Simulating In-Orbit Performance for the CASTOR mission.

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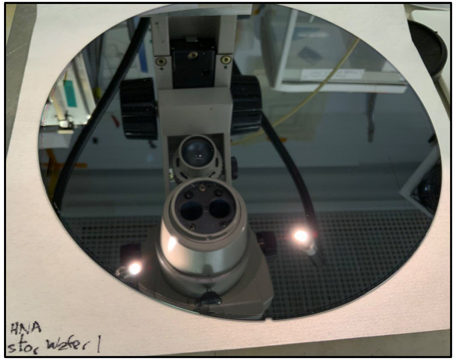
-National Research Council of Canada

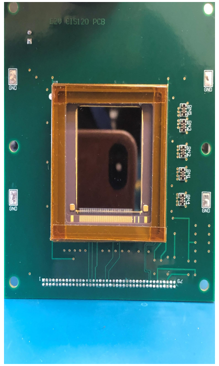
— as part of the CASTOR collaboration.

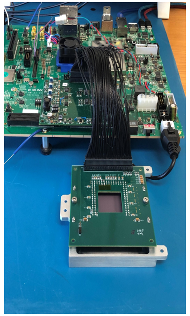

Multi-Messenger Astronomy
Stellar Astrophysics
Solar System
Near-Field Cosmology
Exoplanets
Galaxies and Cosmic Star Formation
Supermassive Black Holes
Cosmology and Dark Energy

Objectives



CIS120 wafer being delta-doped and coated at JPL





- A detector testing and characterization program is underway in a collaboration between NRC, CSA, the U. Calgary, JPL (NASA), T-e2v (UK) and Open U. (UK).

- understanding detector effects and optimizing CASTOR's capabilities is critical in order to prepare the mission for launch by the end of the decade

- characterization of dark current, cosmic ray effects,point spread function among other parameters. Prepare for Phase A.

1) Front of Detector 2)Xilinx and Header board

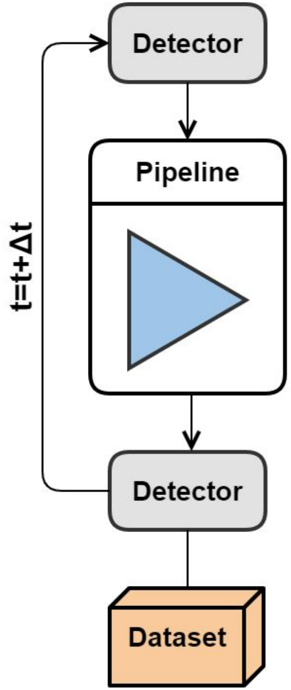
Instruments and Observing Modes

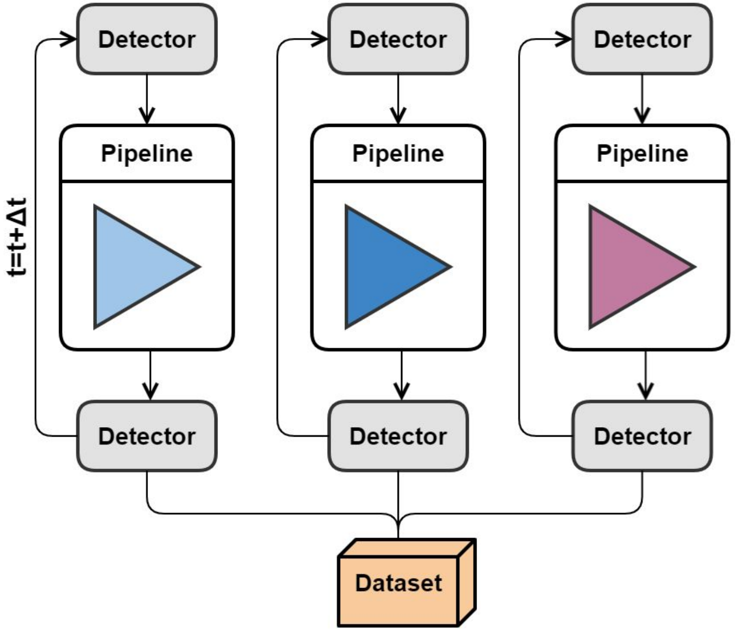
Wide-field Imaging	
Field of View	0.44° x 0.56° = 0.25 deg^2
Image Quality	FWHM = 0.15" in all channels
Photometric Channels	UV (150-300 nm), u (300-400 nm), g (400-550 nm) / Insertable filter to split the UV and u bands
Spacecraft Orientation	Telescope always points > 90° from sun. Ideal for long duration, continuous observing in the anti-sun direction.
Data Volumes	~200 GB/day with 10-min exposures in survey mode. High-speed optical downlink (~10 Gbps)

Spectroscopy and Precision Photometry	
Multi-slit spectroscopy	DMD UV spectroscopy in parallel field (150-300 nm). FoV = 207”x117”, R ≈ 1500.
Slit-less spectroscopy	Full spatial coverage (0.25 deg^2) in UV and u, simultaneously. R ≈ 300 (UV) and 420 (u)
Precision photometry	High-speed monitoring (10 ppm) in the UV-, u- and g-bands using dedicated CMOS detectors.

Pyxel - A Detector chain simulation software.

Users can provide one or more input images to Pyxel, set the detector and model parameters via a user interface (configuration file) and select which effects to simulate (and hope there are no bugs).

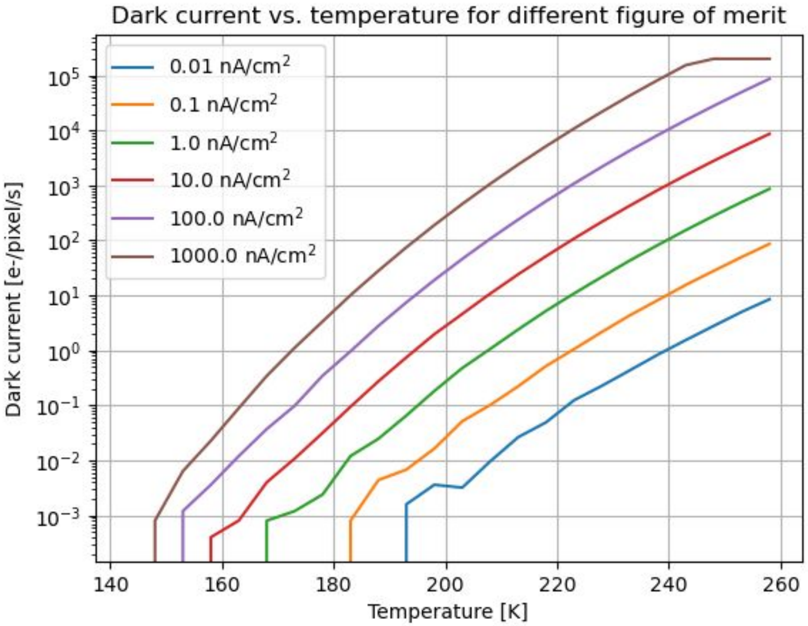


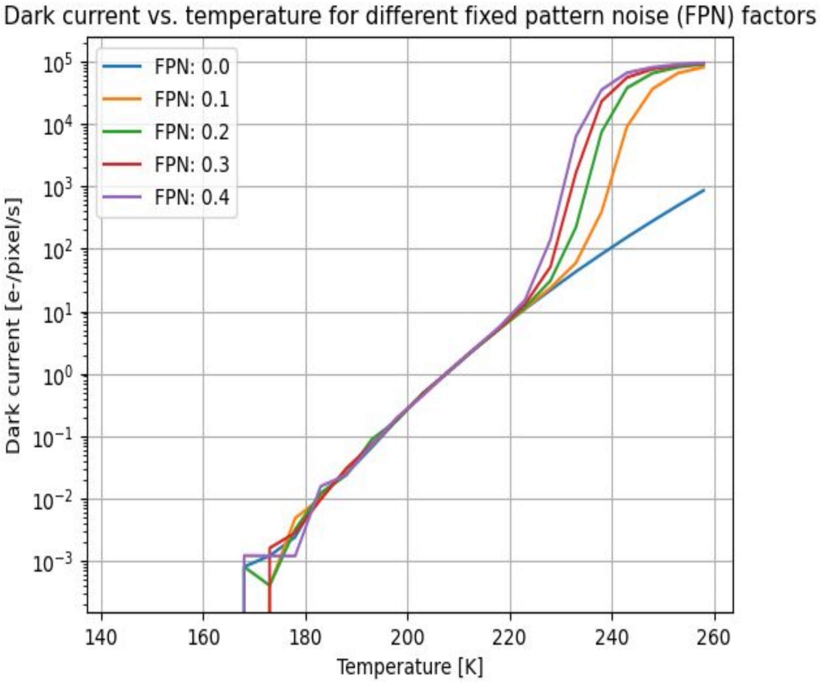


Developed by ESA !!

You can have a single model running(left), or you can combine different models (right).

Dark Current Characterization

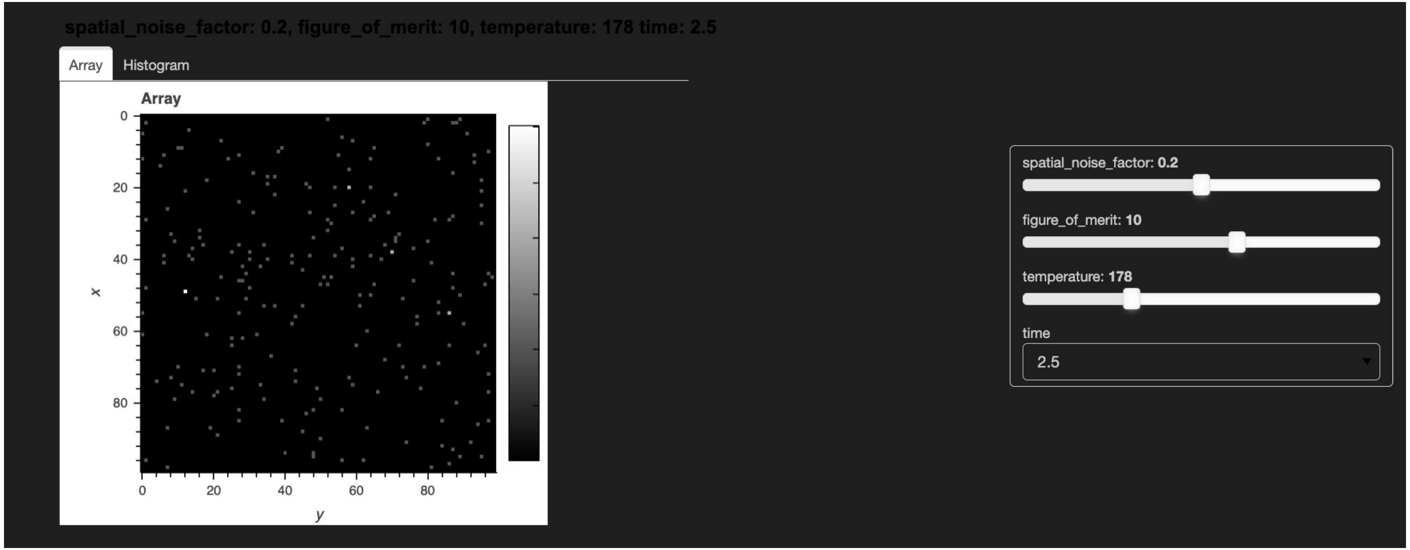




The dark current model used in Pyxel is adapted from this book: "Scientific Charge-Couple Devices." by Janesick, J. (2001). Typical values are taken from this paper: "High-level numerical simulations of noise in CCD and CMOS photosensors" by Konnik, M. and Welsh, J. (2014). Check the dark current model description in the Pyxel Documentation.

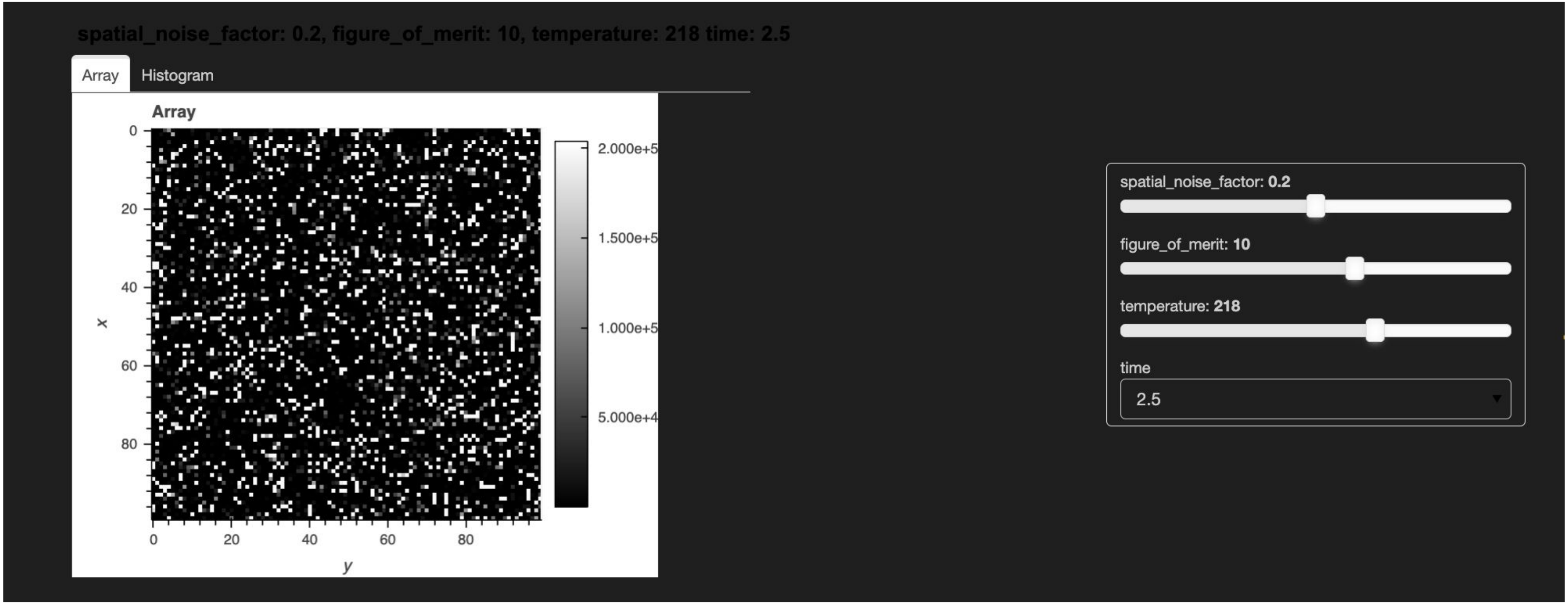
Dark Current Characterization

- Widget allows you to vary parameters, visualize the number of “hot pixels” expected in a section of the detector.



Dark Current Characterization

- Key Question for Science Planning Mission. **How deep can we go for these stars- when the dark current changes?**
-



Cosmic-Ray Simulation, Detection, and Removal by Laplacian Edge Detection

- Pieter G. van Dokkum 1999

- Simulated using a Geant4 based tool, takes in 2 parameters. Initial Energy and Particles per second.

- The Detection and removal algorithm identifies cosmic-rays of arbitrary shapes and sizes by the sharpness of their edges, and reliably discriminates between poorly sampled point sources and cosmic-rays.

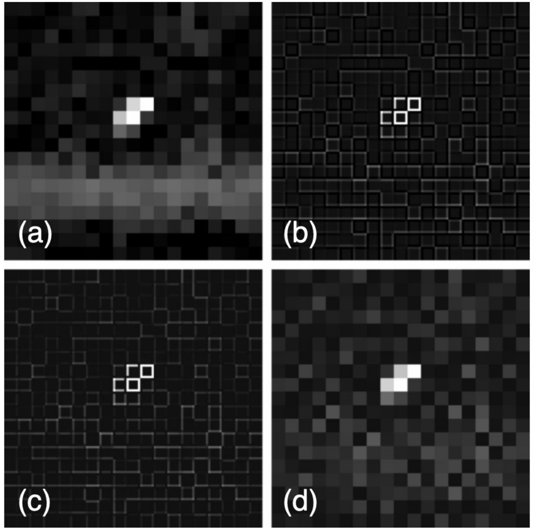
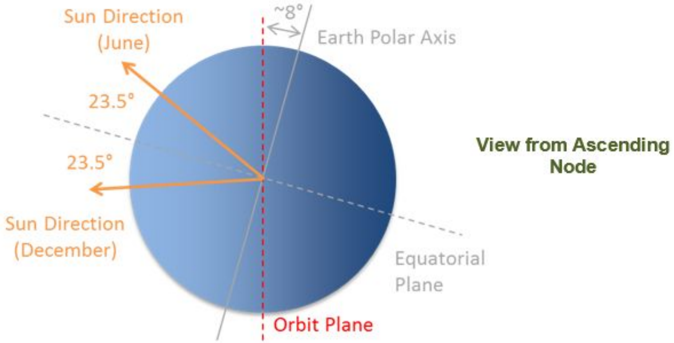
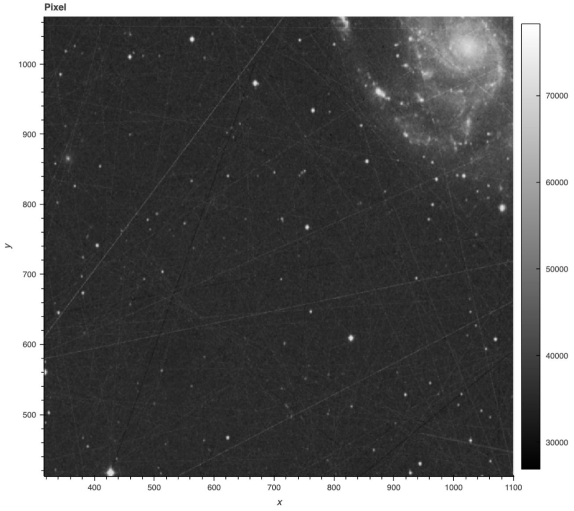


Fig. 1.— Illustration of Laplacian edge detection. The original image is shown in (a). Panel (b) shows the same image after subsampling by a factor six and convolution with the Laplacian kernel. Edges are positive on the inside of the cosmic-ray, and negative on the outside. Negative pixels are set to zero in (c), and the image is block averaged to its original resolution in (d).

Cosmic Ray Simulator and Removal Tool- Short Exposures

-CASTOR has a circumpolar orbit. We expect to see more cosmic rays at the pole! (Easily incorporated in our model)

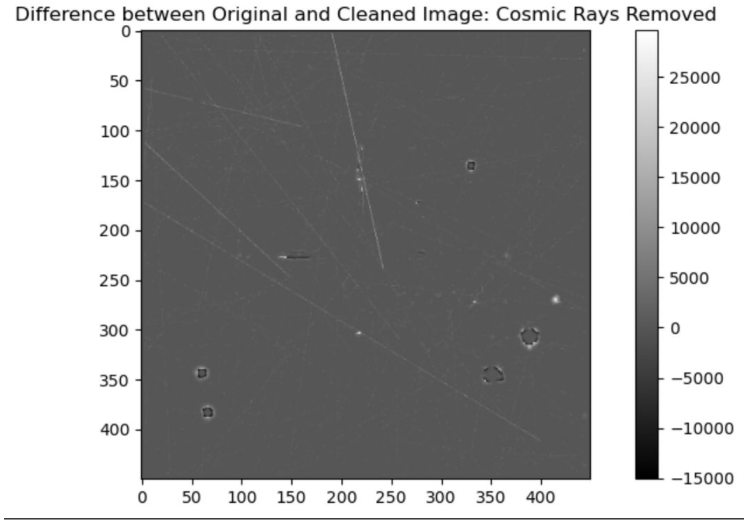




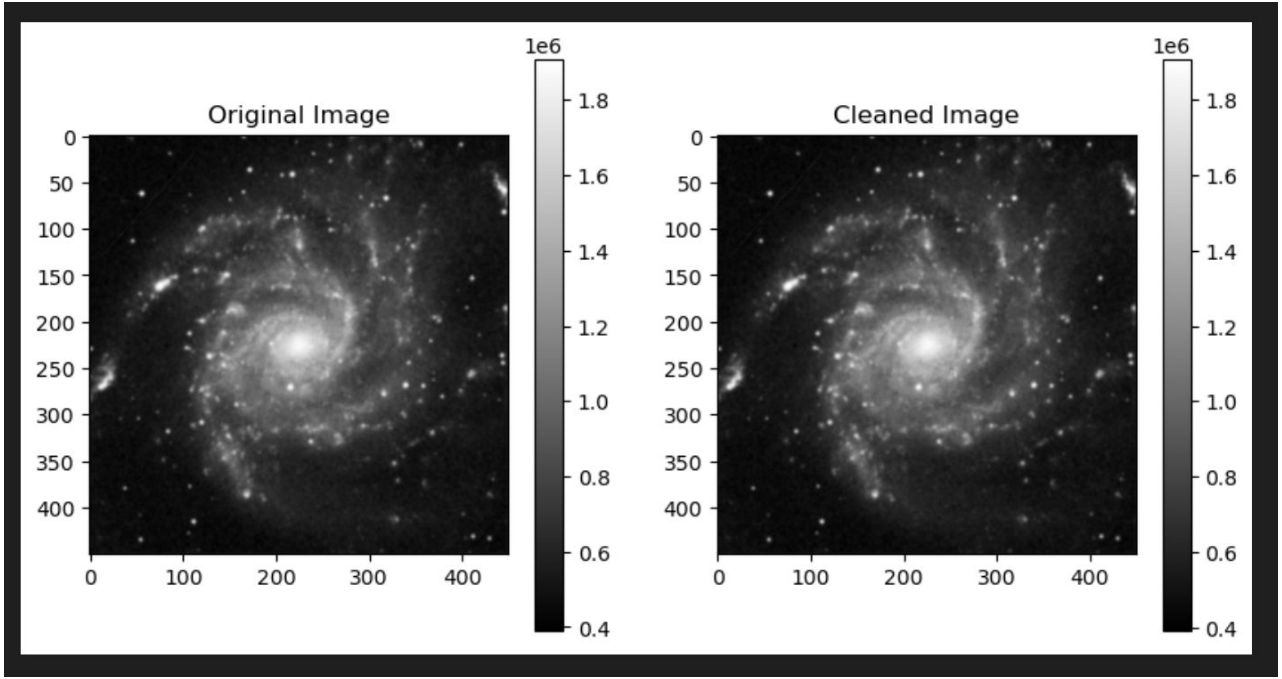
Left: Simulator

Right: Removal tool.

Short Exposures!!

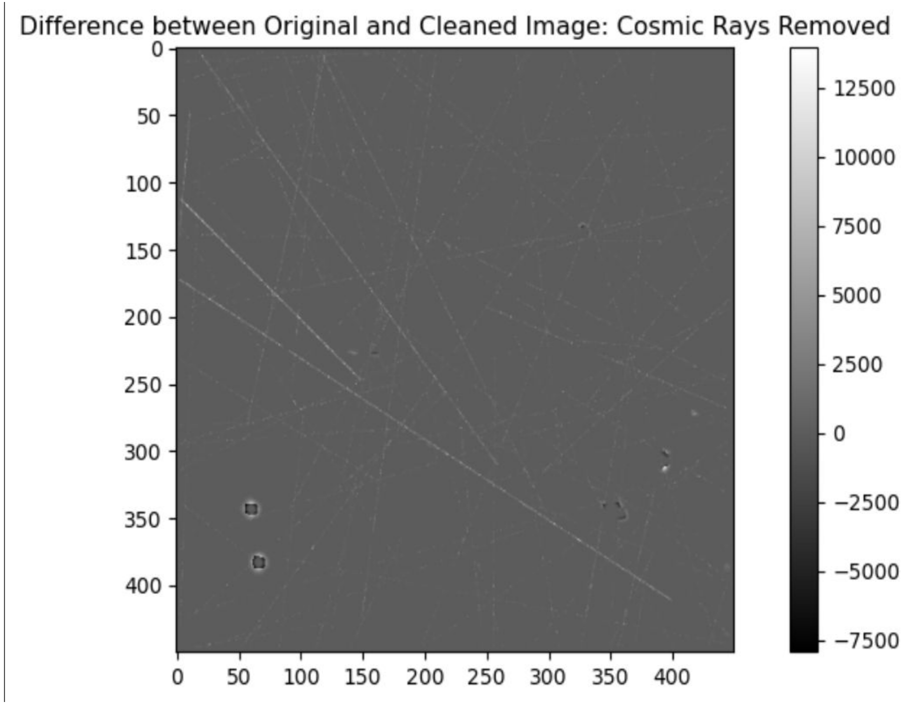


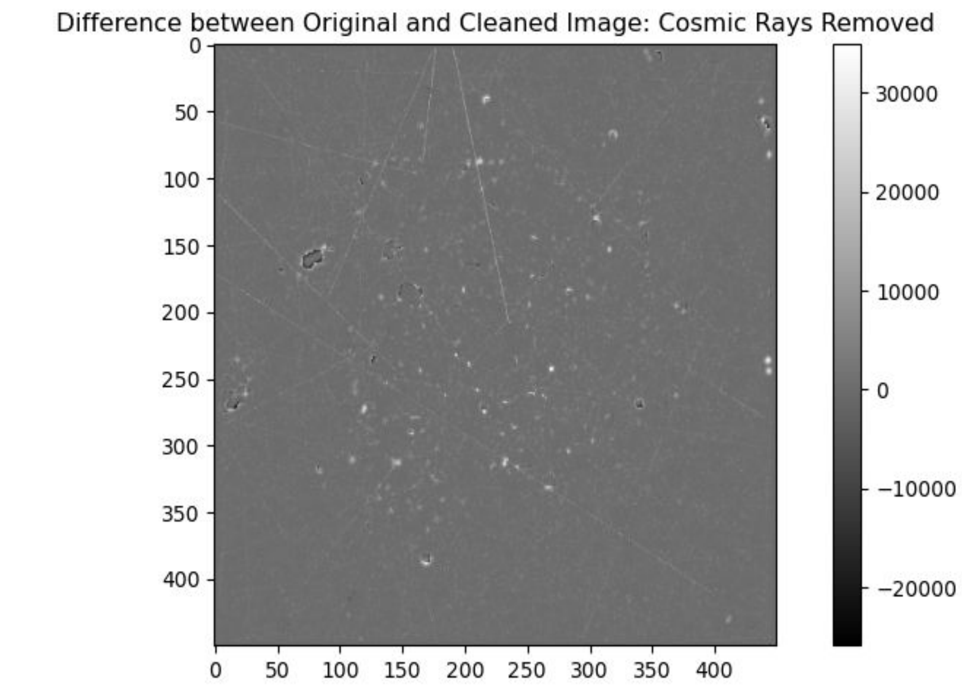
Longer Exposures Simulated



Hard to differentiate by eye!!

Short Exposures (<100s) vs Long Exposures (1000s)





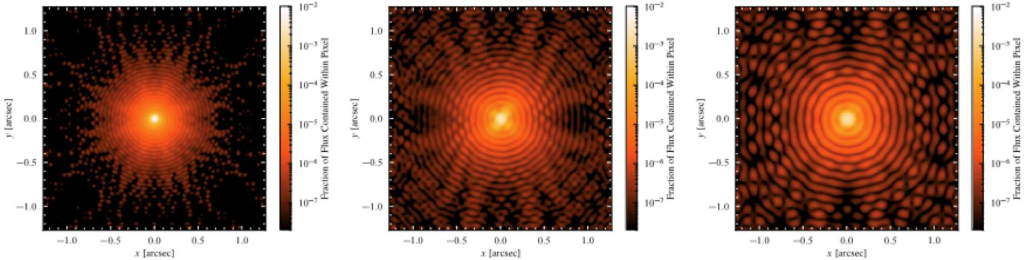
CCDproc generated !

Incorporating + Extending the Exposure Time Calculator.

- The Goal is to use resulting exposure times and point spread function used by Cheng et al. Note that this psf is oversampled.

  Incorporate interpixel capacitance, optical jitter and then convolved various star profiles in our model to the existing psf data.

Expected to recover CASTOR's FWHM



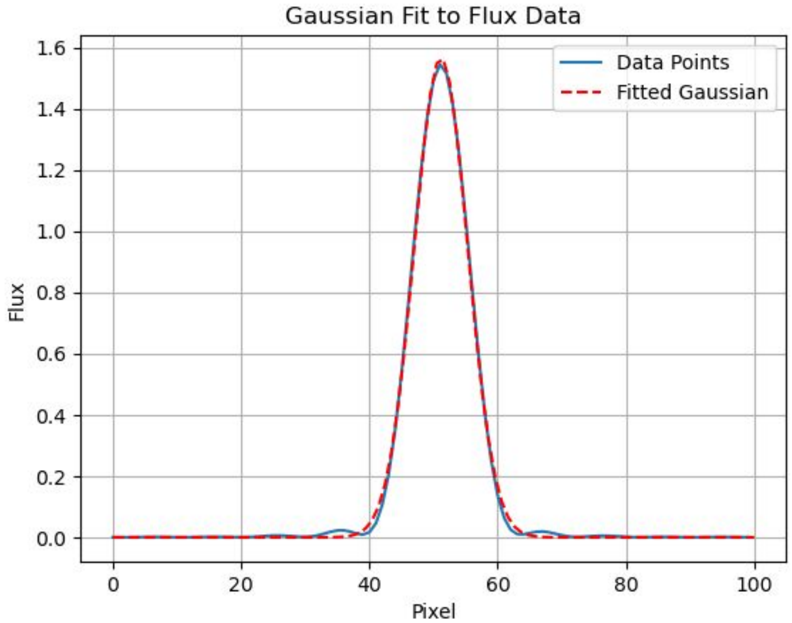
Point spread functions for *CASTOR*'s central field of view, in each of its UV- (left), u- (centre), and g-bands (right). The original PSF simulations are sampled at 10× *CASTOR*'s pixel scale, then interpolated to produce a grid which is 20× the telescope's pixel scale.

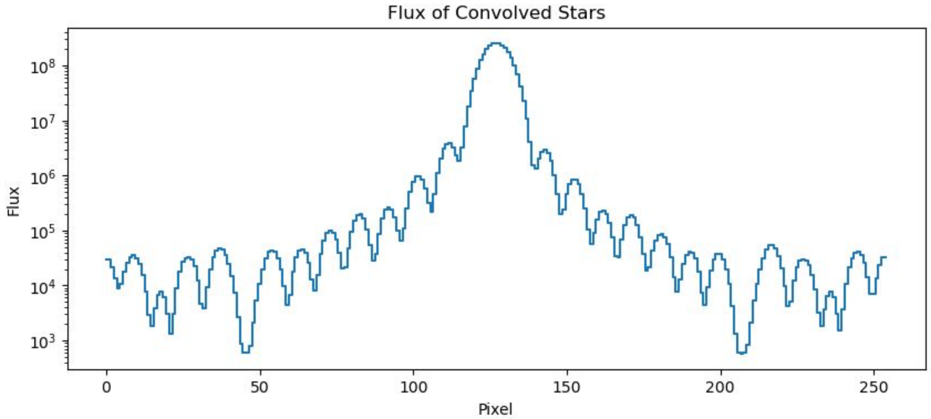
CASTOR Band (AB mag)	UV (s)	u (s)	g (s)
22.0	9.00	7.44	5.66
22.5	14.27	11.82	9.04
23.0	22.65	18.78	14.49
23.5	35.97	29.90	23.38
24.0	57.18	47.71	38.13
24.5	91.07	76.45	63.18
25.0	145.47	123.26	107.23
25.5	233.41	200.68	188.50
26.0	377.17	331.71	347.72
26.5	616.20	560.98	681.03
27.0	1023.90	981.08	1422.74
27.5	1745.22	1797.46	3151.41
27.6	1949.45	2042.54	3716.53
27.7	2181.01	2326.72	4390.34
28.0	3086.46	3492.19	7301.72
28.1	3478.63	4019.24	8673.27
28.2	3928.93	4637.94	10313.86
28.3	4447.37	5365.80	12277.18
28.5	5738.60	7236.97	17442.78

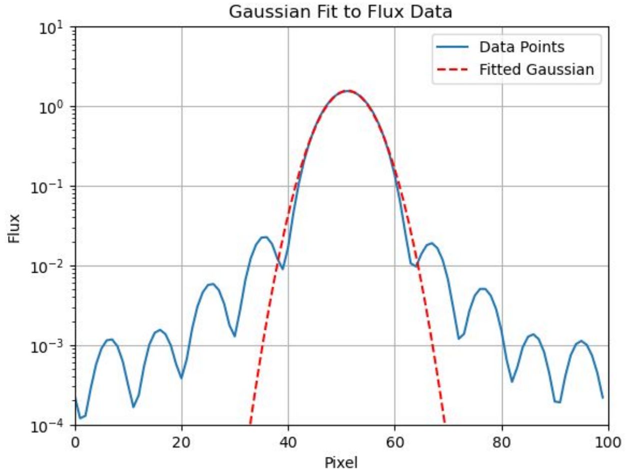
Times needed to reach S/N = 5 for a given magnitude in a *CASTOR* band, assuming a flat continuum, $E(B-V) = 0.09$.

Simulating PSF- Results

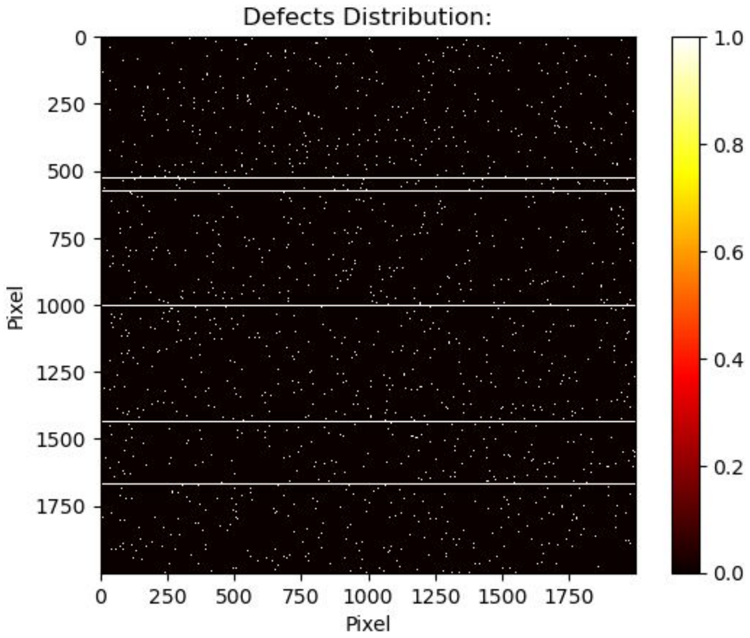
-Model yields **0.146’’**in each band.
(Finely sampled to correct for the oversampling)

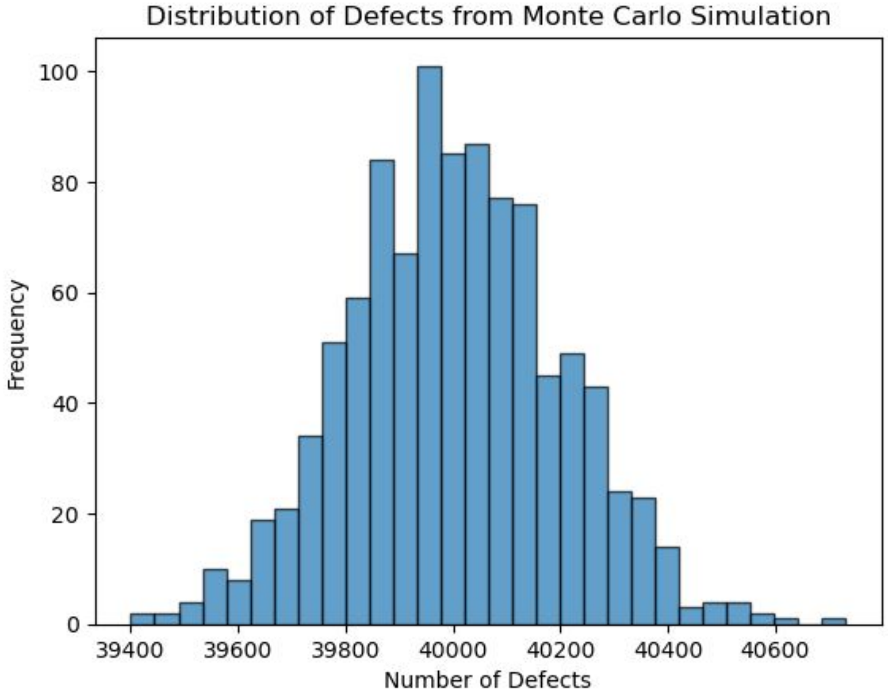




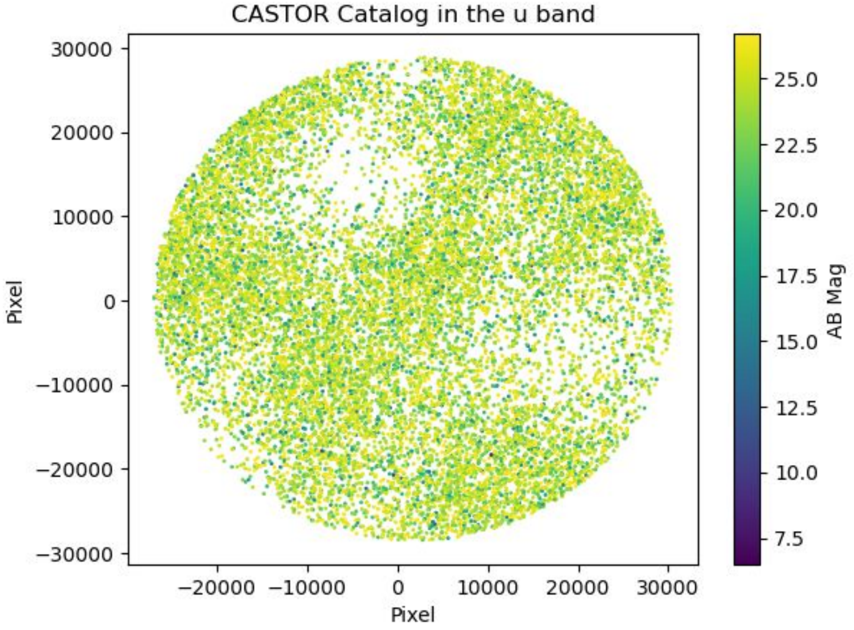


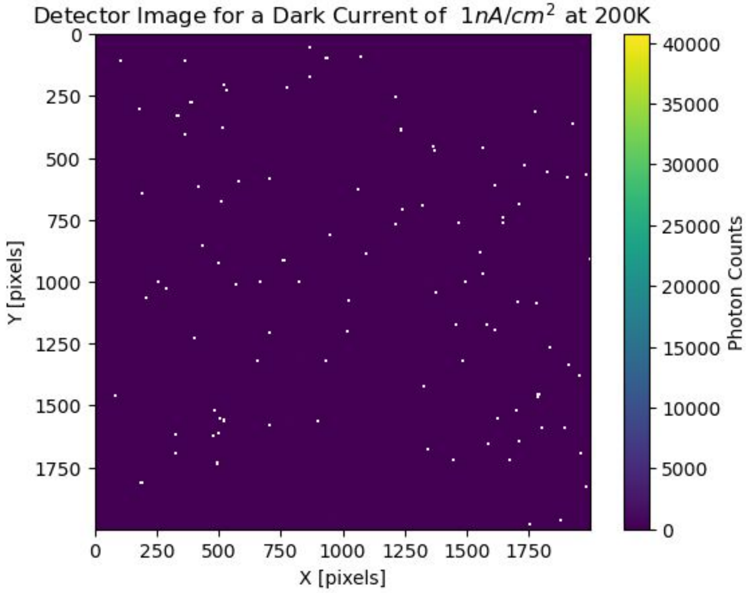
Defect Simulator





Phase 0 Survey Results (Ongoing Work)





- Using Photometry and SEXtractor to compare input and output(ongoing)
- Tools available and in production on Github. https://github.com/wasnaqvi/SIP-CASTOR

Future Works

- Transition from Phase 0 to Phase A. Incorporate these models.
- Honors Project on extensive characterization.
- Impact of Failure rate. Design Study.
- Software Optimization.

Acknowledgements.

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- My Supervisors. Drs. Pat Côtê, Tyrone Woods, and Melissa Amenouche. Would have been impossible without their guidance and patience (I like to ask questions.)

- **Everyone** at :

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  Especially Drs. Alex Hill(would not be in astro without him), JJ Kavelaars(Github, good coding practices),Wes Fraser(Docker), and Alan McConachie(physics related advice)

- CASTOR Collaboration.
- My officemates and fellow co-op students-Lauren,Derek,Ryland,Natalie,Claire, and Kayla.

THE END