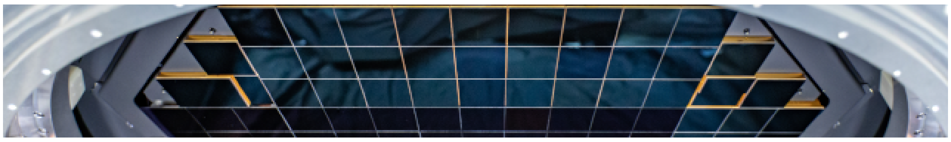
Image Sensors for Precision Astronomy (ISPA 2024)

Tuesday, 12 March 2024 - Thursday, 14 March 2024

SLAC



Book of Abstracts

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Welcome/Introductory session / 3

Detector Technologies for Future Astrophysics and Other Applications

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Astro2020 Decadal Survey study for Astrophysics articulated a number of exciting science ranging from exoplanet characterization to general astrophysics including galactic and stellar science that require high-efficiency, high throughput instrumentation ranging from ultraviolet through visible and near infrared. A major contributing factor to the throughput is determined by the efficiency and signal to noise ratio of the detectors used at the focal plane of the instruments. At the same time, there has been exciting developments in detector architectures especially in silicon-based image sensors.

I will briefly discuss some of the science motivations for UV/Optical/NIR instruments, followed by an overview of some of the promising current and emerging technologies under development. I will also describe the work performed at JPL on high efficiency ultraviolet detectors and the detector-integrated filters that enable high efficiency UV detection and high out of band rejection.

Session 3 - sensor development programs / 4

Teledyne's High Performance Visible and Infrared Focal Plane Arrays for Precision Astronomy

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Teledyne produces high performance visible focal plane arrays (FPAs) at e2v Space Imaging (United Kingdom) and DALSA (Canada). Infrared FPAs are produced at Teledyne Imaging Sensors in Camarillo, California.

This presentation will review the different types of visible and infrared FPAs and discuss the backside illuminated CMOS and CCD visible FPAs and hybrid CMOS IR FPAs offered by Teledyne. A comparison will be made between the artifacts of the different types of FPAs with focus on the attributes of a CTIA (capacitive transimpedance amplifier) pixel that overcomes some of the negative issues that arise in the source follower pixel.

contribution subject matter:

CMOS sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Focal Plane Arrays (FPAs), CMOS, Hybrid CMOS, HgCdTe detector, Source Follower, CTIA

Session 3 - sensor development programs / 6

STA Skipper and CCD Development Status

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STA specializes in the development of custom CCDs, controllers, and imaging systems for a wide variety of applications. We discuss recent sensor fabrication and testing efforts, including performance results from a prototype skipper CCD and derived skipper designs in fabrication now.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Software & Algorithms / 7

Mitigation of the Brighter-Fatter Effect in the LSST Camera

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Thick, fully depleted charge-coupled devices (CCDs) are known to exhibit non-linear behavior at high signal levels due to the dynamic behavior of charges collecting in the potential wells of pixels, called the brighter-fatter effect (BFE). This particularly impacts bright calibration stars, which appear larger than their intrinsic shape, creating a flux-dependent point-spread function (PSF) that if left unmitigated, could make up a large fraction of the error budget in Stage IV weak-lensing (WL) surveys such as the Legacy Survey of Space and Time (LSST). In this presentation, we will discuss the latest characterizations of the BFE in the LSST camera from lab images of flat-fields and artificial stars and discuss the current state-of-the-art correction algorithms.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

First author of recent paper on this topic.
"Mitigation of the Brighter-Fatter Effect in the LSST Camera" (Broughton et. al 2023)

Poster Session / 8

The Dual-Sided CCD

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Existing Charge-Coupled Devices (CCDs) operate by detecting either the electrons or holes created in an ionization event. We propose a new type of imager, the Dual-Sided CCD, which collects and measures both charge carriers on opposite sides of the device via a novel dual-buried channel architecture. This dual detection strategy provides exceptional dark-count rejection and enhanced timing capabilities. These advancements have wide-ranging implications for dark-matter searches, near-IR/optical spectroscopy, and time-domain X-ray astrophysics.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

CCDs, X-ray detection, Optical Spectroscopy, Dark Matter Detectors

Software & Algorithms / **10**

Channel Filtering to Reduce 1/f Noise Structure in SPHEREx Data

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The SPHEREx satellite will survey the full sky between 0.75 - 5.0 micron in over 100 wavelengths to study cosmic inflation, galaxy formation, and bionic ice distribution in the Milky Way. The focal plane assemblies consist of six HAWAII-2RG (H2RG) detectors equipped with linear variable filters (LVF) to vary the spectral response along one spatial direction with resolving power R = 35 to 130. The flight electronics processes the detector data into photocurrent during sampling-up-the-ramp and flag saturation and transients in real time. To meet the spatial 1/f noise requirement on large scales (5 –20 arcminutes), we monitor the amplifier voltage during an exposure to correct for their drift, apply non-sequential pixel sampling ("row chopping") to shift the noise to smaller scales, and increase visits to the optically dark ("reference") pixels to better estimate the detector channel's pedestal offsets. We find the reference pixels are not fully analogous to the optical pixels, so reference subtraction alone does not remove all the channel-to-channel noise. Channel median filtering improves the noise performance in dark exposures but is not effective in sky observation due to the diffuse sky emission, the LVF responses, and the source masking. We present here an improved version of the channel filtering to account for these effects.

contribution subject matter:

noise characteristics

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

H2RG, 1/f noise, spatial correlated noise, channel filtering, intensity mapping, SPHEREx

New Detector Technologies / 11

Fast and sub-electron noise CCDs with the multi-amplifier sensing architecture for astronomy

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Optical detectors in future astronomical facilities require both single-electron resolution and fast readout capability to meet ambitious science goals including obtaining spectra for diffuse dwarf galaxies, identifying rapidly fading transient events, and directly imaging Earth-like extrasolar planets. Skipper CCDs used in dark matter detection experiments have shown their ability to reach deeply sub-electron noise floors that scales inversely with the number of measurements performed for a charge packet at the cost of increasing readout time. As an outgrowth from the Skipper CCD concept, the multi-amplifier sensing (MAS) CCD meets both the fast readout and ultra-low noise priorities by implementing a serial line of non-destructive floating gate amplifiers that independently samples multiple pixels of charges simultaneously. This reduces the readout time by a factor of the number of output stages for an equivalent number of charge measurements compared to a Skipper CCD. Using the successful LBNL thick, fully-depleted, p-channel legacy design, MAS CCDs are expected to retain the advantages of high near-IR quantum efficiency, low fringing, and radiation tolerance for broad adoption in next generation massive spectroscopic surveys and space-based telescopes. We present recent work in instrumenting the first front-illuminated 16-channel MAS CCDs using DESI front-end readout electronics to achieve a combined read noise close to a single electron with only a single sample per amplifier. We discuss the promising charge transfer efficiency, full well capacity, and linearity characterization results that demonstrate the potential of MAS CCDs to serve a wide range of science cases in astronomy. Finally, we describe the current and upcoming efforts on developing large format devices with 64 channels and the accompanying readout electronics that would enable MAS CCDs to be deployed at scale for planned experiments including DESI-II and Stage-V spectroscopy.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Skipper CCDs

New Detector Technologies / 12

Single electron Sensitive Readout (SiSeRO) devices: A novel X-ray detector technology for the future X-ray astronomical missions

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Single electron Sensitive Read Out (SiSeRO) is a novel on-chip charge detector output stage for silicon charge-coupled device (CCD) image sensors that can enable significantly greater responsivity and improved noise performance than traditional CCDs. Developed in collaboration with MIT Lincoln Laboratory and fabricated in their CCD process technology, SiSeRO devices use a p-MOSFET transistor with a depleted internal gate beneath the transistor channel. The transistor source-drain current is modulated by the transfer of charge into the internal gate. At Stanford, we have developed a readout module for these devices and characterized the performance of a number of prototype sensors with different architectures. We have achieved a charge/current conversion gain of better than 800 pA per electron, an equivalent noise charge (ENC) of around 4.5 electrons root mean square (RMS), and a full width half maximum (FWHM) of approximately 130 eV at 5.9 keV, at a readout speed of 625 Kpixel/s and detector temperature of -23 C. Since the charge packet in SiSeRO devices remains unaffected by the readout process, we are also able to implement Repetitive Non-Destructive Readout (RNDR) of the charge, achieving a significantly improved noise performance. In this paper, we discuss the SiSeRO working principle, the readout module developed at Stanford, and the characterization test results of the first SiSeRO prototypes. Second generation SiSeRO devices are currently being fabricated, including configurations with parallel SiSeRO outputs and multiple SiSeRO elements in series. Such advances should improve speed performance whilst maintaining low noise.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

SiSeRO, CCD, X-ray detectors

Systematics and Sensor Characterization / 13

H4RG-15 detector features, performance statistics, and characterization data products for VLT-MOONS

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MOONS is a multi-object spectrograph that will be installed at the Nasmyth focus of the VLT ESO Telescopes in Chile. The instrument has approximately 1000 fibers over a field of view of 500 square arcminutes, with wavelength coverage from 0.6 to 1.8 um using CCDs and NIR detectors. Four of

the six f/0.95 Schmidt cameras are dedicated to the NIR wavebands and are fitted with H4RG-15 detectors.

We present the results of the characterization of the five H4RG-15 detectors produced for MOONS and discuss how the data products from this characterization program can be used by scientists to aid the development of the analysis pipeline and engineers to assess performance anomalies over the lifetime of the instrument. The characterization program run at ESO was focused on measuring detector parameters to verify requirements as well producing standardized datasets and data products for each detector that could be used in the analysis pipeline or for detector models. We present the statistics for the MOONS H4RG-15 detectors for standard detector performance parameters such as RON, dark current, cross talk, and gain from this batch of detectors, highlighting the unique features of the H4RG-15 detectors uncovered during the several years of measurements. We also provide a look into characterization data products that we have produced for this program, such as persistence trap maps that can be used for pipeline persistence correction or detector modelling.

We are extending the characterization program to the detectors to be used in the ELT instruments. With this talk, we hope to spark discussion between scientists and detector engineers in attendance about the potential uses of information obtained during detector characterization programs. How are these products being used now, and what more could be done with them in the future?

contribution subject matter:

CMOS sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

H4RG, NIR detectors, characterization, modeling

Systematics and Sensor Characterization / 14

Science application driven optimization of LSST-Cam CCD clocking

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The e2v and ITL CCDs used in Rubin Observatory's LSST-CAM are tested under realistic LSST f/1.2 optical beam in a lab setup. In the past this facility has been used to characterize these CCDs, exploring the systematic errors due to charge transport. Now this facility is being used to optimize the clocking scheme and voltages. The effect of different sequencers on the on-chip systematics such as non-linear crosstalk, noise, tearing, persistence, photon transfer, etc are explored. The goal is to converge on an optimal configuration for the LSST-CAM CCDs which minimizes resulting dark energy science systematics.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

CCD clocking, CCD systematics, LSST, Rubin Observatory, Dark Energy

Poster Session / 15

Propagating Random Telegraph Noise in Las Cumbres Observatory's CMOS data

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At Las Cumbres Observatory (LCOGTN) we have introduced CMOS-based imagers (QHY600 with Sony IMX455 sensors) as the main cameras in our global network of ten 35-cm telescopes. The uses are for our global education program (Global Sky Partners) and professional astronomy (e.g., TESS planet transit follow-up). The deployment of CMOS detectors in the small telescope network also serves as a pathfinder for a possible future introduction of large-format CMOS cameras to the LCO 1-meter telescope fleet. In this presentation, we report some of the first lessons learned from using CMOS cameras in a production environment.

In particular, we focus on characterizing and treating random telegraph signal (RTS), an additional noise component in CMOS cameras. While RTS can be neglected in very high S/N situations, such as in planet transits, it might bias photometry in the low S/N case. Traditional CCD data reduction has no established data processing paradigms for this additional noise component. At LCOGTN we have developed procedures to model RTS and then seed and propagate a simplified per-pixel noise model in our data processing pipeline BANZAI. We are exploring more advanced mitigation studies, such as using modeled multi-modal RTS distributions as a prior for maximum likelihood fitting when stacking images, which can converge significantly faster than simple averaging.

contribution subject matter:

CMOS sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

CMOS
Random Telegraph Noise

Systematics and Sensor Characterization / 16

Preliminary results from the SuperBIT balloon-borne telescope

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I will present preliminary results from the SuperBIT balloon-borne experiment - a 0.5 meter near-ultraviolet to near-infrared telescope with a Sony IMX 455 CMOS sensor designed to perform diffraction-limited imaging from the stratosphere. SuperBIT observed 30 galaxy clusters during its 45-night flight on a NASA superpressure balloon in the spring of 2023. I will discuss sensor characterization, photometric calibration, the impact of sky background on detected galaxy number density, pre-flight instrument bandpass estimation and post-flight bandpass verification. In particular, I will describe the pre-flight sensor characterization effort, including a setup to measure the quantum efficiency, read noise, conversion gain, and pixel-to-pixel sensitivity variations. Then, I will discuss challenges we faced during the flight, including the impact of hot pixels on fine guidance star trackers and the importance of a real-time image checker program during the flight.

contribution subject matter:

CMOS sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

New Detector Tech / Skippers - 2 / 17

Astronomical Spectroscopy with Skipper CCDs: A Skipper CCD Focal Plane Prototype at SIFS

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Co-authors: Abhishek Bakshi [4]; Brandon Roach [5]; Braulio Cancino [6]; Claudio Chavez [4]; Guillermo Fernandez Moroni [7]; Javier Tiffenberg [4]; Julia Campa [8]; Luciano Fraga [9]; Manuel Gaido [4]; Marco Bonati [6]; Michelle Jonas [4]; Peter Moore [6]; Rachel Hur [10]; Stephen Holland [11]; juan estrada [7]

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Ultra-low readout noise detectors will enable increased sensitivity to high-density and high-redshift spectroscopic surveys to place tighter constraints on dark energy and dark matter (e.g., a Stage-5 Spectroscopic Survey). We present advances towardplans for demonstrating the performance of an ultra-low noise Skipper CCD focal plane prototype for the SOAR Integral Field Spectrograph (SIFS) for the first time. We show results from characterizing and optimizing eight Skipper CCDs for SIFS to achieve σ ~ 0.18 e− rms/pixel for 400 non-destructive readouts, dark current (DC) ~ 2 × 10^-4 e−/pixel/sec., charge transfer inefficiency (CTI) < 3.44 × 10^-7, full-well capacities between ~40,000 − 63,000 e− , and absolute quantum efficiency (QE) ≳ 80% between 450 nm and 980 nm and ≳ 90% between 600 nm and 900 nm. We outline the observation strategy intended to maximize signal-to-noise by optimizing readout time and tunable readout noise via the Skipper CCD's capability to define a region of interest (~5% of the detector area) to be readout with < 0.7 e− rms/pixel while the rest of the detector is readout with the single-sample readout noise (~4.2 e− rms/pixel). Finally, we will offer an outlook on scientific improvements made possible by ultra-low noise detectors.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Skipper CCDs, sub-electron noise, photon-counting detectors, spectroscopy

Poster Session / 18

Tree-rings in LSST Camera

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In this work, we studied the tree-rings in the LSST camera. Specifically, we compared the tree-rings observed in flat images under the normal operating voltage back bias and under a 0-volt back bias. We showed that tree-rings in the 0-volt back bias flat images have higher signal-to-noise ratios (SNR) and are more easily detectable, which therefore can be used to better infer tree-ring centers. However, we demonstrated that there is a large scatter in the relationship between the tree-ring amplitudes in the normal operating voltage and the 0-volt back bias images. This scatter presents a difficulty in estimating the tree-ring profiles using the higher SNR measurements from the latter images, but it may be resolved by further studies on the systematics and noises in the flat images. Meanwhile, we estimated the characteristic tree-ring amplitudes under normal operating voltage in the LSST camera to be
$lesssim$ 0.03%. We also observed wavelength-dependence of the tree-ring amplitudes, particularly in the UV-band of the E2V sensors.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Tree-ring; LSST Camera

Detector Models / 19

FIREBall-2 delta-doped EMCCD for photon starving UV astronomy: modeling, tradeoffs and future upgrades

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In the pursuit of observing fainter astronomical sources and phenomena, a significant challenge in detector development lies in ensuring these devices can detect each individual photon they receive. By amplifying each incoming photon by several orders of magnitude, Electron-Multiplying CCDs (EMCCDs), offer a promising solution to meet this challenge.
While these powerful detectors boast impressive potential, they remain highly sensitive, requiring precise optimization and fine-tuning of their parameters to unlock their full capabilities in the photon-starved regime
The Faint Intergalactic Redshifted Emission Balloon (FIREBall-2) is a stratospheric project that aims to detect and map the low surface brightness environment of galaxies in the UV at z~0.7.
As a technology demonstrator for photon starved astronomy and in order to advance the technology readiness level of UV EMCCD, the spectrograph uses an e2v EMCCDs delta-doped by JPL, combined with a Nüvü controller.

To analyze the detector data and retrieve the device noise contributions, we developed an EMCCD comprehensive model along with DS9 analysis tools to compare the model to actual data under very diverse operating conditions.
This allowed us to examine the current performance and limitations of these devices both on the ground and in the stratospheric environment, to unravel the intricacies of these detectors.

In addition, we will discuss the development and implementation of an Exposure Time Calculator (ETC) designed to optimize the end to end Signal-to-Noise Ratio (SNR) under diverse conditions and analyze the different tradeoffs associated with such devices.
This will be used to explore some EMCCD-related issues encountered on FIREBall-2 and present some recent and future upgrade strategies (controller upgrade, red blocking filter, overspill register implementation, etc.) to mitigate them.

contribution subject matter:

noise characteristics

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

UV, delta-doped, EMCCD, photon-counting, smearing (CTI)

Systematics and Sensor Characterization / 20

Image Persistence Flagging for SPHEREx

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Co-authors: Phil Korngut [2]; Charles D. Dowell [3]; Chi Nguyen [2]; Brendan Crill [3]; Howard Hui [2]

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Image persistence in HAWAII-2RG HgCdTe detectors has been observed by multiple parties. Also known as latent signal, this effect occurs when sensor images following an illumination show a decayed form of the illuminated image even though the source has been removed and the detector has been reset. Using data from an engineering grade detector delivered for SPHEREx testing illuminated with a wide range of fluxes, we demonstrate an interpretation and a working model from which the decaying signal can be estimated, providing the ability to flag pixels subject to excess persistence current beyond a user-defined threshold. Applying this model on a pixel-by-pixel basis may provide the framework for subtracting the offending persistent signal, thus mitigating the effect.

contribution subject matter:

CMOS sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

persistence current, latent imaging, flagging, HAWAII-2RG, HgCdTe

New Detector Technologies / 21

From ground characterization of the 16 H2RGs to the commissioning of the in-flight NISP Instrument of Euclid : lessons learn

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The near-infrared spectrometer and photometer (NISP) focal plane, comprising 16 H2RGs and Sidecar ASICs, was successfully commissioned in the second half of 2023. Flight models of the detectors have been extensively tested on the ground during the C/D phase by NASA and the Euclid consortium, offering a good point of comparison with flight commissioning data.
The proposed presentation aims to provide lessons on characterizing and modeling the detection chain to meet performance requirements. Beyond sensitivity (QE and read noise), the science of Euclid involves in-depth knowledge of the detection chain's systematics, which are mainly determined by the correction of non-linearity and its temporal behavior due to carrier trapping and untrapping (persistence).
After presenting the Euclid NISP implementation and the characteristics measured on this subject, we'll raise a few questions about the characterization strategy to tackle this difficult subject facing future "at less than 1%" IR measurements.

contribution subject matter:

photometric fidelity

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Non-linearity correction, correlated noise, IPC, Flat Filed, commissioning, persistence, reciprocity failure. H2RGs, Sidecar

New Detector Technologies / 22

Leonardo UK high performance shortwave APDs for astronomy

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The linear-mode, avalanche photodiode array (LmAPD) based on bandgap-engineered HgCdTe, grown by Metal Organic Vapour Phase Epitaxy (MOVPE) is an important product type at Leonardo UK. High-value instruments often employ LmAPDs where the photon count is low and conventional detectors cease to be sensitive. Applications now split into three main categories. Firstly, for applications with intrinsically short integration time, such as: wavefront sensors, fringe trackers and devices for rapid-time-domain astronomy, LmAPDs arrays are established in 320x256 and 515x512 formats, with an avalanche gain of >100x at 15V bias and 80-100K operating temperature. Secondly, for free-space telecoms, LIDAR and gated arrays a GHz version of the LmAPD is available. Thirdly, there is a class of applications with very low photon arrival rates and these provide the most demanding of challenges for LmAPDs. The main field is astronomical imaging and interferometry. In a collaboration with the University of Hawaii (UH) a 1kx1k/15μm device been developed and together with a low dark current version of the LmAPD is under detailed characterisation at UH. Initial results show dark currents below 0.001ph/s/pixel and usable avalanche gain up to 10x. A 2kx2k/15μm format device funded by ESA is currently in trial manufacture. This paper provides an update on the technology and the status of our developments and collaborations.

contribution subject matter:

CMOS sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Saphira, MOVPE, LmAPDs, Leonardo, HgCdTe, avalanche gain, infrared astronomy

New Detector Tech / Skippers - 2 / 23

Multi-Amplifier Sensing CCD (MAS-CCD) Detector Concept for the Habitable Worlds Observatory

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The 2020 Decadal Survey of Astronomy and Astrophysics (Astro2020) recommended technology development for a large, 6-m class, infrared/optical/ultraviolet space telescope as its highest priority for strategic space missions. The search for evidence of life on other worlds using spectroscopic biosignatures is a key science aim. Many important biosignatures; including H_2O and O_2, are strong in the visible and near-IR. However, even with 6-m of aperture, this science is photon starved. Sensitive single photon detectors are required. Moreover, the detectors must survive and operate in the harsh space radiation environment.

In this presentation, we describe notional requirements and their rationale for a Multi-Amplifier Sensing CCD (MAS-CCD) optimized for such a mission. We describe the MAS-CCD's architecture, and how we would operate it to meet requirements in space. MAS-CCDs evolved from p-channel Skipper CCDs to mitigate the readout time challenges that Skippers face for space and other applications. MAS-CCDs use many Skipper-like amplifiers in parallel to deliver the photonic performance and radiation tolerance of p-channel Skipper CCDs, but without the very long readout time penalty that is otherwise associated with using multiple non-destructive reads to achieve photon counting.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

CCDs, Space Missions

Poster Session / **24**

Bias Stability and Defect Analysis in LSSTCam

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The Vera C. Rubin Observatory's LSST Camera (LSSTCam) uses an instrument signature removal (ISR) algorithm to generate defect masks for its CCDs. We compare the defect mask generated by ISR to raw bias images from test runs 6 (22/06/2023) and 6b (16/11/2023), and verify the ISR defect algorithm performance. We find some differences in total number counts in the mask, with a detailed assessment underway. We show the bias frames are affected by dust accumulation, differential amplifier response, and detector-wide gradients. This is the first attempt to validate the ISR masking algorithm using camera data from multiple runs. This framework can be used for verification of the masking algorithm for other calibration frames, as well as time-dependent behavior of the detectors during testing and operation of LSSTCam.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

LSSTCam, Systematics, Defect Stability

Poster Session / **25**

Instrument Signature Removal and Calibration Products for the Rubin LSST

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Co-authors: Agnès Ferté ; Chris Waters ; Dan Weatherill ; Eli Rykoff ; Merlin Fisher-Levine ; Robert Lupton

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The Vera C. Rubin Observatory, currently under construction in Cerro Pachón, Chile, will conduct the Legacy Survey of Space and Time (LSST) using the 3.2-gigapixel LSST Camera (LSSTCam) mounted on the 8.4-meter Simonyi Survey Telescope. The LSST aims to probe the nature of dark energy and dark matter, inventory the solar system, explore the transient optical sky, and study the evolution and structure of the Milky Way by surveying 18,000 square degrees of the southern sky more than 825 times over 10 years across six photometric bands: ugrizy.

However, the precision required to achieve these ambitious goals is challenged by systematic errors that could dominate the results from the LSST. Instrument Signature Removal (ISR)—the process of correcting for systematic errors and biases introduced by the instrument itself during the observation process—is therefore of paramount importance. ISR is essential for removing these instrument-induced effects from the raw data, thereby producing a more accurate representation of the observed astronomical objects or fields.

This poster provides a comprehensive overview of the current steps, order, and algorithms used in ISR for the LSST, and outlines improvement plans. It delves into the necessary calibrations and the specific algorithms and corrections required to mitigate systematic errors and enhance precision. The poster also highlights ongoing efforts to optimize these processes, with the ultimate goal of maximizing the LSST's scientific output and ensuring the successful

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

CCDs

Detector Models / 26

Recent advances in UV and soft X-ray photon counting MCP detectors

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Photon counting detectors with Microchannel Plates (MCPs) provide unique capabilities in astronomy applications where detection of photons with very low dark count rate, large dynamic range, high spatial and timing resolution is required. Over the years development of this type of sensor has substantially improved giving enhanced counting rate capabilities, lifetime, spatial and temporal resolution and large / curved formats. Instrument requirements vary widely, from low power,

long lifetime, radiation hard, planetary missions to large area, high spatial resolution, ultra low background sensors in earth orbit. The adaptable nature of the MCP sensor configurations is a key element that has enabled many successfully flown instruments. New enhancements for these sensors include Atomic layer deposited MCPs with long lifetime, high stability, ultra low background (<2 events/pixel/fortnight) and improved quantum efficiency. Photon counting imaging readout technologies of several types have been employed, with some as large as 20 cm x 20 cm^2. Readouts can be pixelated ROICs (Readout Specific Integrated Circuits), enabling high resolution (5 µm) of photons at very high counting rates (GHz levels per detector) at low gain of 10^5, as well as detection of multiple simultaneous photons. Recent Timepix4 chips which are 4-side buttable with all the contacts to the die provided Through Silicon Vias (TSV can support large active areas (e.g. 10x10 cm^2). Cross strip and cross delay line readouts with formats up to 20 cm and modest spatial resolution (20µm) can operate at MHz rates, and can be implemented with low power / ASIC electronics. These sensor properties are established without cooling or out of bandpass filtering. Such large area, high counting rate, low dark count detectors are being developed further for high precision astronomical sensors for a number of selected and prospective future NASA missions.

contribution subject matter:

(Other)

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Photon counting, High resolution, Low dark count rate, Large format, Microchannel Plates

New Detector Tech / Skippers - 2 / 27

Partial charge collection and quantum efficiency of a back-illuminated skipper-CCD

Authors: Ana Martina Botti[1]; et al[None]

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The partial charge collection (PCC) layer is a transition interface between the back-end SiO2 (or SiO2 + ZrO2 + In) death layer and the high-purity Silicon bulk in a CCD. Due to the increased likelihood of re-absorption of electron-hole pairs in this region, the charge collection efficiency is typically below that in the bulk. This layer has a large impact on the efficiency loss of the optical spectrum, particularly in the blue region, significantly influencing the sensitivity and precision of back-illuminated CCD sensors. This study presents a preliminary measurement of the PCC layer using a 677 eV X-ray source and a 200 um back-illuminated thinned skipper-CCD. Additionally, I will discuss a method based on the PCC layer to assess the quantum efficiency of visible light without reliance on a calibrated light source or photodiode.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Skipper-CCD, quantum efficiency

Poster Session / 28

A skipper-CCD light shield for X-ray detection in space

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Co-author: et al

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In this work, we will present advancements in the design of Skipper-CCD sensors tailored for X-ray detection in environments with high optical background levels, such as those expected in space. These packages incorporate a custom-made aluminum shield placed on the CCD surface that successfully blocks over 99% of visible light while preserving the efficiency for keV X-rays. These features allow us to perform precise and reliable X-ray measurements in environments challenged by visible light interference. Furthermore, we briefly discuss the potential implementation of this design concept in frame-transfer CCDs, opening opportunities for broader applications and advancements in imaging technologies.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

X-ray detector, space, transfer frame, skipper-CCD

Poster Session / 29

High-density and low-background Silicon packages for kilogram skipper-CCD instruments

Authors: Ana Martina Botti[1]; et al[None]

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The next generation of experiments for rare-event searches based on skipper Charge Coupled Devices (skipper-CCDs) will bring new challenges for the detector packaging and readout. Scaling the active mass and simultaneously reducing the experimental backgrounds in two orders of magnitude will require a novel high-density Silicon-based package, that must be massively produced and stored. In this work, we present the design, first production, and testing of a 16-channel Silicon package, along with the outlook for the next steps towards producing 1500 wafers that will add up to a 10 kg skipper-CCD detector.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Skipper-CCD, package, electronics

Poster Session / 30

Read Noise Biasing on the Nancy Grace Roman Space Telescope

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The Nancy Grace Roman Space telescope, set to launch in 2026, will bring unprecedented precision to measurements of weak gravitational lensing. Because weak lensing (WL) is an inherently small signal, it is imperative to minimize systematic errors in measurements as completely as possible; this will ensure that the lensing measurements can be used to their full potential when extracting cosmological information. The Roman WL program is further complicated by the undersampled nature of its images, requiring the use of an image combination algorithm to construct oversampled images to simplify signal processing and avoid biases from discontinuity. In this work, we use laboratory tests of the Roman detectors, simulations of the Roman High Latitude Survey observations, and the proposed Roman image combination pipeline to investigate the impact of detector read noise on weak lensing measurements from Roman. We characterize the specific signatures of the noise fields in the resultant images and measure simulated galaxy shapes to determine the magnitude of shear biasing that will be induced by the read noise.

contribution subject matter:

noise characteristics

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Read noise, weak lensing, image processing, Roman telescope

Poster Session / 31

CCDs in Living Color: Understanding the LSST Camera focal plane's visual color via quantum efficiency measurements.

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The LSST Camera focal plane, the largest ever constructed, consists of 201 16-MegaPixel CCDs from two manufacturers. Viewed in room light the CCDs are blue colored, with one vendor's sensors a consistent dark blue while the other ranges from light blue to very light greenish-blue. We interpret the visual appearance as due to the amount of light reflected, or 1 - QE, as a function of wavelength and compare these colors against those expected from our laboratory measurements of Quantum Efficiency. Visually the comparison between digital photographs of the focal plane and the QE-based model is excellent. Finally, we use our photograph of the focal plane in room light to compare with measurements of the CCD to CCD absolute level of QE in visual wavelengths and comment on the utility of this room-light photographic method.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

LSST Camera
Quantum Efficiency

Poster Session / 32

Limiting Atmospheric Emission Lines With On-Detector Guide Windows

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We present first results of an on-telescope demonstration of a new technique to suppress bright atmospheric OH emission lines in near-infrared spectroscopic observations. On large ground-based telescopes, near-infrared spectroscopy is often limited by these lines, which can saturate on the order of minutes. Exposures longer than this will result in the loss of any useful information at these wavelengths and also run the risk of detector effects such as bleeding and persistence. Here, we use the 1.2-m McKellar Spectrograph at the Dominion Astrophysical Observatory in Victoria, Canada, equipped with a HAWAII-2RG detector using multiple configurable, high-cadence subwindows to demonstrate on-detector suppression of these bright lines. This is achieved by resetting detector regions which contain bright emission lines before they have the chance to saturate, while the rest of the detector continues integrating. This allows for significantly increased signal to noise by reducing the read noise overhead required for stacking shorter exposures. In addition, through non-destructive reading we are able to periodically monitor the lines which are being reset, allowing us to retain information about the characteristics and variability of these lines. These features suggest great promise for the application of this method to facility-class instruments on 8-m and larger telescopes.

contribution subject matter:

(Other)

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

IR detectors, guide windows, atmospheric emission, non-destructive reading, OH lines

Sensors for Nancy Grace Roman / 33

The Roman CGI Camera Systems: ExCam and LoCam

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The Nancy Grace Roman Space Telescope is a 2.4 m flagship astrophysics mission currently planned for launch in 2026. The secondary Coronagraph Instrument (CGI) shall demonstrate key technologies required for high contrast imaging and spectroscopy of planetary systems, including adaptive optics, high-speed (1 kHz) wavefront sensing and photon counting detectors in the form of Electron Multiplying CCDs (EMCCDs). The two camera systems, ExCam and LoCam, are integral to each of these demonstrations and operate in contrasting optical environments with almost identical designs. ExCam is the exoplanetary systems camera responsible for planetary system imaging and characterization. It is designed to operate at frame rates of order 1 FPS at flux levels ranging from 10^4 to 10^-3 counts/pix/s. An in-built electron multiplication mechanism on the detector provides single photon sensitivity during CGI science observations. LoCam is responsible for the high speed wavefront sensing and pointing control. It operates at 1000 FPS with targets in the range 10^3 to 10^7 counts/pix/s. Here, the EMCCD is used to provide low system noise while maintaining a high frame rate. Together, each camera is responsible for both high and low order wavefront control that shall enable contrast of up to 10^-8 for science targets; up to a x100 improvement on the current state of the art. Here, we describe the assembly, commissioning and calibration of ExCam and LoCam prior to integration on the CGI optical bench. Electro-optical performance characterization is discussed alongside the development of software readout sequences specific to each camera. We conclude with lessons learned from this work for future generations of such camera systems.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

EMCCDs, CCDs, photon counting, Roman CGI

Detector Models / **34**

Spatial Frequency domain probes of the brighter-fatter effect

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The brighter-fatter effect is an important systematic arising in CCD sensors, and its characterisation and mitigation have become quite routine in recent years, generally by means either of measuring the correlations in flat fields, or by directly measuring the signal dependent width of the point spread function in projected spots.

In this contribution we describe an investigation into measuring the brighter-fatter effect (specifically the “a” matrix by which flat fields are often described in the literature) using laser speckle projection. Laser speckle is a powerful tool to measure the modulation transfer function (MTF) of a sensor because it does not rely on refractive optics and has known spatial frequency domain characteristics. This makes it uniquely suitable for use in sensors with very small pixels, where projection using refractive optics may not probe the sensor characteristics well. However, other properties of laser speckle also make it helpful in probing the brighter-fatter effect as well: The known spatial frequency power spectrum density enables measurement of the MTF with very high statistics, and furthermore the laser speckle samples over many different regimes of contrast ratio in the spatial

domain, as compared to a flat field (which has minimal spatial contrast), or a point source projection (with the maximum possible contrast).

We present theoretical and experimental considerations about probing the brighter-fatter effect in the spatial frequency domain using laser speckle, including comparisons of experiment agains conventional correlation measurement using flat fields.

contribution subject matter:

point spread function fidelity

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

MTF, Laser Speckle, Brighter-Fatter Effect

Sensors for Nancy Grace Roman / 36

H4RG detector analyses for the Roman Space Telescope and Prime Focus Spectrograph

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HAWAII-4RG (H4RG) detectors will provide a substantial portion of the scientific output for both the Nancy Grace Roman Space Telescope (Roman) and the Prime Focus Spectrograph (PFS) on the Subaru Telescope. In the first half of this talk, I will present my work from the last few years on modeling detector-level effects present in Roman's flight candidates. Specifically, I focus on how these effects are expected to impact Roman's cosmic shear analyses. In the second half of this talk, I will present ongoing work to measure and characterize the noise properties of PFS H4RG-15s.

contribution subject matter:

noise characteristics

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

weak lensing systematics

New Detector Technologies / 37

Multi-Amplifier Sensing Charge-Coupled Device as a solution for a fast single quanta CCD

Authors: Ana Martina Botti[1]; Brenda Aurea Cervantes Vergara[2]; CLAUDIO CHAVEZ[2]; Fernando Chierchie[3]; Alex Drlica-Wagner[4]; juan estrada[2]; Guillermo Fernandez Moroni[2]; Miqueas Gamero[5]; Julien Guy[6]; Stephen Holland[6]; Blas Irigoyen Gimenez[3]; Agustin Lapi[3]; Kenneth Lin[7]; Edgard Marrufo Villalpando[8]; Miguel Sofo Haro[9]; Javier Tiffenberg[10]; Sho Uemura[10]

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Non-destructive readout capability of the Skipper Charge Coupled Device (CCD) has been proven to be a powerful technique to reduce the noise limitation of conventional silicon devices even to levels that allow single-photon or single-electron counting. The noise reduction is achieved by spending extra time taking several measurements of the same pixel charge. This extra time has been a limitation for the broader use of the technology in particle physics and astronomy applications beyond its successful use for dark matter searches.
In this talk, we will show the recent results of a new sensor architecture that uses multiple non-destructive floating-gate amplifiers to achieve sub-electron readout noise in a thick, fully-depleted silicon detector as a solution to the readout time limitation. The results show that the readout noise decreases as expected with the square root of the number of amplifiers providing a suitable solution for the construction of fast single quanta devices based on non-destructive readout sense nodes.

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This Multi-Amplifier Sensing Charge-Coupled Device (MAS-CCD) can perform independent charge measurements with each amplifier. These measurements from the multiple amplifiers can then be combined to reduce the readout noise without the penalty of the extra readout time of the repetitive sampling scheme of the Skipper CCD.
During the talk we will show the measurements obtained with devices of 8 and 16 amplifiers per readout stage showing the improved performance compared to the Skipper CCD. The readout time of this detector decreases roughly linearly with the number of amplifiers without requiring segmentation of the active area as in the case of a distributed amplifier scheme. The noise reduction capability of the new technique will be demonstrated emphasizing the ability to resolve individual quanta, low energy particle detection, optical properties, and the ability to combine measurements across amplifiers to reduce readout noise.
The low noise and fast readout of the MAS-CCD have been already identified as a candidate technology for spectroscopy experiments in terrestrial and space missions, and other lab applications such as quantum imaging.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Poster Session / **38**

Focal plane figure - knowledge and control for Rubin Observatory's LSST Camera

Co-authors: Aaron Roodman [1]; Andrew Rasmussen [1]; Homer Neal [1]; Martin Nordby [1]; Matthew Rumore [2]; Paul O'Connor [3]; Peter Takacs [4]; Seth Digel [1]; Stephen Tether [1]; Steve Ritz [5]; Steven Kahn [1]; Tony Johnson [1]; Tony Tyson [6]

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Rubin Observatory has a unique optical beam geometry. The large collecting area of the primary mirror, combined with atmospheric seeing-limited imaging across the large (9.6 deg^2) field-of-view, enables the survey mission.

The combination drives a fast (F/1.2) beam geometry with unprecedented sensitivity to defocus driven, point spread function blur and shape transfer, even under operation (closed loop, active optic compensation).

The LSST focal plane is constructed out of 205 individual sensor surfaces under passive alignment and operates at -100°C within the cryostat vacuum. In this presentation we describe the Manufacturing, Integration and Testing effort that went toward assembly of the ultimate focal plane (achieving 4μm rms deviation from flat), as well as the detailed, underlying as-built characterization knowledge under operating conditions. We anticipate that these data will enable improved point spread function estimation/extrapolation in instances where its contribution may be ambiguous or inadequately quantified.

contribution subject matter:

point spread function fidelity

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

focal plane geometry; point spread function; weak lensing; shape transfer

Poster Session / 39

Direct Signal Injection Crosstalk in LSST Camera Readout Electronics

Authors: Adam Snyder[1]; Daniel Polin[2]; Tony Tyson[2]

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The Rubin Observatory LSST Camera exhibits novel crosstalk between charge-coupled device (CCD) amplifier segments that does not scale linearly with intensity. An open question regarding the characterization of this crosstalk is the fraction sourced in the camera readout electronics as compared with cabling and on-chip effects. Using a custom-made electronics board that simulates the load of a CCD, we can bypass the CCD and inject proxy video signals directly into a Rubin LSST Camera readout electronics board (REB5). In this way, we are able to isolate the sources and shape of crosstalk and its nonlinearity. We will discuss what our tests reveal about the source and mechanism of nonlinear crosstalk the LSST Camera.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

LSST, Rubin Observatory, CCD, Crosstalk

Poster Session / **40**

‘Weather’in LSST Camera: Characterizing Turbulence as seen in Flat Illuminated Images

Author: John Banovetz[1]

Co-authors: Aaron Roodman [2]; Andrew Rasmussen [2]; Maya Beleznay [2]; Pierre ASTIER [3]; Yousuke Utsumi [2]

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During the latest electro-optical testing runs of the LSST Camera, a long-range (>20 pixels) correlation was discovered in flat pair images that was not seen in previous testing runs. As we tried to determine the source, we noticed a turbulence pattern in difference images similar to that of atmospheric weather effects on-sky data. This pattern changes temporally and can be seen changing at the detector and focal plane level. There is strong evidence that this pattern is caused by the air purge system within the camera as changing the fan speed changes the shape and strength of the pattern. This pattern could also only be visible due to our use of a projector to illuminate the focal plane for the production of flat-field images and would not appear if we used a flat screen instead. We characterize this pattern using correlation functions and power spectra under various conditions and simulate what effect it will have on on-sky data.

contribution subject matter:

(Other)

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Detector Models / **41**

On the influence of electrostatic barriers that would modify brighter-fatter corrections for PSF estimations

Author: Andrew Rasmussen[1]

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Weak lensing science relies crucially on high fidelity PSF estimation (using unresolved field stars) in order to estimate underlying shears in large numbers of faint background galaxies. The response of pixel boundary distortions induced (during image integration) - by the building accumulation of

conversions at the channel - is referred to as the brighter-fatter effect (BFE) and its mitigation is a key step of instrument signature removal (ISR).

Recent findings (Broughton et al.) show that even with large volumes of high quality flat pair data to characterize the BFE, the implemented pixel signal redistribution prescription appears to correct only ~90% of the effect, leaving an undesirable, uncorrected shape systematic in spot images. These reveal the rows/columns orientation of the sensor. This is a generic result that spans at least two sensor vendors.

In this presentation we describe a path forward for correcting the evasive, systematic structure that is the residual 10%. We discuss the collective influence of two flavors of confinement barriers present near the channel and explain why their presence, in real sensors, breaks down the curl-free symmetry assumption centrally built into the Coulton et al. (2018) algorithm. This algorithm is employed to invert pixel signal correlation maps (computed with flat pairs) into electrostatic pixel potential solutions which are then used in the ISR signal displacement correction steps. We suggest that any sensors exhibiting anisotropic pixel correlation patterns over 2D lag space share these properties. We provide placeholder lookup tables to reintroduce nonzero curl terms in the influence function, eliminated from the correction by definition, when these unmodified algorithms are utilized.

contribution subject matter:

point spread function fidelity

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

brighter-fatter effect mitigation; PSF retrieval; electrostatic drift modeling

Systematics and Sensor Characterization / 42

LSST Camera testing and optimization

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The focal plane of the LSST Camera for the Vera C. Rubin Observatory consists of 189 science CCD sensors and sensors for guiding (8) and wavefront sensing (4). The science sensors are deep-depletion and back-illuminated 4k x 4k CCDs with segmentation of 16 channels, manufactured by both Imaging Technology Laboratory (ITL; ITL STA3800) and Teledyne E2V (E2V CCD250). Three CCDs are grouped and operated by one Readout Electronics Board (REB), which provides customizable bias voltages and variable clocking signals, and readouts signal from CCD outputs. In the course of construction, we have executed phased testing campaigns of the focal plane. We characterize the focal plane performance with uniform illumination and specialized scene projectors. We identified several non-idealities: distortion in flat images "tearing", persistence, noise performance, bias stability, and gain stabilities. We also attempted mitigations of some of those non-idealities by different clocking and operation voltages as well as switching from unipolar voltages to bipolar voltages in parallel clock rails for E2V devices. We report our testing results and efforts on optimization.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Poster Session / 43

WFC3 Detector Characteristics and Mitigation Techniques

Author: Benjamin Kuhn[1]

Co-authors: Sylvia Baggett [1]; Jay Anderson [1]; Harish Khandrika [1]; Aidan Pidgeon [1]

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Wide Field Camera 3 (WFC3) is a fourth-generation imaging instrument installed on the Hubble Space Telescope during Servicing Mission 4 in 2009. WFC3 features two independent channels: the Ultraviolet-Visible channel (UVIS), sensitive to 200-1000 nm, with a pair of ~2K x 4K CCDs, and the Infrared channel (IR), sensitive to near-IR approximately 800-1700 nm, with a ~1K x 1K HgCdTe array. WFC3 has been performing extremely well over its 15 years on-orbit, although each detector has characteristics that can affect the precision of astronomical measurements and thus require calibration. For example, the UVIS CCDs experience charge transfer efficiency losses due to radiation damage from the orbital environment, as well as dark current and hot pixel growth. UVIS also experiences a small number of anomalous pixels referred to as sink pixels and low-level pixel-to-pixel quantum efficiency fluctuations. The IR focal plane array exhibits persistence, hot/bad pixels, and snowballs. All the detector systematics are well-characterized and routinely monitored, with calibration and/or mitigation strategies updated as needed. Here we discuss some of the UVIS and IR detector systematics as well as the pre- and post-observation techniques we employ to mitigate their effects.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

HgCdTe sensors, photometric and astrometric fidelity

Sensors for Nancy Grace Roman / 44

Summary of the Nancy Grace Roman Space Telescope Flight Detector Performance

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The Nancy Grace Roman Space Telescope will study the dark matter content of the universe, the expansion history of the universe, and the diversity of exoplanets in the Galaxy using unprecedented wide field infrared surveys. Roman will accomplish this using a focal plane of 18 newly developed HgCdTe detectors. Roman's detectors, the H4RG-10, are 4K x 4K format 10 micron pixel pitch devices manufactured by Teledyne Imaging Systems. After acceptance testing at the Goddard Detector Characterization Lab, 18 flight detectors were selected for the flight focal plane. System level testing of the focal plane was completed at Goddard in 2023, after which the focal plane was integrated into the Wide Field Instrument (WFI) at Ball Aerospace. At the end of 2023, the WFI completed its first thermal vacuum test, providing the first instrument level performance measurements of the focal plane. We review the performance of Roman's flight focal plane and lessons learned during integration and testing.

contribution subject matter:

(Other)

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

hybridized photodiode arrays, HgCdTe

Session 3 - sensor development programs / 45

Imaging detector work across multiple astronomical projects (including InGaAs, soft X-ray CMOS/CCDs, and qCMOS detectors)

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At MIT's Kavli Institute for Astrophysics and Space Research, exciting instrumentation/characterization work is being conducted across multiple research groups to push the technology of imaging detectors for astronomy applications. This overview presentation will highlight the recent progress/testing of several detectors across multiple wavelengths.

1. IR/SWIR: The Wide-Field Infrared Transient Explorer (WINTER) is a new fully robotic infrared time-domain survey instrument at the Palomar Observatory, commissioned in June 2023. We have designed a low-noise, cost-effective, room temperature camera based on commercially produced Indium Gallium Arsenide (InGaAs) sensors, at dramatic cost savings over the HgCdTe traditionally favored for research-grade astronomical instruments. An overview of this detector and early commissioning results will be presented along with future directions of larger InGaAs sensors.
2. X-ray: Several groups are conducting research in detection of soft X-rays including The Rocket Experiment Demonstration of a Soft X-ray Polarimeter (REDSoX) which is a NASA-funded sounding rocket program (2027 launch) and will fly a soft X-ray polarimeter utilizing focusing optics, CAT-gratings, laterally grated multilayer mirrors, and imaging detectors to create a polarimeter that measures low energy X-Rays. An overview of the evaluation of off-the-shelf detectors (CCD and CMOS) characterized on our X-ray beamline will be presented.
3. Visible: Recently, a Hamamatsu qCMOS (quantitative Complementary Metal-Oxide-Semiconductor) detector was purchased for future installation at the Magellan telescope as a shared user resource. qCMOS technology will provide astronomers enhanced sensitivity and quantum efficiency enabling state-of-the art detection for astronomical observations. An overview of the initial lab characterization and plans will be presented.

contribution subject matter:

CMOS sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

InGaAs, X-ray, characterization, CMOS

Poster Session / 46

Read Noise Modelling Skipper CCDs

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To be widely adopted as charge quantizing detectors, large format Skipper CCDs must be able to read out in minutes with low enough noise to quantize charge. Careful optimization of the time to reach charge quantization is needed to limit the number of parallel readouts required to values that will fit along the side of a CCD. In this work, we present a python tool developed to estimate the total integrated noise of both conventional CCDs and Skippers. The Skipper Readout Scheme is simulated with any number of non-destructive cycles, including dead-time inherent to charge transfers or reset. . ADC sample rate and anti-aliasing filter are also modelled. To support arbitrarily complex sampling schemes, the tool is based on the discrete Fourier Transform. We show that our proposed differential skipper configuration boosts the SNR by a factor of $\sqrt{2}$. The code has been validated against analytical solutions for simple cases where these exist. This tool is used to formulate requirements for clocking speed (for moving charge on/off sense nodes) and the preamplifier bandwidth, which affects settling time, and then to infer the necessary number of channels to achieve the desired frame readout times, for any given Noise Power Spectrum at the CCD output. We discuss the typical Noise Spectrum of a CCD output transistor, the benefits of keeping 1/f noise corner frequency as low as possible, and the need to optimize transistor noise performance even when high channel count is available.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Skipper CCD, Simulation

Poster Session / 48

Precision 'astrometry' in under sampled spectroscopic data for precise velocity measurement

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The Veloce facility on the Anglo-Australian Telescope aims to implement precision radial velocity capabilities, for a fraction of the traditional cost. One aspect of the required cost saving is compressing an under sampled integral-field unit echelle spectral format onto three 4kx4k e2v CCDs. Analysing the data to obtain precision velocity measurements calibrated with a laser-frequency comb presents many of the same challenges as obtaining precise astrometry with an undersampled imaging telescope like HST. We present initial results from the use of the 'effective PSF' techniques developed for the HST, but deployed in the calibration of a ground-based spectrograph - techniques that could be readily employed on any other precision radial velocity facility to improve milli-pixel-level calibrations.

contribution subject matter:

point spread function fidelity

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

astrometry, data analysis, under-sampled images

Welcome/Introductory session / 49

Detector requirements: some challenges for the future

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Astrophysics demands higher precision in measurements across photometry, spectroscopy, and astrometry. Certain scientific cases necessitate not only precision but also a high level of accuracy. I will highlight the challenges involved, particularly in achieving spectral fidelity, which refers to our ability to accurately replicate the input spectrum of an astrophysical source. Beyond wavelength calibration, this encompasses correcting observed spectra for atmospheric, telescopic, and instrumental signatures.

Elevating spectral fidelity opens avenues for addressing fundamental questions in physics and astrophysics. I will delve into specific science cases, critically analyzing the prerequisites for conducting crucial observations. Special attention will be given to the requirements for spectrograph detectors and their calibrations. Importantly, these considerations align closely with the needs of photometry and astrometry.

contribution subject matter:

point spread function fidelity

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Spectral Fidelity, high precision and accurate spectroscopy, high resolution spectroscopy, PSF reconstruction, data analysis

New Detector Technologies / 50

The DarkNESS CubeSat: demonstrating sub-electron noise with skipper-CCDs for space-based imaging

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Skipper-CCDs with sub-electron noise have been a transformative device for rare event searches. There is growing interest in using skipper-CCDs in future space-based telescopes, but skipper-CCDs need further development to realize their potential for space-based imaging. The DarkNESS mission will deploy an array of skipper-CCDs on a 6U CubeSat in Low Earth Orbit to search for electron recoils from strongly-interacting sub-GeV dark matter as well as X-ray line signatures from sterile neutrino decay. These measurements will demonstrate the single-electron counting capabilities of skipper-CCDs in the space environment, and pave the way for the future implementation of skipper-CCDs for space-based imaging. This contribution will describe the DarkNESS mission, detail the

ongoing DarkNESS R&D efforts, and outline the technical challenges that arise when using skipper-CCDs for imaging and spectroscopy on a satellite.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Skipper-CCDs, Space-based imaging, single-photon counting sensors

Systematics and Sensor Characterization / 51

LSST Teledyne e2v CCD Characterization Under Varying Operating Conditions

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The Vera C. Rubin Observatory will perform the 10-year Legacy Survey of Space and Time using the 3.2-gigapixel LSST Camera that consists of 189 science CCDs. Each of the back-illuminated deep depletion 16-megapixel CCDs consists of 16 segments corresponding to independent video channels that are readout in parallel. Using the LSST Beam Simulator at UC Davis, we characterized the electro-optical properties of single Teledyne e2v CCD under different timing parameters associated with the readout electronics board (REB) ADC and the CCD operating voltages. We calculated the gain, read noise, dark current, amplitude of tearing and photon-transfer curves using the LSST Science Pipelines analysis tasks and compared the results between operating conditions. Measurements of the linear and non-linear crosstalk between pairs of segments sourced by projected streaks with a range of brightness levels were performed to study the effect of changes to the timing parameters. Finally, we studied persistence in flat field images and images of spots as a function of clock voltages was also performed. We report on the results of these measurements and discuss possible optimizations of the REB operating conditions to improve the CCD performance.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

Welcome/Introductory session / 52

Welcome to SLAC & KIPAC

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Brief welcome to open session 1

Poster Session / 53

Measuring the Delayed Crosstalk

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We measure the signal delay of CCD crosstalk using a test stand in preparation for the LSST Camera. We use a collimated beam projector to cast a narrow streak onto the CCD, mimicking a bright satellite track. We measure the strength and delay of the crosstalk signal simultaneously, using a linear (flux-independent) and a non-linear (flux-dependent) model, on individual exposures or on all exposures, respectively. We find stronger crosstalk signals in channels closer to the projected source streak, and weaker signals in more distant channels. We can only measure a sensible signal delay up to 4 channels away, and we find an inverted trend with a smaller delay in nearby channels and larger delay in further-away channels. The measurable signal delays are found to be <0.5 pixels. We further repeat the measurement on a second data set with a different ASPIC Gain configuration in order to locate the source of crosstalk. Unfortunately, the results are yet inconclusive.

contribution subject matter:

CCD sensors

Keywords for your contribution subject matter (this will assist SOC in accurately characterizing your contribution):

CCD; Cross-talk

Welcome/Introductory session / 54

introductions - andres plazas malagon et al.

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Poster Talks / 55

lightning talks

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Sensors for Nancy Grace Roman / 56

(discussion entry points for upcoming coffee break)

please edit the google doc file, read-writable, to help blend and sort your thoughts.
https://docs.google.com/document/d/1_CsWbyvxygkC8uKPoErix7XsEmjOKoEBEtO4LjdSnn4/edit?usp=sharing

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closing words