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

NASA Proposal Number

TBD on Submit

NASA PROCEDURE FOR HANDLING PROPOSALS

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

SECTION I - Proposal Information

Principal Investigator	E-mail Address	Phone Number
Drew Miles	**drewmiles@caltech.edu**	**626-395-8493**

Street Address (1)	Street Address (2)
1200 E California Blvd	**MC 290-17**

City	State / Province	Postal Code	Country Code
Pasadena	**CA**	**91125-0001**	**US**

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

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 / 2024	**12 / 31 / 2027**	**3,308,972.00**	**856,117.00**	**954,998.00**	**904,290.00**	**593,567.00**	**0.00**

SECTION II - Application Information

NASA Program Announcement Number	NASA Program Announcement Title
NNH22ZDA001N-APRA	**D.3 Astrophysics Research and Analysis**

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

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

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

International Participation	Type of International Participation
No	

SECTION III - Submitting Organization Information

UEI	DUNS Number	CAGE Code	Employer Identification Number (EIN or TIN)	Organization Type
U2JMKHNS5TG4	**009584210**	**80707**		**8H**

Organization Name (Standard/Legal Name)	Company Division
California Institute of Technology	

Organization DBA Name	Division Number
CALTECH	

Street Address (1)	Street Address (2)
1200 E CALIFORNIA BLVD	

City	State / Province	Postal Code	Country Code
PASADENA	**CA**	**91125**	**USA**

SECTION IV - Proposal Point of Contact Information

Name	Email Address	Phone Number
Drew Miles	**drewmiles@caltech.edu**	**626-395-8493**

SECTION V - Certification and Authorization

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

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

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

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

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

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

FORM NRESS-300 Version 8.3 03/22/2022

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit
Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**	

SECTION VI - Team Members

Team Member Role	Team Member Name	Contact Phone	E-mail Address	
PI	**Drew Miles**	**626-395-8493**	**drewmiles@caltech.edu**	
Organization/Business Relationship		UEI	DUNS No.	CAGE Code
California Institute of Technology		**U2JMKHNS5TG4**	**009584210**	**80707**
International Participation	U.S. Government Agency		Total Funds Requested	
No			**0.00**	
Team Member Role	Team Member Name	Contact Phone	E-mail Address	
Co-I	**Christopher Martin**	**626-395-4243**	**cmartin@srl.caltech.edu**	
Organization/Business Relationship		UEI	DUNS No.	CAGE Code
California Institute of Technology		**U2JMKHNS5TG4**	**009584210**	**80707**
International Participation	U.S. Government Agency		Total Funds Requested	
No			**0.00**	
Team Member Role	Team Member Name	Contact Phone	E-mail Address	
Co-I	**James Tutt**	**814-865-6338**	**jht12@psu.edu**	
Organization/Business Relationship		UEI	DUNS No.	CAGE Code
Pennsylvania State University		**NPM2J7MSCF61**	**003403953**	**7A720**
International Participation	U.S. Government Agency		Total Funds Requested	
No			**0.00**	
Team Member Role	Team Member Name	Contact Phone	E-mail Address	
Co-I/Institutional PI	**Randall McEntaffer**	**814-863-7350**	**rlm90@psu.edu**	
Organization/Business Relationship		UEI	DUNS No.	CAGE Code
Pennsylvania State University		**NPM2J7MSCF61**	**003403953**	**7A720**
International Participation	U.S. Government Agency		Total Funds Requested	
No			**0.00**	

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

SECTION VII - Project Summary

tREXS-2: The Rockets for Extended-source X-ray Spectroscopy is a successor proposal to a current NASA APRA award that uses a suborbital grating spectrograph to detect emission from faint, diffuse, X-ray-emitting astrophysical plasmas. The spectrograph uses passive, mechanical focusing optics to enable the field of view and produce a ≈2' 1D focus, modules of co-aligned X-ray reflection gratings, and an extended, ≈250 sq. cm focal-plane array of CMOS X-ray detectors. tREXS-2 will continue development of the existing payload, adding additional instrument channels (from two to four, doubling the collecting area), upgrading the reflection gratings to both improve performance and raise the TRL of gratings being developed for future missions, continuing development of subsystems applicable to future sounding rocket missions, and achieving new science observations of supernova remnants and the soft-X-ray background.

This proposal seeks funding for two additional flights, one in 2024 and one in 2026. The 2024 flight will add a third channel to the existing, two-channel instrument and will target a supernova remnant, allowing the first high(er)-resolution observation of a specific region from the remnant. After flight-proving a small-format fine-guidance startracker in the 2024 flight, the 2026 flight will add a fourth instrument channel, replacing the standard startracker used for celestial sounding rocket flights. The 2026 flight will target an enhancement to soft-X-ray background, revealing the different components contributing to emission in those regions and beginning to constrain galactic halo emission. With sensitivity to line emission across the soft-X-ray band, including the ability to separate the forbidden and resonance transitions in the O-VII triplet, tREXS-2 will provide new insight into the content, temperature, and density of these hot plasmas.

As we advance our understanding of these astrophysical plasmas and continue to develop technologies and instrument concepts for future missions, we will prioritize training early-career researchers and outreach opportunities to increase exposure to our field for underrepresented groups. We will continue to heavily involve graduate students, undergraduates, and early-career scientists and engineers to both learn from more experienced project personnel and apply their knowledge and skills in leadership roles throughout this program.

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

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

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

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 : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

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 : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit
Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**	

SECTION IX - Program Specific Data

Question 1 : Short Title:

Answer: tREXS-2

Question 2 : Type of institution:

Answer: Educational Organization

Question 3 : Additional Institution Classification

Answers :

Question 4 : 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 5 : Is this Federal government organization a different organization from the proposing (PI) organization?

Answer: N/A

Question 6 : Does this proposal include the use of NASA-provided high end computing (HEC)?

Answer: No

Question 7 : HEC Request Number

Answer:

Question 8 : Research Category:

Answer: 7) Flight investigation including: suborbital (e.g., airplane, balloon, sounding rockets), orbital (e.g., ISS), or beyond (e.g., Moon, Mars)

Question 9 : Flight Services

Answer: No

Question 10 : Team members not confirmed via NSPIRES

Answer:

Question 11 : Does this proposal contain 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 12 : I have identified the export-controlled material in this proposal.

Answer: N/A

Question 13 : 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 14 : Does the proposed work include any involvement with collaborators in China or with Chinese organizations, or does the proposed work include activities in China?

Answer: No

The National Environmental Policy Act (NEPA) obligates NASA to consider the potential environmental effects of proposed projects, including those that NASA funds which are implemented by grantees. The majority of grant-related activities are categorically excluded as research and development projects that do not pose adverse environmental impacts. These are covered by a NASA Grants Record of Environmental Consideration (REC) available at https://www.nasa.gov/nepa/grants. The following questions enable NASA to confirm that your proposed activity falls within this blanket REC. Proposals that are not covered will require additional NEPA analysis if selected (e.g., filling out an Environmental Checklist) or the completion of NASA's Executive Order (EO) 12114 Checklist for an activity to be conducted abroad. "Yes"responses are not selection criteria, however, if a "Yes" response is marked, proposers should consider NEPA and/or EO compliance in cost and schedule estimates.

Question 15 : Would the proposal involve any activity that includes: a. Construction of new facilities or modification to the footprint of an existing-facility, or b. Ground disturbance (e.g., excavation, clearing of trees, installation of equipment, etc.), or c. Outdoor discharges of water (e.g., waste water runoff), air emissions (e.g., ozone-depleting substances) or generation of noise exceeding 115 dBA (excluding those associated with aircraft operations)?

Answer: No

Question 16 : Would the proposal involve any field activity that would: a. Release equipment (e.g., dropsondes, sensors, etc.) or chemicals (e.g., dyes, tracers, etc.) into the air, bodies of water or on the ground, or b. Release a parachute or use equipment that would not be recovered, or c. Involve equipment or a payload that contains hazardous (e.g., petroleum, hypergols, oxidizers,solid propellants, etc.) or radioactive materials?

Answer: No

Question 17 : Would the proposal involve the launch of a payload, equipment, or instrument (e.g., via launch vehicle, sounding rocket, balloon, etc.)?

Answer: Yes

Question 18 : Would the proposal involve any activity to be conducted outside the United States or its territories excluding travel for meetings or conferences?

Answer: No

Question 19 : Comments

Answer:

Question 17: Proposal is for a suborbital rocket instrument that would launch on sounding rockets supported by NASA's Sounding Rockets Program Office.

Question 20 : Does this proposal contain a citizen science component?

Answer: No

High Impact-High Risk: This year SMD will collect information from proposers and reviewers to assess (intellectual) risk and impact of ROSES proposals. Although generally not part of the peer review process, these are programmatic considerations that may be taken into account by the selection official. For the purposes of this question, the definitions are as follows: A high impact research project is one in which, if confirmed/successful, would have a substantial and measurable effect on current thinking, methods or practice. A high-risk research project tests novel and significant hypotheses for which there is scant precedent or preliminary data or that are counter to the existing scientific consensus. This type of risk is different from implementation risk which refers to the likelihood that the proposed research can be successfully conducted as proposed.

Question 21 : The proposed work is both of high intellectual risk and would be of high impact

Answer: No

Question 22 : Risk/Impact Explanation

Answer:

Question 23 : AI or ML?

Answer: No

Question 24 : Would the results of this proposal advance the strategic objectives of more than one SMD Division?

Answer: Yes

Question 25 : If you checked yes, which Divisions?

Answers :

Astrophysics

Question 26 : Interdivisional Explanation

Answer:

Question 27 : Entry TRL

Answer: N/A

Question 28 : Exit TRL

Answer: N/A

Question 29 : Primary Technology

Answer: TX08 Sensors and Instruments

Question 30 : Technology Subarea(s)
Answers :

TX08.2 Observatories

Question 31 : Proposal Category

Answer: Suborbital/Suborbital-class Investigations

Question 32 : Suborbital Focus

Answer: Science Investigation

Question 33 : Suborbital platform

Answer: Sounding rocket

Question 34 : Proposal Type

Answer: X-ray

Question 35 : Lab Astro Equipment Upgrade

Answer: N/A

Question 36 : RTF Application

Answer: Yes

Question 37 : Previous Support
Answers :

Yes, as a Co-I

Yes, but not in the above roles

Question 38 : Proposal Preparation Time

Answer: 100<=t<200

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

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	63,982.00	66,861.00	69,870.00	53,357.00	0.00	254,070.00
B. Direct Labor - Other Personnel	0.00	0.00	0.00	0.00	0.00	0.00
Total Number Other Personnel	0	0	0	0	0	0
Total Direct Labor Costs (A+B)	63,982.00	66,861.00	69,870.00	53,357.00	0.00	254,070.00
C. Direct Costs - Equipment	203,823.00	355,827.00	336,129.00	220,952.00	0.00	1,116,731.00
D. Direct Costs - Travel	13,409.00	8,564.00	14,481.00	9,249.00	0.00	45,703.00
Domestic Travel	13,409.00	8,564.00	14,481.00	9,249.00	0.00	45,703.00
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	501,830.00	469,549.00	423,365.00	264,785.00	0.00	1,659,529.00
Materials and Supplies	0.00	0.00	0.00	0.00	0.00	0.00
Publication Costs	2,000.00	2,000.00	2,000.00	2,000.00	0.00	8,000.00
Consultant Services	0.00	0.00	0.00	0.00	0.00	0.00
ADP/Computer Services	0.00	0.00	0.00	0.00	0.00	0.00
Subawards/Consortium/Contractual Costs	499,830.00	467,549.00	421,365.00	262,785.00	0.00	1,651,529.00
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	0.00	0.00	0.00	0.00	0.00	0.00
G. Total Direct Costs (A+B+C+D+E+F)	783,044.00	900,801.00	843,845.00	548,343.00	0.00	3,076,033.00
H. Indirect Costs	73,073.00	54,197.00	60,445.00	45,224.00	0.00	232,939.00
I. Total Direct and Indirect Costs (G+H)	856,117.00	954,998.00	904,290.00	593,567.00	0.00	3,308,972.00
J. Fee	0.00	0.00	0.00	0.00	0.00	0.00
K. Total Cost (I+J)	856,117.00	954,998.00	904,290.00	593,567.00	0.00	3,308,972.00
Total Cumulative Budget						3,308,972.00

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2024	**12 / 31 / 2024**	**Project**	**1**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Martin, Christopher	**Co-I**	**0.00**				**2,819.00**	**677.00**	**3,496.00**
Miles, Drew	**PI**	**0.00**				**48,767.00**	**11,719.00**	**60,486.00**
							Total Key Personnel Costs	**63,982.00**

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)	**63,982.00**

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit
Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**	

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2024	**12 / 31 / 2024**	**Project**	**1**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
1	**Fabrication Labor**	**92,921.00**
2	**Travel Related to Fabrication**	**61,102.00**
3	**Materials for Fabrication**	**49,800.00**
	Total Equipment Costs	**203,823.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including U.S. Territories and Possessions)	**13,409.00**
2. Foreign Travel (Including Canada and Mexico)	**0.00**
Total Travel Costs	**13,409.00**

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 : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2024	**12 / 31 / 2024**	**Project**	**1**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**2,000.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**499,830.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
8. Other:	**0.00**
9. Other:	**0.00**
10. Other:	**0.00**
Total Other Direct Costs	**501,830.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**783,044.00**

H. Indirect Costs

	Indirect Cost Rate (%)	**Indirect Cost Base ($)**	Funds Requested ($)
Modified Total Direct Costs	**70.00**	**104,391.00**	**73,073.00**
Cognizant Federal Agency: **Office of Naval Research**		Total Indirect Costs	**73,073.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**856,117.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**856,117.00**

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2025	**12 / 31 / 2025**	**Project**	**2**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Martin, Christopher	**Co-I**	**0.00**				**2,946.00**	**708.00**	**3,654.00**
Miles, Drew	**PI**	**0.00**				**50,961.00**	**12,246.00**	**63,207.00**
							Total Key Personnel Costs	**66,861.00**

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)	**66,861.00**

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2025	**12 / 31 / 2025**	**Project**	**2**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
1	**Materials for Fabrication**	**144,784.00**
2	**Fabrication Labor**	**211,043.00**
	Total Equipment Costs	**355,827.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including U.S. Territories and Possessions)	**8,564.00**
2. Foreign Travel (Including Canada and Mexico)	**0.00**
Total Travel Costs	**8,564.00**

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 : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2025	**12 / 31 / 2025**	**Project**	**2**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**2,000.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**467,549.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
8. Other:	**0.00**
9. Other:	**0.00**
10. Other:	**0.00**
Total Other Direct Costs	**469,549.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**900,801.00**

H. Indirect Costs

	Indirect Cost Rate (%)	**Indirect Cost Base ($)**	Funds Requested ($)
Modified Total Direct Costs	**70.00**	**77,425.00**	**54,197.00**
Cognizant Federal Agency: **Office of Naval Research**		Total Indirect Costs	**54,197.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**954,998.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**954,998.00**

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit
Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**	

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2026	**12 / 31 / 2026**	**Project**	**3**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Martin, Christopher	**Co-I**	**0.00**				**3,078.00**	**741.00**	**3,819.00**
Miles, Drew	**PI**	**0.00**				**53,254.00**	**12,797.00**	**66,051.00**
							Total Key Personnel Costs	**69,870.00**

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)	**69,870.00**

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2026	**12 / 31 / 2026**	**Project**	**3**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
1	**Materials for Fabrication**	**38,000.00**
2	**Fabrication Labor**	**220,539.00**
3	**Travel Related to Fabrication**	**77,590.00**
	Total Equipment Costs	**336,129.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including U.S. Territories and Possessions)	**14,481.00**
2. Foreign Travel (Including Canada and Mexico)	**0.00**
Total Travel Costs	**14,481.00**

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 : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2026	**12 / 31 / 2026**	**Project**	**3**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**2,000.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**421,365.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
8. Other:	**0.00**
9. Other:	**0.00**
10. Other:	**0.00**
Total Other Direct Costs	**423,365.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**843,845.00**

H. Indirect Costs

	Indirect Cost Rate (%)	**Indirect Cost Base ($)**	Funds Requested ($)
Modified Total Direct Costs	**70.00**	**86,351.00**	**60,445.00**
Cognizant Federal Agency: **Office of Naval Research**		Total Indirect Costs	**60,445.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**904,290.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**904,290.00**

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit
Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**	

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2027	**12 / 31 / 2027**	**Project**	**4**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Martin, Christopher	Co-I	0.00				3,078.00	740.00	3,818.00
Miles, Drew	PI	0.00				39,941.00	9,598.00	49,539.00
							Total Key Personnel Costs	53,357.00

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)	53,357.00

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2027	**12 / 31 / 2027**	**Project**	**4**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
1	**Materials for Fabrication**	**30,900.00**
2	**Fabrication Labor**	**190,052.00**
	Total Equipment Costs	**220,952.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including U.S. Territories and Possessions)	**9,249.00**
2. Foreign Travel (Including Canada and Mexico)	**0.00**
Total Travel Costs	**9,249.00**

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 : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
01 / 01 / 2027	**12 / 31 / 2027**	**Project**	**4**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**0.00**
2. Publication Costs	**2,000.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**262,785.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
8. Other:	**0.00**
9. Other:	**0.00**
10. Other:	**0.00**
Total Other Direct Costs	**264,785.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**548,343.00**

H. Indirect Costs

	Indirect Cost Rate (%)	**Indirect Cost Base ($)**	Funds Requested ($)
Modified Total Direct Costs	**70.00**	**64,606.00**	**45,224.00**
Cognizant Federal Agency: **Office of Naval Research**		Total Indirect Costs	**45,224.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**593,567.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**593,567.00**

PI Name : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

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 ($)	Funds Requested ($)
Miles, Drew	**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 : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

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 U.S. Territories and Possessions)	**0.00**
2. Foreign Travel (Including Canada and Mexico)	**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 : **Drew Miles**	NASA Proposal Number
Organization Name : **California Institute of Technology**	TBD on Submit

Proposal Title : **tREXS-2: The Rockets for Extended-source X-ray Spectroscopy**

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**
8. Other:	**0.00**
9. Other:	**0.00**
10. Other:	**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**

tREXS-2: The Rockets for Extended-source X-ray Spectroscopy

A proposal in response to:
Solicitation NNH22ZDA001N-APRA
ROSES 2022
Astrophysics Research and Analysis
Suborbital investigations

Submitted by:
California Institute of Technology

Period of Performance:
01/01/2024 – 12/31/2027

PI: Drew M. Miles
Co-I: D. Christopher Martin
Co-I: Randall McEntaffer, Penn State University
Co-I: James Tutt, Penn State University

December 15, 2022

Table of Contents

1 Proposal Summary

The Rockets for Extended-source X-ray Spectroscopy grating spectrograph is designed to observe the faint, soft-X-ray emission from extended astrophysical plasmas [21]. This program (tREXS-2), a continuation of a previous award, will make observations of emission from a ≈10 deg^2 region of the Vela supernova remnant (SNR) and (relatively) bright enhancements in the soft-X-ray background with higher spectral resolution than ever before. With sensitivity to line emission across the soft-X-ray band, including the ability to separate the forbidden and resonance transitions in the O-VII triplet, tREXS-2 will provide new insight into the content, temperature, and density of these hot plasmas.

The tREXS-2 program develops, tests, and flight validates key grating technologies and science strategies for future orbital-class X-ray missions. The first flight of this instrument, in late 2022, saw the first space demonstration of modules of aligned X-ray gratings fabricated with modern techniques, providing a pathway to developing and verifying high-performance grating arrays for future X-ray missions, a technology gap that must be address to enable future NASA astrophysics missions.[1]. This program will double the total number of gratings used in the instrument (to 152) and will fly four co-aligned modules of gratings, the most representative implementation of large-mission grating arrays that will have flown in space. In addition, tREXS-2 further matures an instrument concept that can help advance key science objectives in the most recent decadal survey. The >10 deg^2 field of view (FOV) and moderate spectral resolution (R > 40, with the potential to achieve R ≈ 100 in an orbital variant) provides an ideal instrument to map the structure of the Milky Way's hot halo with unprecedented resolving power.

This program will continue the development of the suborbital spectrograph, improving from two spectrograph channels to four and upgrading the instrument gratings and readout electronics to further improve performance. These upgrades will more than double the effective collecting area and improve the instrument's sensitivity to faint sources by over an order of magnitude. The flight program is built around two flights over the 4-year study. First, we will add a third spectrograph channel at the outset of the award and launch the first flight of tREXS-2 in 2024. We will then take two years to upgrade instrument components and add a fourth channel before the second flight, in late 2026. These launches will target compelling sources of soft-X-ray emission that are best observed by instruments with large FOVs and will offer an instrument sensitive to the line emission that dominates the flux from such sources.

As we advance our understanding of these astrophysical plasmas and continue to develop technologies and instrument concepts for future missions, we will prioritize training early-career researchers and outreach opportunities to increase exposure to our field for underrepresented groups. We will continue to heavily involve graduate students, undergraduates, and early-career scientists and engineers to both learn from more experienced project personnel and apply their knowledge and skills in leadership roles throughout this program.

2 tREXS-2 Relevance and Impact

2.1 tREXS-2 F1 Science Objectives

The main science goal of the first flight of this program (tREXS-2 F1) is to characterize diffuse soft-X-ray emission from the Vela SNR. Vela is a typical shell-type, middle-aged SNR located at a distance of ≈250 pc with an angular diameter of ≈8° [6]. Its relatively large apparent size, high surface brightness, and low intervening hydrogen column density make it an ideal target for investigating the physics of SNRs. The majority of X-ray emission is due to post-shock, interstellar-medium-dominated cooling plasma, but Vela also exhibits a wealth of structure including ejecta

[1] https://apd440.gsfc.nasa.gov/technology.html

bullets [2, 7] and a complex pulsar wind nebula [25].

Diffuse emission from some sections of Vela has been characterized by sounding rockets [24, 9, 4] and several space telescopes: Einstein [12], ROSAT [2, 13], Chandra [3], XMM-Newton and Suzaku [7], and the HaloSat CubeSat [26]. Most authors find that ionization equilibrium conditions exist [12, 13], whereas others find non-equilibrium or a combination of a equilibrium and non-equilibrium conditions to best describe the detected emission [26]. In both cases, various temperature models and uncertainty around the prevalence of a second temperature component exist.The morphology of Vela suggests that the local interstellar medium (ISM) has been swept up by the SN blast wave or the precursor wind into a nearly spherical zone of interaction. Shock-heated plasmas in this zone reach collisional-ionization equilibrium (CIE) on a timescale that is inversely proportional to density. Therefore, denser regions reach equilibrium more quickly and cool more efficiently than rarefied regions that remain hot with higher-energy emission. This scenario is seen in other Type II shell remnants (e.g. the Cygnus Loop SNR [17, 16]). Our observation of Vela will be most sensitive to these plasmas and will provide a basis for comparison to other shell-type remnants.

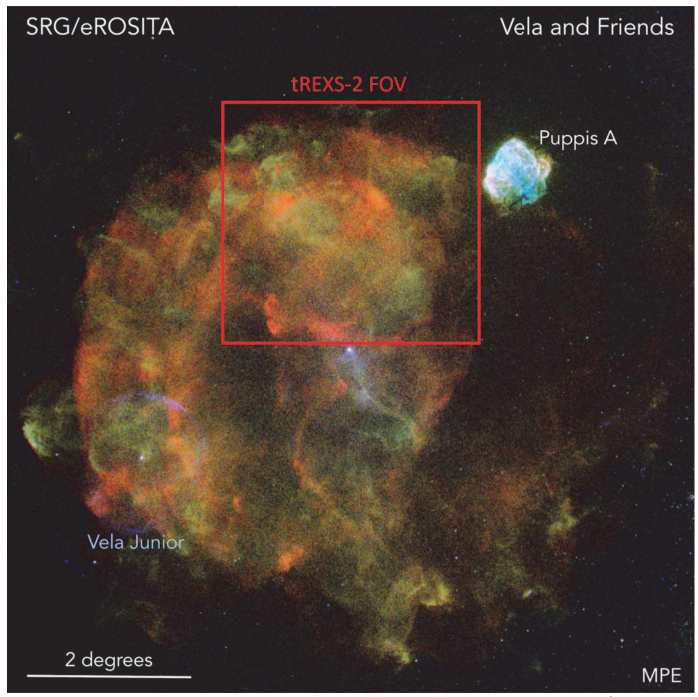


Figure 1: The Vela SNR as seen by eROSITA (credit: P. Predehl), with an overlay of the tREXS-2 FOV. tREXS-2 F1 will target the bright region in the north of the remnant while avoiding contamination from the pulsar near the center of the remnant and the Puppis A and Vela Jr. remnants.

The tREXS-2 FOV is $\approx$10 deg^2, as shown in Fig. 1. This FOV is optimal to capture the northern central region of the remnant without significant contamination from other distinct sources and emission mechanisms, and in particular avoids emission from the other nearby remnants. This area is relatively unexplored by existing missions and fills the FOV with some of the brightest emission in the entire remnant. The morphology evident in the eROSITA image suggests that our spectrum will be indicative of blast wave/ISM interactions at the rim of the Vela SNR, in general, and is unlikely to be contaminated by other bright sources. tREXS-2 differs from other large-FOV X-ray instruments in its spectral resolving power, offering an order-of-magnitude increase over ROSAT, HaloSat, and eROSITA, for example. The improved spectral resolution will allow for new diagnostic capabilities for Vela and similar X-ray-emitting plasmas.

We use two approaches to produce a simulated observation of the Vela SNR using the tREXS-2 spectrograph. First, we consider the calculated flux and best-fit spectral models produced in Silich et al. [26], which studied emission from Vela using the HaloSat CubeSat [11]. Silich et al. use offset HaloSat pointings to subtract off the contributions of Puppis A to Vela and separately fit emission from the Vela and Puppis SNRs. In our first approach to a simulated Vela observation, we take the calculated flux from Silich et al. and assume that flux to be uniformly distributed over the full remnant (a conservative assumption in our case, where the tREXS-2 FOV is centered on a relatively bright portion of the remnant). We then consider the best-fit models from Silich et al., a low-temperature component in CIE and a non-equilibrium ionization (NEI) high-temperature component, to be applicable to the region studied in our FOV. We use XSPEC [1] to generate source models based on the flux and best-fit model parameters. Finally, we fold the source model through our instrument response, re-binning the spectra for our spectral resolving power and using our instrument throughput to reduce the model spectrum to a simulated spectrum in detected counts as a function of wavelength, as seen in Fig. 2. For the model based on Silich et al.'s HaloSat observations, we use an absorbed flux of 1.6×10^{-8} erg cm^{-2} s^{-1}, scaled to our FOV, and apply the two-temperature absorbed CIE/NEI model found as the best fit for the HaloSat data: a TBabs*(apec + pshock) model with $N_H = 0.5 \times 10^{21}$ cm^{-2}, $kT_1 = 0.19$ keV, $kT_2 = 1.06$ keV, and an ionization timescale $\tau = 0.33 \times 10^{10}$ s cm^{-3} for the NEI component.

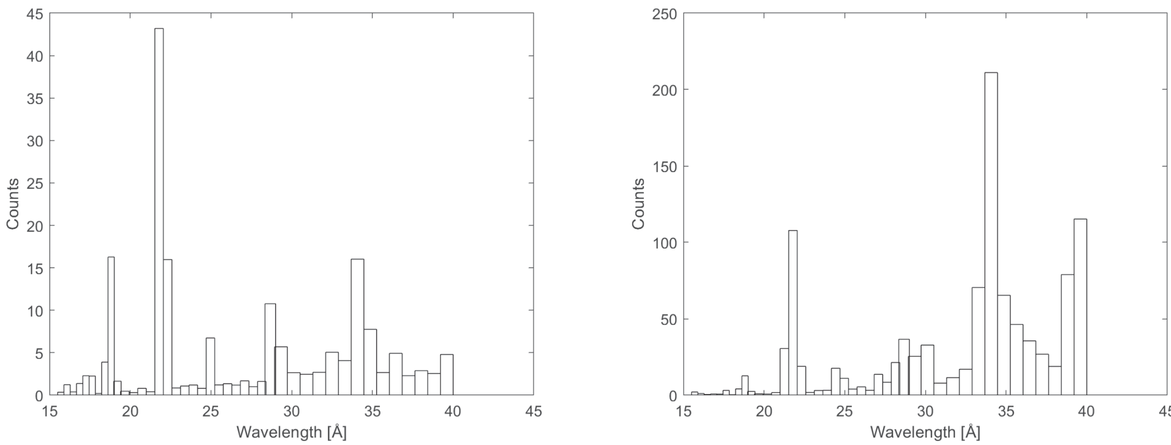


Figure 2: *Left*: A simulated tREXS-2 spectrum modeled after Silich et al's [26] HaloSat observation. *Right*: A simulated spectrum based on Lu & Aschenbach's [13] analysis of ROSAT observations.

Our second approach to producing a simulated observation of Vela uses data from the ROSAT mission. To estimate the flux in our FOV we use the HEASARC X-ray Background Tool, which calculates the count rates from the ROSAT All-Sky Survey corrected for our FOV, which is $\approx 3\times$ larger than ROSAT's. We then use these rates as inputs to WebPIMMS to get an integrated soft-X-ray flux for the targeted region. We again use XSPEC to create a model spectrum of Vela based on Lu & Aschenbach [13], which tiled multiple ROSAT pointings to create a spatially resolved model of Vela's emission. We focus on the Lu & Aschenbach pointing on the north-central region of the remnant, the most representative of our target FOV. We apply the best-fit model for that region, an absorbed two-temperature CIE model (TBabs*(apec+apec)) with $N_H = 0.17 \times 10^{22}$ cm^{-2}, $kT_1 = 0.12$ keV, and $kT_2 = 0.76$ keV at solar elemental abundances. The emission measure is scaled so that the integrated flux of the model in the appropriate band matches the result from WebPIMMS. The resulting spectrum was then convolved with the instrument response of the payload and binned to the spectral resolving power, as in the previous case.

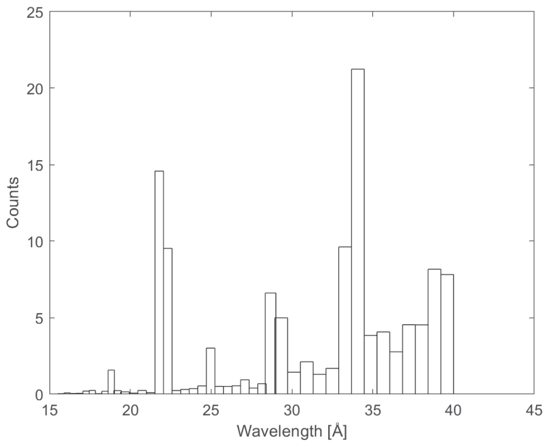
The simulated spectra for both Vela models are shown in Fig. 2, with the bandpass of interest determined by the dispersion of our gratings and the size of our detectors. There are stark contrasts between the two simulated spectra in both the number of detected events and the dominant emission features. In the simulated spectrum using the HaloSat source model, O VII is the dominant emission line (near 22 Å) and we see a notable contribution from O VIII near 19 Å. In the simulation based on Lu & Aschenbach, the emission is dominated by lower energies, with C VI as the dominant line. In addition, there is virtually no O VIII component. The differences between the two models can be explained with two considerations. First, Silich et al. report a flux over the full remnant and in this simulation we take the emission to be uniform across the remnant, which is not the case in reality; instead, tREXS-2 F1 will specifically target a brighter-than-average region of Vela. This should mean that our expected count rate is higher than represented in the left side of Fig. 2 and potentially approaches the count rate from the Lu & Aschenbach model, which is a more similar pointing to the one we will target. Then, the Lu & Aschenbach model is dominated by a low-energy component, with their observed spectrum peaking at >30 Å, which explains the relative intensity at longer wavelengths. In either case, this observation would produce the highest-resolution spectrum ever achieved for this region and provide new constraints on the multiple components along the line of sight. In combination with higher resolution, the multiple ionization states allow for a more accurate determination of temperature than previous measurements and will provide insight into the potential departure from equilibrium.

2.2 tREXS-2 F2 Science Objectives

The scientific goal of the second flight of tREXS-2, tREXS-2 F2, is to detail the spectra of enhancements within the soft-X-ray background. The emission in the $\frac{1}{4}$-keV band from the ROSAT All-Sky Survey shows the presence for a local, unabsorbed component – the Local Hot Bubble (LHB) [14, 27, 28]. Toward higher galactic latitudes, the $\frac{1}{4}$-keV emission exhibits patchy enhancements that are several times brighter than observations near the galactic plane. The latitude of these enhancements, combined with shadowing observations [5, 29] suggest an origin in the galactic halo for this plasma; however, this contribution is spatially variable and has not been well studied.

Although there are a number of enhanced regions of soft X-ray emission on the sky, there are few detailed studies of these regions due to their low flux. The soft, diffuse nature of the background makes it difficult to observe unless the instrument has a large FOV, which typically means low spatial and spectral resolutions. The Draco region of the sky is one such region that is enhanced significantly in the $\frac{1}{4}$ keV band but not in the $\frac{3}{4}$ keV band, allowing for better characterization of the lower temperature emission, given the appropriate spectral resolving power and line sensitivity. The most in-depth spectral study was performed by a suborbital rocket instrument [18]. The rocket payload used a CCD to measure the spectrum from a large, 30° x 60° region of Draco centered at l = 96.3°, b = +48.1°. Spectral fits were performed concurrently with ROSAT PSPC data from three pointings within the rocket FOV. The modest CCD spectral resolution (<10) could not resolve any lines, but a good fit was obtained for a thermal model at 0.13 keV with solar abundances. Contributions from a second temperature component were attempted, but not found statistically significant. This finding is contradictory to previous studies that found significance in two temperature components throughout the background [8, 23]. Therefore, there remain unanswered questions about this region: Is Draco an example of a rare region with only one temperature component? Is there any halo emission in this direction? Is another component present but not detectable due to the low resolution CCD spectrum?

The primary science objective of tREXS-2 F2 is to revisit the Draco region of the soft-X-ray background and produce a high-quality spectrum capable of addressing these outstanding questions. The FOV of the payload is much smaller than the previous PSU mission and will therefore concentrate on a bright knot within the same region: a pointing centered on l = 92.5°, b = +43.25°. To model the emission from this region we chose two approaches based on prior observations. The first is the one-temperature best-fit model from the PSU CCD rocket study [18], with kT = 0.13 keV, emission measure = 0.0075 cm^{-6} pc, and $N_H = 0.056 \times 10^{21}$ cm^{-2}. The second model selected was a two-temperature model consistent with previous studies [8]: an unabsorbed LHB component with $kT_1 = 0.11$ keV and emission measure = 0.0022 cm^{-6} pc, and an absorbed component with $kT_2 = 0.18$ keV, emission measure = 0.0058 cm^{-6} pc, and NH = 0.45×10^{21} cm^{-2}. We again used XSPEC to generate the source models and passed each of these models through the tREXS-2 payload response, with the resulting spectra shown in Fig. 3.



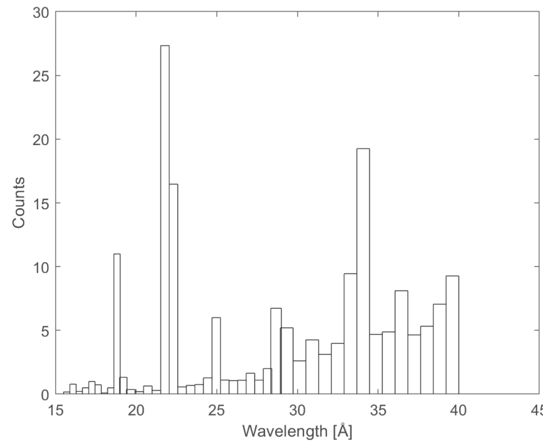


Figure 3: *Left:* A simulated spectrum of the Draco enhancement following the one-temperature model used by Mendenhall et al. [18]. *Right:* A simulated Draco spectrum using a two-temperature model consistent with Garmire et al. [8].

Of note in the simulated Draco observations is the obvious presence of O VIII in the two-temperature model and its absence in the one-temperature model. If a higher-temperature components is present, then we will detect >10 counts in O VIII and >40 counts in O VII thus providing significant detections of these lines and the presence of a plasma distinct from the low-temperature LHB contribution. Using our observed data, we will compare fits of single- and two-temperature models to determine the significance of the second component. The ratio of the distinct O VII and O VIII lines, combined with CIE conditions and appropriate emission measures for each component, will determine the temperature. The He-like O-VII triplet can also be used to constrain temperature and density. The line detection in C VI will also assist with constraining these spectral fits at somewhat lower energies and providing insight on relative abundances. A detection of the hot component will demonstrate a halo contribution to this region of the background while fits consistent with a single, low-temperature component will verify the previous PSU rocket observation, albeit at a smaller spatial scale. Such an observation is a natural progression toward our greater understanding of the enhancement in Draco and the soft-X-ray background in general, and to what extent emission from our galaxy's halo factors into X-ray observations.

Another region that is relatively bright in the $\frac{1}{4}$-keV band with decreasing brightness at $\frac{3}{4}$ keV is in Eridanus. This region has been well studied with ROSAT [10, 27], but the poor spectral resolving power (22 degrees of freedom from 0.1-2.0 keV) provides poor constraints on modeling. Multiple-component spectral fits have been attempted to account for contributions from various sources including the LHB, the halo, the cosmic background, and a source in Eridanus, but the small number of resolution bins are not capable of detecting any lines, and therefore ratios, or determining the most likely number of components with any significance. A high-resolution spectrum will assist in determining how many contributions are likely and their relative temperatures, as with the Draco observation. In the case of Eridanus, there is some disagreement to its nature and origin. Snowden et al. [27] argue that the enhancement corresponds to a low-column-density region that allows us to see halo gas at the same temperature. Guo et al. [10] suggest that the enhancement is X-ray gas in the Orion-Eridanus superbubble, which may be interacting with the LHB. An observation with higher spectral resolving power is necessary to adequately constrain temperature components and shed light on the situation. As an alternative to Draco (based on launch site availability), we can observe a bright $\frac{1}{4}$-keV enhancement in the Eridanus region with tREXS-2 F2 and help distinguish the components contributing to emission in this region.

In addition to addressing questions pertaining directly to the nature of Draco and Eridanus, tREXS-2 F2 will begin to elucidate spectral characteristics of the soft-X-ray background in general and, in particular, potential contributions from the galactic halo. Although ubiquitous, the soft-X-ray background has been poorly studied spectrally. Nearly all observations have relied on coarse proportional-counter spectra that provide few bins, yet are fit with complex plasma models that are dominated by discrete spectral lines.To truly characterize the hot plasma that surrounds our solar system we require higher-resolution spectra that detect the dominant lines and use them to constrain the plasma parameters. The simulations above assume that the existing coarse spectral fits are accurate, but there exists a possibility that these instruments were not sensitive to other spectral components or statistically incapable of determining their presence. Having a line-sensitive payload such as tREXS-2 opens up new exploration space to find the true spectrum of the soft-X-ray background. In particular, we note that in each case our models indicate an insubstantial contribution from the intercombination transition in O VII, so that the instrument's resolving power can safely separate the resonance and forbidden transitions and provide both temperature and density information on the observed fields. At the end of this investigation we will have gained additional insight into the nature of the soft-X-ray background, while also providing the community with an instrument design capable of unraveling further details with future launches and orbital instrument adaptions.

2.3 Relevance to NASA

tREXS-2, a successor to a previous suborbital rocket investigation, continues to directly address high-priority areas in NASA astrophysics. This proposal will use its payload and series of launches to achieve science results, develop instruments and technology, and train future contributors to NASA missions over a multi-year program.

The report from the National Academy of Sciences for the 2020 decadal survey in astronomy and astrophysics, "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" (Astro2020) [22], outlines recommendations to guide the next several decades of astronomy research and development. The survey's proposed strategy touts ambitious science objectives to both push the limits on our knowledge of the Universe and to maximize the return from advancements in technology and instrumentation. To enable such revolutionary scientific advancements, the report asserts as a chief priority a "Great Observatories Mission and Technology Maturation Program" to invest in mission and technology development for future NASA probes and flagship missions. tREXS-2 aligns nicely with such a program, maturing an instrument concept that can directly address key science questions and serve as a pathfinder for future missions, providing an avenue to space-demonstrate high-performance grating technologies applicable to future missions, and training scientists and engineers for roles on future great observatories.

Among the key science questions posed by Astro2020 is the role that baryonic matter plays in galaxy evolution and where (and to what extent) that matter resides in our Universe. Astro2020's panel on galaxies discusses the importance of new, more advanced spectroscopic observations of galaxy halos, including our own, and prioritizes mapping the circumgalactic and intergalactic media (CGM and IGM, respectively) in emission across a range of wavelengths. After tREXS-2 F1 continues to mature the instrument, adds collecting area, and collects a new observation of the Vela SNR, the second flight will begin to probe the Milky Way CGM directly by observing enhancements to the soft-X-ray background that are thought to originate from our galaxy's halo. While we space-prove technology and mature the instrument concept, we will simultaneously directly address a key science area prioritized in Astro2020.

The tREXS design was conceived with an eye toward adaptability to an orbital format. While tREXS-2 itself will ultimately be a four-channel spectrograph, each optical channel operates independently and is integrated in a modular manner; the optics and grating modules can be fabricated with various combinations of dimensions and performance specifications without requiring a different manufacturing approach or impacting other channels. We can therefore manufacture new optics modules with different focal lengths, line-spread functions (LSFs), and physical footprints for a variety of spacecraft formats and instrument designs. Similarly, the same grating fabrication processes can be applied to smaller grating or gratings with different densities and facet angles. We will therefore leverage the advancements made in this program – both in terms of instrument and personnel development and in scientific results – to study an orbital variant that can map the entire soft-X-ray background and halo of our galaxy. In particular, we propose to study a specific adaption for this instrument concept for the NASA Pioneers program; after proving performance and capability on the rocket, we can refine the design to achieve higher spectral resolution (driven by resolving the intercombination transition in O VII) in an ESPA-class payload. Early designs indicate an ESPA-class SmallSat can achieve a comparable grasp as the full tREXS-2 instrument and a factor of two higher resolving power. We will continue to mature this concept through this award as the rocket instrument continues to develop and achieve science success.

In addition to the technology and instrument maturation and science significance, the third pillar of this program will be the training of students and early-career researchers. We will continue a long tradition of suborbital programs that place students in leadership roles and provide spaceflight experience for young scientists and engineers. The predecessor award was a primary focus of one astrophysics PhD (the PI of this proposal) and a second PhD expected next year. The project also provided the first post-graduate space-based instrument experience for four early-career technicians and engineers and served as the primary funding and research source for 10 undergraduate students across 6 different disciplines.

Finally, tREXS-2 will put into practice initiatives in response to Astro2020's report on the state of the profession. In an effort to use our program to help foster a diverse and inclusive work force and provide equitable access to our field, tREXS-2 will dedicate a small section of the payload for outreach. The predecessor award served as a launching point for Rockets for Inclusive Science Education (RISE), a year-long program aimed at providing high school students from underrepresented groups with opportunities to learn and grow as young scientists. RISE meets weekly during the academic year to engage secondary-school students in astronomy instrumentation projects including modeling rocket performance, basic Python coding, soldering, and electronics breadboarding. RISE culminates in the launch of student-built model rockets with small, functional instruments that the students program, recover, and analyze. As part of this proposal we will progress to the next phase of RISE: an opportunity for students to contribute to a small, standalone, ride-along payload to fly with future tREXS-2 flights. We plan for a small, $\approx$1U-sized payload to be isolated from the primary instrument and from NASA systems and placed in an otherwise unused portion of the payload. Successful RISE students will have the opportunity to collaborate on developing the 1U unit and can contribute small sensors and/or experiments that can reach space. While we will ensure that the subpayload has no interaction with or impact on the primary instrument and science objective, this effort can have a substantial impact on our efforts to engage the future leaders of our field.

3 The tREXS-2 Payload Design

The tREXS-2 science objectives will be achieved with a multi-channel grating spectrograph that consists of three primary elements: mechanical beam-shaping (MBS) modules, co-aligned stacks of X-ray reflection gratings, and an extended focal-plane camera. Each grating stack is aligned to a MBS module to form a two-component spectrograph channel and each spectrograph channel shares the full focal-plane camera.

3.1 Mechanical Beam Shapers

The ≈10 deg^2 FOV of the tREXS spectrograph is enabled by MBS modules that sculpt a converging beam from incident light. The MBS modules were selected following a trade study for the most optimal optical system to enable a large FOV, a ≈2' focus (required to achieve spectral resolving-power objectives), and a form factor and cost envelope consistent with a suborbital program. The passive-focusing MBS modules geometrically limit incident light so that a one-dimensional line focus is produced at a set 'focal length', defined for a MBS module as the distance to the plane at which each individual MBS aperture shares a common convergence.

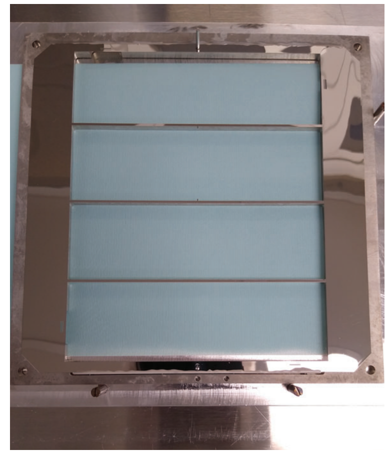


Figure 4: One of the 45 MBS plates used in the tREXS MBS modules, bonded to an Al support frame. The aperture slit positions and sizes converge from the first plate to the last, sculpting a converging beam. The blue backdrop is used to enhance contrast.

Each MBS module is composed of 45 individual plates, each of which contains 241 individual aperture slits. An individual plate is shown in Fig. 4, and a full tREXS-2 MBS module is shown in Fig. 5. The size and position of the aperture slits converge with each successive plate in the module so that the portion of incident beam that is allowed to pass completely through the MBS module is sculpted to match the designed convergence. Each of the 241 slit channels share a common convergence at a specified focal length, so that the line-spread function at the focal plane is a ≈2-arcminute superposition of 241 overlapping aperture channels. Arraying a series of individual aperture channels allows the overall instrument FOV and effective area to be increased, where each individual aperture channel acts independently of the rest and 'observes' a specific portion of the observation target, without degrading the focus.

3.2 Reflection-grating Modules

The reflection gratings used in the tREXS-2 spectrograph are a product of recent development efforts in nanofabrication techniques at the Penn State University (PSU) Nanofabrication Laboratory[2] [19, 20, 32]. With a relatively modest resolving power objective by modern grating standards, R ≈ 50, the tREXS-2 spectrograph utilizes fabrication techniques that maximize diffraction efficiency and serves as a technology demonstrator for next-generation X-ray reflection gratings. The grating fabrication process used for the current gratings follows the steps discussed in Miles et al. (2018) [20], with significant effort toward optimizing the electron-beam lithography (EBL) exposure and subsequent pattern-transfer processes [McCurdy et al. in progress]. Each grating is 107-mm wide, which matches the width of the sculpted beam exiting the MBS modules at the position of the grating modules, and 100-mm long, the longest reasonably achievable grating length on a 150-mm-diameter wafer (the largest standard wafer size that can be accommodated by the required tools at PSU's nanofabrication facility). Two 'master' gratings were fabricated at PSU and were then replicated via substrate-conformal imprint lithography (SCIL) by Philips SCIL Nanoimprint Solutions[3] [32]. The tREXS instrument design calls for 152 total gratings from two unique grating patterns, which have the same groove layout but opposing blaze directions. The flight gratings are then aligned into four modules of 38 gratings each, arranged to capture the full two-dimensional extent of the sculpted beam exiting the modules.

[2] https://www.mri.psu.edu/nanofabrication-lab

[3] https://www.scil-nano.com/

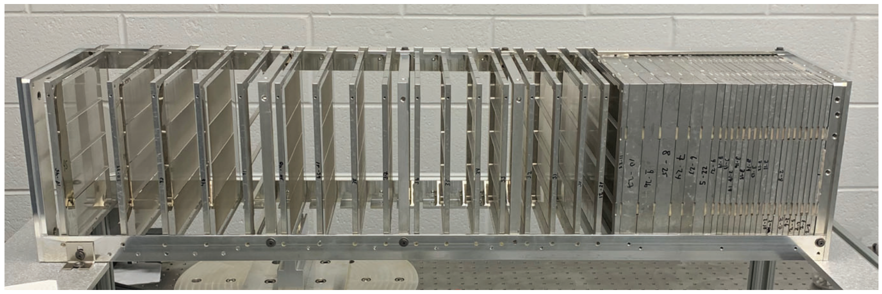


Figure 5: A tREXS-2 MBS module. X-ray light is incident at image right, where the individual MBS plates are more densely packed. As light travels through the module from right to left, the plate separation grows while the slit apertures and positions on each plate converge. Light that passes completely through the module without geometric occultation naturally matches the designed convergence and forms a one-dimensional line focus.

The tREXS-2 gratings were designed to maximize diffraction efficiency for specific wavelengths, with a blaze envelop centered around $n\lambda \approx 88$ Å. With the emission from target sources expected to be dominated by line emission from highly ionized C, N, and O, the tREXS spectrograph was designed to preferentially diffract to integer or half-integer orders for each relevant spectral transition while also ensuring focal-plane coverage sufficient to capture the blaze order and nearby orders at each wavelength. The dispersion-direction coverage of the focal-plane camera covers ≈ 51 – 121 Å, with diffraction efficiency maximized toward the center of that range. For O VII, for example, the notional blaze order is $n_b = 4$, and the focal plane camera captures orders $n = 3$ – 5.

3.3 Focal-plane Camera

Extended focal-plane coverage, >230 cm^2, is required to read out the full spectra produced by the multi-channel tREXS spectrograph. Selected for both their ability to cover the tREXS focal plane and their performance specifications, 11 Teledyne/e2v CIS113 CMOS [21, 30, 31] sensors are arrayed in a one-dimensional column. Each CIS113 will capture the spectrograph's full-dispersion direction spectral extent (≈65 mm) with their ≈74-mm active area along that dimension, and the array of 11 devices will cover nearly the full cross-dispersion extent of the tREXS spectra.

In addition to the focal-plane coverage allowed from their 3-side-buttable package design, the CIS113 sensors are capable of low noise (<3 e^-) and readout capabilities suitable for the rocket-based observation. Each individual CIS113 sensor has a detector carrier board (DCB) that connects to the pins native to each sensor and interfaces directly with the detector. The DCBs, which are housed inside a vacuum chamber in flight, are connected to vacuum-transition boards (VTBs), which provide an interface between the tREXS electronics section and the sealed detector chamber. The non-vacuum side of the VTBs connects to a tREXS camera readout (TCR) stack, which provide power and readout capabilities to the detectors. The TCR stacks relay data from the detectors to an RTD Embedded Technologies Intelligent Data Acquisition Node[4] (IDAN) that houses an on-board computer to store detector data, perform on-board data processing, and interface with the rocket telemetry system. During the rocket flight, the on-board analysis on the IDAN system identifies and passes X-ray events through the telemetry system to provide real-time information on flight performance. Full detector frames, read out every ≈15 s, are stored on the flight computer and retrieved after payload recovery to obtain the full flight data set. A more comprehensive description of the focal plane camera, including the flight electronics developed at PSU, is given in [30].

[4] `https://www.rtd.com/IDAN/idan_desc.htm`

3.4 Full tREXS Instrument

The previously discussed spectrograph components come together to form the tREXS-2 primary instrument. To allow the spectrograph to function properly and achieve the science objectives, however, there are several supporting features of the tREXS-2 payload. The focal-plane camera is housed in its own separate vacuum section, the "detector chamber", to isolate the cold detectors (operated at ≈200 K during flight) from the main payload during various ground testing and the rocket ascent and descent. The detector chamber contains a custom, internal, vacuum-compatible shutter door developed specifically for this payload through a collaboration with the engineers with the NASA Sounding Rockets Operations Contract (NSROC). The internal shutter door operates independently from the primary shutter door and opens as the instrument arrives on its observation target. The isolated detector chamber has a dedicated turbo pump that is integrated into the experiment electronics section and flies with the payload. A pull-away roughing line is connected to a roughing pump at the launch pad that allows the detector chamber to be actively pumped until the rocket leaves the launch rail, ensuring high-vacuum levels in the chamber and a safe environment for the cold focal-plane camera. The ground-based pumping system that attaches to the launch rail was developed for this payload and is serving as a baseline design for broad adaption into the NSROC support portfolio for other payloads.

Although the four-channel tREXS spectrograph design maximizes collecting area within the physical dimensions allowed by the rocket skins, the MBS layout does not allow for a traditional, aft-pointing NSROC star-tracking camera. tREXS-2 will therefore have a dedicated section forward of the instrument electronics that houses a side-looking star tracker. To ensure that the NSROC attitude-control system (ACS) can still achieve the pointing requirements for the tREXS-2 missions, a complementary aspect camera is integrated into the instrument design. The Stanford Photonics, Inc.[5] (SPI) camera used by tREXS-2 is based on a camera solution developed for NSROC and has a much smaller physical footprint than the NSROC-standard celestial star tracker. The smaller SPI camera is to be mounted on the aft end of the MBS modules and is aligned to the bore sight of our instrument. Pre-flight alignment will allow us to calculate the offset of the SPI (and spectrograph) relative to the side-looking star tracker that guides the ACS, and the offset can then be compensated for in flight. As the rocket slews to the observation target guided by the side-looking camera, a pointing algorithm developed for the SPI camera will provide feedback for fine guidance. The SPI camera, its pointing algorithm, and the system's interfacing with NSROC ACS will be demonstrated on tREXS-2 F1, whose three-channel spectrograph will allow for the traditional aft-facing star tracker as the primary pointing system, before becoming the primary system for the four-channel tREXS-2 F2.

A CAD draft of the full, four-channel tREXS-2 payload is shown in Fig. 6. A standard, aft-facing, 22-inch shutter door opens up in space to allow the four MBS channels to collect light from the target. An optics bulkhead that is isolated from the external rocket skins serves as the mechanical interface plate for the four MBS modules and corresponding grating modules. Attached to the optics bulkhead are two ≈20-inch-diameter internal skins that serve as the optical bench. The optical bench is mounted to the detector bulkhead, which also serves as the mechanical interface between the 22-inch external skins and the internal payload structure. The internal shutter door is built into the detector bulkhead and opens aftward to expose the detector chamber to the main payload bay. Forward of the detector chamber is the instrument electronics section, which is separated from the vacuum chambers via a vacuum interface plate and houses the detector readout electronics, on-board turbo pump, and all support electronics. Immediately foreward of the electronics section, which also serves as the forward transition from the payloads' 22-inch diameter

[5] http://stanfordphotonics.com/Products/products.htm

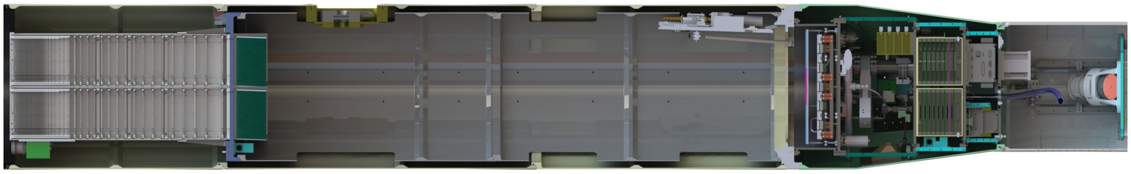


Figure 6: A CAD presentation of the full tREXS-2 payload. At image left, a 22-inch shutter door seals the entire science instrument until the payload reaches space. The optics portion of the instrument houses the four MBS modules and, on the fore side of an optics bulkhead, four corresponding grating modules. There is then 2 m of empty space over which the gratings disperse the spectral lines before reaching the focal plane. The detector chamber that houses the focal-plane camera includes an internal, vacuum-compatible shutter door (shown open in the image). Further forward of the isolated detector chamber are the instrument electronics, umbilicals that interface with NASA support systems, and a section dedicated to a side-looking star-tracking camera.

to the standard 17.26-inch diameter rocket fairing, is the dedicated section for the side-looking star tracker. This section, which is largely empty save for the side-looking camera, is where the RISE ride-along payload would reside.

4 State of the Payload Following 2022 Flight

This proposal is a successor program to a previous award. As such, the payload exists in a flyable state and there is a clear path forward for instrument upgrades and future flights. Currently, the tREXS instrument has two complete spectrograph channels, the full focal-plane camera, and all support electronics, hardware, and software systems in place.

4.1 MBS Modules

The tREXS MBS modules were designed as part of the primary instrument preceding the tREXS-1 flight. MBS plates, frames, and module housings were acquired for all four channels at the outset, but at this point only two channels have been fully assembled and integrated into the payload. An image of the two MBS modules integrated into the payload is shown on the left side of Fig. 7, compared to a CAD model of the full four-channel design at image right. Each of the two modules were self-aligned via a table-top alignment system, then aligned to the remaining instrument components during instrument assembly.

The MBS alignment scheme uses a series of laser and alignment features on the MBS plates to position each plate prior to fixing it into the MBS housing. As is visible in Fig. 4, there are alignment slots in each of the four corners of the MBS plates, and a small alignment 'tab' in the center slit on each plate. We use a set of five lasers, all pre-aligned to match the convergence of the MBS design, to position each plate. As can be seen in Fig. 8, each of the five lasers is read out with its own CCD camera, where we centroid the position of the laser to determine its location. As each plate is positioned using a long-travel linear stage (which indexes the plate positions along the optical axis) and a hexapod offering six degrees of freedom, the plate orientation is manipulated until the laser centroid returns to its reference position, indicating that plate is aligned to coordinate system defined by the aligned lasers. Each plate is then fixed in place with UV-curable epoxy before proceeding to the next plate.

4.2 Grating Modules

The tREXS flight gratings are carried on flat (<10-μm peak-to-valley), thin ($\approx$425 μm) fused-silica substrates. Each grating was coated with Ni, which allows for high reflectivity across the

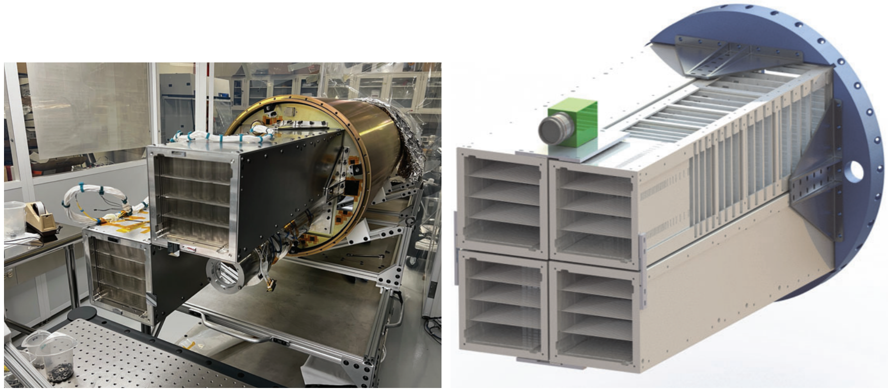


Figure 7: *Left:* The current state of the tREXS MBS modules. Two modules are installed and aligned into the instrument. *Right:* A CAD representation of the four tREXS MBS modules. Each module is mounted to a bulkhead that then mechanically mates to rocket skins. The four modules are mechanically coupled with brackets at their base and braces near the entrance apertures to prevent vibrational misalignments during the rocket launch. The small camera mounted on top of the MBS modules is a guidance camera used for fine pointing during the rocket flight.

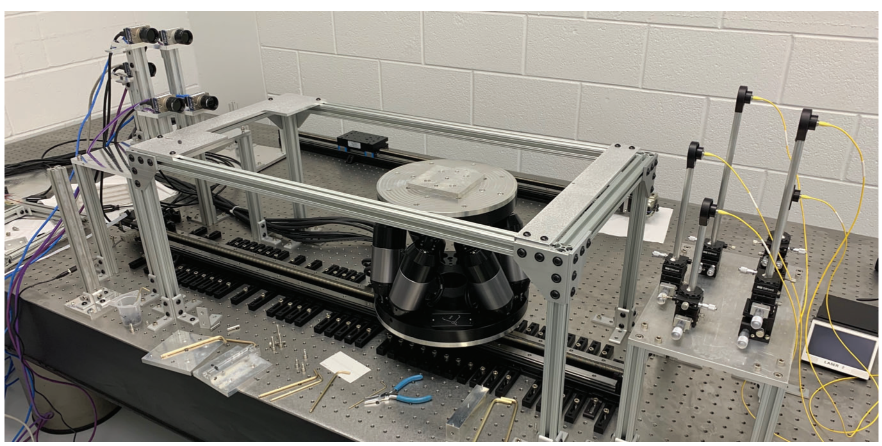


Figure 8: The tREXS MBS alignment setup. At image right are five co-aligned lasers, which are incident on five CCD detectors at image left. The platform in the center of the image support the MBS module housing, and the long-travel linear stage and six-axis hexapod (visible below the MBS platform) support individual plates during alignment.

tREXS soft-X-ray bandpass, and diced to a 100-mm × 109-mm rectangle. The substrate is slightly oversized in one dimension relative to the width of the grating pattern (107 mm) to allow for alignment spacers without interfering with the grating surface. Although the four-channel instrument was designed to use 152 total gratings, 200 replicas were produced to allow for margin on processing consumption and selection of the flight units.

A random sample of the flight gratings were selected for diffraction efficiency testing. The samples were transported to the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory, where a tunable X-ray monochromator allowed us to measure grating diffraction efficiency across our entire bandpass. The measured absolute diffraction efficiency of a representative grating sample averages ≈45% across our bandpass, lower than anticipated in comparison to comparable gratings [19, 32, 15]. We believe the reduced efficiency realized in the tREXS gratings is due to a combination of non-optimized thermal conditions during resist cure during the substrate imprint process and EBL field-stitch aberrations that caused conformality difficulties during the nanoimprint process. The resulting effect is that the replica gratings have a shallower facet angle and more rounded facet apexes than specifications. Though this does not impact the grating dispersion or instrument resolving power, the deviation from design in facet shape and angle cause the diffraction efficiency to be lower in the instrument configuration. We have collaborated with our collaborators at Philips SCIL Innovation, the team that performs the high-volume replication for tREXS, and identified the shortcomings that led to the defect in tREXS gratings. We anticipate that more carefully controlled and more thoroughly tested thermal conditions in future applications will avoid this issue and allow us to realize the specified groove profile.

Each of the tREXS spectrograph channels uses an array of 38 identical gratings. The gratings are aligned by precision-cut spacers that specify the separation between gratings and their roll and pitch alignments. Three one-mm-wide spacers are bonded to each grating, one each on the outer edges and one in the grating center, as indicated in the left side of Fig. 9. Yaw, x, and y alignment are constrained by the grating stack alignment hardware, which uses a 3-point precision mount. The stack alignment hardware is shown in the left side of Fig. 9, with a completed grating stack in the center of the figure and a stack integrated into a module housing on the right. Three complete grating stacks have been integrated into module housings, and two modules have been aligned and installed into the instrument; the third grating module is being stored until a third spectrograph channel is ready for implementation.

4.3 Focal-plane Camera

The full tREXS focal-plane camera and support electronics have been designed, built, and integrated into the instrument. The 11-detector focal-plane, shown in Fig. 10 provides >250 cm^2 of collecting area to capture the dispersed spectra from the multi-channel spectrograph. Every other CMOS sensor is flipped 180-degrees relative to its nearest neighbor to allow mechanical clearance for the DCBs and ribbon cables coming from each detector. The detectors are isolated in a dedicated vacuum chamber that is sealed on one side by the internal shutter door and on the other side by the vacuum-interface flange visible in Fig. 10. Two VTBs, sealed into the vacuum-interface flange with Arathane, provide a vacuum feedthrough for the readout electronics. Custom, free-standing Luxel[6] optical-blocking filters (OBFs) are installed just in front of the detectors. The tREXS OBF is a single, modular unit with three filters, each of which are 150-nm Al supported by a 95% clear-aperture Ni mesh.

4.4 2022 Flight of tREXS-1

The current iteration of tREXS, tREXS-1, launched successfully from White Sand Missile Range (WSMR) in late 2022. The two-channel spectrograph observed the soft-X-ray emission from the

[6]https://luxel.com/

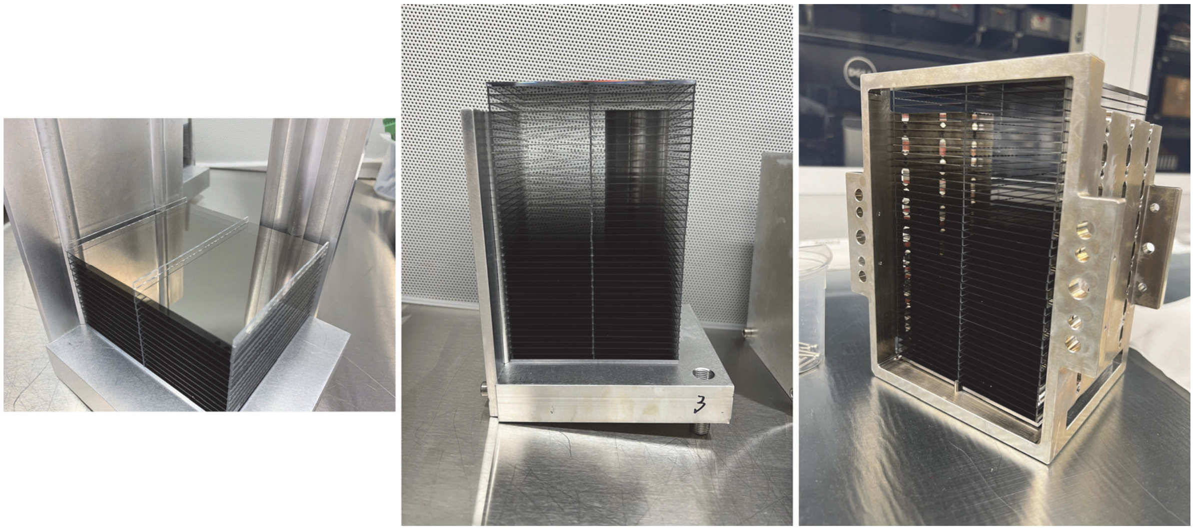


Figure 9: *Left*: A tREXS alignment jig with a partially populated grating stack. The three reference bevels constrain the grating position in three dimensions, with the remaining three constrained by the spacers bonded to each substrate. *Center*: A complete grating stack with 38 flight gratings and a thick reference substrate on the top and bottom of the stack. *Right*: A grating stack integrated into a tREXS module. The module affixes to the payload's optics bulkhead using the flared mounting feet seen on the module.

Cygnus Loop SNR, for which tREXS can capture the entire remnant with a single pointing. Although there was an anomaly with telemetry during flight that prevented real-time data transmission, the payload was recovered after the flight and the on-board data were recovered successfully. In addition to the failure of the detector telemetry stream during flight, the SPI camera feed and signal to the SPI camera itself were also lost. All affected systems were tested at WSMR after recovery and verified to be functional. The telemetry failures and loss of signal to the SPI camera – none of which were required for missions success – are currently being investigated by the NASA support team. Post-flight testing and calibration are currently under way after the payload was returned to Penn State and data reduction and analysis of the flight detector frames are ongoing, along with publications from instrument design, alignments, calibration, and flight performance.

Post-flight alignment checks after the payload was recovered but before shipping away from the launch site indicate that alignment of our instrument to the star-tracking ACS camera held well through the launch and landing. Following the launch and recovery, the tREXS-1 MBS modules were measured to have shifted by <1' in both altitude and azimuth relative to the ACS star tracker and retain a total misalignment of <1', well within the 2' requirement. Additional alignment analysis using the positions of the spectral lines on the focal-plane camera will be performed in post-flight analysis.

Pre-flight testing and calibration gave an indication of the current performance of the tREXS focal plane. Dark frames, for which the detectors are cooled to flight operating temperature and are sheltered from any light source, indicated an average noise performance of $\approx$5.0 e^-/pixel/frame under flight-like ground testing. The detector background resulted in a low frequency of events that were 'X-ray like' – detected events that had energies comparable to expected X-ray energies. For example, the detectors produced events that had energies comparable to O VII, a key transition for tREXS science, at a rate of $\approx 1.9 \times 10^{-3}$ events s^{-1} cm^{-2} across the entire focal plane. For comparison, the expected count rate for O-VII events from the Cygnus Loop for the two-channel tREXS-1 was $\approx 1.0 \times 10^{-2}$ events s^{-1} cm^{-2}, focused into discrete spectral lines. In addition, we observe that the X-ray-like events seen in dark calibration images are predominately single-pixel events, ≈80%. By contrast, soft-X-ray events from our calibration source used in ground testing (which includes Cr-L lines that are nearly the same energy as O VII) show that true X-ray events have single-pixel rates of ≈30-40% (depending on energy), with the remainder as two- or more pixel events. We therefore expect to be able to further differentiate between noise events and true X-ray events using event grades, effectively increasing our ability to isolate source counts.

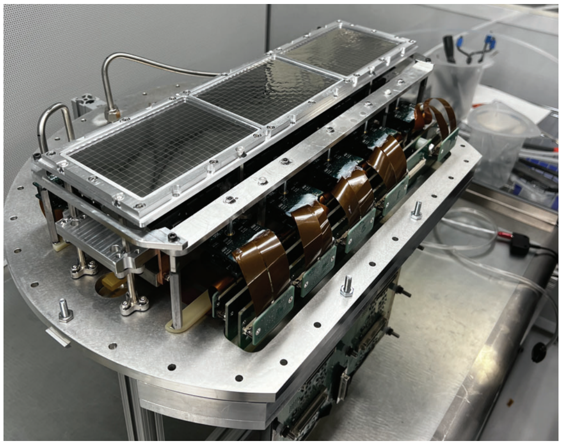


Figure 10: The tREXS focal-plane assembly. 11 CMOS detectors are arrayed to form an extended, ≈250 cm^2 focal-plane camera. The DCBs mounted to each detector are connected to the VTBs with ribbon cables. Also visible are the optical-blocking filters installed in front of the detector

Although the flux from Cygnus is expected to allow a sufficient signal-to-noise ratio (SNR, ≈5) for tREXS-1, we will improve the noise performance for tREXS-2, for which the count rates from the observation targets will be lower. The path forward for reducing detector noise for future flights, which will have lower expected source count rates, is discussed in §5.

5 tREXS-2 Upgrades

The specifications of the tREXS-2 spectrograph as designed, currently realized, and expected by the end of this program are shown in Fig. 11. To achieve the full performance, we expect several instrument additions and improvements throughout this program.

5.1 Activities During No-cost Extension

The predecessor award to this proposal is entering a no-cost extension (NCE) phase through 2023. To both continue preparing the instrument and ensure a continuous transition into this proposed program, there are several activities that will be undertaken during the NCE over the next year. Remaining, partial funding support for several key team members enable the baseline tasks during the NCE and is made possible due to the delays and in-person work stoppages experienced during the COVID-19 pandemic.

The most substantial effort during the NCE will be preparing the addition of a third optics channel to the tREXS spectrograph. Since the ultimate, four-channel design shares the same focal-plane camera, the addition of a third channel is dependent on a new MBS module and corresponding grating module. A third grating module was already prepared at the same time that the two existing flight modules were built and aligned and sits in a cleanroom awaiting installation in the instrument. Similarly, the alignment system for the MBS modules, shown in Fig. 8, is established in a cleanroom and ready to align a new module. The required module housing, MBS plates, and support frames were all acquired in bulk for the full 4-channel system, which means that all hardware required to produce and align a third spectrograph channel are already on hand. We will target completing the alignment and construction of the third MBS module during the NCE so that the MBS and grating modules are ready for integration into the instrument at the outset of the new award.

While the optics team builds the third instrument channel, the team's lead engineer and electrical engineers will work to reduce the noise in the focal-plane detectors. Though the detectors were tested at <4 e^-/pixel read noise in a lab setting, their performance in flight-like conditions was over a full electron higher. The team has identified two potential areas of improvement that can be accomplished during the NCE and are expected to improve noise performance. First, we will plan to electrically isolate the focal-plane detectors from the non-readout electronics, which we have shown in lab testing to contribute noise to the detectors. This will include removing

Performance Specifications			
Metric	**Requirement**	**Current Specs**	**tREX-2 F2 (expected)**
FOV	>10.0 deg^2	≈10.7 deg^2	≈10.7 deg^2
Grasp (at 570 eV)	4 cm^2 deg^2	1.9 cm^2 deg^2	4.3 cm^2 deg^2
Grasp (at 370 eV)	3 cm^2 deg^2	1.5 cm^2 deg^2	3.2 cm^2 deg^2
Bandpass	18 - 35 Å	16 - 40 Å	16 - 40 Å
Spectral resolution	1.9 Å	1.3 Å	1.5 Å
False event rate (sec^{-1} cm^{-2})	1E-5	≈2E-3	1E-6
LSF quality	3'	2.4'	2.8'
Focal-plane coverage	>230 cm^2	≈252 cm^2	≈252 cm^2
Grating facet angle	28 - 30^o	≈24^o	≈29^o
Grating efficiency (abs.)	>55% average	≈45% average	≈65% average
Det. energy res. (at 570 eV)	120 eV	≈105 eV	85 eV

Figure 11: Performance specifications for the tREXS-2 instrument.

the detector chamber from the payload, replacing the flex cables that run from the DCBs to the VTBs, and modifying the layout of the detector electronics in the detector chamber. No additional electronics replacements are expected to be necessary, and the detector chamber modification will proceed in tandem with the optics channel alignment such that the revised electronics are ready to be implemented in advance of the addition of the third channel.

5.2 Upgrades for tREXS-2

5.2.1 Third Spectrograph Channel (F1)

As indicated in the preceding section, the addition of the third spectrograph channel will be the most impactful upgrade for the first flight of this award (tREXS-2 F1), increasing the instrument's collecting area by 50% over the current state of the payload. The third grating module is already fully aligned and assembled and the third MBS module will be aligned during the NCE leading up to this program. The MBS alignment will be led by the PI and a Penn State graduate student, the same team that also led the alignment and construction of the two existing MBS modules, with support from the same mechanical engineer and new undergraduate researchers. The graduate student will prepare and re-calibrate the alignment system with local support at Penn State, and the PI will arrange a visit to perform the assembly of the MBS module with the same work system as the existing modules. Following the alignment of the MBS module itself, the MBS system and grating module will be integrated into the payload. Full-channel integration includes aligning each module to its mechanical constraints in the instrument, aligning the MBS module to the grating module, and aligning the two-component optical channel to the focal-plane camera.

5.2.2 Fourth Spectrograph Channel and New Gratings (F2)

In the two-year gap between tREXS-2 F1 and F2, we will implement the final upgrades to complete the full, four-channel instrument. As was outlined in the preceding sections, the fourth spectrograph channel will require an additional MBS module and grating module. Although we have the materials for the final two MBS modules and the third grating module has already been aligned and is ready for integration into the instrument, we do not currently possess the gratings for the fourth module; replication quality for the final module's gratings was determined to be not suitable for flight. In addition, there is the potential for increased diffraction efficiency (and therefore the ability to collect more source flux) if we produce new grating replicas with the revised processing discussed in §4.2. We therefore plan to manufacture new grating masters and new replicas for tREXS-2 F2. The fabrication processing will follow those used for the current tREXS gratings [20] and the techniques developed for future NASA missions, with expected performance improvements from a modified approach to EBL write fields and better-optimized thermal processing during replication. We expect that the new gratings will give us a $\approx 30-40\%$ relative throughput increase, which will be critical to maximize the return of F2 and potential future flights that target the faint halo emission that is our ultimate objective.

To continue to utilize the state of the art in grating production and pathfind for future missions, the tREXS-2 F2 gratings will carry a true radial pattern (as opposed to the radial approximation used in the current gratings). A radial pattern will allow us to avoid the discontinuities in the write fields that result from discrete period steps in the radial approximation, where the abrupt change in groove spacing, though small (several Å), cause EBL overexposures that negatively affect the imprint process. In addition, a true radial groove convergence is the layout baselined for future X-ray probes and strategic missions, which will allow us to apply our efforts toward development for such missions.

5.2.3 Fine-guidance Camera (F2)

Throughout this program will continue our work in developing a fine-guidance solution to accompany the side-looking star tracker we will fly on tREXS-2 F2; tREXS-2 F2 will consist of four instrument channels and will therefore require, as part of comprehensive mission success, a fine-guidance camera to complement the NSROC-standard star tracker, which will not fit in our optics section with all four spectrograph channels realized. As the investigation into the SPI failure on tREXS-1 continues, we will work in collaboration with NSROC in evaluating additional fine-guidance cameras. Since we have only one more flight (tREXS-2 F1) to flight-prove a fine-guidance system, we will investigate additional options in tandem with continued SPI camera development, including the NSROC-provided Wallops Integrated Star Tracker (WaIST), which has recently flow as a technology demonstration. In addition, another currently funded sounding rocket instrument, 36.383 (PI: Zemcov), is working toward integrating their own fine-guidance system that interfaces directly with ACS. We will monitor their progress and explore the applicability of their system for use on our payload, assuming successful space performance. Finally, we will integrate the side-looking star tracker with full functionality (in addition to the standard aft-looking star-tracker) on tREXS-2 F1 to measure the in-flight offset between the two and the potential of the side-looking camera to meet our pointing requirements.

5.2.4 On-board Calibration (F1, F2)

An additional upgrade to the instrument planned for future flights is the implementation of a switchable shutter system in front of an on-board Fe-55 calibration source. As currently implemented, a radioactive Fe-55 source, which produces high-energy Mn-K X-rays that are used for detector calibration, can provide constant illumination onto the detectors. Mounted to the inside of the internal shutter door, the Fe-55 source intensity is highest when the internal door is closed but continues to put flux on the detectors when the door is open. A shutter over the Fe-55 source will allow us to completely 'turn off' X-rays when desired for full detector dark calibration and to actuate the shutter during flight to turn on and off the in-flight calibration source.

To further develop our ground- and space-calibration plans for future flights, we will investigate the acquisition of a second X-ray source to fly with the payload on future launches. The Miniature High-speed Modulated X-ray Source (MXS)[7] was developed by NASA Goddard Space Flight Center and offers an electron-impact source in a small form factor. Though functionally similar to our existing ground-based calibration system, MXS is small enough to be implemented into the payload and can operate contained wholly in vacuum. In our case, we would design an adaptor mount to

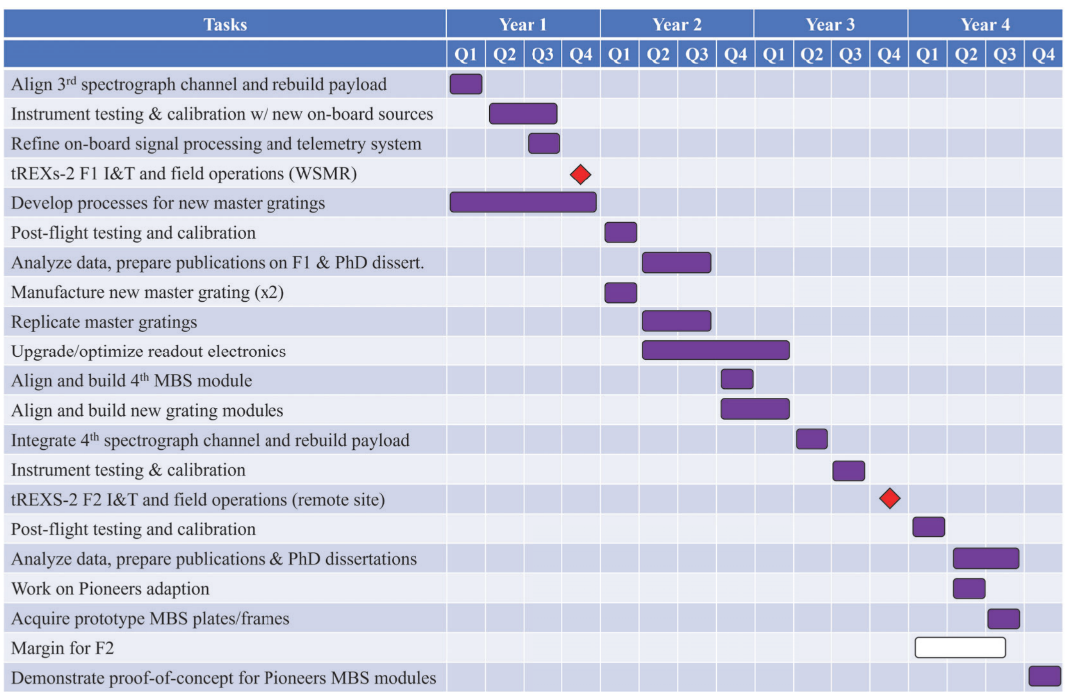
[7]https://technology.nasa.gov/patent/GSC-TOPS-51

affix the MXS on the aft end of our instrument, providing a remotely switchable and tunable soft-X-ray source that can propagate X-rays through our entire instrument. Because the MXS requires a high-voltage power supply (HVPS) to function, we will evaluate the feasibility of adding the MXS and HVPS to our instrument for tREXS-2 F1 against waiting for tREXS-2 F2.

5.2.5 Electronics Upgrades (F1, F2)

After focusing on noise reduction and improved grounding during the NCE leading up to F1, the electronics team will install a more substantial upgrade in preparation for F2. First, a high-gain mode, which was developed for tREXS-1 but was not implemented successfully, will be redesigned and integrated into the readout change. The high-gain mode will give the focal-plane camera a greater dynamic range and will help improve both the on-board signal processing software and the overall false-event rate, which are important upgrades for enabling the F2 science observation. The redesign will also include replacing the current DCBs and transition boards with more optimized versions that will help reduce noise pickup by instrument electronics and make the entire readout chain less susceptible to external factors. The redesign has been planned out by the instrument engineers and can be completed at relatively low cost and with minimal schedule impact.

6 tREXS-2 Schedule and Milestones



The flight schedule for this proposal is borne from a combination of science objectives, instrument development, and available support from our identified launch provider: NASA's Sounding Rockets Program Office (SRPO). We plan for tREXS-2 F1 to target the northern portion of the Vela SNR discussed in §2.1. The three-channel variant of the instrument will allow for a significant observation of Vela's emission that can provide a new understanding of the conditions present while prioritizing the brightest of our planned observation targets as we build toward the full collecting area unlocked with the addition of the fourth instrument channel. We target late 2024 - the first funded year of this proposal – for tREXS-2 F1; with the expected work during the NCE and the current readiness of the payload, we expect tREXS-2 F1 to qualify as a reflight of the 2022 tREXS launch, which will allow us to experience an accelerated design and integration schedule with SRPO and achieve a flight in the first year of this proposal.

Following the 2024 flight, we plan for a two-year gap before our next flight. Two years between flights will allow us ample time to add the fourth channel to the instrument, undergo a smooth transition as new project personnel and resources integrate with the program, and analyze the outcome of the 2024 flight and thoroughly calibrate the instrument for the 2026 flight. We will then plan for two potential flight paths in 2026, pending results of the 2024 flight and the available launch locations. If SRPO plans for support at Poker Flat Research Range in 2026, we can launch to observe the region of enhanced emission toward Draco (§2.2). If, however, a remote campaign is scheduled for Kwajalein or Australia, we can target a southern region in Eridanus that is best observed from the southern hemisphere. In either case, we expect the four-channel instrument to provide new insight into these vastly unexplored regions of the soft-X-ray sky and progress our understanding of the composition of the Milky Way's CGM.

The fourth year of this proposal will serve several purposes. First, the year following the 2026 flight will allow for post-flight calibrations, analysis and publications before the expiry of the award. The additional year after the planned 2026 flight will also provide margin in the event that a flight is not realized in 2026 and must be delayed to 2027. Lastly, we will use the final year to continue work toward adapting the tREXS-2 instrument to an orbital format that can directly map emission from our galaxy's halo and provide the highest-resolution survey of the soft-X-ray background to date. Following two flights, we expect to be able to apply the results of the suborbital flights and calibrated instrument performance to best inform the orbital variant, which can then be proposed as a NASA Pioneers project or Mission of Opportunity to provided unprecedented spectral resolution in an instrument capable of mapping emission from our galaxy's halo.

The observation targets and flight cadence outlined here has been discussed with SRPO, resulting in a statement of support from SRPO (appended to this proposal) that approves the feasibility of this program and the proposed launches.

7 Management Structure

Much of the management of this program will follow the management structure of past and current rocket programs, NASA programs, and SAT programs by the proposing team that have preceded or are parallel to these efforts. Dr. Miles, who designed the tREXS spectrograph during his dissertation work and has led two previous rocket launches in predecessor awards, will take over as principal investigator of this program. Dr. Miles has extensive experience in managing suborbital programs, designing and building instruments, and coordinating multidisciplinary teams and projects. They received and managed a NASA graduate fellowship award, including regular reporting and the project schedule and development path, and have served as program manager for both rockets and, most recently, a high-altitude balloon project. Dr. Miles will ultimately be responsible for the remaining design, construction, alignment, assembly, integration, testing, and calibration of all payload components, and for overseeing the full duration of this program. To ensure a smooth transition from the preceding award to this program, Dr. Miles will be assisted in programmatic considerations by Dr. Martin and Dr. McEntaffer. Dr. Martin is the lead of the Space Astrophysics Lab at Caltech and will use his decades of experience as the PI of space missions and instrument development to support Dr. Miles with this program at the host institution. Dr. McEntaffer will serve as a Co-I and institutional PI at Penn State University (PSU) and assist Dr. Miles throughout the tREXS-2 program; Dr. McEntaffer was the PI of the preceding award (as well as several previous rocket programs and other APRA-funded projects) and will provide guidance to Dr. Miles throughout the management of tREXS-2 as we transition the program to the new PI and host institution. Dr. McEntaffer will continue to serve as the lead for PSU contributions, as he did on the previous award.

As Dr. Miles takes over as the PI of the program, he will also serve as a mentor to existing and new project personnel ranging from undergraduate students to research staff and engineers. Like the predecessor award and as evidenced by the transition of leadership for this program, this proposal places high importance on training the next-generation of PIs and contributors to NASA missions. While working toward securing and establishing a tenure-track position, Dr. Miles will maintain a similar team composition to previous awards: the day-to-day payload leadership (build, testing, calibration, etc.) for tREXS-2 flights will be by senior graduate students working toward their PhDs, undergraduate students and early-career researchers will lead smaller-scale contributions and investigations, and the Co-Is and engineers will support component-level and full-system build and testing to ensure a successful realization of the science and instrument objectives. The senior graduate students will be assisted by and help train a junior graduate student that will then take the lead role on the following flight. tREXS-2 F1 will be led by Mr. Ross McCurdy, who served as the junior graduate student to Dr. Miles for much of the instrument design and took a leadership role on the build toward the first flight of tREXS in the predecessor award. An additional, to-be-named graduate student will be brought on for tREXS-2 F1 and progress toward a management role on F2, establishing a two-graduate-student cadence for planned and future launches.

The PI will be further assisted by an experienced and established rocket team with flight heritage from several previous payloads. Dr. James Tutt will continue his role as lead engineer and detector-system lead, building on his experience with three previous rocket flights. Dr. Tutt will oversee modifications and upgrades to the focal-plane camera and associated electronics, help the PI coordinate system-level integration and testing, and continue to mentor the PSU students and early-career researchers on their contributions to the flight program. Dr. Tutt will be assisted with all efforts relating to the focal-plane camera and readout electronics by Mr. Daniel Washington and Mr. Michael Betts. Mr. Washington is an electrical engineer that designed the readout electronics for the tREXS focal-plane camera and will be the lead engineer for tREXS-2 electronics upgrades. Mr. Betts is a software-oriented electrical engineer that designed the telemetry interfacing for the tREXS payload and will help optimized and streamline the telemetry system for future flights. This expertise and experience will be key to optimizing the data storage and telemetry solutions for the planned flights. Dr. Tutt will further support payload integration and testing and interfacing with NASA systems, as he did on the predecessor award, and will be supported by Dr. Bridget O'Meara on the mechanical design and integration of the remaining instrument components.

Dr. Miles will be assisted on the spectrograph optics, including MBS modules and gratings, by Dr. McEntaffer, graduate student Ross McCurdy, research technologist Jessica Mondoskin, and the to-be-named new team members. Mr. McCurdy implemented the alignment system for the tREXS MBS modules and built existing grating modules, and will reprise his role as alignment lead for the additional channels. Ms. Mondoskin assisted the full-system build, testing and calibration of the existing instrument and will contribute to the same efforts for tREXS-2 F1, as well as provide field support during both planned flights. Mr. McCurdy and Ms. Mondoskin will also help train and mentor new project personnel, including the to-be-named graduate students and new research associates. The new team mebmers will initially learn from existing project personnel on the optical system, alignment methodology, and full-system integration before assuming leadership on those tasks later in the program, ensuring a transfer of knowledge from existing personnel and continued training new students and researchers.

Through this team makeup and an emphasis on outreach and early-career opportunities, the proposing team will maintain the tradition of instrumentation, flight, and PI training through the suborbital rocket program. The PI institution does not allow postdoc-led proposals to fund other postdocs and students. We will therefore maintain a strong student involvement with the Co-I institution and propose to replace student participation with early-career research associates at the host institution.

References

[1] Arnaud, K. A. 1996, in Astronomical Society of the Pacific Conference Series, Vol. 101, Astronomical Data Analysis Software and Systems V, ed. G. H. Jacoby & J. Barnes, 17

[2] Aschenbach, B., Egger, R., & Trümper, J. 1995, Nature, 373, 587

[3] Bamba, A., Yamazaki, R., & Hiraga, J. S. 2005, ApJ, 632, 294

[4] Burkert, W., Zimmermann, H. U., Aschenbach, B., Braeuninger, H., & Williamson, F. 1982, A&A, 115, 167

[5] Burrows, D. N. & Mendenhall, J. A. 1991, Nature, 351, 629

[6] Cha, A. N., Sembach, K. R., & Danks, A. C. 1999, ApJL, 515, L25

[7] Gaetz, T. J., Edgar, R. J., Plucinsky, P. P., Smith, R. K., Haverkorn, M., Sankrit, R., & Aschenbach, B. 2009, in American Institute of Physics Conference Series, Vol. 1156, The Local Bubble and Beyond II, ed. R. K. Smith, S. L. Snowden, & K. D. Kuntz, 236–240

[8] Garmire, G. P., Nousek, J. A., Apparao, K. M. V., Burrows, D. N., Fink, R. L., & Kraft, R. P. 1992, ApJ, 399, 694

[9] Gorenstein, P., Harnden, F. R., J., & Tucker, W. H. 1974, ApJ, 192, 661

[10] Guo, Z., Burrows, D. N., Sanders, W. T., Snowden, S. L., & Penprase, B. E. 1995, ApJ, 453, 256

[11] Kaaret, P., Zajczyk, A., LaRocca, D. M., Ringuette, R., Bluem, J., Fuelberth, W., Gulick, H., Jahoda, K., Johnson, T. E., Kirchner, D. L., Koutroumpa, D., Kuntz, K. D., McCurdy, R., Miles, D. M., Robison, W. T., & Silich, E. M. 2019, ApJ, 884, 162

[12] Kahn, S. M., Gorenstein, P., Harnden, F. R., J., & Seward, F. D. 1985, ApJ, 299, 821

[13] Lu, F. J. & Aschenbach, B. 2000, A&A, 362, 1083

[14] McCammon, D. & Sanders, W. T. 1990, ARA&A, 28, 657

[15] McCoy, J. A., Verschuuren, M. A., Miles, D. M., & McEntaffer, R. L. 2020, arXiv e-prints, arXiv:2011.14771

[16] McEntaffer, R. L. & Brantseg, T. 2011, ApJ, 730, 99

[17] McEntaffer, R. L. & Cash, W. 2008, ApJ, 680, 328

[18] Mendenhall, J. A. & Burrows, D. N. 2001, ApJ, 563, 716

[19] Miles, D. M., Hull, S. V., Schultz, T. B., Tutt, J. H., Wages, M., Donovan, B. D., McEntaffer, R. L., Falcone, A. D., Anderson, T., Bray, E., Burrows, D. N., Chattopadhyay, T., Eichfeld, C. M., Empson, N., Grisé, F., Hillman, C. R., McCoy, J. A., McQuaide, M., Myers, B. J., Steiner, T., Verschuuren, M. A., Yastishock, D., & Zhang, N. 2019, Journal of Astronomical Telescopes, Instruments, and Systems, 5, 044006

[20] Miles, D. M., McCoy, J. A., McEntaffer, R. L., Eichfeld, C. M., Lavallee, G., Labella, M., Drawl, W., Liu, B., DeRoo, C. T., & Steiner, T. 2018, The Astrophysical Journal, 869, 95

[21] Miles, D. M., Tutt, J. H., McCurdy, R., Anderson, T. B., Baker, L., Grisé, F., Hillman, C., Hunter, K., O'Meara, B., Washington, D., Weston, J., Zinski, N. M., & McEntaffer, R. L. 2021, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 11821, UV, X-Ray, and Gamma-Ray Space Instrumentation for Astronomy XXII, ed. O. H. Siegmund, 118210K

[22] National Academies of Sciences, Engineering, and Medicine. 2021, Pathways to Discovery in Astronomy and Astrophysics for the 2020s (National Academies)

[23] Nousek, J. A. 1978, PhD thesis, University of Wisconsin, Madison

[24] Palmieri, T. M., Burginyon, G., Grader, R. J., Hill, R. W., Seward, F. D., & Stoering, J. P. 1971, ApJ, 164, 61

[25] Pavlov, G. G., Kargaltsev, O. Y., Sanwal, D., & Garmire, G. P. 2001, ApJL, 554, L189

[26] Silich, E. M., Kaaret, P., Zajczyk, A., LaRocca, D. M., Bluem, J., Ringuette, R., Jahoda, K.,

& Kuntz, K. D. 2020, AJ, 160, 20

[27] Snowden, S. L., Burrows, D. N., Sanders, W. T., Aschenbach, B., & Pfeffermann, E. 1995, ApJ, 439, 399

[28] Snowden, S. L., Freyberg, M. J., Plucinsky, P. P., Schmitt, J. H. M. M., Truemper, J., Voges, W., Edgar, R. J., McCammon, D., & Sanders, W. T. 1995, ApJ, 454, 643

[29] Snowden, S. L., Hasinger, G., Jahoda, K., Lockman, F. J., McCammon, D., & Sanders, W. T. 1994, ApJ, 430, 601

[30] Tutt, J. H., Miles, D. M., McEntaffer, R., Anderson, T., Washington, D., Hillman, C., McCurdy, R., Zinski, N., O'Meara, B., & Baker, L. 2021, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 11821, UV, X-Ray, and Gamma-Ray Space Instrumentation for Astronomy XXII, ed. O. H. Siegmund, 118210V

[31] Tutt, J. H., Miles, D. M., McEntaffer, R. M., Anderson, T., Weiss, M., & O'Meara, B. C. 2019, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 11118, UV, X-Ray, and Gamma-Ray Space Instrumentation for Astronomy XXI, ed. O. H. Siegmund, 111180C

[32] Verschuuren, M. A., McCoy, J., Huber, R. P., van Brakel, R., Paans, M., & Voorkamp, R. 2018, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 10584, Novel Patterning Technologies 2018, 105840Z

tREXS-2: The Rockets for Extended-source X-ray Spectroscopy

Data Management Plan

The data created during this program will be used to write peer-reviewed publications, PhD dissertations, and Master's theses. These data consist of laboratory measurements, ground calibrations, and flight observations using our multi-channel grating spectrograph. In order to reproduce and validate our results, we will provide these data in either the publications' supplementary material or in a public repository on https://data.nasa/gov at the time of publication. Any data collected during the flight observations will likewise be available on a public repository and/or available upon request.

Accepted versions of peer-reviewed articles and related publications will be uploaded to NASA PubSpace within one year of completion.

tREXS-2: The Rockets for Extended-source X-ray Spectroscopy

Inclusion Plan

Within this program and in our research group in general, we strive for an inclusive and welcoming research environment that provides a sense of belonging to all members of the team. Within this program we will combine inclusive hiring practices, a clear code of conduct, and interpersonal group interactions to develop and maintain a productive and inclusive project.

As we seek to incorporate new members of the project team, including students and other early-career researchers, to join our experienced group, we will do so through an inclusive approach to recruitment and retention. Our efforts to hire new graduate students, undergraduates, and early-career research associates will begin with advertising open positions across multiple departments in the university. Active advertisement and recruitment efforts, including targeted listservs and job board advertisements, will help us provide equitable access to the positions and generate a broader applicant pool. We will solicit application materials that will be evaluated using a pre-determined rubric, the details of which will also be available in the job postings. Each application will be reviewed by more than one project personnel to attempt to minimize the impact of biases that may be present within our team, and all potential interviewees will be asked the same set of questions or discussion prompts. The project team will take care to avoid relying heavily on candidate experience, instead identifying qualities or traits that the applicants can respond to in their own way. This approach will help avoid traditional “word-of-mouth” or recommendation-based job opportunities, which by their nature are exclusionary. As we add new team members we will continue to evaluate the effectiveness of these approaches, including the applicant pool, candidates that receive offers, and ultimately the candidates that accept positions, to determine whether the outlines approaches are having a positive effect on hiring inclusively.

Within the project team, we will establish and maintain a code of conduct by which all members shall abide. The code will outline expectations for group contributions and interpersonal interactions, and provide resources and guidelines for how to address any concerns that may exist or develop. We feel that establishing and maintaining such expectations for group conduct helps create an inclusive climate and one in which all team members can feel comfortable with group interactions. We will solicit feedback from all new and existing team members to help craft the code, and we will re-visit the code of conduct annually to both evaluate its effectiveness and update the content as the team grows and cycles new project personnel.

Throughout this program we will also hold regular, team-wide meetings. These meetings will cover relevant research and progress reports, but also allow opportunities for group discussion regarding the group climate and current events in our profession. Rather than have such meetings dominated by the PI or a small subset of the team, we will encourage active participation and will provide built-in opportunities for all members of the team to present work or lead discussions.

Lastly, the project team values mentorship and fostering an inclusive team environment through our day-to-day interactions. Each member of the team will have at least one informal mentor that can help them become integrated into the project and provide a resource beyond the standard group hierarchy. Providing such an outlet can help both with fostering a sense of belonging and community within the group, and ensuring that there are built-in “checks” on the group dynamic. We will continue to identify and enroll team personnel in training programs on mentoring and maintaining an inclusive research program to help create effective mentors and mentees.

To monitor and evaluate the effectiveness of these efforts, we will allow for open-floor discussions at regular team meetings and solicit anonymous feedback from team personnel. Anonymous feedback, in particular, can be valuable in assessing and understanding how our intentions are received and whether a truly inclusive group is being realized.

NASA Flight Opportunities and Science Mission Directorate Payload Requirements Document (PRD) for Rocket-Powered Vehicles and High-Altitude Balloon Flight Platforms in ROSES

Revision Date: 11-17-2022

Investigation title:	tREXS-2: The Rockets for Extended-source X-ray Spectroscopy
ROSES NOI number:	N2-APRA22-0083

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Participating **Foreign Nationals**: No Indicate if there are any Foreign Nationals (non U.S. persons) who will be participating on the payload team. This is necessary to ensure the appropriate safeguards are put in place for the interchange of technical data covered under the Arms Export Control Act, Export Administration Act, or other applicable regulations/laws.

The following sections are designed to help the Flight Opportunities (FO) program and the Science Mission Directorate (SMD) assess the appropriate flight service provider. Principal Investigators (PI) may express their preference on suborbital platform provider, but NASA reserves the right to make this assignment as appropriate.

Based on the information provided in the NOI-stage PRD form, the proposed investigation will likely be supported by:
Flight Opportunities Program / Balloon Program Office / Sounding Rocket Program Office
as potential suborbital flight provider pending NASA's assessment of this final (proposal-stage) PRD. Please include this completed form with your proposal and use the flight provider above for developing your travel budget for payload integration and launch support. Please note that the proposed budget must include all aspects of the investigation (for example any payload consumables) but should exclude the cost for the launch provider.

For any questions related to NASA's Flight Opportunities program, please contact:
nasa-flightopportunities@mail.nasa.gov

For details on the NASA Sounding Rocket Program Office (SRPO) as potential flight provider, please visit:
https://sites.wff.nasa.gov/code810/srpo.html

For details on the NASA Balloon Program Office (BPO) as potential flight provider, please visit:
https://sites.wff.nasa.gov/code820/index.html

FORM INSTRUCTIONS

- **Sections A through E must be completed by all proposers.**
- **Sections F through I are required only if your potential flight provider is through Flight Opportunities.**

A

SCHEDULE CONSTRAINTS

Please be as specific as possible with the dates below. Resolution at least to the quarter year is desired. For required completion date, please provide rationale (i.e., research/technology is slated for orbital launch, development program funding, etc.). Add details about any hard requirements in the field provided below.

Estimated date payload ready to ship to flight provider:		Q2 2024 (flight 1), Q2 2026 (flight 2)		
Planned flight readiness date:		Q3 2024, Q3 2026		
Required launch commencement date:	no earlier than	Q3 2024, Q3 2026	no later than	Q3 2024, Q4 2027
Required launch completion date:		Q3 2024, Q3 2026	no later than	Q3 2024, Q4 2027

The above data are broken up into the two planned launches. Driving completion date for flight 1 is the need to develop for flight 2, and the driving completion date for flight 2 is the end of the proposed program.

B

FLIGHT OBJECTIVES & SUCCESS CRITERIA

Describe the objectives and success criteria for each requested flight of this payload. These criteria are the basis for planning each flight, and should convey clear and measurable outcomes for each objective. It is anticipated that each investigation/technology may have multiple payload versions. (For example: a high-altitude balloon payload and a suborbital rocket payload.) Please reference any other versions, but remain specific to the flights requested in this form.

The flight objectives are to observe and detect soft-X-ray emission from supernova remnants and enhancements in the soft-X-ray background. Expected success criteria include:

C1: Instrument pointed to within 5' of observation target for >280 seconds above 150 km altitude.
C2: Shutter door and internal detector door remain open for duration of science observation, exposing instrument to target flux.
C3: Experiment detector temperatures must not exceed 208K before end of science observation.
C4: Experiment detector data must be telemetered to ground station and/or payload must be recovered with on-board data preserved.
C5: >50 / 40 (Flight 1 / Flight 2) X-ray events to be detected in source spectrum.

Continue to next page if you need more space.

Continued from previous page.

The flight objectives are to observe and detect soft-X-ray emission from supernova remnants and enhancements in the soft-X-ray background. Expected success criteria include:

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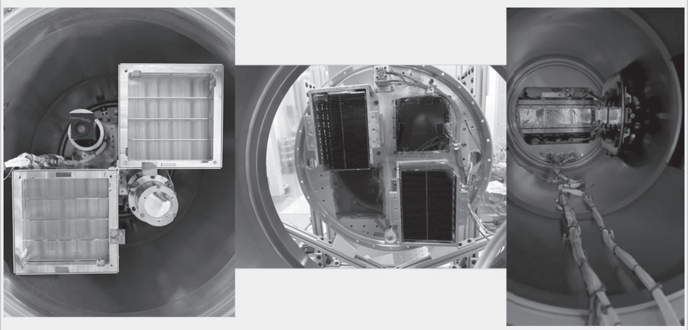
C4: Experiment detector data must be telemetered to ground station and/or payload must be recovered with on-board data preserved.
C5: >50 / 40 (Flight 1 / Flight 2) X-ray events to be detected in source spectrum.

Please append any sketches or diagrams showing the payload and annotating important features/dimensions as necessary.



Left-most images show payload as-built. Visible from left-to-right are instrument optics with startrackers, grating modules and accelerometer, and the internal shutter door (shown open) that isolates the detector chamber. Harnessing from the instrument electronics to the aft shutter door, accelerometers, and star tracker cameras is also visible.

On the right is a full payload CAD cross-sectional model. From left-to-right (aft-to-fore) are X-ray optics modules mounted to optics bulkhead, grating modules on the fore-side of the bulkhead, a 2-m optics bench in the form of 20-inch interior skins, then a 22-to-20-inch detector bulkhead with integrated internal shutter door. Mounted on the fore side of the detector bulkhead is a detector chamber housing the X-ray detectors and readout electronics, which are then fed via vacuum-interface boards to the electronics section. Fore of the forward transition is a dedicated section for the side-looking star tracker used in this mission. Total payload mass and dimensions are given in section E.

C

FLIGHT PROFILE REQUIREMENTS

Describe the test environment requested for the payload. Please indicate "N/A" if not applicable, or "TBD" if not defined at the time of completing the form.

Requirements for *rocket-powered vehicle* flight(s)

Number of flights requested:		2		
Altitude (km):		>150 km		
Duration at altitude:	Minimum:	280s	Maximum:	No limit
Microgravity duration:	Minimum:	N/A	Maximum:	N/A
Microgravity level and quality tolerance (i.e., 0 *g*, +/- 0.1 *g*, etc.):		N/A		
Pointing requirements (detail below, if needed):		5' (instrument optics)		
Need for in-flight release, deployment, or ejection of payload/components?		◯ Yes (details)		◉ No
Need for recovery of ejected payload? (If answered yes to previous question):		◯ Yes		◯ No

Payload recovery requirements (Please include details here and continue below if needed):

Payload recovery required for first flight to both recover full data set and develop payload for 2nd fl.

Requirements for exposure to external ambient conditions? ◉ Yes ◯ No

Is there a specific launch location and/or science-driven launch condition requirement? ◉ Yes (details) ◯ No

Locations are driven by observation target accessibility. See below

Please include any additional information/details here:

This program considers three potential launch targets: the Vela supernova remnant and one pointing in either the region near the Draco Nebula or near the Eridanus X-ray hot spot. Targets are accessible with a combination of White Sands Missile Range and either Poker Flats Research Range or a southern launch site (Kwajalein or Australia). The relative fluxes expected from the targets and incremental performance upgrades to the payload make the ideal launch cadence the following:

White Sands Missile Range in 2024 (payload recovery required)
Poker Flats or southern range in 2026

Detailed flight profile/trajectory requirements:

Standard ballistic sounding rocket trajectory acceptable. Flight requirements specified as time above 150km, with no specified max altitude.

Requirements for *high-altitude balloon* flights

Number of flights requested:					
Altitude (km):	Minimum (required):		Preferred:		Maximum:
Duration at altitude:		Minimum:		Maximum:	
Pointing requirements (detail below, if needed):					
Need for in-flight release, deployment, or ejection of payload/components?			◯ Yes (details)		◯ No
Need for recovery of ejected payload? (if answered yes to previous question)			◯ Yes		◯ No
Payload recovery requirements (please include details here and continue below if needed):					
Requirements for exposure to external ambient conditions?			◯ Yes		◯ No
Is there a specific launch location and/or science-driven launch condition requirement?			◯ Yes (details)		◯ No
Please include any additional information/details here:					
Detailed flight profile/trajectory requirements:					

D LAUNCH PROVIDER / VEHICLE PREFERENCE

Provide a preference for launch provider and vehicle and the rationale behind this preference.

Is there a preferred launch provider and vehicle? (●) Yes, Launch Provider: SRPO Vehicle: BBIX ( ) No

If so, please provide a detailed rationale.

SRPO were previously identified as our provider following the NOI PRD submission, and this payload was launched successfully by SRPO in 2022. Our interfaces and requirements are designed and implemented based on SRPO infrastructure and the instrument exists in an SRPO-supported format.

E PAYLOAD SIZE AND MASS

If the payload consists of multiple standalone modules, please break down the size and mass by module. Indicate actual or estimated measures.

Size (cm)**:** Describe any required location or orientation relative to the vehicle or the Earth. Actual

Payload is housed in 22"-diameter rocket skins with an aft and forward transition that taper to 17".

Length of instrument section, as measured from forward transition to aft shutter door: 380 cm. Side-looking startracker sectino, which will be necessary for the second flight of this proposal, adds another 58.4 cm.

Final length of full payload, including NASA support systems, is 857.73 cm from tip of nose cone to the BBIX igniter.

Mass of payload (kg)**:** Actual

264 kg in current configuration. Mass expected to increase with addition of third and fourth instrument channels. Estimated final mass is ≈290 kg.

National Aeronautics and Space Administration

Goddard Space Flight Center
Wallops Flight Facility
Wallops Island, VA 23337

December 2, 2022

Reply to Attn of: 810

TO: The California Institute of Technology, Dr. Drew Miles

FROM: 810/Chief, Sounding Rockets Program Office

SUBJECT: Letter of Support for Proposal

The Rockets for Extended-source X-ray Spectroscopy (tREXS-2) mission is proposed to launch in Q3 of 2024 from White Sands Missile Range (WSMR), and either Kwajalein, Australia, or Poker Flat Research Range (PFRR) in Q2-Q3 2026. I understand this new mission is similar in size and scope as the previously flown tREXS from WSMR. The Sounding Rockets Program Office (SRPO) has performed a mission formulation assessment for the proposed investigation by Dr. Drew Miles and has determined that the investigation is feasible for a sounding rocket mission.

The mission proposed to launch from WSMR would be a refly of the 36.367 McEntaffer tREXS mission that successfully launched from WSMR in September 2022. A summer of 2024 launch is a reasonable target for the current launch manifest. To provide a northern launch site, PFRR has been successfully used for launch and recovery of telescope payloads. The manifest for PFRR in early 2026 should be able to accommodate the proposed mission.

To provide a southern latitude location, launch and recovery of the payload may also be possible from either the Reagan Test Site (RTS) in Kwajalein, or the Equatorial Launch Australia (ELA) in Nhulunbuy. Water recovery has been proven at RTS, and land recovery of the payloads during the Australia campaign in summer of 2022 were also successful. RTS water recovery carries elevated risk versus ELA or another land-based Australia Range. While both Kwajalein and Australia may be feasible launch locations, the actual schedule for returning to either site is yet to be determined.

If the Caltech proposal is selected, the SRPO stands ready to conduct the mission.

Digitally signed by GIOVANNI ROSANOVA
Date: 2022.12.02 13:41:15 -05'00'

Giovanni Rosanova, Jr.

Drew M. Miles

Drew Miles is a postdoctoral research associate at the California Institute of Technology. He specializes in technology development, instrument design, and suborbital investigations. His research topics include designing, fabricating, and verifying UV and X-ray reflection gratings, designing space-based spectrographs, and conceiving and managing suborbital investigations to advance science, technology, and personnel. Dr. Miles is particularly interested in applying grating technologies and instruments to advancing our understanding of the baryonic matter that resides beyond the planes of galaxies and how that matter drives galactic evolution.

EDUCATION

Ph.D. in Astronomy & Astrophysics Dec. 2021
M.S in Astronomy & Astrophysics Dec. 2018
Penn State University, University Park, PA, USA

B.S. in Astronomy and B.S. in Physics Dec. 2015
University of Iowa, Iowa City, IA, USA

POSITIONS HELD

Postdoctoral Scholar Research Associate, Caltech 2022 – Present

NASA Space Technology Research Fellow, Penn State University 2017 – 2021
Graduate Research Assistant, Penn State University 2016 – 2017
Undergraduate Research Assistant, University of Iowa 2013 – 2016

SELECT FELLOWSHIPS AND AWARDS

Presidential Management Fellow, U.S. Office of Personnel Management 2022 – 2023
NASA Space Technology Research Fellowship, NASA 2017 – 2021
Downsbrough Graduate Fellowship for outstanding success, Penn State University 2019 – 2020
NASA Pennsylvania Space Grant Graduate Fellowship, Penn State University 2017 – 2018
Newport Award for Outstanding Achievement, SPIE 2017
Braddock/Roberts Fellowship, Penn State University 2016
Iowa Center for Research by Undergraduates Fellow, University of Iowa 2015

PROFESSIONAL MEMBERSHIPS AND WORKSHOPS

Member, LEM CGM and All-sky Survey Working Groups 2022 – Present
Member, AXIS Probe Instrument Working Group 2022 – Present
Member, Lynx Instrument Working Group 2017 – 2021
Member, American Astronomical Society 2015 – Present
Member, SPIE 2015 – Present

Relevant Experience

The Faint Intergalactic-medium Redshifted Emission Balloon (FIREBall-2)
Duration: 01/01/2022 - 12/31/2023 (expected)
Role: Project scientist and project manager for balloon-borne multiobject UV spectrograph.

Rockets for Extended-source Soft-X-ray Spectroscopy
Duration 01/01/2018 - 12/31/2022
Role: Project scientist & instrument designer for suborbital X-ray grating spectrograph.

Calibration of Soft-X-ray Components for Flight Missions I, II, & III
Duration: 08/01/2017 – 12/31/2023
Role: Proposals writer and experiment lead

High-performance X-ray reflection gratings using nanofabarication techniques
Duration: 08/01/2017 – 07/31/2021
Role: Graduate Research Fellow

SELECT PUBLICATIONS

1. **D. M. Miles** et al., "Design of the Rockets for Extended-source X-ray Spectroscopy", *J. Astron. Telesc. Instrum. Syst.*, 2022 (expected).
2. V. Picouet, et al. (inc. **D. M. Miles**), "FIREBall-2: flight preparation of a proven balloon payload to image the intermediate redshift circumgalactic medium", *Proc. ESA Symposium on European Rocket and Balloon Programmes*, 25th ESA PAC Symposium, 2022 (in press).
3. **D. M. Miles et al.**, "An update on the rockets for extended-source X-ray spectroscopy", *Proc. SPIE 11821* UV, X-ray, and Gamma-Ray Space Instrumentation for Astronomy XXII, 118210K (2021).
4. J. H. Tutt, **D. M. Miles**, et al., "Developments of the focal plane camera for tREXS", *Proc. SPIE 11821* UV, X-ray, and Gamma-Ray Space Instrumentation for Astronomy XXII, 118210V (2021).
5. R. C. McCurdy, **D. M. Miles**, J. A. McCoy, F. Grise, & R. L. McEntaffer, "Diffraction efficiency of a small-period astronomical X-ray reflection grating fabricated using thermally-activated selective topography equilibration", *J. Astron. Telesc. Instrum. Syst.* 6(4), 045003 (2020).
6. P. Kaaret, et al. (inc. **D. M. Miles**), "HaloSat - A CubeSat to Study the Hot Galactic Halo", *The Astrophysical Journal* 884 (2), 11 pp (2019).
7. **D. M. Miles**, et al., "Water Recovery X-ray Rocket grating spectrometer", *J. Astron. Telesc. Instrum. Syst.* 5(4), 044006 (2019).
8. **D. M. Miles**, et al., "Fabrication and Diffraction Efficiency of a Large-Format, Replicated X-ray Reflection Grating", *The Astrophysical Journal* 869 (2), 12 pp (2018).

Caltech Department of Astronomy
1200 E. California Blvd. MC 278-17
Pasadena, CA 91125

Roman Technology Fellowship Application
NASA APRA Addendum

Dear Review Panel,

Please consider this document an application for the Roman Technology Fellowship (RTF) program that complements this NASA APRA proposal. Although I submit this proposal as a postdoctoral research associate at Caltech, I will look to move to a permanent tenure-track position in the coming years. The RTF program would prove a valuable resource to help me establish my lab and research group as I build my career.

Through my graduate research and my postdoctoral career, I have been a leader in developing technology and flight instruments to explore extended sources of emission throughout our Universe. I used a NASA graduate research fellowship to investigate new approaches in reflection-grating fabrication, resulting in several publications detailing high-performance X-ray and UV gratings and helping enable multiple instrument concepts, including the one in this APRA proposal. I then designed the multi-channel spectrograph for the tREXS payload around high-efficiency X-ray gratings, which allow us to combine a large FOV and moderate spectral resolution to perform new observations of extended X-ray sources. The long-term goal of tREXS, which will help be realized with this award, is to map the soft-X-ray background and Milky Way halo with unprecedented spectral resolving power.

Beginning this past year and carrying into when this award would begin, I have served as the project scientist and project manager for the FIREBall-2 balloon instrument. The FIREBall-2 payload is a multi-object UV spectrograph designed to detect the faint emission from the circumgalactic medium (CGM) of low-redshift ($z < 1$) galaxies, which allows me to continue my efforts in understanding the presence and kinematics of baryonic matter as it pertains to galaxy evolution and the structure of the CGM.

As a Roman Technology Fellow, I will continue my emergence as a leader in developing technology and instruments to serve as pathfinders for future large NASA missions and to use suborbital platforms to unlock new discoveries in astrophysics. Being able to secure RTF support to establish my research program in addition to the proposed rocket investigation will help me clearly demonstrate my abilities as a PI and my potential to lead a successful program in the coming years in a tenure-track position.

Sincerely,

Drew Miles

Drew Miles

D. Christopher Martin

MS 278-17, Cahill Center for Astronomy and Astrophysics
California Institute of Technology
Pasadena, CA 91125
(626) 395-4243, cmartin@srl.caltech.edu

Education and Employment

Professor of Physics, California Institute of Technology (Caltech), 1993-
Associate Professor of Physics, Columbia University, 1990-1993
Assistant Professor of Physics, Columbia University, 1987-1990
Ph. D. University of California, Berkeley 1986, Physics. (Advisor: Stuart Bowyer)
B.A. Oberlin College 1978, Physics.

Recent Awards and Honors

NASA Exceptional Scientific Achievement Medal, 2014.
NASA Group Achievement Award, FUV Detector Recovery Team, 2007.
NASA Public Service Medal, Galaxy Evolution Explorer Mission Science Achievement, 2005.
NASA Public Service Medal, Galaxy Evolution Explorer Mission Development 2004.
NASA Group Achievement Medal, GALEX Project Group, 2004.

Synergistic Activities

NASA Panels: Cosmic Origins Program Analysis Group (Chair) 2011-2013; NASA Astrophysics Subcommittee, 2009-2013; NASA Small Explorer Phase 1 Review Team, 2008-2009; NASA Astrophysics Sounding Rocket Assessment Team, 2008-

Keck Science Steering Committee, 2006-2013; Caltech Co-chair, 2008-2013

Thirty Meter Telescope Science Advisory Committee, 2013-

Taught introductory Physics at Caltech (E&M, Quantum Mechanics, Statistical Mechanics, Waves) 1996-2010: developed many new lecture demonstrations using computer simulations of physical scenarios in E&M and Quantum Mechanics.

Students and Post-Docs

Graduate Students: David Schiminovich, Andrew Rasmussen, Brian Kern, Ben Mazin, Thiago Gonçalves, Matt Matuszewski, Shahin Rahman, Daphne Chang, Nicole Ligner, Donal O'Sullivan, Prachi Parahar

Post Docs: Ted Wyder, Todd Small, David Schiminovich, Don Neill, Patrick Morrissey, Suvi Gezari, Janice Hester, Gillian Kyle, Erika Hamden, Behnam Darvish, Keri Hoadley

Related Publications

Darvish, B., Martin, D. C., Goncalves, T., Mobasher, B., Scoville, N. Z. and Sobral, D. "*Quenching or Bursting: The Role of Stellar Mass, Environment, and Specific Star Formation Rate to z~1*", 2018, ApJ, 853, 155.

Martin, D. C., Goncalves, T. S., Darvish, B., Seibert, M., & Schiminovich, D. "*Quenching or Bursting: Star Formation Acceleration—A New Methodology for Tracing Galaxy Evolution*", 2017, ApJ, 842, 20

Martin, D. C., Chang, D., Matuszewski, M, Rahman, S., Morrissey, P., Moore, A. , Steidel, C.S., Trainor, R. "*A Newly Forming Giant Protogalactic Disk, A Signature of Cold Accretion from the Cosmic Web",* 2016, ApJLett, 824, L5.

Curriculum Vitae
RANDALL L. MCENTAFFER

Business Address:

Department of Astronomy and Astrophysics, Pennsylvania State University
525 Davey Lab, University Park, PA 16802
Phone: 814-863-7350 E-mail: rlm90@psu.edu

Higher Education

University of Colorado, 2000-2007, Astrophysics, MS, Dec. 2002, PhD, Dec. 2007
University of Iowa, 1994-2000, Physics, Astronomy, BS, BS, May 2000

Recent Professional and Academic Positions

Department Head, Astronomy & Astrophysics, Aug. 2021 – present, Pennsylvania State University
Associate Head for the Graduate Program, Astronomy & Astrophysics, Aug. 2018 – July 2021, Pennsylvania State University
Professor, Astronomy & Astrophysics/Physics/Materials Science & Engineering Aug. 2016 – present, Pennsylvania State University

Selected Honors and Awards

NASA Group Achievement Award, Co-Chair: Lynx Instrument Working Group, 2019.
Scholar of the Year, University of Iowa, 2015
Presidential Early Career Award for Scientists and Engineers, 2012
Nancy Grace Roman Technology Fellow, NASA, 2011

Selected Relevant Experience

- "Rockets for Extended Source Soft X-ray Spectroscopy," NASA Astronomy and Physics Research and Analysis Grant, duration 01/2018 – 12/2022, status – PI
- "X-ray Rocket Payloads for Key Technologies and Core Science," NASA Astronomy and Physics Research and Analysis Grant, duration 01/2017 – 1/2019, status – PI
- "Pushing the Boundaries of Soft X-ray Spectroscopy," NASA Astronomy and Physics Research and Analysis Grant, duration 01/2013 – 12/2018, status – PI

Selected Relevant Publications

Donovan, B. D., McEntaffer, R. L., et al., "Performance Testing of a Large-Format X-ray Reflection Grating Prototype for a Suborbital Rocket Payload," Journal of Astronomical Instrumentation, 9(4), 2050017-497, 25 pages, 2020.

Miles, D. M., et al., "Water Recovery X-ray Rocket grating spectrometer," Journal of Astronomical Telescopes, Instruments, and Systems, 5, 044006, 2019.

Tutt, J. H., Miles, D. M., McEntaffer, R. L., Anderson, T., Weiss, M., & O'Meara, B. C., "The focal plane camera for tREXS," Proceedings of the SPIE, 11118, 111180C, 12 pages, 2019.

James H. Tutt

The Pennsylvania State University
Department of Astronomy and Astrophysics
Davey Laboratory, University Park, PA

Tel: (814)865-0150
E-mail: jht12@psu.edu

Education:
2012: Ph.D. Physics, The Open University, Milton Keynes, UK
2006: MPhys (Hons), Physics with Astrophysics, The University of Manchester, Manchester, UK

Professional History:
2021 - Associate Research Professor, The Pennsylvania State University
2016 - 2021 Assistant Research Professor, The Pennsylvania State University
2014 – 2016: Post-Doctoral Research Scholar, University of Iowa
2013 – 2014: January 2013 – April 2014, The Open University, UK
2012 – 2012: Post-Doctoral Research Scholar, The Open University, UK

Honors and Awards:
1. Japanese Society for the Promotion of Science (JSPS) summer fellowship, 2013
2. STFC Studentship Enhancement Program (STEP) award, 2012

Scientific and Technical Experience from Prior Research Efforts
As a Post-Doctoral Research Scholar at the University of Iowa and as a Research Professor at Penn State University, I have been heavily involved in the design, build, and testing of suborbital rocket payloads. My experience includes the design of instrument electronics, the building and testing of a large focal plane camera, and taking part in integration, testing, and launch operations. I was the lead engineer on the tREXS payload.

Selected Publications:
Donovan, B. D., McEntaffer, R. L., Tutt, J. H., O'Meara, B. C., Grisé, F., Zhang, W. W., Biskach, M. P., Saha, T. T., Holland, A. D., Evan, D., Lewis, M. R., Soman, M. R., Holland, K., Colebrook, D., Cooper, F., & Farn, D. (2021). Comprehensive line-spread function error budget for the off-plane grating rocket experiment (Erratum). *Journal of Astronomical Telescopes, Instruments, and Systems*, *7*(01), 19801. https://doi.org/10.1117/1.jatis.7.1.019801

Evan, D. A., Holland, A., Endicott, J., Holland, K., Gopinath, D., Tutt, J. H., & McEntaffer, R. L. (2022). *The focal plane camera for the Off-plane Grating Rocket Experiment*. *1219115*(August), 40. https://doi.org/10.1117/12.2637135

Miles, D. M., Tutt, J. H., McCurdy, R., Anderson, T. B., Baker, L., Grisé, F., Hillman, C., Hunter, K., O'Meara, B., Washington, D., Weston, J., Zinski, N., & McEntaffer, R. L. (2021). *An update on the rockets for extended-source X-ray spectroscopy*. *August 2021*, 17. https://doi.org/10.1117/12.2594291

Tutt, J. H., Miles, D. M., McEntaffer, R. L., Anderson, T. B., Washington, D., Hillman, C., McCurdy, R., Zinski, N., O'Meara, B., & Baker, L. (2021). *Developments of the focal plane camera for tREXS*. *August 2021*, 26. https://doi.org/10.1117/12.2594563

Drew M. Miles

Current and Pending Support

Current:

Source of Support:	NASA
Project Title:	Ultraviolet Spectroscopy for the Next Decade Enabled Through Nanofabrication Techniques
PI:	Randall McEntaffer
Total Award Amount:	$2,132,063
Total Award Period Covered:	10/01/2022 – 09/30/2025
Person Months Per Year:	3 calendar months
Role:	Co-I

Pending:

Source of Support:	NASA
Project Title:	tREXS-2: The Rockets for Extended-source X-ray Spectroscopy
PI:	Drew Miles
Total Award Amount:	$3,308,972
Total Award Period Covered:	01/01/2024 – 12/31/2027
Person Months Per Year:	7.5 calendar months
Role:	PI

Source of Support:	NASA
Project Title:	X-ray Reflection Gratings: Key Developments for the Next Decade
PI:	Drew Miles
Total Award Amount:	$113,641
Total Award Period Covered:	10/01/2023 – 09/30/2026
Person Months Per Year:	~1.67 calendar months
Role:	PI

James Tutt

Current and pending support

Current:

Source of Support:	NASA
Project Title:	Rockets for Extended Source Soft X-ray Spectroscopy
PI:	Randall McEntaffer
Agency Point of Contact:	Julie Bloxom, Telephone: 757-824-1119, Email: Julie.b.bloxom@nasa.gov
Total Award Amount:	$4,117,663
Total Award Period Covered:	01/01/2018 – 12/31/2022
Person Months Per Year:	6 calendar months
Role:	Co-I

Source of Support:	NASA
Project Title:	X-ray Reflection Gratings: Limitations and Improvements
PI:	Randall McEntaffer
Agency Point of Contact:	Julie Bloxom, Telephone: 757-824-1119, Email: Julie.b.bloxom@nasa.gov
Total Award Amount:	$1,611,619
Total Award Period Covered:	03/07/2019 – 03/06/2023
Person Months Per Year:	4 calendar months
Role:	Co-I

Source of Support:	NASA
Project Title:	Phase 2 of the Off-plane Grating Rocket Experiment (OGRE)
PI:	Randall L. McEntaffer
Agency Point of Contact:	Michael R. Garcia, Telephone: 202-358-1053, email: Michael.r.garcia@nasa.gov
Total Award Amount:	$1,355,597
Total Award Period Covered:	01/01/20 – 09/25/2023
Person-Months Per Year:	4 calendar months
Role:	Co-I

Source of Support:	PhotonFoils (NASA Phase 2 SBIR Subcontract)
Project Title:	Silicon Carbide Grid Fabrication and Vibration Qualification
PI:	James Tutt
Agency Point of Contact:	Bruce Lairson, President, PhotonFoils bruce.lairson@photonfoils.com
Total Award Amount:	$155,571
Total Award Period Covered:	08/01/2022 – 07/31/2024
Person-Months Per Year:	3 calendar months

Source of Support:	NASA
Project Title:	Large-Format X-ray Zone Plates: Enabling Flight-like Calibrations for Future Missions
PI:	Fabien Grisé
Agency Point of Contact:	Garik Gutman, Telephone: 202-358-0276, email: ggutman@nasa.gov
Total Award Amount:	$150,000
Total Award Period Covered:	01/01/23 – 12/31/2023
Person-Months Per Year:	0.75 calendar months
Role:	Co-I

Pending:

PROPOSAL BUDGET (Redacted)

START DATE:	1/1/2024
END DATE:	12/31/2027

YEARS	4

			YEAR 1			YEAR 2			YEAR 3			YEAR 4			TOTAL
SENIOR PERSONNEL	NAME	BASE	MONTHS	%	BUDGET	MONTHS	%	BUDGET	MONTHS	%	BUDGET	MONTHS	%	BUDGET	
EQUIPMENT															
Fabrication					203,823			355,827			336,129			220,952	1,116,731
TOTAL EQUIPMENT					203,823			355,827			336,129			220,952	1,116,731
TRAVEL															
Total Domestic Travel					13,409			8,564			14,481			9,249	45,703
TOTAL TRAVEL					**13,409**			**8,564**			**14,481**			**9,249**	45,703
OTHER DIRECT COSTS															
Publications					2,000			2,000			2,000			2,000	8,000
TOTAL OTHER DIRECT COSTS					2,000			2,000			2,000			2,000	8,000
GRAND TOTAL COSTS					**856,117**			**954,998**			**904,290**			**593,567**	**3,308,972**

FABRICATION - DETAIL (Redacted)															
YEARS	4														
INFLATION	4.50%		YEAR 1			YEAR 2			YEAR 3			YEAR 4			TOTAL
OTHER PERSONNEL	Name	BASE	MONTHS	%	BUDGET	MONTHS	%	BUDGET	MONTHS	%	BUDGET	MONTHS	%	BUDGET	TOTAL
Staff Salaries	Research Technician		12.00	100.0%		12.00	100.0%		12.00	100.0%		12.00	100.0%		
	Research Technician		0.00	0.0%		12.00	100.0%		12.00	100.0%		12.00	100.0%		
	Crabill, Marty		2.00	16.7%		6.00	50.0%		6.00	50.0%		2.00	16.7%		
TOTAL OTHER PROFESSIONAL SALARIES					74,918			170,154			177,811			153,231	576,115
TOTAL OTHER PERSONNEL					74,918			170,154			177,811			153,231	576,115
Staff Benefits (SB)			24.0%												
TOTAL SALARIES, SB, TR					92,921			211,043			220,539			190,052	714,555
TRAVEL (only if related to installation)		INFLATION	3.00%												
Domestic			# Days												
Total Domestic Travel		# Trips	0		61,102	0			0		77,590	0		-	138,692
Total Foreign Travel		# Trips	0		-	0		-	0		-	0		-	-
TOTAL TRAVEL					61,102			-			77,590			-	138,692
MATERIALS AND SUPPLIES															
ITEM: Supplies					10,000			10,000			10,000			10,000	40,000
ITEM: Shipping					3,000			-			3,000			-	6,000
ITEM: Gratings					15,000			98,000			-			-	113,000
ITEM: Fabrication Consumables					800			-			-			-	800
ITEM: Fabrication Tool Time					15,000			20,000			-			-	35,000
ITEM: Electronics Placeholder					6,000			16,784			-			-	22,784
ITEM: Alighment Apparatus					-			-			25,000			-	25,000
ITEM: MBS Plates					-			-			-			12,000	12,000
ITEM: MBS Frames					-			-			-			8,900	8,900
TOTAL MATERIALS AND SUPPLIES					49,800			144,784			38,000			30,900	263,484
TOTAL FABRICATION COSTS					203,823			355,827			336,129			220,952	1,116,731

Budget Justification (Redacted)

Travel

The proposal requests funds for travel for the duration of the project. Costs are estimated based on current pricing and previous purchases for similar travel. Travel costs are estimated based on the following planned trips:

Domestic conferences – we request funds for 3 people to attend a domestic conference (SPIE Optics and Photonics) in years 2 and 4 of this award. Cost inputs calculated as of Nov. 2022:

- $400 flight based on LA to San Diego
- $74/day meal per diem x 7 days total travel days
- $161/day lodging per diem x 6 nights
- $60/day ground transportation x 6 days
- $610 conference registration fee (member rate)

International conferences – we request funds for 3 people to attend an international conference (SPIE Telescopes and Instrumentation) in years 1 and 3 of this award. Cost inputs calculated as of Nov. 2022:

- $1100 flight from LA to Tokyo
- $131/day meal per diem x 7 total travel days
- $208/day lodging per diem x 6 nights
- $60/day ground transportation x 6 days
- $910 conference registration fee (member rate)

Integration and testing – we request funds for 3 people to attend integration and testing of the instrument at Wallops Flight Facility for 25 days in year 1. In year 3, we request funding for 4 people for 25 days for the same purpose, with an increase in effort to compensate for the decrease in effort from our subcontract.

- $700 flight from LA to Virginia
- $64/day meal per diem
- $124/day lodging
- $60/day ground transportation

Launch – we request funds for 3 people to attend field operations and launch for the tREXS-2 instrument for 21 days in year 1 from White Sande Missile Range. In year 3, we request funding for 4 people to attend field operations and launch of the second flight, expected to be from Poker Flats, Alaska, for 30 days.

- $450 flight from LA to New Mexico (year 1)
- $59/day meal per diem
- $98/day lodging per diem
- $60/day ground transportation
- $750 flight from LA to Fairbanks (year 3)
- $86/day meal per diem
- $204/day lodging per diem
- $60/day ground transportation

Collaboration meetings – we request funding for 3 people to work at Penn State University for 30 days in year 1 to support instrument buildup and calibration preceding the launch in year 1.

- $800 flight from LA to State College, PA
- $69/day meal per diem
- $100/day lodging per diem
- $60/day ground transportation

Publications

We assume an average of $2000/year in all years for page fees for publications to be led from the PI institution throughout this project. Costs are estimated based on current pricing and previous purchases for similar expenses.

Equipment/Fabrication Costs

- In year 1 we budget for the acquisition of master grating substrates to make new gratings, based on the cost of comparable substrates acquired in the previous award from vendor Virginia semiconductor ($15000 budgeted).
- In year 2 we budget for the acquisition of grating replica substrates, the replication of the master gratings, wafers and modules used to align and integrate the gratings into the instrument, and tool/personnel time to dice the gratings. All costs based on comparable purchases in the previous award: $30000 for 200 fused-silica substrates from Sydor, $25000 replication fee from Philips SCIL Innovations, $10000 for spacer substrates from Sydor, $25000 to dice fused silica substrates from DISCO Technologies, and $8000 to manufacture grating modules.
- In year 1 we plan for the acquisition of fabrication consumables and fabrication tool/staff expense to develop the new master gratings, based on prior fabrication experience. Consumables budget ($800) covers electron-beam resist, substrate holders, tweezer, etc. and fabrication tool/staff expense of $15000 is estimated based on hours and person-time used to produce existing project gratings.
- In year 2 we budget for the final fabrication of the new master gratings.
- We plan for upgrades to the instrument electronics in year 1 and an optimization-focused redesign in year 2, based on cost of COTS components as of Nov. 2022.
- In year 3 we plan for the acquisition of alignment apparatus to allow the fourth instrument channel to be aligned to the first three and the instrument focal-plane camera.
- In year 4 we budget for the acquisition of prototype MBS plates and frames for the adaption to the Pioneers concept, based on previous work for tREXS-1 by Vacco Industries and Laser Precision, Inc, respectively.
- We budget for an average of $10k each year in misc supplies and equipment to support the ongoing lab activities (instrument alignment, build, testing, etc.) and launch support.
- We plan for shipping of the instrument to/from integration and the launch location in year 1 and 3.
- We budget for one early-career research associate in year 1 and two early-career research associates in years 2-4. The research associates will support all aspects of the project, including instrument assembly, integration, testing, and launch support as well as design, characterization, and data analysis.
- Finally, senior research technician Marty Crabill will support post-launch activities in year 1 and lab support at the host institution in years 2-4.

Astronomy and Astrophysics (Eberly College of Science) / The Pennsylvania State University
tREXS-2: The Rockets for Extended-source X-ray Spectroscopy ***REDACTED BUDGET***
California Institute of Technology (National Aeronautics and Space Administration)
Project Dates: 01/01/2024 - 12/31/2027

	01/01/2024 - 12/31/2024	01/01/2025 - 12/31/2025	01/01/2026 - 12/31/2026	01/01/2027 - 12/31/2027	Total
Direct Costs					
Salaries (Category I)					
Tutt, James Henry (Principal Investigator)	0	0	0	0	0
McEntaffer, Randall L (Co-Investigator)	0	0	0	0	0
Mondoskin, Jessica (Technician)	0	0	0	0	0
O'Meara, Bridget (Other)	0	0	0	0	0
Washington, Daniel (Principal Investigator)	0	0	0	0	0
Betts, Michael (Other)	0	0	0	0	0
Total Salaries	0	0	0	0	0
Graduate Assistants (Category II)					
2 - Grad Asst - Grade 19	0	0	0	0	0
Total Graduate Assistants	0	0	0	0	0
Wages (Category III)					
2 - Undergraduate Student - TBD	0	0	0	0	0
2 - Grad Asst-Summer	0	0	0	0	0
Total Wages	0	0	0	0	0
Student Wages (Category IV)					
2 - Undergraduate Student - TBD	0	0	0	0	0
Total Student Wages	0	0	0	0	0
Total Salaries and Wages	0	0	0	0	0
Fringe					
Category I @ 36.00%	0	0	0	0	0
Category II @ 10.40%	0	0	0	0	0
Category III @ 8.00%	0	0	0	0	0
Category IV @ 0.40%	0	0	0	0	0
Total Fringe	0	0	0	0	0
Total Salaries, Wages and Fringe	0	0	0	0	0
Modified Total Direct Costs					
Domestic Travel	0	6,604	0	3,695	10,299
Travel to participate in scientific conference, San Diego, CA Years 2 & 4					
Domestic Travel	15,350	0	10,650	0	26,000
Travel to Wallops - 1 month - I&T					
Domestic Travel	0	7,900	7,900	0	15,800
PSU travel to support Drew					
Domestic Travel	12,645	0	0	0	12,645

Astronomy and Astrophysics (Eberly College of Science) / The Pennsylvania State University
tREXS-2: The Rockets for Extended-source X-ray Spectroscopy ***REDACTED BUDGET***
California Institute of Technology (National Aeronautics and Space Administration)
Project Dates: 01/01/2024 - 12/31/2027

	01/01/2024 - 12/31/2024	01/01/2025 - 12/31/2025	01/01/2026 - 12/31/2026	01/01/2027 - 12/31/2027	Total
Launch - WSMR - 1 month-Trips 1 Persons/3 Days/21 Airfare/568 Per Diem/157 Ground transportation/Car Rental 50					
Foreign Travel	16,575	0	10,364	0	26,939
Travel to participate in scientific conference, Japan Years 1 & 3					
Foreign Travel	0	0	34,750	0	34,750
Launch - Remote - 1 month					
Publications	1,500	1,500	1,500	1,500	6,000
Total Modified Total Direct Costs	46,070	16,004	65,164	5,195	132,433
Other Direct Costs					
Tuition Remission	0	0	0	0	0
Total Other Direct Costs	0	0	0	0	0
Total Direct Costs	46,070	16,004	65,164	5,195	132,433
F&A Costs (MTDC basis)					
Total Requested From Sponsor	46,070	16,004	65,164	5,195	132,433
Total Project Costs	46,070	16,004	65,164	5,195	132,433

Budget Narrative (Redacted)
The Pennsylvania State University
Dr. James Tutt

Salaries:
The principal investigator is budgeted at the percentage of time shown using his/her actual salary in the calculation. The principal investigator's time includes both technical and project management functions. Any other individuals/positions shown are technical staff with the percentage of time shown and actual salaries used.

Personnel:
Co-Investigator – Randall McEntaffer (0.12 calendar month per year/no salary): Randall McEntaffer's effort is covered by his academic salary with Penn State, but he has freedom to self-assign research interests/efforts as needed.

Co-Investigator – James Tutt (6 calendar months effort years 1 and 3, 4 calendar months years 2 and 4): James Tutt will support the payload design, build, and testing across all years of the proposal, with additional effort during the years when a launch in scheduled. This will be to assist in integration and testing and launch operations.

Research Technologist - Jessica Mondoskin (6 calendar months effort year 1, 4 calendar months year 2): The research technologist will support the payload design, build, and testing across all years of the proposal, with additional effort during the years when a launch in scheduled. This will be to assist in integration and testing and launch operations.

ME - Bridget O'Meara (2 calendar months years 1 and 2): The Engineer will assist in the design and build-up of the payload.

EE – Daniel Washington (2 calendar months effort year 1 and 3, 4 calendar months year 2): The EE's role is to assist in the continued development of the camera readout system. Large scale changes to the electronics are planned during year 2 which requires more work effort.

EE – Michael Betts (1 calendar month effort in year 1, 3 calendar months effort in year 2): The EE's role is to update the firmware on the tREXS readout system. Few changes will be made before the re-flight in year 1, but more effort will be required before the second launch.

Two Graduate Assistants –TBN at 50% of 9 academic months and 50% of 3 summer months (4.5 academic months and 1.5 summer months) effort in all years: This students' roles are to be involved in every aspect of the proposal. They will be involved in the re-flight of the tREXS payload and in the re-build for the proposed second flight.

Two Undergraduates – TBN (10 hours per week during the semester and 40 hours per week over the summer in years 1 and 2): The undergraduates will be trained in laboratory tasks that are required for a rocket program.

Travel:
Mileage estimates are based on the travel rate posted on the Penn State travel web site on Date. All travel will be in accordance with university travel regulations and mileage will be charged at the current rate on the date of travel.

Travel costs are estimated as follows:

Conferences – SPIE Optics and Photonics, San Diego, CA – years 2 and 4
Funding is for 1 trip for 2 people lasting 7 days in year 2 and 1 person lasting 7 days in year 4.

Conferences – SPIE International Conference – years 1 and 3
Funding is for 1 trip for 3 people lasting 7 days in year 1 and 2 people lasting 7 days in year 3 based on the conference being in Yokohama, Japan.

Integration and Testing – NASA Wallops Flight Facility, VA
Funding is for 3 people to go to integration and testing for 25 days in year 1 and for 2 people to go to integration and testing for 25 days in year 3. A reduced personnel effort in year 3 is expected due to the establishment of a group at the PI host institution

Launch – White Sands Missile Range, NM
Funding is for 3 people to go to launch operations for a month in year 1

Launch – remote location
Funding is for 2 people to go to integration and testing for 30 days in year 3. A reduced personnel effort in year 3 is expected due to the establishment of a group at the PI host institution

Penn State Support
Funding is for 2 people to travel to the PI host institution in years 2 and 3 to assist in the establishment of the group's lab and to help build-up the group for integration and testing, and launch operations.

Publication and Page Charges:
Funding is requested to enable the publication of results in peer reviewed open access journals with the expectation of 1 paper per year at $1,500/year.

Tuition:

Computed using the approved tuition charges for a one-half (1/2) time graduate assistant of $10,190 (pre-comprehensive) and $3,320 (post-comprehensive) for fall and spring semesters 2022/2023, and $5,095 for summer session 2023. The charges quoted above are increased by three percent (4%) for any project period occurring after summer session 2023, and each summer session thereafter.

Definition of a Year:

The University defines the term "year" as the fiscal year (July – June).

tREXS-2: The Rockets for Extended-source X-ray Spectroscopy

Facilities: Caltech

The Space Astrophysics Lab (SAL), to which the proposing team belongs, at the California Institute of Technology offers a wealth of resources to support this project. The SAL maintains a 4000 ft^2 well-equipped laboratory in the Caltech Synchrotron Annex for experimental astrophysics research. The lab space includes a 1000 ft^2 clean room with optical tables, laminar flow benches, nitrogen supply, and a crane that can support the fully assembled rocket payload.

Figure 1. Left: A portion of the lab space in the SAL's Synchrotron laboratory. Right: Several work tables and a window overlooking the 1000 ft^2 cleanroom. The one-ton crane is visible through the window.

Adjacent to the ground-floor SAL is the Caltech PMA division High Bay Facility, which includes a high-profile crane, extended roll-up entryway, and large clean tent for instrument assembly, testing and calibration.

Figure 2. Left: The roll-up door on the high bay floor will allow a rocket payload to easily enter and exit the SAL lab space. Right: The high bay floor space and integration clean tent.

Multiple previous and current space- and ground-based instruments have been developed in the SAL laboratory, including the NUVIEWS sounding rocket payload, the GALEX small-explorer mission, ground spectrographs for the Palomar and Keck Telescopes, and the FIREBall balloon payload.

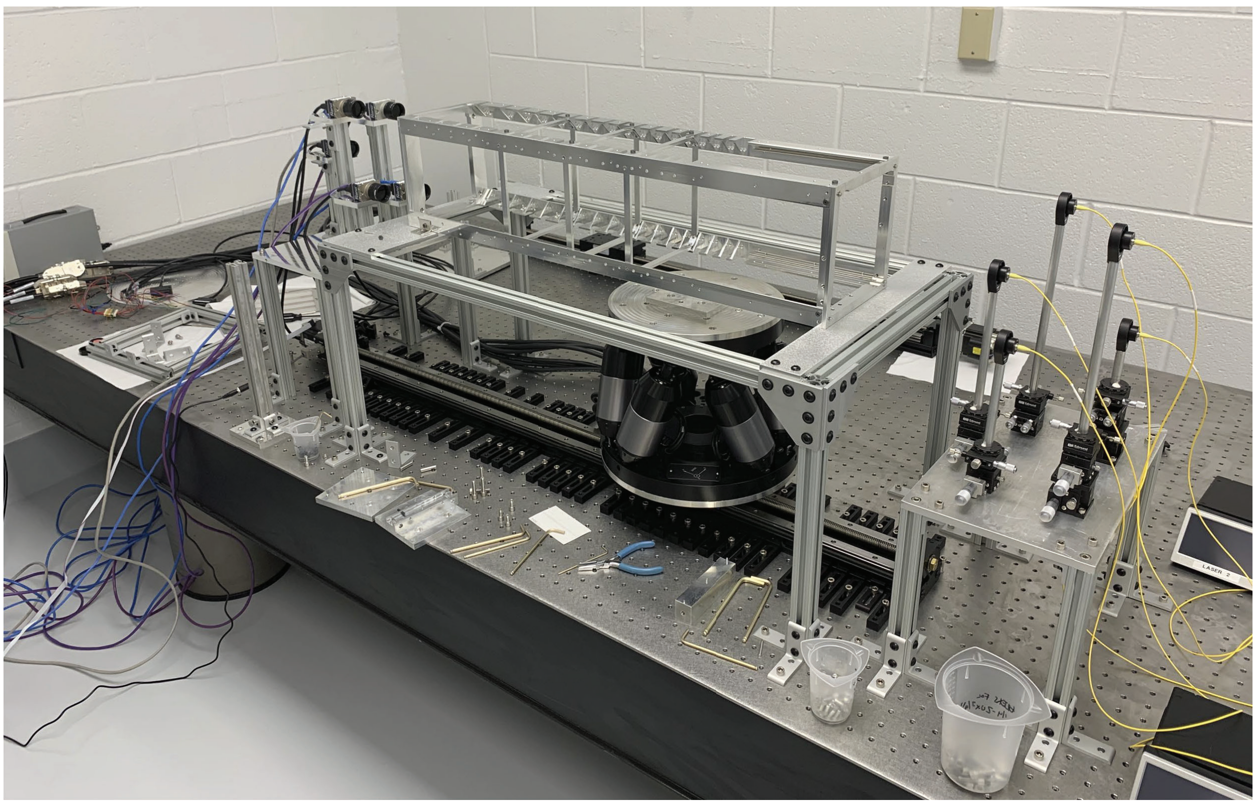
The Caltech Kavli Nanoscience Institute (KNI) is a 10000 ft^2 technical laboratory with a 7500 ft^2 cleanroom equipped with state-of-the-art instruments. The facility is managed full time by technical staff and is accessible to members of the Caltech and external academic communities. The KNI offers all fabrication tooling needed for tREXS-2 gratings, including two high-performance Raith electron-beam lithography tools, several dry- and wet-etch stations, and all tools needed for deposition, characterization, and grating pattern transfer.

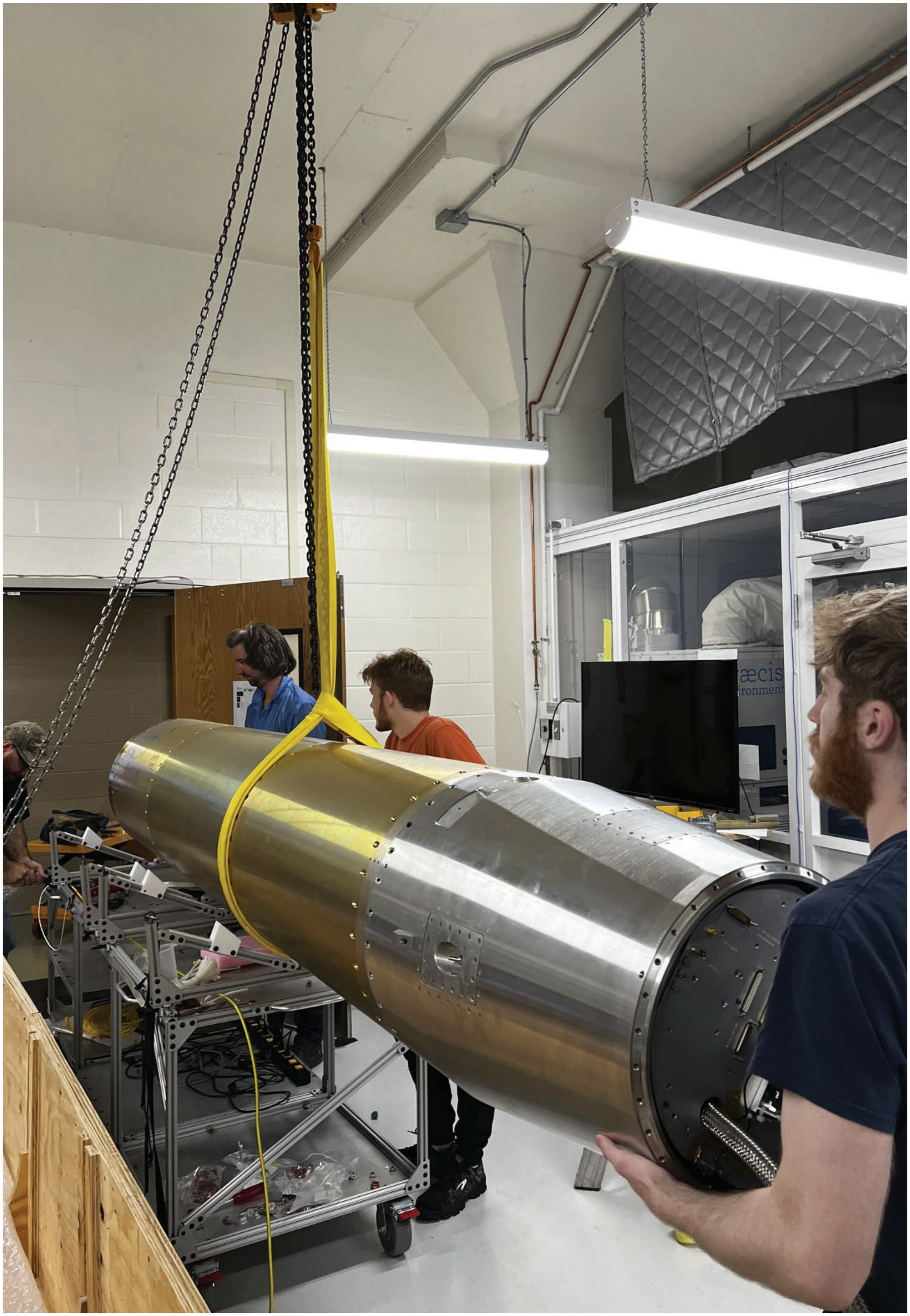
tREXS-2: The Rockets for Extended-source X-ray Spectroscopy

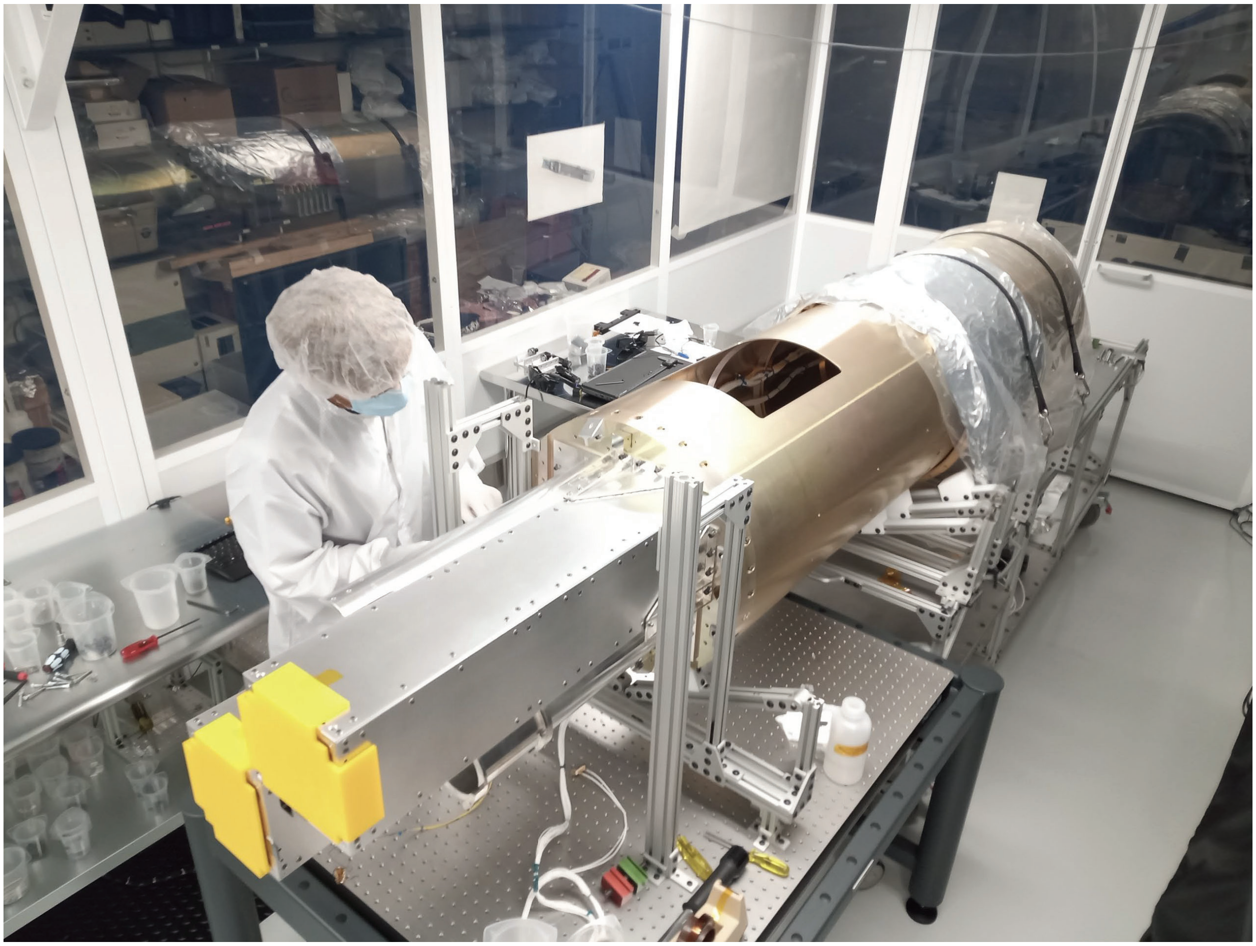
Facilities – Penn State

135/138/142 Davey Laboratory
The cleanrooms in 135 and 142 Davey Laboratory will be used for instrument build-up and the building of the third focuser channel respectively prior to the first rocket flight in 2024. The cleanroom in 142 contains the hexapod, linear stages, lasers, and cameras required to complete the alignment and build-up of the additional focuser channel. The cleanroom in 135 has access to a crane, allowing the instrument to be moved pose final assembly.

The lab space in 135 Davey Laboratory will be used for instrument testing and calibration. The lab space in 138 Davey Laboratory will be used for making the harnessing for the rail pumping system and instrument electronics section.







Nanofabrication Facility

The Nanofabrication Lab in the Penn State Materials Research Institute (MRI) supports nearly 100 research groups in science and engineering at the nano scale. The Nanofab is supported by full-time technical staff that maintain tools and support internal and external user research. The Penn State Nanofab was used to produce the current tREXS grating and has all tools necessary to produce the tREXS-2 gratings, including two Raith electron-beam lithography tools, reactive-ion etchers, wet- and dry-etch benches, and advanced microscopy for characterization.

tREXS-2: The Rockets for Extended-source X-ray Spectroscopy

Work Effort and Statement of Work

Institution	Person/Role	Year 1 FTE	Year 2 FTE	Year 3 FTE	Year 4 FTE
CIT	PI: Drew Miles	0.67	0.67	0.67	0.5
CIT	Co-I: Chris Martin	0.01	0.01	0.01	0.01
CIT	Research tech: TBD	1.0	1.0	1.0	1.0
CIT	Research tech: TBD	-	1.0	1.0	1.0
CIT	Technician: Marty Crabill	0.17	0.5	0.5	0.17
PSU	Co-I: James Tutt	0.5	0.33	0.5	0.33
PSU	Co-I: Randall McEntaffer	Unfunded	Unfunded	Unfunded	Unfunded
PSU	GRA: Ross McCurdy/TBD	0.5	0.5	0.5	0.5
PSU	GRA: TBD	0.5	0.5	0.5	0.5
PSU	ME: Bridget O'Meara	0.17	0.17	-	-
PSU	EE: Daniel Washington	0.17	0.33	0.17	
PSU	EE: Michael Betts	0.08	0.25	-	-
PSU	Technician: Jessica Mondoskin	0.5	0.17	-	-
PSU	Undergraduates	1.0	1.0	1.0	1.0
TOTAL FTEs		4.77	6.43	5.85	5.01

Year 1

In year 1 of this proposal we will launch the instrument from White Sands Missile Range to observe the Vela supernova remnant. In support of this launch, we will align and install the third optics channel, rebuild the instrument, and test and calibration the payload. We will integrate and perform field operations in advance of the launch. After the launch, the payload will be returned to the PI institution for post-flight calibration and analysis.

In support of this effort, Caltech personnel will travel to Penn State University to support instrument testing and calibration, Wallops Flight Facility to support payload integration and testing with NASA components, and launch operations at White Sands Missile Range.

Year 2

In year 2, we will implement upgrades to the tREXS payload in preparation for the second flight in year 3. Upgrades will include producing and replication new flight gratings, reoptimizing the detector readout electronics, and preparing the fourth instrument channel.

Year 3

In year 3 we will prepare and execute the second launch of this proposal, this time from a remote launch site (currently planned for Alaska) to access additional science targets. Effort will include rebuilding the payload with all four instrument channels, testing and calibrating the instrument at the PI institution, and supporting integration at Wallops Flight Facility and launch operations at the remote launch site. Following the launch, the payload will be returned to the PI institution for post-flight calibration and analysis.

Caltech personnel will travel to Wallops Flight Facility to support integration, and a remote launch site (Poker Range Research Flats is expected) to support field operations and the launch of the instrument.

Year 4

In year 4 we will finalize post-flight calibrations and data analysis from the third flight and prepare publications. We will also use year 4 to begin design of an orbital adaption of the instrument to be submitted to a later NASA solicitation, leveraging the instrument performance and testing outcomes from the preceding three years. Year 4 will also serve as contingency for the second flight of this program (currently planned for year 3) should any delays occur to push the second launch into year 4.

tREXS-2 Statement of work

Year 1

In Year 1, Penn State will support the proposal by preparing the payload for the re-flight of the tREXS payload. This will include upgrades to the payload as well as support for integration and testing, and launch operations. This support will require several personnel at Penn State including Dr. James Tutt (6 calendar months) to support the build-up and testing leading to the re-flight, Dr. Randall McEntaffer (1 calendar month) to assist the re-flight as required, a research technologist staff member (6 calendar months) to support the build-up and testing leading to the re-flight, a mechanical engineer (2 calendar months) to support the design and build-up of the payload, and 2 electrical engineers (2 calendar months and 1 calendar months respectively). The first electrical engineer will support improvements of the camera readout system and the second will update flight hardware and software. In addition to this support staff, two graduate students will be involved in all aspects of the re-flight of tREXS and undergraduates will also be brought in to support the re-flight efforts.

To support the proposal, Penn State personnel will travel to integration and testing at NASA Wallops Flight Facility and launch operations at White Sands Missile Range. Personnel will also travel to a conference to disseminate technology developments and science results.

Year 2

In year 2, Penn State will support the proposal by working on the upgrades to the tREXS payload in preparation for the second flight in year 3. This will include the relocation of the payload to the host institution and support from Penn State personnel to assist in this relocation. This support includes Dr. James Tutt (4 calendar months) to support the payload relocation to the PI host institution, upgrades to the focal plane camera, and upgrades to the payload electronics; Dr. Randall McEntaffer (1 calendar month) to assist the re-flight as required, a research technologist staff member (2 calendar months) to support the upgrades to the payload, a mechanical engineer (2 calendar months) to support upgrades to the payload, and 2 electrical engineers (4 calendar months and 3 calendar months respectively). The first electrical engineer will support upgrades to the focal plane camera and the second will update flight hardware and software. In addition to this support staff, two graduate students will be involved in all aspects of the tREXS redesign and two undergraduates will also be brought in to support the redesign efforts.

To support the proposal, Penn State personnel will travel to the PI host institution to aid in establishing the payload in a new lab facility. Personnel will also travel to a conference to disseminate technology developments.

Year 3

In year 3, Penn State will support the proposal by preparing the payload for a re-flight. This will include final build-up of the payload, integration and testing for the payload, and the launch campaign. This support will require several personnel at Penn State including Dr. James Tutt (6 calendar months) to support the re-flight, Dr. Randall McEntaffer (1 calendar month) to assist the re-flight as required, and an electrical engineer (2 calendar moths) to support final build-up of the payload camera and electronics hardware. In addition to this support staff, two graduate students will be involved in all aspects of the re-flight of tREXS and two undergraduates will also be brought in to support the re-flight efforts.

To support the proposal, Penn State personnel will travel to the PI host institution to aid in the final build-up and testing of the payload. Penn State personnel will travel to integration and testing at NASA Wallops Flight Facility and launch operations at a remote launch facility TBN. Personnel will also travel to a conference to disseminate technology developments and science results.

Year 4

In year 4, Penn State will support the proposal by working on the post-flight calibration of the payload and analysis of flight-data. This support includes Dr. James Tutt (4 calendar months) to support the post-flight calibration and Dr. Randall McEntaffer (1 calendar month) to assist the re-flight as required. In addition to this support staff, two graduate students will be involved in all aspects of the post-flight calibration and data analysis of tREXS and two undergraduates will also be brought in to support the post-flight efforts.

To support the proposal, Penn State personnel will travel to a conference to disseminate technology developments and science results.

PROPOSAL BUDGET

START DATE:	1/1/2024
END DATE:	12/31/2027
INFLATION	4.50%

YEARS	4

SENIOR PERSONNEL	NAME	BASE	YEAR 1 MONTHS	YEAR 1 %	YEAR 1 BUDGET	YEAR 2 MONTHS	YEAR 2 %	YEAR 2 BUDGET	YEAR 3 MONTHS	YEAR 3 %	YEAR 3 BUDGET	YEAR 4 MONTHS	YEAR 4 %	YEAR 4 BUDGET	TOTAL
PI	Miles, Drew		8.00	66.7%	48,767	8.00	66.7%	50,961	8.00	66.7%	53,254	6.00	50.0%	39,941	192,923
Co-PI	Martin, Christopher		0.12	1.0%	2,819	0.12	1.0%	2,946	0.12	1.0%	3,078	0.12	1.0%	3,078	11,921
TOTAL SENIOR PERSONNEL					51,586			53,907			56,333			43,019	204,845
Staff Benefits			24.03%		12,396			12,954			13,537			10,338	49,224
TOTAL SALARIES, STAFF BENEFITS					63,982			66,861			69,870			53,357	254,069
EQUIPMENT															
Fabrication					203,823			355,827			336,129			220,952	1,116,731
TOTAL EQUIPMENT					203,823			355,827			336,129			220,952	1,116,731
TRAVEL															
Total Domestic Travel					13,409			8,564			14,481			9,249	45,703
TOTAL TRAVEL					13,409			8,564			14,481			9,249	45,703
OTHER DIRECT COSTS															
Publications					2,000			2,000			2,000			2,000	8,000
TOTAL OTHER DIRECT COSTS					2,000			2,000			2,000			2,000	8,000
SUBAWARDS															
Subaward - 1st $25,000	Penn State				25,000										25,000
Subaward > $25,000					474,830			467,549			421,365			262,785	1,626,529
TOTAL SUBAWARD COSTS					499,830			467,549			421,365			262,785	1,651,529
TOTAL DIRECT COSTS					783,044			900,800			843,845			548,343	3,076,032
INDIRECT COST BASE					104,391			77,425			86,351			64,606	332,772
TOTAL INDIRECT COSTS			70.0%		73,073			54,197			60,445			45,224	232,940
GRAND TOTAL COSTS					856,117			954,998			904,290			593,567	3,308,972

Budget Justification

If selected for an award, the proposer anticipates the instrument of that award being a grant. Budgeted amounts include a 4.5% inflation adjustment for years 2 through 4.

Senior Personnel

Drew Miles, PI - Funds are requested for Drew Miles, who will be devoting 8.0 (66.7% FTE) calendar months in Years 1-3 and 6.0 (50% FTE) calendar months in Year 4 to executing all the proposed research as described in the statement of work.

Chris Martin, Co-I – Funds are requested for Dr. Martin who will be devoting 0.12 (1% FTE) calendar months to coordinate all research activities associated with the project and will be responsible for overall project management in addition to the lead PI.

Fringe Benefits

The Fringe Benefit rate of 24.03% is assessed on all salaries. This rate is based upon the University's most recent indirect cost agreement with the Office of Naval Research, dated October 3, 2022, and is subject to change.

Travel

The proposal requests funds for travel for the duration of the project. Costs are estimated based on current pricing and previous purchases for similar travel. Travel costs are estimated based on the following planned trips:

Domestic conferences – we request funds for 3 people to attend a domestic conference (SPIE Optics and Photonics) in years 2 and 4 of this award. Cost inputs calculated as of Nov. 2022:

- $400 flight based on LA to San Diego
- $74/day meal per diem x 7 days total travel days
- $161/day lodging per diem x 6 nights
- $60/day ground transportation x 6 days
- $610 conference registration fee (member rate)

International conferences – we request funds for 3 people to attend an international conference (SPIE Telescopes and Instrumentation) in years 1 and 3 of this award. Cost inputs calculated as of Nov. 2022:

- $1100 flight from LA to Tokyo
- $131/day meal per diem x 7 total travel days
- $208/day lodging per diem x 6 nights
- $60/day ground transportation x 6 days
- $910 conference registration fee (member rate)

Integration and testing – we request funds for 3 people to attend integration and testing of the instrument at Wallops Flight Facility for 25 days in year 1. In year 3, we request funding for 4 people for 25 days for the same purpose, with an increase in effort to compensate for the decrease in effort from our subcontract.

- $700 flight from LA to Virginia
- $64/day meal per diem

- $124/day lodging
- $60/day ground transportation

Launch – we request funds for 3 people to attend field operations and launch for the tREXS-2 instrument for 21 days in year 1 from White Sande Missile Range. In year 3, we request funding for 4 people to attend field operations and launch of the second flight, expected to be from Poker Flats, Alaska, for 30 days.

- $450 flight from LA to New Mexico (year 1)
- $59/day meal per diem
- $98/day lodging per diem
- $60/day ground transportation
- $750 flight from LA to Fairbanks (year 3)
- $86/day meal per diem
- $204/day lodging per diem
- $60/day ground transportation

Collaboration meetings – we request funding for 3 people to work at Penn State University for 30 days in year 1 to support instrument buildup and calibration preceding the launch in year 1.

- $800 flight from LA to State College, PA
- $69/day meal per diem
- $100/day lodging per diem
- $60/day ground transportation

<u>Publications</u>

We assume an average of $2000/year in all years for page fees for publications to be led from the PI institution throughout this project. Costs are estimated based on current pricing and previous purchases for similar expenses.

<u>Equipment/Fabrication Costs</u>

- In year 1 we budget for the acquisition of master grating substrates to make new gratings, based on the cost of comparable substrates acquired in the previous award from vendor Virginia semiconductor ($15000 budgeted).
- In year 2 we budget for the acquisition of grating replica substrates, the replication of the master gratings, wafers and modules used to align and integrate the gratings into the instrument, and tool/personnel time to dice the gratings. All costs based on comparable purchases in the previous award: $30000 for 200 fused-silica substrates from Sydor, $25000 replication fee from Philips SCIL Innovations, $10000 for spacer substrates from Sydor, $25000 to dice fused silica substrates from DISCO Technologies, and $8000 to manufacture grating modules.
- In year 1 we plan for the acquisition of fabrication consumables and fabrication tool/staff expense to develop the new master gratings, based on prior fabrication experience. Consumables budget ($800) covers electron-beam resist, substrate holders, tweezer, etc. and fabrication tool/staff expense of $15000 is estimated based on hours and person-time used to produce existing project gratings.
- In year 2 we budget for the final fabrication of the new master gratings.
- We plan for upgrades to the instrument electronics in year 1 and an optimization-focused

redesign in year 2, based on cost of COTS components as of Nov. 2022.

- In year 3 we plan for the acquisition of alignment apparatus to allow the fourth instrument channel to be aligned to the first three and the instrument focal-plane camera.
- In year 4 we budget for the acquisition of prototype MBS plates and frames for the adaption to the Pioneers concept, based on previous work for tREXS-1 by Vacco Industries and Laser Precision, Inc, respectively.
- We budget for an average of $10k each year in misc supplies and equipment to support the ongoing lab activities (instrument alignment, build, testing, etc.) and launch support.
- We plan for shipping of the instrument to/from integration and the launch location in year 1 and 3.
- We budget for one early-career research associate in year 1 and two early-career research associates in years 2-4. The research associates will support all aspects of the project, including instrument assembly, integration, testing, and launch support as well as design, characterization, and data analysis.
- Finally, senior research technician Marty Crabill will support post-launch activities in year 1 and lab support at the host institution in years 2-4.

Subaward

$1,651,529 in total is requested for a subaward to Penn State University. The subaward will be utilized by the organization to achieve project goals as described earlier in the Statement of Work.

Indirect Costs

The IDC approved rate of 70% is assessed on a modified total direct costs basis, where Equipment/Fabrication and subaward expenses over the first $25,000 are excluded from the calculation. This rate is based upon the University's most recent indirect cost agreement with the Office of Naval Research, dated October 3, 2022, and is subject to change.

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
875 NORTH RANDOLPH STREET
SUITE 1425
ARLINGTON, VA 22203-1995

IN REPLY REFER TO:

Agreement Date: September 29, 2022

NEGOTIATION AGREEMENT

INSTITUTION: **CALIFORNIA INSTITUTE OF TECHNOLOGY**
PASADENA, CALIFORNIA 91125

The Facilities and Administrative (F&A) cost rates contained herein are for use on grants, contracts and/or other agreements issued or awarded to the California Institute of Technology (Caltech) by all Federal Agencies of the United States of America, in accordance with the provisions and cost principles mandated by 2 CFR Part 200. These rates shall be used for forward pricing and billing purposes for Caltech's Fiscal Year 2023. This rate agreement supersedes all previous rate agreements/determinations related to these rates for Fiscal Year 2023.

Section I: RATES - TYPE: PROVISIONAL (PROV)

F&A Rates:

TYPE	FROM	TO	RATE	BASE	APPLICABLE TO	LOCATION
PROV	10/1/2022	9/30/2023	70.0%	(a)	Organized Research (except JPL)	On-Campus
PROV	10/1/2022	9/30/2023	26.0%	(a)	Organized Research (except JPL)	Off-Campus

DISTRIBUTION BASE

(a) Modified Total Direct Costs (MTDC) means all direct salaries and wages, applicable fringe benefits, materials and supplies, services, travel, and up to the first $25,000 of each subaward (regardless of the period of performance of the subawards under the award). MTDC excludes equipment, capital expenditures, charges for patient care, rental costs, tuition remission, scholarships and fellowships, participant support costs and the portion of each subaward in excess of $25,000.

SECTION II - GENERAL TERMS AND CONDITIONS

A. **LIMITATIONS**: Use of the rates set forth under Section I is subject to availability of funds and to any other statutory or administrative limitations. The rates are applicable to a given grant, contract or other agreement only to the extent that funds are available and consistent with any and all limitations of cost clauses or provisions, if any, contained therein. Acceptance of any or all of the rates agreed to herein is predicated upon the following conditions: (1) that no costs other than those incurred by the institution were included in this indirect cost pool as finally accepted and that such costs are legal obligations of the institution and allowable under governing cost principles; (2) that the same costs that have been treated as indirect costs are not claimed as direct costs; (3) that similar types of costs have been accorded consistent accounting treatment; and (4) that the information provided by the institution which was used as a basis for acceptance of the rates agreed to herein, and expressly relied upon by the Government in negotiating and accepting the said rates is not subsequently found to be materially incomplete or inaccurate.

B. **ACCOUNTING CHANGES**: The rates contained in Section I of this agreement are based on the accounting system in effect at the time the agreement was negotiated. Changes to the method(s) of accounting for costs, which affect the amount of reimbursement resulting from the use of these rates require the prior written approval of the authorized representative of the cognizant agency for indirect costs. Such changes include but are not limited to changes in the charging of a particular type of cost from indirect to direct. Failure to obtain such approval may result in subsequent cost disallowances.

C. **PROVISIONAL RATES**: The provisional rates contained in this agreement are subject to unilateral amendment by the Government or bilateral amendment by the contracting parties at any time.

D. **USE BY OTHER FEDERAL AGENCIES**: The rates set forth in Section I are negotiated in accordance with and under the authority set forth in 2 CFR Part 200. Accordingly, such rates shall be applied to the extent provided in such regulations to grants, contracts and other agreements to which 2 CFR Part 200 applies, subject to any limitations in part A of this section. Copies of this document may be provided by either party to other federal agencies to provide such agencies with documentary notice of this agreement and its terms and conditions.

E. **SPECIAL REMARKS**: The Government's agreement with the rates set forth in Section I is not an acceptance of Caltech's accounting practices or methodologies. Any reliance by the Government on cost data or methodologies submitted by Caltech is on a non-precedence-setting basis and does not imply Government acceptance.

Accepted:
FOR THE CALIFORNIA INSTITUTE OF TECHNOLOGY:

Sharon E. Patterson

SHARON E. PATTERSON
Associate Vice President for Finance and Treasurer

9/29/2022
Date

FOR THE U.S. GOVERNMENT:

SHARON GALES
Contracting Officer

10/3/2022
Date

For information concerning this agreement contact:
Sharon Gales
Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995
Phone: (571) 463-8028
E-mail: sharon.j.gales.civ@us.navy.mil

Astronomy and Astrophysics (Eberly College of Science) / The Pennsylvania State University
tREXS-2: The Rockets for Extended-source X-ray Spectroscopy
California Institute of Technology (National Aeronautics and Space Administration)
Project Dates: 01/01/2024 - 12/31/2027

	01/01/2024 - 12/31/2024	01/01/2025 - 12/31/2025	01/01/2026 - 12/31/2026	01/01/2027 - 12/31/2027	Total
Direct Costs					
Salaries (Category I)					
Tutt, James Henry (Principal Investigator)	49,370	34,094	53,401	36,876	173,741
@ 50% of time 12 months (6 months) years 1 & 3, @ 33.2% of time 12 months (4 months) years 2 & 4					
McEntaffer, Randall L (Co-Investigator)	0	0	0	0	0
@ 1% of time 12 months (0.12 months) ****NO SALARY****					
Mondoskin, Jessica (Technician)	19,095	6,593	0	0	25,688
@ 50% of time 12 months (6 months) years 1 @ 16.6% of time 12 months (2months) year 2					
O'Meara, Bridget (Other)	14,771	15,363	0	0	30,134
@ 16.6% of time 12 months (2 months)					
Washington, Daniel (Principal Investigator)	13,736	28,569	14,856	0	57,161
@ 16.6% of time 12 months (2months) years 1 & 3, @ 33.2% of time 12 months (4 months) year 2					
Betts, Michael (Other)	7,311	22,900	0	0	30,211
@ 8.3% of time 12 months (1 months) years 1 @ 25% of time 12 months (3 months) year 2					
Total Salaries	104,283	107,519	68,257	36,876	316,935
Graduate Assistants (Category II)					
2 - Grad Asst - Grade 19	59,670	62,057	64,539	67,120	253,386
@ 50% of time 9 AY months (4.5 months) post - comp					
Total Graduate Assistants	59,670	62,057	64,539	67,120	253,386
Wages (Category III)					
2 - Undergraduate Student - TBD	14,542	15,512	0	0	30,054
@ 40hr/wk, $15/hour, 12 SU weeks Years 1 & 2					
2 - Grad Asst-Summer	19,701	20,489	21,305	22,157	83,652
@ 50% of time 3 SU months (1.5 months)					
Total Wages	34,243	36,001	21,305	22,157	113,706
Student Wages (Category IV)					
2 - Undergraduate Student - TBD	10,906	11,634	0	0	22,540
@ 10hr/wk, $15/hour, 36 AY weeks					
Total Student Wages	10,906	11,634	0	0	22,540

Astronomy and Astrophysics (Eberly College of Science) / The Pennsylvania State University
tREXS-2: The Rockets for Extended-source X-ray Spectroscopy
California Institute of Technology (National Aeronautics and Space Administration)
Project Dates: 01/01/2024 - 12/31/2027

	01/01/2024 - 12/31/2024	01/01/2025 - 12/31/2025	01/01/2026 - 12/31/2026	01/01/2027 - 12/31/2027	Total
Total Salaries and Wages	209,102	217,211	154,101	126,153	706,567
Fringe					
Category I @ 36.00%	37,542	38,708	24,572	13,276	114,098
Category II @ 10.40%	6,206	6,454	6,712	6,981	26,353
Category III @ 8.00%	2,740	2,880	1,705	1,773	9,098
Category IV @ 0.40%	44	47	0	0	91
Total Fringe	46,532	48,089	32,989	22,030	149,640
Total Salaries, Wages and Fringe	255,634	265,300	187,090	148,183	856,207
Modified Total Direct Costs					
Domestic Travel Travel to participate in scientific conference, San Diego, CA Years 2 & 4	0	6,604	0	3,695	10,299
Domestic Travel Travel to Wallops - 1 month - I&T	15,350	0	10,650	0	26,000
Domestic Travel PSU travel to support Drew	0	7,900	7,900	0	15,800
Domestic Travel Launch - WSMR - 1 month-Trips 1 Persons/3 Days/21 Airfare/568 Per Diem/157 Ground transportation/Car Rental 50	12,645	0	0	0	12,645
Foreign Travel Travel to participate in scientific conference, Japan Years 1 & 3	16,575	0	10,364	0	26,939
Foreign Travel Launch - Remote - 1 month	0	0	34,750	0	34,750
Publications	1,500	1,500	1,500	1,500	6,000
Total Modified Total Direct Costs	301,704	281,304	252,254	153,378	988,640
Other Direct Costs					
Tuition Remission	14,088	14,651	15,237	15,847	59,823
Total Other Direct Costs	14,088	14,651	15,237	15,847	59,823
Total Direct Costs	315,792	295,955	267,491	169,225	1,048,463
F&A Costs (MTDC basis)					
F&A Rate: 61.00%	184,038	171,594	153,874	93,560	603,066
Total Requested From Sponsor	499,830	467,549	421,365	262,785	1,651,529

Budget Narrative
The Pennsylvania State University
Dr. James Tutt

Salaries:
The principal investigator is budgeted at the percentage of time shown using his/her actual salary in the calculation. The principal investigator's time includes both technical and project management functions. Any other individuals/positions shown are technical staff with the percentage of time shown and actual salaries used. For project time occurring after July 1 of any given year, the salaries have been adjusted at the University approved rate of 4%.

Personnel:
Co-Investigator – Randall McEntaffer (0.12 calendar month per year/no salary): Randall McEntaffer's effort is covered by his academic salary with Penn State, but he has freedom to self-assign research interests/efforts as needed.

Co-Investigator – James Tutt (6 calendar months effort years 1 and 3, 4 calendar months years 2 and 4): James Tutt will support the payload design, build, and testing across all years of the proposal, with additional effort during the years when a launch in scheduled. This will be to assist in integration and testing and launch operations.

Research Technologist - Jessica Mondoskin (6 calendar months effort year 1, 4 calendar months year 2): The research technologist will support the payload design, build, and testing across all years of the proposal, with additional effort during the years when a launch in scheduled. This will be to assist in integration and testing and launch operations.

ME - Bridget O'Meara (2 calendar months years 1 and 2): The Engineer will assist in the design and build-up of the payload.

EE – Daniel Washington (2 calendar months effort year 1 and 3, 4 calendar months year 2): The EE's role is to assist in the continued development of the camera readout system. Large scale changes to the electronics are planned during year 2 which requires more work effort.

EE – Michael Betts (1 calendar month effort in year 1, 3 calendar months effort in year 2): The EE's role is to update the firmware on the tREXS readout system. Few changes will be made before the re-flight in year 1, but more effort will be required before the second launch.

Two Graduate Assistants –TBN at 50% of 9 academic months and 50% of 3 summer months (4.5 academic months and 1.5 summer months) effort in all years: This students' roles are to be involved in every aspect of the proposal. They will be involved in the re-flight of the tREXS payload and in the re-build for the proposed second flight.

Two Undergraduates – TBN (10 hours per week during the semester and 40 hours per week over the summer in years 1 and 2): The undergraduates will be trained in laboratory tasks that are required for a rocket program.

Fringe Benefits:
FY23 – FIXED RATES
Fringe benefits are computed using the fixed rates of 36.0% applicable to Category I Salaries, 10.4% applicable to Category II Graduate Assistants, 8.0% applicable to Category III Wages, 0.4% applicable to Category IV Student Wages, and 25.4% for Category V, Postdoctoral Scholars and Fellows, for fiscal year 2023 (July 1, 2022, through June 30, 2023). If this proposal is funded, the rates quoted above shall, at the time of funding, be subject to adjustment for any period subsequent to June 30, 2023, if superseding Government approved rates have been established. Fringe benefit rates are negotiated and approved by the Office of Naval Research, Penn State's cognizant federal agency.

Travel:
Mileage estimates are based on the travel rate posted on the Penn State travel web site on Date. All travel will be in accordance with university travel regulations and mileage will be charged at the current rate on the date of travel.

Travel costs are estimated as follows:

Conferences – SPIE Optics and Photonics, San Diego, CA – years 2 and 4
Funding is for 1 trip for 2 people lasting 7 days in year 2 and 1 person lasting 7 days in year 4.

Conferences – SPIE International Conference – years 1 and 3
Funding is for 1 trip for 3 people lasting 7 days in year 1 and 2 people lasting 7 days in year 3 based on the conference being in Yokohama, Japan.

Integration and Testing – NASA Wallops Flight Facility, VA
Funding is for 3 people to go to integration and testing for 25 days in year 1 and for 2 people to go to integration and testing for 25 days in year 3. A reduced personnel effort in year 3 is expected due to the establishment of a group at the PI host institution

Launch – White Sands Missile Range, NM
Funding is for 3 people to go to launch operations for a month in year 1

Launch – remote location
Funding is for 2 people to go to integration and testing for 30 days in year 3. A reduced personnel effort in year 3 is expected due to the establishment of a group at the PI host institution

Penn State Support
Funding is for 2 people to travel to the PI host institution in years 2 and 3 to assist in the establishment of the group's lab and to help build-up the group for integration and testing, and launch operations.

Publication and Page Charges:
Funding is requested to enable the publication of results in peer reviewed open access journals with the expectation of 1 paper per year at $1,500/year.

Tuition:
Computed using the approved tuition charges for a one-half (1/2) time graduate assistant of $10,190 (pre-comprehensive) and $3,320 (post-comprehensive) for fall and spring semesters 2022/2023, and $5,095 for summer session 2023. The charges quoted above are increased by three percent (4%) for any project period occurring after summer session 2023, and each summer session thereafter.

F&A – On Campus Research:
F&A rates are negotiated and approved by the Office of Naval Research, Penn State's cognizant federal agency. Penn State's current provisional on-campus rate for research is 61.0% of MTDC from July 1, 2022, through June 30, 2023. New awards and new competitive segments with an effective date of July 1, 2023, or later shall be subject to adjustment when superseding Government approved rates are established. Per 2 CFR 200 (Appendix III, Section C.7), the actual F&A rates used will be fixed at the time of the initial award for the duration of the competitive segment.

Definition of a Year:
The University defines the term "year" as the fiscal year (July – June).

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
875 NORTH RANDOLPH STREET
SUITE 1425
ARLINGTON, VA 22203-1995

IN REPLY REFER TO:

June 23, 2022

NEGOTIATION AGREEMENT

INSTITUTION: **THE PENNSYLVANIA STATE UNIVERSITY**
UNIVERSITY PARK, PA 16801-3857

The Facilities and Administrative (F&A) cost rates contained herein are for use on grants, contracts and/or other agreements issued or awarded to the Pennsylvania State University (PSU) by all Federal Agencies of the United States of America, in accordance with the provisions and cost principles mandated by 2 CFR Part 200. These rates shall be used for forward pricing and billing purposes for the PSU's Fiscal Year 2023. This rate agreement supersedes all previous rate agreements/determinations related to these rates for Fiscal Year 2023.

SECTION I – RATES – TYPE: PROVISIONAL (PROV)

UNIVERSITY PARK

TYPE	FROM	TO	RATE	BASE	APPLICABLE TO	LOCATION
PROV	07/01/22	06/30/23	61.0%	(a)	Organized Research	On-Campus
PROV	07/01/22	06/30/23	26.0%	(a)	Organized Research	Off-Campus
PROV	07/01/22	06/30/23	52.0%	(a)	Instruction	On-Campus
PROV	07/01/22	06/30/23	26.0%	(a)	Instruction	Off-Campus

APPLIED RESEARCH LABORATORY

TYPE	FROM	TO	RATE	BASE	APPLICABLE TO	LOCATION
PROV	07/01/22	06/30/23	10.0%	(a)	Organized Research - ARL[1]	On-Campus
PROV	07/01/22	06/30/23	10.0%	(a)	Organized Research - ARL	Off-Campus

HERSHEY COLLEGE OF MEDICINE

TYPE	FROM	TO	RATE	BASE	APPLICABALE TO	LOCATION
PROV	07/01/22	06/30/23	66.0%	(a)	Organized Research - HCM[2]	On-Campus
PROV	07/01/22	06/30/23	26.0%	(a)	Organized Research - HCM	Off-Campus

[1] Applied Research Laboratory
[2] Hershey College of Medicine

DISTRIBUTION BASE

(a) Modified Total Direct Cost (MTDC) means all direct salaries and wages, applicable fringe benefits, materials and supplies, services, travel, and up to the first $25,000 of each subaward (regardless of the period of performance of the subawards under the award). MTDC excludes equipment, capital expenditures, charges for patient care, rental costs, tuition remission, scholarships and fellowships, participant support costs, and the portion of each subaward in excess of $25,000.

SECTION II - GENERAL TERMS AND CONDITIONS

A. **LIMITATIONS**: Use of the rates set forth under Section I is subject to availability of funds and to any other statutory or administrative limitations. The rates are applicable to a given grant, contract or other agreement only to the extent that funds are available and consistent with any and all limitations of cost clauses or provisions, if any, contained therein. Acceptance of any or all of the rates agreed to herein is predicated upon the following conditions: (1) that no costs other than those incurred by the institution were included in this indirect cost pool as finally accepted and that such costs are legal obligations of the institution and allowable under governing cost principles; (2) that the same costs that have been treated as indirect costs are not claimed as direct costs; (3) that similar types of costs have been accorded consistent accounting treatment; and (4) that the information provided by the institution which was used as a basis for acceptance of the rates agreed to herein, and expressly relied upon by the Government in negotiating and accepting the said rates is not subsequently found to be materially incomplete or inaccurate.

B. **ACCOUNTING CHANGES**: The rates contained in Section I of this agreement are based on the accounting system in effect at the time the agreement was negotiated. Changes to the method(s) of accounting for costs, which affect the amount of reimbursement resulting from the use of these rates require the prior written approval of the authorized representative of the cognizant agency for indirect costs. Such changes include but are not limited to changes in the charging of a particular type of cost from indirect to direct. Failure to obtain such approval may result in subsequent cost disallowances.

C. **PROVISIONAL RATES**: The provisional rates contained in this agreement are subject to unilateral amendment by the Government or bilateral amendment by the contracting parties at any time.

D. **USE BY OTHER FEDERAL AGENCIES**: The rates set forth in Section I are negotiated in accordance with and under the authority set forth in 2 CFR Part 200. Accordingly, such rates shall be applied to the extent provided in such regulations to grants, contracts, and other agreements to which 2 CFR Part 200 applies, subject to any limitations in part A of this section. Copies of this document may be provided by either party to other federal agencies to provide such agencies with documentary notice of this agreement and its terms and conditions.

E. **SPECIAL REMARKS**:

1. The rates included in Section I are not intended to be applied to Intergovernmental Personnel Act (IPA) costs. If the Pennsylvania State University elects to seek

reimbursement of F&A or internal overhead costs associated with IPA agreements, then the University and the Office of Naval Research shall establish special F&A and/or internal overhead rates for IPA agreements in accordance with the provisions of 2 CFR Part 200.

2. The Government's agreement with the rates set forth in Section I is not an acceptance of Pennsylvania State University's accounting practices or methodologies. Any reliance by the Government on cost data or methodologies submitted by Pennsylvania State University is on a non-precedence-setting basis and does not imply Government acceptance.

Accepted:

FOR PENNSYLVANIA STATE UNIVERSITY:	FOR THE U.S. GOVERNMENT:
	TINGLE.BETTY.JOHNSON.1204289359 Digitally signed by TINGLE.BETTY.JOHNSON.1204289359 Date: 2022.06.27 09:15:55 -04'00'
Joseph J. Doncsecz Associate Vice President for Finance and Corporate Controller	Betty J. Tingle Contracting Officer
6/24/22	June 27, 2022
Date	Date

For information concerning this agreement contact:
Betty Tingle, Contracting Officer
Office of Naval Research

Phone: (703) 696-7742
E-mail: betty.tingle@navy.mil