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

NASA Proposal Number

08-APRA08-0027

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 : **A 4-6K Cryocooler for ULDB Astronomy**

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 / 2010	12 / 31 / 2012	1887944.00	1293303.00	462371.00	132270.00	0.00	0.00

SECTION II - Application Information

NASA Program Announcement Number	NASA Program Announcement Title
NNH08ZDA001N-APRA	Astronomy and Physics 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
03 / 26 / 2009	Electronic Submission Only		

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

International Participation	Type of International Participation
No	

SECTION III - Submitting Organization Information

DUNS Number	CAGE Code	Employer Identification Number (EIN or TIN)	Organization Type
806345617	0LJH3	742652689	2A

Organization Name (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	857210001	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 the two Certifications and one Assurance contained in this NRA (namely, (i) the Assurance of Compliance with the NASA Regulations Pursuant to Nondiscrimination in Federally Assisted Programs, and (ii) Certifications, Disclosures, and Assurances Regarding Lobbying and Debarment and Suspension.

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
Jessica Peck	peck@email.arizona.edu	520-626-6128

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**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION VI - Team Members

Team Member Name	E-mail Address	Phone Number
Christopher Walker	**cwalker@as.arizona.edu**	**520-621-8783**

Organization Name	Team Member Role	International Participation
University of Arizona	**PI**	**No**

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

Team Member Name	E-mail Address	Phone Number
Michael Schein	**mschein@optics.arizona.edu**	**520-621-5751**

Organization Name	Team Member Role	International Participation
University of Arizona	**Co-I**	**No**

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

Team Member Name	E-mail Address	Phone Number
Pietro Bernasconi	**pietro.bernasconi@jhuapl.edu**	**443-778-8970**

Organization Name	Team Member Role	International Participation
JHU/Applied Physics Laboratory	**Co-I**	**No**

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

Team Member Name	E-mail Address	Phone Number
Thomas McMahon	**tjm@as.arizona.edu**	**520-621-6916**

Organization Name	Team Member Role	International Participation
University of Arizona	**Other Professional**	**No**

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

Team Member Name	E-mail Address	Phone Number
Wilfred Gully	**wgully@ball.com**	**303-939-5416**

Organization Name	Team Member Role	International Participation
Ball Aerospace	**Co-I**	**No**

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

Team Member Name	E-mail Address	Phone Number
Craig Kulesa	**ckulesa@as.arizona.edu**	**520-621-6540**

Organization Name	Team Member Role	International Participation
Steward Observatory	**Collaborator**	**No**

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

Team Member Name	E-mail Address	Phone Number
David Glaister	**dglaister@ball.com**	**303-888-6973**

Organization Name	Team Member Role	International Participation
Ball Aerospace	**Co-I**	**No**

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

PI Name : **Christopher Walker**

Organization Name : **UNIVERSITY OF ARIZONA**

NASA Proposal Number

08-APRA08-0027

NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION VII - Project Summary

We propose to develop, test, and demonstrate an efficient, low-power, low-mass, 4-6K cryocooler for balloon-borne experiments. The cooler will be initially flown on the Stratospheric TeraHertz Observatory (STO). The upper limit for flight times of LDB experiments with detector arrays requiring cooling in this temperature range has been limited by the liquid cryogens they must carry. Even with a large (120-200 liter), well engineered dewar (e.g. for BOOMERanG1) flight times of only ~14 days have been possible. For these types of experiments to reach flight times of ~40 days for zero pressure and ultimately 50+ days for super pressure balloons, cryogenic systems are needed that can keep detectors at their required operating temperatures for comparable periods. Ultra long hold time liquid helium cryostats capable of such lifetimes are too heavy to meet the ~1 ton payload target for ULDB missions. Fortunately, light weight cryocoolers have been under development by NASA in support of space-based telescopes for some time. One such cryocooler developed by Ball Aerospace as a prototype for the MIRI instrument on JWST more than meets the cooling requirements for STO. By upgrading the STO cryostat from a liquid helium based system to one utilizing the Ball cryocooler, the STO flight time can be extended to match that of the balloon, potentially tripling the science return for each flight. The potential savings in logistics costs and man years of effort to achieve the same science return is, in itself, significantly more than the cost of the proposed effort. The cooler will be designed so that similar units can be reconfigured to meet the needs of other potential users. The demonstration of the cooler on STO will help pave the way for the ~100 day flights of ULDB missions in the future.

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

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?
No

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

Explanation :

NASA Civil Servant Project Personnel

Are NASA civil servant personnel participating as team members on this project (include funded and unfunded)?
No

Fiscal Year	Fiscal Year	Fiscal Year	Fiscal Year	Fiscal Year
Number of FTEs	Number of FTEs	Number of FTEs	Number of FTEs	Number of FTEs

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

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
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

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**

Organization Name : **UNIVERSITY OF ARIZONA**

NASA Proposal Number

08-APRA08-0027

NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION IX - Program Specific Data

Question 1 : Short Title:

Answer: A 4-6K Cryocooler for ULDB Astronomy

Question 2 : Research Area:

Answer: Suborbital Investigation

Question 3 : If Detector Development, Supporting Technology, or Suborbital Investigation, select proposal type:

Answer: Infrared/Sub-mm

Question 4 : Type of institution:

Answer: Educational institution

Question 5 : 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: No

Question 6 : Is this Federal government organization a different organization from the proposing (PI) organization?

Answer: N/A

Question 7 : Does this proposal include the use of NASA-provided high end computing?

Answer: No

Question 8 : Research Category:

Answer: 7) Suborbital rocket/balloon/airplane investigation

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 : Is this a suborbital proposal?

Answer: Yes

Question 14 : Proposal Type:

Answer: PI

Question 15 : If a Co-I proposal, identify the Lead PI (name and institution) and the title on the Lead proposal.

Answer:

Question 16 : Requested Launch Vehicle:

Answer:

Question 17 : Launch Site:

Answer:

Question 18 : Launch date and window:

Answer:

Question 19 : Apogee and/or observation time:

Answer:

Question 20 : Special launch considerations:

Answer:

Question 21 : Pointing Accuracy:

Answer:

Question 22 : Telemetry rates, number of links:

Answer:

Question 23 : Special systems:

Answer:

Question 24 : Recovery:

Answer:

Question 25 : Hardware to be built by NSROC:

Answer:

Question 26 : Experiment section diameter:

Answer:

Question 27 : Approximate experiment section weight:

Answer:

Question 28 : Approximate experiment section length:

Answer:

Question 29 : Experiment section CG estimate:

Answer:

Question 30 : Approximate experiment section power:

Answer:

Question 31 : Experiment section contamination sensitivity:

Answer:

Question 32 : Experiment section cleanliness:

Answer:

Question 33 : Experiment section purge requirements:

Answer:

Question 34 : Experiment section deployments:

Answer:

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

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	32431.00	33501.00	41944.00	0.00	0.00	107876.00
B. Direct Labor - Other Personnel	25718.00	25619.00	43495.00	0.00	0.00	94832.00
Total Number Other Personnel	1	1	2	0	0	4
Total Direct Labor Costs (A+B)	58149.00	59120.00	85439.00	0.00	0.00	202708.00
C. Direct Costs - Equipment	161000.00	50000.00	0.00	0.00	0.00	211000.00
D. Direct Costs - Travel	5730.00	2130.00	0.00	0.00	0.00	7860.00
Domestic Travel	5730.00	2130.00	0.00	0.00	0.00	7860.00
Foreign Travel	0.00	0.00	0.00	0.00	0.00	0.00
E. Direct Costs - Participant/Trainee Support Costs	0.00	0.00	0.00	0.00	0.00	0.00
Tuition/Fees/Health Insurance	0.00	0.00	0.00	0.00	0.00	0.00
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	1014820.00	318032.00	3000.00	0.00	0.00	1335852.00
Materials and Supplies	15100.00	2000.00	2000.00	0.00	0.00	19100.00
Publication Costs	0.00	0.00	0.00	0.00	0.00	0.00
Consultant Services	0.00	0.00	0.00	0.00	0.00	0.00
ADP/Computer Services	600.00	800.00	800.00	0.00	0.00	2200.00
Subawards/Consortium/Contractual Costs	998920.00	315032.00	0.00	0.00	0.00	1313952.00
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	200.00	200.00	200.00	0.00	0.00	600.00
G. Total Direct Costs (A+B+C+D+E+F)	1239699.00	429282.00	88439.00	0.00	0.00	1757420.00
H. Indirect Costs	53604.00	33089.00	43831.00	0.00	0.00	130524.00
I. Total Direct and Indirect Costs (G+H)	1293303.00	462371.00	132270.00	0.00	0.00	1887944.00
J. Fee	0.00	0.00	0.00	0.00	0.00	0.00
K. Total Cost (I+J)	1293303.00	462371.00	132270.00	0.00	0.00	1887944.00

Total Cumulative Budget	1887944.00

PI Name : **Christopher Walker**	**NASA Proposal Number**
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2010	**12 / 31 / 2010**	**Project**	**1**

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
Schein，Michael	CO-I	105060.00	2.874			25160.00	7271.00	32431.00
							Total Key Personnel Costs	32431.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
1	Project Management	3.127			17928.00	7790.00	25718.00
1	Total Number Other Personnel					Total Other Personnel Costs	25718.00

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	58149.00

PI Name : **Christopher Walker**	**NASA Proposal Number**
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2010	**12 / 31 / 2010**	**Project**	**1**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
1	**Power Supply**	**20000.00**
2	**Commercial Compressor (CSFIC)**	**46000.00**
3	**2-Bypass Valve & 3 Heat Exchangers**	**85000.00**
4	**G-M Coldhead**	**10000.00**
	Total Equipment Costs	**161000.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**5730.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**5730.00**

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**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2010	**12 / 31 / 2010**	**Project**	**1**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	15100.00
2. Publication Costs	0.00
3. Consultant Services	0.00
4. ADP/Computer Services	600.00
5. Subawards/Consortium/Contractual Costs	998920.00
6. Equipment or Facility Rental/User Fees	0.00
7. Alterations and Renovations	0.00
8 . Other: **Communication costs (phone/Fax, Postage/Fedex, copying)**	200.00
Total Other Direct Costs	1014820.00

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	1239699.00

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MTDC @ 51%	51.00	71385.00	36406.00
MTDC @ 51.5%	51.50	33395.00	17198.00
Cognizant Federal Agency: **DHHS Audit Agency, Jeanette Lu, (415) 437-7820**		Total Indirect Costs	53604.00

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	1293303.00

J. Fee

	Funds Requested ($)
Fee	0.00

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	1293303.00

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2011	**12 / 31 / 2011**	**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
Schein, Michael	CO-I	108527.00	2.874			25990.00	7511.00	33501.00
							Total Key Personnel Costs	33501.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
1	Project Management	3.012			17865.00	7754.00	25619.00
1	Total Number Other Personnel					Total Other Personnel Costs	25619.00

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	59120.00

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027** NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2011	**12 / 31 / 2011**	**Project**	**2**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
1	**Cryocooler Electronic Box**	**50000.00**
	Total Equipment Costs	**50000.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**2130.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**2130.00**

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**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2011	**12 / 31 / 2011**	**Project**	**2**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	2000.00
2. Publication Costs	0.00
3. Consultant Services	0.00
4. ADP/Computer Services	800.00
5. Subawards/Consortium/Contractual Costs	315032.00
6. Equipment or Facility Rental/User Fees	0.00
7. Alterations and Renovations	0.00
8 . Other: **Communication costsw (Phone/Fax, Postage/Fedex, Copying)**	200.00
Total Other Direct Costs	318032.00

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	429282.00

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MTDC @ 51.5%	51.50	64250.00	33089.00
Cognizant Federal Agency: DHHS Audit Agency, Jeanette Lu, (415) 437-7820		**Total Indirect Costs**	33089.00

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	462371.00

J. Fee

	Funds Requested ($)
Fee	0.00

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	462371.00

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2012	**12 / 31 / 2012**	**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	98794.00			.817	5690.00	1644.00	7334.00
Schein, Michael	CO-I	112108.00	2.874			26850.00	7760.00	34610.00
							Total Key Personnel Costs	41944.00

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			3	12523.00	4508.00	17031.00
1	Project Management	3.012			18454.00	8010.00	26464.00
2	Total Number Other Personnel					Total Other Personnel Costs	43495.00

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	85439.00

PI Name : **Christopher Walker**	**NASA Proposal Number**
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2012	**12 / 31 / 2012**	**Project**	**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**

Organization Name : **UNIVERSITY OF ARIZONA**

NASA Proposal Number

08-APRA08-0027

NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2012	**12 / 31 / 2012**	**Project**	**3**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	2000.00
2. Publication Costs	0.00
3. Consultant Services	0.00
4. ADP/Computer Services	800.00
5. Subawards/Consortium/Contractual Costs	0.00
6. Equipment or Facility Rental/User Fees	0.00
7. Alterations and Renovations	0.00
8 . Other: **Communication costs (Phone/Fax, Postage/Fedex, Copying)**	200.00
Total Other Direct Costs	3000.00

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	88439.00

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MTDC @ 51.5%	51.50	85108.00	43831.00
Cognizant Federal Agency: DHHS Audit Agency, Jeanette Lu, (415) 437-7820		Total Indirect Costs	43831.00

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	132270.00

J. Fee

	Funds Requested ($)
Fee	0.00

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	132270.00

PI Name : **Christopher Walker**	NASA Proposal Number
Organization Name : **UNIVERSITY OF ARIZONA**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
		Project	**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**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

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**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

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**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

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**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
		Project	**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**	**08-APRA08-0027**
	NASA Proposal Number

Proposal Title : **A 4-6K Cryocooler for ULDB Astronomy**

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

A 4-6 K Cryocooler for ULDB Astronomy

Summary

We propose to develop, test, and demonstrate an efficient, low-power, low-mass, 4-6K mechanical refrigerator (i.e. *cryocooler*) for balloon-borne experiments. The cooler will be initially flown on the Stratospheric TeraHertz Observatory (STO). The upper limit for flight times of LDB experiments with detector arrays requiring cooling in this temperature range has been limited by the liquid cryogens they must carry. Even with a large (120-200 liter), well engineered dewar (*e.g.* for BOOMERanG[1]) flight times of only ~14 days have been possible. For these types of experiments to reach flight times of ~40 days for zero pressure and ultimately 50+ days for super pressure balloons, cryogenic systems are needed that can keep detectors at their required operating temperatures for comparable periods. Ultra long hold time liquid helium cryostats capable of such lifetimes are too heavy to meet the ~1 ton payload target for ULDB missions. In ground-based astronomy where detector systems routinely run for >100 days at a time, the community has been using commercially available cryocoolers to meet experimental requirements for many years. These coolers require an initial investment which is often more than a liquid cryogen based system, but their reliability, lifetime, and low operating cost more than pay for the extra investment. However, the power and weight requirements of a present off-the-shelf system capable of cooling even a modest size detector array to 4-6 K make them impractical for LDB and ULDB flights. Fortunately, light weight cryocoolers have been under development by NASA in support of space-based telescopes for some time. One such cryocooler developed by Ball Aerospace as a prototype for the MIRI instrument on JWST more than meets the cooling requirements for STO. By upgrading the STO cryostat from a liquid helium based system to one utilizing the Ball cryocooler, the STO flight time can be extended to match that of the balloon, potentially tripling the science return for each flight. The potential savings in logistics costs and man years of effort to achieve the same science return is, in itself, significantly more than the cost of the proposed effort. The cooler will be designed so that similar units can be reconfigured to meet the needs of other potential users. The demonstration of the cooler on STO will help pave the way for the ~100 day flights of ULDB missions in the future. Additionally, the successful development of the 4-6 K ULDB Cryocooler will be transitional to space flight and improve the Technology Readiness Level (TRL) for future low temperature space astronomy missions.

1.0 Scientific Justification

> The proposed cryocooler development and implementation is an *enabling technology* that will help provide *a paradigm shift* in what is possible on extended balloon flights in a variety of leading-edge astrophysics research areas.

Throughout much of NASA's history of high altitude balloon flights cryogenically cooled detectors have been used to gain new insights into the origins and evolution of stars, planets, and the Universe itself. Many of these instruments served as pathfinders to test both the scientific theories and technologies for space based observatories. One principal advantage of space based platforms has been the ability to conduct observations over much larger periods of time than has been available from balloons. However, with the new capability of ~40 day LDB flights from the Antarctic and, in the future, even longer (~100 day) flights through the ULDB program, the science that has traditionally been only achievable on SMEX and/or MIDEX class missions can now be realized at ≤ 1/10 the cost. This cost savings means that a larger number and variety of science and technology path finding missions can be performed and a new generation of students and future PI's trained.

One key to realizing the full potential of these longer flights for astrophysics is the availability of cryogenic systems that can meet both instrument and mission related requirements. The amount of helium (and subsequent tank size and weight) required to cool even modest sized focal planes to 4-6 K makes the realization of a dewar capable of >20 day hold times extremely difficult and/or impracticable for extended LDB and ULDB flights. Mechanical cryocoolers are an attractive alternative to liquid cryogen systems and have been employed at ground based observatories for decades. However, the power requirements for these systems (≥ 1.3 kW) makes them problematic for balloon payloads.

Here we propose to adapt an efficient, low-power, low-mass, Ball Aerospace cryocooler originally designed, built, and tested as a prototype for the MIRI instrument on JWST for use on LDB and ULDB flights. Once fully characterized in the lab, the cryocooler will be employed on the Stratospheric TeraHertz Observatory (STO). In its first Antarctic flight scheduled for 2010, STO will use a 200 liter liquid helium dewar to cool its 8, hot electron bolometer (HEB) focal plane mixers. By using a small cryocooler to cool a radiation shield to ~77K, the lifetime of the dewar is expected to be ~16 days. The Ball 4-6K cryocooler will replace the helium tank for the next expected science flight in 2012. With the implementation of the cryocooler the STO mission lifetime is, in principle, set only by the maximum time the balloon can remain aloft, ~40 days. The increased flight time dramatically increases the science return of the project with a significant reduction in cost in manpower and other resources compared to achieving the same science goals with multiple flights. As is, the Ball cooler meets all the STO technical requirements. The same basic cooler design will be capable of being readily modified to achieve either lower temperatures or greater cooling capacity as maybe required by other LDB/ULDB efforts. The cooler will have vibration levels comparable to or better than a more power hungry pulse tube cooler, making it suitable as a pre-cooler for bolometric detector arrays requiring sub-Kelvin temperatures. This type of detector is most commonly used for cosmic background and interstellar dust observations in the far-infrared.

The implementation of the cooler on STO directly addresses NASA Research Objective 3D.3. Through the cooler's potential use on future LDB/ULDB projects where cooling of bolometric detectors is required for long periods, the proposed effort also addresses NASA Research Objectives 3D.1 and 3D.2. In its most recent report (20 December 2008) the Scientific Balloon Assessment Group identified three high priority needs over the next decade; 1) Fund an increased number of more sophisticated balloon payloads suitable for multiple missions and exploiting the new balloon capabilities, 2) Complete the development of super pressure balloons to enable operational programs at mid latitudes, and 3) Build capability for 100-day flights. The proposed cryocooler development and implementation is an *enabling technology* that will help provide *a paradigm shift* in what is possible on extended balloon flights in a variety of leading-edge astrophysics research areas and, in doing so, help meet these critical needs.

1.1 The Stratospheric TeraHertz Observatory: Overview

The Stratospheric TeraHertz Observatory (STO)[2] is a Long Duration Balloon (LDB) experiment designed to address a key problem in modern astrophysics: understanding the Life Cycle of the Interstellar Medium (ISM). In its first science flight in December 2010 STO will survey a section of the Galactic plane in the dominant interstellar cooling line [C II] (158 μm) and the important star formation tracer [N II] (205 μm) at ~1 arc minute angular resolution, sufficient to spatially resolve atomic, ionic and molecular clouds at 10 kpc. Our mission goals for this survey 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.

STO will be using the telescope and gondola originally used in APL's Flare Genesis Experiment (see Figure 1). With the 80 cm telescope aperture, STO will have an angular resolution ~1' and be able to discriminate clouds in a given beam and determine their distance from Galactic rotation. STO will utilize a heterodyne receiver system with a resolving power, $R > 10^6$. The first flight receiver will consist of eight, phonon-cooled HEB mixers; four optimized for the [CII] line and four for the [NII] line. The STO spectrometer will have sufficient bandwidth to detect all clouds participating in Galactic rotation in each of the 8 pixels. STO is capable of detecting *every* giant molecular cloud in the Galaxy, *every* HII region of significance, and *every* diffuse HI cloud with $A_V > 0.3$.

Gondola: waiting to be reconfigured from APL's Flare Genesis Experiment

1.2 Science Return from a ULDB STO

The realization of the proposed cryocooler effort will revolutionize the scientific grasp of astronomical LDB and ULDB missions, and increase the per-mission impact of the suborbital program without the additional logistical cost (i.e. by increasing the number of launches). Here, we illustrate what the impact would be for a second flight of STO, nominally proposed for

December 2012. STO's first LDB science flight will map approximately 30 square degrees of the Southern Galactic Plane in the pivotal fine structure lines of [C II] and [N II], with a corresponding "Deep Survey" covering up to one square degree at increased sensitivity. Not including the expected improvements in terahertz heterodyne focal plane technology for the second LDB flight, a 40 day mission would allow an additional 80 square degrees of coverage in both the Inner and Outer Galaxy; *a truly definitive Galactic Plane survey* (Figure 2). Because conditions in the interstellar gas are sensitive to environment, and vary dramatically as a function of Galactocentric radius[3], we must sample the entire Galactic Plane to construct a comprehensive map of the interstellar gas and star formation in the Galaxy. In addition to the Galactic Plane survey, the corresponding "Second Deep Survey" would *encompass significant portions of the two nearest bright satellite galaxies of the Milky Way*: the Large and Small Magellanic Clouds (the LMC and SMC respectively). Understanding the life cycle of interstellar clouds and star formation in these low-metallicity environments is a necessary step toward constructing a template for the galactic interstellar gas, to be ultimately applied to more distant galaxies[4]. STO would be able to map large portions of these galaxies with high sensitivity ($10^{-6.5}$ erg/s/cm^2/sr), *an unachievable feat with the limited amount of time available on larger missions such as SOFIA and Herschel*.

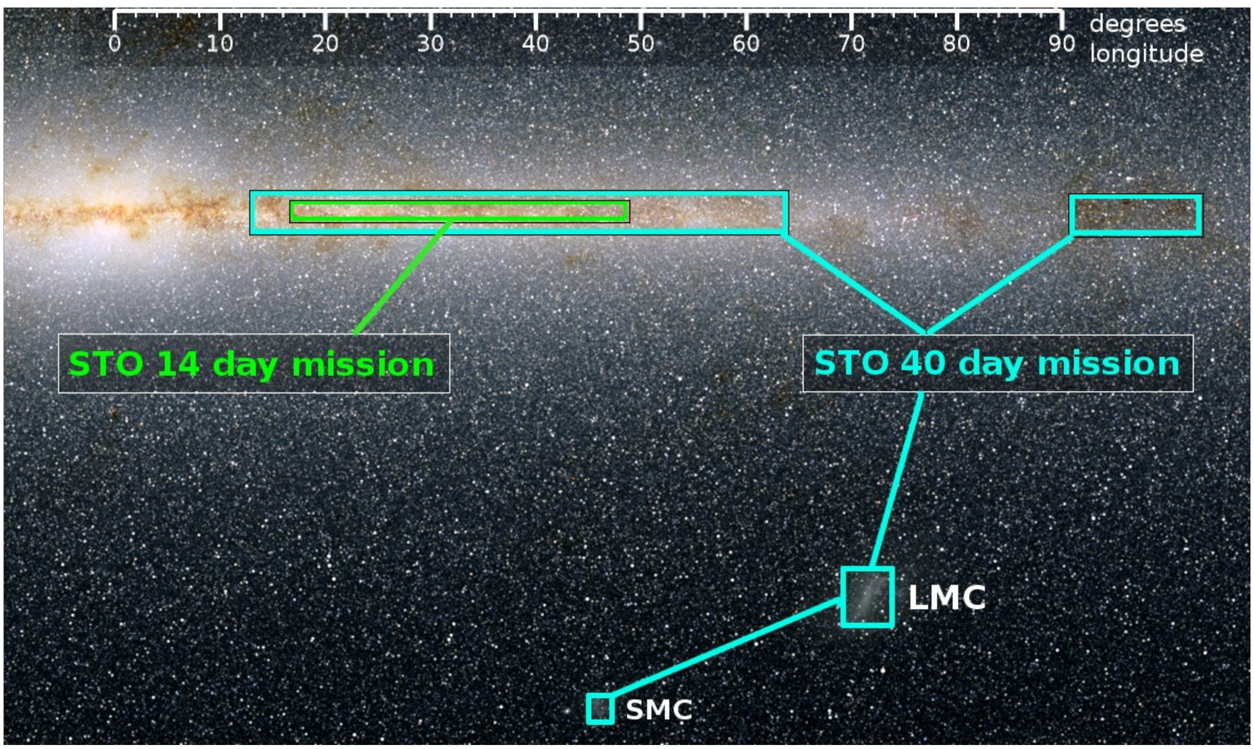

Figure 2. *The scientific return from an extended duration (~40 day) balloon flight of STO, made possible by the cryocooler development proposed here would otherwise take three separate flights and at least 6 years to complete!*

The resulting science return would take STO from the realm of the Milky Way interstellar medium to studies with direct extragalactic application! The proposed cryocooler could also be used with the newest generation of incoherent detectors such as BIB photoconductor arrays[5] in the mid infrared and TES bolometers and MKID arrays in the far infrared[6]. As with heterodyne arrays, the scientific applications would span from comets to cosmology. In particular, high resolution spectroscopy (both with coherent and incoherent detectors) in the mid- and far-infrared will be a regime whose surface will only be scratched by Herschel during its lifetime, and represents a fraction of the scientific scope of SOFIA. Astrochemical studies of circumstellar disks, atmospheric studies of transiting extrasolar planets, and serendipitous spectral imaging and monitoring of active galactic nuclei and galactic black hole candidates would all be tractable scientific campaigns. LDB experiments will be able to make significant scientific progress on these and many other fronts in the next decade(s), but only if the capability of flying long, productive missions can be realized on the cryogenic front.

2.0 Choice of Cryocooler Technology

The proposed ULDB cryocooler leverages off NASA space cryocooler development to provide a compact, low-power (< 400 W), low-weight (< 40 kg), low-vibration, 4-6 K cryogenic system for extended (≥ 100 day) operation.

The purpose of the STO cryogenic system is to hold the instrument at its required operating temperatures. Superconducting mixer elements require temperatures of 6 Kelvin or below, and the low noise amplifiers are optimally held below 18 K. The simplest and most common way to provide this environment is with expendable liquid helium, such as on the BOOMERanG program[1]. That will be the initial method used for the STO science flight scheduled for 2010.

The essential cryogenic components in the STO cryocooler system are shown in Figure 3. The cryogen is the ultimate source of cooling for the mixers, LNA's and LO multipliers. Besides the usual MLI insulation and low conductivity structural support, the dewar has a thermal shield surrounding the helium tank for blocking parasitics. On BOOMERanG, the shield was cooled by vapor escaping the dewar and an additional nitrogen dewar. On STO, the shield is actively cooled by a single stage mechanical cooler.

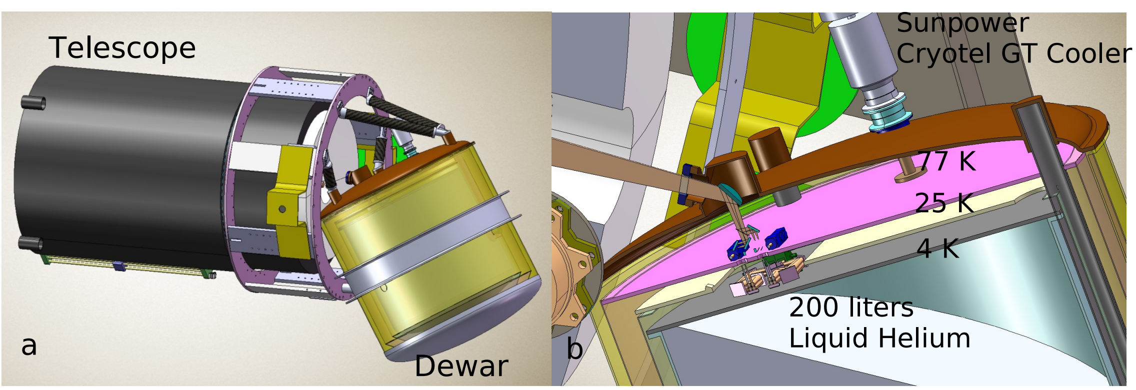

Figure 3. The essential elements of the existing STO cryogenic system. a) Telescope and dewar assembly. b) The detector focal plane is cooled to ~4K by ~200 liters of ^{4}He. A cryogenic lifetime of ~14 days is achieved by using a small, low-power cryocooler to hold the radiation shield at ~77K.

However, a liquid helium cryogenic system imposes inherent limitations on the mission. The most significant limitation is the limited helium lifetime. Other mission impacts from an expendable liquid cryogen system include large cooling system volume, relatively high mass, limited cooling capacity, and significant thermal shielding complexity. For the BOOMERanG program, a state of the art liquid helium system, has a lifetime limit of less than 17 days, required an additional nitrogen cryostat to reduce heat loads, had a cryostat volume of 140 liters (1.6 m height by 0.8 m diameter), and a cryostat mass of about 250 kg.

The current proposal is to upgrade the STO expendable cryogen system to a mechanical refrigerator, or *cryocooler*. Compared to an expendable cryogen system, cryocoolers inherently have long unattended lifetimes (10 years or more for space systems, a year or more for terrestrial systems), small volumes and system mass, and large cooling capacities. The enhanced lifetime is especially important for the STO mission and would enable both Ultra-Long Duration Balloon flights (over 100 days) and apply to future space missions in excess of 5 years in duration.

Providing cooling to 6 K or below, there are commonly two cryocooler options for the STO Mission: existing laboratory grade cryocoolers, such as the Sumitomo Gifford-McMahon (GM) or the CryoMech G-M Pulse Tube (P-T) coolers, or emerging, medium TRL (Technology Readiness Level) space coolers such as the Ball 4-6 K Hybrid Cooler. The lab coolers have the advantage of lower cost and higher maturity, while the space coolers have the advantages of lower power, lower induced vibration and jitter, and smaller size. Ball proposes to utilize the advantages of both lab and space coolers by developing a custom version of our space cryocooler using commercial cooler components that will meet the program requirements and enable the longer duration missions, at a much lower cost. The STO Cooler will be a long lifetime (over a year), low power (under 400 W), low mass (less than 40 kg), high capacity (over 80 mW at 4 to 6 K) system with a recurring cost 10 times lower than a space cryocooler. This will not only enable ULDB type missions, but also translate to higher TRL levels and lower costs for future space Terahertz and Infrared Astronomy missions.

2.1 STO Cryocooler System and Requirements

The ULDB cryocooler will be a ``drop-in'' replacement to the conventional liquid helium system to be used in the first STO Antarctic flight, extending mission lifetime to match that possible with the balloon.

The STO Cryocooler System is shown in Figure 4.The mixers are mounted on a much lighter instrument cooling plate that replaces the helium dewar, leaving most of the former dewar volume empty. The STO cryocooler system consists of a compressor assembly driving two cold heads. The G-M precooler cold head is mounted on the shell alongside the existing single stage cooler and produces cooling to 15 K. A passive J-T (Joule-Thomson) remote cold head is mounted on the instrument cooling plate and provides the final stage of cooling, from 15 to 4-6 K. This remote cold head provides the refrigeration necessary for the mixers. A cryogenic thermal model was developed and generated the cryogenic cooling requirements (with margin) shown in Table I.   A list of key requirements for the mechanical cryocooler is given in Table II.

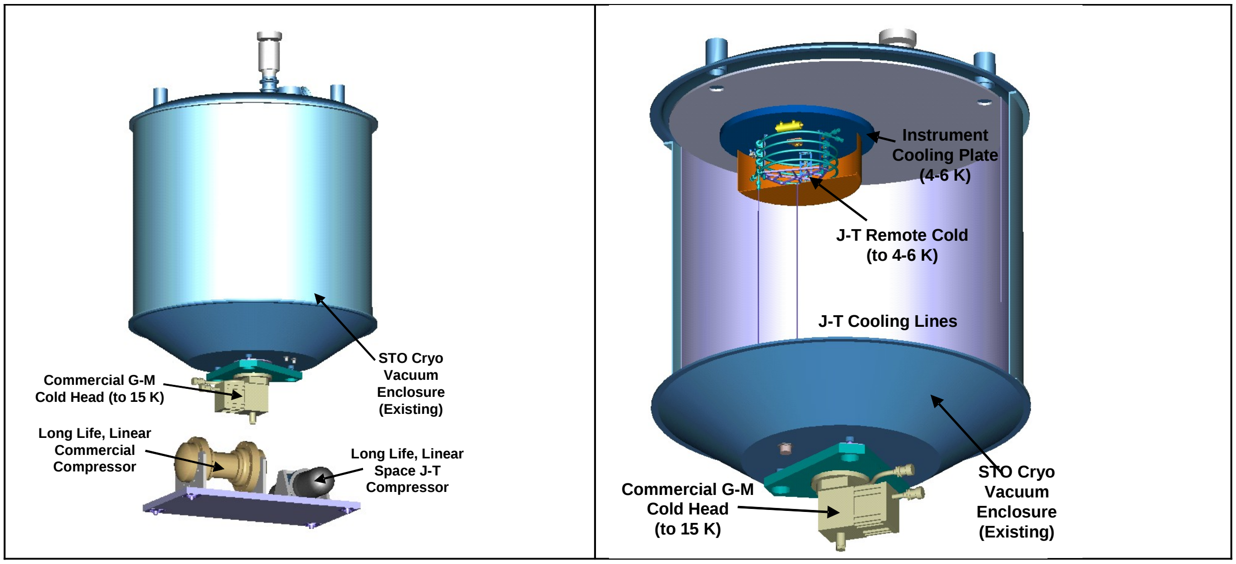

Figure 4. STO cryogenic system retrofit with an active cryocooler. Helium cooling gas circulates through small tubes between the Compressors and the Cold Heads (tubes not shown).

Table I. STO Cryocooler cooling capacity requirements and performance.

Stage	Components	Cooling Source	Requirements			Performance			
			Temp	Load		Temp	Capacity	Margin	
				No margin	w/ margin			Capacity	Temp
			K	mW	mW	K	mW	%	K
Arrays	mixer arrays (2), array	Cryocooler	6	38.1	57.1	6	80	110	0
LNAs	array LNAs, power leads, thermal shield	Cryocooler	18	66	85	17	220	232	1
77K	multipliers and msc.	Auxiliary Cooler	77	3548	-	77	5000	41	0

Table II. STO Cryocooler Key Requirements

Requirement	***Specification***
Detector Cooling	>60 mW at <6 K
LNA and Shield Cooling	>85 mW at <20 K
Detector Temperature Stability	±0.01 K
Lifetime	>100 days continuous
Input Power	<500 W
Mass	<50 kg
Induced Vibration	<100 mN at any frequency
Shock Environment	10 g
Ambient Temperature	-40 ºC to 30 ºC survival -5 ºC to 20 ºC operating

These requirements would be beyond the capabilities of typical laboratory cryocooler systems. The power efficiency has to be high because of the limited amount of power available on a balloon flight. The low operating environment temperature is a challenge to conventional oil lubricated machines. The low noise requirements of the scientific instruments place serious induced vibration constraints on a cooler. Microphonics, EMI, and temperature variations must be minimized. Finally, operating times in excess of 100 days are necessary, and reusability is mandatory. The following section outlines how these requirements are met by the proposed STO cooler in comparison to commercially available coolers.

2.2 STO Cryocooler Options and Selection

A list of candidate cryocoolers for STO is shown in Table III. There are several sources for coolers in the 4 K temperature range that would meet the cryogenic needs of the program. The ones in the table were selected as the most attractive options available. Examples of the hardware are shown in Figure 5.

Table III. A list of cryocoolers that meet the STO heat lift and lifetime requirements.

Requirement	**Candidate Cooler**		
	GM Sumitomo	GM-PT CryoMech	STO Hybrid GM-JT Cooler
Model	SRDK-101D	PT405	Commercial version of Ball 4-6 K hybrid space cooler
Heat lift	100 mW at 4 K	570 mW at 4.2 K	80 mW at 4-6K
Power	1.3 kW	4.7 kW	≤0.4 kW
Mass	50 kg	143 kg	40 kg
Lifetime	>10,000 hr	>10,000 hr	>10,000 hr
Vibe Export	Moderate	Low	Low
Environmental Specification	0-40°C >600 mbar	0-40°C >600 mbar	Space qualifiable
Cost	Low	Low-Moderate	Moderate

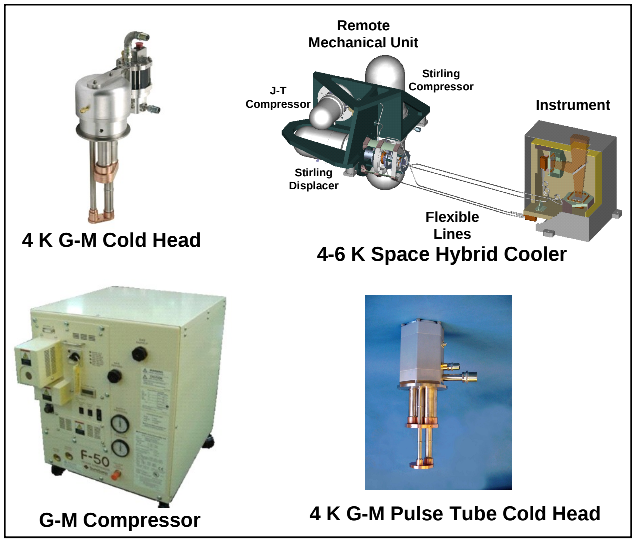

Figure 5. Candidate cooler options for STO.

The key discriminating attribute in the table is the required input power (highlighted in yellow). The custom STO ULDB Hybrid (combination of GM and J-T) cooler is much lower in power than the other candidates. Its input power is 1/3 that of the GM and 1/10 that of the power inefficient Pulse Tube. The low power requirement makes the mechanical cooler option feasible for the STO Balloon flight and also translatable to space missions, where power is even in shorter supply. Increasing the power available on the gondola is not an adequate solution for existing GM-type coolers. Because extended solar panels act like wind sails even in the greatly reduced atmospheric pressure (1-5 mbar) at float altitude, tripling the surface area of existing panels would lead to much poorer pointing, slewing and tracking performance. This is unsatisfactory even for the far-infrared observations that STO will perform; for thermal infrared applications, this problem is even more severe.

Another key attribute is the exported vibration (highlighted in blue). Pulse tubes are attractive because their cold head vibrations are an order of magnitude less than those of GMs. However, the STO Hybrid cryocooler has exported vibration levels *equal to or lower* than the Pulse Tubes. This low exported Hybrid vibration is the result of the isolation provided by the remoteness of the cold head. Simple mechanical precoolers will use an "S-link" a few inches long, which can provide some amount of isolation. But the completely passive, no moving parts Hybrid remote J-T cold head can be separated from the active compressors by several feet of small diameter (<2 mm) capillary tubing for exceptionally good isolation. Additionally, the Hybrid cooler uses a small, balanced, linear compressor with significant lower vibration than the large oil lubricated Pulse Tube compressors, which are themselves not rated for the high-elevation, (potentially) low temperature LDB environment. Thus, the transmitted vibration from the remote Hybrid compressor will be lower than for the Pulse Tube compressor, and it is already rated for the environmental conditions present at float altitude.

2.3 STO ULDB Cryocooler System

The STO ULDB cryogenic system will use components developed for space where needed to meet design specifications and off-the-shelf components where possible to provide optimum performance at ~1/10th the cost of a comparable space borne system.

A schematic of the STO ULDB Hybrid Cooler shown in Figure 6. The hybrid cryocooler consists of two coolers, each used in its optimum range. The central precooler is a regenerative cooler, which cools the system from ambient to about 15 K. A second cooler provides J-T cooling from 15 to 6 K, where it is particularly efficient. Regenerative coolers, which includes pulse tubes, GM's, and Stirlings, are cyclic engines that repetitively expand gas at their cold end. They all use a metal matrix as a regenerator to store the gas heat as it shifts into the cold end. Regenerators rapidly lose their ability to store heat below 15 K, which makes them become increasingly inefficient. This leads to very high input power when regenerative coolers are forced down to 4-6 K. The Hybrid cooler only uses the precooler where it is efficient to do so and then takes advantage of the recuperative J-T cycle to provide the last stage of cooling from 15 to 4-6 K.

The recuperative J-T uses the regenerative precooler as a starting point. The precooler absorbs the loads associated with cooling its gas to 15 K. The gas leaves the precooler at a high pressure, travels down a counterflow heat exchanger where it exchanges heat with incoming gas and expands through the valve (a porous plug) to 6 K. The expanded gas returns via the heat exchanger and is available to be routed to other components to pick up heat as it makes its way back to the precooler. Even though the separate J-T compressor requires extra power, the combination is so efficient that the total power is far less than that taken to drive a regenerative cooler to 6 or especially 4 K.

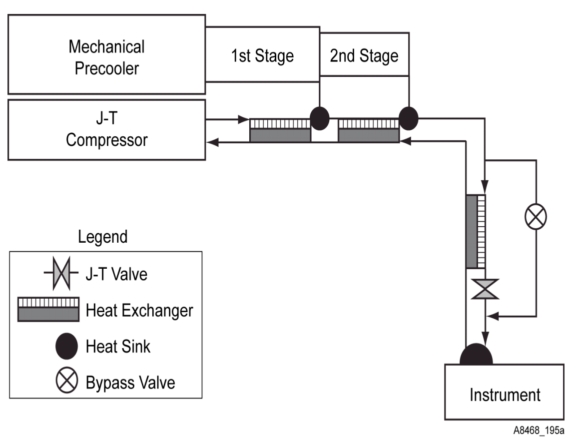

Figure 6. Schematic of a STO ULDB-Type hybrid cryocooler.

Ball built and characterized a 4-6 K hybrid cooler with NASA JPL during the latter's ACTDP (Advanced Cryocooler Technology Development Program). The cooler in test is shown in Figure 7 and the performance is shown in Figure 8. It easily met the STO cooling requirements with ~320 W of total input power.

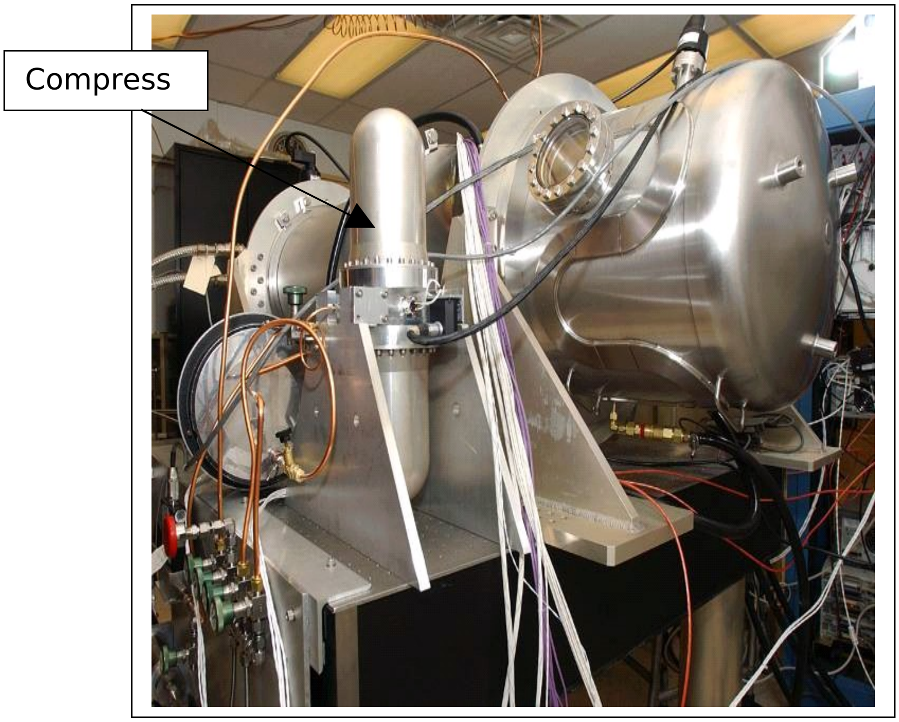

Figure 7. Ball Hybrid ACTDP cooler in test. J-T Compressor is on outside of vacuum test chamber and is same unit to be used for STO Cooler.

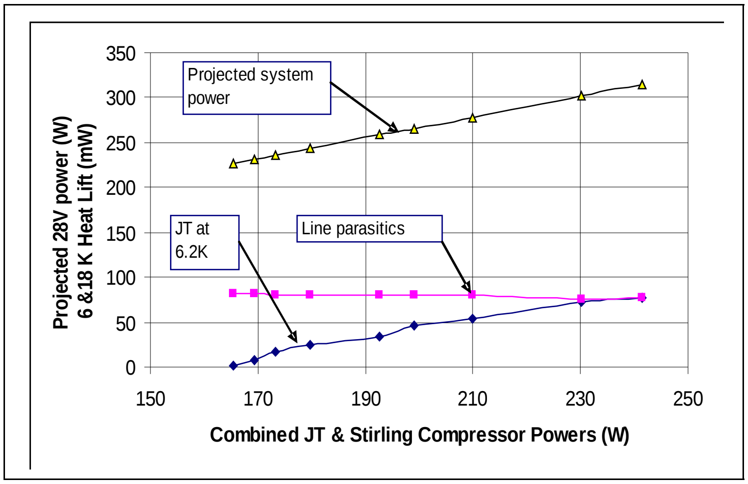

Figure 8. Performance data from ACTDP shows that it will meet the STO requirements for an input power of under than 400 Watts.

The cooler proposed for STO will essentially be the Ball ACTDP cooler built using a blend of space and commercial equipment to keep down costs. The J-T system will be the same as the one tested in Figure 7. All passive components will built from the same prints, and will be driven by the identical high performance J-T compressor, which has been transferred to the existing STO program. However, the ACTDP Stirling Precooler will be replaced with a "GM type" regenerative cooler assembled from commercial components. It will consist of a standard GM Coldhead, but the GM compressor will be replaced with an oil free, reed valve equipped, linear commercial compressor similar to the one used to drive the Stirling and built by CFIC. The pressure in the GM type cooler will be lowered to match the precooling required, accounting for the reduced power and extended life. The drive electronics will be a modified version of the electronics used in the ACTDP test. It will include two custom cooler control boards and commercial power equipment (power supplies and H-bridge amplifiers) for driving the compressors.

The system is expected to last at least 2 years without maintenance. The J-T system should be good for more than 10 years. Eliminating the oil filled GM compressor reduces the contamination that is the usual life-limiting aspect of the GM, and reducing the pressure should reduce any internal wear. If longer operating times are needed in the future, the precooler can be replaced with a space based type long life Stirling without much difficulty, given the "plug-in" component nature of the system.

As configured, the system will operate efficiently down to 6.0 K. The limit is due to the use of ^4He in the J-T system. At lower temperatures, the condensation of ^4He forces the system to lower pressures, which limits the mass flow that can be produced by the existing pump. However, as verified in test on the ACTDP Program, by substituting ^3He for ^4He, the existing system can be used to produce cooling down to 4 K, if required.

3.0 Implementation on STO

The 4-6 K cryocooler will be designed as a drop-in replacement for the liquid helium reservoir in the STO dewar. Therefore, the dewar mounting and instrument relay optics will remain unchanged. The instrument cold plate and outer vacuum shell, which are presently in detail design, will incorporate mechanical mounting details to accommodate the Ball cryocooler system in anticipation of its availability. The total weight of the cryocooler, compressor, and drive electronics (~40kg), is (to within a few kg) equal to the weight it is replacing. However, the majority of the weight is in the compressor and electronics which will be located off the telescope itself. The reduction in weight on the elevation axis will reduce the burden on the telescope drive system. In fact, the dewar drive system will be considerably simplified by the elimination of an existing moving mass required to counterbalance the loss of liquid helium at one end of the telescope over the duration of a mission. The <400W of power required by the 4-6 K cooler is within the power handling capability of the gondola design (1600W). To increase margin, additional solar cells will be added.

4.0 Management

This project inherits a diverse, focused, and experience management team already working together to complete the goals of STO. The PI, Chris Walker, the Project Manager, Tom McMahon, and the Deputy PM, Brian Duffy have worked together successfully on several large scale projects over the last 10 years. Along with the management at Johns Hopkins Applied Physics Laboratory (APL) and Ball Aerospace, all necessary infra-structure exists to track and manage the proposed effort.

The development, integration and operation of the balloon-borne, 4-6 K ULDB cryocooler is a collaborative effort between the University of Arizona, Ball Aerospace, and the Johns Hopkins APL. The majority of the effort and cost within this proposal lies in the subcontract with Ball Aerospace. It is therefore necessary to implement the subcontract with the lowest risk possible. To accomplish this we will develop a well defined Statement of Work, Tasks Management, Task Metrics with which to gauge progress, "go, no-go" milestone gateways, communications milestones such as weekly telecoms and on-site visits, all designed to achieve the project goals on schedule and within the allocated budget. The subcontract will be implemented as a Cost Plus Fixed-Fee with a cost ceiling of $1.314M. Ball Aerospace has reduced their fee to 5% (from the nominal 15%) to make the proposal more competitive. To further reduce costs, UofA will acquire key, commercially available capital hardware taking advantage of the University's zero overhead for such acquisitions.

4.1 Project Management & Organization

The development and implementation of the balloon-borne, 4-6 K ULDB cryocooler is a team effort between the University of Arizona, Ball Aerospace, and the Johns Hopkins Applied Physics Laboratory. The organizational structure of the project, shown in Figure 9, is designed to provide effective control of the effort while allowing delegation of authority to be made at the proper level within the team. Dr. Walker (PI) is responsible for all aspects of the successful development and implementation of the cryocooler on STO, for which he is also PI. He will be assisted at the University of Arizona by Tom McMahon, Project Manager (PM) and Brian Duffy, D-PM. The PM and D-PM will oversee the subcontract to Ball Aerospace, handle all procurements, and assist the PI in keeping the project on target in terms of both schedule and cost. Co-I's Glaister and Gully will lead the cryocooler development at Ball and ensure it meets the specified operational and interface requirements. Co-I Schein (UofA) will be responsible for specifying and implementing the cryogenic & mechanical interfaces between the pre-existing STO dewar and the Ball cryocooler. Collaborator Kulesa (UofA and STO D-PI) will ensure the electrical and computer interface between the upgraded cryogenic system and the STO instrument package are in order. Co-I Bernasconi will ensure the cryogenic system meets the interface and operational requirements of the gondola and telescope.

The project team 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 pertinent management and control information will be posted on a secure STO website and available to all participants. These tools will be used in daily interactions as well as in weekly team telecons and monthly status briefings to ensure that major issues are visible to and addressed by all affected team members. In addition, face-to-face team meetings will be conducted when appropriate, usually in conjunction with program milestones.

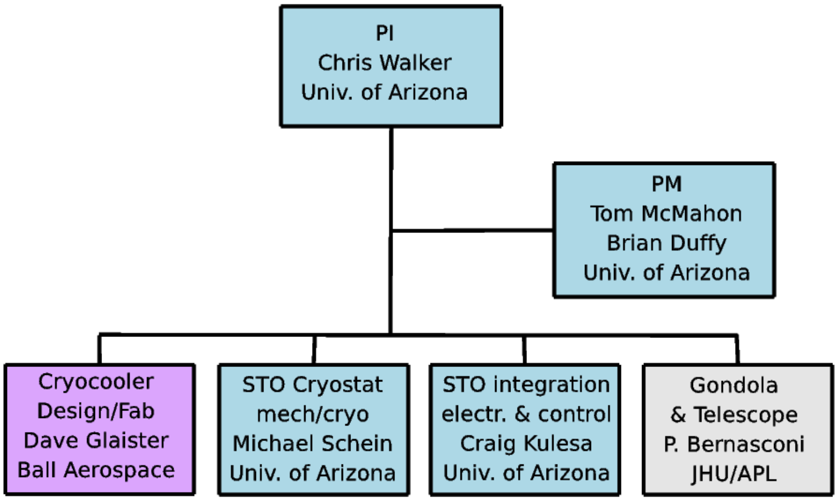

Figure 9. STO ULDB Cryocooler Organization Chart

4.2 Master Schedule

The project network flow diagram in Figure 10 shows the major task elements and the responsible parties.

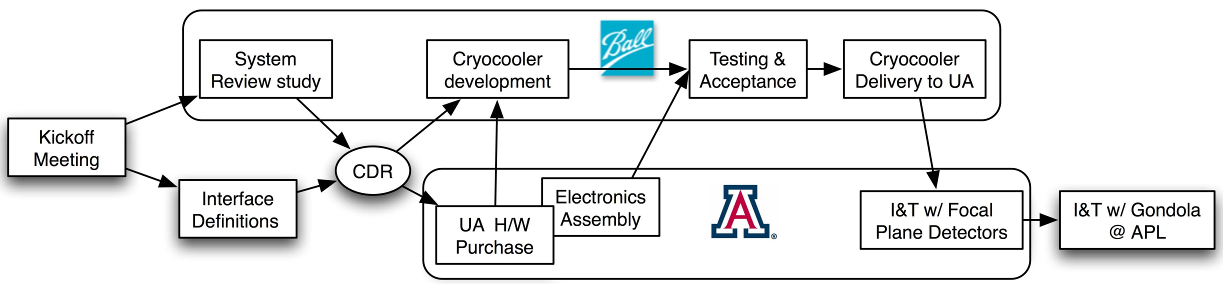

Figure 10: Network Flow Diagram

The master schedule shown in Figure 11 identifies the project's major milestones and development activities. Starting at the January 1, 2010 start date, the project would launch into a focused 6 month risk-reduction phase where all aspects of the cooler design and interface requirements will be carefully reviewed. A Critical Design Review (CDR) will be conducted in mid-June 2010. The scope of the CDR covers the entire cryogenic system and its implementation on STO. During the 12 months following the CDR, all required components for the cryocooler are procured or fabricated, integrated, and tested. To reduce cost, the UofA will procure the off-the-shelf components for the system and assemble the cooler drive electronics using existing Ball designs. The drive electronics will be built by the UofA to balloon thermal, launch load, and operating condition specifications and provide the necessary mechanical and electrical interface to the STO gondola. Ball will assemble the cryocooler itself and verify its performance using the drive system built at the UofA. Integration of the cryocooler into the STO flight cryostat will occur between June and December 2011. Performance tests of the STO focal plane detectors with the upgraded cryogenic system will take place at the UofA from January to June 2012, after which the instrument will be sent to APL for integration into the STO gondola.

A separate proposal will be submitted to the suborbital program in March-April 2011 to support an extended (~40 day) Antarctic flight of STO in December 2012.

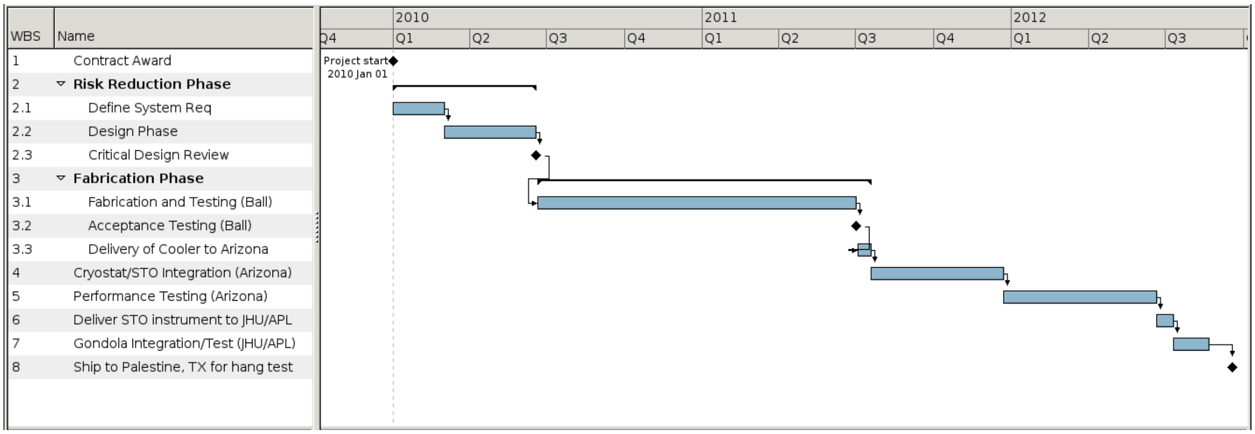

Figure 11. Project Schedule

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

Education

Ph.D.: Astronomy, University of Arizona, 1988
Advisor: Charles J. Lada
Thesis: "Observational Studies of Star Forming Regions"

M.S.: Electrical Engineering, Ohio State University, 1981
Advisor: John D. Kraus
Thesis: "Upgrading the Ohio State Radio Observatory"

B.S.: Electrical Engineering, Clemson University, 1980
Graduated with Honors

Experience

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

Honors and Awards

- Antarctic Service Medal of the USA (1999)
- NSF Young Investigator (1994-1999)
- Millikan Fellow in Physics at Caltech (1988-1991)
- Graduated Cum Laude B.S.E.E.
- Tau Beta Pi, General Engineering Honors Society
- Eta Kappa Nu, Electrical Engineering Honors Society

Professional Societies

- American Astronomical Society
- International Society of Optical Engineers

Research and Management Experience

The Principal Investigator (PI), Prof. Christopher Walker of the University of Arizona (UA), has over 20 years of experience designing, building, and using state-of-the-art receiver systems for radio astronomy. He has advanced degrees in both astronomy and electrical engineering and has worked in industry (TRW Aerospace and JPL) as well as academia. As a Millikan Fellow in Physics at Caltech, he led the effort to develop the first low-noise, SIS waveguide receiver above 400 GHz. At the University of Arizona he began the Steward Observatory Radio Astronomy Lab (SORAL), which has become a world leader in developing leading-edge submillimeter-wave receiver systems. SORAL constructed 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. These instruments are multi-institutional efforts, with key components coming from JPL, several universities, and a number of industrial partners. Prof. Walker manages and coordinates these efforts. 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. Funded by the NSF, Prof. Walker is leading the effort to design and build the world's largest submillimeter-wave heterodyne array receiver (64 pixels). His team is also employing laser micromachining techniques to the fabrication of integrated THz array receivers. He is the PI of the Stratospheric TeraHertz Observatory (STO), a long duration, balloon-borne observatory. Prof. Walker has published numerous papers on star formation and protostellar evolution and served as dissertation director for nine Ph.D. students (7-Astronomy, 2-Optical Sciences). He currently supervises three graduate (1-Astronomy, 1-Optical Sciences, and 1-Electrical Engineering) and two undergraduate (Physics/Astronomy) students.

Publications

Recent Publications (Refereed Journal)

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.

Narayanan, D., Kulesa, C., Boss, A., and Walker, C. K., 2006, *Molecular Line Emission from Gravitationally Unstable Protoplanetary Disks, Ap.J.*, **647**, Issue 2, pp. 1426-1436

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., in press.

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

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Professional Preparation

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

Appointments

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

Selected Papers Relevant to This Proposal

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. "Millimeter and Submillimeter Survey of the R Coronae Australis Region", Groppi, C. E., Kulesa, C., Walker, C., & Martin, C. L. 2004, ApJ, 612, 946
3. "Interstellar H_3^+ Line Absorption toward LkHα 101", Brittain, S. D., Simon, T., Kulesa, C., Rettig, T.W., 2004, ApJ, 606, 911.
4. "Abundances of H_2, H_3^+ & CO in Molecular Clouds and Pre-planetary Disks", Kulesa, C. A. & Black, J. H. 2002, Chemistry as a Diagnostic of Star Formation, 60
5. "SuperCam: a 64-pixel heterodyne imaging array for the 870-micron atmospheric window", Groppi, C., Walker, C., Kulesa, C., Puetz, P., Golish, D., Gensheimer, P., Hedden, A., Bussmann, S., Weinreb, S., Kuiper, T., Kooi, J., Jones, G., Bardin, J., Mani, H., Lichtenberger, A., Narayanan, G., 2006, Proc. SPIE, vol 6275, 62750O.

Instrumentation Experience Relevant to this Proposal:

1. Deputy-PI of the *Stratospheric Terahertz Observatory* (STO), a technological forerunner to STIM. Responsible for the overall development and integration of the flight instrument.
2. Deputy-PI of *Supercam*, a 64-beam, 345 GHz heterodyne receiver to be deployed at the 10-meter HHT telescope in Arizona. Responsibilities focus on the I&T of IF processor and spectrometer, system level testing, telescope integration, data system.
3. Constructed *Pre-HEAT*, an automated 0.2-meter terahertz telescope with heterodyne receiver deployed in January 2008 to Dome A, the isolated summit of the Antarctic ice plateau.
4. Integrated submm heterodyne receivers at the Arizona HHT and the 1.7-meter AST/RO telescope (South Pole) from 1998-2005.

David Glaister
Advanced Systems Manager

RELEVANT EXPERIENCE

Mr. Glaister has over 20 years of Cryogenic and Thermal Systems Engineering experience in satellite design, development, test, and production. Mr. Glaister is a recognized expert in the field of space cryogenics, cryogenic refrigerators (or cryocoolers), and cryogenic system integration. In his career, Mr. Glaister has managed over 15 cryogenic space programs and provided technical expertise to over 40 space cryogenics programs, 25 cryocooler programs, and 12 space flights of cryogenic systems. In the area of Thermal System Engineering, he has supported over 30 spacecraft programs with responsibilities that included analysis and design of spacecraft thermal systems, requirements development, thermal test development and support, launch support, and participation in design, source selection, and readiness reviews.

EDUCATION

Master of Science, Chemical Engineering, University of Washington, 1986
Bachelor of Science, Chemical Engineering, Colorado School of Mines, 1984

PROFESSIONAL EXPERIENCE

- **Ball Aerospace & Technologies Corp., October 1998–Present**
  Advanced Systems Manager, Business Area Manager, Program Manager, Senior Technical Manager, and Principal Engineer
- **The Aerospace Corporation, January 1995–October 1998**
  Project Engineer
- **The Aerospace Corporation, February 1987– January 1995**
  Senior Member of the Technical Staff

PROFESSIONAL SOCIETY POSITIONS

- Program Committee Member for 10th (1998) and 11^{th} (2000) and 12^{th} (2002) International Cryocooler Conferences
- Program Chairman for the 1992 and 1993 Aerospace Spacecraft Thermal Workshops
- Program Committee Member for the 1994, 1995, 1996, 1997, and 1998 Aerospace Spacecraft Thermal Workshops.
- Program Subcommittee Member for the 1999 and 2001 Cryogenic Engineering Conferences
- Member of AIAA 1996, 1997, and 1998 Thermophysics Technical Committees and Publicity Subcommittees.
- Session Chairman at over 30 Conferences.
- Member of AIAA, AIChE, IEEE, and Tau Beta Pi Honor Societies.

PUBLICATIONS

Mr. Glaister has over 60 technical paper and journal presentations that can be provided upon request. Mr. Glaister is also the author of the Cryogenic Analysis Chapter of the Satellite Thermal Control Handbook, Aerospace Press, 2003.

Dr. Wilfred J. Gully
Staff Consultant

RELEVANT EXPERIENCE

Dr. Gully is an experimental physicist with more than 35 years of experience in cryogenics. He has taken a number of cryogenic refrigeration systems from conceptual design through production. His contributions include thermodynamic analysis, detailed mechanical and electromagnetic hardware design, electronic development, and laboratory testing.

EDUCATION

Ph.D., Physics, Cornell University, 1976
Fulbright Fellow, TKK Cold Laboratory, Helsinki, Finland, 1975
B.S., Physics, University of Pittsburgh, 1970

PROFESSIONAL EXPERIENCE

Staff Consultant, Ball Aerospace & Technologies Corp., Boulder, CO, 1991–present
Technical lead on a number of current cryogenic programs at Ball Aerospace. Activities include:

- Systems engineer on the 10 K Hybrid Cooler, NASA ACTDP Hybrid 4-6 K Stirling J-T Cooler, DoD 35 K High Capacity Variable Load Cryocooler, and the HIRDLS Flight Cooler Programs. He defined the system architecture and is now managing the various subsystems. Currently heavily contributing to the detailed design of the multi-stage Stirling precooler, which includes the thermodynamic design, the top-level mechanical design, and the definition of the electronic requirements.

Primary technical lead in the development of BATC's mechanical coolers

- For the NASA 6 K Explorer program, planned and carried out a number of lab tests with customized hardware to characterize the performance of regenerators in Stirling coolers at temperatures below 20 K.
- For the 10 K cryocooler program, sponsored by the Air Force Research Laboratory, BATC did the initial development of a hybrid Stirling J-T cooler combination to provide 100 mW at 10 K. Performed the technical modeling, ran trades, and contributed to the design and testing of the unique rotary vane compressor.
- Systems engineer on the NASA GSFC multistage Stirling 30 K cryocooler program. Developed the first verifiable non-contacting Stirling cryocooler that used internal sensors to monitor close tolerance clearance seals. Developed this cooler from a clean sheet of paper.
- Systems engineer on the 35/60 K program, a three-stage derivative of the 30 K cooler that produced cooling at two stages simultaneously.

Senior Scientist, GM Hughes Electronics, Torrance, CA, 1984–1990
Developed a number of tactical style split linear Stirling cycle cryocoolers.

- Technical lead on the One Watt Linear (OWL) Cooler program for the Night Vision Laboratory. Performed the mechanical, thermal, and electrical design, and conducted the acceptance tests. Developed hybrid control circuits for the cooler at the Hughes Newport Beach Microelectronics facility.

Assistant Professor, University of Massachusetts, Amherst, MA, 1979–1984
Conducted research, taught classes, supervised graduate students.

MICHAEL E. SCHEIN, Aero / Mech / Cryo Engineer

- ***Principal Engineer, U of Ariz 2006 – Present***

Designed and built small terahertz telescope now based in Antarctica. Now responsible for programmatics, mechanical design, integration, and flight test of a new atmospheric research instrument, funded by NSF.

- ***Principal Engineer, Andrews Space Inc. 2005 – 2006***

Developed new launch propulsion system technology for DARPA, using high g rotary air separation to provide liquid oxygen at first stage boost, eliminating on-board oxidizer and dramatically decreasing launch weight.

- ***Lead Engineer, National Oceanic & Atmospheric Administration Aeronomy Lab 94 - 05***

Primary program engineer/designer/analyst for several new types of high altitude atmospheric research payloads carried on board NASA and NOAA research aircraft.

- ***Aerospace/Cryogenic Engineering Consultant 94 - 06***

- Developed concept for keeping high power laser optics in vacuum free from particulate contamination to prevent mirror burning in operation, for the Airborne Laser Project, Northrop-Grumman Space & Technology.

- Designed and equipped a large facility with machine shop, assembly areas, and test labs for aircraft and spaceflight hardware. Included machining tool specification, clean room integration, tool & part storage, etc.

- Designed and built a new concept combination helium instrument cooler / envelope gas replenishment system with the capacity for up to quadrupling the lifetime of NASA scientific balloon systems.

- Provided design and on-site engineering support for a variety of engineering projects, including manned around the world ballooning, world record speed rocket cars, single stage to orbit vehicles, Mars habitability and soil processing equipment design studies, long range hang gliders, Mars flyers, research dropsonde design, etc.

- ***Senior Engineer, Cryogenic Technical Services Inc. 92 - 94***

- Member of the team supporting the EarthWinds Manned Balloon Project circumglobal flight. Responsible for liquid helium gas makeup tank design, servicing, and numerous real time modifications to all balloon systems.

- Designed, built, & tested a prototype miniature liquid oxygen generator for home medical use. Concept was bought by a major company in the field and is now a widely used product.

- Designed and supervised the construction of the first large diborane cryogenic liquid storage system.

- Designed innovative thermal multilayer insulation schemes and high speed rotating cryogenic fluid carrythru designs for several national-scale projects, including the National Superconducting Mag. Energy Storage Project.

- ***Aerospace /Cryogenics Engineer, NASA Goddard Space Flight Center 84 – 92***

- Lead Servicing Engineer for the Superfluid Helium On-Orbit Transfer (SHOOT) experiment, the STS-57 Space Shuttle payload aimed at developing zero gravity liquid helium storage and transfer technology.

- Task Leader for Broad Band X-Ray Telescope (BBXRT) Shuttle Payload Cryogenic Operations. Responsible for dual solid argon cooler design, fabrication, and servicing, along with launch servicing and firing room duties.

- Developed and patented a new technology liquid cryogen cooler for zero-g use. Built working model for sounding rocket observation of the 1987A supernova. Follow-on design now used on-board Space Station.

- Member of the NASA-Goddard Mechanical Cooler Development Group. Involved in the procurement and evaluation of industry state of the art space qualified coolers. Suggested future improvements to venders.

EDUCATION: B.S. Aerospace & Ocean Engineering, Virginia Tech, 1985
Materials Engineering, New Mexico Tech, 1982

CURRICULUM VITAE

PIETRO N. BERNASCONI: CO-I

Current Position

The Johns Hopkins University / Applied Physics Laboratory
Senior Scientist
Space Department, Space Science Group, Solar Physics Section

Education

1992 Diploma (Physics) (equivalent to American Master's Thesis), Swiss Federal Institute of Technology Zürich (ETH-Z)
1997 Ph.D. (Natural Science), Swiss Federal Institute of Technology Zürich (ETH-Z)

Relevant experience

2008 - present: Payload PI, Stratospheric TeraHertz Observatory.
2007 - 2008: PI, Solar Bolometric Imager.
2001 - 2007: Project Scientist, Solar Bolometric Imager.
1997 - 2004: Project Scientist, Flare Genesis Experiment.
1992 - 1997: Research Fellow, Institute for Astronomy of the Swiss Federal Institute of Technology Zürich, Solar Physics Group.

Professional Societies

Member American Astronomical Society, Solar Physics Division (SPD)
Member American Geophysical Union (AGU)
Member Society of Photo-Optical Instrumentation Engineers (SPIE)

Relevant Publications

Bernasconi P.N., Rust D.M., Murphy G.A., Eaton H.A.C., High resolution polarimetry with a balloon-borne telescope: the Flare Genesis Experiment, in High Resolution Solar Physics: Theory, Observations and Techniques, T.R. Rimmele, K.S. Balasubramaniam, and R.R. Radick (Eds.), Astron. Soc. Pacific Conf. Series Vol. 183, 279-287 (1999)

Bernasconi P.N., Rust D.M., Eaton H.A.C., Murphy G.A., A balloon-borne telescope for high resolution solar imaging and polarimetry, in Airborne Telescopes Systems, Ramsey K. Melugin, Hans-Peter Röser (Eds.), Proceedings of SPIE Vol. 4014, 214-225 (2000)

Bernasconi P.N., Rust D.M., Eaton H.A.C., High resolution vector magnetograms with the Flare Genesis vector polarimeter, in Advanced Solar Polarimetry - Theory, Observation, and Instrumentation, M. Sigwarth (Ed.), Astron. Soc. Pacific Conf. Series Vol. 236, 399-406 (2001)

Bernasconi P. N., Rust D. M., Georgoulis M. K., LaBonte B. J. 2002, Moving Dipolar Features in an Emerging Flux Region, Sol. Phys. 209, 119-139 (2002)

Bernasconi, P. N., Eaton, H. A. C., Foukal, P., Rust, D. M., The Solar Bolometric Imager, Advances in Space Research 33, 1746 (2004)

Bernasconi, P. N., Rust, D. M., Hakim, D., Advanced Automated Solar Filament Detection and Characterization Code: Description, Performance, and Results, Solar Physics 228, 99 (2005)

Current and Pending Research Support
Investigator: Christopher K. Walker

CURRENT SUPPORT:

Project title: Development of a Submillimeter-wave Superheterodyne Camera (SuperCam) for the Heinrich Hertz Telescope
Source of Support: NSF MRI Program AST-0421499
POC: Andrew Clegg, aclegg@nsf.gov, (703) 292-4892
Total Award Amount: $2,137,481 Total Award Period Covered: 09/01/04 - 12/31/09
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 1.0

Project title: The Stratospheric TeraHertz Observatory
Source of Support: NASA NNX08AG39G
POC: Bernice Merrit, bernice.a.merritt@nasa.gov, (757) 824-1353
Total Award Amount: $1,735,879 Total Award Period Covered: 01/28/08 - 01/27/12
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 1.0

Project title: STTR Phase II: Coherent THz Sources and Amplifiers Using Carbon Nanotubes
Source of Support: NSF MRI Program AST-0421499
POC: Juan Figueroa, jfigueroa@nsf.gov, (703) 292-8050
Total Award Amount: $496,705 Total Award Period Covered: 02/15/08- 02/14/10
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 1.0

Project title: A 2.7 THz Local Oscillator Chain to Enable Spectroscopy from a Balloon Platform
Source of Support: JPL - SURP
POC: Imran Mehdi, imran.mehdi@jpl.nasa.gov, (818) 354-2001
Total Award Amount: $48,500 Total Award Period Covered: 07/ 7/10/08-08/03/09
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 0.56

Project title: HIGGS: Herschel Guest Investigator Key Project
Source of Support: NASA Herschel Science Center
POC: George Helou, gxh@ipac.caltech.edu, (612) 626-2067
Total Award Amount: $354,584 Total Award Period Covered: 07/14/08- 01/15/12
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 1.0

Project title: A 1900 GHz Local Oscillator chain for STO
Source of Support: JPL- SURP
POC: Imran Mehdi, imran.mehdi@jpl.nasa.gov, (818) 354-2001
Total Award Amount: $48,500 Total Award Period Covered: 02/01/09- 01/31/10
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 0.5

PENDING SUPPORT:

Project title: Operation and Return of the PreHEAT Telescope to Dome A
Source of Support: NSF Polar
POC: Vladimir Papitashvili, vpapita@nsf.gov, (703) 292-7425
Total Award Amount: $5,946 Total Award Period Covered: 12/10/08- 12/09/10
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 0.13

CURRENT AND PENDING RESEARCH SUPPORT
Investigator: David Glaister

PENDING RESEARCH SUPPORT:

N/A

CURRENT AND PENDING RESEARCH SUPPORT
Investigator: Willy Gully

CURRENT RESEARCH SUPPORT

Project title: 35 K High Capacity Variable Load Cryocooler (PM: D. Glaister)
Source of Support: DoD
Total Award Amount: $7.8M Total Award Period Covered: 08/01/04 – 4/1/10
Location of Project: Ball Aerospace
Person-Months Per Year Committed to the Project: Cal: 2.5 Acad: Sumr:

Project title: 10 K Cryocooler (PM: D. Glaister)
Source of Support: The Aerospace Corporation
Total Award Amount: $3.4M Total Award Period Covered: 2/1/07 - 8/1/09
Location of Project: Ball Aerospace
Person-Months Per Year Committed to the Project: Cal: 2.5 Acad: Sumr:

PENDING RESEARCH SUPPORT:

N/A

CURRENT AND PENDING RESEARCH SUPPORT
Investigator: Michael E. Schein

CURRENT RESEARCH SUPPORT

Project title: Development of the Active Temperature Ozone and Moisture Microwave Spectrometer (ATOMMS) cm and mm-wave Occultation Instrument
Source of Support: NSF-MRI ATM-0723239
Total Award Amount: $1,883,695 Total Award Period Covered: 01/01/08 – 12/31/10
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: 6.0 Acad: Sumr:

Project title: The Stratospheric Terahertz Observatory (STO)
Source of Support: NASA NNX08AG39G
POC: Bernice Merrit, bernice.a.merritt@nasa.gov, (757) 824-1353
Total Award Amount: $1,735,879 Total Award Period Covered: 01/28/08 - 01/27/12
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: 3.0 Acad: Sumr:

PENDING RESEARCH SUPPORT:

N/A

Steward Observatory
933 North Cherry Avenue
Tucson, Arizona 85721-0065

THE UNIVERSITY OF
ARIZONA®
TUCSON ARIZONA

Telephone: (520) 621-2288
Telefax: (520) 621-1532

25 March 2009

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

Dear Prof. Walker,

I acknowledge that I am identified by name as a collaborator to the investigation, entitled "A 4-6K Cryoooler for LDB and ULDB Astronomy", that is submitted by Christopher K. Walker to the NASA Research Announcement NNH08ZDA001N, 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.

The proposed cryocooler development represents a bold new advance in the capabilities of balloon-based astronomy, and will lead the way for new capabilities for the Stratospheric Terahertz Observatory. I look forward to the opportunities and challenges that this development will provide.

Best regards,

Craig Kulesa

Dr. Craig A. Kulesa
Assistant Astronomer
Steward Observatory
The University of Arizona

Ball Aerospace & Technologies Corp.
1600 Commerce Street, Boulder, CO 80301 (303) 939-4000
Reply to: P.O. Box 1062, Boulder, CO 80306-1062

March 23, 2009

LETTER OF COMMITMENT

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

Dear Prof. Walker,

I acknowledge that I am identified by name as a Co-I to the investigation, entitled ``A 4-6 K Cryocooler for LDB and ULDB Astronomy'', that is submitted by Christopher K. Walker to the NASA Research Announcement NNH08ZDA001N, 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.

Ball's role on this program includes the 4 K cryogenic and cryocooler system and is highly relevant and leveraged off our past, current, and future cryogenic programs. Ball has been a leader in the space cryogenics market for nearly half a century with over 150 cryogenic space flights to date. Our recent low temperature cryocooler programs include the 4-6 K NASA/JPL Advanced Cryocooler Technology Development Program (ACTDP) and the Aerospace Corporation 10 K Cooler Program. Our technical approach on these two programs as well as the ULDB Cooler Program is to employ a "hybrid" cooler that synergistically combines regenerative (Stirling, Pulse Tube, and/or Gifford-McMahon) and recuperative (Joule-Thomson) thermodynamic cooling cycles. This approach yields the minimum power consumption, an aspect that is critical to the ULDB Cooler Program.

We look forward to working with you and the Steward Observatory on this project.

Sincerely,

Dave Glaister
Cryogenics Business Area Lead
Component Technologies Directorate

Ball Aerospace & Technologies Corp.
1600 Commerce Street, Boulder, CO 80301 (303) 939-4000
Reply to: P.O. Box 1062, Boulder, CO 80306-1062

March 23, 2009

LETTER OF COMMITMENT

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

Dear Prof. Walker,

I acknowledge that I am identified by name as a Co-I to the investigation, entitled ``A 4-6 K Cryocooler for LDB and ULDB Astronomy'', that is submitted by Christopher K. Walker to the NASA Research Announcement NNH08ZDA001N, 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.

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We look forward to working with you and the Steward Observatory on this project.

Sincerely,
Sincerely,

Willy Gully

Dr. Wilfred Gully
Cryogenics Technical Lead
Component Technologies Directorate

Steward Observatory

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933 N. Cherry Avenue
Tucson, AZ 85721-0065
(520) 621-2288
Fax: (520) 621-1532

March 25, 2009

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

To whom it may concern:

I acknowledge that I am identified by name as a Co-I to the investigation, entitled "A 4-6K Cryoooler for LDB and ULDB Astronomy", that is submitted by Christopher K. Walker to the NASA Research Announcement NNH08ZDA001N, 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.

Sincerely,

Michael E. Schein
Principal Engineer
Steward Observatory
The University of Arizona

March 23, 2009

The Johns Hopkins University
APPLIED PHYSICS LABORATORY

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

Dear Dr. Walker

I Pietro Bernasconi acknowledge that I am identified by name as a Co-I to the investigation, entitled "A 4-6K Cryoooler for LDB and ULDB Astronomy", that is submitted by Christopher K. Walker to the NASA Research Announcement NNH08ZDA001N, 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.

Sincerely,

Pietro Bernasconi

Pietro Bernasconi

BUDGET JUSTIFICATION

BUDGET NARRATIVE INTRODUCTION

This Budget Element explains the total cost the University of Arizona (UA) is expected to incur during the 2 plus year period of performance of this project (January 1, 2010 – June 30, 2012). The estimates include all labor costs, materials, capital expenses, travel, and indirect (F&A) charges. This budget also includes the costing details of the Ball Aerospace subcontract, a major component of this proposal. The total project cost is $1.88 million. The Principal Investigator, Dr. Christopher Walker, is a UA faculty.

Sponsor:
PI:
Performance Period:

FOR INTERNAL USE ONLY

Project Title:	YEAR 1A: 1/1/10 - 6/30/10			YEAR 1B: 7/1/10 - 12/31/10			YEAR 2			YEAR 3			3 YEAR TOTALS
	Year 1 Rate	Labor Hrs.	TOTAL YEAR 1	Year 2 Rate	Labor Hrs.	TOTAL YEAR 2	Year 3 Rate	Labor Hrs.	TOTAL YEAR 3	Year 4 Rate	Labor Hrs.	TOTAL YEAR 4	
PERSONNEL													
Senior Personnel													
Dr. Christopher Walker, 1/2 summer month in year 3	$ 66.66	-	$ -	$ 66.66	-	$ -	$ 68.86	-	$ -	$ 71.13	80	$ 5,690	$ 5,690
Senior Personnel Subtotal		*-*	*$ -*		*-*	*$ -*		*-*	*$ -*		*80*	*$ 5,690*	*$ 5,690*
Appointed Personnel													
Mechanical Engineer (Schein)	$ 50.32	250	$ 12,580	$ 50.32	250	$ 12,580	$ 51.98	500	$ 25,990	$ 53.70	500	$ 26,850	$ 78,000
McMahon	$ 59.11	12	$ 709	$ 59.11	12	$ 709	$ 61.06	24	$ 1,465	$ 63.07	24	$ 1,514	*$ 4,397*
	$ -	-	$ -	$ -	-	$ -	$ -	-	$ -	$ -	-	$ -	*$ -*
Appointed Personnel Subtotal		*262*	*$ 13,289*		*262*	*$ 13,289*		*524*	*$ 27,455*		*524*	*$ 28,364*	*$ 82,397*
Classified Staff													
Project Manager (Duffy)	$ 31.75	260	$ 8,255	$ 31.75	260	$ 8,255	$ 32.80	500	$ 16,400	$ 33.88	500	$ 16,940	$ 49,850
	$ -	-	$ -	$ -	-	$ -	$ -	-	$ -	$ -	-	$ -	*$ -*
Classified Staff Subtotal		*260*	*$ 8,255*		*260*	*$ 8,255*		*500*	*$ 16,400*		*500*	*$ 16,940*	*$ 49,850*
Graduate Students													
Graduate Research Assistant - AY (9-months) @ 50% FTE	$ 21.53	-	$ -	$ 21.53	-	$ -	$ 22.24	-	$ -	$ 22.97	-	$ -	*$ -*
Graduate Research Assistant - summer (3-months) @ full-time	$ 25.30	-	$ -	$ 25.30	-	$ -	$ 26.13	-	$ -	$ 26.99	464	$ 12,523	$ 12,523
Graduate Students Subtotal		*-*	*$ -*		*-*	*$ -*		*-*	*$ -*		*464*	*$ 12,523*	*$ 12,523*
Labor Subtotal		**522**	**$ 21,544**		**522**	**$ 21,544**		**1,024**	**$ 43,855**		**1,568**	**$ 63,517**	**$ 150,460**
FRINGE BENEFITS - Rates effective 7/1/08 and beyond													
Faculty and Appointed Personnel @ 28.9%		$ 13,289	$ 3,841		$ 13,289	$ 3,841		$ 27,455	$ 7,934		$ 34,054	$ 9,842	*$ 25,458*
Classified Staff @ 44.7%		$ 8,255	$ 3,690		$ 8,255	$ 3,690		$ 16,400	$ 7,331		$ 16,940	$ 7,572	*$ 22,283*
Graduate Students @ 36% (26.6% IDC exempt)		$ -	$ -		$ -	$ -		$ -	$ -		$ 12,523	$ 4,508	*$ 4,508*
Fringe Benefits Subtotal			**$ 7,531**			**$ 7,531**			**$ 15,265**			**$ 21,922**	**$ 52,249**
Personnel Labor + ERE Totals			**$ 29,075**			**$ 29,075**			**$ 59,120**			**$ 85,439**	**$ 202,709**
OTHER DIRECT COSTS													
OPERATIONS			**$ 15,400**			**$ 500**			**$ 3,000**			**$ 3,000**	**$ 21,900**
Computer			$ 300			$ 300			$ 600			$ 600	
Computer support			$ -			$ -			$ 200			$ 200	
Materials and Supplies			$ 15,000			$ 100			$ 2,000			$ 2,000	
Communications (postage/Fedex, phone/fax, copying/printing)			$ 100			$ 100			$ 200			$ 200	
TRAVEL			**$ 1,910**			**$ 3,820**			**$ 2,130**			**$ -**	**$ 7,860**
varying trips a year for 2 days , 1nite each to Colorado		Domestic	Intern'l		Domestic	Intern'l		Domestic	Intern'l		Domestic	Intern'l	
Airfare @ $300 RT (Tucson-Denver); 3px1trp,3px2trp,1px3trp		$ 900	$ -		$ 1,800			$ 900	$ -			$ -	
Lodging @ $150/night (domestic)		$ 450	$ -		$ 900	$ -		$ 450	$ -			$ -	
Per diem @ $75/day (domestic)		$ 450	$ -		$ 900	$ -		$ 450	$ -			$ -	
Rental car @ $55/day (domestic)		$ 110	$ -		$ 220			$ 330	$ -			$ -	
Total per trip		$ 1,910	$ -		$ 3,820	$ -		$ 2,130	$ -		$ -	$ -	
CAPITAL EQUIPMENT			**$ 161,000**			**$ -**			**$ 50,000**			**$ -**	**$ 211,000**
Capital Equipment			$ -			$ -							
Cryocooler Electronics Box (order in 2nd year)			$ -						$ 50,000				
Temp Controller and power supply (20K)			$ 20,000										
Commercial Compressor (CFIC)			$ 46,000										
2-Bypass Valve & 3 Heat Exchangers			$ 85,000										
G-M coldhead and power supply (10K)			$ 10,000			$ -			$ -			$ -	
SUBCONTRACTS			**$ 182,592**			**$ 816,328**			**$ 315,032**			**$ -**	**$ 1,313,952**
Ball Aerospace			$ 182,592			$ 816,328			$ 315,032			$ -	
Total Other Direct Costs			**$ 360,902**			**$ 820,648**			**$ 370,162**			**$ 3,000**	**$ 1,554,712**
TOTAL DIRECT COSTS			[illegible]			[illegible]			[illegible]			[illegible]	[illegible]
INDIRECT COSTS - [illegible]													
MTDC BASE = Total Direct Costs (TDC) less capital equipment, less Tuition Remission (26.6% of Graduate Student fringe), and on first $25K of each subcontract													
		Base	IDC		Base	IDC		Base	IDC		Base	IDC	
Base (on salaries, operations, travel)		$ 46,385	$ 23,656		$ 33,395	$ 17,198		$ 64,250	$ 33,089		$ 85,108	$ 43,831	
Base (on first $25K of each subcontract)		$ 25,000	$ 12,750		$ -	$ -		$ -	$ -		$ -	$ -	
Total Indirect Costs			**$ 36,406**			**$ 17,198**			**$ 33,089**			**$ 43,831**	**$ 130,524**
TOTAL PROJECT COSTS			**$ 426,383**			**$ 866,921**			**$ 462,371**			**$ 132,270**	**$ 1,887,945**

3.3% inflationary rate applied to all eligible costs in Years 2, 3, 4 and 5.

3/25/2009 11:16 AM

Summary of Personnel and Work Efforts

Personnel	Organization	Compensated Work Effort	Role
Chris Walker	UA	4%	Principal Investigator. Responsible for all aspects of the success and integrity of STO cryocooler project as well as for the existing STO project
Craig Kulesa	UA	0%	Unpaid Collaborator. Assists PI with STO tasks. Serves as paid Co-PI on STO Project
David Glaister	Ball	7%	Co-I. Ball Project Manager with overall responsible of development effort
Willy Gully	Ball	14%	Co-I. Ball Engineering lead responsible for the technical aspects of the cryocooler development.
Mike Schein	UA	25%	Co-I. System Engineer responsible for the execution of the UA technical tasks.
Tom McMahon	UA	1%	Project Manager. In charge of Ball subcontract implementation and oversight
Brian Duffy	UA	25%	Deputy Project Manager. Responsible for technical tasking and tracking of UA tasks
Pietro Bernasconi	JHAPL	0%	Unpaid Co-I. Provides assistance in interface control assurance relative to the balloon gondola. Serves as paid Co-I on STO Project

Facilities and Equipment

University of Arizona, Steward Observatory

The PI and his team have the facilities and experience needed to design, build, and implement THz receiver systems in liquid, hybrid, and closed-cycle 4K cryogenic systems.

In 1992 the PI established a laboratory (the Steward Observatory Radio Astronomy Laboratory, SORAL) for the development of state-of-the-art, THz receiver systems. SORAL possess all the equipment (spectrum analyzers, network analyzer's, vacuum pumps, cryogenic support facilities, etc.) needed for the development of receivers. We also have 4He, 3He, and closed-cycle cryostats, a full receiver testbed, 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 Hewlett Packard's High Frequency Structure Simulator (HFSS) and Advanced Design System (ADS) software packages, as well as Agilent HFSS and CST Microwave Studio. These programs are used to accurately model and optimize mixers and other crucial receiver components. In addition, we have licenses for optical and mechanical design packages such as Zemax , Code V, Solid Works, and Inventor.

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 the 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 mult-institutional project, much like STO, and utilizes a commercial 4K cryocooler.

BUDGET DETAILS

UA COST MODEL

The UA budget elements were generated using a “bottoms-up” analysis of a necessary tasks in the development, integration, and testing of the close cycle cryocooler that will enable ultra-long duration balloon flights of the Stratospheric Terrahertz Observatory (STO). STO is an pre-existing project funded by the NASA Suborbital program. Figure B1 shows the top level WBS for the project. The primary product of this project is an efficient, low power cryocooler, balloon-flight capable which is easily interfaced with the STO instrument package and gondola. Ball Aerospace will produce the cryocooler. UA will provide a purchasing support role for Ball Aerospace as well as integrate and test the cryocooler with the flight cryostat. The purchasing support service is designed to reduce the overall cost of the project, leveraging the University’s reduced or zero overhead.

Figure B1: Work Breakdown Structure

The costs for each of the project’s tasks were derived using a combination of recent and real costs of similar projects and efforts, vendor quotes for required hardware, and cost models used by the Steward Observatory and Ball Aerospace. Labor estimates were assembled by evaluating the experience required, scope of task, employee type, and availability. Project management costs are maintained at a low level for the following reasons: 1) Steward Observatory has a mature and effective infrastructure to track the projects financially; 2) The management team has developed an array of highly effective, streamlined, and successful methods of project management.

REAL YEAR DOLLARS AND INFLATION ESTIMATES

The budget was calculated using *Real Year* (RY$) dollars. The inflationary factor used to acquire the real year values is 3%. Each of the category cost elements was multiplied by this factor annually starting in January.

DIRECT LABOR

Summary

The labor hours applied to the research in the period specified is 3706 labor hours. This is equivalent to 2.0 FTE for the period of performance (based on 1840 hr work year). The UA labor FTEs are broken down by calendar year in Table B2:

Table B2: UA Annual Labor Breakdown

Year	**2010**	**2011**	**2012**	**All Years FTE**
Science & Tech FTE	0.25	0.25	0.29	0.79
Management FTE	0.25	0.25	0.25	0.75

Layout
The The UA budget attached has been divided into the basic categories of: 1) Labor; 2) Capital Equipment; 3) Travel; 4) Operations; 5) Indirect costs (F&A). The budget details start with the direct labor calculations for all participants that are to be directly compensated. The direct labor is calculated using the base hourly wages and the level of effort (number of hours) of each individual. The detailed budget includes the starting hourly wages (projected from March 2009 values). The grand total of the direct labor is the sum of all wages with the
benefits.

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 39 weeks in duration. The summer term is 3 months or 13 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 154.6 hours per month. The faculty hourly rate is calculated using the following formula: Rate = (Academic Salary)*.00072.Graduate and undergraduate students are allowed to work a total of 800 hours (89 hrs/month) during the academic period. The academic hourly rate is defined by the Department of Astronomy to be $21.31 for the 2007 fiscal year based upon a annual salary of $17,052 ($17,052/800 hrs). Hourly wages for under-graduate students vary from $7.50 to $10.00, depending on work experience and time in position.

Graduate students are allowed to work a total of 880 hours (98 hrs/month) during the academic term and 540 hours (180 hrs/month) during the summer term. The hourly rate is calculated using the formula: *Rate = (2*Academic Salary)*.00067.*

UA Appointed Personnel and Classified Staff Hours
Appointed and Classified staff hourly rates are calculated using a 2080-hour work year or approximately a 173-hour work month.

Fringe Benefits Rates
The benefits rates are listed in Table B3. The dollar value is calculated by multiplying the benefits rate to the wages earnings for the specified period.

Benefits $ = Hours x Hourly Rate x Benefit rate

Table B3: Benefits Schedule

Employee Type	Jan ’10 – Jun ’12
Faculty	28.9%
Appointed Staff	28.9%
Classified Staff	44.7%
Graduate Students	
Tuition Remission	26.6% (excluded from indirect)
Fringe Benefits	9.4%
Under Graduate	3.3%

SUBCONTRACTS
A single subcontract shall be let in this project. Ball Aerospace will receive a sole-source Fixed Cost Plus contract to develop, test, and deliver a Hybrid 4-6K cryocooler to the UA for use in the Stratospheric Terrahertz Observatory. The Ball cryocooler design is unique and proprietary David Glaister of Ball is named as Co-Investigator of this proposal and will be leading the effort of tailoring the system for use with . Details of the Ball Aerospace budget can be found in the attached appendix. The total contract cost at Ball Aerospace is $1,313,952.

Ball Aerospace & Technologies Corp.
1600 Commerce Street
Reply to: P.O. Box 1062, Boulder, Colorado 80306-1062

ISO 9001 CERTIFIED
FM 39220

23 March 2009
ND.09.KAP.019

University of Arizona
933 North Cherry Avenue
Tucson, AZ 85721

Attention: Christopher Walker/Tom McMahon
Department of Astronomy

Subject: Proposal No. P0309-2336
Stratospheric Terahertz Observatory (STO) Cryocooler

Reference: a) Request for Proposal and Specification dated 11 March 2009

Ball Aerospace & Technologies Corp. (Ball Aerospace) is pleased to submit our Firm-Fixed Price Level-of-Effort (FFP/LOE) Proposal **P**0309-2336 in response to the referenced a) request. Our offered price represents our best understanding of the requirements stated in the RFP to provide an upgrade to the cryocooler to replace the liquid helium tank in the present STO dewar concept.

Our offered price is $1,313,952 and contingent upon the follow groundrules and assumptions:
1) Level-of-effort tasks and hours provided per the attached table.
2) Monthly billings with payment terms net 30 days.
3) Customer (University of Arizona) Furnished Equipment (CFE):

Description	**Required at Ball (Schedule attached)**
Cryocooler control electronics (based on Ball Aerospace supplied drawings), including parts	1-14-2011
J-T Compressor (Assumes Ball receives rent free use purchase order from University of Arizona **STO** Program (reference: NASA contract NNC07CB29C)).	6-04-2010
Cryocooler Compressor (from CFIC)	6 04 2010
Heat exchangers (from CTS based on Ball supplied drawings)	11-19-2010
By-pass valve (based on Ball Aerospace supplied drawings)	12-31-2010
Commercial and G-M (Gifford-McMahon) cooler power supply	7-30-2010/2-12-2010
G-M cold head	6-04-2010
Commercial temperature controller	7-30-2010
Cables, including materials and fabrication	1-14-2011

4) Deliverables include best effort to develop a cryocooler meeting the specification and a final report.
5) Period of performance is: January 2010 through June 2011.
6) Mutually agreeable terms and conditions.
7) Our offer will remain valid for 90 (ninety) days from the date of this proposal.
8) Assumes the UofA program is ITAR compliant.

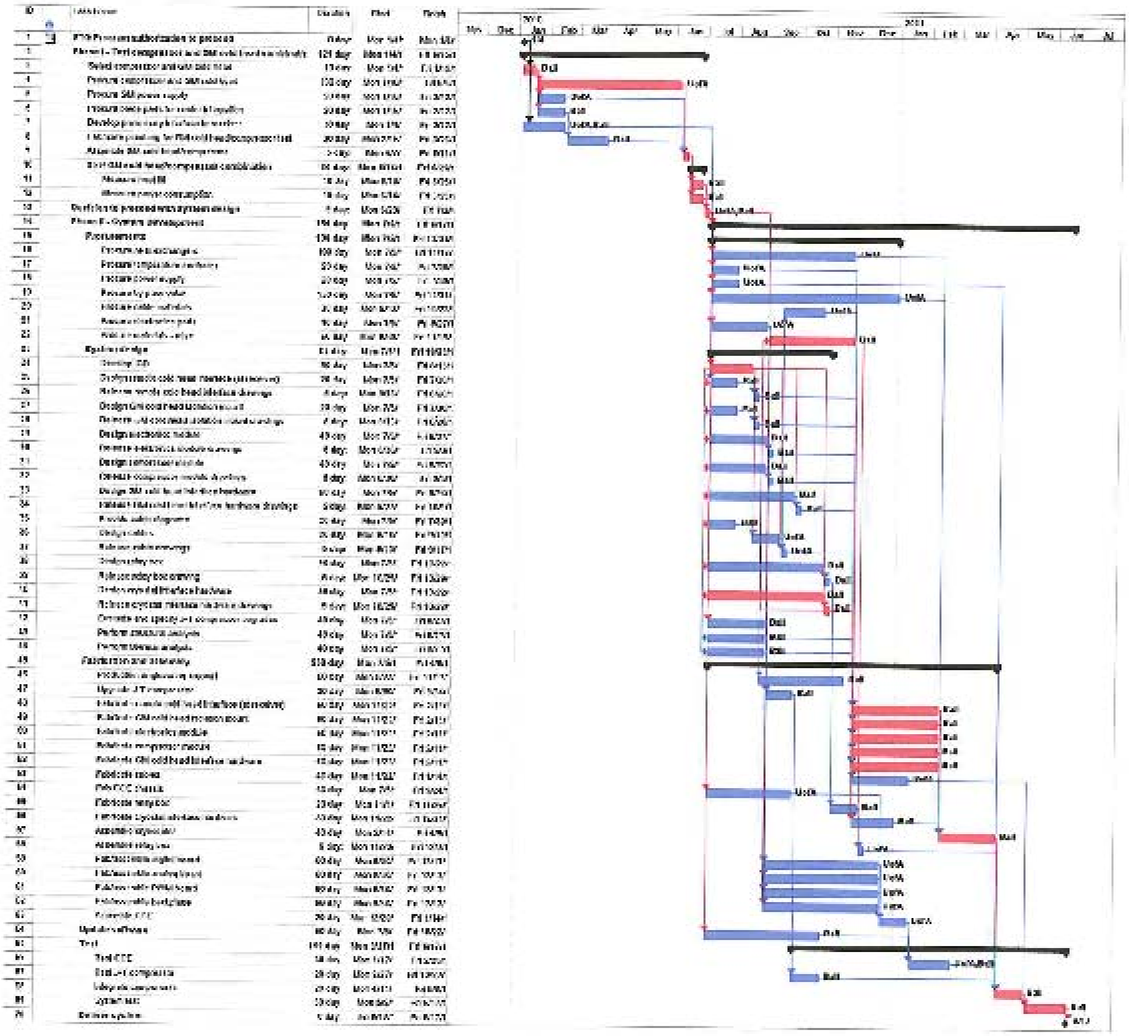
Ball Aerospace also provides an option price of $27,178 for post delivery support that assumes labor only (with all travel costs covered by University of Arizona or the National Science Foundation) and includes 1 (one) week of travel and 1 (one) week of on-site support in the Antarctic.

We want to express our appreciation for this opportunity to provide this proposal in support of the STO program and look forward to working with the University of Arizona team. If you have questions of a technical nature, please contact Mr. Dave Glaister, 303.939.5842 (dglaiste@ball.com). Questions of a contractual nature should be addressed to Ms. Kathy Prentice at 303.939.7288 (kprentic@ball.com).

Sincerely,

Karl J. Pendergast
Director, Advanced Systems
Ball Aerospace & Technologies Corp.

Enclosure: Proposal Pricing P0309-2336



Stratospheric THz Observatory (STO)
WBS Hours and Costs by Month

	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	TOTAL PHASE 1	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	TOTAL PHASE 2	TOTAL PRICE
Hours	276	146	48	68	68	118	714	622	624	804	712	604	634	314	286	196	84	216	164	6,200	5,974
01 - Program Office	196	28	18	18	18	10	296	64	54	54	54	54	44	36	36	36	36	36	54	568	864
02 - Systems Engineering	40	40		40	40	40	200	40	40	20	20	20	20	20	-	-		40	40	280	480
03 - Design	40	10	10	10	-	-	70	510	410	370	250	210	210	10	10	-		-	-	1,980	2,050
04 - Manufacturing	-	60	20	-	-	-	80		120	360	320	320	380	240	240	40	40	40	40	2,120	2,200
05 - Test	-	-	-	-	-	60	60		-	-	80	-	-	-	-	120	-	100	-	280	340
06 - Materials / Shipping	-	8	-		-	-	8	8	-	-	8	-	-	8	-	-	0		20	52	60
06.01 - Materials / Shipping	-	-	-		-			-		-	-	-	-	-	-		-		-		-
Price	$ 67,232	$ 34,447	$ 11,689	$ 19,887	$ 16,970	$ 32,598	$ 182,592	$ 136,672	$ 127,084	$ 162,720	$ 146,586	$ 119,952	$ 124,654	$ 61,875	$ 63,176	$ 51,100	$ 26,088	$ 61,020	$ 51,986	$ 1,131,360	$ 1,313,952
01 - Program Office	44,657	7,036	4,382	4,382	4,382	4,382	69,822	14,541	12,261	12,261	12,261	12,261	9,981	8,609	9,152	9,152	9,152	9,152	17,132	136,111	205,932
02 - Systems Engineering	12,116	12,588	-	12,588	12,588	12,588	52,467	12,588	12,588	6,294	6,294	6,294	6,294	6,294	-	-	-	13,078	13,078	92,802	145,269
03 - Design	10,460	2,717	2,717	2,717	-	-	18,610	107,577	84,777	77,287	49,718	40,598	40,598	3,147	3,270	-	-	-		406,972	425,581
04 - Manufacturing	-	10,640	4,560	-	-	-	15,200	-	18,239	66,579	60,799	60,799	61,243	42,559	44,217	9,475	9,475	9,476	9,475	392,637	407,837
05 - Test	-	-	-	-	-	15,628	15,628	-	-	-	15,628	-	-	-	-	32,473	-	29,315	-	77,416	93,043
06 - Materials / Shipping	-	866	-	-	-	-	866	866	-	-	866	-	-	866	-		900	-	3,158	6,657	7,523
06.01 - Materials / Shipping	-	-	-	-	-			-	-	-	-	-	5,536	-	6,536	-	6,538	-	9,153	28,766	28,766

EQUIPMENT

Capital equipment purchases ($211k) are budgeted in the proposal to support the construction of the cryocooler system. UA will purchase the items and deliver them to Ball for integration into the cryocooler system. This "purchasing support" at UA will allow the project costs to be kept as low as possible. The costs were estimated via a combination of recent acquisitions carried out by the Ball, specific vendor quotes, and estimates generated from WBS development and parametric scaling from other current projects. Table B4 describes the acquisitions and the role they play in the instrument.

Capital Item	Description	Cost	Method of Estimate	Notes
Temperature Controller and Power supply	Simple commercially available components used in the cryocooler system .	$20000	Estimate from recent purchases	
Cryocooler elecreonics	3 custom designed PCBorads used to control the cryo system	$50,000	Parts quote & recent like-costs analysis	Ball to provide parts list and design. UA to outsource fabrication
Compressor	Commercially available Compressor used to drive GM cold head	$46,000	Vendor quote	
Bypass valve & Heat exchangers	Custom parts used in cryocooler system	$85,000	Previous and recent purchase	Vendor: CTR
Gifford-McMahon Cold head and power supply	Used as the 1st stage of the cryocooler	$10,000	Similar purchase	

TRAVEL

Travel is budgeted to facilitate inter-organizational communications subcontract oversight. The baseline trip is travel from Tucson to Ball Aerospace in Boulder CO. The trip costs include airfare, per diem, rental car, lodging, and airport parking. The travel schedule is shown in Table B5. No international travel is anticipated.

	Single Person 2 day Trip Cost	3 person 2 day Trip Costs
Transport	300	900
Lodging ($150/night	150	450
Per Diem ($75/day)	150	450
Rental car ($55/day)	110	110
Total	710	1910

Type of Trip	Year 1	Year 2	Totals
Single Person		3	2130
3 Person	2		3820

SUPPLIES, MATERIALS, & OPS

Office Supplies and Services

All supplies described in this budget are charged at the indirect rates described below. All estimates of cost of supplies are based on a history of usage within Steward Observatory. A description of supplies includes office supplies (i.e. copy charges, pens, paper, toner for printers, filers, folders, etc…), small parts, laboratory supplies (unless notes elsewhere), graphic/photo, and other expendable materials, cost of technical and user documentation production, shipping and postage.

INDIRECT COSTS

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

The following table describes the University's Indirect rates for the period of performance of this proposal.

Table B6: UA Indirect Cost Schedule

	Year 1a (1/10-6/10)	Year 1b and beyond (7/10-6/12)
Indirect Rate	51.0%	51.5%

BUDGET PREPARATION

The UA Cost Element summary was

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