# High-altitude balloon demonstration and observations with a novel LWIR spectro-polarimeter for future CubeSat applications

NASA FINNEST ROSES20 Proposal – Earth Science


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## I. Personal Statement

During my time pursuing a B.S. in astrophysics at UCLA, I found it remarkable that there is an incredible amount of information generated simply through the collection of photons. From the invention of the telescope to interferometers, all the major advances in astronomy were preceded by an innovation in optical instrumentation. This necessary relationship between optical instruments and scientific research is not limited to astronomy; is true for all fields of science. Inspired by this realization, I switched my major to physics, and began conducting undergraduate research in florescence microscopy. My work focused on methods to build high performing isotropic microscopes at a fraction of the on-market costs. Looking to diversify my skill set and take advantage of the numerous research opportunities available to me at the time, I was also a part of a team at UCLA working on signal sorting algorithms to flag potential sources of extraterrestrial intelligence as a part of the SETI project. In this endeavor I gained experience in large scale collaboration, where I worked alongside computer scientists, planetary scientists, radio engineers and physicists. I found that an interdisciplinary team and the inherent symbiosis between the technology of data collection and the science of data analysis produced exciting new hypotheses and drove new innovation in the instrumentation.

Following my research experiences as an undergraduate, I decided to pursue my Ph.D. in Optical Sciences, with the ultimate goal of addressing the most pressing instrumentation needs of the scientific community. As the changing global climate is of the utmost concern to humanity, I was motivated to pursue research which would assist in monitoring the effects and implications of climate change. I was attracted to the Polarization Lab at the University of Arizona for the opportunity to work on an infrared polarimeter for cirrus ice cloud measurement as a part an ESTO instrument incubator project out of NASA's Goddard Space Flight Center (GSFC) called the Sub-mm Wave and InfraRed Polarimeter (SWIRP). I saw the collaborative nature of this project as an opportunity to continue to learn more about atmospheric physics and chemistry, as well as tackle an instrumentation project crucial to unlocking information about ice cloud microphysical properties and subsequently unanswered questions about the Earth's radiation budget.

Through my experience on the SWIRP project, I have experienced instrument development from concept to delivery. In my first year in the Ph.D. program I completed the instrument optical design and tolerancing of the polarimeter, bringing the proposed instrument to fruition while considering cost constraints, power and size budgets, and available optical components. Given infinite time and resources, there is always an idealized design to pursue. However, an expensive instrument that will not be deployable for decades does not provide the crucial information needed to access measurement of the changing climate of today. Through this project I had to weigh engineering decisions and make cost-benefit choices that reduced risk while continuing to deliver on the required specifications for a successful instrument. In addition, I had the opportunity to work on an instrumentation team comprised of scientists and engineers from many different fields. A successful instrument requires cohesion and cooperation between thermal, optical and mechanical engineers to deliver performance metrics that meet the needs of the scientists who will use it. Through the design process I had to make multiple revisions to accommodate a thermal or mechanical budget, once having to scrap my existing optical design in its entirety to re-scope the design to meet the needs of the other subsystems. When it became apparent that the initial proposal design would not produce a reliable radiometric measurement due to ozone absorption in the atmosphere, I proposed a novel dual path instrument which would improve radiometric accuracy while maintaining a compact form factor. Exploratory instrumentation programs require creativity and interdisciplinary communication to meet their desired measurement target, and I am very fortunate to have had the opportunity to collaborate with such an incredible team on this endeavor.

Following the construction of the instrument, I designed a calibration protocol and data reduction algorithm for the instrument. This instrument is the first of its kind to use an uncooled microbolometer detector, and there were many unknowns when it came to long term stability and responsivity as a function of temperature. I chose to begin by confirming that the response of the camera could be stabilized over time, methodically scaling to demonstrate that the stability and calibration of the full instrument was possible. Once the instrument was successfully demonstrated and calibrated at the conclusion of my second year in the Ph.D. program, I began to turn my attention to other potential applications of this technology. While thermal imaging has exploded, there has been little exploitation in spectro-polarimetric measurement of targets in the long-wave infrared (LWIR). It became increasingly apparent that LWIR polarimetry was a new frontier in both remote sensing and target detection. Improvements and demonstrations of this technology will open a new frontier in understanding atmospheric and land-based processes of global significance.

In January 2020 I successfully passed my comprehensive exam and advanced to Ph.D. candidacy. In this next phase of the doctoral process I am looking forward to devoting my full attention to an exploration of the applications of LWIR polarimetry in remote sensing. If awarded this grant, I will be able to grow my collaboration with the team at GSFC to continue to gain an understanding of the challenges in current remote sensing and motivate future applications of this technology which will benefit the entire global sensing community. In addition to my academic work, I currently serve as the President of Women in Optics at UA. In my capacity as president, I organize professional development events and mentorship programs to support women and underrepresented minorities in the optics field who historically make up less than 15% of the student body. I believe that service in this capacity is important to cultivate a thriving and productive academic community.

After defending my dissertation and obtaining my Ph.D. it is my long-term goal to pursue a postdoctoral role either at a NASA facility or in a government research lab. In my career I plan to continue to work on multidisciplinary teams solving complex instrumentation problems. In this endeavor I hope to not only apply my engineering and design skills but also continue to learn about the driving physics, chemistry, geology, and biology motivating the next generation of remote sensing missions. I feel passionately about working on challenging problems which benefit the global good. In addition, I hope to have the opportunity to step into leadership and systems engineering goals, guiding and enabling diverse and skilled teams to address the optical sensing problems of the future.

**II. Science/Technical/Management Section**

Until recently, compact and rapidly deployable instruments operating in the long-wave infrared (LWIR) were not feasible due to the necessity of large and costly cooling systems for infrared detector architectures. In the past several years, the emergence of compact uncooled microbolometers has opened the door for LWIR remote sensing projects [1]. In the summer of 2019, the Polarization Lab at the University of Arizona delivered the first prototype InfraRed Channeled Spectro-Polarimeter (IRCSP) to NASA's Goddard Spaceflight Center for integration into the SWIRP CubeSat instrument (Sub-mm Wave and Infrared Polarimeters) funded by the 2016 Earth Space Technology Office's Instrument Incubator Program. Less than 10 cm in length, the IRCSP measures the linear Stokes parameters (I, Q and U) with 0.5-micron spectral resolution from 8.5 -12.5 micron. [2] Once deployed this instrument will be the first to produce measurements of polarized light scattered from the Earth's atmosphere and surface in the LWIR.

The SWIRP mission targets the measurement of cirrus ice clouds. Climate models must account for several sources of uncertainty in their analysis; one major source is the effect of clouds, and ice clouds in particular [3]. The effect of ice particles embedded in the clouds is poorly constrained, which allows ice clouds to be used as a tuning parameter to balance the budget of incoming and outgoing radiation at the top of the atmosphere. [4] [3] This lack of precise knowledge of cloud ice and its microphysical properties leads to large uncertainty about clouds and their processes within the atmosphere. Thus, the 2017 Earth Science Decadal Survey (DS), recommended that a science payload with submillimeter wave (sub-mm) and longwave infrared (LWIR) radiometers be developed for such cloud ice measurement [4]. To continue characterization and testing of the novel IRCSP delivered to GSFC, a second copy of the instrument was built at the University of Arizona. This proposal does not utilize a currently deployed NASA instrument, but instead it utilizes the second copy of the NASA prototype for exploratory research in remote sensing.

This proposal builds on the success of the SWIRP project and demonstrate a first flight of the IRCSP instrument while the project proceeds into the CubeSat integration phase. To date, no polarimetric measurements of clouds at this wavelength have ever been collected to compare with the existing scattering and radiative transfer models. The compact size and low power consumption of this novel instrument makes it an ideal candidate for high-altitude balloon flight. The proposed body of work will include developing an inflight data acquisition and storage pipeline for this application, balloon deployments over the south-eastern United States, and the generation of the first LWIR polarimetric measurements of ice clouds. In addition, while this instrument was designed to meet the need for cloud ice measurements outlined in the Earth Science Decadal Survey, other IRCSP observations, such as surface polarimetric properties, from balloon or mountain top will provide new information for land remote sensing. Because rapidly deployable LWIR polarimetry has only recently become feasible, the successful demonstration of this instrument will open the door for new frontiers in LWIR spectro-polarimetric remote sensing. This project is unique in that in addition to collecting data crucial to atmospheric science, it also pioneers the use of an entirely new instrument concept. The collaboration of optical scientists and engineers with atmospheric and planetary scientists on this project presents an exciting opportunity to explore how iterations of this technology could contribute to future Landsat missions.

***Science: Applications of Polarimetry to remote sensing***

**LWIR Channeled Polarimeter Theory and Design**

The polarization of light describes the direction of oscillation of the transverse electric field. While all monochromatic light is fully polarized, broadband light can be fully, partially, or un - polarized. The linear Stokes parameters uniquely quantify the polarization state of incoherent linearly polarized light with three real numbers [I,Q,U] which describe the polarization of the light field. These terms can be combined to describe all linearly polarized stated with just 2 numbers

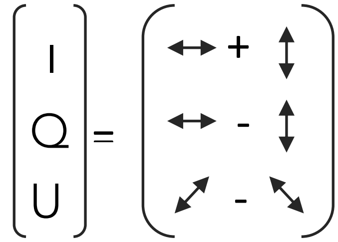

*Figure 1. Graphical Description of the linear Stokes parameters*

$$AoLP = \frac{1}{2}\, tan^{-1}\left(\frac{U}{Q}\right), \qquad DoLP = \frac{\sqrt{Q^2 + U^2}}{I}$$

called the angle and degree of linear polarization (AoLP, DoLP). When light interacts with a material, the orientation of the electric field can rotate causing a change in the AoLP, or the amount of the light field that is polarized can change causing a reduction or increase in the DoLP. For that reason, polarimetry can provide information about the texture, orientation, and refractive index of targets in the field of view [5] [6] [7]. This can be used to enhance contrast in traditional imaging, classify materials, or gain information about the microphysical properties of scattering particles in the atmosphere [8] [6] [9].

A polarimeter is used to modulate the polarization of incoming light in a way which can be measured by a detector. A channeled spectro-polarimeter is utilized to measure the spectrally dependent AoLP and DoLP in a compact instrument. For compact space-based applications, it is ideal to eliminate the need for rotating components and measure the linear Stokes parameters in a single snapshot. [10] This also significantly reduces the integration time required to take a polarized measurement. A channeled spectro-polarimeter accomplishes this by modulating the polarization state as a function of wavelength instead of in time. To introduce a wavelength dependent frequency to the spectral signal, the incoming linear polarization is first rotated as a function of wavelength. This operation is performed by a quarter wave retarder (QWR) with a fast axis at $45^\circ$ followed by a CdSe crystal high order retarder (HOR) which together act as wavelength-dependent circular retarder. In the SWIRP instrument the rotated polarized light is then modulated by a wire grid linear polarizer (LP) tilted at $20^\circ$, which separates the light into two different paths with orthogonal polarizations. Following the LP are two spectrometers comprised of a diffraction grating and imaging lens which image the modulated spectrum onto an uncooled microbolometer. The amount of modulation is proportional to the DoLP, and the phase of the modulation describes the AoLP. In this design, the DoLP and AoLP are measured with 0.5-µm resolution, as rapid variation with wavelength is not expected. [1] [2] The measurement of both the reflected and transmitted paths by the LP enables the distinction between wavelength dependent transmission and the degree of polarization. Added together the two orthogonal spectra measure the spectral radiance of the target. The final existing prototype IRCSP instrument has a total dimension of 2 x 2 x 10 cm and power consumption of 0.5 W.

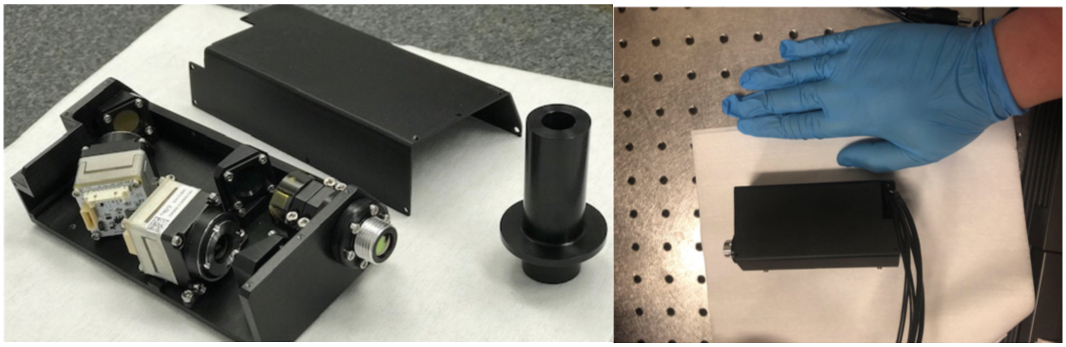

*Figure 2 Assembled instrument is less than 10 cm long*

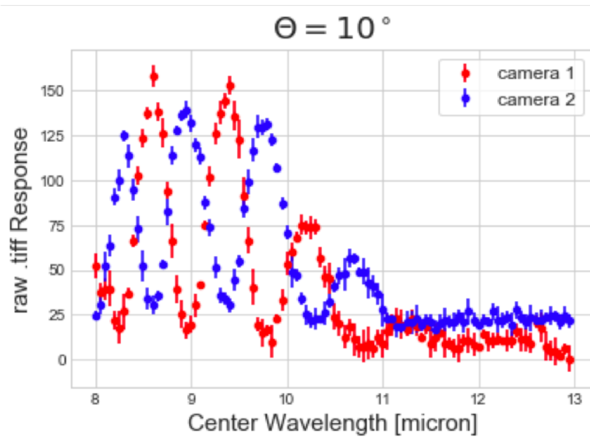


*Figure 3 Polarized response of system in paths 1 and 2 show good signal to noise from 8 - 11.5 micron*

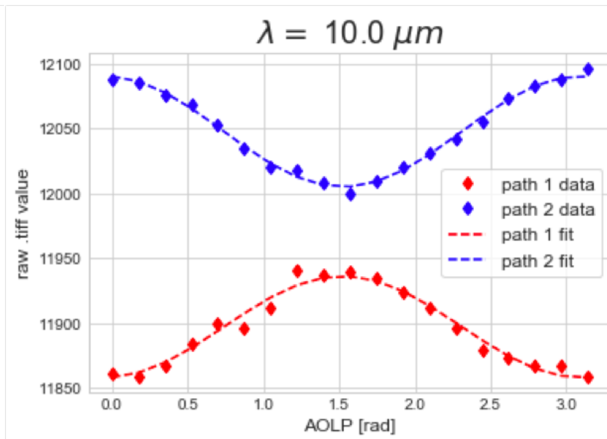


*Figure 4 Agreement of system performance with measurement equation*

In June 2019, the IRCSP was delivered to NASA Goddard Space Flight center for first light characterization. To evaluate the response of the system as a function of wavelength the system was placed in a testbed with a monochromator and blackbody source. All tests were performed at room temperature with the detectors operating at constant focal plane temperature. The calibration confirmed agreement of the instrument performance with the measurement equation (Figure 4) and successfully demonstrated the feasibility of the IRCSP concept (Figure 3). [2] [10] [1]

**Polarimetry for cirrus ice cloud microphysical properties**

The first global polarimetric study of ice crystals was performed by the Global Precipitation Measurement Microwave Imager (GMI) which investigated H-V polarization variances in the 89 and 166 GHz channels. [3] [4] This mission attained great success demonstrating the ability to constrain particle shape factor, however uncertainty in density and size impacted results significantly. Higher frequency polarimetric measurements are necessary to probe crystals of smaller diameters in order to decode the full microphysical information [8] [7]. While simulations conducted by Gong and Wu have demonstrated that a polarimetric signal is expected from cloud ice in the LWIR, this instrument will provide the first data of cloud ice in the LWIR to test these models [3]. One important final deliverable of this proposal is to produce a study comparing the measured data with the theory.

## Study of thermal spectral polarimetric signal for Earth surface observation

All targets in a terrestrial scene produce peak radiation in the LWIR. While emission from a perfect blackbody is unpolarized, in the physical world absorptivity α is always less than 1 and thermally emitted light at angles greater than normal incidence will exit the media partially polarized. For these "graybody" radiators, the Fresnel coefficients describe the amount of internally emitted radiation that is transmitted as opposed to reflected back into the media. Figure 2 shows the DoLP and AoLP of light emitted and reflected from an optically thick slab of ice as a function of viewing angle. The AoLP and DoLP of light measured is dependent upon the relative radiance of the fields reflected and emitted by the object. This signature is material dependent, and polarimetric measurements can thus be used to discriminate between different materials, even when they have the same thermal brightness. Tyo et. have demonstrated that this phenomenon can be utilized to increase contrast and discriminate between different targets in a scene using LWIR polarimetry. [6] [5] [7]

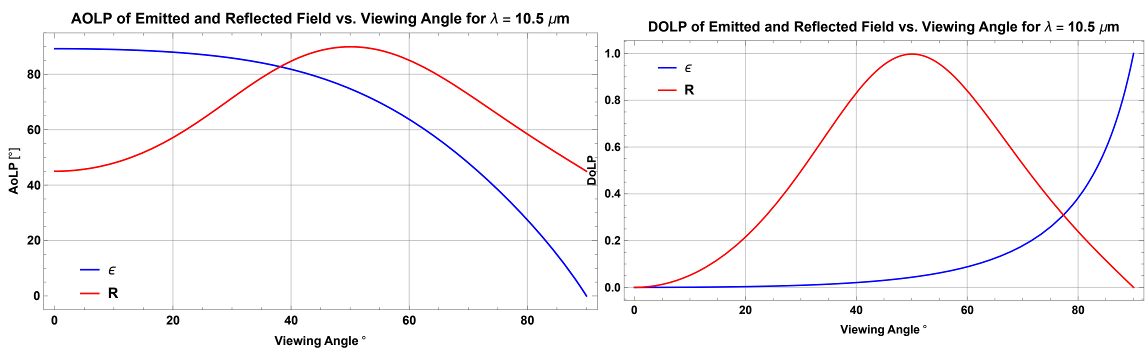


*Figure 4. AoLP and DoLP for light reflected and emitted from water ice as a function of viewing angle*

While the benefit of polarimetry is well motivated for visible wavelength channels in the remote sensing of both aerosols and land targets, applications of LWIR polarimetry to enhance thermal remote sensing for Earth systems sensing remains largely unexplored. In-progress polarimetric remote sensing missions such as MAIA (Multi-Angle Imager for Aerosols) demonstrate the additional robustness that polarization measurement can bring to global monitoring needs [11]. Even as thermal polarimetry remains a new area of research, thermal imaging has already been identified as a part of the next generation of LandSat instruments [12]. The need for small, cost-effective thermal infrared imagers which can be launched as secondary payloads have been targeted for future instruments [4] [12]. Because the IRCSP is designed for CubeSat deployment, it could fly in support of other thermal land sensing instruments with little modification. The addition of spectro-polarimetric measurements could assist in the snow-cloud discrimination, detection of petroleum spills, land surface topography, costal margins, among other desired Landsat data streams [7] [6] [12]. To motivate these applications, this project will also include the measurement of water, ice, snow, and different types of landmass to demonstrate spectro-polarimetric material discrimination as a function of viewing angle.

***Technical: Adaptation of instrument and measurement campaign***

**Adaptation of instrument for increased footprint**

The original prototype was designed to have a spatial resolution that matched that of the sub-mm instruments in the SWIRP CubeSat, this proposal includes adapting the clone instrument prototype to have a larger field of view. To do this, the field stop in the clone instrument will be replaced with a larger slit, increasing the field of view from 5.6° to 20°. At the balloon cruising height of 39,000 m, this modification will image a 1.4 km footprint. This modification will require that the instrument be recalibrated. To accomplish this, the monochromator test bed set up at GSFC is used to calibrate the IRCSP for on and off axis polarized and partially polarized light. This calibration will also determine the achieved spatial resolution of the increased FOV IRCSP. The final dimension of the slit will be chosen to maximize FOV and spatial resolution during the calibration stage.

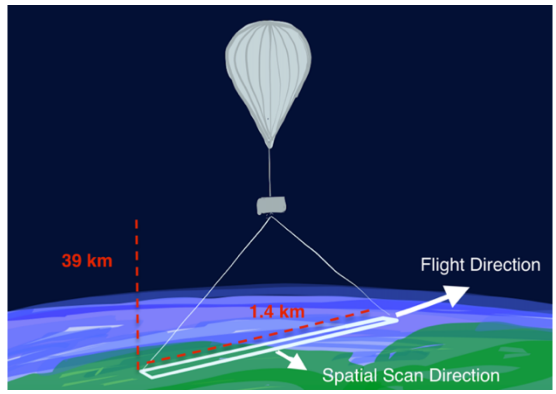


*Figure 5. Proposed Balloon Flight Geometry*

In addition to the increased field of view, a motorized stage will be added to the instrument to enable push broom imaging. The stage will spatially scan perpendicular to the flight path to produce mosaic polarization image of the ground below. An onboard instrument control and data storage pipeline will need to be optimized for balloon flight. Instrument control using Linux based onboard communications with both cameras operating in mater-slave mode has been demonstrated by the team at GSFC for in space control. This data pipeline will be configured to work with an on-balloon data storage system and be synchronized with the motion of the push broom scanner. Over the course of flight, the imaging system should collect both cloud and land measurements. Since the system is uncooled, signal to noise performance will increase at the flight altitude of 39 km where the stratosphere temperature around -30°C. This operating temperature is within the thermal tolerance for both the optics and electronics of the prototype. To prevent frost condensing on the optics in the troposphere, the IRCSP will be heated during takeoff and landing. Once assembled, the onboard stage and data acquisition pipeline will undergo rooftop testing.

**Measurement Campaign**

To probe potential applications of this technology for future Landsat instruments, the IRCSP will be used to probe the spectro-polarimetric properties of landcover targets (Table 1). The measurement campaign will begin with in lab measurement of different materials as a function of viewing angle and wavelength. Based on the Fresnel coefficients (Figure 4), we anticipate a polarized signal which varies with material, viewing angle, temperature, and wavelength [2] [13]. The expected polarimetric behavior of the smooth materials can be simulated using polarization ray tracing in conjunction with radiometric modeling for comparison with the in-lab measurements. While soil is more challenging to model,

| | |
|---|---|
| Water Phase Measurements | Ice, snow, water |
| Metals | Aluminum, Copper, Silver |
| Water Pollution | Oil on water |
| Soil | Sand, Silt, Clay (loosely and densely packed) |

*Table 1: Proposed targets for material study*

there is existing research which provides evidence that soil texture gives rise to an identifiable polarimetric signature [7] [6]. Since we expect the balloon flight testing to produce cloud, land, and land-cloud combination measurements, these in lab results will be compared to the data produced in-flight.

***Project Management***

**Risk Mitigation**

The proposal reduces risk through an iterative design plan. A full year of instrument modification, verification, and testing will be performed before balloon flight. The parallel development of the onboard balloon and SWIRP instrument data pipelines will reduce risk on that critical path. Finally, the PI and Co-I's experience in preparing prototype instrumentation for high altitude flight will be leveraged to anticipate potential problems and address them [13].

**Collaboration with NASA Goddard Spaceflight Center**

Over the course of the SWIRP project, the FI and PI have benefitted from a close collaboration with the team at Goddard Space Flight center. As an extension to the SWIRP instrumentation project, this proposal would benefit from the continued access to GSFC calibration and testing facilities. The FI and other Polarization Lab personnel are familiar with the calibration facilities at GSFC reducing the risk and unknowns in the calibration process. SWIRP PI Project Scientist Dr. Dong Wu will remain a project collaborator and continue to advise on the bridge between cloud ice measurements and microphysical models.

**NASA Wallops Flight Facility**

The high-altitude balloon deployment will be requisitioned through the NASA Wallops Flight Facility's Missions of Opportunity program. As a small payload, the IRCSP can be flown at no additional cost as a tag along to an already planned payload. To secure flight time, the submissions are due in June in the year preceding the deployment. This request will be submitted in the first year of this proposal to deploy in the second year, and a second deployment will be targeted in the final year of the proposal to gather additional data.

**University of Arizona Resources**

This project benefits from the infrastructure available at the Wyant College of Optical Sciences at the University of Arizona. As the largest optics program in the US, the college provides crucial resources and infrastructure. In particular the Large Optics Fabrication and Testing Facility is accessible to the FI and provides the required cleanroom space. In addition, the FI will have a dedicated optical table in the Polarization laboratory facilities, a blackbody source, and a dedicated computer for this project. The Polarization Laboratory already has collected a variety of LWIR optics and a low power CO2 laser which can be utilized for in lab experimental set ups. In addition, the Polarization Lab lends a history of experience to the development of high accuracy polarimeters for remote sensing. Both the PI and CO-I were involved in the development, testing, and deployment of both ground- and air-MSPI, the Multiangle SpectroPolarimetric Imager [14] [15] [16] [13]. GroundMSPI was a landmark instrument which produced the first highly sensitive linear Stokes images. Following from groundMSPI's success, the Polarization Lab collaborated with NASA Jet Propulsion Laboratory and the University of Texas to build airMSPI, the predecessor of the MAIA instrument [11].

## Works Cited


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[12] National Research Council, " Landsat and Beyond: Sustaining and Enhancing the Nation's Land Imaging Program," The National Academies Press, Washington D.C., 2013.

[13] M. Kupinski, C. Bradley, D. Diner, F. Xu and R. Chipman, "Estimating surface orientation from microfacet Mueller matrix bidirectional reflectance distribution function models in outdoor passive imaging polarimetry," *Opt. Eng.,* vol. 58, no. 8, pp. 082416-082424, 2019.

[14] K. M. Kupinski, C. Bradley, D. Diner, F. Xu and R. Chipman, "Applying a microfacet model to polarized light scattering measurements of the Earth's surface," in *Polarization Science and Remote Sensing VII*, San Diego, 2015.

[15] M. K. Kupinski, C. Bradley, D. Diner, F. Xu and R. Chipman, "Angle of linear polarization images of outdoor scenes," *Optical Engineering,* vol. 58, no. 8, pp. 082419 -36, 2019.

[16] M. Kupinski and R. Chipman, "Power spectra trends in imaging polarimetry of outdoor solar illuminated scenes," in *SPIE* Baltimore, 2016.


**Both the Personal Statement and Science/Technical/Management Plan are the work of the Future Investigator (FI) Kira Hart.**

## III. Personnel Curriculum Vitae


**Kira Hart**
Ph.D. Candidate
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**Education**

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| May 2022 (Expected) | Ph.D. in Optical Sciences<br>University of Arizona |
| June 2017 | B.S. in Physics with College Honors<br>University of California, Los Angeles |

**Experience**

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|---|---|
| 2017 – Present | *Graduate Research Assistant*, University of Arizona<br>Polarization Laboratory<br>Infrared polarimetry design and calibration |
| Summer 2019 | *Research Intern,* Facebook Reality Labs<br>Project: "Coupling finite difference time domain simulations with machine learning for optimization of novel optical and display technologies" |
| 2015 – 2017 | *Undergraduate Researcher*, UCLA Electrical Engineering<br>Ozcan Research Group<br>Project: "Design and modeling of high throughput multi-view isotropic florescence microscope" |
| 2016 – 2017 | *Undergraduate Researcher*, UCLA SETI Project |

**Awards**

*Roland V. Shack Endowed Scholarship* University of Arizona, 2017
The Roland V. Shack Scholarship is awarded to a first-year graduate students with an undergraduate degree in the physics, optics, engineering, mathematics, computer science or related fields and an undergraduate GPA of 3.7 or better on a 4.0 scale with research interests optical design and engineering.

*Student Speaker Award* American Meteorological Society, 2019

**Skills**

*Software*:
Zemax · CodeV · Mathematica · Polaris-M · Matlab · Python · LabView · C ++ · Excel · SQL

*Experience*:
Polarization Ray Tracing · Optical Design · Tolerancing · Thermal Imaging · Spectrometers · IR Optics · Polarimeter Calibration· Polarimeter Design · FDTD · RCWA · Data Science · Remote Sensing · Polarization Image Science · Scattering Models · Radiative Transfer

*Equipment:*
3-D Printing · Lasers (class -4 training) · Interferometers · Polarimeters

**Selected Conference Presentations and Proceedings**

1. SPIE Polarization: Measurement, Analysis, and Remote Sensing 2020
   **Presentation**: *Stokes measurement of thermal targets using compact LWIR spectropolarimeter*
   **Hart, K.A.,** Kupinski, M. K., Wu, D.L. and Chipman, R., "Linear Stokes measurement of thermal targets using compact LWIR spectropolarimeter" Proc. SPIE Polarization: Measurement, Analysis, and Remote Sensing XIV (to appear 2020).
2. SPIE Polarization Science and Remote Sensing 2019
   **Presentation**: *Demonstration of LWIR channeled spectropolarimeter*
   **Hart, K.A.,** De Amici, G., Horne, T., Kupinski, M. K., Langworthy, K., Stohn, A., Wu, D.L. and Chipman, R., 2019, September. "Demonstration of LWIR channeled spectropolarimeter." In Polarization Science and Remote Sensing IX (Vol. 11132, p. 1113207). International Society for Optics and Photonics.
3. American Meteorological Society 2019
   **Presentation:** *LWIR Spectro-Polarimeter for Cloud-Induced Polarization Measurements*
4. Geoscience and Remote Sensing (IGARSS), IEEE International Symposium 2019
   D. Wu, M. Vega, M. Solly, V. Marrero, **K. Hart** , S. Guerrero , W. Gaines, C. Du Toit , G. De Amici , W. Deal, A. Dabrowski , M. Coon, R. Chipman. "Swirp (Submm-Wave and Long Wave Infrared Polarimeter); A New Tool for Investigations of Ice Distribution and Size in Cirrus Clouds," IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium, Yokohama, Japan, 2019, pp. 8436-8439.
5. SPIE Polarization: Measurement, Analysis, and Remote Sensing 2018
   **Poster**: *Compact LWIR polarimeter for cirrus ice properties*
   **Hart, K.A**., Chipman, R.A. , Wu, D.L., "Compact LWIR polarimeter for cirrus ice properties," Proc. SPIE 10655, Polarization: Measurement, Analysis, and Remote Sensing XIII, 106550V (14 May 2018).

**Peer Reviewed Publications**

1. **Hart, K.A**., Kupinski, M. K., Wu, D.L. and Chipman, R., (in review) "First results from a Uncooled LWIR Polarimeter for CubeSat Deployment" Optical Engineering.
2. Pinchuk, Margot , J., Greenberg, Ayalde , Bloxham , Boddu , Chinchilla-Garcia , Cliffe , Gallagher , **Hart, K.A**., Mizrahi , Pike , Rodger, Sayki , Schneck , Tan, Xiao , Lynch, R.S., (2019) Pinchuk, Pavlo, et al. "A Search for Technosignatures from TRAPPIST-1, LHS 1140, and 10 Planetary Systems in the Kepler Field with the Green Bank Telescope at 1.15–1.73 GHz." The Astronomical Journal 157.3 (2019): 122.

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**Education:**

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| 2003 – 08 | Ph.D. | Optical Sciences University of Arizona<br>Dissertation: "Estimating Signal Features from Noisy Images with Stochastic Backgrounds for Tomographic Nuclear Medicine"<br>Advisor: Harrison Barrett, UA Regents Professor |
| 2001 – 03 | M.S. | Optical Sciences University of Arizona |
| 1998-2001 | B.S. | Imaging and Photographic Technologies with Highest Honors<br>Rochester Institute of Technology |

**Employment:**

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|---|---|
| 2010 – Present | Associate/Assistant Research Professor College of Optical Sciences<br>University of Arizona |
| 2008 – 2010 | Director of Education Center for Integrated Access Networks<br>National Science Foundation (NSF) Engineering Research Center<br>College of Optical Sciences University of Arizona |
| 2002 – 2008 | Graduate Research Assistant Center for Gamma-Ray Imaging<br>College of Optical Sciences<br>University of Arizona |
| 1999 – 2001 | Image Quality Engineer<br>Eastman Kodak Company |

**Honors and Awards:**

2017 Jean d'Alembert Visiting Scholar for "Binary Classification of Polarimetric Images for Cervical Cancer detection." Awarded by the French government to 3 applicants per year. I was a visiting scientist at École Polytechnique for 8 months working on using polarization to image early signs of cervical cancer.

2013 NSF Fellow Science, Engineering and Education for Sustainability (SEES) Awarded to approximately 5% of applicants to facilitate investigations that cross traditional disciplinary boundaries and allow early-career scientists to investigate topics beyond their core disciplinary expertise.

2010 Women in Science and Engineering (WiSE) Mentoring Award Nominated by UA students for individuals who have made outstanding contributions to promoting the success of women in science and engineering.

**Selected, Peer-reviewed Articles**:

1. Hart, K.A., **Kupinski, M. K.**, Wu, D.L. and Chipman, R., (in review) "First results from a Uncooled LWIR Polarimeter for CubeSat Deployment" Optical Engineering.
2. Zhan, H., Voelz, D.G. and **M. K. Kupinski**, (2019). "Parameter-based imaging from passive multispectral polarimetric measurements." Opt. Ep., 27(20), pp.28832-28843.
3. Bradley, C.L., Diner, D.J., Xu, F., **M. K. Kupinski** and Chipman, R.A., (2019). "Spectral Invariance Hypothesis Study of Polarized Reflectance With the Ground Based Multiangle SpectroPolarimetric Imager." IEEE Transactions on Geoscience and Remote Sensing, 57(10), pp.8191-8207.
4. **M. K. Kupinski**, Bradley, C. L., Diner, D. J., Xu, F., & Chipman, R. A. (2019). " [13] [14]." Optical Engineering, 58(8), 082419.
5. **M. K. Kupinski**, Bradley, C., Diner, D., Xu, F., & Chipman, R. (2019). "Estimating surface orientation from microfacet Mueller matrix bidirectional reflectance distribution function models in outdoor passive imaging polarimetry." Optical Engineering, 58(8), 082416.
6. **M. K. Kupinski**, Boffety, M., Goudail, F., Ossikovski, R., Pierangelo, A., Rehbinder, J., Vizet, J. and Novikova, T., (2018). "Polarimetric measurement utility for pre-cancer detection from uterine cervix specimens." Biomedical Optics Express, 9(11), pp.5691-5702.
7. **M. K. Kupinski**, Bankhead, J., Stohn, A., and Chipman, R. (2017). "Binary classifi-cation of Mueller matrix images from an optimization of Poincaré coordinates." JOSA A, 34(6), 983-990

**Selected, Conference Proceedings**:

6. Hart, K.A., **Kupinski, M. K.**, Wu, D.L. and Chipman, R., "Linear Stokes measure-ment of thermal targets using compact LWIR spectropolarimeter" Proc. SPIE Polarization: Measurement, Analysis, and Remote Sensing XIV (to appear 2020).
7. Hart, K.A., De Amici, G., Horne, T., **Kupinski, M. K.**, Langworthy, K., Stohn, A., Wu, D.L. and Chipman, R., 2019, September. "Demonstration of LWIR channeled spectropolarimeter." In Polarization Science and Remote Sensing IX (Vol. 11132, p. 1113207). International Society for Optics and Photonics.
8. Richter, J.M., Chipman, R., Daugherty, B., Diner, D.J., Eldering, A., Hyon, J.J., **Kupinski, M. K**., Neu, J.L. and Fu, D., 2019. Specifying polarimetric tolerances of a high-resolution imaging multiple-species atmospheric profiler (HiMAP). In Pho-tonic Inst Eng VI (Vol. 10925, p. 109250F). International Society for Optics and Photonics.
9. Davis, J., **Kupinski, M. K.**, Chipman, R.A. and Breckinridge, J.B., 2018, July. HabEx polarization ray trace and aberration analysis. In Space Telescopes and Instrumentation 2018: Optical, Infrared, and Millimeter Wave (Vol. 10698, p. 106983H). International Society for Optics and Photonics.
10. **Kupinski, M. K**., J. Rehbinder, H. Haddad, S. Deby, J. Vizet, B. Teig, A. Nazac, A. Pierangelo, F. Moreau, and T. Novikova, "Tasked-based quantification of measure-ment utility for ex vivo multi-spectral Mueller polarimetry of the uterine cervix," in Clinical and Preclinical Optical Diagnostics, J. Brown, ed., Vol. 10411 of SPIE Proceedings (OSA, 2017), paper 104110N.

College of Optical Sciences
THE UNIVERSITY OF ARIZONA

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**Education:**
University of Arizona, Optical Sciences, Ph.D., 1987
University of Arizona, Optical Sciences, M.Sc., 1984
MIT, Physics, B. Sc., 1976

**Appointments:**
University of Arizona (Tucson, AZ, USA) Full Professor 2002
JDS Uniphase, (San Jose, CA, USA), Senior Manager 2000 – 2002
TeraStor Corp. , (San Jose, CA, USA), Senior Manager 1999 – 2000
Johnson & Johnson, Inc., (Roanoke, VA, USA) Director of Optics R & D 1997 – 1998
The University of Alabama in Huntsville, (Huntsville, AL, USA)
Full Professor, Physics, 1996 – 1997
Associate Professor, Physics 1992 – 1996
Assistant Professor, Physics 1987 – 1992

**Professional Affiliations and Awards:**
The Optical Society of America (OSA)- *Fellow*
- Joseph Fraunhofer Award/Robert M. Burkley Prize, 2015

Society of Photo-Optical Instrumentation Engineers (SPIE)- *Fellow*
- G.G. Stokes Award in Polarization Optics, 2007
-Board of Directors 1996 - 1998

NASA: Tech Brief Award, 2005

**Significant Publications Related to the Project:**

***Polarized Light and Optical Systems***, Russell A. Chipman, Wai Sze Tiffany Lam, Garam Young, 2018 ISBN: 9781498700566

***Dual-photoelastic-modulator-based polarimetric imaging concept for aerosol remote sensing***, Diner, D.J., Davis, A., Hancock, B., Gutt, G., Chipman, R. A., & Cairns, B., Applied Optics, vol. 46, issue 35, pp. 8428-8445 (2007).

***First results from a dual photoelastic-modulator-based polarimetric camera***, Diner, David J; Davis, Ab; Hancock, Bruce; Geier, Sven; Rheingans, Brian; Jovanovic, Veljko; Bull, Michael; Rider, David M; Chipman, Russell A; Mahler, Anna-Britt; McClain, Stephen C, Applied Optics, Vol. 49 Issue 15, pp.2929-2946 (2010)

***The Airborne Multiangle SpectroPolarimetric Imager (AirMSPI): a new tool for aerosol and cloud remote sensing***, Diner, David J; Davis, Ab; Hancock, Bruce; Geier, Sven; Rheingans, Brian; Jovanovic, Veljko; Bull, Michael; Rider, David M; Chipman, Russell A; Mahler, Anna-Britt; McClain, Stephen C, Atmospheric Measurement Techniques 6.8 (2013): 2007.

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**Research Interests**

Remote sensing of clouds and dynamics; Atmospheric gravity waves; Radiative transfer and retrieval algorithms; Sun-climate connection

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**Experience**

- NASA Goddard Space Flight Center (2011-present)
  - PI, SWIRP: Compact Submm-Wave and LWIR Polarimeters for Cirrus Ice Properties
  - PI, IceCube: Spaceflight demonstration of 883-GHz cloud radiometer on cubesat
  - Co-I, Terra Multi-angle Imaging SpectroRadiometer (MISR)
  - Cloud ice measurements and analyses with AMSU-B, MLS and AIRS
- Jet Propulsion Laboratory (1994-2011)
  - Co-I, Terra Multi-angle Imaging SpectroRadiometer (MISR)
  - Co-I, Aura Microwave Limb Sounder (MLS)
  - NASA GNSS science team member (Small-scale analysis)
  - CloudSat science team member (Radar and passive microwave cloud ice)
- The University of Michigan, Ann Arbor, MI (1990-1994)
  UARS High Resolution Doppler Imager (HRDI) Project

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**Education**

Ph.D. in Atmospheric Sciences, The University of Michigan, Ann Arbor, 1994

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**Selected Awards**

- NASA Exceptional Achievement Medal (2001, 2008)
- JPL Ed Stone Award, (2006)

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**Selected Publications**

Cooke, C., …, D. L. Wu (2019), A 220 GHz InP HEMT Direct Detection Polarimeter. IEEE Trans. Microwave Theory and Techniques (TMTT-2019-05-0529). ISSN: 0018-9480,

Wu, D. L., et al., (2019), IceCube: Submm-Wave Technology Development for Future Science on a CubeSat. "The Nanosatellite Revolution: 25 Years and Counting". Ed. Siegfried Janson and Henry Helvajian. pp.

Wu, D. L., et al. (2017), "Toward Global Harmonization of Derived Cloud Products." *Bulletin of the American Meteorological Society*, 98 (2): ES49-ES52 [10.1175/bams-d-16-0234.1]

Wu, D. L., T. Wang, T. Várnai, J. A. Limbacher, R. A. Kahn, G. Taha, J. N. Lee, J. Gong and T. Yuan (2018), MISR Radiance Anomalies Induced by Stratospheric Volcanic Aerosols. Remote Sens. 10, 1875; doi:10.3390/rs10121875.

Gong, J., and D. L. Wu (2011), View-angle dependent AIRS cloud radiances: Implications for tropical anvil structures. Geophys. Res. Lett., 38, L14802, doi:10.1029/2011GL047910.

Wu, D. L., et al., Comparisons of global cloud ice from MLS, CloudSat, and other correlative data sets. J. Geophys. Res., CloudSat special section, 114, D00A24, doi:10.1029/2008JD009946, 2009.

## IV: Mentorship Agreement

FI: Kira Hart
PI: Dr. Meredith Kupinski
Co-I: Dr. Russell

The Future Investigator (FI) on the proposed "High-altitude balloon demonstration and observations with a novel LWIR spectro-polarimeter for future CubeSat applications" project will engage in structured mentoring activities connected to The Wyant College of Optical Science and the University of Arizona. The **goal** of the mentoring plan is to provide the FI with the necessary skills, knowledge and experiences to continue to develop independence as a researcher and to excel within her chosen career path.

**Orientation**

The University of Arizona (UA) Office of Postdoctoral Affairs offers a postdoctoral orientation program three times a year (January, May, and September) that focuses on career and professional development resources, fostering an inclusive academic community, and promoting excellence in research. If awarded this Grant, the FI will have the opportunity to attend these postdoctoral workshops to gain a greater understanding of project management and postdoctoral career trajectories.

**Individual Development Plan –** The IDP address the following key areas:

- ***Career guidance and counseling.*** The FI and PI/supervisor will continue to discuss the FI's career goals for five- and ten-year horizons, setting expectations and the areas of focus. The PI and FI have already established publication and research goals which will guide the FI to a strong dissertation defense and put the FI in a competitive position for NASA postdoctoral positions. The FI will be expected to
    - Attend interdisciplinary Remote Sensing Group meetings at UA and receive feedback from the scientific remote sensing community
    - Present bi-annually at the College of Optical Science's Industrial Affiliates program to receive feedback on the optical system
- ***Enhancement of technical skills.*** The FI will be encouraged to strengthen advanced technical skills, especially in areas
    - Technical writing for publications with a wide impact
    - Testing scattering model hypotheses with polarimetric remote sensing data
    - Advancing technical knowledge of existing scattering models
    - Representation of polarimetric data in image form
    - Writing topical review papers for publication
- ***Leadership training, mentoring, and responsible professional practices.*** The FI and PI/supervisor will meet weekly [13] [14] to discuss strategies and techniques to become a successful mentor and leader. This will include discussions of how to resolve conflicts within a cross-disciplinary integrated research setting. The FI will be provided with opportunities for mentoring undergraduate students in the Polarization Lab. Each graduate student is required to receive instruction in the "Responsible Conduct of Research" through UA's Research, Innovation, and Impact training and education team. FIs may also earn a UA RCR certificate

that meets NSF and other federal sponsor training requirements. UA requires a minimum of 6 hours of RCR instruction; however, more hours are encouraged.

- ***Enhancement of communication/teaching skills.*** The FI and PI/supervisor will define goals to improve oral and written communication skills. For example, the FI will be encouraged to participate actively in project team meetings by leading at least 1 meeting a month, attend at least one national meeting per year to present research, work closely with the PI/Co-PIs on multi-authored manuscript and grant proposal preparation (at least 3 manuscripts and 1 grants), and learn best practices in proposal preparation. The FI will be expected to take the lead on at least 2 peer-reviewed publications. The FI will
    - Attend and present progress at the annual Polarization in Remote Sensing section at the SPIE Optics and Photonics Conference
    - Attend an American Geophysical Union meeting to present research to an interdisciplinary audience
    - Publish 2 peer reviewed publications on the results of this proposal, 1 additional publication of the FI's current research in LWIR polarimetry and 1 peer reviewed review article on LWIR polarimetry for remote sensing applications. This will culminate in a net 5 peer reviewed publications at the time of the FI's defense
- ***Effective collaboration with researchers from diverse backgrounds and disciplinary areas.*** The PI/supervisor will mentor the FI in aspects of working effectively in a collaborative, interdisciplinary environment and team, and approaches to successfully managing highly collaborative projects. This will include guidance on team building and collaborative research plans. The FI and PI are unique in this case as they serve as the President and Faculty Advisor for the Women in Optics Organization respectively. The FI will continue to have the opportunity to serve in a leadership capacity related to promoting institutional diversity.
- ***Technology transfer*.** The FI will be exposed to technology transfer aspects of federally funded research in collaborative environments, such as confidentiality agreements and invention disclosures via UA's Tech Launch Arizona programs and workshops.
- ***Outreach activities*.** The FI will be encouraged and given opportunities to participate in the outreach activities.
- ***Other Programming***: FIs will be encouraged to participate in other established UA campus workshops, training, and networking events for Graduate Students through the UA Graduate College.

**Evaluation Plan –** The success of the mentoring plan will be assessed through a formal annual review with the FI and PI/supervisor and by regular, informal interactions to track and determine ongoing progress. In addition, this proposal is designed to culminate the FI's dissertation. As such, the dissertation committee will provide continued feedback and evaluation of the direction of work. PI of the SWIRP project and NASA project scientist Dr. Dong Wu will serve on the FI's dissertation committee

PI, Dr Meredith Kupinski

FI Kira Hart

## V: Budget, Timeline and Narrative

| **Year 1 : Instrument Modification and Calibration** | Completion | Deliverable |
|---|---|---|
| Slit Modification and alignment | 10/2020 | |
| Design of scanning motor | 11/2020 | |
| Calibration at GSFC | 1/2021 | Report outlining modified slit instrument performance |
| Modification of on-board software | 2/2020 | |
| Construction of scanning motor | 3/2021 | |
| Construction and thermal/vibrational testing of completed instrument | 4/2021 | Completed balloon instrumentation |
| Test long term stability of motors, bolometers, data acquisition | 5/2021 | Document measured payload weight, stability, and final dimensions for WFF flight |
| Request WFF flight | 6/2021 | |
| **Year 2 : Measurement Campaign and Instrument Deployment** | | |
| Begin in lab measurement campaign | 7/2021 | |
| Conclude in lab measurement campaign | 9/2021 | |
| Analysis of material signatures in the LWIR complete | 12/2021 | Publish peer reviewed journal paper on LWIR polarimetric signatures for different materials |
| First Balloon Deployment | Spring 2022 | |
| Taking ground-based measurements of targets in the field | Spring 2022 | |
| **Year 3 : Models vs. Measurement** | | |
| Comparison of cloud ice measurements with models | Summer 2022 | Publish Peer reviewed paper on first measurements of cirrus ice clouds |
| Request 2$^{nd}$ WFF Flight | 6/2022 | |
| Begin more in-depth exploration of land targets which produced polarimetric signal | Fall 2022 | |
| Develop radiometric scattering emission model for potential polarimetric Landsat targets | Winter 2022-2023 | |
| Second Balloon deployment | Spring 2023 | |
| Analysis of second balloon deployment and conclusion | Summer 2023 | Peer reviewed review article about LWIR polarimetry |