCE

Dr. Goldsmith is the NASA Project Scientist for the Herschel Space Observatory, a far-infrared / submillimeter-wave spectroscopic and photometric mission launched in 2009. He is also leading the JPL involvement with heterodyne array camera for the Cornell-Caltech Atacama Telescope (CCAT) project. Dr. Goldsmith's recent work has focused on determining time scales of processes associated with the formation of molecular clouds and young stars. This has included use of atomic hydrogen in molecular clouds as a tracer of their evolution and history. He has also worked on determining the conditions for formation of massive stars by using molecular line and dust continuum emission.

EDUCATION

A.B. (Physics), University of California, Berkeley, 1969
Ph.D. (Physics), University of California, Berkeley, 1975

RECENT POSITIONS HELD

2009 - Adjunct Professor of Astronomy, University of Arizona, Tucson
2008 - Present Chief Technologist, Astronomy, Physics, and Space Technology Directorate, JPL
2006 - Present NASA Project Scientist, Herschel Space Observatory
Visiting Associate, Department of Astronomy, Calif. Inst. Technology, Pasadena
2000, 2001, 2004 Professeur Invité, Ecole Normale Supérieure, Paris, France
1999 - 2005 James Weeks Professor in the Physical Sciences, Dept. of Astronomy, Cornell Univ.
1993 - 2002 Director, National Astronomy and Ionosphere Center

HONORS AND AWARDS

NASA Exceptional Achievement Medal, 2010
Senior Research Scientist, Jet Propulsion Laboratory, California Institute of Technology, 2006
Professor Emeritus of Astronomy, Cornell University, 2005
IEEE Microwave Theory & Techniques Society – Distinguished Lecturer, 1992
Fellow, Institute of Electrical and Electronics Engineers, 1991

SELECTED PUBLICATIONS

Goldsmith, P.F., "Molecular Depletion and Thermal Balance in Dark Cloud Cores," *ApJ*, 557, 736, 2001.
Goldsmith, P.F., "Radio Telescopes and Measurements at Radio Wavelengths," *ASP Conf. Series* Vol. 278, Proc. Conf. Single Dish Radio Astronomy Techniques and Applications, S. Stanimirovic, D.R. Altschuler, P.F. Goldsmith, and C.J. Salter eds., San Francisco ASP, 45, 2002.
Goldsmith, P. F. & Li, D., "HI Narrow Self-Absorption in Dark Clouds: Correlations with Molecular Gas and Implications for Cloud Evolution and Star Formation," *ApJ*, 622, 983, 2005.
Krco, M. & **Goldsmith, P.F.**, "A Survey of HI Self-Absorption in Molecular Cores," *ApJ*, 724, 1402.
Velusamy,T., Pineda,J.L.,Langer, W.D., **Goldsmith, P.F**., Li, D., & Yorke, H.W., "[CII} Observations of H2 Molecular Layers in Transition Clouds," *Astron. & Astrophys.,* 521, L18, 2010.
Monje, R.R.,Emprechtinger, M., Phillips, T.G., Lis, D.C., **Goldsmith, P.F.** et al., "Herschel/HIFI Observations of Hydrogen Flouride Towards Sagittarius B2(M)," *ApJ*, 734, L23, 2011.
Goldsmith, P. F., Liseau, R., Bell, T.A. et al., "Herschel Measurements of Molecular Oxygen in Orion,", *ApJ*, 737, 96, 2011.

3.6 Co-investigator: Dr. Harold Yorke

Harold W. Yorke

Jet Propulsion Laboratory, California Institute of Technology
MS 169-506, 4800 Oak Grove Drive, Pasadena, CA 91109-8099
Harold.Yorke@jpl.nasa.gov
Tel: 818-354-5515 Fax: 818-393-6546

Dr. Yorke's scientific research has been oriented towards numerical simulations of astrophysical phenomena, but his interests in astronomy are broad and varied. He has observing experience at X-ray, optical, UV, IR, and mm-radio wavelengths. As PI or Co-I on observing proposals he has contributed to the direct modeling and interpretation of astrophysical data from modern instruments. Prior to August 2006 he was the NASA Project Scientist for the Herschel Space Observatory and Section Manager for JPL's Astrophysics and Space Sciences Section. For the following six years he was the Division Manager of JPL's Science Division.

In recent years Dr. Yorke has focused his research efforts in the study of early phases of star formation and the associated impact on the surrounding ISM. His emphasis has been on the radiation hydrodynamic behavior of the dusty gas including the influence of UV irradiation on the protostellar disk by both the central (proto-)star and by external sources. Having made significant contributions to the theory of formation of population I massive stars and their effect on their local environment, he is currently studying the formation of zero-metallicity stars in the early universe and the chemical evolution of the local ISM.

Education: University Göttingen (1971-74; 1968-69); Caltech (1970-71); UCLA (1966-1970)

Academic Degrees: B.S. (UCLA, 1970), Physik-Diplom (1972, Göttingen), Dr. rer.nat. (1974, Göttingen), Habilitation (1979, Göttingen)

Scientific Positions: Senior Research Scientist (Jet Propulsion Laboratory, 1998-present), C3-Prof. (Univ. Würzburg: 1988-98), Prof. (Göttingen: 1983-88), tenured Research Scientist (Göttingen: 1978-83); Scientist (MPI for Astrophysics Munich: 1975-78; Göttingen: 1973-75), R.A. (Caltech, 1970-71)

Selected Awards: NASA Exceptional Achievement Medal (2003, 2010); Fulbright Fellow (1972-73); Fulbright Scholar (1971-72)

Memberships: AAS, IAU, AGU; Science Advisory Council of MPI Astronomy (Heidelberg), Editorial Board of *Astronomy Notes* (founded 1821)

Selected Publications and Recent Preprints:

Kuiper R, **Yorke HW**, 2013, *On the Effects of optically thick Gas (Disks) around massive Stars*, **ApJ** 763, 104K 2012arXiv:1211.6432K

Hosokawa T, Yoshida N, Omukai K, **Yorke HW**, 2012, *Protostellar Feedback and Final Mass of the Second-Generation Primordial Stars,* **ApJ**, 760, L37; 2012arXiv1210.3035H

Hosokawa T, Omukai K, **Yorke HW**, 2012, *Rapidly Accreting Supergiant Protostars: Embryos of Supermassive Black Holes?* **ApJ** , 756, 93; 2012arXiv1203.2613H

Tassis K, Willacy K, **Yorke HW**, Turner N, 2012, *Non-Equilibrium Chemistry of Dynamically Evolving Prestellar Cores: II. Ionization and Magnetic Field*, **ApJ**, 754, 6; 2011arXiv1111.4218T

Tassis K, **Yorke HW**, 2011, *A New Recipe for Obtaining Central Volume Densities of Prestellar Cores from Size Measurements*, **ApJ**, 735L

Langer WD, Velusamy T, Pineda JL, Goldsmith PF, Li D, **Yorke HW**, 2010, *C+ detection of warm dark gas in diffuse clouds*, **A&A**, 521, 17L

+32 additional recent letters in two **A&A** Special Issues (Herschel Science & Herschel HIFI Science)

Zinnecker H, **Yorke HW**, 2007, *Toward Understanding Massive Star Formation*, **ARAA**, 45, 481

3.7 Co-investigator: Dr. Imran Mehdi

Dr. Imran Mehdi

Principal Member of Technical Staff
Jet Propulsion Laboratory
4800 Oak Grove Drive • Ms 168-314
Pasadena, CA 91109
(818) 354-2001

RELEVANT EXPERIENCE

Over 17 years of experience in research and development of high frequency components and instrumentation for NASA applications. He led the effort of developing planar diodes for Terahertz applications and led the team that developed and delivered flight qualified local oscillator sources (to 1.9 THz) for the Herschel Space Observatory (an ESA cornerstone mission to be launched in 2008). He was instrumental in developing high performance Schottky diode mixers that have now been used for a number of space missions such as MIRO (a comet probe) to MLS (Microwave Limb Sounder, a earth remote sensing mission). These mixers allow for the remote detection of water with unprecedented resolution. He was the technical lead on two heterodyne instruments on orbiting platforms that were recently proposed for Mars and Venus.

EDUCATION:

Ph.D. (Electrical Engineering), University of Michigan, Ann Arbor, Michigan, 1990.
M.S.E.(Electrical Engineering), University of Michigan, Ann Arbor, Michigan, 1985.
B.S.E.(Electrical Engineering), University of Michigan, Ann Arbor, Michigan, 1984.
Three Year Certificate, Letters and Science, Calvin College, Grand Rapids, Michigan, 1983.

Technical Accomplishments:

- Led the Herschel HIFI Isolator failure Tiger Team, February 2007.
- Over a dozen NASA Certificates of Recognition "For the creative development of a technical innovation", 1991 till present.
- United States Patent granted for a fabrication scheme to obtain semiconductor microwave circuits on quartz substrates, July 1994. US patent #5,276,345. Two patents pending.

PROFESSIONAL ACTIVITIES:

Fellow IEEE, Member of International Organizing Committee of the Symposium on Space Terahertz Technology

RELEVANT REFEREED PUBLICATIONS:

1) A. Maestrini, J. Ward, J. Gill, C. Lee, B. Thomas, R. Lin, G. Chattopadhyay, and I. Mehdi, " A Frequency-Multiplied Source with more than 1 mW of Power across the 840-900 GHz Band," to appear in the special issue of IEEE Transaction on Microwave Theory and Techniques, 2010.
2) Alain Maestrini, John S. Ward, Charlotte Tripon-Canseliet, John J. Gill, Choonsup Lee, Hamid Javadi, Goutam Chattopadhyay, and Imran Mehdi, "In-Phase Power-Combined Frequency Triplers at 300 GHz," IEEE Microwave and Wireless Components Letters, March 2008.
3) I. Mehdi, G. Chattopadhyay, E. Schlecht, J. Ward, J. Gill, F. Maiwald, and A. Maestrini, THz Multiplier Circuits," Proceedings of the IEEE-MTTS Symposium, June 2006.
4) A. Maestrini, J. Ward, J. Gill, H. Javadi, E. Schlecht, C. Tripon-Canseliet, G. Chattopadhyay and I. Mehdi, "A 540-640 GHz High Efficiency Four Anode Frequency Tripler," *IEEE Trans. Microwave Theory Tech*, Vol. 53, pp. 2835 – 284, September 2005.
5) A. Maestrini, J. S. Ward, H. Javadi, C. Tripon-Canseliet, J. Gill, G. Chattopadhyay, E. Schlecht, and I. Mehdi, "Local Oscillator Chain for 1.55 to 1.75 THz with 100 µW Peak Power," IEEE Microwave and Wireless Components Letters, Vol. 15, no. 12, pp. 871-873, December 2005.

INSTITUTIONAL PI: DAVID HOLLENBACH (PROJECT SCIENTIST)

BIOGRAPHICAL DATA: PhD. (Theoretical Physics), Cornell University, 1969; Principal Investigator of the Center for Star Formation Studies 1985-2002; Member of the core IR panel of the Bahcall Committee, 1989-1990; Member of the SOFIA Science Working Group, 1990-1996; Member of the Submillimeter Science Working Group, 1990-1996; Member of the Submillimeter Wave Astronomy Satellite Team, 1988-2005, Associate Member of SWS Team of ISO, 1989-1998; Executive Council of AAS, 1992-1995; Member of the National Academy of Sciences Task Group for Space Astronomy and Astrophysics 1995-1997; Executive Officer of the Astronomy and Astrophysics Survey Committee (National Research Council for the National Academy of Sciences) (1998-2000); Member of the National Academy of Sciences Committee on Astronomy and Astrophysics (2003-2005); Member of the ALMA North American Science Advisory Committee (2003-2005); CoI on 2 Spitzer Legacy Teams (team leader on one), a Key ISO Project team, and a Herschel key project team (HOP). Project Scientist for STO-1.

SELECTED AWARDS: Exceptional Scientist Award (NASA 1995), Outstanding Leadership Medal NASA 2002), NASA Exceptional Achievement Medal (NASA 2005)

CURRENT POSITION: Senior Research Scientist, Carl Sagan Center, SETI Institute

RELEVANT PUBLICATIONS:

Wolfire, M., Hollenbach, D.J., McKee, C., Tielens, A., “The Neutral Atomic Phases of the Interstellar Medium”, Ap. J., 443, 152, 1995.

Hollenbach, D. and Tielens, A., "Photodissociation Regions (PDRs) in the Interstellar Medium of Galaxies", Rev. Mod. Phys., 71, 173, 1999.

Kaufman, M., Wolfire, M., Hollenbach, D., Luhman, M., "Far Infrared and Sub-millimeter Emission from Galactic and Extragalactic Photodissociation Regions", ApJ, 527, 795, 1999.

Wolfire, M., McKee, C., Hollenbach, D., Tielens, A. "Neutral Atomic Phases of the Interstellar Medium in the Galaxy", ApJ, 587, 278, 2003

Kaufman, M.J., Wolfire, M.G., & Hollenbach, D.J. “Si II], [Fe II], [C II], and H_2 Emission from Massive Star-forming Regions”, ApJ, 644, 283, 2006

Wolfire, M.G., Hollenbach, D., & McKee, C.F. “The Dark Molecular Gas”, ApJ, 716, 1191, 2010

Steiman-Cameron, T.Y., Wolfire, M., & Hollenbach, D. “COBE and the Galactic Interstellar Medium: Geometry of the Spiral Arms from FIR Cooling Lines”, 2010, ApJ, 722, 1460, 2010

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)

Appointments

2012-	Associate Astronomer (Univ. of Arizona)
2006-	Assistant Astronomer (Univ. of Arizona)
2003-2006	Assistant Staff Scientist (Univ. of Arizona)
1994-2002	Teaching/Research Assistant (Univ. 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, 782, 72.
5. "Abundances of H_2, H_3^+ & CO in Dark Molecular Clouds", Kulesa, C. A. & Black, J. H. 2015, ApJ, submitted

Experience Relevant to this Proposal:

1. PI of *HEAT*, an automated 0.6-meter terahertz telescope with 0.5-2 THz heterodyne receivers deployed in January 2012 to Ridge A, Antarctica, the best ground-based site 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 2016.
3. Deputy-PI of *Supercam*, a 64-beam, 345 GHz heterodyne receiver deployed at the 10-meter HHT telescope in Arizona and the 12-meter 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.

ANTONY A. STARK

PROFESSIONAL PREPARATION

Princeton University, Ph.D. 1979, (Astrophysical Sciences)
Princeton University, M.A. 1977, (Astrophysical Sciences)
California Institute of Technology, B.S. with honors, 1975 (Physics and Astronomy)

APPOINTMENTS

2015– Senior Astronomer, Harvard-Smithsonian Center for Astrophysics
1991– Astronomer, Harvard-Smithsonian Center for Astrophysics
2003– Co-P.I., The South Pole Telescope
1988–2006 P.I., Antarctic Submillimeter Telescope and Remote Observatory (AST/RO)
1980–1992 Visting Lecturer, Department of Astrophysical Sciences, Princeton University
1979–1991 Member of Technical Staff, Radio Physics Research Department, Bell Labs
1975–1976 Physicist, Lawrence Livermore National Laboratory
1974–1975 Programmer, Space Radiation Laboratory, Caltech
1973–1974 Observing Assistant, Owens Valley Radio Observatory

RELATED PUBLICATIONS

1. Stark, A. A., Chamberlin, R. A., Cheng, J., Ingalls, J. G., and Wright, G. A. 1997, "The Optical and Mechanical Design of the Antarctic Submillimeter Telescope and Remote Observatory", Rev. Sci. Instr., 68, 2200
2. Stark, A. A., Carlstrom, J. E., Israel, F. P., and Menten, K. M. 1998 "Plans for a 10-m Submillimeter-wave Telescope at the South Pole" in *Advanced Technology MMW, Radio, and Terahertz Telescopes* SPIE Vol. 3357, 495
3. Martin, C. L., Walsh, W. M., Xiao, K., Lane, A. P., Walker, C. K., and Stark, A. A. 2004, "The AST/RO Survey of the Galactic Center Region. I. The Inner 3 Degrees", ApJS, 150, 239.
4. Stark, A. A., Gammie, C. F., Wilson, R. W., Bally, J., Linke, R. A., Heiles, C., and Hurwitz, M. 1992, "The Bell Laboratories H I Survey", ApJS, 79, 77
5. Lee, Y., Stark, A. A., Kim, H. G., and Moon, D. 2001, "The Bell Laboratories ^{13}CO Survey: Longitude-Velocity Maps", ApJS, 136, 137.

POSTDOCTORAL ADVISEES:

R. Balm (UCLA), R. Chamberlin (Caltech), J. Harnett (NRAO), A. Loehr (CfA), C. Martin (Oberlin), R. Ojha (ONR),B. Stalder(CfA), N. Tothill (CfA), W. Walsh (UNSW), M. Yan (industry), K. Xiao (Case), X. Zhang (NASA).

STUDENT ADVISEES:

H. Hsieh, senior honors thesis at Harvard University; Northeastern U. students E. Walters, K. Farinaella, D. Atkins, and C. Tran, capstone design project; also played a major role advising Boston U. students A. Bolatto (Berkeley) and J. Ingalls (IPAC), and Princeton U. student G. Heiligman (Lincoln Labs).

GRADUATE ADVISOR: Arno A. Penzias (New Enterprise Associates)

Gary J. Melnick

Current Position

Senior Astronomer, Harvard-Smithsonian Center for Astrophysics

Education

Cornell University	B.A.	Physics	1974
Cornell University	M.S.	Astronomy	1979
Cornell University	Ph.D.	Astronomy	1980

Professional Employment

1995 – Present	Senior Astronomer, Smithsonian Astrophysical Observatory
1980 – 1995	Astronomer, Smithsonian Astrophysical Observatory
1980 – Present	Lecturer, Harvard University, Department of Astronomy
1976	Research Fellow, IBM Thomas J. Watson Research Center

Project Experience

Principal Investigator, Submillimeter Wave Astronomy Satellite (SWAS)

Deputy Principal Investigator, Infrared Array Camera (IRAC)/Spitzer Space Observatory

Co-Investigator, Heterodyne Instrument for the Far-Infrared (HIFI)/Herschel Space Observatory

Co-Investigator, Infrared Telescope/Spacelab II

Far-Infrared/Submillimeter-Wavelength Instrument Builder and Observer, NASA Lear Jet Observatory & Kuiper Airborne Observatory

Principal Investigator, Cosmic Inflation Probe (CIP), a NASA Astrophysics Strategic Mission Concept Study

Deputy-Principal Investigator, Extrasolar Planetary Imaging Coronagraph (EPIC), a NASA Astrophysics Strategic Mission Concept Study

For 40 years I have been active in the design and building of infrared and submillimeter instrumentation, along with the interpretation of the data derived from these instruments, including more than 300 publications. These efforts include the design and building of infrared spectrometers for the NASA Lear Jet and Kuiper Airborne Observatories in the 1970s and 1980s. For 16 years, from 1989 through 2005, I served as the Principal Investigator for NASA's *Submillimeter Wave Astronomy Satellite (SWAS)*, a highly successful Explorer mission. During this same period and continuing to the present, I serve as the Deputy Principal Investigator for the Infrared Array Camera (IRAC) instrument aboard the *Spitzer Space Telescope*. Finally, I was a Co-Investigator on the Heterodyne Instrument for the Far-Infrared (HIFI), one of three focal plane instruments that operated aboard the *Herschel Space Observatory* during its 2009 to 2013 lifetime. In 2004 and again in 2008, I served as PI on two competitively-selected NASA studies of the Probe-class mission *Cosmic Inflation Probe* – a 1.5 m diameter, passively-cooled, telescope at L2 designed to measure the spatial distribution and redshifts of more than 100 million galaxies between z of 3 and 6.5 with the goal of measuring the primordial power spectrum to better than 1%, thereby constraining models of inflation. In 2008, I was also Deputy-PI on another competitively selected NASA Astrophysics Strategic Mission Concept, *Extrasolar Planetary Imaging Coronagraph (EPIC)*, designed to enable direct detection of extrasolar planets. I am presently a co-investigator on two NASA Explorer Phase A studies and a SOFIA Phase A instrument study. My main areas of current research include star and planet formation, astrochemistry, and early universe – i.e., inflation – studies.

MATTHEW L. N. ASHBY

PROFESSIONAL PREPARATION

Cornell University, Ph.D. 1995, (Astronomy)
Cornell University, M.S. 1991, (Astronomy)
University of Colorado at Boulder, B.A. 1988 (Physics, *magna cum laude*)

APPOINTMENTS

2009– Operations lead for Spitzer Space Telescope/IRAC Instrument Team
1999– Member of Spitzer Space Telescope/IRAC Instrument Team
1998– Astrophysicist, Harvard-Smithsonian CfA
1995–2001 Member of SWAS Mission Science Team, Harvard-Smithsonian CfA
1995–1998 Computer Specialist, Harvard-Smithsonian CfA
1991–1995 Graduate Research Assistant, Cornell University
1988–1991 Graduate Teaching Assistant, Cornell University

RELATED PRODUCTS

1. A Remarkably Luminous Galaxy at $z = 11.1$ Measured with Hubble Space Telescope Grism Spectroscopy, Oesch et al., 2016, ApJ accepted, available at `arxiv.org/abs/1603.00461`.
2. Ultraviolet luminosity density of the universe during the epoch of reionization, Mitchel-Wynne et al., 2016, Nature Communications, 6, 7945.
3. S-CANDELS: the Spitzer-Cosmic Assembly Near-Infrared Deep Extragalactic Survey. Survey Design, Photometry, and Deep IRAC Source Counts, Ashby et al., 2015, ApJS 218, 33.
4. The Spitzer-South Pole Telescope Deep Field: Survey Design and Infrared Array Camera Catalogs, Ashby et al., 2013, ApJS 209, 22.
5. SEDS: The Spitzer Extended Deep Survey. Survey Design, Photometry, and Deep IRAC Source Counts, Ashby et al., 2013, ApJ 769, 80.

EXAMPLES OF SYNERGISTIC ACTIVITIES:
Since 1995 Dr. Ashby has been heavily involved in two NASA mission/instrument teams (SWAS; Spitzer/IRAC) as well as large, multinational scientific collaborations (e.g, the Hubble Space Telescope Multi-Cycle Treasury Team CANDELS). To support these projects Dr. Ashby contributed various computational tools (e.g., artifact-mitigation codes and simulators for Spitzer/IRAC; reduction/pipeline software for SWAS). Dr. Ashby is a Co-I on SPHEREx, a proposed NASA SMEX mission now in a Phase A study.

COLLABORATORS: In the past five years Dr. Ashby has advised one graduate student, who has since graduated with her doctoral degrees. Lauranne Lanz will soon begin her second postdoc with Ryan Hickox at Dartmouth. Dr. Ashby also advised five undergraduates during this time. These are Zequn Li (a senior at Swarthmore), Peter Senchyna (now a graduate student at the University of Arizona), Emmet Golden-Marx (2012, now a graduate student in Astronomy at Boston University), and Gabriel Vasquez (a senior at the University of Florida).

Dr. Ashby has also served as reviewer many times in the past five years for Monthly Notices of the Royal Astronomical Society, The Astrophysical Journal, and Astronomy and Astrophysics, and has served on proposal review panels (including for NASA and Spitzer).

Table of Personnel and Work Effort

Participant	Affiliation	Participation Activity	% Effort/year
Walker, Christopher	Univ. of Arizona	Project PI	8
Ashby, Matthew	SAO	Data archive	7
Beatty, Jim	JHU/APL	Mechanical technician & recovery lead	16
Bernasconi, Pietro	JHU/APL	Institutional PI, gondola lead	13
Carkhuff, Bliss	JHU/APL	Power system & harness lead	3
Carpenter, Michael	JHU/APL	Antarctic ground system & mission ops	8
Duffy, Brian	Univ. of Arizona	Project Manager (PM), STO-2 recovery	15
Eaton, Harry	JHU/APL	Systems engineer, pointing system lead	10
Goldsmith, Paul	JPL	Project Scientist	4
Groppi, Christopher	Arizona State	Institutional PI, STO-2 ops & science	4
Hollenbach, David	SETI Institute	Science Team lead	15
Kawamura, Jonathan	JPL	Institutional PI, FPU lead	4
Kulesa, Craig	Univ. of Arizona	Deputy PI, data system	15
Langer, William	JPL	Galactic Plane and LMC Surveys	2
Mehdi, Imran	JPL	Local oscillator lead	1
Peters, William	Univ. of Arizona	Software development, data system	15
Pineda, Jorge	JPL	Galactic Plane and LMC Surveys	6
Siles, Jose	JPL	Local oscillator lead	9
Stambaugh, Katherine	JHU/APL	Mission Systems engineer	8
Stark, Antony	SAO	Submm surveys, Analysis software	12
Tolls, Volker	SAO	Submm surveys, Analysis software	20
Yorke, Harold	JPL	Galactic Plane and LMC Surveys	2
Young, Abram	Univ. of Arizona	Instrument Systems Engineering	8

Walker, Christopher K.

Current Research Support:

Project Title:	Spherical Reflectors for Space-Based Applications
Source of Support:	Office of Naval Research
Project Location:	The University of Arizona
Total Award Amount:	$827,000
Start and End Date:	1/1/16 – 12/31/17
Months Committed:	1 month/year

Project Title:	GUSTO: Phase A
Source of Support:	NASA Explorer SALMON
Project Location:	The University of Arizona
Total Award Amount:	$500,000 ($35M if we win Phase B)
Start and End Date:	10/1/2015 – 12/31/16
Months Committed:	2 months/year

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
Start and End Date:	1/01/2014 – 12/31/2016
Months Committed:	1 month/year

Pending Research Support:

Project Title:	STO-2: Support for 4th Year Operations, Recovery, and Science (this proposal)
Source of Support:	NASA
Project Location:	The University of Arizona
Total Award Amount:	$682,753
Start and End Date:	1/1/17 – 12/31/17
Months Committed:	1 month/year

Project Title:	Space TeraHertz Telescope (TST): A Far-Infrared Probe Class Concept
Source of Support:	NASA
Project Location:	The University of Arizona
Total Award Amount:	$5,104,670
Start and End Date:	1/1/17 – 13/31/19
Months Committed:	1 month/year

CURRENT AND PENDING SUPPORT

PIETRO N. BERNASCONI

Function **Project Title**	**Sponsor** **Project PI (if not self)**	**Period of Performance**	**Commitment (WY)**
Current			
Co-I GUSTO Phase A	NASA Explorer Mission of Opportunity 2014 NNH12ZDA006O-APEXMO2 Sponsor point-of-contact: Wilton Sanders Explorer Program Office. NASA HQ Project PI: Chris Walker, University of Arizona	FY16	0.25
Participant in Project Science Team Solar Probe Plus Phase-C. Project Scientist Support	NASA, Heliophysics Division, LWS program NASA NNN06AA01C Sponsor point-of-contact: Dr. Elsayed Talaat Heliophysics Division. Science Mission Directorate NASA HQ	FY 16 - FY21	0.15
Pending			
Co-I GUSTO Phase B through E	NASA Explorer Mission of Opportunity 2014 NNH12ZDA006O-APEXMO2 Sponsor point-of-contact: Wilton Sanders Explorer Program Office. NASA HQ Project PI: Chris Walker, University of Arizona	FY17 - FY21	Variable for each FY. On average: ~ 0.6

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: Groppi, Christopher E	Other agencies(including NSF) to which this proposal has been/will be submitted

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

Project/Proposal Title: Balloon-borne Large Aperture Submillimeter Telescope - BLAST

Mark Devlin 215-573-7558

Source of Support: UNIV OF PENNSYLVANIA

Total Award Amount: $317,997.00 Total Award Period Covered: 6/1/2013 - 5/31/2018

Location of Project: Arizona State University

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

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

Project/Proposal Title: Reflight of the Strastospheric TeraHertz Observatory: (STO-2) ASU Co-I

Tina Landes 877-677-2123 nssc-contactcenter@nasa.gov

Source of Support: NASA-GODDARD SPACE FLIGHT CTR

Total Award Amount: $323,189.00 Total Award Period Covered: 1/16/2014 - 1/15/2017

Location of Project: Arizona State University

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

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

Project/Proposal Title: Collaborative Research: Polarization Sensitive Multi-Chroic MKIDs
Elizabeth Gebremedhin 703-292-4444

Source of Support: NSF-MPS-AST

Total Award Amount: $194,802.00 Total Award Period Covered: 8/1/2015 - 7/31/2017

Location of Project: Arizona State University

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

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

Project/Proposal Title: Risk Retirement for WAMS: The Water and Ash MM-wave Spectrometer
Russell Kelz 703-292-8558

Source of Support: NSF-GEO-EAR

Total Award Amount: $72,577.00 Total Award Period Covered: 12/15/2015 - 12/14/2016

Location of Project: Arizona State University

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

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

Project/Proposal Title: GUSTO

Source of Support: UNIV OF AZ

Total Award Amount: $697,495.00 Total Award Period Covered: 6/1/2015 - 7/31/2021

Location of Project: Arizona State University

Person-Months Per Year Committed to the Project. Cal: 0 Acad: 0 Sumr: 1.0

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

Project/Proposal Title: SOFIA Heterodyne Array for Spectroscopic Terahertz Astronomy (SHASTA)

Source of Support: JPL

Total Award Amount: $1,168,723.00 Total Award Period Covered: 7/25/2016 - 2/5/2019

Location of Project: Arizona State University

Person-Months Per Year Committed to the Project. Cal: 0 Acad: 0 Sumr: 1.5

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

Project/Proposal Title: Collaborative Research: Demonstration of a Waveguide Filter Bank Spectrometer (W-SPEC) for Millimeter-Wave Cosmology and Astrophysics

Source of Support: NSF-MPS-AST

Total Award Amount: $654,452.00 Total Award Period Covered: 9/1/2016 - 8/31/2019

Location of Project: Arizona State University

Person-Months Per Year Committed to the Project. Cal: 0 Acad: 0 Sumr: 0.5

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

Project/Proposal Title: BAND 7 FOCAL PLANE ARRAYS FOR ALMA

Source of Support: NRAO

Total Award Amount: $199,933.00 Total Award Period Covered: 8/30/2015 - 8/29/2016

Location of Project: Arizona State University

Person-Months Per Year Committed to the Project. Cal: 0 Acad: 0 Sumr: 0.5

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

Project/Proposal Title: Cubesat Interferometry for THz Astrophysics, Planetary Science and Earth Observing

Source of Support: NASA

Total Award Amount: $99,867.00 Total Award Period Covered: 5/1/2016 - 1/31/2017

Location of Project: Arizona State University

Person-Months Per Year Committed to the Project. Cal: 0 Acad: 0 Sumr: 0.5

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

Project/Proposal Title: MRI: Development of WAMS, the Water and Ash Millimeter Wave Spectrometer, a MM-Wave Radiometer and Radar System to Probe Volcanic Plumes

Source of Support: NSF

Total Award Amount: $1,211,374.00 Total Award Period Covered: 8/1/2016-7/31/2019

Location of Project: Arizona State University

Person-Months Per Year Committed to the Project. Cal: 0 Acad: 0 Sumr: 1.0

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

Project/Proposal Title: The Spectroscopic Terahertz Airborne Receiver for Far-InfraRed Exploration (STARFIRE): a Next-Generation Experiment for Galaxy Evolution Studie

Source of Support: University of Penn State

Total Award Amount: $652,369.00 Total Award Period Covered: 10/1/2016-9/30/2021

Location of Project: Arizona State University

Person-Months Per Year Committed to the Project. Cal: 0 Acad: 0 Sumr: 0.5

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

Project/Proposal Title: BFORE: A balloon-borne mission to characterize millimeter and submillimeter-wave polarized emission

Source of Support: NASA

Total Award Amount: $352,938.00 Total Award Period Covered: 1/1/2017-12/31/2021

Location of Project: Arizona State University

Person-Months Per Year Committed to the Project. Cal: 0 Acad: 0 Sumr: 0.5

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

Project/Proposal Title: STO-2: Support for 4^{th} Year Operations, Recovery, and Science ASU Co-I

Source of Support: NASA

Total Award Amount: $61,544.00 Total Award Period Covered: 1/1/2017-12/31/2017

Location of Project: Arizona State University

Person-Months Per Year Committed to the Project. Cal: 0 Acad: 0 Sumr: 0.5

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

4 Current and Pending Support

4.1 Current Awards

Dr. Jonathan Kawamura

Name of Principal Investigator on Award	Award/Project Title	Program Name/ Sponsoring Agency/ Point of Contact telephone and email	Period of Performance/Total Budget	Commitment (Person-Months per Year)
Paul Goldsmith	SHASTA: SOFIA heterodyne array for spectroscopic terahertz astronomy (ICS)	NASA SOFIA/Hashima Hasan (202) 358-0692 hhasan@nasa.gov	2/1/2016-7/19/2016 $0.4M	3
Jonathan Kawamura	Galactic Evolution Mapper: an Explorer concept	JPL R&TD/Daniel McCleese (818) 354-2317 daniel.j.mccleese@jpl.nasa.gov	10/1/16-9/30/17 $100k	2
Boris Karasik	Ultra-wideband MgB2 mixer for high-resolution terahertz spectroscopy	NASA APRA/ Dr. Kartik Sheth, 202-358-4805 Kartik.sheth@nasa.gov	1/1/2013-12/31/2016	1
Imran Mehdi	A Far-Infrared Heterodyne Array receiver for CII and OI Mapping	Dr. Mario Perez Mario.perez@nasa.gov 202-358-1535	10/2013-09/2016 $1,900 K	2
Boris Karasik	TACIT: a frequency-agile heterodyne detector for submillimeter spectroscopy of planets and comets	NASA PICASSO Dr. Janice Buckner janice.l.buckner@nasa.gov 202.358.0183	9/1/2015-8/31/2018	1

4.2 Pending Awards

Dr. Jonathan Kawamura

Name of Principal Investigator on Award	Award/Project Title	Program Name/ Sponsoring Agency/ Point of Contact telephone and email	Period of Performance/Total Budget	Commitment (Person-Months per Year)
Imran Mehdi	A compact far-infrared heterodyne array system	Dr. Mario Perez Mario.perez@nasa.gov 202-358-1535	10/2016-09/2018 $1,900 K	2

CRAIG A KULESA, Co-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
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)	Phase B-F: 2/1/2017 – 09/30/2021
Months Committed to the Project:	3 months per year (average)

CRAIG A KULESA, Co-PI (continued)
The University of Arizona, Steward Observatory

PENDING AWARDS as Co-Investigator

Project Title:	MAPS: the MMT Adaptive optics exoPlanetary characterization System
Source of Support:	NSF MSIP
Project Location:	The University of Arizona
Total Award Amount:	$8.3M
Start and End Date: (MM/DD/YY)	9/1/2016 – 06/30/2021
Months Committed to the Project:	3 months per year

PENDING AWARDS as Co-Investigator

Project Title:	Terahertz Space Telescope (TST) : A Far-Infrared Probe Class Concept
Source of Support:	NASA ROSES SAT 2016
Project Location:	The University of Arizona
Total Award Amount:	$5.1M
Start and End Date: (MM/DD/YY)	1/1/2017 – 12/31/2019
Months Committed to the Project:	1 month per year

PENDING AWARDS as Co-Investigator

Project Title:	STO-2: Support for 4th Year Operations, Recovery and Science (THIS PROPOSAL)
Source of Support:	NASA ROSES APRA 2016
Project Location:	The University of Arizona
Total Award Amount:	$682,753
Start and End Date: (MM/DD/YY)	1/1/2017 – 12/31/2017
Months Committed to the Project:	2 months

CURRENT AND PENDING SUPPORT
Antony Stark

CURRENT AWARDS

Project title: **Cosmological Observations with the 10-meter South Pole Telescope (June 2012)**
Name of PI on Proposal: Antony A. Stark, Smithsonian Astrophysical Observatory
Sponsoring agency or organization: NSF
Performance period: 11/1/12 – 10/31/17
Total budget: $511,150
Commitment by PI: 4 months

Project title: **Reflight of the Stratospheric TeraHertz Observatory: STO-2**
Name of PI on Proposal: Antony A. Stark, Smithsonian Astrophysical Observatory
Sponsoring agency or organization: NASA
Performance period: 1/1/14 – 12/31/17
Total budget: $212,137
Commitment by PI: 1 month

Project title: **An ACS Snapshot Survey of the Most Massive Distant Galaxy Clusters in the South Pole Telescope Sunyaev-Zel'dovich Survey**
Name of PI on Proposal: Antony A. Stark, Smithsonian Astrophysical Observatory
Sponsoring agency or organization: STScI
Performance period: 2/1/14 – 1/31/17
Total budget: $19,988
Commitment: 0 months

Project title: **GUSTO: GAL/XGAL U/LDB Spectroscopic/Stratospheric THz Observatory**
Name of PI on Proposal: Gary Melnick (Stark is Co-I)
Sponsoring agency or organization: NASA
Performance period: 6/1/15 – 7/31/21
Total budget: $340,000
Commitment: 0.5 months

PENDING PROPOSALS

Proposal Title: **Collaborative Research: Characterization of the SPT Cluster Sample with PISCO for Cosmology, Galaxy Evolution, and Neutrino Properties**
PI: Antony Stark
Source of Support: NSF
Proposed Amount: $1,254,126
Total Award Period Covered: 9/1/16 – 8/31/20
Location of Project: Cambridge, MA
Person-Months per Year Committed to Project: 4

Current and Pending Support

Volker Tolls

Current

Project Title:	**Why Are Outflows Under-Producing Water? A Study of the Abundances of the Key Species H2O, OH, CO, and OI as Seen by Herschel and the Changes to Shock Models They May Impose**
PI:	Gary Melnick
Program Name:	ADAP
Sponsoring Agency:	NASA
Point of Contact:	Douglas Hudgins, 202-358-0988, douglas.m.hudgins@nasa.gov
Performance Period:	1/24/13 – 1/23/17
Total Budget:	$385,759
Person-Months per Year Committed to Project:	0.1

Project Title:	**Star Formation and Cloud Dynamics in the Galactic Bar Region**
PI:	Volker Tolls
Program Name:	ADAP
Sponsoring Agency:	NASA
Point of Contact:	Douglas Hudgins, 202-358-0988, douglas.m.hudgins@nasa.gov
Performance Period:	2/6/15 – 2/5/18
Total Budget:	$500,827
Person-Months per Year Committed to Project:	4.8

Project Title:	**Star Formation in the Outer Galaxy**
PI:	Joseph Hora
Program Name:	ADAP
Sponsoring Agency:	NASA
Point of Contact:	Douglas Hudgins, 202-358-0988, douglas.m.hudgins@nasa.gov
Performance Period:	2/17/16 – 2/16/19
Total Budget:	$588,257
Person-Months per Year Committed to Project:	1.0

Pending

Project Title:	**GUSTO: GAL/XGAL U/LDB Spectroscopic/Stratospheric THz Observatory**
Lead PI:	Christopher Walker
SAO PI:	Gary Melnick
Program Name:	NASA Explorer Mission of Opportunity
Sponsoring Agency:	University of Arizona

Point of Contact:	Christopher Walker, 520-621-8783 iras16293@gmail.com
Performance Period:	6/1/16 – 7/31/21
Total Budget:	$340,000
Person-Months per Year Committed to Project:	0.9
Project Title:	**The High Resolution Mid-Infrared Spectrometer (HIRMES)**
Lead PI:	S. Harvey Moseley
SAO PI:	Gary Melnick
Program Name:	SOFIA Third-Generation Science Instrument
Sponsoring Agency:	NASA GSFC
Point of Contact:	S. Harvey Moseley, 301-286-2347 samuel.h.moseley@nasa.gov
Performance Period:	5/1/16 – 4/30/19
Total Budget:	$121,100
Person-Months per Year Committed to Project:	1.4
Project Title:	**Star Formation and Feedback in the Central Molecular Zone**
Lead PI:	John Bally
SAO PI:	Volker Tolls
Program Name:	Astronomy & Astrophysics Research Grants
Sponsoring Agency:	NSF
Point of Contact:	John Bally, 303-492-5786, john.bally@colorado.edu
Performance Period:	1/1/17–12/31/19
Total Budget:	$270,309
Person-Months per Year Committed to Project:	3.4
Project Title:	**Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx)** (Currently in Phase A Study)
Lead PI:	James Bock
SAO PI:	Gary Melnick
Program Name:	NASA Astrophysics Small Explorer
Sponsoring Agency:	Caltech/JPL
Point of Contact:	James Bock, 818-354-0715, james.j.bock@jpl.nasa.gov
Performance Period:	3/1/17 – 11/30/23
Total Budget:	TBD
Person-Months per Year Committed to Project:	TBD

Harvard-Smithsonian Center for Astrophysics

Antony A. Stark
60 Garden St. Mail Stop 42
Cambridge, MA 02138

tel: 617-496-7648
FAX: 617-495-7345
email: aas@cfa.harvard.edu

9 March 2016

Prof. Christopher K. Walker

Steward Observatory

933 N. Cherry St.

Tucson, AZ 85721

Dear Chris,

I acknowledge that I am identified by name as a Co-Investigator to the investigation, entitled **STO-2: Support for 4th Year Operations, Recovery, and Science** that is submitted by Prof. Christopher Walker to the NASA Research Announcement, NNH15ZDA001N-APRA, 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 have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation. For the purposes of conducting work for this investigation, my participating organization is the Smithsonian Astrophysical Observatory.

Yours truly,

Antony A. Stark

Smithsonian Astrophysical Observatory

14 March 2016

Prof. Christopher K. Walker

Steward Observatory

933 N. Cherry St.

Tucson, AZ 85721

Dear Chris,

I acknowledge that I am identified by name as a Co-Investigator to the investigation, entitled **STO-2: Support for 4th Year Operations, Recovery, and Science** that is submitted by Prof. Christopher Walker to the NASA Research Announcement, NNH15ZDA001N-APRA, 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 have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation. For the purposes of conducting work for this investigation, my participating organization is the Smithsonian Astrophysical Observatory.

Sincerely,

Gary Melnick

Gary Melnick

SMITHSONIAN INSTITUTION
60 Garden Street
Cambridge, MA 02138-1516
617.495.7000 Telephone

Smithsonian Astrophysical Observatory

14 March 2016

Prof. Christopher K. Walker

Steward Observatory

933 N. Cherry St.

Tucson, AZ 85721

Dear Chris,

I acknowledge that I am identified by name as a Co-Investigator to the investigation, entitled **STO-2: Support for 4th Year Operations, Recovery, and Science** that is submitted by Prof. Christopher Walker to the NASA Research Announcement, NNH15ZDA001N-APRA, 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 have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation. For the purposes of conducting work for this investigation, my participating organization is the Smithsonian Astrophysical Observatory.

Sincerely,

Matthew Ashby

SMITHSONIAN INSTITUTION
60 Garden Street
Cambridge, MA 02138-1516
617.495.7000 Telephone

Smithsonian Astrophysical Observatory

14 March 2016

Prof. Christopher K. Walker

Steward Observatory

933 N. Cherry St.

Tucson, AZ 85721

Dear Chris,

I acknowledge that I am identified by name as a Co-Investigator to the investigation, entitled **STO-2: Support for 4th Year Operations, Recovery, and Science** that is submitted by Prof. Christopher Walker to the NASA Research Announcement, NNH15ZDA001N-APRA, 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 have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation. For the purposes of conducting work for this investigation, my participating organization is the Smithsonian Astrophysical Observatory.

Sincerely,

Volker Tolls

SMITHSONIAN INSTITUTION
60 Garden Street
Cambridge, MA 02138-1516
617.495.7000 Telephone

3/14/16

Prof. Christopher K. Walker
Steward Observatory
933 N. Cherry St.
Tucson, AZ 85721

Dear Chris,

I acknowledge that I am identified by name as a Co-Investigator to the investigation, titled STO-2: Support for 4th Year Operations, Recovery, and Science, that is submitted by Prof. Christopher Walker to the NASA Research Announcement NNH15ZDA001N-APRA, 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 have read the entire proposal, including the management plan and budget, and I agree that the proposal correctly describes my commitment to the proposed investigation. For the purposes of conducting work for this investigation, my participating organization is Arizona State University.

Sincerely,

Dr. Christopher Groppi
Assistant Professor
School of Earth and Space Exploration

COLLEGE OF LIBERAL ARTS AND SCIENCES
School of Earth and Space Exploration
PO BOX 871404, TEMPE, AZ 85287-1404
(480) 965-5081 FAX: (480) 965-8102
sese.asu.edu

University of Arizona Cost Proposal

Part 1 –

BUDGET DETAILS

This Budget Element explains the total cost the University of Arizona (UA) is expected to incur during the period of performance of this project (January 21, 2017 – December 31, 2017). The estimates include all labor costs, research materials & services, subcontracts, travel, and indirect (F&A) charges.

DIRECT LABOR

Summary

The labor hours applied to the research in the period specified is 2,544 labor hours.
This is averages out to an average of 0.98 FTE Year 1 and 0.86 FTE Year 2 for the period of performance (based on 2088 hr work year).

Table B1: Proposed Work Effort

Table of Proposed Work Effort	
Name	**Effort**
PI: Christopher Walker	**10%**
Co_PI, Craig Kulesa	**15%**
PM: Brian Duffy	**15%**
Instrument Scientist: Abram Young	**8%**
Programmer: Bill Peters	**15%**
TBN: Graduate Research Assistant	**59%**
TBN: Undergraduate Student	**50%**

Personnel

Christopher Walker (PI) is a Professor in the Department of Astronomy at the University of Arizona. Walker will contribute 160 hours. devoted to this project at unburdened direct labor rate of $63.07 per hour Prof. Walker will lead the proposed effort, coordinate efforts between the subcontract institutions, and supervise the work on the project.

Craig Kulesa (Co-PI) is an Associate Astronomer at the Steward Observatory. Kulesa will contribute 320 hours to this project support at unburdened direct labor rate of $27.84 per hour. He will assist the PI in management duties, and will provide flight operations support, flight software development, and delivery, archival and publication of STO-2 data products.

Brian Duffy (PM) is currently a Project Manager in Steward Observatory at the University of Arizona. Duffy will contribute 320 hours to this project, providing project management support at unburdened direct labor rate of $40.71 per hour Management tasks are essential for the completion of the project objectives. These management tasks include but not restricted to: coordination with Steward Observatory management; local coordination of tasks and resources; documentation and planning generation; financial tracking; Antarctic operations and field recovery.

Abram Young (Instrument Scientist) is currently a Specialist, Technical/Research at the University of Arizona. Young will contribute 160 hours to this project, providing technical expertise in the areas of mission operations and flight software development instead at unburdened direct labor rate of $34.87 per hour.

William "Bill" Peters A Staff Scientist at the Steward Observatory. Peters will contribute 320 hours to this project support at unburdened direct labor rate of $35.69 per hour. He will provide flight operations support, flight software development, and delivery, archival and publication of STO-2 data products.

TBD (Graduate Research Assistant): This student will contribute 4.5 mo/year (50% time during the academic year) to the project at unburdened direct labor rate of $22.61 per hour And 414 hours of effort over the 3 month non academic summer at unburdened direct labor rate of $29.20 per hour.

TBD (Undergraduate Student Assistant): This student will contribute 10 hours per week (200 hours to this project at unburdened direct labor rate of $10.00 per hour Year 1.

UA Academic and Summer Terms

The Faculty and Student employee year is broken into the academic and the summer terms. The academic term is 9 months, or 40 weeks in duration. The summer term is 3 months or 12 weeks in duration.

UA Faculty and Student Academic and Summer Hours and Rates

Faculty members are allowed a total of 464 hours of compensation during the summer term And 1600 hours during the Academic term. The faculty summer rate is calculated using 155 hours per month. The faculty hourly rate is calculated using the following formula: *Rate = (Academic Salary)*.00072*.

Graduate students are allowed to work a total of 800 hours (89 hrs/month) during the academic term and 414 hours during the summer term.

UA Appointed Personnel and Classified Staff Hours

Appointed and Classified staff hourly rates are calculated using a 2088-hour work year or approximately a 174-hour work month.

UA Project Management Support for this Project

The project management effort will include detailed financial tracking as well as project requirements and goal tracking. The effort for these duties is over and above the typical departmental duties provided.

<u>FRINGE BENEFITS</u>

The benefits rates are listed in Table B2. The dollar value is calculated by multiplying the benefits rate to the wages earnings for the specified period.

Table B2: Benefits Schedule

Employee Type	July 2015 and beyond	Year 1
Full Benefits Personnel	34.70%	16,959
Graduate Students	13.90%	$4,398
Undergrad Student	3.50%	$158

Benefits $ = Hours x Hourly Rate x Benefit rate

<u>INDIRECT COSTS</u>

University indirect costs (Facilities & Administrative) apply to the subtotal of: 1) Direct Labor (including benefits); 2) Travel; 3) Supplies and materials (including equipment items costing under $5000). The University of Arizona defines capital equipment as equipment items costing $5000 or above.

Indirect cost rates are also only applied to the first $25,000 of each subcontract

Indirect cost excludes Graduate Student tuition and fees that are direct charged to the grant.

Indirect Cost Rates

The following table describes the University's indirect rates for the period of performance of This proposal.

Table B3: UA Indirect Cost Schedule:

On-Campus Research Rates	
7/1/16-6/30/2017	53.50%

TRAVEL

International Travel to and from Christchurch, New Zealand is paid for by the NSF with separate funds, Transportation and from Christchurch and McMurdo Station Antarctic is aboard military aircraft. Lodging and expenses are not covered by NSF while in New Zealand. Funds are requested to cover the cost of hotels and per diem while returning from Antarctica.

The cost estimate for the basic trip is described in detail in Table B4.

Table B4: Travel

Travel	2017 (Year 1)
Destination	*Christchurch, New Zealand*
Lodging	5 people x 3 nights x 150
Per Diem	5 people x 3 nights x 100
Per Person totals	**$750**

Subcontracts

No Subcontracts are requested for this project

CONSULTANTS

The main activity in the post launch period is to help the Project Scientist oversee as well as work on the data analysis, comparison with other ancillary data sets, modeling, testing the various hypotheses, and finally the production of published refereed papers. Dr. Hollenbach will help the Project Scientist oversee the production of the survey results with adequate error analysis, and its incorporation into the web based data archive, which will include the ancillary data as well.

Dr. Hollenbach will collaborate with other members of the team in the modeling and the testing of various hypotheses set out in the proposal. He will ensure that the complementary ancillary data is properly used to maximize the scientific return on the STO-2 data. The prelaunch models will now be applied to the STO-2 data in order to attain the 4 main science goals.

Dr. David Hollenbach will work 313 hours on this project at an hourly rate of $112 per hour.

.

SUPPLIES, MATERIALS, & OPS

We request funding for research supplies **($1,000)** and work-flow/data capture and telecommunications expenses required for the conduction of this investigation inclusive of the material costs of creating, replicating, backing up (archiving), distributing and presenting all project related documentation, memoranda, technical reports, analysis, summaries, etc. directly related to this project. We request funding for shipping **($5,000)**, materials and work-flow/data capture **($1,000**), and telecommunication expenses **($500)** required for the conduction of this investigation inclusive of the material costs of creating, replicating, backing up (archiving), distributing and presenting all project related documentation, memoranda, technical reports, analysis, summaries, etc. under PI Christopher Walker's responsibility. Additionally we request **($4,000)** for publication costs the costs were estimated based on historical usage for projects of this size and scope of work per year. All supplies described in this budget are charged at the indirect rates.

EQUIPMENT

This work relies on the use of existing facilities at the University of Arizona.

OTHER DIRECT COSTS

We request funds for the graduate student tuition and fees that are direct charged to research funds.

FEE/PROFIT

The University of Arizona has no fee/profit costs in this proposal.

Prepared by:
Program Manager
Steward Observatory
933 North Cherry Ave.
Tucson, AZ 85721
0158 (520) 621-6916
(520) 621-9843 (FAX)

Reviewed by:
Director, Sponsored Projects
University of Arizona
PO Box 210158
Tucson, AZ 85721-
(520) 626-6000
(520) 626-4130 (FAX)

Facilities and Equipment

University of Arizona, Steward Observatory

In 1992 the PI established a laboratory (the Steward Observatory Radio Astronomy Laboratory, SORAL) for the development of state-of-the-art submillimeter-wave receiver systems. SORAL served as the central I&T facility for the STO-1 flight instrument. SORAL will continue working closely with JPL and Ball Aerospace on the planned upgrades of the STO-2 receiver system. SORAL possesses all the equipment (spectrum analyzers, network analyzer's, vacuum pumps, cryogenic support facilities, etc.) needed for the development and characterization of receivers. We have 4He, 3He, and closed-cycle cryostats, a full receiver test-bed, local oscillator sources (including a Coherent/DEOS FIR laser), and an antenna test range which allow us to characterize a wide range of receiver systems. SORAL has licenses for CST Microwave Studio, Zemax, and Code V. These programs are used to accurately model the electrical and optical performance of instrument components. SolidWorks is used to accurately portray the instrument in 3-D. The 3-D models are exchanged between Instrument Team members to insure mechanical interface compatibility.

Using these facilities, SORAL has designed and built a number of receiver systems; including single pixel 230, 490, and 810 GHz receivers and the world's first 345 and 810 GHz arrays. SORAL has been a primary facility instrument builder for both the 10m Heinrich Hertz Telescope on Mt. Graham, Arizona and the AST/RO telescope at the South Pole. Based upon the success of these instruments, the PI was awarded a NSF Major Research Instrumentation (MRI) grant to design and construct the world's largest submillimeter wave heterodyne instrument; a 64 pixel, 345 GHz array receiver. The instrument (known as *SuperCam*, short for Superheterodyne Camera) is a multi-institutional project, much like STO, with many of the same team members. SuperCam will begin its survey of the Milky Way in CO J=3-2 later this year. Much of the instrument control electronics/software flown on STO-1 was originally developed for SuperCam.

STO-1 Dewar Integration:

The UofA has the facilities, personnel, and support equipment needed to assemble, operate, and test leading-edge THz instrumentation for balloon-borne astronomy.

JHU/APL STATEMENT OF WORK

1. SUMMARY

This is a collaboration Co-I Institution proposal for the proposal "STO-2: Support for the 4th Year Operations, Recovery, and Science" whose lead proposal is submitted by the University of Arizona with Christopher Walker as PI.

For the STO2 program APL provides the telescope, observing platform (gondola), pointing system, power system, command and control system, and the ground support equipment to interface with NASA-CSBF telemetry system. The STO2 hardware was integrated and tested in Antarctica during the November 2015 – January 2016 summer season and was declared flight ready on January 1 2016 (figure 1). Because of unfavorable ground weather conditions it was not possible to launch it during the 2015/2016 season. STO has been partially disassembled and is currently stored in Antarctica. The current plan is to launch STO2 in mid-December 2016.

APL personnel will also be responsible for commanding and controlling the STO2

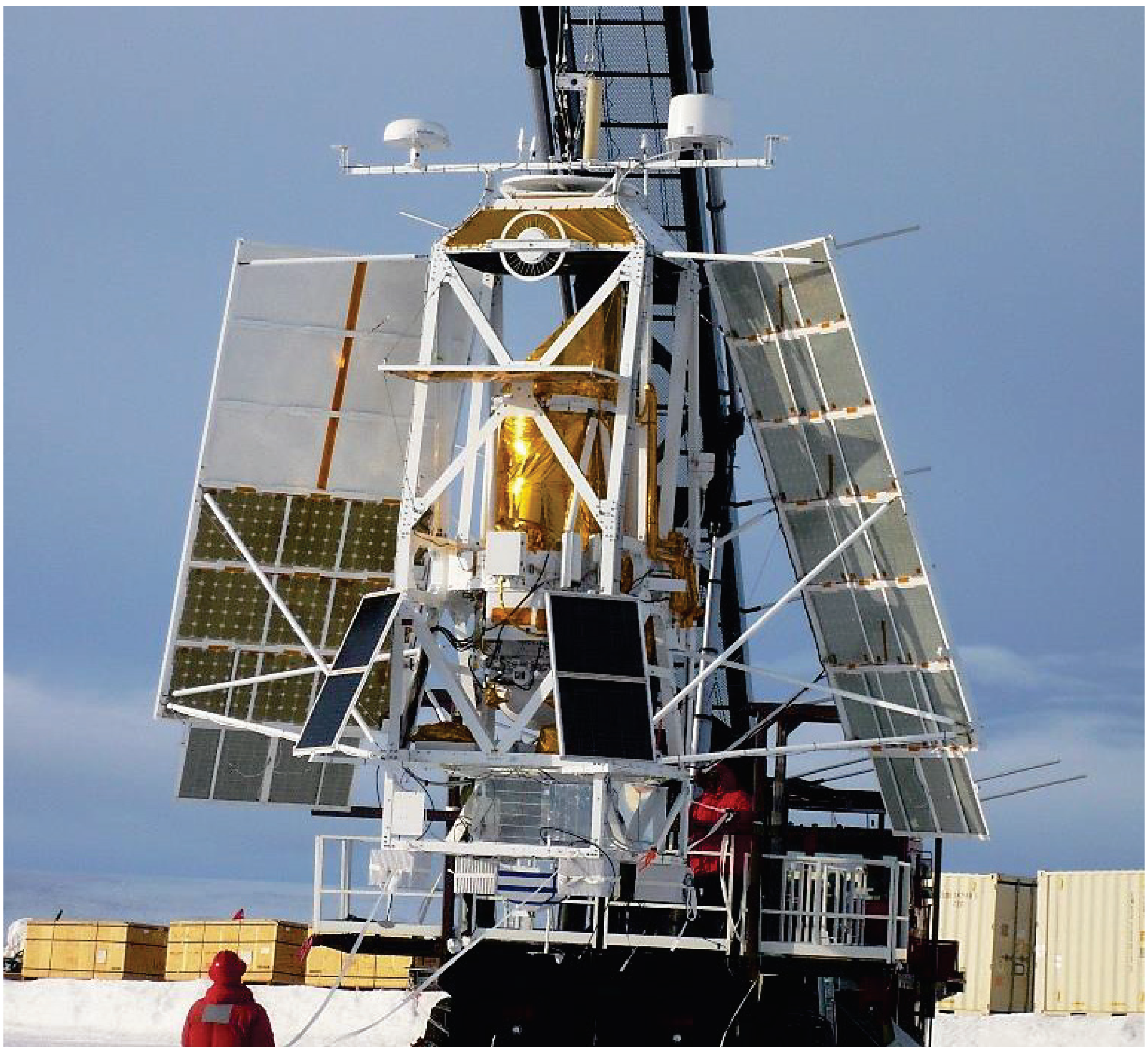

Figure 1: STO2 during final compatibility test in Antarctica on January 1 2016

observatory for a 30-day scientific flight with projected launch in mid-December 2016 from Antarctica. The flight is predicted to last for 15 to 30+ days, with a projected mission termination at around mid-January 2017. Following the Antarctic flight APL will support the gondola recovery and will participate in the data analysis and in publication of the results.

2. LIST OF APL PERSONNEL WITH ROLES AND RESPONSIBILITIES

Person	Role	Tasks, Responsibilities
Pietro Bernasconi	APL PI/PM and Mission Operations Lead	Lead APL team; project manager for APL grant, Mission Operations manager, POC with University of Arizona. Remote support for Mission Operations after first 24 hours of flight. Support post-flight data analysis and publications.
Katherine Stambaugh	Mission Systems engineer and Antarctica Mission Ops Lead	Lead APL team in Antarctica. Responsible for gondola and observatory I&T in Antarctica. Mission Operations Manager for launch and first 24 hours of flight. Support post-flight data analysis and publications.
Harry Eaton	G&C lead	Lead development of G&C systems and overall gondola systems engineer. Remote support of Antarctica I&T and mission operations after the first 24 hours of flight. Support post-flight data analysis and publications
Bliss Carkhuff	Power & harness lead	Lead development of gondola power system and harness. Remote support of Mission Operations after the first 24 hours of flight.
Michael Carpenter	G&C, Antarctica ground systems & mission ops	Lead G&C and ground systems in Antarctica. Responsible for gondola command and control and pointing control system during launch and first 24 hours of flight
Jim Beatty	Gondola Mechanical Technician, and Recovery	Responsible for gondola mechanical integration in Antarctica. Support hang test and launch operations. After landing support gondola recovery.

3. WORK PLAN

The proposed work will be carried out over one year, from January 1, 2017 to December 31, 2017. It will include the following tasks:

- Support launch and first 24 hours of operations in Antarctica in the case that launch takes place in January 2017 (Personnel assigned to task: Stambaugh, Beatty, Carpenter; Everybody will return to the US right after launch, expected by no later than mid-January 2017)
- Support recovery in Antarctica in January 2017 (Personnel assigned to task: Beatty, will redeploy to Antarctica in mid-January 2017)
- Launch and flight operations remotely from APL for January 2017. Planning for 30 days flight (Personnel assigned to task: Bernasconi, Eaton, Carkhuff)
- Support post flight data analysis and papers preparation for the period February 2017 to December 2017 (Personnel assigned to task: Bernasconi, Eaton, Stambaugh, Carpenter)

- Support return shipment of equipment to APL (Personnel assigned to task: Bernasconi for oversight, and Beatty will be deployed to Antarctica for the recovery)

The STO2 work plan will follow established APL Space Department practice for science instrument development in preparation for balloon-borne flight. The plan features rigorous subsystem testing and then whole payload operation under simulated flight conditions. Following the practice for the first STO program, we will perform functional tests on the pointing system components, optics and other systems and we will document the results. Software tests will be carried out with the actual payload, both in the laboratory and in the open air, to test pointing and data acquisition while tracking a celestial target.

BUDGET JUSTIFICATION

SUMMARY OF PERSONNEL AND WORK EFFORTS

Personnel	**Role**	**FTEs of efforts for calendar year 2017**
Pietro Bernasconi	PI,PM & Mission Ops Lead	0.125
Katherine Stambaugh	Mission Systems engineer and Antarctica Mission Ops Lead	0.083
Harry Eaton	Systems Engineer & Pointing System Lead	0.108
Bliss Carkhuff	Power System & Harness Lead	0.033
Michael Carpenter	G&C, Antarctica ground systems & mission ops	0.083
Jim Beatty	Mechanical Technician & Recovery Lead	0.167

TRAVEL COSTS

On January 2017 one APL person, Jim Beatty, will be sent to Antarctica to recover the STO2 gondola. The trip from US to Antarctica includes a 2 to 3 days layover in Christchurch, New Zealand. NSF will sponsor the costs of commercial airline ticket from the US to Christchurch, as well as the air transportation from Christchurch to McMurdo Antarctica and lodging and accommodations while in McMurdo. Cost to this grant will be only the lodging and periderm during the transit stay in Christchurch, which will be 4 days each way (inbound and outbound) for a total of 8 days.

MISCELLANEOUS OTHER DIRECT COSTS:

- Shipping costs of recovered gondola and other GSE equipment from Palestine (Texas) to APL

FACILITIES AND EQUIPMENT

APL is well equipped to carry out the proposed program. The facilities needed for launch in Antarctica are already provided by NSF/NASA. For remote mission operations from APL all is needed is Ethernet connectivity and at least 1 computer running GSEOS ground receiving software. APL has the needed Ethernet connectivity as well as several computers running GSEOS.

The Laboratory does not need to acquire any new test or handling equipment for this program. By signing this proposal, JHU/APL management commits JHU/APL personnel, facilities and resources, as proposed, to be available to the project.

THE JOHNS HOPKINS UNIVERSITY - APPLIED PHYSICS LABORATORY

for

AD-49994

"STO-2: Support of 4th Year Operations, Recovery, and Science JHU/APL Co-I"

PERIOD OF PERFORMANCE - January 1, 2017 - December 31, 2017

	Total
Labor & Fringe	$93,688
Travel	$1,927
MODC	$9,927
Indirect Costs	$41,962
Total	$147,504

Budget Justification

A. **Senior Key Personnel**

The Key Personnel for APL staff is based on a staffing plan prepared by the Principal Investigator. The rates used for APL staff are based on hourly rates for those levels of staff being used by the project. Standard forward pricing rates are used to calculate salary rates.

Dr. Pietro N. Bernasconi
(Effort = 1.5 staff months)

Dr. Bernasconi will be the APL lead and project manager for the effort entitled "STO-2: Support of 4th Year Operations, Recovery, and Science JHU/APL Co-I." He will act as the Mission Operations manager and will be the APL point of contact for the University of Arizona. He will provide remote support for Mission Operations after the first 24 hours of flight and support the post-flight data analysis and publications.

Ms. Katherine A. Stambaugh
(Effort = 1 staff month)

Ms. Stambaugh will be the APL team leader in Antarctica. She will be responsible for gondola and observatory I&T in Antarctica. She will be the Mission Operations manager for launch and the first 24 hours of flight, as well as support post-flight data analysis and publications.

Mr. Harry A. Eaton
(Effort = 1.3 staff months)

Mr. Eaton will lead the G&C systems development and act as the overall gondola systems engineer. He will provide remote support of Antarctica I&T and mission operations after the first 24 hours of flight. He will also support the post-flight data analysis and publications.

Mr. Bliss G. Carkhuff
(Effort = 0.4 staff months)

Mr. Carkhuff will lead the development of the gondola power system and harness. He will provide remote support of Mission Operations after the first 24 hours of flight.

Mr. Michael S. Carpenter
(Effort = 1 staff month)

Mr. Carpenter will lead the G&C and ground systems in Antarctica. He will be responsible for gondola command and control and pointing control system during launch and the first 24 hours of flight.

Mr. James T. Beatty
(Effort = 2 staff months)

Mr. Beatty is the mechanical technician who will be responsible for gondola mechanical integration in Antarctica. He will support hand test and launch operations after landing support gondola recovery.

B. Other Personnel

Financial Manager
(Effort = 0.06 staff months per project year)

The financial manager provides JHU/APL's financial support by tracking project spending, preparing grant financial summary reports for internal JHU/APL use, responding to all financial questions from internal technical personnel and external sponsor requests and assisting with grant closeout activities and follow-on grant documentation.

C. Fringe Benefits and Indirect Costs

The employee fringe benefits cost is calculated by applying the employee fringe benefits rate to APL direct labor. Department overhead is applied to the sum of APL and LW direct labor. Administration and research burden is applied to the sum of the direct labor cost (including employee fringe and department overhead on direct labor) and Other Direct Costs.

JHU/APL currently does not have an approved DCMA rate agreement. APL uses forward pricing rates (FPR) for cost estimates. These rates are based on projected expenses and the labor base. They are submitted to DCMA for review and approval (sometimes several times a year). DCMA will issue a recommendation for rates, and there is usually a slight variance between what JHU/APL proposes. APL uses the proposed rates, as many other government contractors do. JHU/APL labor is proposed on an hourly, by fiscal year basis, by labor classification. Each labor classification is priced on the basis of its forward pricing labor rate by fiscal year. APL does not use actual salary figures in our proposals.

The Rate Table used in this proposal is under BSA-FIN-16-L002, Table ID 084. This can be verified by our DCMA representative, Ms. Karen Williams at 443-884-1345 or karen.williams@dcma.mil. The mailing address is: 217 E. Redwood Street, Suite 1800, Baltimore, Maryland 21202-5299. She will be able to provide DCMA recommended rates and provide an audit report of our most current rate table.

D. Travel

Travel shall consist of one trip for one person to Christchurch, New Zealand. This is a portion of a trip to Antarctica to participate in the STO-2 recovery. This estimate is for lodging and per diem in Christchurch only. The airfare, lodging, and per diem in Antarctica will be provided by NSF at no cost to this grant. The total cost of planned travel is $1,927. Please refer to the following table with highlights the details of the estimated travel.

Costs were escalated using the 4th Quarter FY2015 Global Insight Cost Planner. Per Diem is based on government CONUS rates.

Destination/		# of		Airfare x #	Per Diem		# Cars / Total @	Airport	RT Miles Airport/	RT Miles Dest/	Reserv	Car Pool	Cost	FY17	Total
(Purpose for Travel)	# Travelers	Day	Airfare	Travelers	Hotel	M&IE	$/day	Parking	Cost	Cost	Fee	$/Day	Per Trip	# of Trips	Travel
Christchurch, New Zealand					152	95	0		36		5			1	1
(Participation in STO2 recovery)	1	8	-	-	1,064	713	0	80	19	-	5	-	1,881	1,927	1,927
TOTAL TRAVEL COSTS														**$ 1,927**	**$ 1,927**

E. Other Direct Costs

Other direct costs consist of shipping expenses to transport equipment from Palestine, TX to APL. The total estimated cost for shipping of $9,927 includes the use of one enclosed and one flatbed truck.

Costs were escalated using the 4th Quarter FY2015 Global Insight Cost Planner.

MODC Detail

Item	Vendor	Description	Basis	FY17 Qty	Unit Cost	FY Basis	FY17	Total
MATXXX		Miscellaneous Other Direct Costs					9,927	9,927
1	APL	Shipping equipment from Palestine, TX to APL	VQ	1	9,668	FY16	9,927	9,927
		Total MODC Cost					**9,927**	**9,927**

VQ = Vendor Quote; EJ = Engineering Judgment; PO = Previous Purchase Order,
WP = Web Price, EJ/CC Engineering Judgment based on Credit Card History

1 Task Statement

This task statement describes the Jet Propulsion Laboratory's contribution to the proposal entitled, "STO-2: Support for 4th Year Operations, Recovery, and Science," being submitted to the NASA 2015 ROSES APRA solicitation. The principal investigator of the project is Dr. Christopher Walker of the University of Arizona. After a brief summary of the scientific motivation, we will describe the tasks to be carried out by JPL.

1.1 Proposal Summary

The STO is a long-duration balloon experiment, which will uniquely probe the origin and evolution of the interstellar clouds from which all stars and planets form. STO will use high spectral and angular resolution observations of C^+ and N^+ fine-structure lines, two of the most important galactic gas tracers, to probe the physical conditions in atomic and molecular clouds over the central and outer regions of the Milky Way. The mission's goals are to

1) Determine the life cycle of Galactic interstellar gas
2) Study the creation and disruption of star-forming clouds in the Galaxy
3) Determine the parameters that affect the star formation rate in the Galaxy
4) Provide templates for star formation and stellar/interstellar feedback in other galaxies.

The observational goal of STO is to make high spectral (0.1 km/s) and angular resolution (~1' near 2 THz) maps of the Galactic plane in the astrophysically important transitions of C^+ and 1.9 THz, N^+ at 1.46 THz and OI at 4.67 THz. To make these observations STO has an 80 cm aperture and is equipped with a 5-beam cryogenic heterodyne spectrometer. Unfavorable weather prevented and thus delayed the launch of STO-2 during the austral summer of 2015/16, with the launch opportunity postponed until 2016/2017. Under this SOW JPL will provide I&T and science activity support as described in this plan.

1.2 General plan of work: Tasks at JPL

For STO-2 JPL successfully delivered the 1.46 THz and 1.90 THz local oscillator assemblies and supported their integration into the STO payload during the hand-test at the CSBF and during launch support in McMurdo. Our effort falls into supporting the I&T activities in McMurdo and follow-up science activity.

1.2.1 I&T support

Co-Is Siles and Kawamura were involved with the integration and testing effort for STO-2 and will bring valuable experience learned from that effort. They will participate in the integration and testing of the receiver front-end during launch operations. This support is provided on a level-of-effort basis.

1.2.2 Science support

JPL co-Is (Pineda, Goldsmith, Langer and Yorke) are currently involved Herschel and SOFIA science activities and will be able to provide valuable science support to the PI. Goldsmith is the project scientist.

1.2.3 Schedule

We assume an October 2016 task start date. The local oscillators and spare assemblies will be shipped to the PI institution. JPL personnel will hand-carry spare hardware and instrumentation required to assist the deployment. The JPL effort will support launch activities as the operation of the local oscillators is a critical task. After deployment, during the second half of the period of performance, resources in this SOW will be utilized for science activities.

1.2.4 Management structure, expected contribution by co-Is.

Dr. Jonathan Kawamura is the institutional PI and will manage the task at JPL. This will include overseeing the shipment of the local oscillator assemblies and associated accessories, including spare parts, to the PI institution. Dr. Imran Mehdi, a co-I, will be responsible for the ensuring sufficient resources and key components and equipment are available during the critical deployment period. Dr. Jose Siles will assist in the I&T of the flight instrument.

Drs. Dr. Bill Langer, Paul Goldsmith and Harold Yorke will provide science support, mainly in the latter half of the performance period. They are involved in several Herschel projects observing the 1.9 THz C^+ line and will provide a vital link between Herschel's key science objectives and those of STO-2's. Dr. Jorge Pineda will work on analysis of data from the diffuse interstellar medium, in particular cross calibrating STO-2 and Herschel HIFI data. He will work on combining [CII], [NII], CO and HI data in order to separate the different ISM components in the STO-2 survey region and study their properties.

2 References and Citations

None.

5 Budget Justification

5.1 Budget Narrative

5.1.1 Personnel and Work Effort

Name	Organization	Role	Work Commitment (1-year only)
Dr. Jonathan Kawamura	JPL	Principal Investigator	0.04
Dr. Imran Mehdi	JPL	Co-Investigator	0.01
Dr. Jorge Pineda	JPL	Co-Investigator	0.06
Dr. Paul Goldsmith	JPL	Co-Investigator	0.04
Dr. William Langer	JPL	Co-Investigator	0.02
Dr. Harold Yorke	JPL	Co-Investigator	0.02
Dr. Jose Siles	JPL	Co-Investigator	0.09

5.1.2 Facilities and Equipment

1) None noted

5.1.3 Rationale and Basis of Estimate

The STO-2 cost proposal was prepared using JPL's pricing/accounting system, which has been reviewed and approved by the DCAA. The rates applied in this proposal are JPL's current published rate set (version FY16-01), dated October 2015.

The derivation of the cost estimate is a grassroots methodology based on the expert judgment from a team of experienced individuals who have performed similar work. The team provides the necessary relevant experience to develop a credible and realistic cost estimate. The cognizant individuals identify and define the products and the schedule needed to complete the tasks for each work element. The team developed the grassroots estimate using estimating methods and techniques (analogy, vendor quotes, historical experience) appropriate for each element of work. These methods are used to generate the detailed schedule and resource estimates for labor, procurements, travel, and other direct costs for each work element. The resource estimates are aggregated and priced using JPL's pricing/accounting system. JPL's process assures that lower level estimates are developed and reviewed by the performing organizations and their management who will be accountable for successfully completing the proposed work scope within their estimated cost.

5.2 Budget Details – Year 1

Direct Labor – Year 1

- Dr. Jonathan Kawamura is the Institutional PI and will oversee all aspects of the proposed work to occur at JPL. He will assist in the delivery and integration of the local oscillator assemblies. Time Commitment is 0.04 wy. ($4,860 requested salary with $2,730 fringe benefits)
- Dr. Jose Siles will serve as a co-Investigator on this effort. Dr. Siles will oversee the integration and testing of the local oscillator assemblies. Time commitment is 0.09 wy. ($8,050 requested salary with $4,530 fringe benefits)
- Dr. Imran Mehdi will serve as a Co-Investigator on this effort. Dr. Mehdi will oversee that sufficient resources from the group will be assigned to undertake the delivery and local oscillators and support integration and test. Time Commitment is .01 wy. ($1,4700 requested salary with $840 fringe benefits).
- Dr. Paul Goldsmith will serve as co-Investigator on this effort and as Project Scientist. In this role he will be responsible for the overall science program of the STO-2 mission and ensuring publication of results. Time Commitment is 0.04 wy.($8,400 requested salary with $4,760 fringe benefits)
- Dr. Harold Yorke, Dr. William Langer, and Dr. Jorge Pineda will serve as co-Investigators on this effort. (Time commitments are 0.02 wy, 0.02 wy, and 0.06 wy respectively; $4800 requested salary with $2720 fringe benefits, $4800 requested salary with $2720 fringe benefits, and $6980 requested salary with $3940 fringe benefits, respectively.

Other Direct Costs – Year 1

Subcontracts/Subawards

- Desktop Network Chargebacks (calculated at $6.73/hr.): All JPL computers are subject to a monthly service charge that includes hardware, software, and technical support. ($3,300)

Consultants

- There are no consultants required for this task.

Equipment

- There are no major equipment purchases necessary.

Services

- None.

Supplies and Publications

- None.

Travel

- 2 team members will support I&T activities in McMurdo, Antarctica. All on-continent M&IE are provided. Transit via Christchurch, NZ, requires 4 days in-transit travel ($247 per diem) and ground transportation ($0.3k; ($2.3k total requested). 2 team members will hand-carry equipment to Tucson, AZ ($200 a/f + 2 days @ $148 per diem; $1k requested). $3.2k total requested.

Other

- Multiple Program Support (MPS) $5.75K.

Facilities and Administrative (F&A) Costs – Year 1

- Allocated Direct Costs (ADC) $15.29K.
- Applied General ADC $10.93K.

Total Estimated Costs for Year 1: $100,070

STO2: operations and science

APRA
Timephased Cost Estimate Sheet
Dollars (Does not include Gov't Co-I's)

	Oct 2016 - Sep 2017		Total Program		
Hours / (FTEs)					
J. Kawamura	85	(0.05 FTE)	85	(0.05 FTE)	Hours / (FTEs)
J. Siles	138	(0.09 FTE)	138	(0.09 FTE)	Hours / (FTEs)
P. Goldsmith	70	(0.04 FTE)	70	(0.04 FTE)	Hours / (FTEs)
W. Langer	40	(0.02 FTE)	40	(0.02 FTE)	Hours / (FTEs)
J. Pineda	112	(0.06 FTE)	112	(0.06 FTE)	Hours / (FTEs)
H. Yorke	40	(0.02 FTE)	40	(0.02 FTE)	Hours / (FTEs)
Total Hours:	485	(0.28 FTE)	485	(0.28 FTE)	Subtotal
Amount		$39,360		$39,360	JPL Direct Labor Cost w/o Fringe
Fringe		$22,240		$22,240	Fringe
Category A		$0		$0	Cat A Direct Labor Cost
Total Direct Compensation (includes Employee Benefits)		$61,600		$61,600	Subtotal
Travel		$3,200		$3,200	Direct Travel Cost
JPL Services		$0		$0	Direct Services Cost
Procurements					
Chargebacks		$3,300		$3,300	Direct Chargebacks cost
Subcontracts		$0		$0	Direct PS cost
Procurement RSA		$0		$0	Direct RSA cost
Purchase Orders		$0		$0	Direct PM cost
Caltech Transfers		$0		$0	Direct CT cost
Multi-Program Support		$5,750		$5,750	Direct MPS cost
Total Direct Costs		**$73,850**		**$73,850**	Subtotal
Allocated Direct Charge		$15,290		$15,290	Total ADC
General & Admin		$10,930		$10,930	Total G&A
Reserves (Burdened)		$0		$0	
Total JPL Costs		**$100,070**		**$100,070**	Subtotal
Government Co-I's Not in JPL's Costs		**$0**		**$0**	Bypass
Total Costs		**$100,070**		**$100,070**	Subtotal

JPL Cost Accumulation System

Introduction

All costs incurred at the Laboratory, including JPL applied burdens, are billed to the Government as direct charges at the rates in effect at the time the work is accomplished.

Allocated Direct Costs

Allocated Direct Cost (ADC) rates contain cost elements benefiting multiple work efforts, including Project Direct, MPS, and Support and Services activities. Rate applications for cost estimates are specific to the given category as stated below:

1) Engineering and Science (E&S)
2) Procurement: Purchase Order, Subcontract, Research Support Agreement (RSA)
3) General and Administrative (G&A): Basic, RSA
4) Specialized G&A applications: Remote Site

The accounting process fully distributes these costs to the respective project/task(s).

Multiple Program Support

The Multiple Program Support (MPS) rate applies costs for program management and technical infrastructure. Cost estimates and system application tools will apply the composite rate to all project direct hours charged to projects managed by JPL.

Employee Benefits

All costs of employee benefits are collected in a single intermediate cost pool, which is then redistributed to all cost objectives as a percentage of JPL labor costs, including both straight-time and overtime. Functions and activities covered by this rate include paid leave, vacations, and other benefits including retirement plans, group insurance plans, and tuition reimbursements.

For this proposal the estimated costs have been derived in the same manner as stated above. However, presentation of the estimated costs in the required tables has been adapted in the following ways:

1. The costs for Employee Benefits are included in the Direct Labor costs stated in this proposal.
2. Engineering and Science ADC and Procurement ADC along with MPS costs are displayed in the "Other" category in the Other Direct Costs section.
3. G&A is shown in the Facilities and Administrative Costs section.
4. JPL's forecasted labor rates equal an hourly laboratory-wide average for each job family and are further broken down by career level within the job family. Labor cost estimates apply the family average or family average career level rate to the estimated work hours. An actual individual's labor is considered discrete and confidential information and is only released on an exception basis and only if a statement of work identifies that specific individual as the only one able to perform a task. The use of family average or family average career level rates is consistent with the JPL CAS disclosure statement and the Cost Estimating Rates and Factors CDRL published in response to a requirement in NASA Prime Contract NNN12AA01C.

The proposed budget of the NRA proposal also covers labor costs for serving on NASA peer-review panels and advisory committee at the request of NASA discipline scientists or program managers.

I. SAO PROPOSAL SUMMARY

This is a collaboration Co-I Institution proposal for the lead proposal STO-2: Support for 4th Year Operations, Recovery, and Science. The Lead Proposal for this investigation originates from the University of Arizona, Steward Observatory under Principal Investigator Dr. Christopher K. Walker. The Smithsonian Astrophysical Observatory (SAO) is pleased to submit this subsidiary proposal for scientific collaboration and data analysis and management on the reflight of the Stratospheric TeraHertz Observatory (STO-2). This proposal covers Support for 4th Year Operations, Recovery, and Science as a result of the failure to launch due to weather in the 2015-2016 season. The Institutional Principal Investigator for the SAO effort is Antony A. Stark, and scientific Co-Investigators Gary Melnick, Volker Tolls, and Matthew Ashby. SAO will provide pre-flight engineering and flight monitoring support for the second Long Duration Flight (LDF) from McMurdo Sound in Antarctica. Subsequent to the flight, SAO Co-Is will contribute to data management and analysis, scientific interpretation, publication of results, and public distribution of data.

II. SAO TASK STATEMENT

A. Statement of Work

Tasks to be accomplished at SAO are:
1. Participation in the second LDF from McMurdo Sound, Antarctica.
2. Contributions to data reduction and analysis in collaboration with project personnel at University of Arizona.
3. Management and documentation of data products and long-term dissemination of results.

B. Roles and Responsibilities

The Institutional P.I., Dr. Antony Stark, will be responsible for technical and scientific oversight of the project at SAO. As the P.I. of the successful AST/RO (Antarctic Submillimeter Telescope and Remote Observatory) project from 1989 through 2006, and as a Co-Investigator for the on-going, NSF-funded South Pole Telescope project (P.I.: Dr. John Carlstrom, University of Chicago), Dr. Stark has extensive, directly-related experience in design, fabrication, and use of submillimeter telescopes in extreme environments such as Antarctica, and extensive experience in the acquisition, reduction, and analysis of data from such instruments. Dr. Stark has collaborated on the STO project from the beginning, and has designed and developed some of its hardware and software. Stark will travel to the Launch Facility in McMurdo Sound to participate in instrument launch preparation.

STO Co-Investigators Dr. Gary Melnick, Dr. Matthew Ashby and Dr. Volker Tolls were participants in the successful NASA SWAS (Submillimeter Wave Astronomy Satellite; Melnick was PI) mission. Like STO, the SWAS mission produced high-frequency heterodyne spectral line survey data of the Milky Way. All SAO Co-Is will participate in the planning of STO scientific observations and in the data analysis and publication of results.

Dr. Melnick will work with Drs. Tolls and Ashby to ensure that the STO data reduction and web page meet the needs of the mission. (Dr. Melnick needs no salary support from this proposal to carry out this responsibility.)

Co-I Ashby will be responsible for creating a website to document STO2 publications and data, which will include at minimum a high-level mission summary page, a mission status page, a description of the scientific background and goals of the mission for both professional astronomers and non-astronomers, as well as publicly visible links to the STO2 data archive. The website will be constructed immediately upon selection at the PI's institution and will be continuously updated from the time of selection through flight operations and into the data archiving phase as directed by the PI. Subject to the final configuration of the data archive, the website may also serve as a means to share data descriptions, technical memoranda, and other documentation useful to the community. Co-I Ashby has created and maintained many websites of comparable complexity. Most of these were for purposes of sharing ground test data for Spitzer/IRAC and are no longer in the public view. However, the website most recently created by Dr. Ashby, and one which he is still actively maintaining for public access, is that for JPL's SPHEREx mission concept study (SPHEREx is a proposed NASA SMEX now in Phase A), is found at http://spherex.caltech.edu.

STO Co-I Dr. Volker Tolls will participate in the in-flight monitoring of STO, as well as the data reduction, analysis, and publication of results. Dr. Tolls has extensive experience in heterodyne instrumentation and the acquisition and reduction of astronomical data. He was instrument scientist for SWAS. He planned and led all its scientific ground-testing and in-orbit check-out and participated in all observations. He has also extensive experience in observations using the Spitzer Space Telescope (IRS spectroscopy) and the Herschel Space Telescope (HIFI and PACS spectroscopy and PACS and SPIRE photometry), participating in many GO and GTO observing programs.

C. Schedule

This proposal covers calendar year 2017. The plan is to prepare the STO for reflight beginning December 2016, with the flight likely ending early in 2017. Science results will then be analyzed and written up for publication, and the data made publicly available into the indefinite future.

D. Facilities

A. Stark, G. Melnick, M. Ashby and V. Tolls all have fully-equipped offices on the second floor of the Harvard-Smithsonian Center for Astrophysics building at 160 Concord Avenue in Cambridge, MA. Included are computers and access to support staff in the Radio and Geoastronomy and the Optical and Infrared divisions of SAO. The computers, computer peripherals, software, internal and external internet interface, data storage and backup are professionally maintained by the SAO Computation Facility.

In December 2005, SAO relocated its engineering organization to a newly constructed facility that contains sophisticated engineering laboratories that were built to the specifications developed by senior engineers to meet the requirements for fabrication and assembly of advanced instrumentation for both space-borne and ground-based scientific research. These laboratories include a large assembly area with the ceiling height and crane capacity required for the complete assembly and test of the gondola and telescope, and integration of the science instrument. Additional facilities include an electronics assembly area; a materials/environmental test laboratory that supports thermal vacuum and temperature test, and contamination bakeout; and product assurance capabilities including a coordinate measurement machine (CMM) and optical comparator for fabricated parts inspection.

The Harvard College Observatory (HCO) Model Shop was also relocated with SAO-CE, to permit closer coordination of parts fabrication. The integration of CNC (Computer Numerically Controlled) machinery into the shop has increased the machinists' ability to work to very tight tolerances (+/- .000 1 "), as well as reducing production time.

VI. BUDGET JUSTIFICATION

We request **$128,744.40** for an additional year research and development program beginning 1 January 2017 and ending 31 December 2017.

This budget would support science, and the engineering consultation required to prepare the STO gondola for reflight. Other funds requested are for travel to technical meetings and field support for flight. Specific budget categories are as follows:

Direct Labor:
Salary and benefits are included for SAO Institutional P.I. (Stark) at 240 hours and SAO Astrophysicist Matthew Ashby at 140 hours (less than 10% effort) and Astronomer Volker Tolls at 400 hours. Gary Melnick requires no salary support for his efforts on this project.

Summary of Proposal Personnel & Work Efforts (hours)

	Yr 1
Antony Stark, SAO PI	240
Gary Melnick	other
Matthew Ashby	140
Volker Tolls	400

Travel:

The projected travel requirements are: Year 1 - $1700 domestic+ $2000 travel to Antarctic. Costs are estimated based upon current government air fares and GSA per diem rates.

Domestic travel costs involve a trip for A. Stark to the University of Arizona for technical meetings with the Project Principal Investigator and science instrument development team to coordinate the project's technical requirements and progress. Expenses include a rental car in Tucson and taxis to/from the airport in Boston.

Foreign travel costs for A. Stark to travel to Antarctica include only the costs of a stopover in Christchurch, NZ, en route to and from McMurdo base. The U.S. Antarctic Program provides air tickets and covers all costs of lodging and meals in Antarctica. New Zealand expenses are budgeted for 1 traveler spending up to 8 days in Christchurch en route to and from McMurdo. Expenses include taxis to/from the airports and in Christchurch, and miscellaneous expenses for polar travel.

Other Direct Costs:

Supplies

Included in the budget is $1,500 for materials and supplies, including the cost of data storage disks. An additional $3,500 is requested for a computer to be used in monitoring the flight.

ESTIMATE OF COST

Period of Performance: 01-JAN-2017 through 31-DEC-2017

Title: STO-2: Support for 4th Year Operations, Recovery, and Science: Smithsonian Astrophysical Observatory Co-I

Sponsor: NASA Headquarters
PI: STARK
Proposal ID: 000000000003177

					01/01/2017 thru 12/31/2017
Productive Labor			**Hours**		**Dollars**
PI, Senior Astronomer			240	$	19,094.40
Astrophysicist			140	$	9,650.20
Astronomer			400	$	23,336.00
Total Productive Labor			**780**	**$**	**52,080.60**
Leave @ 20%				$	10,416.12
Total Direct Labor				$	62,496.72
Fringe Benefits @ 26.3%				$	16,436.63
SAO Direct Operating Overhead Base				$	78,933.35
SAO Direct Operating Overhead @Rate 32.8%				$	25,890.14
Travel - Domestic (PI 5 days, Tucson, STO2 Team meeting)				$	1,700.00
Travel - Foreign (PI 8 days, New Zealand, en route to McMurdo)				$	2,000.00
SAO Materials Burden @Rate 4.3%				$	215.00
SAO General & Administrative Base				$	108,738.48
SAO General & Administrative @Rate 13.8%				$	15,005.91
Equipment less than 5K (Laptop computer for flight monitoring)	$	3,500.00			
Materials (3 External disks for flight data storage)	$	1,500.00			
Material Base				$	5,000.00
TOTAL ESTIMATED COST				**$**	**128,744.40**

MATERIALS SCHEDULE

Budget Period : 1
01-JAN-2017 Thru 31-DEC-2017

COST BASIS	DESCRIPTION	VENDOR	COST	
Estimate	External disks, 3 @ $500 Each	TBD	$	1,500.00
TOTAL MATERIALS for Budget Period : 1			**$**	**1,500.00**

TRAVEL SCHEDULE

Budget Period : 1

01-JAN-2017 Thru 31-DEC-2017

Destination	Purpose	# Trips	# Travellers	Days/ Trip	Per Diem	Total Per Diem	Airfare	Total Airfare	Auto Rate per Trip	Misc.	Total
Christchurch NZ	En route to McMurdo	1	1	8	$ 250.00	$ 2,000.00	$ 0.00	$ 0.00	$ 0.00	$ 0.00	$ 2,000.00
Tucson AZ	STO-2 Project Team meeting	1	1	5	$ 165.00	$ 825.00	$ 575.00	$ 575.00	$ 200.00	$ 100.00	$ 1,700.00

TOTAL TRAVEL for Budget Period : 1 **$ 3,700.00**

Departures from Boston MA
Misc. Expense includes taxis, ancillary fees.

CONTRACTUAL AND COST INFORMATION INCLUDING CERTIFICATIONS

The Smithsonian Institution, an independent trust establishment was created by an act of the Congress of 1846 to carry out the terms of the will of James Smithson of England, who had bequeathed his entire estate to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge." After accepting the trust property for the United States, Congress vested responsibility for administering the trust in a Smithsonian Board of Regents.

The Smithsonian performs research, educational and other special projects supported by grants and contracts awarded under the cost principles of Title 2 of the Code of Federal Regulations (CFR) Part 230. It is audited by the Defense Contract Audit Agency, Landover, Maryland.

The Charter of the Smithsonian Institution carries a mandate for the "increase and diffusion of knowledge." Therefore, any grant or contract that may be awarded as a result of this proposal must be unclassified, in order not to abridge the Institution's right to publish, without restriction, findings that result from this research project.

Considering the nature of the proposed effort, it is requested that a Research Grant with reimbursement via electronic funds transfer be awarded to cover the proposed project in accordance with Title 2 CFR Part 200.305.

It is requested that title to all exempt property and equipment purchased or fabricated under the proposed contract be vested irrevocably in the Institution upon acquisition.

In accordance with a negotiated agreement between the Office of Naval Research and the Smithsonian dated 9 January 2015, the Institution operates with approved fixed overhead rates with carry-forward provisions. The Indirect Cost and Fringe Benefits Rates are developed in accordance with Title 2 CFR Part 230. These rates are valid only for the Fiscal Year periods 2015 and 2016.

The Fringe Benefits Rate will be applied to the Total Direct Labor Costs. The Material Overhead Rate will be applied to the cost of materials, equipment and subcontracts. The Direct Operating Overhead Rate will be applied to the Direct Labor and Benefits costs. The G&A Rate will be applied to the base consisting of total costs, excluding the costs associated with materials, equipment and subcontracts.

Rate verification can be made by contacting Ms. Linda B. Shipp, Office of Naval Research, Indirect Cost Branch (BD0242, Rm. 368), 875 N. Randolph Street Arlington, Virginia 22203, telephone (703) 696-8559, or e-mail linda.shipp@navy.mil.

The following approved rates, provided by ONR Negotiation Agreement dated 9 January 2015, shall be used for forward pricing and billing purposes for Fiscal Years 2015 and 2016:

Direct Operating Overhead Rate (Base consists of Total Direct Labor and Fringe Benefits Costs)	32.8%
General and Administrative Rate (G&A) (Base consists of all Direct Cost Activities and includes Direct Operating Overhead & Material Burdens, but excludes Costs Associated with Materials, Subcontracts and Equipment)	13.8%
Material Burden Rate (Base consists of Direct Cost of Materials, Equipment and Subcontracts)	4.3%
Personnel Leave Rate (Base consists of Total Direct Productive Salary Costs	20.0%
Central Engineering Overhead Rate (Base consists of Central Engineering Direct Labor and Benefits Costs)	28.0%
Fringe Benefits Rate (Regular Full/Part Time Employees) (Base consists of Total Direct Labor Costs)	26.3%
Fringe Benefits Rate (Intermittent & < 90 Day Appointment Employees) (Base consists of Total Direct Labor Costs)	8.4%

Engineering services are provided by the Central Engineering Department as a Cost Center. Charges by the department to research projects are inclusive of Direct Labor, Fringe Benefits, and Central Engineering Overhead.

Pursuant to FAR 52.204-8, ANNUAL REPRESENTATIONS AND CERTIFICATIONS (DEC 2014), for federally funded awards, the Smithsonian Astrophysical Observatory (SAO) is registered with the Online System for Awards Management (SAM). SAM can be viewed at *https://www.**sam**.gov/*using SAO DUNS # 003261823.

Task Statement

Arizona State University

Introduction

As a participant in the STO-2 mission, ASU has participated in instrument design and construction, mission I&T, flight operations and data analysis. ASU has unique capabilities in the field of direct metal micromachining, which was brought to bear on the STO-2 cold optical assembly and LO hardware. In addition, our extensive experience with receiver integration and test supplemented the capabilities of the PI institution during the I&T phase at the University of Arizona, CSBF (Palestine, TX) and in Antarctica. This proposal supports the PI and a graduate student for an additional year, allowing us to deploy again in Antarctica and support science data analysis.

ASU Deliverables

ASU will provide the following hardware and services for the STO-2 mission in the final year

1. Instrument Integration and Test support
    a. Instrument integration and test at the University of Arizona
2. STO-2 Flight support in Antarctica
3. Data analysis and dissemination in the post-flight phase.

Instrument Integration and Test Support

ASU will assist the PI institution at all phases of instrument I&T. ASU has extensive experience with the construction, test and deployment of THz receiver systems. The ASU PI and a student assisted with the STO-1 test flight in Ft. Sumner, NM in 2009, and the hang test in Palestine, TX in 2011. In addition, ASU designed and built the IF processor module for STO-1. This module worked perfectly during the STO-1 flight, and was re-used for STO-2. ASU designed and built the hardware required for ground instrument focusing and end-to-end testing used in Antarctica. The ASU PI and graduate student will travel to the University of Arizona for instrument I&T activities for STO-2.

STO-2 Flight Support

The ASU PI and graduate student spent 6 weeks in Antarctica in 2011 supporting the STO-1 launch. We will also send personnel to the STO-2 launch, supporting pre-launch observatory I&T in Antarctica. Our extensive experience with both THz receiver systems and the STO payload will provide valuable support in the time up to launch. Both the PI and the ASU graduate student were present for the bulk of the 2015-2016 STO-2 deployment.

Data Analysis and Dissemination

The ASU PI is a member of the STO-1 and STO-2 science teams, and will participate directly in data analysis and dissemination through refereed journal publications. The STO-2 graduate student at ASU is funded for the entire project, and will participate in both engineering and science activities. It is expected that the data provided by the STO-2 flight will become a major part of the thesis for the ASU graduate student funded by this proposed work.

ASU Task Timeline

Year 5

- Participate in instrument I&T at the University of Arizona
- Participate in STO-2 launch operations in Antarctica
- Participate in data analysis and dissemination post-launch.

Budget Narrative

The proposed work is performed over a 1-year period. An itemized budget listing expenditures over this period is provided.

Employee-Related Expenses (ERE)
ASU has negotiated ERE rates with DHHS that are effective 05/29/13 and have been used in the proposal for budget planning:

ERE Rates	FY2017
Faculty	31.47%
Staff	40.87%
RA/TA	8.41%

Tuition and Fees
Tuition for graduate students is included as a benefit for graduate students and is charged to projects in proportion to the amount of effort the graduate student will work on the project. Tuition charges are exempt from the Facilities and Administrative (F&A) costs. The tuition charge for graduate students is:

	FY2017
AY	$17,374
Summer	$1,130
Total	$18,504

.
Personnel
Funds are requested for 0.5 month of summer salary for the PI (C. Groppi). PI Groppi is responsible for overseeing all aspects of the project. A graduate student is funded for one semester and one summer. The graduate student will be responsible for assistance in instrument I&T, launch support and analysis and publication of data.

Travel
Funds to cover deployment to Antarctica cover expenses for lodging and per diem while in Christchurch, NZ on the way to and from the final destination at McMurdo, Antarctica (4 days total). Airfare and expenses while in Antarctica are not borne by the project.

Materials and Supplies
Funding is requested for a small amount of miscellaneous materials and supplies for Antarctic deployment (tools, electronic components etc.) for support of the ASU responsibilities while deployed.

Facilities & Administrative Costs
Facilities & Administrative costs are calculated on Modified Total Direct Costs (MTDC) using F&A rates approved by Department of Health and Human Services. The most

current rate agreement is dated 29 May 2013 and the rate is 54% in FY14 and 54.5% in all out years for Organized Research. Items excluded from F&A calculation include: capital equipment, subcontracts over the first $25,000, student support, participant support, rental/maintenance of off-campus space, and patient care fees.