# 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<br>**Judd Bowman** | E-mail Address<br>**judd.bowman@asu.edu** | Phone Number<br>**480-965-8880** |

Street Address (1): **550 E Tyler Mall**
Street Address (2): **P.O. Box 871404**

| | | | |
|---|---|---|---|
| City<br>**Tempe** | State / Province<br>**AZ** | Postal Code<br>**85287-1404** | Country Code<br>**US** |

Proposal Title : **Phoenix: Thermal Imaging to Explore the Impact of Urban Heat Islands on the Environment**

| Proposed Start Date | Proposed End Date | Total Budget |
|---|---|---|
| **02 / 01 / 2016** | **08 / 01 / 2017** | **No budget required** |

## SECTION II - Application Information

| NASA Program Announcement Number | NASA Program Announcement Title |
|---|---|
| **NNH15ZDA010C** | **Undergraduate Student Instrument Project (USIP) Student Flight Research Opportunity (SFRO)** |

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

| 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

| DUNS Number | CAGE Code | Employer Identification Number (EIN or TIN) | Organization Type |
|---|---|---|---|
| **943360412** | **4B293** | | **2A** |

| | |
|---|---|
| Organization Name (Standard/Legal Name)<br>**Arizona State University** | Company Division<br>**ARIZONA STATE UNIVERSITY** |
| Organization DBA Name<br>**ORSPA** | Division Number<br>**6011** |

Street Address (1): **660 S MILL AVE STE 312**
Street Address (2):

| | | | |
|---|---|---|---|
| City<br>**TEMPE** | State / Province<br>**AZ** | Postal Code<br>**85281** | Country Code<br>**USA** |

## SECTION IV - Proposal Point of Contact Information

| Name | Email Address | Phone Number |
|---|---|---|
| **Judd Bowman** | **judd.bowman@asu.edu** | **480-965-8880** |

## SECTION V - Certification and Authorization

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

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

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

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

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

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

| | |
|---|---|
| PI Name : **Judd Bowman** | NASA Proposal Number<br>TBD on Submit |
| Organization Name : **Arizona State University** | |

Proposal Title : **Phoenix: Thermal Imaging to Explore the Impact of Urban Heat Islands on the Environment**

## SECTION VI - Team Members

| | | | |
|---|---|---|---|
| Team Member Role<br>**PI** | Team Member Name<br>**Judd Bowman** | Contact Phone<br>**480-965-8880** | E-mail Address<br>**judd.bowman@asu.edu** |
| Organization/Business Relationship<br>**Arizona State University** | | Cage Code<br>**4B293** | DUNS#<br>**943360412** |
| International Participation<br>**No** | U.S. Government Agency | | Total Funds Requested<br>**0.00** |

| | | | |
|---|---|---|---|
| Team Member Role<br>**Co-I** | Team Member Name<br>**Nathaniel Butler** | Contact Phone<br>**510-402-8652** | E-mail Address<br>**nat.butler@asu.edu** |
| Organization/Business Relationship<br>**Arizona State University** | | Cage Code<br>**4B293** | DUNS#<br>**943360412** |
| International Participation<br>**No** | U.S. Government Agency | | Total Funds Requested<br>**0.00** |

| | | | |
|---|---|---|---|
| Team Member Role<br>**Co-I** | Team Member Name<br>**Philip Christensen** | Contact Phone<br>**480-965-1790** | E-mail Address<br>**phil.christensen@asu.edu** |
| Organization/Business Relationship<br>**ARIZONA STATE UNIVERSITY** | | Cage Code<br>**03HE7** | DUNS#<br>**806345658** |
| International Participation<br>**No** | U.S. Government Agency | | Total Funds Requested<br>**0.00** |

| | | | |
|---|---|---|---|
| Team Member Role<br>**Co-I** | Team Member Name<br>**Thomas Sharp** | Contact Phone<br>**480-965-3071** | E-mail Address<br>**tom.sharp@asu.edu** |
| Organization/Business Relationship<br>**Arizona State University** | | Cage Code<br>**4B293** | DUNS#<br>**943360412** |
| International Participation<br>**No** | U.S. Government Agency | | Total Funds Requested<br>**0.00** |

| | | | |
|---|---|---|---|
| Team Member Role<br>**Co-I** | Team Member Name<br>**Jekanthan Thangavelautham** | Contact Phone<br>**617-301-1301** | E-mail Address<br>**jekan@asu.edu** |
| Organization/Business Relationship<br>**Arizona State University** | | Cage Code<br>**4B293** | DUNS#<br>**943360412** |
| International Participation<br>**No** | U.S. Government Agency | | Total Funds Requested<br>**0.00** |

| | | | |
|---|---|---|---|
| Team Member Role<br>**Collaborator** | Team Member Name<br>**Gary Yale** | Contact Phone<br>**928-777-6966** | E-mail Address<br>**yaleg@erau.edu** |
| Organization/Business Relationship<br>**Embry-Riddle Aeronautical University, Inc.** | | Cage Code<br>**7B563** | DUNS#<br>**052104791** |
| International Participation<br>**No** | U.S. Government Agency | | Total Funds Requested<br>**0.00** |

|  |  |
|---|---|
| PI Name : **Judd Bowman** | NASA Proposal Number<br>TBD on Submit |
| Organization Name : **Arizona State University** |  |

Proposal Title : **Phoenix: Thermal Imaging to Explore the Impact of Urban Heat Islands on the Environment**

## SECTION VII - Project Summary

**Urban environments have become an important component of the global climate system, yet regional (km-scale) environmental monitoring of cities and their surroundings remains lacking. Routine orbital imaging of cities can address the effects of urbanization on local and regional land-atmosphere interactions, air quality, health, hazard assessment, water and energy transportation, and other climate factors. We propose a 3U CubeSat to demonstrate the effectiveness of nanosat platforms to conduct scientific investigations of urban environments. The Phoenix CubeSat will carry a thermal-IR imaging payload to study spatial and temporal changes in the heat properties of Phoenix, Arizona. The imager is based on the THESIS instrument developed by an ASU student using commercial micro-bolometer arrays. The system will yield secondary science from thermal imaging of ocean currents, volcanic plumes, and other surface processes.**

**Minimum orbital requirements are satisfied by 40-degree inclinations and 400 km or higher altitudes. Launch will be coordinated through CSLI and operations will be conducted from ASU’s Tempe campus using its ground data station.**

**Phoenix will be designed and fabricated by ASU’s Sun Devil Satellite Lab undergraduate organization with mentoring from an ASU graduate student and faculty, including the PI and Prof. Phil Christensen. Senior capstone teams from ASU’s Schools of Engineering will work with interdisciplinary teams of geoscience and sustainability undergraduates to conduct the mission. ASU will create new internships for journalism undergraduates to be embedded in the project for documentation. Graphic design undergraduates will provide dedicated artwork for the spacecraft, mission materials, and data analytics.**

| | |
|---|---|
| PI Name : **Judd Bowman** | NASA Proposal Number<br>TBD on Submit |
| Organization Name : **Arizona State University** | |

Proposal Title : **Phoenix: Thermal Imaging to Explore the Impact of Urban Heat Islands on the Environment**

## 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 : **Judd Bowman** | NASA Proposal Number<br>TBD on Submit |
| Organization Name : **Arizona State University** | |

Proposal Title : **Phoenix: Thermal Imaging to Explore the Impact of Urban Heat Islands on the Environment**

## SECTION VIII - Other Project Information

### Environmental Impact

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

Environmental Impact Explanation:

Exemption/EA/EIS Explanation:

| | |
|---|---|
| PI Name : **Judd Bowman** | NASA Proposal Number<br>TBD on Submit |
| Organization Name : **Arizona State University** | |

Proposal Title : **Phoenix: Thermal Imaging to Explore the Impact of Urban Heat Islands on the Environment**

## 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 : **Judd Bowman** | NASA Proposal Number<br>TBD on Submit |
| Organization Name : **Arizona State University** | |
| Proposal Title : **Phoenix: Thermal Imaging to Explore the Impact of Urban Heat Islands on the Environment** | |

## SECTION IX - Program Specific Data

**Question 1 : Short Title:**

**Answer: Phoenix 3U CubeSat To Study Urban Heat Islands**

**Question 2 : Type of institution:**

**Answer: Educational Organization**

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

**Answer: No**

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

**Answer: N/A**

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

**Answer: No**

**Question 6 : Research Category:**

**Answer: 7) Suborbital rocket/balloon/airplane investigation**

**Question 7 : Team Members Missing From Cover Page:**

**Answer:**

**Question 8 : 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 9 : I have identified the export-controlled material in this proposal.**

**Answer: N/A**

**Question 10 : 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 11 : Does the proposed work include any involvement with collaborators in China or with Chinese organizations, or does the proposed work include activities in China?**

**Answer: No**

**Question 12 : Are you planning for undergraduate students to be involved in the conduct of the proposed investigation?**

**Answer: Yes**

**Question 13 : If yes, how many different undergraduate students?**

**Answer: 20**

**Question 14 : What is the total number of student-months of involvement for all undergraduate students over the life of the proposed investigation?**

**Answer: 360**

**Question 15 : Provide the names and current year (1,2,3,4) for any undergraduate students that have already been identified.**

**Answer:**

**Question 16 : Are you planning for graduate students to be involved in the conduct of the proposed investigation?**

**Answer: Yes**

**Question 17 : If yes, how many different graduate students?**

**Answer: 1**

**Question 18 : What is the total number of student-months of involvement for all graduate students over the life of the proposed investigation?**

**Answer: 4**

**Question 19 : Provide the names and current year (1,2,3,4, etc.) for any graduate students that have already been identified.**

**Answer:**

**Question 20 : Space Grant**

**Answer: Yes**

**Question 21 : Are all funded team members, including the PI, U.S. Citizens?**

**Answer: Yes**

**Question 22 : Sub-orbital platform**

**Answer: CubeSat**

**Question 23 : Requested Funding**

**Answer: $198,128**

**Question 24 : Total Project Cost**

**Answer: $198,128**

| | |
|---|---|
| PI Name : **Judd Bowman** | NASA Proposal Number<br>TBD on Submit |
| Organization Name : **Arizona State University** | |
| Proposal Title : **Phoenix: Thermal Imaging to Explore the Impact of Urban Heat Islands on the Environment** | |

## SECTION X - Budget

**Total Budget: No budget required**

## B. TABLE OF CONTENTS

## SECTION C: TEAM DEFINITION

**A. Team Definition:** This Space Grant Consortium proposal for OE funding was developed and written by the proposing ASU undergraduate student team and edited by the PI.

The proposed *Phoenix* 3U cubesat mission aims to investigate increasingly important urban heat island effects on the environment, focusing on the Phoenix, Arizona metropolitan region (home to ASU campuses), as well as several other U.S. cities, including Seattle, Minneapolis, New York, and Honolulu. The planned science investigation acquires regular thermal images of urban communities to address the evolving and variable role of urban environments on climate at regional and global scales, while providing a direct and immediate local impact for the student team and for our many of our home cities around the U.S.

The *Phoenix* project builds on existing student activities at ASU. The science investigation was conceived by our team members participating in *SES 494 Commercialization Opportunities in Space*, where students are challenged to build business cases for entrepreneurial activities exploiting the space environment. Our space commercialization team pitched CubeSat-based Earth-observing thermal imaging applications to members of the *Sun Devil Satellite Lab (SDSL) student club* and others at a weekly engineering coffee meeting. The project was selected as the most compelling to pursue in USIP. Our specific science objective was further strengthened by our science team members who had recently completed a unit on urban heat islands in *SOS 100 Introduction to Sustainability*, instructed by faculty mentor Brigette Bavousett. This project leverages the work of our graduate student mentor, Mike Veto, who developed the core design of our thermal infrared camera payload as part of his undergraduate senior thesis, in addition to lessons from *AEE 445 Fundamentals of Spacecraft Design, AEE 462 Space Vehicle Dynamics and Control,* and *SES 494 Interplanetary CubeSat Design I,* instructed by faculty mentors Daniel White and Co-I Jekan Thanga. Lastly, *Phoenix* builds on the longstanding interest of faculty mentor Co-I Phil Christensen in small satellites for monitoring urban environments (e.g. CitySat concept).

The project plan proposed here has been developed by a strong interdisciplinary team of 22 participating students, one graduate mentor, and 13 faculty mentors. The tables below summarize the core team already in place. Additional students will join the team through course offerings and internship competitions associated with the project once it begins. Our partner institution is Embry Riddle Aeronautical University (ERAU) in Prescott, Arizona. ERAU will recruit a student team to participate in telemetry communications, high-altitude balloon tests, and science operations training. Planned public engagement activities will bring the experience of the mission to the entire ASU and ERAU campus populations.

### Faculty Mentors

| Name | Department | Summary |
|---|---|---|
| Judd Bowman (PI) | School of Earth and Space Exploration | Dr. Bowman will guide the project and be the main mentor to participating students. He will co-instruct a new cross-listed cubesat design course. |
| Nat Butler (Co-I) | School of Earth and Space Exploration | Dr. Butler will integrate cubesat software design into his 300-level numerical methods course. |
| Jekan Thanga (Co-I) | School of Earth and Space Exploration | Dr. Thanga instructs the Earth and Space Exploration senior capstone course. He will provide training on space systems engineering and design. |

| | | |
|---|---|---|
| Thomas Sharp (Co-I) | School of Earth and Space Exploration | Dr. Sharp will provide mentoring and expertise regarding engineering and design as well as scientific implications of the project. |
| Philip Christensen (Co-I) | School of Earth and Space Exploration | Dr. Christensen is an expert on infrared systems for planetary science. He will provide mentoring and expertise for three students to work in his group. He will integrate the project into his introductory exploration systems design course. |
| Erinanne Saffell | School of Geographical Sciences and Urban Planning | Dr. Saffell advised the student science team on environmental effects of heat islands for this proposal and will work with the science team to plan and interpret observations. |
| David Sailor | School of Geographical Sciences and Urban Planning | Dr. Sailor will provide mentoring and expertise regarding environmental effects of heat islands |
| Brigitte Bavousett | Julie Ann Wrigley Global Institute of Sustainability | Dr. Bavousett is an expert on local urban planning and will advise the student team on local partnerships and dissemination within the Phoenix metropolitan area. |
| Daniel White | Ira A. Fulton College of Engineering | Dr. White is the faculty advisor for the Sun Devil Satellite Lab student club that will lead the design and fabrication of the cubesat. He will assist with technical coordination. |
| Fran Matera | Walter Cronkite School of Journalism and Mass Communication | Dr. Matera, is the instructor for the Public Relations Laboratory. He will coordinate our journalism professional internship program. |
| Lance Gharavi | Herberger Institute for Design and the Arts | Dr. Gharavi will support graphic and performance art students to serve as creative design team members, aiding with mission development and visual arts. He will co-instruct a new cross-listed cubesat design course. |
| Jacob Pinholster | Herberger Institute for Design and the Arts | Dr. Pinholster will provide mentoring and help create media content to communicate the mission of Phoenix |
| Kaela Martin | Embry-Riddle Aeronautical Univ. | Dr. Martin will help students operate the amateur radio station on Embry-Riddle's campus for communicate with high altitude balloons and the satellite. |
| Gary Yale | Embry-Riddle Aeronautical Univ. | Dr. Yale will provide mentoring on telemetry and high-altitude balloon testing. He will be the lead mentor of 5-10 students at Embry Riddle. |

## Graduate Mentor

| | | |
|---|---|---|
| Michael Veto | School of Earth and Space Exploration | Mr. Veto will provide day-to-day support to the student team and expertise in thermal IR camera integration on cubesats. This project is based on lessons from his THESIS instrument, which he began as an ASU undergraduate. |

## Student Team

| Name | Role | Mayor | Year | Team |
|---|---|---|---|---|
| Sarah Rogers | Team Leader | Aerospace Eng. | Freshman | SDSL |
| Jaime Sanchez de la Vega | Project Manager | Aerospace Eng. | Sophomore | SDSL |
| William Merino | Project Scientist | Exploration Systems Design | Junior | SDSL |
| Chad Stewart | Systems Engineer | Aerospace Eng. | Senior | SDSL |
| Jesus Acosta | Payload Lead | Mechanical Eng. | Junior | SDSL |
| Sarah Smallwood | Payload | Aerospace Eng. | Junior | SDSL |
| Raymond Barakat | Power Lead | Electrical Eng. | Junior | SDSL |
| Aditya Rai Khuller | Power | Aerospace Eng. | Freshman | SDSL |
| Zachary Burnham | Communications Lead | Electrical Eng. | Junior | SDSL |

| | | | | |
|---|---|---|---|---|
| TBD (2-3 students) | Communications | TBD | TBD | Embry-Riddle Aeronautical Univ. |
| Bradley Cooley | Flight Software Lead | Computer Science | Junior | SDSL |
| Shota Ichikawa | ADCS Lead | Aerospace Eng. | Senior | SDSL |
| Ryan Fagan | ADCS | Aerospace Eng. | Freshman | SDSL |
| Eduardo Vinciguerra | Thermal Lead | Mechanical Eng. | Junior | SDSL |
| Ryan Czerwinski | Thermal | Aerospace Eng. | Freshman | SDSL |
| Mireya Ochoa | Thermal | Earth and Space Exploration | Junior | SDSL |
| Ifeanyi Umunna | Space Commercialization | Aerospace Eng. | Junior | Space Commercialization |
| Jabril Muhammad | Space Commercialization | Astrophysics | Senior | Space Commercialization |
| Nick Price | Space Commercialization | Biochemistry | Senior | Space Commercialization |
| Tory Luttermoser | Science | Geological Sciences | Sophomore | Sustainability |
| Kezman Saboi | Science | Earth and Space Exploration | Sophomore | Sustainability |
| Giana-Maria Parisi | Science | Sustainability | Freshman | Sustainability |
| Jake Shellenberger | Risk Management | Exploration Systems Design | Junior | Business |
| TBD (2-3 students) | Public Relations | Journalism, Web Development, Social Media | TBD | Journalism |
| TBD (2-3 students) | Creative Design | Graphic Design, Film, Dance, Theater | TBD | Creative |
| TBD (5 students) | High Altitude Balloon Tests | TBD | TBD | Embry-Riddle Aeronautical Univ. |

## B. Training and Mentoring Plan

Through the *Phoenix* mission, ASU and ERAU faculty mentors will provide a comprehensive array of formal and informal training and mentoring to the interdisciplinary student team in order to prepare the next generation of creative, project-based leaders for NASA and the United States. Learning of core engineering, science, creative-design, communication, and management skills will be supported through formal classroom lessons, as well as informal, unstructured activities. The project bridges classroom instruction, project-based capstone activities, professional internships, and extracurricular self-driven student organization experience. Teamwork across interdisciplinary boundaries will be integral to the project. We have arranged for *Phoenix* to be connected to for-credit and/or paid student experiences in six of ASU's schools, including: art and design, journalism, engineering, sustainability science, geographical and urban planning, and Earth and space exploration.

### Integration into Courses

The School of Earth and Space Exploration and the Herberger Institute for Design at ASU plan the creation of a cross-listed interdisciplinary hands-on course to begin Fall 2016. The course is intended for the core student team members on the project. Through the course, our design, science, journalism, and engineering students will collaborate for credit on project-based activities contributing to the actual development of *Phoenix* cubesat. At the same time, our student team will learn the unique perspectives brought to project design by an interdisciplinary team. Faculty mentors Gharavi and Bowman plan to instruct the course and will pair hands-on activities with related group discussions led weekly by each of the 13 faculty mentors on the project. The discussions will cover the full range of disciplines on the project, from technical design to communication to sustainability science.

Faculty mentor Christensen will leverage *Phoenix* to introduce infrared instrumentation into his undergraduate course *SES 100 An Introduction to Space Exploration*. This course is taken by a large community of freshman undergraduate students studying in the areas of Aerospace Engineering (Astronautics) and Earth and Space Exploration, thus enabling them to gain a strong foundation in the principles of space exploration during the early stages of their college career. The course is themed around the search for life in the Solar System. Student teams are challenged to design and a build a simple planetary imaging system able to identify motion of an object (e.g. an alien lifeform) on the ground when flown on a helium balloon to an altitude of 100 feet. Christensen plans to leverage the *Phoenix* mission by augmenting the science objective in the course to include a challenge to identify a hot object in the field, as might indicate the presence of a lifeform.

The *Computer Science* and *Computer Systems Engineering capstone courses* at ASU are year-long project-based programs in which teams of five students are matched to submitted faculty proposals and then proceed through the entire engineering cycle from establishing design requirements to delivering a software solution. We will provide at least two software projects for the computer science capstone program. These projects will be to implement the CubeSat onboard command and imaging processing and to implement the ground-based data analysis pipeline. The projects will be overseen by our student team and the results will be directly integrated into mission operations. Faculty mentor Bowman has successfully advised computer science capstone teams to implement drone attitude determination and control, petabyte-scale database management and visualization, and Bluetooth beacon tracking in mobile apps. In addition, software development for CubeSat missions is a planned part of future offerings of faculty mentor Butler's *SES 350 Engineering Systems and Experimental Problem Solving*. *SES 350* students will apply computer programming solutions to support planned and future ASU CubeSat's as part of the course's month-long final project.

Faculty mentors Thanga and White will use *Phoenix* examples in their spacecraft design courses *AEE 445 Fundamentals of Spacecraft Design, AEE 462 Space Vehicle Dynamics and Control*, and *SES 494 Interplanetary CubeSat Design I*. These courses will provide opportunities for *Phoenix* student team members to present and discuss with enrolled students the mission design components and lessons learned through their direct experiences. This will develop the communication skills of the student team members, while benefiting the learning experience for students in the courses since it has been shown that peer-to-peer communication is an effective educational tool.

An essential part of this project is outreach and reporting of information to the public to promote student led research in space exploration and to promote STEM education and careers. To help our team define an effective communication strategy, we will partner with the *Public Relations*

*Laboratory* (PR Lab) in the Cronkite School of Journalism and Mass Communication at ASU. The PR Lab is a full-immersion capstone for students studying public relations. This capstone experience employs advanced public relations students to develop PR campaigns and strategies for real clients. The lab's services include: strategic communications plans and campaigns; crisis communication; event planning and promotion; image and reputation management; internal and external communication management; and corporate communications. We will participate as a PR-Lab client to develop a PR strategy and proposal in the spring 2016 semester and to implement that plan in the following fall 2016 and spring 2017 semesters. We will coordinate this activity with faculty mentor Matera, who leads the PR Lab and who has worked with ASU Space Grant in the past. Students from the PR Lab, Herberger Institute for Design, and from science and engineering will collaborate to create promotional content, including short video documentaries, social media posts, a project web site, and other materials.

## Student Mentoring and Organization Structure

All *Phoenix* faculty mentors will meet regularly with the student team to advise on relevant aspects of the project. In addition to technical mentoring, the faculty mentors will engage in psychosocial mentoring by hosting team social events to celebrate major milestones and to provide “stress relief”, wherein students have the opportunity to get to know the mentors as people, in addition to as professionals. Psychosocial mentoring has been shown to be an important component of effective mentorship to expose students to the culture of the profession they are preparing to enter.

A graduate student mentor will provide day-to-day guidance and support to the student team. Our graduate mentor is Mike Veto, supervised by faculty mentor Co-I Phil Christensen. Mike developed the infrared camera design that we will employ for the mission when he was an undergraduate and has recently delivered his instrument for integration testing into its spacecraft. Mike is knowledgeable on both thermal imaging science and instrumentation. As a former ASU undergraduate, he can relate directly to the student team, providing the ideal scaffolded-mentoring arrangement to impart the lessons he learned from recently progressing through stages of development that the student team is encountering currently.

The *Phoenix* student team is centered on the *Sun Devil Satellite Laboratory (SDSL)*, a student organization within the Ira A. Fulton Schools of Engineering at ASU. The SDSL will serve as the managing organization for the *Phoenix* mission, similar to the mission management role typically conducted through a NASA center, such as Goddard or JPL. Team members have specific assigned responsibilities for mission management roles, including as the Team Leader, Project Manager, Project Scientist, Systems Engineer, and several sub-systems leads. Science, public relations, business, and creative teams will be integrated into this core management structure.

The SDSL focuses primarily in the design, development, and operation of satellites. Its fundamental goal is to bring together a diverse group of students to foster experience among its members not only in the fields of mechanical and aerospace engineering, but also in a wide range of disciplines, such as electrical engineering and computer programming. Ultimately the organization seeks to advance the exploration of the Solar System and the betterment of life on

Earth. The organization was founded in 2011 and has grown into a large and vibrant student community of 20+ members.

The *Phoenix* mission provides the first opportunity for the SDSL to undertake a complete CubeSat mission, including launch and LEO operations. To date, SDSL has participated in many competitions, in both design-build-fly and proposal based contests. The organization participates yearly in the AIAA CanSat Competition, an annual event in which teams from universities around the world design and build a mock satellite capable of deploying from a container the size of a small can and landing successfully back on Earth's surface. In late 2014, members of SDSL participated in the Mars One University Challenge, an international competition in which teams competed by proposing a payload to attach to a Mars lander projected to launch in 2018 by the Dutch company. SDSL proposed a satellite that would study Martian weather patterns using a variety of sensors and visual cameras. The proposal placed in the top ten internationally. SDSL is currently partnering with the American Helicopter Society at ASU in order to develop a method to harvest lunar ice as rocket fuel for the RASC-AL competition.

Recently SDSL entered into the development of an unprecedented long-term partnership with Orbital ATK to design and operate 50-75 pound satellites to fly on Orbital missions and be released from second-stage ballast holds following successful primary payload deployments. Launches will be free. The satellites will be themed on a variety of topics, including Earth imaging and space debris analysis. The skills gained through the *Phoenix* project will form the foundation for SDSL to leverage this unique opportunity to establish a comprehensive and lasting self-driven student satellite program at ASU.

### Partner Institution Collaboration

Interactions between the student teams at ASU and ERAU will be managed following the model of a typical distributed mission team. Team members from the two partner institutions will collaborate weekly through video and teleconference services. Project documentation will be stored using cloud services accessible from all sites. In person meetings will be scheduled for major design, implementation, and verification milestones. We have budgeted in-state travel funds to ensure a healthy collaborative relationship between the teams.

## SECTION D: SCIENCE INVESTIGATION AND IMPLEMENTATION

### A. Science Investigation

Urban environments have become an important component of the global climate system, yet regional (km-scale) environmental monitoring of cities and their surroundings remains lacking. Routine orbital imaging of cities can address the effects of urbanization on local and regional land-atmosphere interactions, air quality, health, hazard assessment, water and energy transportation, and other climate factors.

We propose the *Phoenix* 3U CubeSat to demonstrate the effectiveness of nanosat platforms to conduct scientific investigations of urban environments. The *Phoenix* CubeSat will carry a

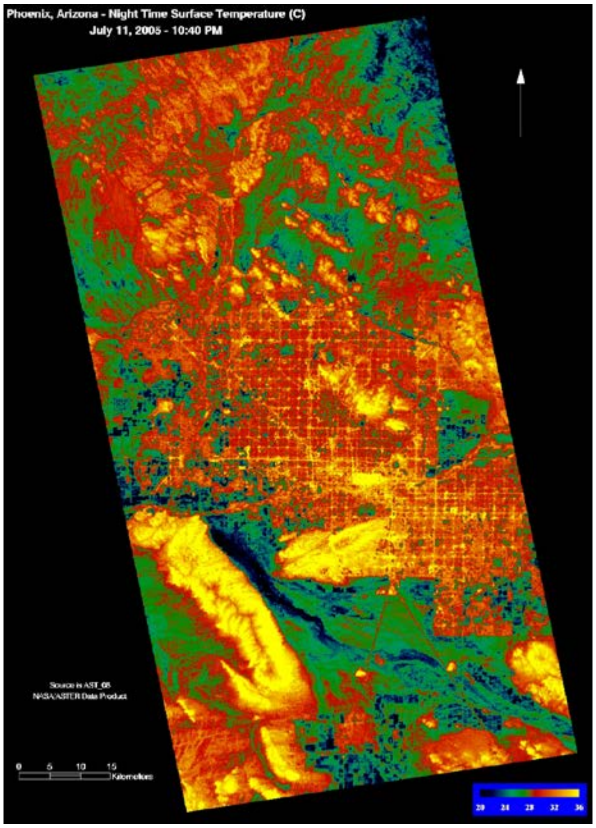

*Figure 1. Example urban heat map of Phoenix, Arizona acquired by ASTER in 2005. Colors indicate surface temperature. The proposed mission will provide similar maps nearly every day, sampling many times of day over the course of the 365 day target mission lifetime.*

thermal-infrared (IR) imaging payload to study spatial and temporal changes in the thermal properties of Phoenix, Arizona and several other U.S. cities. The system will yield secondary science from thermal imaging of ocean currents, volcanic plumes, and other target-of-opportunity surface processes.

## Urban Heat Islands

As urban areas develop, changes occur in the landscape. Phoenix, Arizona is the 11th fastest growing city in the U.S. (Forbes "Top Twenty Fastest Growing Cities 2015") and its land coverage and land usage are both increasing faster than in most other cities. In most cases, as land cover and land usage increase, the change from a rural/agricultural landscape to an urban metropolis yields warmer temperatures than in the surrounding areas (e.g. Figure 1). This complex phenomenon is called the *urban heat island* (UHI).

Urban heat islands create negative impacts for sustainability and overall quality of life. The goal of this project is to advance the understanding of urban heat island impacts on key parameters such as water and energy sustainability, elevated air pollutant and greenhouse gas emissions, and human health through *day-to-day* thermal imaging of Phoenix, Arizona and other selected cities over a period of up to one year.

During the summer afternoons, urban surface temperatures can be 50 to 90 degrees F hotter than air temperatures due to increased heat absorption related to low albedo material, such as dark pavement and roofs (Berdahl and Bretz 1997). After sunset these surfaces radiate their stored heat and induce elevated air temperatures that are as much as 22 degrees F warmer than surrounding less developed areas (Akbari 2005). During the summer, elevated temperatures from UHI can have significant and sometimes deadly consequences on a community's environment and quality of life. The negative impacts of UHI lead to four main areas of concern: 1) surges in energy consumption, 2) augmented emissions of greenhouse gasses and air pollutants, 3) compromised human health and comfort, and 4) impacts regarding water quality and scarcity.

**Energy and Air Pollution:** Intense summertime temperatures in urban areas increase the demand for cooling and add stress to the energy grid. Based on EPA estimates, energy demand increases 1.5 to 2.0% for every one degree F increase in summertime temperature (Akbari 2005).

The steady increase in temperatures due to global warming over the past few decades means that 5 to 10% of community-wide power demand is due to the impact of UHI effects. During heat waves, UHI can escalate these temperatures, which have led to overloaded systems and required energy companies to institute rolling blackouts to avoid power outages. Along with increased energy usage comes increased levels of air pollutants and greenhouse gas emissions. The United States' bulk of energy production comes from the combustion of fossil fuels. When there is a surge in energy demand, power plants produce more pollutants and greenhouse gases that create health hazards and contribute to global climate change.

**Human Health:** The EPA estimates that, in the next 50 years, 80% of the population will be living in or near UHI. With a rapidly increasing part of the world's population living in urban areas, the risks of UHI health hazards are also rising. Increased urban temperatures are associated with reduced nighttime cooling, increased energy usage, and resulting higher levels of pollutants in the air. These changes can contribute to respiratory difficulties, heat exhaustion, non-fatal heat stroke, and also heat related mortalities. For example, the Midwest experienced a heat wave in summer 1995 to which 1000 deaths have been attributed (Taha et al. 2005). During the 2003 heatwave in Paris, France, the high nighttime temperatures associated with the UHI effect were linked to a high mortality rate (Laaidi et al., 2012). The extreme heat conditions were especially fatal to the most vulnerable parts of the population, namely children and the elderly. It was estimated that Paris had an excess death rate of 141% during the heatwave (Canouï-Poitrine et al., 2006).

**Water Quality and Scarcity:** UHI has a negative impact on water quality due to increased surface temperatures that heat storm waters. EPA field measurements found UHI water runoff to be 20-30 degrees F hotter for most cities in the United States compared to those of nearby rural areas. Due to the presence of land surfaces that are made of concrete and asphalt, through which water does not easily percolate, floods result and form undesired stagnant water. The heated runoff that is transferred into streams, rivers, and lakes raises their overall temperatures. According to the EPA, "This in turn could be detrimental to aquatic life by causing stress and shock affecting the overall metabolism and reproduction of certain species" (EPA 2003). Poor percolation of flood and rain water into the ground significantly reduces the amount of groundwater on which most cities like Phoenix and Houston highly depend on. The overarching effect of this is the disturbance of the natural hydrological cycle which ultimately becomes both inefficient and improperly organized. Along with water quality, water scarcity is also an increasing concern in UHI areas. Predicting droughts and studying dry areas is crucial to growing cities because their weather patterns have been altered over the past five decades. As water droughts and heat waves become more prevalent, rapid temporary mass migration is predicted to occur. Spontaneous rapid migration into and out of UHI zones raises the amount of heat produced during heavy use periods.

## Dynamic Urban Environments

Urban environments are highly dynamic. Layered on top of the evolving land coverage and land use trends, short timescale (daily, weekly, seasonal, and transient) activities affect the UHI properties of a city or region. Traffic patterns are diurnal and vary between weekdays, weekends, and holidays. Similarly, commercial areas and office buildings, entertainment sites and restaurants, and residential neighborhoods are all populated at different times of the day and to varying degrees on different days and seasons. The overall population of a city or suburb can experience large variation in number or demographic makeup due to the influx of temporary residents or visitors, such as college students, tourists, or “snowbirds”. Major public events, conventions, or sporting competitions can alter all of the above patterns for periods of hours to weeks. Weather influences urban routines and severe weather can disrupt the routine and alter the environment.

What impact do these human activities and human reactions to natural events have on the UHI effect? Despite the importance of human activity in urban areas, the role of anthropogenic short-timescale urban activity on UHI has remained largely uncharacterized to date. Large Earth observing platforms such as Landsat 8 and Aster are in sun-synchronous orbits that provide recurring coverage only after long periods (once every 16 days in the case of Landsat) and always at the same two times of day (10:30am and 10:30pm). Hence, existing orbital assets are not suited to short timescale monitoring of events across the full diurnal period that characterizes the primary urban activity cycle.

How will patterns of human activity in an urban area influence the regional climate and environmental impact of UHI? Understanding this key question would enable urban planners to better design efficient and sustainable cities. It would further enable the local impact of climate change to be better forecasted and mitigated. Advancements in understanding UHI effects and the associated impacts are of great importance to scientists, policy-makers, and citizens alike. The models that are developed from the thermal data will allow policy-makers to incorporate remotely sensed data into their local and regional planning efforts, which in turn can help negate the negative impacts of UHI. With the *Phoenix* mission, we aim to demonstrate the power of small satellites to resolve this long overlooked aspect of urban environmental monitoring. We seek to better prepare the citizens of the world for our urban future by addressing three specific science questions:

1. What are the observable short timescale variations in the thermal properties of urban environments?
2. How does human activity influence UHI?
    a. What are the impacts of diurnal commuter patterns, temporary and seasonal changes in population, large public and sporting events, etc.)?
3. How does weather influence UHI?
    a. How do weather-related changes to the environment affect UHI (e.g. runoff, reservoir levels, ground water deposition, solar insolation, changes in albedo due to snow cover or plant growth, etc.)?
    b. What is the indirect effect on UHI due to changes in human activity (e.g. temporary changes to commuting patterns, energy consumption, land use, etc.)?

In order to address these science questions, the *Phoenix* mission will deliver high-resolution thermal imaging of several target cities with a typical recurrence rate of 0.5 to 3 times per day (depending on target city and orbit parameters) for up to one year. This will enable a time series of observations for each of the target cities that can be correlated with local weather, social events, and other metrics. Importantly, our mission will provide the first routine, thermal imaging of cities and surrounding environments on short timescales.

With its science questions, the *Phoenix* mission addresses NASA's strategic goal to "advance our understanding of our home planet and improve the quality of life" through the SMD science objective to "advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet" (NASA 2014 Science Plan). The *Phoenix* mission science objectives map to three Earth Science Division goals:

1. Detect and predict changes in Earth's ecosystems and biogeochemical cycles, including land cover, biodiversity, and the global carbon cycle
2. Enable better assessment and management of water quality and quantity to accurately predict how the global water cycle evolves in response to climate change
3. Improve the ability to predict climate changes by better understanding the roles and interactions of the ocean, atmosphere, land and ice in the climate system

### Target Cities

We will focus on five representative cities in the U.S. for our science investigation: 1) Phoenix, Arizona, 2) Seattle, Washington, 3) Minneapolis, Minnesota, 4) New York, and 5) Honolulu, Hawaii. These cities are chosen based on our assumed orbital parameters to maximize recurring coverage in order to provide dense temporal sampling of the environments. Phoenix is chosen as the primary target because it has a well-established ground-based environmental monitoring network (see Figure 2) that will provide ample data for cross-comparison with our remote sensing data.

## B. Science Requirements

Here, we summarize the requirements for the science payload. The full Science Traceability Matrix is provided in Appendix A. The science goals require thermal images of urban regions that span 10s of kilometers with sufficient spatial resolution to resolve typical city-block and neighborhood feature zones of 100-1000 meters. In order to study diurnal patterns, temporal sampling is needed that spans the full 24 hour clock. To study weekly patterns, recurring coverage is needed at least every other day to ensure one weekend day is captured per week. To study seasonal patterns and to provide a high probability of sampling many weather and human activity conditions, multiple months of coverage

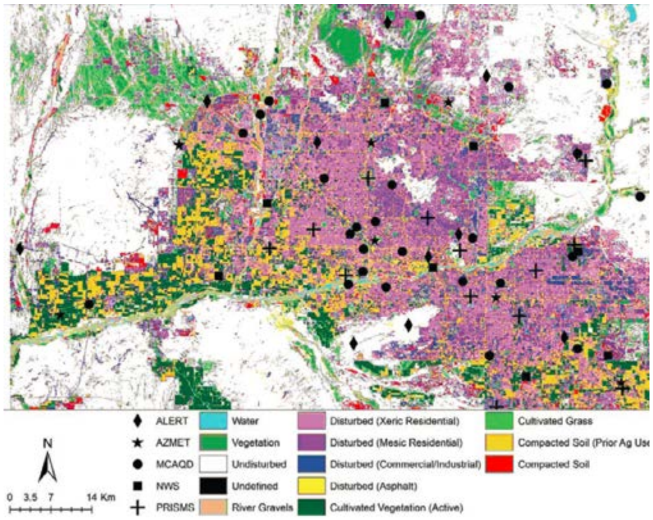

*Figure 2. Phoenix, Arizona is a well-studied environment from ground-based monitoring stations. Here, land use classification is over-plotted with the locations of environmental monitoring stations. Credit: Chow et al. 2010*

*Figure 3. (left) Science payload is based on the FLIR Tau2 640 thermal imager. The imager is 4cm per side. (middle) Rear panel with USB connector interface board. (right) Imager with 100mm focal length lens as configured for our science payload.*

are required and we set the minimum mission duration requirement at 90 days.

## C. Science Payload

To provide the science observations and meet the science requirements, the science payload will consist of a Tau2 640 micro-bolometer uncooled long-wavelength infrared thermal imager (Figure 3) with a 100mm lens, both purchased from FLIR. The imager spectral respond band is 8 to 15 microns. The Tau2 640 thermal image has a mass of 200g and dimensions of 4.4x4.4x3.0 cm, excluding the optics. With the 100mm focal-length lens (85 mm diameter), the field of view is 6.2 x 5.0 degrees. The camera provides 640x512 pixels with intrinsic thermal sensitivity of 30mK at f1.0, scaling to 77mK with our f1.6 optics. At an orbital altitude of 400 km, the imaging system yields a footprint on the ground of 43.5 x 34.8 km with a resolution of 68m, nearly twice the 100m resolution of Landsat 8 and better than the 90m Aster resolution. The power consumption is approximately 1 W with an input supply voltage of 4 to 6 V. The operating temperature range is -40 to +80 degrees C and scene thermal range is -25 to +135 degrees C.

The Tau2 640 will integrate with the satellite electronics by connecting with a USB interface board to handle image packaging from the camera's 50-pin Hirose interface to the CubeSat's onboard computer. The computer will then handle any additional data processing and storage required before transmission. The camera will be mounted at the head of the satellite with a view through the top plate and secured to the frame of the CubeSat with a mounting bracket. The lens will be secured at the top plate. We will perform a thermal analysis to ensure that the camera is well isolated from heat sources in both the environment and subsystem components in order to maximize sensitivity. Using vendor product drawings, mounts will be developed to securely interface the camera and lens to the CubeSat structure. Initial testing will be developed in house for computer interfacing and data handling. With completion of sub system integration thermal imaging testing will be conducted in house with known thermal sources to ensure accurate readings are maintained. With the integration and imaging tested additional testing and verification will take place with ERAU. This test will include a mock flight launch to test flight conditions for fully integrated subsystems and payload. This test will afford our satellite the chance to test system integration, payload operation and performance, radio communications, inflight data handling, and final checks from mission readiness.

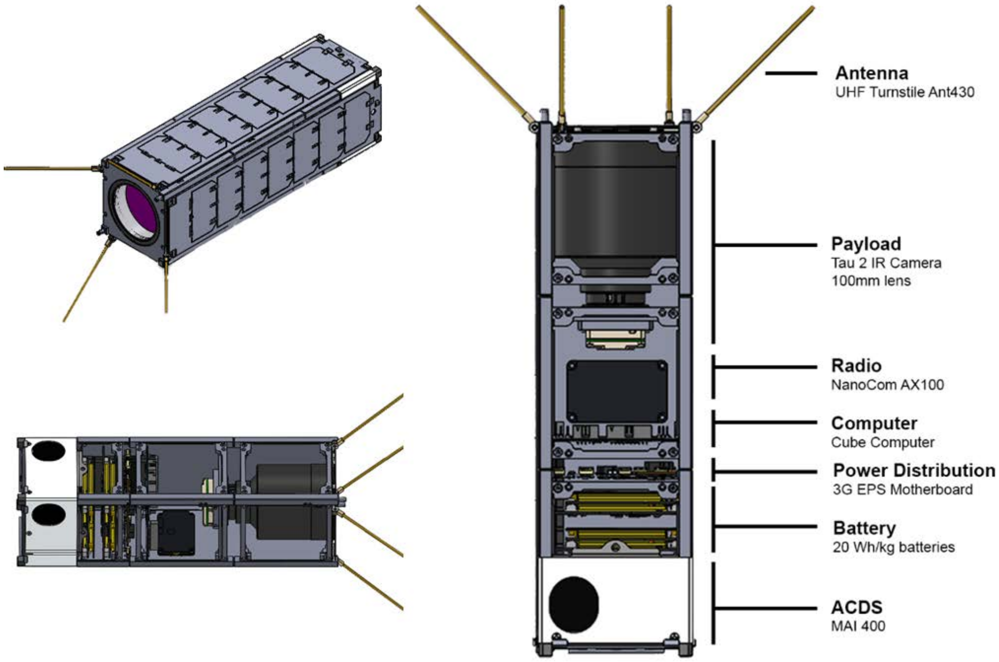

*Figure 4. Renderings of the Phoenix 3U CubeSat. (upper-left) external view including solar panels. (lower-left) cut-away view with solar panels removed to expose interior. (right) Labeled layout view.*

Calibration and verification of the science payload imaging system will be performed in the laboratory following the manufacturer specified procedure. FLIR provides detailed documentation for each imager, as well as advanced radiometric controls and spectral passband curves.

## SECTION E: MISSION IMPLEMENTATION

The full mission traceability matrix is shown in Appendix B. The mass budget summary is shown in Table 1.

### A. Payload Interface

#### *Power System*

The power system will consist of solar panels fixed to five of the CubeSat's sides, two batteries, and a power systems distribution board. The solar panels chosen were the Clyde Space 3U, 2U, and 1U panels. Two 3U panels and two 2U will be mounted on the long sides of the spacecraft. The 2U panels will be used because the ADCS system has sensors which cannot be covered by the panels. The 1U panel will be mounted on the 1U face on the top ADCS system. These solar panels will provide maximum power output of 26.4 W and an orbital average power of 4.4 W. There will be two 20 Whr Clyde Space Battery Boards for a total of 40 Whr of nominal battery capacity. These come with integrated battery heaters to ensure the batteries are within operable temperatures. Power will be managed by the Clyde Space 3G EPS Motherboard which will connect to the solar panels, the batteries, and the load devices. This system will provide power to the radio (0.1815W RX/2.64W TX), ADCS (1.2W Nadir stable, 8.47W max), IR-camera (1.2W), and the on-board computer (0.2W).

Below are tables summarizing the power consumption in the four operating modes of the satellite: safe mode, recovery mode, data collection, and downlink mode (see four small tables). Significant power reserves are available. The CubeSat will generate 4.18Wh per orbit on average. In safe mode, the system will have an excess of 1.81 Wh per orbit, a 43% positive margin. Typical data collection orbits have an excess of 1.51 Wh per orbit, while a downlink orbit without data collection has a 1.64 Wh excess. The most power-intensive orbit (see large bottom table) is when the CubeSat passes over Phoenix and performs both data collection and downlink. This orbit has 0.17 Wh excess, yielding a positive margin of 4.6%. The substantial margin in the power system will ensure batteries are well chargerd, providing additional risk mitigation.

| **Safe Mode** | Power (W) | Operation (minutes) | Energy (Wh) |
|---|---|---|---|
| Shadow | 0 | 33 | 0 |
| Direct Sun | 0 | 57 | 0 |
| Energy Gain | 4.4 | 57 | 4.18 |
| Coms | -0.18 | 90 | -0.27 |
| ADCS | -1.2 | 90 | -1.8 |
| Camera | 0 | 0 | 0 |
| On Board Computer | -0.2 | 90 | -0.3 |
| | | Total: 1.81 Wh (43% margin) | |

| **Recovery Mode** | Power (W) | Operation (minutes) | Energy (Wh) |
|---|---|---|---|
| Shadow | 0 | 33 | 0 |
| Direct Sun | 0 | 57 | 0 |
| Energy Gain | 4.4 | 57 | 4.18 |
| Coms | -0.18 | 90 | -0.27 |
| ADCS | -8.47 | 30 | -4.24 |
| Camera | 0 | 0 | 0 |
| On Board Computer | -0.2 | 90 | -0.3 |
| | | Total: -0.63 Wh | |

| **Data Collection** | Power (W) | Operation (minutes) | Energy (Wh) |
|---|---|---|---|
| Shadow | 0 | 33 | 0 |
| Direct Sun | 0 | 57 | 0 |
| Energy Gain | 4.4 | 57 | 4.18 |
| Coms | -0.18 | 90 | -0.27 |
| ADCS | -1.2 | 90 | -1.8 |
| Camera | -1.2 | 15 | -0.3 |
| On Board Computer | -0.2 | 90 | -0.3 |
| | | Total: 1.51 Wh | |

| **Downlink** | Power (W) | Operation (minutes) | Energy (Wh) |
|---|---|---|---|
| Shadow | 0 | 33 | 0 |
| Direct Sun | 0 | 57 | 0 |
| Energy Gain | 4.4 | 57 | 4.18 |
| Coms | -2.64 | 10 | -0.44 |
| ADCS | 1.2 | 90 | -1.8 |
| Camera | 0 | 0 | 0 |
| On Board Computer | 0.2 | 90 | -0.3 |
| | | Total: 1.64 Wh | |

| **Most Power-Intensive Typical Orbit**: Data Collection + Downlink (2 out of 15 per day) | Power (W) | Operation (minutes) | Energy (Wh) |
|---|---|---|---|
| Shadow | 0 | 40 | 0 |
| Direct Sun | 0 | 50 | 0 |

| | | | |
|---|---|---|---|
| Energy Gain | 4.4 | 50 | 3.67 |
| Coms (receive) | -0.18 | 90 | -0.27 |
| Coms (transmit) | -2.64 | 5 | -0.22 |
| ADCS (idle) | -0.87 | 0 | 0 |
| ADCS (stable) | -1.2 | 85 | -1.7 |
| ADCS (max) | -8.47 | 5 | -0.71 |
| Camera | -1.2 | 15 | -0.3 |
| On Board Computer | -0.2 | 90 | -0.3 |
| | | Total: 0.169 Wh (4.6% margin) | |

### *Attitude Determination and Control System (ADCS)*

The science requirements dictate that the thermal imager be pointed in various directions in order to face the target cities. Pointing accuracy of 1 degree is required so that the no more than 20% of a target field is unintentionally omitted. Thus, an active attitude control system must be used in order to accomplish the mission goals. We will use the Maryland Aerospace (MAI) three reaction-wheel and magnetorquer combination system to ensure high accuracy pointing. Reaction wheel systems have high heritage. Similar units have flown on five CubeSats designs possessing cameras, three of which were 3U size. This includes, most notably, Planet Labs Dove-1 and Dove-2 systems with over 41 successful Earth imaging missions flown. MAI's ADCS has various attitude determination sensor options. We plan to employ Earth limb sensors to provide the necessary 1 degree accuracy. More expensive star tracker sensors can provide 0.018 degree accuracy and provide risk mitigation avenues. Should reaction wheels fail in orbit, the units magnetorquers can be used to provide approximate nadir pointing, enabling alternate science imaging of the Earth's surface.

### *Communications and Telemetry*

Communications will use UHF communication uplink and downlink through a NanoCom AX100 communication modules operating in the 70cm UHF amateur band. The module supports up to 30 dBm (1 W) transmitter power and sustained downlink speeds between 0.1 and 115.2 kbps. The transceiver will be connected to a phased four-monopole, circularly-polarized, NanoCom ANT430 deployable antenna system with low directivity. The SDSL group will apply for an amateur radio club license for the spacecraft and seek coordination with the IARU as well as with other amateur band spacecraft on the same launch. Faculty mentor Martin is licensed to operate in this band and will assist students in obtaining their own amateur licenses for ground-side operations. As per-FCC rules, positive control of the transmitter will be maintained by a watchdog timer on the spacecraft to limit extraneous transmissions and a transmitter deactivate code will be available to ground-side operators.

Throughout nominal operations, basic spacecraft health telemetry will routinely be included in an automatic heartbeat message, transmitted at intervals of 30 seconds. Data downlinks will include full spacecraft state telemetry, along with science images and supporting metadata, including timestamps and orientation. Each science image is 490 kB uncompressed. Downlink data rate calculations indicate a typical sustained date rate of 100 kbps to ASU ground station over a 3-minute peak-response period per pass. Hence, we will be able to transfer a minimum of

5 raw images per downlink pass. Two downlink passes will occur per day on average, for a minimum total 10 raw images transferred per day. The total data volume from the full 365 day mission consists of 3600 images equating to 1.8 GB of raw data. One image per day per target city is the science return goal, hence only five images are required to be downlinked per day. The downlink budget provides a margin of 5 images per day (100%).

| Component | Mass (g) |
|---|---|
| 3U (Primary and Secondary) | 500 |
| Camera Mount | 48 |
| Cover Plate (with hardware) | 34 |
| Adapter Plate | 32 |
| Camera Endplate | 6.5 |
| MAI-400 with IREHS sensors | 694 |
| 2x 3U Solar Panel | 270 |
| 2x 2U Solar Panel | 138 |
| 1U Top Panel Solar Panel | 42 |
| 2x 20 Wh/kg Battery | 266 |
| 3G EPS Motherboard | 86 |
| Cube Computer | 70 |
| UHF Radio | 24.5 |
| UHF Antenna | 30 |
| Tau2 imager with 100mm lens | 475 |
| **TOTAL** | **2716** |

*Table 1 – Mass budget. The Phoenix CubeSat and science payload bus total 2716 g, leaving a margin of 1384 g (35%).*

*Flight Computer*

The onboard command and data handling will be controlled by the CubeComputer from Electronic Systems Laboratory. It was primarily chosen for its nominal power usage (less than 200 mW) and ability to interface with all other flight components. The I2C ports will allow communication with the NanoCom AX100 UHF Transceiver and ClydeSpace EPS Power management system.

*Thermal Control*

The thermal control system of the satellite will consist of a partially passive, partially active system. The majority of thermal control will be done by using multi-layer insulation (MLI) secured with thermal tape to reduce the radiative and conductive heat transfer to the structure and the internal systems. The active part of the systems consists of a battery that has an internal heater. It is self-controlled and will heat the battery to maintain a minimum of 0 degrees C. A passive thermal control system has been used on many previous CubeSats. Some notable examples that have also relied on a battery heater include CU Boulder’s CSSWE and University of Applied Sciences’ Aachen’s Compass-1.

## B. Suborbital Platform/Concept of Operations (CONOPS)

*Orbit Selection*

The optimal orbit for this science mission was selected based on three mission parameters. They are spatial resolution, the number of passes over Phoenix, and mission life period of the spacecraft. We limit our orbital analysis to circular orbits. Circular orbits are preferred for constant image resolution. First, to meet the science requirement of high-resolution images, we limit orbit altitude range to less than 500 km. Next, the minimum mission life objective is set to 90 days, with a target mission life of 365 days. Atmospheric drag at low altitude orbits will be significant for the spacecraft and determine the maximum mission lifetime. Based on the spacecraft configuration and estimated space whether parameters[1], orbital decay was calculated and shown in Table 2. From this analysis, a 350 km altitude orbit is the lowest feasible orbit for a 90 day minimum month mission duration, however; as the orbital altitude decays, the attitude control will be more complex due to the external torque caused by the aerodynamic drag. Thus, it is better to be able to stay on a stable orbit for the mission period. We find that the optimal altitude to ensure the desired mission lifetime and sub-100 meter image resolution is 400 km. The final consideration in our analysis is the number of passes permitted over Phoenix and the other target cities. This is influenced by the inclination of the orbit. The number of opportunities to image Phoenix for different inclinations was analyzed using Systems Tool Kit (STK). Inclination angles between 33.45 degrees (latitude of Phoenix) and 55 degrees were analyzed. We calculated the number of imaging opportunities assuming that the science payload could image effectively up to 30 degrees off a nadir pointing. From this analysis, the optimal inclination to maximize the number of imaging opportunities of Phoenix was found to be 35 degrees, which yields over 220 opportunities in the minimum 90 day mission lifetime (two opportunities per day). We note that even for the highest inclination orbit studied (55 degrees), 47 imaging opportunities are available, corresponding to the minimum science requirement of one opportunity every other day on average.

| Altitude | Mission life | Time to 90% of Original Altitude |
|---|---|---|
| 350 km | 0.49 years | 0.25 years |
| 400 km | 1.66 years | 1.00 years |
| 450 km | 5.23 years | 3.25 years |
| 500 km | 15.46 years | 9.96 years |

*Table 2. Orbital decay with different altitudes.*

We conclude that a circular, 400 km orbit with 35 degree inclination is desired (see Table 3). However, we note that a standard ISS orbit with 51.6 degrees inclination provides sufficient imaging opportunities to meet the science requirements even if Phoenix is the only target city. We have selected our planned secondary target cities (particularly Seattle, Minneapolis, and New York) in order to optimize the science return assuming a standard ISS orbit. The inclination of the ISS orbit yields many opportunities to image cities in the northern U.S. since the most coverage occurs at latitudes just below the orbit inclination angle. Many secondary city targets are available and final selection will be made after the orbit is known.

## *Ground Data Station*

Uplink and downlink for *Phoenix* will be controlled and monitored through the new ASU satellite ground station that is under construction with a scheduled completion by December 2016. The ERAU ground station will serve as an existing, operation backup facility. The ASU ground station is designed to communicate with small research spacecraft in LEO using a variety of common frequency bands and protocols. The system will support VHF, UHF, and S-band in its first year of operations (2016) and is expected to include X-band support by 2017. The ground station consists of an operator control center (located in the first floor of ASU's ISTB4 research building where it is visible to students and the public), receivers and transmitters, data

<table>
<tr><th colspan="9">CubeSat Mission Parameters</th></tr>
<tr><th>Mission Name</th><th>Mass</th><th>Size</th><th colspan="2">Desired Orbit</th><th>Acceptable Orbit Range</th><th>400 km @ 51.6 degree incl. Acceptable?</th><th>Readiness Date</th><th>Desired Mission Life</th></tr>
<tr><td rowspan="2"><em>Phoenix</em></td><td rowspan="2">2716 g</td><td rowspan="2">3U</td><td>Altitude (km)</td><td>400</td><td>380-500</td><td rowspan="2">yes</td><td rowspan="2">August 1, 2017</td><td rowspan="2">365 days</td></tr>
<tr><td>Inclination (degrees)</td><td>35</td><td>33-55</td></tr>
</table>

*Table 3. Orbit parameters*

processing hardware, and a switching network to select between frequencies. The receiver/transmitter pair uses software defined radios (Ettus x310 and N210). A high-gain directional dish antenna (DH Antenna, Gibraltar series with 3-meter diameter) with actuated pointing capability in 2-axis is used for S-band communication. *Phoenix* will use the station's UHF capabilities that employ two antennas: 1) an omnidirectional antenna consisting of a Rohde & Schwarz HK033 for low-bandwidth (~1000 bps) communication, and 2) a separate high-gain UHF directional antenna (Yagi) mounted to the side of the dish to enable tracking for high-bandwidth uplink/downlink. The ground station will be augmented with spacecraft coordinative tracking capability using GPS. Faculty mentor Thanga oversses construction of the ASU ground station.

## SECTION F: SCHEDULE NARRATIVE

The schedule will be managed and maintained with a series of semesterly small-scale review events, and three externally facing reviews. Attention has been paid to ordering deadlines for long lead COTS items to ensure schedule slip is minimized. All of the main aspects of the payload will start development immediately, with design elements defined and resulting in the Preliminary Design Review, which will take place in May 2016. After this point the design will be frozen and new changes will require top level review, PDR authorizes and provides guidance to primary subsystem assembly.

The Critical Design Review assesses the as-built instrument and spacecraft subsystem designs, detailed flight profile modeling (thermal, vibration, communications and power). CDR authorizes and provides guidance to final flight assembly, and will be scheduled to occur in December 2016. Once we have passed CDR, we will notify the CubeSat Flight Opportunities office of our projected payload delivery date. We will target completion of the payload assembly by February 2017 and proceed with evaluation of both the payload and its integral subsystems through thermal, vacuum, vibration and EMI testing both at ASU and at local partner Orbital-ATK during Spring 2017. This will allow time to evaluate the test results and make necessary changes to retire the risk associated with the testing outcomes.

Flight Readiness Review assesses the as-built performance of the spacecraft, operations software, instrument calibration and pre-flight testing. FRR verifies that spacecraft meets programmatic, Cubesat and launch provider requirements and authorizes integration and launch. FRR will be performed in Summer 2017 as we prepare to deliver the payload for integration.

We will assemble a defined mission profile with some margin and eventuality for the operations phase of the mission. Direct communication with the payload on a daily basis will be planned with a corresponding analysis and mission operations update to evaluate next steps and the success of the project. We expect a minimum mission duration of 90 days and target mission lifetime of 365 days to provide enhanced deliverables of the project to NASA.

In parallel with hardware implementation, our science team will prepare for the mission through a mock science test. SDSL has developed a multi-institutional arrangement with a team of students at the Arizona Near Space Research (ANSR). Through this relationship, SDSL has organized a mock flight launch with our partners at ERAU, scheduled for mid-November of

2016. This opportunity will be used to simulate mission operations by flying an inexpensive camera as a stand-in for the science payload.

Finally, as stated in current regulations established under Title II of the Land Remote Sensing Policy Space Act of 1992, any U.S. person or institution who operates a private remote sensing space system shall obtain a license of operation from the National Oceanic and Atmospheric Administration (NOAA). We have submitted an initial contact form to NOAA and will submit full licensing application once notification of approval is received. The waiting period for application's response is a maximum of 120 days.

## SECTION G: MANAGEMENT REQUIREMENTS

### A. Management

Management for USIP is instituted by means of a faculty Principal Investigator (PI), whose assigned responsibilities fall under the role of overseeing the student team. The student Team Leader will act as the student PI, responsible for all team management and deliverables. This includes maintaining contact with the students associated with all of the various interdisciplinary institutions that assist with both the science and engineering of the project. In addition, it is the duty of the student TL to have a concise overview of the mission, its components, and its progress, while maintaining communication with the faculty PI regarding the position of these elements of the design process. Student management for USIP is facilitated by a team of student officers within the SDSL, as the organization is to be responsible for overseeing the engineering component of the project as it develops along its projected timeline. A precise and structured organization of team roles has been defined in order to ensure that every angle of the mission is examined in its entirety. The Team Lead is further aided by the student Project Manager, who is to assist with the organization of the team as well as maintain an understanding of the progress of the mission against schedules, milestones, deliverables, and budget. In order to have a structure for designing the components of the mission, the individual subsystems are instituted with lead roles, who are to develop a deep understanding of their individual subsystems and facilitate a smaller team of undergraduate members as a means of allowing all the components of the CubeSat to be defined.

Subsystem leading roles, and therefore the more technical components of the design of *Phoenix*, are primarily comprised of the senior student officers of SDSL, along with many of the organization's affiliated members who have been heavily involved in the past projects of SDSL and therefore have experience in mission design. These individuals are assisted by many of SDSL's newer undergraduate members, who worked as a network to define each subsystem in conducting deeper research into more specific areas. This is manifested under a deep and intensive collaboration of the many individuals associated in the development of *Phoenix*.

Scientific investigation is central to the *Phoenix* mission. The project is heavily guided by various students and faculty who focus on the scientific aspects of the mission. Of particular interest are students from the Julie Ann Wrigley Global Institute of Sustainability and the School of Geographical Sciences and Urban Planning at ASU who, together with faculty of their respective institutions, form a strong body that will plan the science investigations, operate the science payload, and ultimately utilize the information obtained from the mission.

## B. Risk Management

Implementation risk for the Phoenix mission stems from several sources. Most are minor or intrinsic to all CubeSat platforms. The top three implementation risks are:

1. **Medium - Damage to equipment or parts during assembly or testing.** Due to expense and budget limitations, spare and replacement parts cannot be purchased for the major component systems in the CubeSat, particularly the ADCS. Should damage occur to any of these parts during integration and testing, additional funding sources would need to be sought to procure replacements. Schedule delay would be likely due to the time necessary to find funding, as well the intrinsic procurement time of the parts. This risk will mitigated by exercise of extreme caution during integration and careful subsystem planning during design.
2. **Low – Loss of project knowledge due to student turnover.** As a student project, it is expected that several of the senior students currently involved in the project will graduate during the 18 month implementation period. These students may possess critical knowledge of the system or of how to design and implement the system that may be lost when they depart. Schedule delay would likely result from their departure until other students could gain the knowledge and experience to replace them. This risk will be mitigated by a careful documentation plan and work structure where senior students work with junior partners to ensure continuous transfer of knowledge.
3. **Low – ASU Ground Station delivery delayed.** The ASU ground station that is planned for primary communication with the CubeSat is under construction. It is scheduled to be completed and tested by the end of 2016, however if the completion is substantially delayed or the performance does not meet specification, other communications plans would be necessary. This risk is mitigating through the availability of the existing, proven communications station at ERAU.

## SECTION H: COST ESTIMATE

**Stipends:** $15,600 in Y1 and $16,080 in Y2 is budgeted to provide salaries to the core student team members. We assume approximately $10/hour for 15 students for 100 hours/year of support. Additional student time will be supported through related grants, REUs, and Space Grant internships. We expect some students will have the option to participate in the project for course credit. Salary is escalated by 3% for out years. One graduate student will be supported at 1/4 time to mentor the undergraduate research assistants.

**Employee-Related Expenses (ERE):** Arizona State University defines fringe benefits as direct costs, estimates benefits as a standard percent of salary applied uniformly to all types sponsored activities, and charges benefits to sponsors in accordance with the Federally-negotiated rates in effect at the time salaries are incurred. Benefit costs are expected to increase approximately 3% per year; the rates used in the proposal budget are based on the current Federally-negotiated Rate Agreement rate plus annual escalation for out years.

| **TYPE** | **2017** | **2018** | |
|---|---|---|---|
| Faculty | 29.56% | 30.45% | |
| Post Doc | 25.75% | 26.52% | |
| Staff | 41.82% | 43.07% | |
| RA | 12.98% | 13.37% | |
| Hourly Student | 1.75% | 1.80% | |
| Part Time < .49 | 11.33% | 11.67% | |

**Equipment:** $111,100 is budgeted to purchase the CubeSat hardware components. Component costs are as follows:

| **ITEM** | **Cost** |
|---|---|
| ISIS 3-Unit CubeSat structure | $4,000 |
| MAI-400 (Complete Integrated ADACS) | $42,000 |
| ClydeSpace Integrated Battery Daughter Boards | $4,100 |
| ClydeSpace Solar Panels | $24,000 |
| ClydeSpace Motherboard | $7,000 |
| Cube Computer | $5,000 |
| NanoCom AX100 UHF Transceiver | $7,000 |
| NanoCom ANT430 antenna | $6,000 |
| Dunmore Aerospace SATKIT thermal protection | $500 |
| FLIR Tau2 640 IR camera and interface board | $9,500 |
| FLIR 100-mm narrow-angle lens | $2,000 |

**Travel:** $2,000 per year is budgeted for domestic travel to offset travel expenses for collaboration between ASU and Embry Riddle groups located in Prescott AZ. Student teams will regularly travel between the partner institutions and will be reimbursed for mileage and per diem. We assume 10 trips per year, with $100 in mileage and $100 in per diem for a typical group of four students.

**Materials and supplies:** $2,000 per year is budgeted for miscellaneous materials and supplies, 3D printing, etc. $1,500 is budgeted for a dedicated balloon test flight of prototype hardware to test systems and mission operations

**Tuition:** Tuition for the graduate student is included as a mandatory benefit and is charged in proportion to the amount of effort the graduate student will work on the project. The student is anticipated at 12.5% effort in year one and 6.25% in year two. Year 1: $4,039.00. Year 2: $2,272.00

**Indirect Costs:** Facilities & Administrative costs are calculated on Modified Total Direct Costs (MTDC) using F&A rates approved by Department of Health and Human Services. The most current rate agreement is dated 6/15/15 and the rate is 54.5% for Organized Research. Items excluded from F&A calculation include: capital equipment, subcontracts over the first $25,000, student support, participant support, rental/maintenance of off-campus space, and patient care fees.

# TOTAL PROJECT FUNDING PROFILE

| WBS | WBS Element | FY2016 $RY | | | FY2017 $RY | | |
|---|---|---|---|---|---|---|---|
| | | Requested Funding | University Contributions | Total Cost | Requested Funding | University Contributions | Total Cost |
| **01** | **Project Team** | **$26,802** | --- | **$26,802** | **$22,345** | --- | **$22,345** |
| | Undergraduate Salaries | $15,600 | --- | $15,600 | $16,080 | --- | $16,080 |
| | Graduate Student Stipends | $5,949 | --- | $5,949 | $3,186 | --- | $3,186 |
| | Graduate Student Tuition | $4,208 | --- | $4,208 | $2,363 | --- | $2,363 |
| | Fringe Benefits | $1,045 | --- | $1,045 | $716 | --- | $716 |
| **02** | **Support Equipment** | **$2,000** | --- | **$2,000** | **$2,000** | --- | **$2,000** |
| | Lab, Machine Shop, 3D Printing Instruments | $2,000 | --- | $2,000 | $2,000 | --- | $2,000 |
| **03** | **Payload** | **$111,100** | --- | **$111,100** | --- | --- | --- |
| | ISIS 3-Unit CubeSat structure | $4,000 | --- | $4,000 | --- | --- | --- |
| | MAI-400 (Complete Integrated ADACS) | $42,000 | --- | $42,000 | --- | --- | --- |
| | ClydeSpace Integrated Battery Daughter Boards | $4,100 | --- | $4,100 | --- | --- | --- |
| | ClydeSpace Solar Panels | $24,000 | --- | $24,000 | --- | --- | --- |
| | ClydeSpace Motherboard | $7,000 | --- | $7,000 | --- | --- | --- |
| | Cube Computer | $5,000 | --- | $5,000 | --- | --- | --- |
| | NanoCom AX100 UHF Transceiver | $7,000 | --- | $7,000 | --- | --- | --- |
| | NanoCom ANT430 antenna | $6,000 | --- | $6,000 | --- | --- | --- |
| | Dunmore Aerospace SATKIT thermal protection | $500 | --- | $500 | --- | --- | --- |
| | FLIR Tau2 640 IR camera and interface board | $9,500 | --- | $9,500 | --- | --- | --- |
| | FLIR 100-mm narrow-angle lens | $2,000 | --- | $2,000 | --- | --- | --- |
| **04** | **Integration and Testing** | **$1,500** | --- | **$1,500** | --- | --- | --- |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | On/Off Campus | --- | --- | | --- | --- | --- |
| | Test Facilities | $1,500 | --- | | --- | --- | --- |
| **05** | **Mission Operations** | **---** | **---** | **---** | **---** | **---** | **---** |
| **06** | **Travel and Shipping** | **$2,000** | **---** | **$2,000** | **$2,000** | **---** | **$2,000** |
| **07** | **All Direct Costs (1-6)** | **$143,402** | **---** | **$143,402** | **$26,345** | **---** | **$26,345** |
| **08** | **Indirect Costs** | **$15,311** | **---** | **$15,311** | **$13,070** | **---** | **$13,070** |
| **09** | **Total Requested Funding** | **$158,713** | **---** | **$158,713** | **$39,415** | **---** | **$39,415** |
| **10** | **University Contributions** | **---** | **---** | **---** | **---** | **---** | **---** |
| **11** | **Total Project Cost** | **$158,713** | **---** | **$158,713** | **$39,415** | **---** | **$39,415** |

# APPENDICES

## APPENDIX A: SCIENCE TRACEABILITY MATRIX

| **Science Goals** | **Science Objectives** | **Measurement Requirements** | | **Instrument Requirements** | | **Projected Performance** | **Mission Requirements (Top Level)** |
|---|---|---|---|---|---|---|---|
| | | **Physical Parameters** | **Observables** | | | | |
| Goal:<br>Advance the understanding of urban heat island impacts on energy and water sustainability, air pollution and greenhouse gas emissions, and human health | Objective:<br>1. Identify short timescale variations in the thermal properties of urban environments<br>2. Characterize influence of human activity on UHI<br>3. Characterize influence of weather on UHI | Surface temperature | Thermal infrared flux | Temperature resolution | 200 mK | 77 mK | Uncooled long-wavelength IR imager |
| | | | | Temperature range | -10 deg C | 50 deg C | |
| | | Size of features | Cities, suburbs, neighborhoods, large buildings | Ground footprint | 30 km | 45 km | Narrow field of view optics |
| | | | | Spatial resolution | 200 m | 68 m | |
| | | Time dependent patterns | 1.Differential emission across different times of day<br>2.Differential emission across different week days<br>3.Differential emission across seasonal trends and transient events | Temporal coverage | Sample distribution of hours | Random sampling of hours over mission lifetime | Excludes sun-synchronous orbits |
| | | | | | Sample each target at least once per two days | 0.5 to 3 samples of given target per day | Active attitude control for off-nadir pointing to increase sampling |
| | | | | | Minimum of 90 days operation | 1 year | 350 km or higher orbital altitude |

## APPENDIX B: MISSION TRACEABILITY MATRIX

| Mission Requirements | Mission Design Requirements | Spacecraft Requirements | Ground System Requirements | Operations Requirements |
|---|---|---|---|---|
| Uncooled long-wavelength IR imager<br>Narrow field of view optics<br>Excludes sun-synchronous orbits<br>Active attitude control for off-nadir pointing to increase sampling<br>350 km or higher orbital altitude | Mission length:<br>Minimum requirement of 3 month, target duration of 1 year<br>Orbit altitude requirement:<br>Minimum orbit altitude of 350 km to ensure minimum mission length.<br>Geographic coverage:<br>Daily passes over Phoenix, Arizona for communication and science.<br>Orbit local time:<br>Requires varying orbit local time in order to meet science requirement of temporal sampling.<br>Type of orbit:<br>Exclude sun-synchronous orbits to meet orbit local time requirement. Requires low eccentricity orbit for consistent spatial resolution. | Stabilization:<br>Active stabilization for nadir and off-nadir imaging<br>Mass:<br>2716 g<br>Power:<br>4W orbit average<br>Volume:<br>3U CubeSat<br>798.05 cm$^3$<br>Data Rate:<br>2.5 MB per day<br>Temperature range for operation:<br>0 deg C to 100 deg C<br>Pointing control:<br>1 degree accuracy for ground footprint target. Stable over 5 minutes for targeting. No jitter on millisecond time scales of the imager.<br>Detector radiation shielding:<br>Metal enclosure around imager to reduce cosmic ray artifacts. Thickness in mm range. | Passes Per Day and Duration:<br>Minimum of 2 passes per day with average 169 seconds duration (based on a 51.6 degree inclined orbit). Increased passes for lower inclination orbit.<br>Assumed Antenna Size:<br>6 meter parabolic reflector and/or high-gain (>15dB) Yagi.<br>Data Volume Per Day:<br>2.5 MB/day (up to 8.2 MB/day)<br>Real Time Data:<br>None<br>Transmit Frequency<br>437.5 MHz<br>Power available for comm (Watts):<br>1 Watt<br>Downlink data rate:<br>30 kbps (up to 115 kbps)<br>Number of data dumps per day:<br>2 (up to 4)<br>Spacecraft data destination:<br>Mission operations center at ASU<br>Science data destination:<br>Mission operations center at ASU | General spacecraft maneuver requirements and frequency:<br>De-tumble following orbit insertion. One time.<br>Target pointing up to 30 degrees off-nadir with 1 degree accuracy. Once per orbit.<br>Optimal solar panel power orientation. Once per orbit following image targeting.<br>Nadir pointing for downlink. Twice per day.<br>Special maneuvers requirements:<br>None<br>Rationale for maneuvers<br>Target pointing increases sampling rate to meet science requirements.<br>Maximal solar power pointing maintains battery levels.<br>Changes in viewing modes and directions per orbit, per day or over longer time periods.<br>One view mode for entire mission.<br>One change to viewing direction per orbit to image desired target. |

| | | | | |
|---|---|---|---|---|
| Observing Strategy:<br>Near-nadir pointing requiring yaw and roll maneuvers | | Slew Rate:<br>1 degree/s<br>Settle:<br>Stability < 0.1 degree/s after 60 seconds | | Target planning on 3 day centers<br>Ephemeris accuracy TBD. |
| Instrument Precision | | Thermal stability:<br>10 deg C per hour<br>S/C bus stability:<br>TBD | Time correlation to 0.01 seconds | Weekly time correlation |

# APPENDIX D: ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ADCS | Attitude Determination Control System |
| ANSR | Arizona Near Space Research |
| ASU | Arizona State University |
| COTS | Commercial-Off-The-Shelf |
| MLI | Multi-Layer Insulation |
| MT | Magnetotorquer |
| NASA | National Aeronautics and Space Administration |
| PI | Principal Investigator |
| PL | Project Lead |
| RW | Reaction Wheel |
| SDSL | Sun Devil Satellite Laboratory |
| Space Grant | National Space Grant College and Fellowship Program |
| TIR | Thermal Infrared |
| USIP | Undergraduate Student Instrument Proposal |

## APPENDIX E: REFERENCES

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## APPENDIX F: SPACE GRANT PROPOSAL ADDITION

### Student Internships, Stipends, and Consortium

Stipends will be provided to eligible undergraduates on the student team.

Undergraduate student leads will also be eligible to receive stipend for their contributions to the project. The award of stipends is intended to allow students to allocate more of their time to the project and further motivate them. $31,680 is budgeted for the duration of the project to fund the stipends. We anticipate awarding stipends to 15 core team members per year, with each stipend totaling $1000. Some students on the team are ineligible for stipends due to citizenship status and/or course credit restrictions.

Participating graduate mentor, Michael Veto, will receive a stipend comparable to 25% of the typical ASU research stipend for graduate students for his mentoring contributions to the project. ASU graduate students receiving stipends also receive tuition remuneration and both are included in our budget.

We anticipate that 4 to 5 paid student positions will be hired and managed through the Space Grant Program at ASU. Team leaders will be supported as undergraduate Space Grant Scholars. Like other undergraduates supported by Space Grant, they will participate in the annual Space Grant Research Poster Session (February at ASU) and in the Research Symposium (April 2016 UoA, April 2017 ASU). Reporting and tracking of student success will be reported through Space Grant. One graduate student will be supported at 25% as a Space Grant Fellow.

## Innovation Technology Research

### *Identification and Discussion of Key Innovative Technologies*

#### IR CAMERA

To study urban heat islands, surface temperatures need to be examined to help determine their size and development. By using the thermal infrared spectrum, this can be achieved. For the specific science goals of this project to be accomplished, the thermal infrared Tau 2640 camera developed by FLIR was selected. The Tau 2640 camera core uses a vandium-oxide uncooled microbolometer for its thermal detector with a focal pixel array (FPA) of 640 x 512. This model provides a sensitivity of less than 30 mK, 640/60 Hz frame rates, and powerful image processing modes that improve detail and contrast. Alongside the selected camera core, the 100 mm lens attachment, also made by FLIR, was chosen. With a 6.2 x 5.0 degree field of view and an orbit altitude of 400 km, a resolution of 68 m can be achieved. The resolution of the selected camera and lens combination is better than both Landsat8 and Aster thermal infrared image resolutions whose resolutions are 100 m and 90 m, respectively

#### ADCS

A key aspect to space travel is orienting the spacecraft, whether that is to fulfill scientific mission goals or to point solar panels at the sun. During much of the 1900's, spacecraft accomplished this through mass expulsion through thrusters. The expulsion of mass is one direction creates a torque on the spacecraft in the opposite direction in accordance with Newton's third law. This technology unfortunately had one drawback—fuel. Every time a spacecraft would make an adjustment it would use fuel. That means that in order to survive a mission of any length a large and heavy fuel tank is required. This simply is not viable for small satellites to use. However, near the turn of the 20th century systems that could rely exclusively on reaction wheels and magnetorquers were being perfected and implemented on more and more spacecraft due to their self-contained nature. This became especially useful as science missions began to gravitate towards smaller and smaller satellites with the growth of commercial and university interests in scientific missions. This growth of interest allowed for aerospace manufacturing companies to miniaturize and modularize these systems to allow for easier integration into projects without customization. Due to the 3U constraints on this missions, these newer, smaller reaction wheel systems are the ideal choice and will prove instrumental in the success of this mission.

### *Identification of relevant patented NASA technologies*

The CubeSat will be built using off the shelf components. By sourcing parts from different aerospace companies we expected to find the technology related to our science payload readilyin the NASA patents database. The component most likely relevant to NASA patents is the thermal IR camera, however a search of the patent database for "thermal," "IR," "infrared," "infrared camera," and "thermal camera" come up with no results for comparison.

### *Discussion of Relevant Commercial Applications*

Relevant commercialization opportunities have been discussed and studied in the context of the *Commercial Opportunities in Space* course at ASU instructed by Dr. Jim Bell and Dr. Philip Mauskopf as a part of ASU's Space Technology and Science ("NewSpace") Initiative. The objective of the course is to review and investigate the history and current/future status of non-governmental (private and commercial) activities in space science, technology, and exploration. Through literature reviews, discussions and presentations by guest speakers from both the established commercial space entities like JPL, Ball Aerospace and DigitalGlobe and new commercial companies like SpaceX, Planetary Resources, XCOR and Spire, the course aims to peer into the future evolution of commercial space activities.

By bringing in mentors from the startup business and venture capitalists, the course provides direct contact with commercial markets. Members of our student team are proposing to start an aerospace company to image the entire planet every single day in the thermal infrared part of the spectrum using the CubeSat platform. The core idea behind the project is to use a constellation of small satellites to monitor the Earth and generate a large database of thermal infrared images. This database will prove to be a valuable tool to better understand the ever-changing planet. The commercialization team believes that the data will be useful both to the scientific community and commercial enterprises. Of interest to the scientific community would be applications such as monitoring the changes in polar ice caps, water reservoirs, urban heat island effect etc. The commercial utility of the data would be in the airline (volcanic ash monitoring), oil and natural gas (pipeline leak checks), and real estate (urban heat islands) industries to name a few. All of these applications can be supported by recent case studies with industry experts made by our team.

The high refresh rate that will be possible with the proposed constellation of CubeSats will enable applications in the defense sector of the American government. Although the resolution will not be comparable to the defense assets, the refresh rate could prove to be very useful. The high refresh rate will provide data continuously and enable the Department of Defense to correct the trajectories of their assets as and when required saving valuable time and fuel.

The Phoenix mission enables the commercialization team to study the technological readiness and performance levels of the COTS instruments and also to more realistically assess the available potential utility for such imagery. *Phoenix* will also benefit from the team's case studies, which have shown a need for TIR data in many sectors of the commercial industry, proving that the data can be valuable beyond the science community.

Arizona Space Grant Consortium

*Timothy D. Swindle, Ph.D.*
Director, Arizona Space Grant Consortium
Department Head and Laboratory Director
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November 19, 2015

Prof. Thomas Sharp
Director, ASU/NASA Space Grant Program
Arizona State University
Tempe AZ

Dear Tom,

I am pleased to support your Space Grant Undergraduate Student Instrument Program (USIP) proposal, “Phoenix: Thermal Imaging to Explore the Impact of Urban Heat Islands on the Environment”, submitted through the Arizona Space Grant Consortium (AZSGC). As Associate Director of the AZSGC and leader of the Space Grant Program at Arizona State University, you are well suited to participate in the Space Grant USIP program as Co-Investigator. As Co-Investigator and AZSGC Associate Director, you will be responsible for proper management of this project and all required Space Grant reporting associated with this project. The statewide consortium office will provide support as needed.

Good luck.

Sincerely,

Timothy D. Swindle