OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jul **Proposal type:** engineering

On-Sky Testing and Calibration of Next-Generation Blue-Sensitive Delta-Doped Detectors

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CoI(s): Alex Miller⋆ (ASU), Todd Veach (NASA-GSFC)

Abstract of Scientific Justification

We propose for engineering time with the 61” telescope to perform on-sky testing and validation of a prototype blue-sensitive large format detector. This is the third and final stage of a 3-year collaboration with JPL to develop new blue/UV-sensitive devices in a large form-factor. ASU’s role in the collaboration is to not only bench-calibrate the devices in the LASI lab at ASU, but also to provide on-sky validation of stability, low- and high-light level performance, photometric calibration, linearity, and electronic characterization across a range of targets and operational conditions. We request 3 nights of time with the 61” and use of the Mont4k support structure to enable a simple operational environment at the telescope for our custom dewar.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	61”	f/13.5	Custom/Mont4k+UBV	R		3	bright	Apr–Jun	Apr–Jun	no	no

Scheduling constraints and unusable dates *(up to 4 lines)*: We need dates after Apr 1 due to the development and delivery schedule for the final detector product from our collaborators at JPL.

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Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	M42	05:35:17	+05:23.466	HII Region with OB stars, V=4.0
2	M101	14:03:13	+54:20.952	Sc Spiral galaxy, V=9.6
3	M51	13:29:53	+47:11.718	Late-type interacting spiral, V=8.4
4	Double Cluster, Caldwell 14	02:20:00	+57:08:00	Open Cluster, V=3.7, 3.8
5	95 301	03:52:41	+00:31:21	V=11.216 photometric standard
6	95 317	03:53:44	+00:29:50	V=13.449 photometric standard
7	97 351	05:57:37	+00:13:42	V=9.781 photometric standard
8	Other Landolt Standards			As appropriate

Approval for Instrument Use from PI: ______________________

(have instrument PI signature appear on, or attach PI e-mail to, ***all*** *copies)*

Graduate students *(provide the following information for* ***each*** *student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on* ***all*** *submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis
Alex Miller	Paul Scowen		no	no

Scientific Justification

Introduction

Our group at ASU is engaged in a collaboration with the Microdevices Lab at JPL to develop next generation blue and UV-sensitive CCD technology to demonstrate new manufacture and post-processing techniques to increase response and reliability. In 2012, through APRA and JPL internal funding, we completed an aggressive and highly successful technology demonstration of high QE, solid-state, UV photon-counting arrays by applying JPLs back illumination processes including thinning, delta doping technology, and developing advanced antireflection (AR) coatings to commercially available Electron Multiplied Charge-Coupled Devices (EMCCDs). Using molecular beam epitaxy (MBE) and atomic layer deposition (ALD) to achieve atomic-scale control over the surface, our technology approach is unique in producing silicon detectors with exceptional stability and world-record QE (50-80%) throughout the ultraviolet (UV).

Our program will advance the TRL of our technology by: 1) Increasing detector format size in response to the requirements of future missions for large pixel count, 2) Determining the limits of detector noise and out-of-band performance in realistic spectroscopic and imaging applications, 3) Performing space qualification of the detector through relevant environment testing (thermal tests, radiation tests, and lifetime testing), 4) Advancing the manufacturability and reliability as a byproduct for other high efficiency silicon imagers, 5) On-sky validation over a wide range of flux levels using astrophysical imaging and spectroscopic instruments, and 6) Flight testing of the detectors on the synergistic and balloon experiment FIREBALL (flight accommodation and operations already funded by APRA) during a 2014-2015 launch. This technology maturation plan will create a routine and reliable source for production of high efficiency and innovative UV/Optical detector arrays for the community. The versatile and robust fabrication techniques presented here will have a major impact on future instrument capabilities and new scientific discoveries.

As emphasized in NWNH (Decadal 2010), a future UV/optical large telescope requires high QE, low noise, large format, space qualified UV detectors. Future medium-class concepts (Probes) could be furnished with flagship-class science capabilities if the large shortfalls in detector performance were made up. Recognizing this, the NASA Advisory Committee/Astrophysics Subcommittee charged the Cosmic Origins Program Analysis Group (COPAG) with assessing technology priorities. The COPAG in its 2012 Technology Assessment judged that blue/UV photon-counting detectors with large formats and low noise were Mission Enabling and therefore the highest priority. The Cosmic Origins Program Office Annual Technology Report made a similar finding.

Because future frontier blue/UV capabilities will exploit high resolution and wide-field highly-multiplexed imaging spectroscopy, and wide-field high angular resolution imaging, the key detector performance requirements are high efficiency, low noise, and large, scalable formats. A detector that is capable of providing a factor of 3-10 improvement in blue/UV efficiency over those in HST must do so without introducing a commensurate increase in noise. As we discuss further below, the detector that we are developing is the most advanced technology with demonstrated high QE, low noise, and large format performance required for future missions.

Quantitative Detector Performance Goals

Key detector metrics are anchored to the representative mission error budgets including the 4-m aperture UV/Optical mission requirements summarized in Science Traceability matrix in Table 1. Our approach is described in Table 2, in which the major milestone, TRL 6 demonstration of medium to high fidelity component prototype, is accomplished through a series of measured steps and quantified metrics that are tied to the error budgets of these representative mission concepts.

The part of this work that the ASU group is providing is step 5 above - on-sky validation, testing and calibration with wavelength and over a large range of target brightnesses. Our target sample ranges from stellar clusters of varying magnitudes, to large nearby galaxies with bright and faint surface brightnesses. We will use photometric standard stars to investigate the on-bench versus on-sky spectral performance of the detector as well as field dependent performance across the face of the detector. Repetitive sequences will investigate linearity, the gain achieved by the detector and readout circuitry, as well as the stability and reproducibility of the response. Detector stability, particularly in the readout circuitry, is a known issue with the larger format detectors (4k and above) that is requiring new and innovative pre-amp design for system such as DECam and LSST. We have our own variant on this solution and this run will demonstrate its performance.

The circuitry and dewar for the project, including cryo wiring and interface to the control computer, have all been completed (see Figure 1). This is the third proposal in support of this work through the use of UAO facilities. The first run in January 2014 was very productive but because of a series of hardware failures we were unsuccessful in getting the on-sky data we needed to calibrate and characterize the detectors from SAT year one. As of this writing the second run in support of this work has not yet happened, and is scheduled for November 2014. This proposal will continue on from the work we intend to complete in the second run to on-sky test the final products to come out of the SAT work with JPL. Despite the lack of success on the first run, we have taken extensive steps in rebuilding our readout circuitry and performing on-bench testing before going to the mountain, and we are confident the problems encountered have been fixed.

Table 1: Traceability Matrix for UV/Visible Detectors

NASA Science Objective/Questions	Science Sub-goal		Mission Concept	UV/Visible Detector Requirement	SAT Deliverable and/or Key Milestone
Understand the many phenomena and processes associated with galaxy, stellar and planetary system formation and evolution from the earliest epochs to today: How did the universe originate and evolve to produce the galaxies, star and planets we see today?	Absorption-line spectra of IGM, CGM, warm ISM. Composition of hot, warm and cold gas, both atomic and molecular.	Flagships/Probes	UV/Vis flagship: 4m+ w/ high-R spectrograph, (e.g. R~30k-100k). Bright/faint QSO	2x(50k x1k) focal plane, high QE w/ multi-λ AR, phot. counting	QE>50% @100-300nm, Yield > 80% Documented test results demonstrating performance
	Map IGM, CGM, ISM, outflows. Investigate signatures of star formation across galaxy types and redshift.		UV/Vis flagship: 4m+ w/ IFU/faint obj. spectrograph (e.g. R~2.5k-5k, FOV~20', 1" pix) IGM/CGM emission	Multi-slit/IFU >100 Mpix focal plane w/ high QE, multi-λ AR, photon counting	QE>50% @100-300nm, w/ nominal L3CCD photon-counting noise perf. Yield > 80% Documented test results demonstrating performance
	Map and study star-forming regions, deep galaxy surveys, nearby galaxies/stellar populations		UV/Vis flagship: 4m+ w/ wide field imager, high ang. res.	>500 Mpix focal plane (e.g. SFC), high QE + Broadband resp., fast readout	QE > 50% at 200 nm, 80%@ 656.3 nm, 60% @ 372 nm, > 60% @ 900nm Yield > 80% Documented test results demonstrating performance
	IGM, CGM, ISM.	Spin-off: Explorer class + attached payloads	IGM/ISM explorer (IFU, slit, NB)	~25-100 Mpix UV FPA of proposed explorers, concept studies	TRL 6 Device-level prototype/Design & performance guidelines
	Planet detection and characterization		Exoplanet explorer	>100 Mpix (e.g. Kepler).Photo-metric stability	TRL 6 Device-level prototype/Design & performance guidelines
	Multi-wavelength transient characterization and monitoring, corollary surveys		UV/Optical Monitor	Efficient wide-field imaging, fast readout ~10 Mpix	TRL 6 Device level prototype, guidelines and/or flight ready devices
	UV/Visible Transient monitoring:study energetic universe, exoplanets		Transient monitor	Wide field, large FP, fast readout 10-100 Mpix, Photomet. Stab.	TRL 6 Device level prototype guidelines, and/or flight ready devices
	Mapping IGM, CGM, ISM, how universe evolved into galaxies stars	Spin-off: Sub-orb.	Suborbital platform (balloon)	Wide-field survey/IFU UV spectroscopy	Deployable flight-ready devices
	Planet detection & characterization. High res. observ of local ISM, IGM		Suborbital Rocket payload	Time-domain, high QE, high resolution UV spectroscopy	Deployable flight-ready devices

Table 2: Major Milestones and Metrics

Major Milestone	Detector Requirement	Quantified Metrics (from table 1)
Medium to High fidelity (TRL 5-6) component prototype demonstration of delta-doped, AR-coated EMCCDs.	*High QE*	QE > 50% in UV
		Stability: Hysteresis < 1% in operational environment.
		Uniformity, operational robustness, and simplicity
	Photon Counting Low Noise	*Noise*: Sky background limited @ -120°C-140°C (not dominated by dark, read or clock induced charge)
		Gain: Single photon counting operation w/ zero read noise
	Manufacturable	Wafer-scale (up to 200 mm) bonding, thinning, delta-doping, AR-coating processes. Multiple wafer batch processing
		Scalability: 2 Megapixel detectors (and larger) in four-side buttable packages
		Throughput and yield: Bonding, thinning, delta-doping, AR-coating half lot run (12 wafers) in one month with 80% yield @ <$30K / wafer
	Operational environment	*Environmental testing*: Temperature, illumination, illumination history, radiation

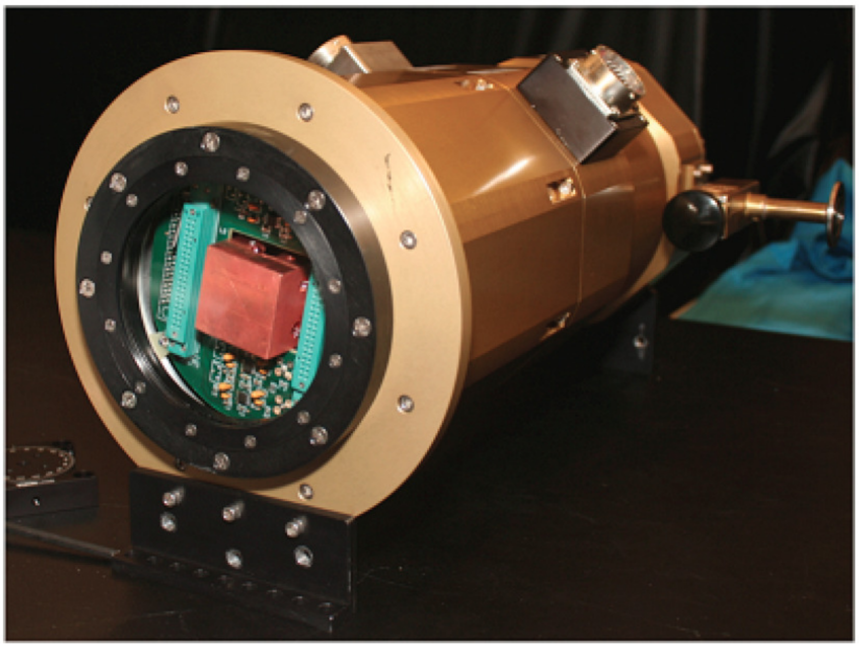

Figure 1 - the test dewar for the developmental CCD and readout circuitry. The image shows the dewar wired with the readout pre-amplifiers and detector mounting interface (ZIF socket) - the only thing missing is the detector itself.

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

This proposal represents the ongoing on-sky testing of detectors from the development sequence of our SAT program. The work is funded over 3 years to deliver functional UV-sensitive CCDs as well as the support and readout circuitry to go along with them. Our role (ASU) is to provide calibration and performance baseline tests as the development proceeds. The third and final set of detectors is scheduled to be delivered to ASU by April 2015 whereupon they will be tested on the bench as ASU for typical performance metrics such as linearity, gain, etc. However, there is a need to demonstrate the performance on-sky using extended objects, with some broad band filters, and using photometric standards to measure stability, low-light level performance, performance near saturation, ghosting and hysteresis, photometric reproducibility and other parameters.

We have chosen to use the 61" as it provides enough aperture to reach a large population of stars both Galactic and extragalactic, and provides enough field of view to target face-on spirals in the Local Group. The performance of the detector for low-surface brightness targets is of particular interest because of the types of observations these detectors are likely to enable - imaging of diffuse ionized clouds and blue stellar populations in nearby galaxies. We have manufactured our own interface to the instrument flange on backside of the Mont4k support structure, with its filter wheel assembly, and will again simply replace the dewar used with our dewar assembly. Our previous run involved a lot of work with Steward support staff but we believe we resolved all issues associated with the custom use of the Mont4k and are now ready to focus on the data acquisition rather than the cutting of metal. The mounting configuration we spent at least one of the three nights building with the support staff is illustrated below.

Figure 2 - the equipment box with associated hardware mounted on the side of the 61" instrument backplane with the Mont4k assembly. This hardware has now been fabricated during the first run and is ready to be bolted on and used immediately with the second run scheduled for November 2014. We are anticipating a much more streamlined operational system for the third run if approved.

The schedule of tests and many, many observations to achieve the goals outlined above is somewhat tedious but requires as many as 3 nights of telescope time to complete, since it involves a great level of repetition, and monotonic increases in exposure time. The schedule for these observations is more driven by the delivery and development schedule for the detector itself, but we believe that April-June 2015 would be an appropriate window for this work.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

This is the third request in support of this work. We expect to make one additional request of this kind for 2015B to complete ASU's part of this project. As outlined above we believe the arcade of observations necessary to complete the on-sky testing and demonstration needed will take 3 nights of time. We are the only members of our collaboration that have access to telescopes for the kind of work we need to do. It is the role ASU assumed when this project was being assembled. While JPL technically has access to Palomar, the only appropriate or available telescope there for this kind of work is the 48" and that has now been taken over 100% as a so-called robo-scope in support of the Caltech Supernova Factory.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). **(up to one page)***

⋆ This is the third proposal to UAO in support of this engineering development. The first run (in 2013B) was very useful and productive but was unsuccessful in allowing us to take the data we needed.

For our second run, scheduled for November 2014, we are migrating to a new dewar, have had the Gen-III Leach controller overhauled and repaired by Bob Leach, and have resolved the technical control glitches. The mounting hardware was manufactured as part of the first run and awaits our return. We expect a much more productive second run.

Liebst & Scowen were awarded 3 nights in 2014B on the 90" telescope for Galactic Star Formation mapping in Nearby Galaxies to complete their sample for their survey. This run has not happened yet as of this run and is scheduled for late November 2014.

Liebst & Scowen were awarded 2 nights in 2014A on the 90" telescope for Galactic Star Formation mapping in Nearby Galaxies. Data reduction is ongoing and will feature in a new paper this year.

Falcon & Scowen were awarded 1 night in 2014A on the 90" telescope for Galactic Star Formation mapping in Nearby Galaxies. Data reduction is ongoing and will feature in the Senior Thesis of Falcon as well as a paper on M101 next year.

Scowen et al were awarded 3 nights in 2014A on the MMT to Complete Commissioning of the MAESTRO Instrument.