National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Advanced Ultraviolet Silicon Detector Technologies Enabling Astrophysics Missions

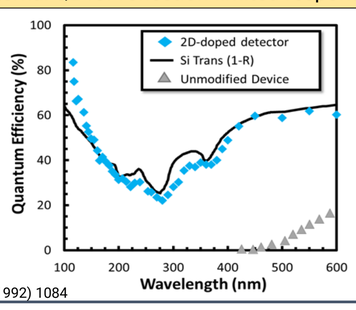
April D. Jewell, Nathan Bush, John Hennessy, Michael Hoenk, Todd J. Jones, Charles Shapiro, and Shouleh Nikzad

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

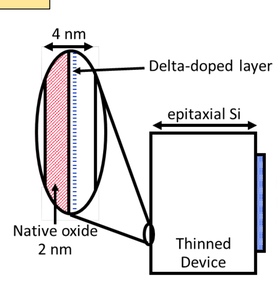
Delta-doped Silicon Detectors

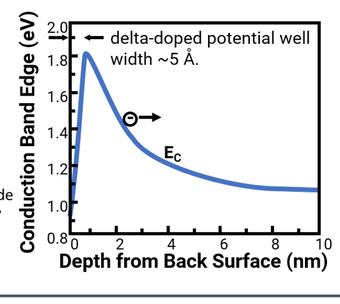
See also: Abstract 113, presenter M. Hoenk "Delta-doped sensors for X-ray to ultraviolet imaging and spectroscopy"

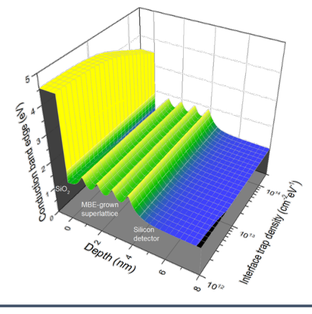
JPL's delta-doped Si detectors exhibit ~100% internal QE for reflection-limited response.



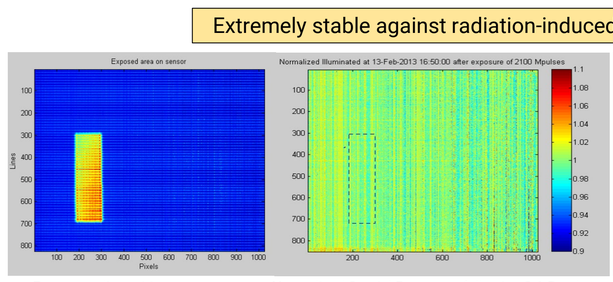
Hoenk, *et al.*, APL, **61** (1992) 1084







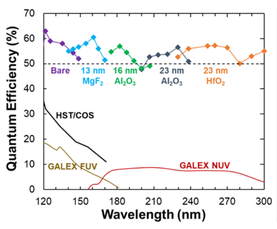
Extremely stable against radiation-induced surface damage



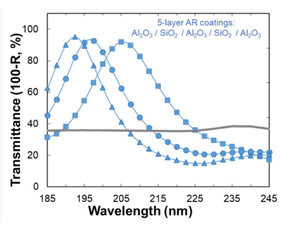
Exposure slit position on sensor | Normalized Spatial Response following 2.1 B pulses | High modulation transfer function (MTF)

Bandpass Tailoring and Response Optimization

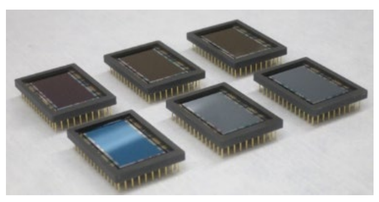
Detector response is tailored/optimized for specific applications with AR coatings and device-integrated UV bandpass filters. Specified wavelengths or bands can be targeted through selection of coating materials and overall design.



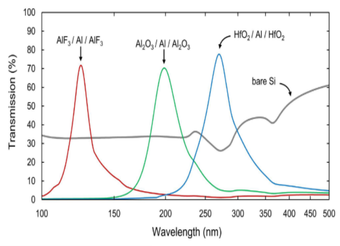
Single layer AR coating

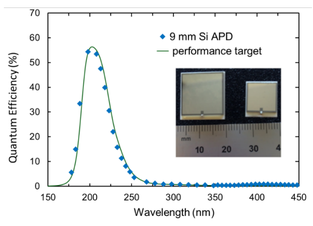


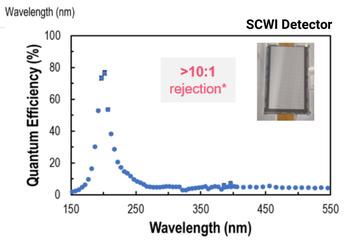
Multi-layer AR coatings



1k x 2k EMCCDs with different AR coatings







Nikzad, *et al.*, *Applied Optics*, **51** (2012) 365
Hamden et al., *JATIS* **2** (2016) 036003

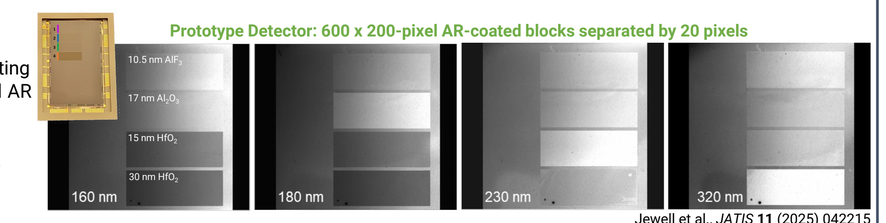
Hennessy et al., *Applied Optics* **54** (2015) 3507
Jewell et al., *JATIS* **11** (2025) 042215
See also: Abstract 167, presenter J. Hennessy "Detector-integrated and stand-alone filter coatings for UV/Vis/NIR instrumentation"

Coating Techniques for Spectroscopy Applications

Newly developed coatings technologies enable us to deliver silicon detectors with patterned AR coatings for a spatially varying response spanning the ultraviolet (UV) and visible wavelength ranges.

Block Pattern –Prototype

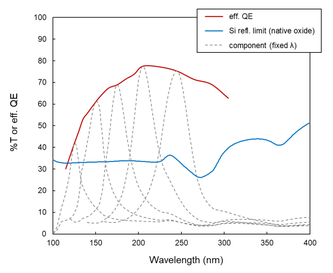
- Four regions each with a unique AR coating
- The contrast/sensitivity of the individual AR coated regions varies as a function of wavelength
- The edges of the patterned regions look sharp/well-defined



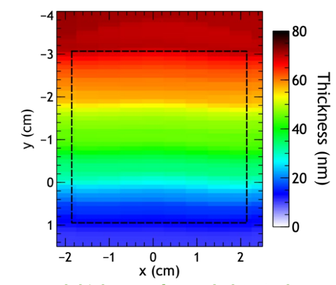
Jewell et al., *JATIS* **11** (2025) 042215

Gradient Thickness Coating

- A continuously graded thickness ALD layer can be achieved by deposition into a lateral cavity
- Can be combined with a metal-dielectric structure to create a variable wavelength optical cavity on a detector
- Can provide red rejection and order-sorting while preserving throughput
- Baselined for UVEX long slit spectrograph instrument

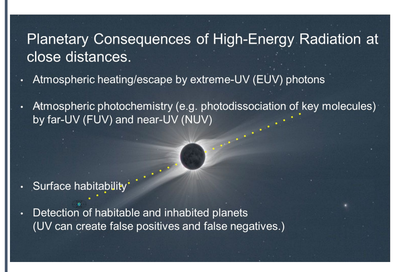


Model QE for FUV gradient thickness



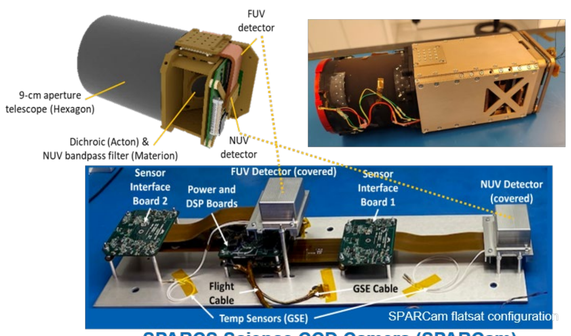
Measured thickness of a graded ALD AlF_3 coating (dashed line is 4x4 cm target area for UVEX detectors)

Delta-doped UV CCDs on Orbit – SPARCS

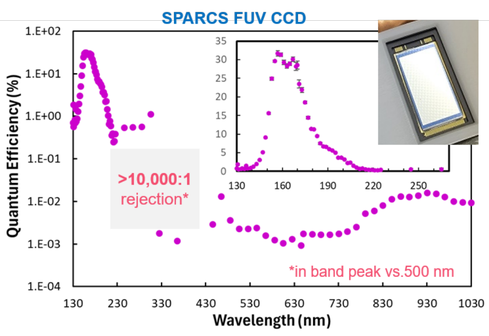


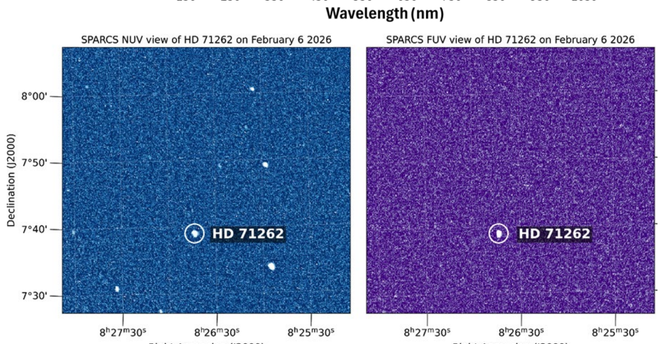
Star-Planet Activity Research CubeSat

- NASA/APRA funded CubeSat, PI Evgenya Shkolnik (ASU)
- JPL developed and delivered SPARCam: two UV detectors optimized for SPARCS near UV (NUV) and far UV (FUV) band passes plus readout electronics
  - NUV: delta-doped detector with AR coating (JPL); commercial UV bandpass filter (Materion)
  - FUV: delta-doped detector with device-integrated UV bandpass filter (JPL)



SPARCS Science CCD Camera (SPARCam)





First light Feb. 6, 2026

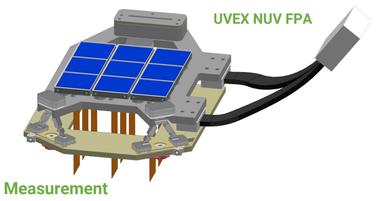
Stars observed simultaneously in NUV and FUV. One star is seen in the FUV while multiple are seen in NUV offers insights into the temperatures of these stars, with the one visible in both colors being the hottest

Jewell et al., *Proc SPIE* **13093** (2024) 1309304
Shkolnik et al., *JATIS* **11** (2025) 042212
Jewell et al., *JATIS* **11** (2025) 042215

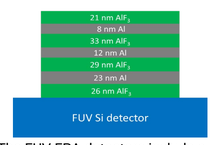
Delta-doped CMOS in Development – UVEX and Beyond

UVEX baselines delta-doped CMOS focal planes >300 Megapixels

- FUV and NUV imaging with two 3x3 mosaic focal planes 18 delta-doped SRI 4k × 4k CMOS imagers
- Spectroscopy using two delta-doped CMOS with graded integrated filters (115-265 nm)



FUV Coating

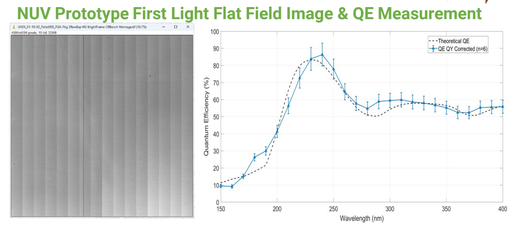


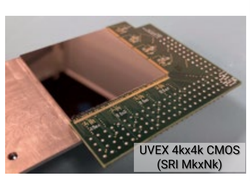
The FUV FPA detectors include a detector-integrated filter to define the bandpass and out-of-band rejection (similar to SPARCS)

LSS-Short Coating

Long Slit Spectrometer (LSS) detector will feature a graded filter to optimize response to match the instrument's spectral dispersion

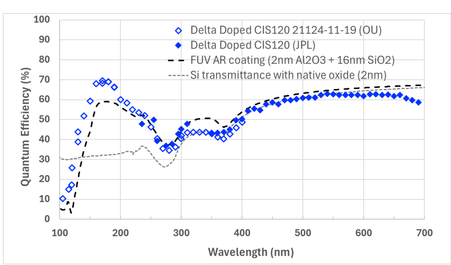
NUV Prototype First Light Flat Field Image & QE Measurement

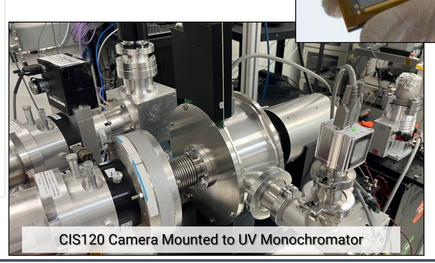




CASTOR baselines large format delta-doped CMOS focal planes

- FUV (160 nm band center) imaging with a single 9k × 9k CMOS (Teledyne-e2v CIS300)
- Prototype/TRL Advancement with delta-doped device with smaller format 2k × 2k CIS120 device with an SiO_2 AR coating



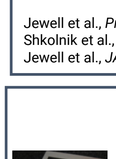


Côté et al., *JATIS* **11** (2025) 042202

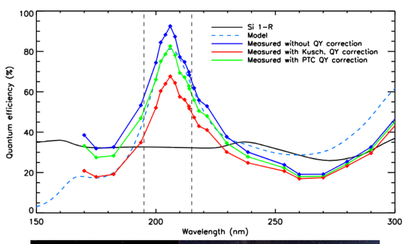
9kx9k CMOS
(Teledyne-e2v CIS300 family)

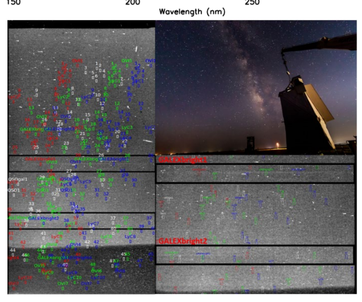
Giant focal planes in development toward e.g. HWO

Delta-doped Detectors in Suborbital Campaigns

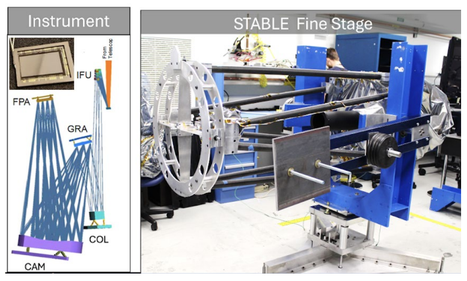


The Faint Intergalactic Red-shifted Emission Balloon (FIREBall-2) mission used a delta-doped EMCCD with a multilayer AR coating.

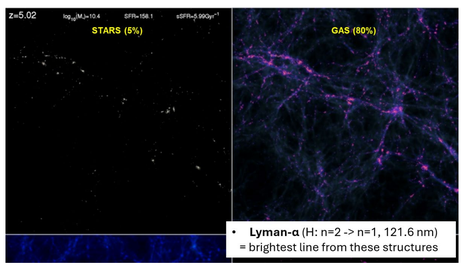




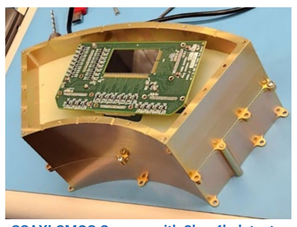
Images from FIREBall-2 2018 flight campaign



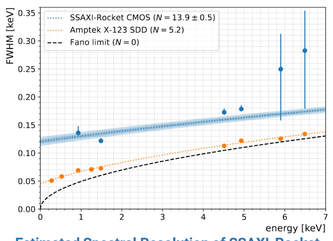
The Stratospheric Cosmic Web Imager (SCWI) mission in development currently baselines an EMCCD with a UV bandpass filter coating (see above)



The SSAXI X-ray sounding rocket experiment used a delta-doped CMOS image sensor



SSAXI CMOS Camera with 2k × 4k detector

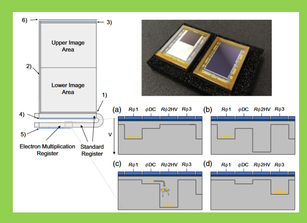


Estimated Spectral Resolution of SSAXI-Rocket CMOS Camera

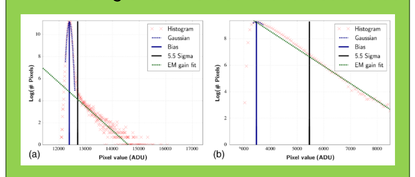
Hamden et al., *JATIS* **2** (2025) 036003
Kyne et al., *JATIS* 6 (2020) 011007
Sánchez-Maes, et al., Proc. SPIE 13103 (2024) 131030N

Photon Counting Technologies in Silicon

EMCCDs



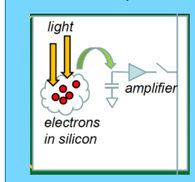
Signal is amplified through impact ionization and avalanche multiplication through a stochastic process.
Thresholding allows for removal of read noise

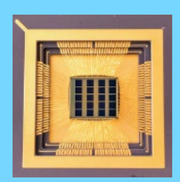


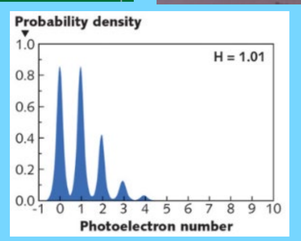
Effective Read noise: << 1 e- rms
Dark Current: *similar to typical CCD*

Quanta Image Sensor

Read noise is reduced by lowering the capacitance of the sense node



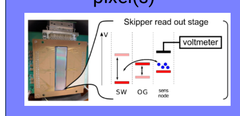


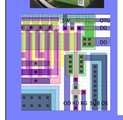


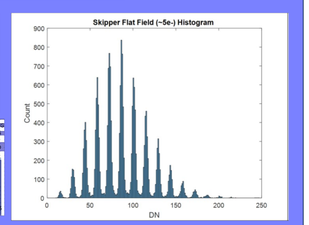
Read noise: < 0.5 e- rms
Dark Current: *0.2 e- at RT*

Skipper CCDs

Read noise is reduced by repeated non-destructive sampling of individual pixel(s)







Read noise: < 0.1 e- rms
Dark Current: *similar to typical CCD*

Bush et al., *JATIS* **11** (2025) 031503
Kyne et al., *JATIS* 6 (2020) 011007

Tiffenberg et al., *PRL* **119** (2017) 131802
Bredthauer, G., *Scientific Detectors Workshop* (2025)

2026 © California Institute of Technology. Government sponsorship acknowledged.

This document has been reviewed and determined not to contain export controlled technical data