

Simulating Satellite Streaks in the Rubin Camera

Rubin PCW - Satellite Constellations - 20220809

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and thanks to Tony Tyson, Aaron Roodman, Adam Snyder, Dan Polin, Yousuke Utsumi, Homer Neal, Craig Lage, Stuart Marshall, Claire Juramy, and the Rubin Camera team

Millions of streaked images

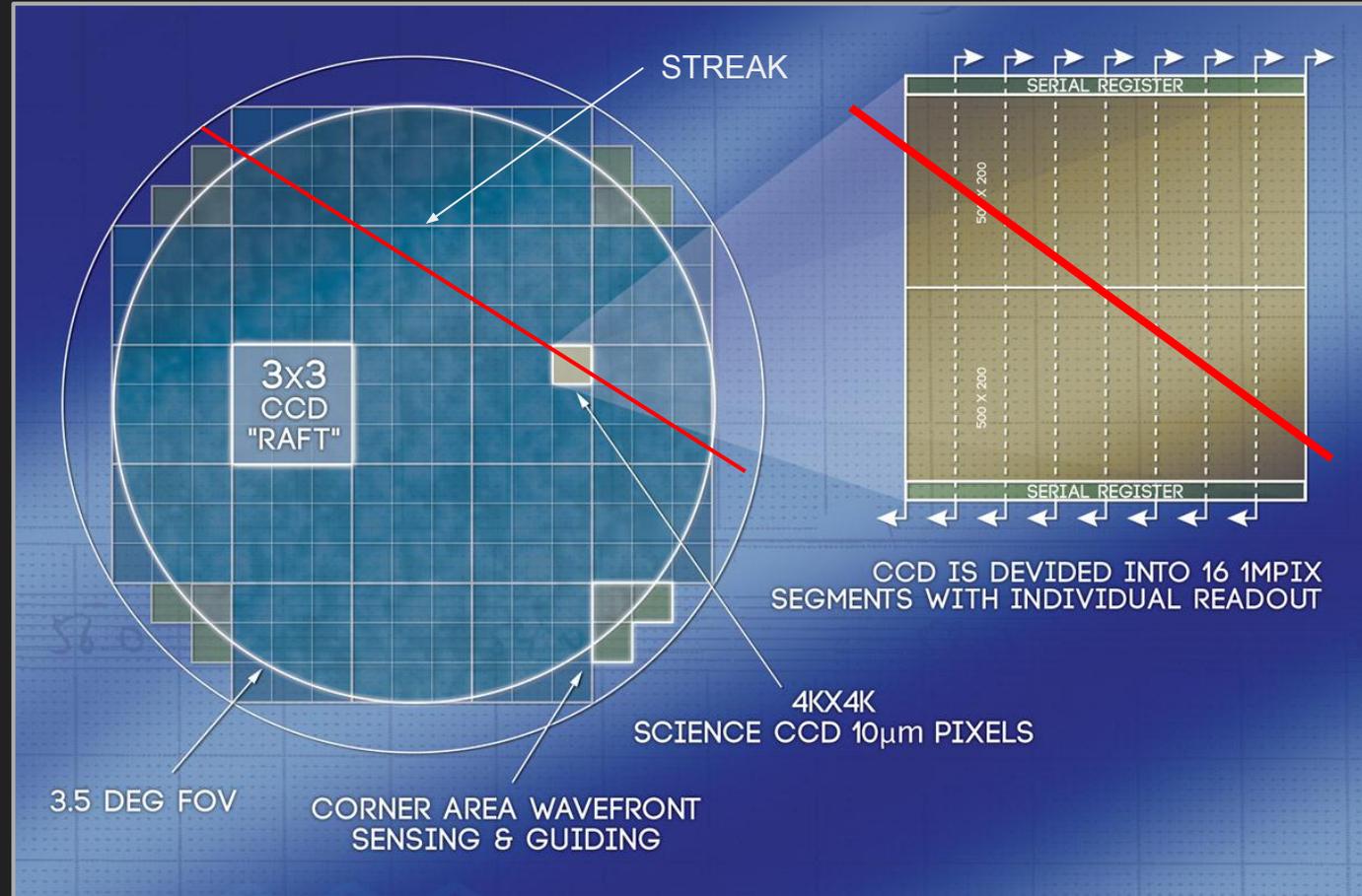
LSSTCAM has 189 CCDs and 3024 readout channels

Each CCD + read channel has a *unique* response to light/color and charge/time

With just **1%** of pixels on **~10 CCDs** streaked, each echos into **~200 readout amplifier pairs** per CCD

→ **$>10^7$ pixel corrections** for each streak images to N-year (<1%?) precision

(plus the main streak, which needs masking and/or modeling, see next talk!)



Streak simulation at SLAC

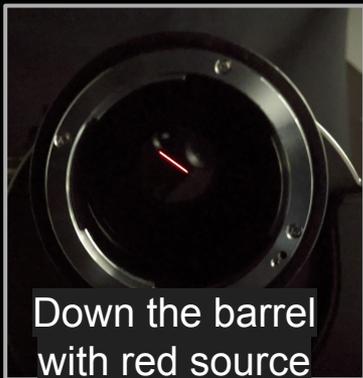
10 μm wide photolithographic slit

→ 10 pixel FWHM w/ spot projector lens

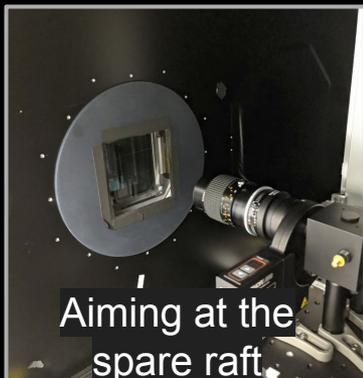
LSST electronics & config, but optical beam differs



Slit mask



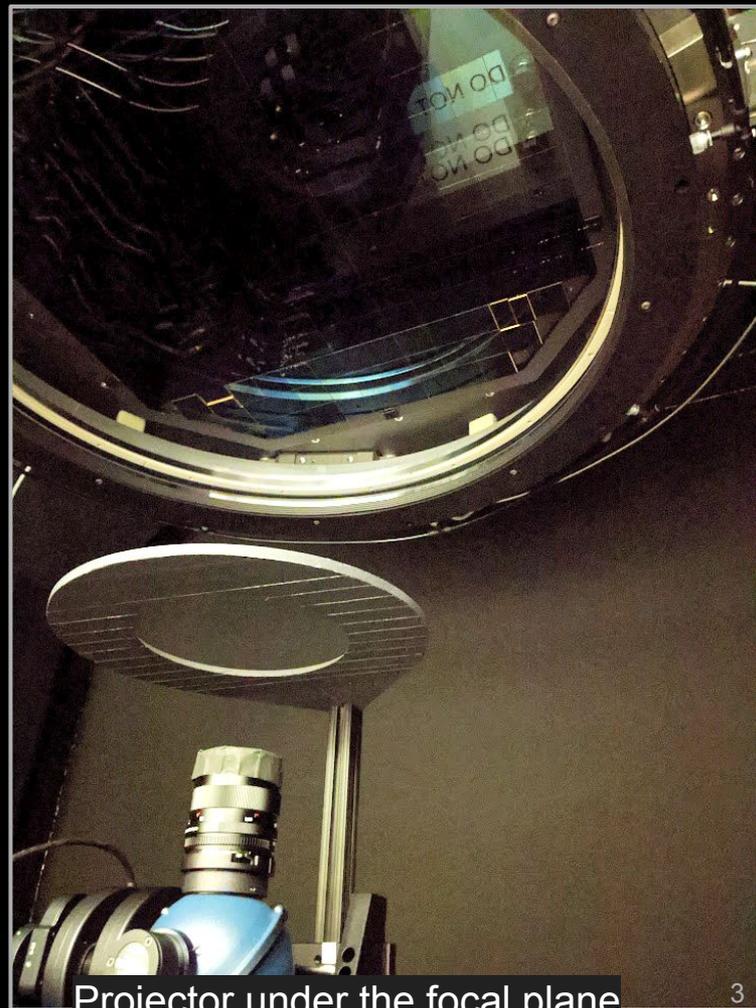
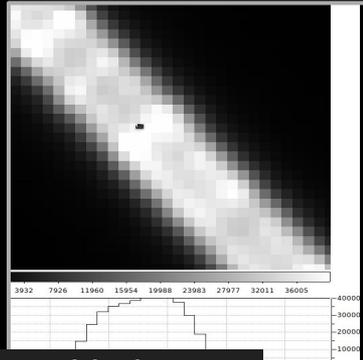
Down the barrel
with red source



Aiming at the
spare raft



Measure 1st IRL and in images



Projector under the focal plane

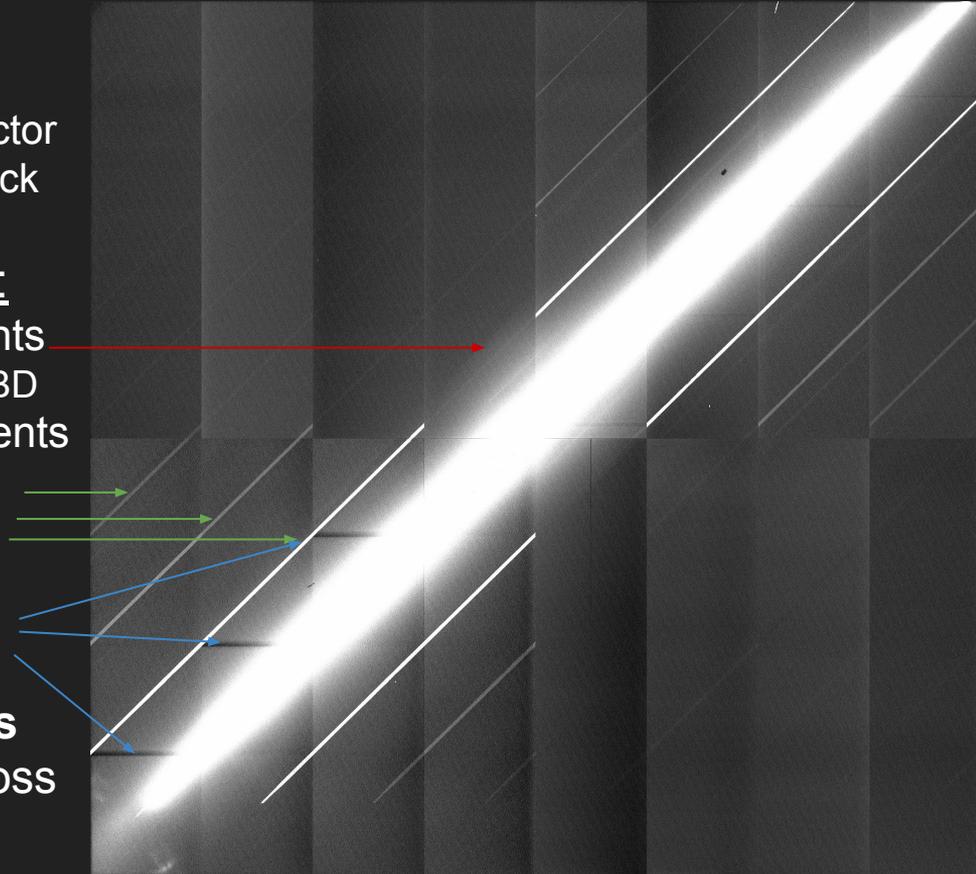
Studying satellite streaks

- Studies on LSST sensors began in July 2019
- Using LSST f/1.2 beam & full focal plane projector
- Tested under diff flux, pos, angle, voltage & clock

General observed behavior in simulation:

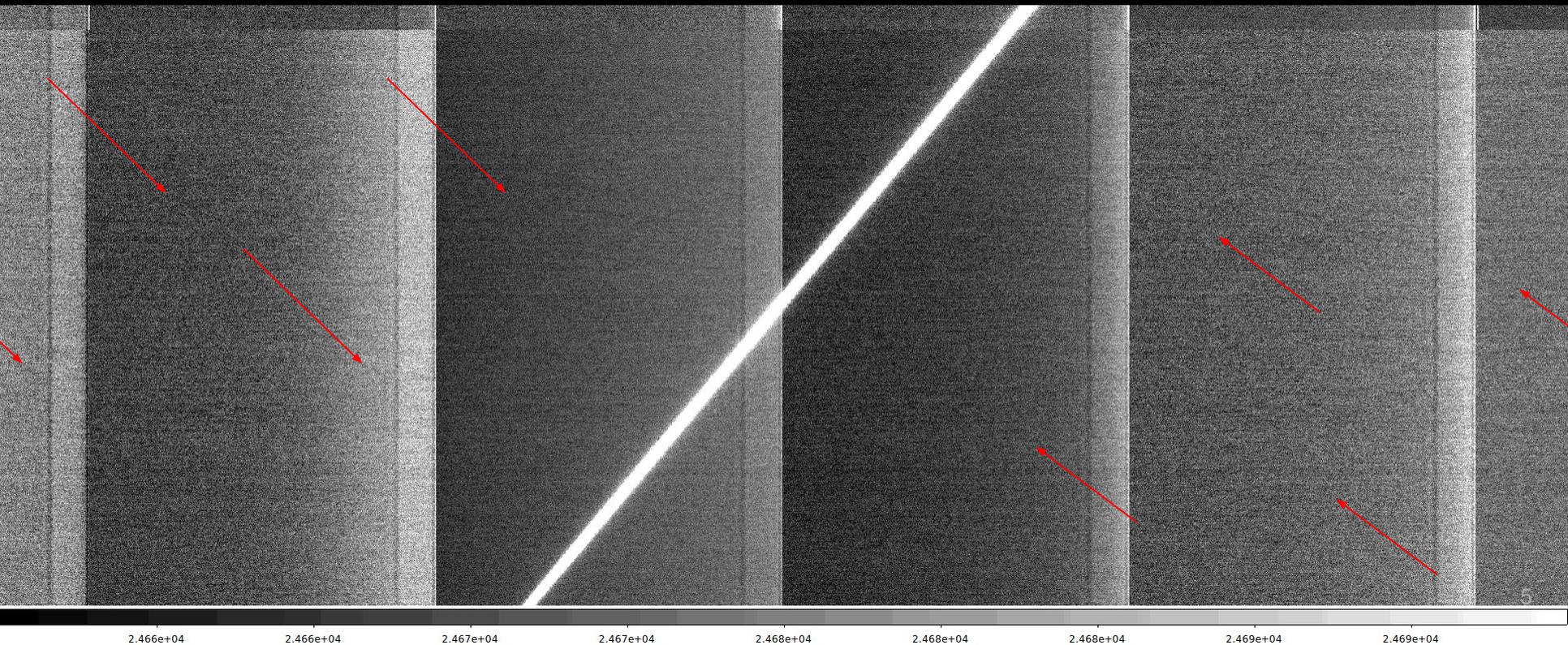
- **Scattered light** extends trail across segments
+ Main trail > read noise for > 100 pix, sky level TBD
- Multiple orders of **crosstalk** between segments
+/- 1E-4 to 1E-6 in amplitude
+ **Non-linearity** of crosstalk vs. signal
- **Bias shift** at some CCD segment crossings
- Fixed in firmware update?

Tallest pole after main streak removal is crosstalk, which multiplies main streak across affected CCDs in a non-linear way

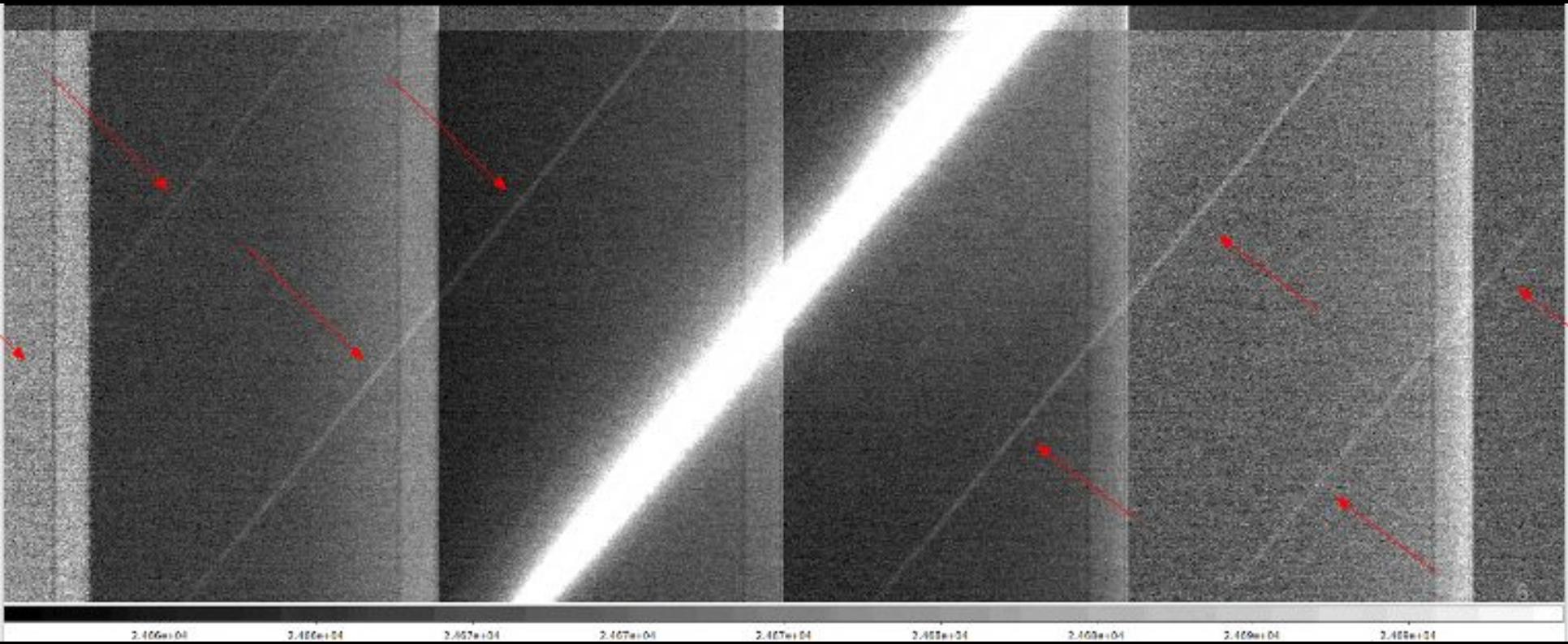


Raw image of a streak beamed onto Rubin CCD

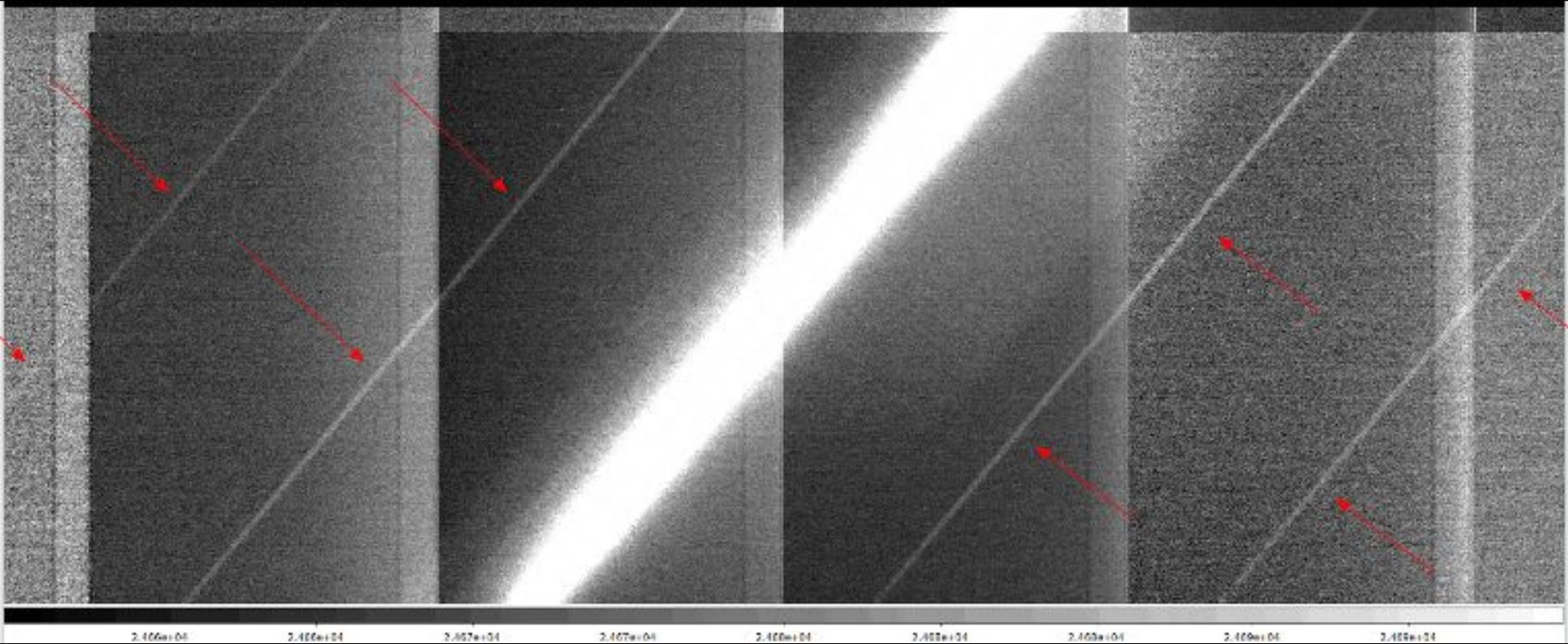
10k electron peak \rightarrow \sim 0-1 electron xtalk pattern



30k electron peak \rightarrow \sim 1-5 electron xtalk pattern



50k electron peak \rightarrow \sim 10-20 electron xtalk pattern
crosstalk $>$ read noise, approaching sky noise



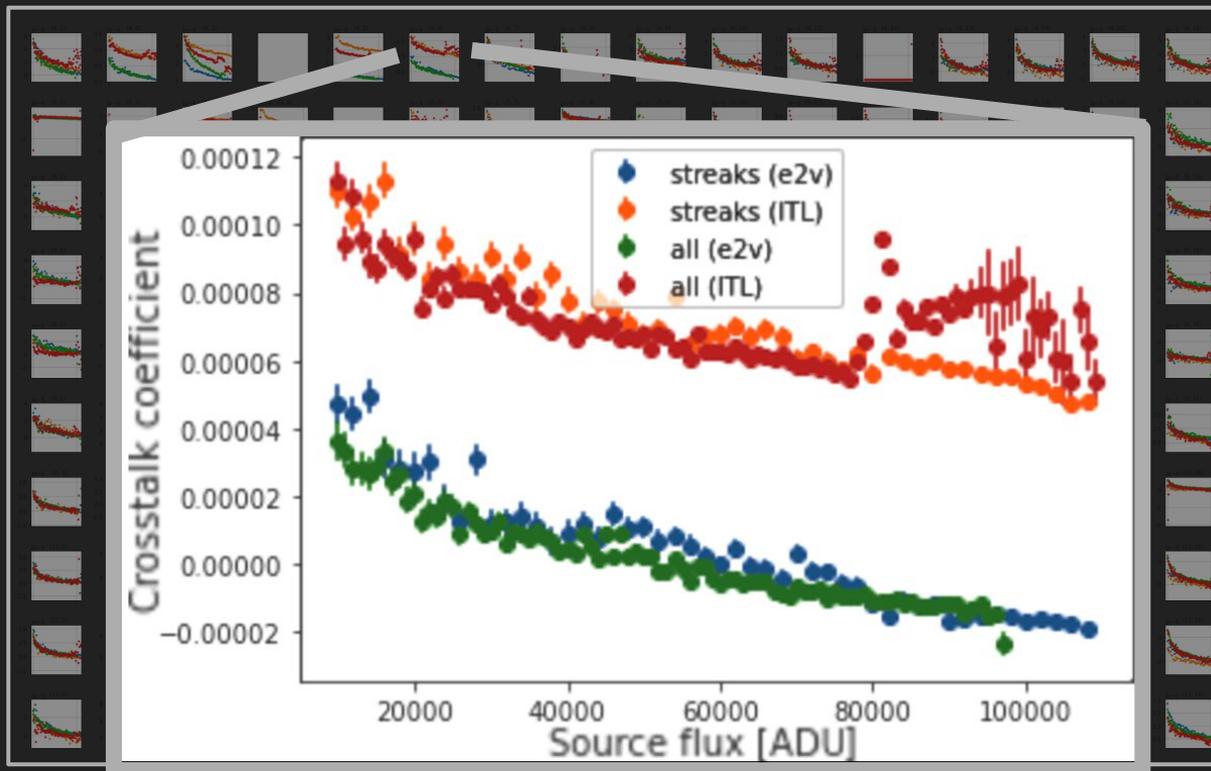
Non-linear crosstalk difficult to fully calibrate: 1 of 256 (x189)

Significant variation seen in amplifier crosstalk vs flux

Different for ITL/e2v CCDs

Just measuring is hard:
sub-electron crosstalk in read noise, scattered light, CCD features... ~50k CPU-hours →

Each pixel may need a unique flux-dependent correction coefficient for sensor + i,j



Crosstalk coefficients vs. flux, for a single 2nd nearest neighbor pair
CCD flavor & color: e2v **streaks spots**, ITL **streaks spots**

Correction depends on operation & optimization

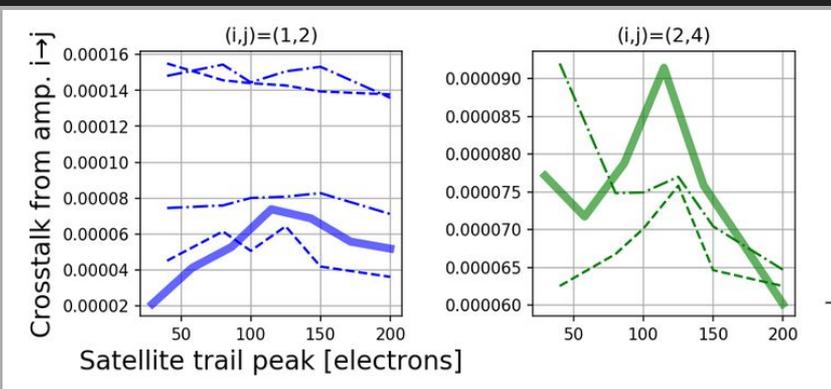
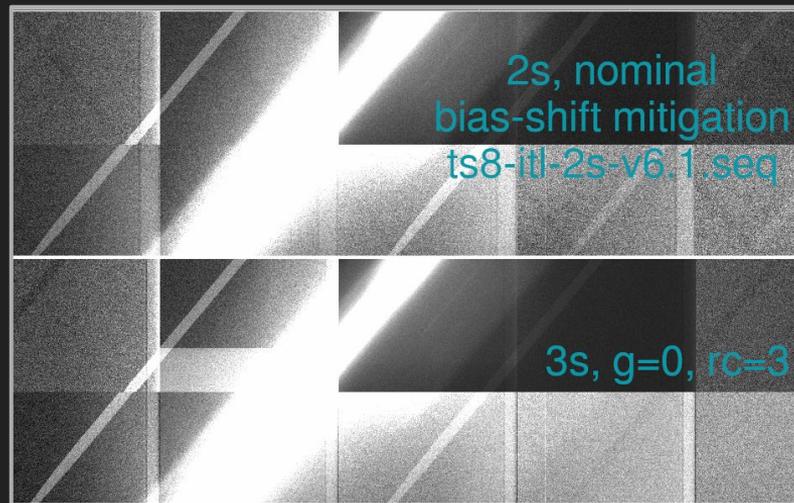
Different gain & RC on pixel processor
→ different crosstalk pattern

Multiple sources of signal to measure, model,
and disentangle!

Impact depends on: gain, bias level, sky level,
voltages, clocking, and readout. Ohm's broke?

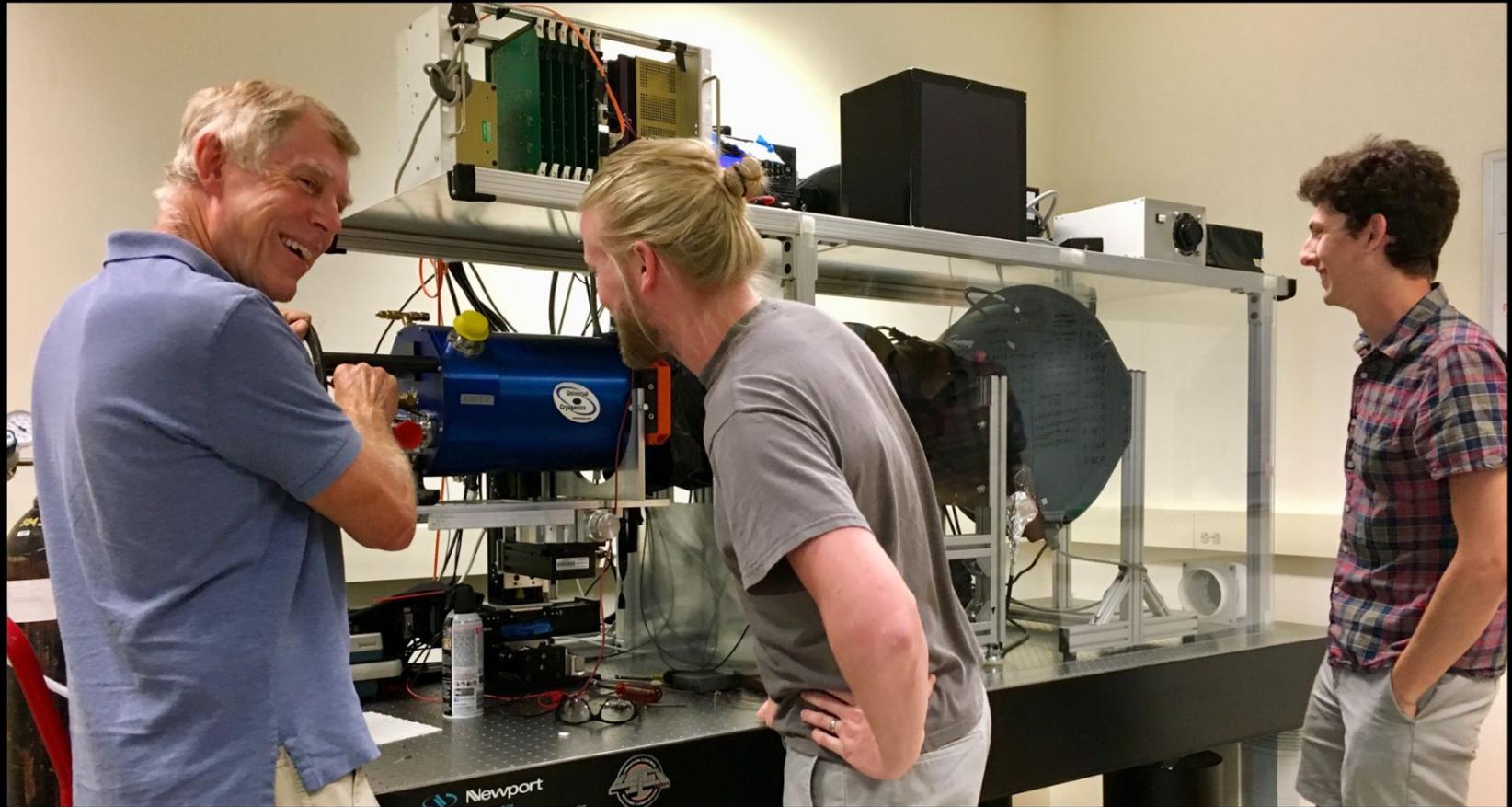
Optimize camera ops mitigating systematics:
tearing, BF, read noise, edges, etc...or crosstalk?

Complicated questions in need of more data &
sims of systematics impact on survey science



Streaks images, and crosstalk pairs compared **ASPIC**

Testing the streaks on the UCD LSST f/1.2 beam



Correctability vs Flux

A non-linear crosstalk algorithm must correct to \sim electron precision

At 6.5 mag, a 10% error on any given coefficient could create a false faint galaxy image in a co-add

Given a widely variable systematic, and limited calibration, how can we best correct for crosstalk of streaks?

Work together, and keep experimenting on our camera!

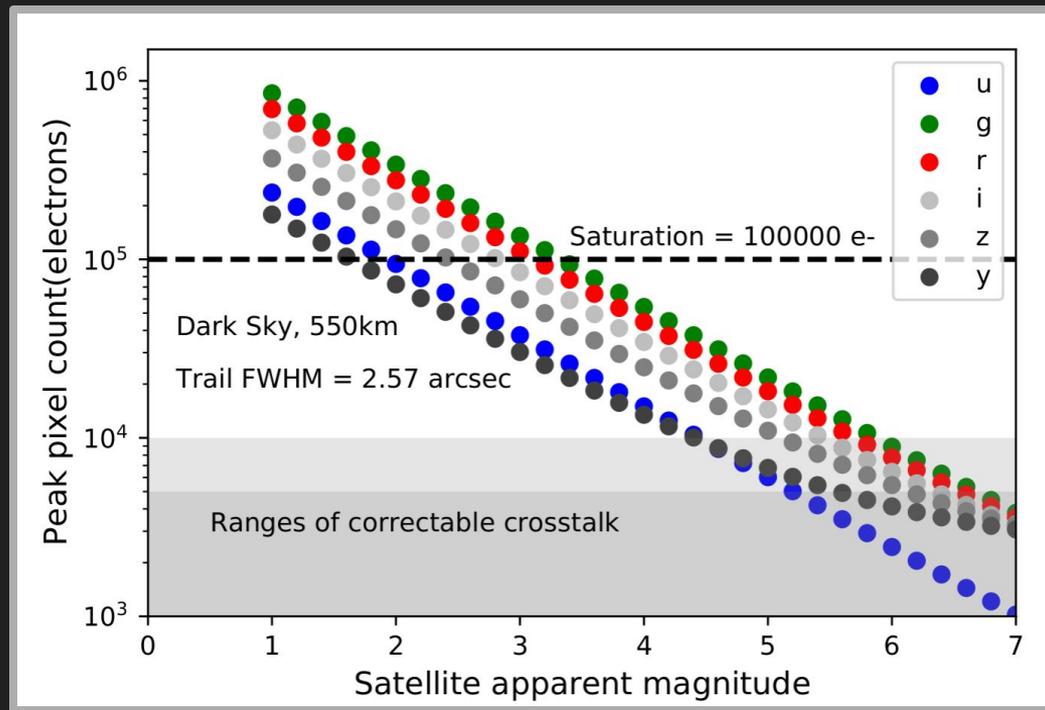


Figure 5. The peak trail brightness in e^- per pixel for a Starlink satellite at 550 km as a function of apparent AB mag as seen by Rubin Observatory. Colors correspond to the six different LSSTCam filter bands. The approximate saturation level of an LSSTCam CCD is indicated. The approximate dynamic ranges over which camera crosstalk artifacts can be corrected down to below the noise level, using our current algorithm, are shown in the shaded regions (see Section 7).

Conclusions

- Streaks are clearly not good for the camera or survey
- Non-linear crosstalk & bias shift among many issues, but correction of collateral damage is feasible
- Impact of streaks on survey is TBD, will depend on satellite engineering and the physics of our camera
- Darkening is of course much appreciated!