Table of Contents

1 Future Investigator's Personal Statement

1.1 Goals, motivation, expertise and research experiences:

My long term career goal is to design and build novel instruments and detectors technologies to address open scientific questions in astrophysics and cosmology. This goal is driven by my passion for working on challenging hardware and instrumentation problems.

I was 14 years old when my parents bought me my first computer, an expense that they could barely afford. My first internet search, with the speed of a 56kps connection, was for NASA's website. As I look back over the last 15 years, a deep realization sinks in of the distance I have traveled in my quest. FINESST is the next step in that journey. I believe my previous research experiences have provided the right tools and training to conduct proposed instrumentation work and succeed in graduate research. At the same time, my scientific curiosity in the origins and evolution of the universe will continue to motivate me through this journey.

As a graduate student working with Dr. Erika Hamden at the Steward Observatory, University of Arizona, I developed an interest in galaxy formation and evolution through cosmic time and its connection with the large-scale structure of the universe. The pressing questions in this field appeal to my scientific curiosity for understanding the origins and evolution of the universe. Specifically, I am interested in understanding how the nearly uniform baryonic distribution after recombination collapsed to form galaxies. At the same time, the state of the art of this field demands the development of novel Ultraviolet (UV) instrumentation and technologies which aligns with my passion and expertise for hardware.

My doctoral research is focused on the advancement of UV detector technology to enable observations of the diffuse universe and understand the role this tenuous gas plays in the evolution of galaxies and star formation. I am excited about the contribution that my investigation into the performance and noise characteristics of UV detectors would make to current and future NASA Astrophysics missions. This research is exciting as in the near therm this work would provide hands-on training and experience while in the long term experience of working with these detectors will allow me to be involved in building future space missions that use this detector. The prospect that the technologies I help develop today could enable next-generation multi-billion dollar flagship space telescope.

My most recent research experience is working with Dr. Erika Hamden, since spring 2019, while pursuing my MS in Optical Science. For the last two years, I have been working with her on several UV instrumentation projects, including the development of a test facility for UV/Visible characterization, and optical alignment, straylight analysis, and in-flight calibration of Faint Intergalactic Red-shifted Emission Balloon-2 (FIREBall-2) Multi-object Spectrograph (MOS). FIREBall-2 is a balloon-borne sub-orbital telescope designed to measure the faint emission from the Intergalactic Medium (IGM).

The work with FIREBall-2 collaboration gave me the opportunity to work with a diverse international team. I visited the Laboratory of Astrophysics, Marseille (LAM) to work on the throughput measurement and optical-alignment of the MOS. While working with experts on optical testing inside the cleanroom extended my technical capabilities, what I truly valued during this visit was the nurturing work culture and collaborative team spirit. I have been motivated and challenged by the excellent technical training from these projects combined with the opportunity to learn about the scientific drivers for studying the cosmic web, and circumgalactic matter (CGM), and their connection to the formation of stars and galaxies. Encouraged by Dr. Hamden, I applied and was accepted to the Astrophysics program at Steward in fall 2020. Since then I have been working on a one-year project with JPL on building a proof of concept setup for dark current characterization of EMCCDs. Through our lab's ongoing collaboration with the UV detector group at JPL, headed by Dr. Shouleh Nikzad, I am getting trained in specific technical skills required to test and characterize silicon-based UV detectors using the test setup that I have developed.

While my recent experiences have provided invaluable training specific to UV instrumentation dedicated to IGM/CGM science, my past educational and professional experiences are also related to UV instrumentation, albeit for space-borne solar astrophysics.

In 2012, I interned with Prof. Ramaprakash and Prof. Durgesh Tripathi at the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, India. I worked on the design concept of a Miniaturized Extreme-Ultraviolet (M-EUV) Solar Telescope for imaging the solar corona at 17.1 nm (Fe IX emission line). The concept was selected as the primary payload for a student NanoSat project, called Azad-1, at my undergraduate institution. This was an exciting experience as I worked, throughout my senior year, on the end-to-end system design of the telescope. While making key technical contributions to optical design and analysis, selection of Lumogen coated CCD detector, and design of multi-layer mirror coatings (Mo-Si) optimized for narrowband EUV reflectivity, I also led an undergraduate team of forty students working on the design of the different subsystem of the satellite.

Post graduation, in 2014; I was appointed as the Lead Engineer for the Solar Ultraviolet Imaging Telescope (SUIT), at IUCAA. SUIT (Instrument-PI: A. N. Ramaprakash, Science-PI: Durgesh Tripathi) is a payload on-board the Aditya-L1 Spacecraft of the Indian Space Research Organization (ISRO), designed to observe the Sun in the near-ultraviolet region (200-400 nm) from the vantage of the sun-earth Lagrange point (L1). In this role, I lead the end-to-end development of the telescope working with science, payload, spacecraft, and launch vehicle engineering teams across multiple ISRO centers. I gained key competencies in space systems design, UV instrumentation, and development of cleanroom facilities for integration and testing of contamination sensitive UV payloads.

For instance, I led the team for selection, space qualification, and testing of UV-enhanced CCDs (e2v CCD-272) for SUIT. Working with the vendor e2v technologies (now Teledyne-e2v) and the detector team at IUCAA, I developed the detector technical specifications, the space qualification, and flight acceptance test plan, and experimental and support setups for verification, calibration, integration of the flight and engineering detectors. During the course of this work, I stood in for the PIs by making key technical decisions and engaging with stakeholders. This period of accelerated growth propelled by challenges of the project, not only provided me with significant technical knowledge and expertise but also the ability to navigate complex team structures while building authentic leadership.

I hope to pursue rigorous coursework towards earning a master's degree in optical sciences and a doctoral degree in Astrophysics. While previous training and research experiences have become a bedrock for me to conduct instrumentation work and succeed in graduate research. However, I firmly believe that it is the combination of my curiosity, love for scientific inquiry, and the right mentorship that will drive my growth as a well-rounded scientist and ensure my success as a recipient of the FINESST grant.

1.2 Graduate study timeline

I am currently enrolled in the MS Optical Sciences (since spring 2019) and Ph.D. Astronomy and Astrophysics programs (since fall 2020) at the University of Arizona. I intend to obtain the MS degree after finishing two required optics-related lab credits in Spring 2022. I am currently focusing on astronomy coursework, while working on research projects in parallel, in preparation for the written prelims in Spring 2022. I intend to defend my thesis and graduate from the doctoral program by Summer 2025.

2 Scientific/Technical/Management

2.1 Advancing UV detectors for new perspectives on galaxy evolution

Mapping the distribution and flow of baryons at different scales of the universe is necessary to understand the formation and evolution of galaxies and stars [41]. A significant fraction of baryons in the universe reside outside of galaxies and are difficult to observe and account for [36, 12, 4]. Recent simulations and observations to resolve the 'missing baryon' problem point at three possibilities: the baryons could be distributed in larger-scale filamentary structures in the cosmic web, [16, 13], in clouds of warm gas in galactic halos [42, 28], or in a dilute hydrostatic halo of hot gas near the virial temperature [9, 14, 27].

Extensive Ultraviolet (UV) observations are required to probe the density, morphology, physical extent and kinematics of this tenuous gas in the Intergalactic (the cosmic web), and Circumgalactic (warm and hot gas around galaxies) matter (IGM, and CGM, respectively)[41, 29]. UV observations offer a cornucopia of spectral features (absorption/emission lines, continuum emission, and fluorescence) from atomic and molecular hydrogen (for e.g., Ly-α from HI) and trace metals (for e.g., OIV, CIV, NV, MgII, etc.) that can be used to study these media [1, 31]. While these emission signatures are typically very faint, deep observations are possible due to the very low UV sky background (several orders of magnitude below that of the visible) [29]. The challenge for galaxy evolution studies, then, is to detect the faint UV signals that are expected from this mostly unobserved diffuse gas in galactic halos.

Despite the scientific value of UV observations of emission from the faint IGM and CGM, there are precious few telescopes currently carrying out these observations (e.g. *Hubble Space Telescope-Cosmic Origins Spectrograph, HST/COS)* [15]). This is partly due to the historical limitations of UV detector and mirror technology. Low efficiencies, low reflectivity, and the high impact of contamination have plagued UV instruments and made them less competitive compared to missions at other wavelengths. A concerted effort by the UV community over the last decade, supported by the Decadal [8] and NASA priorities [24], have resulted in more advanced detectors and mirror coatings [33]. These high efficiency UV detectors and stable, high reflectivity coatings are motivating an explosive growth in the number of UV mission proposals.

My proposed research program takes the recent innovations in UV technology and leverages them for further improvement by identifying and understanding the dominant noise sources and drawbacks of their operation, and finding solutions. I will complete four distinct but interrelated projects that combine instrument building and technology development to advance my scientific motivation of mapping and understanding the diffuse universe. These projects address well known issues in the current state of the art of UV detectors, including dark current plateaus, difficulties in photon counting for long exposure time images, and red leak of visible wavelength photons in UV observations. My planned projects are: 1) Understanding the persistent Dark current plateau in silicon Charge Coupled Devices (CCDs) (§2.2.1), 2) Design and characterisation of Electron multiplying CCDs (EMCCDs) with detector integrated coatings (§2.2.2), 3) Characterisation of Skipper CCDs and delta-doped UV-enhanced Skipper CCDs (§2.2.3), 4) Characterization of Microchannel Plate (MCP) detectors for Aspera-SmallSat (§2.2.4).

As a member of the Hamden UV/Vis Detector (HUVD) lab (PI: Prof. Erika Hamden), at the University of Arizona, I am surrounded by experts at the forefront of developing high-efficiency, single-photon counting silicon detectors for UV spectroscopy and imaging. My current one-year project with the Jet Propulsion Laboratory (JPL) and our lab's ongoing collaboration with the UV detector group there, headed by Dr. Shouleh Nikzad, provides access to experimental detectors and advice on experimental design, in addition to secondary mentoring.

The ultimate goal of this work is the advancement of UV detector technology for

NASA-supported astrophysics missions (future flights of FIREBall-2+, Institutional-PI: Erika Hamden; *Aspera*, PI: Dr. Carlos Vargas), future NASA-Flagship mission concept studies (*Large Ultraviolet Optical Infrared Surveyor, LUVOIR* and *Habitable Exoplanet Observatory, HabEx*), as well as recent proposals in smaller classes of astrophysics missions (e.g., *Hyperion*, a proposed Small-class Explorer, SMEX, concept in preparation for proposal as Medium-class Explorer, MIDEX, PI: Prof. Erika Hamden).

2.2 Projects: Scope and specific aims

2.2.1 Understanding the persistent Dark current plateau in silicon CCDs

Traditionally, Photocathode based MCP detectors (eg. those used on *Far Ultraviolet Spectroscopic Explorer (FUSE)* [32], *Galaxy Evolution Explorer (GALEX)* [30], with ∼10% QE in UV) have been the workhorse detectors for single photon counting applications in the UV. These were preferred over silicon-based CCD detectors with surface UV-enhancements which suffered from several drawbacks: read noise, surface-generated dark current, and Quantum Efficiency Hysteresis (QEH) (for e.g. *Hubble Space Telescope Wide Field Camera 3 (HST/WFC3)* [7, 2]). Over the past few decades, significant gains have been made in improving Silicon-based single photon counting detectors for photon starved, low-background UV Astronomy[33, 25, 18].

Notably, the Microdevices Laboratory (MDL) at JPL have developed high-performance photon-counting detectors by delta-doping EMCCDs with Molecular-beam epitaxy (MBE); to achieve internal QE of up to 100% from UV to Near-IR. Combined with novel anti-reflection coatings applied using Atomic Layer Deposition (ALD), these devices provide an unprecedented UV QE of up to 65% [33]. The architecture and functionality of these devices in a near-space environment have already been demonstrated in FIREBall-2 (FB-2), a stratospheric balloon-bore telescope with a Near-UV Multi-object Spectrograph(MOS), flown in 2018 with future flights planned in 2021 [26, 17, 34].

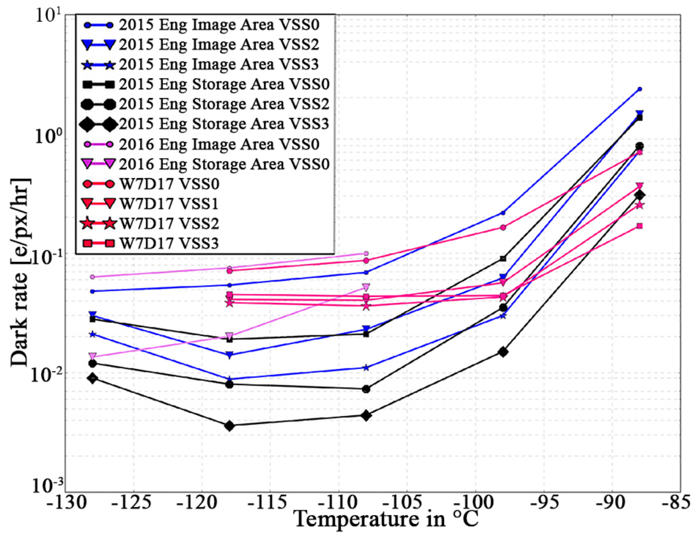

Figure 1: Dark current rates as a function of temperature. This plot shows dark current rates for two engineering grade devices and a delta-doped device. Image area and storage area are plotted for engineering devices. Colours represent different devices and substrate voltages. (Adapted from [25])

The primary challenge for using these devices is to minimize the noise contribution from dark current and Clock Induced Charge (CIC). EMCCD architecture overcomes the low frequency readout noise by amplifying the signal in the serial gain registers using avalanche photo multiplication [21]. EMCCDs can accommodate a wide dynamic range of signals by operating with a variable gain (from >1,000 e$^-$/e$^-$ in photon-counting mode to 1 for conventional CCD mode [10]. But with this pre-amplifier gain approach, the noise due to dark current and CIC, which is normally negligible compared to read noise in traditional CCDs, is also amplified like the photo-electrons. Furthermore, the avalanche photo-multiplication process generates additional noise from cosmic ray trails, deferred charge, and coincidences [26, 10].

In previous measurements for the FB-2 flight detectors (the Te2V EMCCD 201-20), Kyne et al. [26, 25] found that the CIC can be reduced with lower parallel and serial wells as well as optimizing the clock shaping. After achieving optimal CIC, they also investigated the variation of dark current with detector temperature and substrate voltages. It was found that the dark current decreased with detector temperature as expected until plateauing at $\sim$ -110 °C. Lowering the temperature beyond this did not significantly reduce the Dark Current (Fig.1).

It is suspected that this plateau could be due to a combination of ambient VIS/IR from the dewar, low level light leaks, and/or a non-temperature dependent component, that varies with substrate voltage, caused by spurious charge generation in the detector pixels and/or emission from the detector packaging. Similar plateaus have been observed in other CCDs and an investigation to understand this noise will **have a wide and profound impact on understanding low noise CCDs and CMOS arrays of all types.**

To further investigate the dark current plateau, I am building an innovative setup (see §2.3.2 for the test setup and plan) to eliminate the thermal blackbody emission from the detector dewar and ambient environment. This setup will measure EMCCD dark current with and without the noise due to visible photons from the tail of thermal blackbody emission and we will use it to investigate the temperature dependence of contributions from the dewar walls to the dark current plateau. The system is designed to eliminate low level light leaks and enable investigation of non-temperature dependent noise components. With my current support from the JPL-UARIZONA-SURP grant for FY-21, I am working on demonstrating the proof of concept for this setup by testing existing FB-2 EMCCDs. With FINESST support, I will continue my investigation into sources of dark current with EMCCDs supplied by JPL.

The goals of this project are to identify the noise source(s) and develop mitigation strategies, including design of the environment in which these detectors have to be operated. Although this effect is observed in all Si devices, the high gain amplification of this noise in Electron Multiplying Charge-Coupled Devices (EMCCDs) allows for a robust measurement of this noise at much higher SNR than conventional CCDs. Combined with modular capabilities of CCCP v3 controllers (Controller for Counting Photons v3) from NÜVÜ Camēras [10], the noise characteristics of the EMCCDs can be measured much more accurately than in previous experiments.

A better characterization and understanding of these devices is of great importance to the broader detector community. We hope to improve SNR by reducing the noise floor in the detector through additional control of the detector ambient environment (a common practice in Infrared (IR) missions with significant space heritage). Understanding and minimizing the noise of these devices is crucial for future and proposed missions, including the *Nancy Grace Roman Telescope*, *Hyperion*, and future flights of FIREBall-2 that will use similar detectors.

2.2.2 Characterization of EMCCDs with detector integrated filters

A significant advantage of delta-doped Silicon detectors is their near 100% internal quantum efficiency from UV to near-IR. These detectors can be combined with ALD coatings to achieve tailored spectral response for a range of scientific applications [33].

For instance, Hamden et. al. (2012) [18] achieved up to 70% QE in the NUV region with all-dielectric ALD ARC on delta-doped EMCCDs for FIREBall-2 (QE of 67.6% with a five-layer coating of SiO2 and Al2O3). However, these coatings had a significant broadband response extending up to 900 nm. Achieving a selective narrowband response in UV with complex multilayer dielectric structures by limited number of UV transmitting materials.

With ALD metal-dielectric filters (MDF) deposited on silicon detectors, Hennessy et. al. (2015 and 2017) [20, 19] achieved a narrow-band response in the UV with up to three orders of magnitude out-of-band rejection in visible. These detectors, with metal-dielectric device-integrated filters (MDDIFs), could suitable for UV missions that require suppression of red-leak noise. Fig.2 an example of model spectral response and out of band suppression of MDF EMCCD design for Far-UV (S-FUV) channel of Star-Planet Activity Research CubeSat (SPARCS) [23].

Patterned ARC on silicon-detectors with Area Select-ALD (AS-ALD) techniques are in the early stages of development at JPL. With this method, all-dielectric ARC filters can be applied either as a wedged or stepped coating on a single detector. Such patterned ARC detectors are useful for applications in UV spectrometry where different parts of the detector need different optimizations.

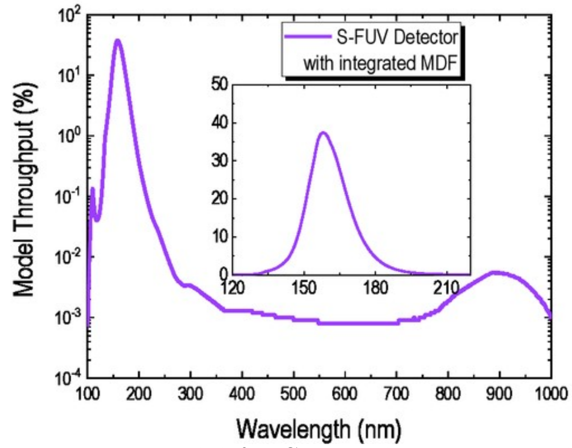

Figure 2: Model for Spectral response and out-of-band suppression for delta doped detector with MDF for S-FUV channel of SPARC cubesat. Insert shows throughput on a linear scale. From [23]

Through the on-going collaboration with JPL, Dr. Hamden is part of the team that is developing UV EMCCDs with integrated MDFs as well as patterned ARCs for application in UV astronomy. Within the scope of the FINESST proposal, I will work on the design of these detector integrated coatings for delta-doped EMCCDs motivated by specific science cases for the study of CGM/IGM. The detectors based on these designs will be fabricated by JPL and I will characterize the QE, spectral response, and dark current noise performance at HUVD lab. These measurements will allow us to understand the behaviour of these coatings and compare their performance.

2.2.3 Skipper CCDs for UV/Visible astronomy

A major drawback of EMCCDs is that the avalanche photo-multiplication process enhances the dark and CIC noise form each pixel and also generates additional noise. This noise amplification is absent in the Skipper CCD architecture that implements a multiple non-destructive readout technique that reduces the low-frequency readout noise by using a floating gate output stage to perform repeated measurements of the charge in each pixel [22, 40]. A drawback of this sampling method is the long readout time required to reach sub-electron level read noise (for e.g. up to 3 hours for detector with 4126×866 pixels) [40]. Although, different methods to reduce this readout time are being explored [5, 6], **extensive characterisation of the noise performance of these detectors is important for their application in astronomy.**

Furthermore, as these devices are fabricated with the same processes as CCDs and EMCCDs, they can be made UV-sensitive with the same MBE delta-doping and ALD AR coating techniques. With her existing collaboration with JPL, Dr. Hamden plans to develop delta-doped UV-enhanced skipper CCDs for application in UV Astronomy.

In this project, I will work on the QE, spectral response and noise performance (including dark current measurements) characterisation of visible Skipper CCDs (not optimized for UV) and the proposed delta-doped, UV enhanced Skipper CCDs. The test setup for these devices would be similar to the characterization setup for EMCCDs (see §2.3.1) with the exception of the customized readout electronics skipper CCDs [3]. Although, not in the scope of this work, it is interesting to note that CMOS sensors with the skipper readout architecture applied to each pixel are on the horizon [38]. This work could motivate development of delta-doped UV-enhanced CMOS sensors with much lower readout time in the near future.

2.2.4 Characterization of MCP detectors for *Aspera*

Aspera (PI: Carlos Vargas) is a UV SmallSat mission concept, recently selected for the NASA Astrophysics Pioneers program [39], designed to map O VI emission ($\lambda\lambda = 1032$, 1038 Å rest frame) from nearby galaxy halos. It has four identical UV spectrographs that are designed to achieve a moderate spectral resolving power (R ~ 2000) at 1035 Å with a spatial resolution of 45” (FWHM) over a 30’ slit length FoV to resolve the O VI line emission, and distinguish its spatial distribution along the slit length direction. The four spectrographs share two cross delay line (XLD) microchannel plate (MCP) detectors from Sensor Sciences, LLC. Each MCP borosillicate micro-capillary array is coated with a CsI photo-cathode via atomic layer deposition (ALD), which enhances the QE of detection to > 40% at 1020–1050 Å [37].

As a part of the detector team for *Aspera*, I will work on the pre-flight performance verification and characterisation of MCP detectors, and integration of the detector into the spectrographs. For characterization of QE of the detectors, I will design and develop the detector test setup using the VUV monochromater (§3) HUVD lab. The detector with electronics will be calibrated (with NIST calibrated photo-diodes) in a vacuum chamber attached to the monochromator for different MCP bias voltages and counting rates. The measured DQE will be used to create the instrument response model for in-flight calibration and science data reduction. The NASA Pioneers program offers a unique opportunity for early career researchers and graduate students to gain experience of working on flight hardware for space missions.

2.3 UV Detector performance and noise characterisation setup

2.3.1 Vacuum UV (VUV) monochromator setup: QE and spectral response

The VUV monochromator, shown in Fig.3), is custom built (Mcpherson Model 207, 0.67 m focal length, f/4.7, Czerny Turner design) with dual index-able light sources, at the entrance slit, to provide extended wavelength coverage between 115 to 1000 nm. The wavelength is selected by a stepper motor driven scan mechanism that turns the grating. Routine QE and spectral response measurements for UV/visible detectors would be carried out with NIST Calibrated VUV-photodiodes that are read out using a Dual-Channel Picoammter (Tektronix Model 6482).

This setup will be used in detector QE and spectral response characterization for EMCCDs with detector integrated filters (§2.2.2), Visible and UV Skipper CCDs (§2.2.3), and *Aspera* MCP detectors (§2.2.4). For the setup will be customized for wavelength coverage to 100 nm for characterization of *Aspera's* detectors.

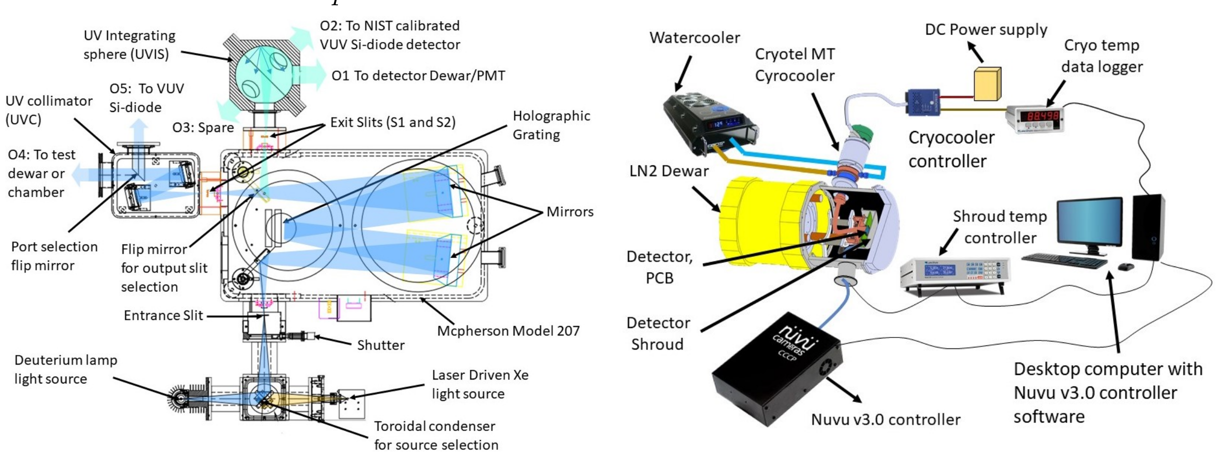

Figure 3: Left: Vacuum UV Monochromator setup being developed for DQE and spectral response measurements. Right: Detector Dark current characterisation setup with two independent cooling chains for the detector (Cryocooler cooling) and detector shroud (LN2 dewar)

2.3.2 Detector Dark current measurement setup

The dark current measurement setup being developed at HUD lab is shown in Fig.3. In this setup, the detector is cooled by a direct thermal link to the stirling cycle cryocooler (Cryotel MT from Sunpower). A shroud, cooled by the independent liquid nitrogen cooling chain, shields the detector from the dewar walls that are at ambient temperature. This arrangement allows for the temperature of the detector and the shroud to be controlled independently (using a lakeshore controller with patch heaters). The noise characterisation for EMCCDs will be performed with CCCP v3 controllers from NÜVÜ Camēras. This setup will also be used for dark current measurements for EMCCDs with detector integrated filters (§2.2.2), and Visible and UV Skipper CCDs (§2.2.3). For Skipper CCDs, a custom-built controller would be used.

For the dark current plateau investigation with EMCCDs, the experimental plan is to conduct a series of dark current measurements while varying the temperature for the cold shroud (shroud at room temperature, -50°C, -150°C) in combination with a range of detector operating temps (-85 to -130°C) and substrate voltages (0-5V). We expect the DC will follow the characteristic exponential decay when the blackbody of the shroud is eliminated. Preliminary calculations indicate the rate of detectable visible photons generated by a room temperature shroud to be around 0.7 e^{-} pix^{-1} hr^{-1}, around the level of the measured plateau.

2.4 Project timeline and publication plan

Fig.4 shows a summary of the timeline for the proposed projects with a top level breakdown of activities.

I expect to publish four SPIE proceedings: one for each project. I also expect to publish two first author peer-review papers on dark characterization of delta-doped EMCCDs by summer 2023 and on Quantum Efficiency, Spectral response characterization of visible and delta-doped Skipper CCDs by Summer 2024. I expect that my doctoral thesis, comprising of the work done for these projects, would be ready for submission by early 2025.

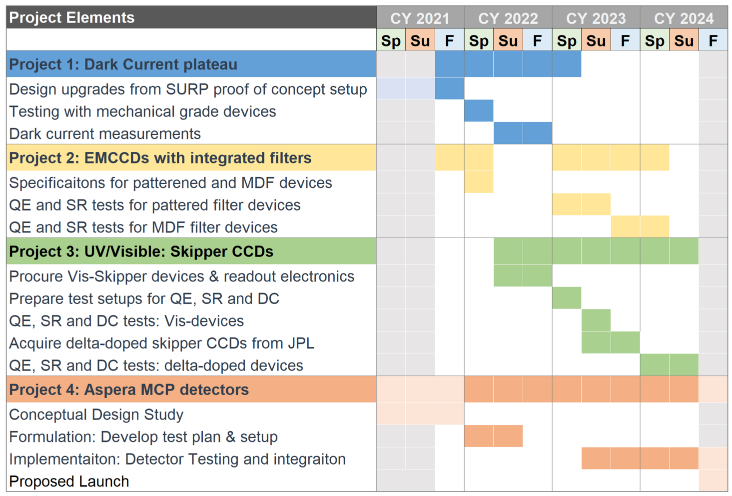

Figure 4: Summary of the schedule from calendar years(CYs) 2021-2024 for the proposed projects with a breakup of activities. (Fall-F, Spring-Sp, Summer-Su).

2.5 Significance of high-QE, low-noise UV detector for future NASA missions

The development of high quantum efficiency (QE), low noise, photon counting, UV detectors, that I will be testing in this proposal, is the result of a concerted program supported by priorities of the UV community over the last decade. Nearly all community reports in the last decade have stressed the importance of improved UV detectors for applications in Astrophysics and Planetary Science; including the 2010 Decadal report[8], and reports by Association of Universities for Research in Astronomy (AURA) [11], and Cosmic Origins Program Analysis Group (COPAG) [35]. Furthermore, two of the NASA-supported astrophysics Flagship mission concept studies (LUVOIR and HabEx) have established the need for these high performance UV detectors. The recent proliferation of UV missions proposals (e.g., Hyperion, SPARCS etc.), with delta-doped EMCCDs as baseline detectors, has increased the profile and priority of the proposed research.

Every recent breakthrough scientific discovery in astrophysics/cosmology was enabled by incremental technology development efforts spanning decades. The characterization of UV detectors proposed in this work is part of a two decade long progress made in the UV detector technology. There is compelling scientific evidence that UV observations of the distribution of gas in the IGM/CGM, enabled by these detectors, could significantly improve our understanding of the evolution of galaxies. As a graduate student, I am excited that I am working on these detectors when they are at the threshold of enabling breakthrough science.

3 References and Acknowledgements

Acknowledgements: I, **Aafaque R. Khan**, hereby declare that contents of this proposal are my own original work for the Future Investigators in NASA Earth and Space Science and Technology research grant.

The PI, **Erika T. Hamden**, declares that the contents of this proposal are the original work of the FI, Aafaque R. Khan.

I would like to acknowledge the contributions of the following individual in writing this proposal. Dr. Erika Hamden provided constant support and encouragement while patiently reviewing the outlines, ideas and drafts for all sections of the proposal. Jessica Li reviewed the draft of the STM and provided valuable editorial feedback. Aman Kaleem provided creative and editorial feedback on the personal statement.

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4 Biographical Sketches

Aafaque R. Khan

University of Arizona
Steward Observatory
933 N Cherry Ave
Tucson, AZ 85719 USA

phone: 520-223-5171
arkhan@email.arizona.edu

EDUCATION

Steward Observatory, University of Arizona, Tucson, AZ
Ph.D., Astronomy, 2020-Present, Advisor: Prof. Erika T. Hamden
Research Areas: UV detectors and instrumentation, Galaxy Evolution, CGM
College of Optical Sciences, University of Arizona, Tucson, AZ
M.S, Optical Sciences, 2019-Present
Maualana Azad National Institute of Technology (MANIT), Bhopal, India
B. Tech., Mechanical Engineering, 2009-13

WORK EXPERIENCE

Graduate Research Assistant, Hamden UV/Vis Detector Lab, 2019-Present
Steward Observatory, University of Arizona, Tucson, USA
Development of UV/Vis detector calibration facility and cleanroom, Dark current characterization of Electron-multiplying CCDs (EMCCDs), Optical alignment and testing, Straylight analysis, On-board calibration for FIREBall-2 Multi-Object Spectrograph

Lead Engineer, Solar Ultra-violet Imaging Telescope (SUIT) on Aditya-L1, 2015-2019
Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, India
SUIT is a payload on-board the Aditya-L1 Spacecraft of the Indian Space Research Organization (ISRO), designed to observe the Sun in the near-ultraviolet region (200-400 nm) from the vantage of the sun-earth Lagrange point (L1). Expected Launch: Early 2022.

CURRENT RESEARCH

1. Aspera SmallSat, (PI: Dr. Carlos Vargas)
Aspera is a SmallSat focused on imaging emission from OVI coronal gas in nearby edge-on galaxies. Accepted for 2020 NASA PIONEERS **($20M)**.
Detector Characterization and testing for Borosillicate Micro-channel Plate (MCP) detectors

2. Hamden UV/VIS Detector Lab, (HUVD)
Development of Vacuum UV detector characterization facility and cleanroom; Characterizing QE, noise, and dark current for UV optimized EMCCDS for use on future space missions. Dark current of measurement cryocooled EMCCDs in collaboration with Micro-devices Laboratory (MDL) at Jet Propulsion Laboratory (JPL) supported by JPL-Strategic University Partnership grant. PIs: Erika Hamden (UArizona), Shouleh Nikzad (JPL-MDL)

3. Faint Intergalactic Redshifted Emission Balloon (FIREBall-2)
FIREBall-2 is a balloon borne sub-orbital telescope with a multi-object spectrograph (MOS) designed to measure the faint emission from the Intergalactic Medium.
Optical Alignment and throughput measurement of spectrograph at Laboratory of Astrophysics, Marseille (Summer 2019); Straylight analysis of MOS in Zemax Opticstudio, Development of calibration system of the MOS

PAST RESEARCH

1. Solar Ultra-violet Imaging Telescope (SUIT) on-board Aditya-L1
SUIT is a payload on-board the Aditya-L1 Spacecraft of the Indian Space Research Organization (ISRO), designed to observe the Sun in the near-ultraviolet region (200-400 nm) from the vantage of the sun-earth Lagrange point (L1).

2. Azad-1 Student Satellite Project
Azad-1 was an undergraduate nanosatellite concept for technology demonstration of an Extreme Ultraviolet Solar Imaging telescope on a nanosatellite platform.

SKILLS

Optical Design: Zemax Opticstudio, Zemax Lens Mechanix, Synopsys Code V, Synopsis Light tools; **Programming:** Python, R, C, MATLAB, Mathematica; **Mechanical Design (CAD) and FEM Software:** Solidworks CAD and Simulation, NX Nastran Structural, Ansys, Autodesk Inventor, Autodesk Mechanical Simulation

RELEVANT PUBLICATIONS

1. A. Ghosh, S. Chatterjee, **A. R. Khan**, et al., “The Solar Ultraviolet Imaging Telescope onboard Aditya-L1”, in Space Telescopes and Instrumentation 2016: Ultraviolet to Gamma Ray, Proceedings of SPIE Vol. 9905 (SPIE, Bellingham, WA 2016), 990503. (Proceeding)
2. D Tripathi, A. N. Ramaprakash, **A. R. Khan**, et al., ”The Solar Ultraviolet Imaging Telescope onboard Aditya-L1”, in Special Section: Astronomy, Current Science Vol. 113, No. 11, 10 December 2017. (Article)
3. Keri Hoadley, Erika T. Hamden, Bruno Milliard, **Aafaque R. Khan**, et al., ”The FIREBall-2 UV balloon telescope: 2018 flight and improvements for 2020,” Proc. SPIE 11118, UV, XRay, and Gamma-Ray Space Instrumentation for Astronomy XXI, 1111815 (9 September 2019); (Proceeding)

AWARDS AND HONORS

1. Emerging Space Leaders Grant 2012 IAF
2. DCSP Grant from the IAF and ESA
3. Full tuition scholarship for the B.Tech. degree (2009-13) at MANIT, Bhopal awarded by Ministry of Minority Affairs, Govt. of India
4. Full tuition scholarship for Young India Fellowship (2013-14) by the International Foundation for Research in Education, New Delhi

Erika T. Hamden

University of Arizona
Steward Observatory
933 N Cherry Ave
Tucson, AZ 85719 USA

office: 520-621-9524
hamden@email.arizona.edu
http://ehamden.org

APPOINTMENTS

Assistant Professor, University of Arizona, 2018 - Present

Postdoctoral Fellow, California Institute of Technology, 2014 - 2018

R.A. & G.B. Millikan Prize Postdoctoral Fellowship in Experimental Physics, 2017-2018

NSF Astronomy and Astrophysics Postdoctoral Fellowship, 2014-2017

EDUCATION

Columbia University, New York, NY
Ph.D., Astronomy, July 2014
M.Phil, Astronomy, 2010 & **M.A.**, Astronomy, 2009

Harvard College, Cambridge, MA
A.B., Astronomy & Astrophysics, June 2006

SELECTED AWARDS AND HONORS

NASA Group Achievement Award, FIREBall-2 Detector Team, 2020.
NASA Early Career Public Achievement Medal, 2020.
AAAS If/Then Ambassador, 2019.
Presidential Early Career Award for Scientists and Engineers (PECASE), 2019.
2019 TED Fellow
Nancy Grace Roman Technology Fellowship in Astrophysics for Early Career Researchers

SELECTED RESEARCH GRANTS

∼$25 Million USD

NASA PIONEERS 2021: Aspera is a mission concept for a SmallSat focused on imaging emission from OVI coronal gas in nearby edge-on galaxies. (PI: Dr. Carlos Vargas. **Deputy PI $20M**)

JPL SURP 2020: Advancing Ultraviolet Detectors: Dark current characterization towards fundamental understanding of silicon detectors for future astronomical missions (Institutional **PI, $45K**)

NASA APRA 2018 (18-APRA18-0150): FIREBall-2: Trailblazing the discovery of CGM Emission in the low-redshift universe (Institutional **PI, $605K**)

TEACHING

Graduate Advanced Extra-galactic Astrophysics, Spring 2021, UArizona, 8 students
The Physical Universe, Fall 2020, UArizona, 190 Students
The Physical Universe, Spring 2020, UArizona, 60 Students
The Physical Universe, Fall 2019, UArizona, 70 Students

SELECTED MEDIA FEATURES

How to move on after failure — and rebuild your confidence, Ideas.TED.com, January 2021.

Radio conversation on confidence and resilience, DOVE, 2020.

Fast Forward Girls, YouTube Episode GEM Sisters Miss Space Challenge, June 2020.

Four UA women in STEM selected for inaugural class of AAAS ambassadors, The Daily Wildcat, November 2019.

ACADEMIC SERVICE & MEMBERSHIP

Review Panels: NASA DALI, NASA APRA, NASA NESSF

Article Reviewer: Nature Astronomy, JATIS

Grad Student Admissions Committee: University of Arizona, 2018-2020

Prize Postdoc Hiring Committee: University of Arizona, 2018-2019

MOST RECENT PUBLICATIONS

Note: Bold and underlined indicates a student/postdoc under Hamden's supervision.

1. "Long-slit cross-dispersion spectroscopy for Hyperion UV space telescope". H. Choi, I. Trump, Y. Feng, H. Kang, J. Berkson, **E. T. Hamden**, D. Kim. *JATIS* submitted October 2020.
2. "End-to-end ground calibration and in-flight performance of the FIREBall-2 instrument". V. Picouet, B. Milliard, **G. Kyne**, D. Vibert, D. Schiminovich, D. Martin, **E. T. Hamden**, **K. Hoadley**, J. Montel, N. Melso, D. **O'Sullivan**, J. Evrard, E. Perot, R. Grange, S. Nikzad, P. Balard, P. Blanchard, F. Mirc, N. Bray, A. Jewell, S. Quiret. *JATIS* 20091R. Accepted September 2020.
3. "FIREBall-2: The Faint Intergalactic Medium Emission Balloon Telescope". **E. T. Hamden**, et al., *Astrophysical Journal*, August 2020.
4. "The FLASHES Survey. I. Integral Field Spectroscopy of the CGM around 48 z =2.3-3.1 QSOs". **D. B. O'Sullivan**, C. Martin, M. Matuszewski, **K. Hoadley**, **E. T. Hamden**; J. D. Neill, Z. Lin, P. Parihar. *Astrophysical Journal*, May 2020.
5. "Delta-doped electron-multiplying CCDs for FIREBall-2". **G. Kyne**, **E. T. Hamden**; S. Nikzad, **K. Hoadley**, A. Jewell, T. Jones, M. Hoenk, S. Cheng, D. C. Martin, **N. Lingner**, D. Schiminovich, B. Milliard, R. Grange, O. Daigle. *Journal of Astronomical Telescopes, Instruments, and Systems*, January 2020.
6. "Emission from the Circum-Galactic Medium: From Cosmological zoom-in Simulations to Multi-Wavelength Observables". R. Augustin, S. Quiret, B. Milliard, C. Péroux, D. Vibert, J. Blaizot, Y. Rasera, R. Teyssier, S. Frank, J. M. Deharveng, V. Picouet, D. C. Martin, **E. T. Hamden**, N. Thatte, M. Pereira Santaella, L. Routledge, S. Zieleniewski, S. , August 2019.

5 Current and Pending Support

Aafaque Khan
The University of Arizona, Steward Observatory

CURRENT AWARDS (as Co-Principal Investigator)

Project Title:	SURP FY2021: Advancing Ultraviolet Detectors: Dark current characterization towards fundamental understanding
Sponsoring Agency:	JPL
POC, phone #, email:	Susan Scrivner, 818-393-0930, susan.g.scrivner@jpl.nasa.gov
Total Award Amount:	$46,725
Performance Period:	11/13/2020 – 09/30/2023
Months Committed to the Project per year:	

PENDING AWARDS (as Co-Principal Investigator)

None

Erika Hamden
The University of Arizona, Steward Observatory

CURRENT AWARDS (as Principal Investigator)

Project Title:	Advanced Photon-Counting Detectors for UV-VIS Astronomical Use
Sponsoring Agency:	NASA
POC, phone #, email:	Mario Perez, 202-358-1535, Mario.Perez@nasa.gov
Total Award Amount:	$200,000
Performance Period:	10/01/2019 – 09/30/2022
Months Committed to the Project per year:	3 months

Project Title:	The Faint Intergalactic-Medium Redshifted Emission Balloon (FIREBall-2): Trailblazing the Discovery of CGM Emission in the Low-Redshift Universe with Ground-Breaking Instrumentation and Innovative UV
Sponsoring Agency:	NASA
POC, phone #, email:	Michael Garcia, Michael.R.Garcia@nasa.gov
Total Award Amount:	$605,022
Performance Period:	11/15/2019 – 11/14/2022
Months Committed to the Project per year:	2 months

Project Title:	Advance Photon-Counting Detectors for UV/VIS Astronomical Use
Sponsoring Agency:	NASA
POC, phone #, email:	Mario Perez, 202-358-1535, Mario.Perez@nasa.gov
Total Award Amount:	$355,284
Performance Period:	07/14/2020 – 07/13/2023
Months Committed to the Project per year:	1 month

Project Title:	SURP FY2021: Advancing Ultraviolet Detectors: Dark current characterization towards fundamental understanding
Sponsoring Agency:	JPL
POC, phone #, email:	Susan Scrivner, 818-393-0930, susan.g.scrivner@jpl.nasa.gov
Total Award Amount:	$46,725
Performance Period:	11/13/2020 – 09/26/2021
Months Committed to the Project per year:	0.16 month

Project Title:	Advanced Filter Solutions for Multiband ad Broadband Imaging
Sponsoring Agency:	JPL
POC, phone #, email:	Susan Scrivner, 818-393-0930, susan.g.scrivner@jpl.nasa.gov
Total Award Amount:	$106,627
Performance Period:	01/04/2021 – 06/30/2022
Months Committed to the Project per year:	1 month

Project Title:	PI 101: Training in Mission Concept Development Across SMD
Sponsoring Agency:	Heising-Simons Foundation
POC, phone #, email:	650-887-0277
Total Award Amount:	$99,935
Performance Period:	06/01/2020 – 11/30/2021
Months Committed to the Project per year:	0.5 month

CURRENT AWARDS (as Co- Principal Investigator)

Project Title:	Aspera: Unveiling Missing Gas
Sponsoring Agency:	NASA
POC, phone #, email:	Michael Garcia, Michael.R.Garcia@nasa.gov
Total Award Amount:	$19,996,193
Performance Period:	04/01/2021-01/31/2026
Months Committed to the Project per year:	Yr 2: 0.60, Yr 3: 0.60, Yr 4: 0.70, Yr 5: 0.60

PENDING AWARDS (as Principal Investigator)

None

6 Mentoring Plan and agreement

Mentoring plan and agreement for NASA FINESST proposal

The following mentoring agreement has been jointly developed by Dr. Erika Hamden (Principal Investigator, hereafter PI) and Mr. Aafaque R. Khan (Future Investigator, hereafter FI) for the NASA FINESST proposal and for the FI's doctoral studies plan. It outlines the mutually agreed-upon terms and goals of the mentor-mentee relationship.

FI's statement of commitment:

The FI agrees to participate in the mentoring process actively and recognizes that the PI's role is to help him reach his professional goal of becoming a curious, kind, and well-rounded scientist, an active member of the research community, and a champion of diversity and inclusion in academia. The FI agrees that this process is an exercise of mutual learning and growth with the core values of respect, honesty, open communication, and a shared passion for discovery.

PI's statement of commitment:

The PI agrees to provide the FI with intentional guidance, motivation, encouragement, and technical training to help him achieve his professional goals. As a part of this mentoring process, the PI will share her knowledge, experience, and perspective to equip the FI in leading a balanced, fulfilling, and sustainable career.

The Mentorship in practice:

1. **Research and Technical Training:**
   The PI will assist the FI to acquire advanced expertise and depth of knowledge of the proposed research on developing astronomical instrumentation to study the formation and evolution of galaxies and stars. The PI will work in close collaboration with the FI and will invest time to expand the FI's technical skills and background directly. The PI, in collaboration with the FI, will ensure that necessary laboratory facilities and hardware are available to conduct the proposed research. The PI will meet on a weekly basis with the FI to keep track of progress on research activities.
2. **Collaborations and networking:**
   The PI will support the FI in developing research collaborations and create a professional network. The PI will connect the FI to her collaborators, facilitating the growth of the FI's research network. Upon the FI graduation, the PI will invite him to collaborate on relevant projects with her group.
3. **Scientific writing:**
   The PI will train the FI in the best practices and ethics of scientific publishing and proposal writing. The FI will prepare drafts of research papers for publication and proposals for fellowships/grants, and the PI will review these manuscripts while making concrete suggestions on narrative, technical accuracy, and the overall quality of scientific writing.

4. **Science Communication:**
   The PI will encourage and support the FI to give talks on his research. The PI will provide critical feedback for FI's talks, presentations, and necessary training to develop his scientific communication skills. Furthermore, the PI will support and promote travel to domestic and international conferences such as SPIE, AAS meetings, etc., relevant to the FI's research.
5. **Teaching and mentoring students:**
   The PI will help the FI develop teaching and mentoring skills to enable his growth as an academic. The PI will share knowledge on how to develop effective teaching tools for courses in physics and astrophysics. The PI would share her teaching belief and practices providing guidance on developing teaching statements for postdoctoral and faculty position applications.
6. **Sustainable workflow and time management**
   The PI will guide the FI on developing his academic and research schedule to allow for a sustainable work-life balance. The PI will share her experience and best practices in managing multiple time-bound projects. The PI and FI will together identify the scope of work in each project and develop a priority-driven project plan. The FI will work towards maintaining the agreed timelines and report any issues/delays during weekly one-on-one meetings.
7. **Career guidance:**
   The PI will support the FI in developing a career path and help identify relevant fellowships and postdoctoral job opportunities. The PI will support FI's applications to relevant job positions by reviewing the application material and providing constructive feedback. The PI will provide recommendation letters to endorse the FI's job applications.

We, the undersigned, agree to enter into a mentoring relationship based on the commitments identified above.

Mentee: Aafaque R Khan

Place: Tucson, AZ
Date: February 1, 2021

Mentor: Dr. Erika Hamden

Erika Hamden

Place: Tucson, AZ
Date: February 1, 2021

7 Budget Timeline and Narrative

NASA FINESST Budget Justification

Note: Per NNH20ZDA001N-FINESST all costs are considered Participant Support Costs and exempt from IDC.

Participant Support Breakdown:

Personnel - Stipend

Prof. Hamden will supervise the University of Arizona student, Aafaque Khan, working on this FINESST proposal project. Prof. Hamden has worked extensively with CCDs, including the development of ground-breaking anti-reflection coatings for high UV efficiency and overseeing initial noise and dark testing of the FIREBall-2 EMCCD and the first flight test of the EMCCD during the Fall 2018 flight of FIREBall-2. Her postdoc work as Project Scientist of the FIREBall-2 Balloon experiment have given her valuable experience providing scientific and technical guidance to other post-docs and grad students, and she will provide valuable oversight and know-how to this project. Prof. Hamden serves as Aafaque Khan's advisor and is unfunded by the project.

We have requested stipend funds for one graduate student, Aafaque Khan, at 100% during the academic year and 100% during the summer for three years proposed. For graduate students, 0.50 FTE or 800 hours per during academic year is considered full time. Graduate students are also allowed to work up to 420 summer hours. The graduate student will work on developing the innovative test set-up, conducting detector characterization, and the resulting analysis.

We utilized the current graduate student rate at the Department of Astronomy and added the cost of UA Student Health Insurance per year. This was increased by 3% each year to account for annual salary increases and yearly increases to student insurance rates.

Travel

1. Domestic: We request funding for 2 short collaboration meeting to JPL in year 2 for Mr. Khan. These will be domestic trips to discuss the progress of the work.
2. Domestic: We request funding for a conference trip (AAS in year 3) for Mr. Khan to present his work. This also includes funding for the AAS conference fee.

Other Direct costs

1. Publication: We request funds to allow for publication of results by graduate student.
2. Tuition remission: 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, escalated at 8% per year in accordance with University guidelines. Tuition that exceed the yearly max allowed, will be covered by Department and/or College of Science.

DEPARTMENT OF ASTRONOMY
AND STEWARD OBSERVATORY

Project Title:	**Understanding the Dark Current Plateau in Silicon CCDs**						
Principal Investigator:	**Erika Hamden**						
Sponsor:	**NASA (FINESST)**						
Project Period:	**09/01/21 - 08/31/24**						
PARTICIPANT SUPPORT COSTS FOR Aafaque Khan	**YEAR 1**		**YEAR 2**		**YEAR 3**		**TOTALS**
Stipend		$ 30,696		$ 31,617		$ 32,565	$ 94,878
Health Insurance		$ 2,725		$ 2,807		$ 2,807	$ 8,339
Conference Registration Fees		$ -		$ -		$ 350	$ 350
Publication		$ -		$ -		$ 1,200	$ 1,200
Graduate Tuition		$ 11,579		$ 8,240		$ 6,473	$ 26,292
SUBTOTAL OPERATIONS/OTHER DIRECT COST:		**$ 45,000**		**$ 42,664**		**$ 43,395**	**$ 131,059**
TRAVEL DETAIL	**YEAR 1**		**YEAR 2**		**YEAR 3**		
	Domestic	International	Domestic-JPL (2 trips)	International	Domestic-AAS Conf. (New Orleans)	International	
Airfare:	$ -	$ -	$ 500	$ -	$ 500	$ -	**$ 1,000**
Lodging:	$ -	$ -	$ 1,288	$ -	$ 750	$ -	**$ 2,038**
Per Diem:	$ -	$ -	$ 448	$ -	$ 305	$ -	**$ 753**
Ground Transportation:	$ -	$ -	$ 100	$ -	$ 50	$ -	**$ 150**
TOTAL PER TRIP:	$ -	$ -	$ 2,336	$ -	$ 1,605	$ -	
TRAVEL TOTAL:	**$ -**		**$ 2,336**		**$ 1,605**		**$ 3,941**
	YEAR 1		**YEAR 2**		**YEAR 3**		
DIRECT COSTS		**$ 45,000**		**$ 45,000**		**$ 45,000**	**$ 135,000**
Less Tuition Remission		**$ (11,579)**		**$ (8,240)**		**$ (6,473)**	**$ (26,292)**
Other Exclusions		**$ -**		**$ -**		**$ -**	**$ -**
Subaward 1st 25K of each sub are subject to IDC - Add In		**$ -**		**$ -**		**$ -**	**$ -**
MTDC		**$ 33,421**		**$ 36,760**		**$ 38,527**	**$ 108,708**
INDIRECT COSTS (0% Stipulated)		$ -		$ -		$ -	$ -
TOTAL PROJECT COSTS		**$ 45,000**		**$ 45,000**		**$ 45,000**	**$ 135,000**