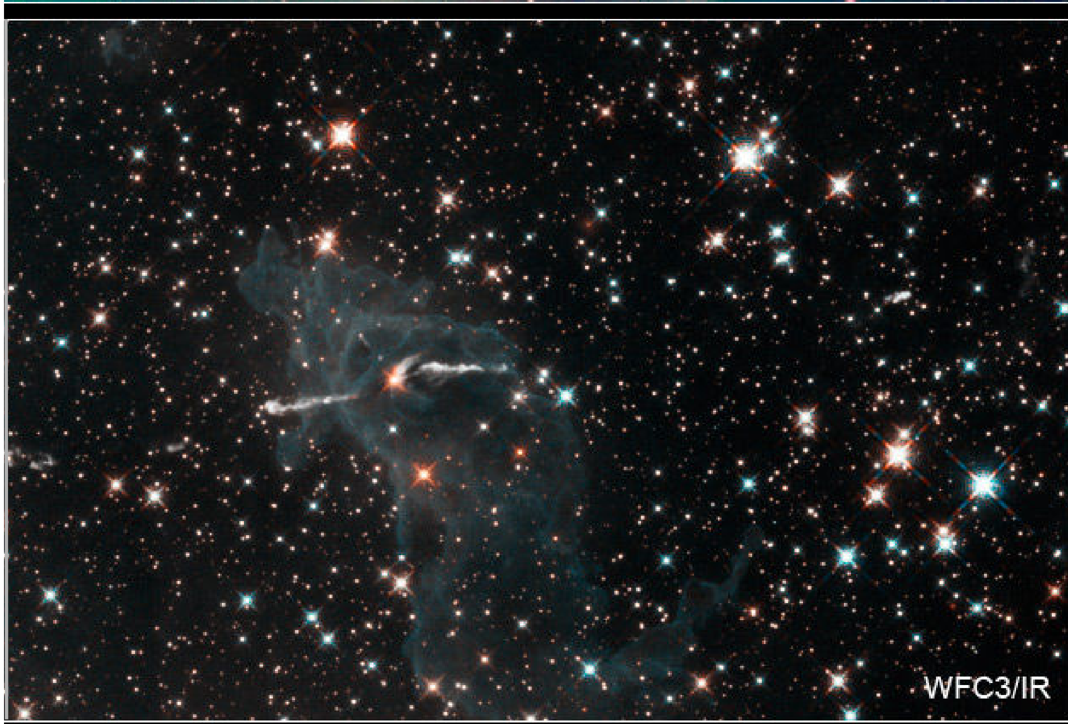


In-Flight Performance of the Detectors on HST/Wide Field Camera 3

Randy Kimble
(NASA/GSFC)
and the WFC3 Team

WFC3 Introduction

- WFC3 is a powerful new imager for HST
- It features two observing channels: UVIS (200-1000nm); IR (800-1700nm)
- WFC3 was successfully installed during SM4 in May, 2009
- It has completed a very successful Orbital Verification program and is into routine observing
- We report on the in-flight performance of its detector systems here

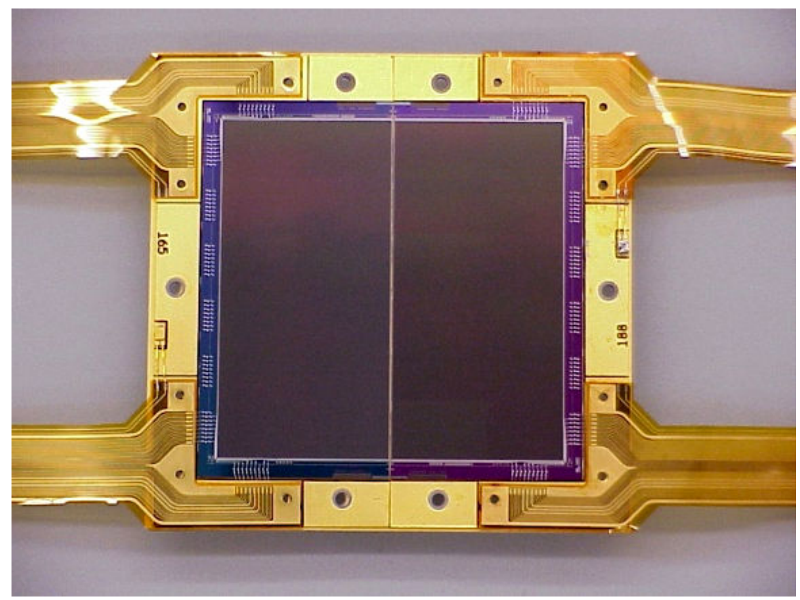
The detector performance analyses that will be shown here come from the efforts of two teams:

- The WFC3 team at STScI for analysis of thermal-vac and Servicing Mission Orbital Verification program data
  - In particular S. Baggett, T. Borders, S. Deustua, M. Dulude, B. Hilbert, J. MacKenty, P. McCullough, A. Riess
- The Detector Characterization Laboratory at GSFC for laboratory investigations of WFC3 detector performance
  - In particular N. Boehm, N. Collins, G. Delo, R. Foltz, R. Hill, E. Malumuth, A. Waczynski

And, most importantly, the detectors themselves were developed by e2v (CCDs) and Teledyne Imaging Sensors (HgCdTe FPA) and packaged by Ball Aerospace

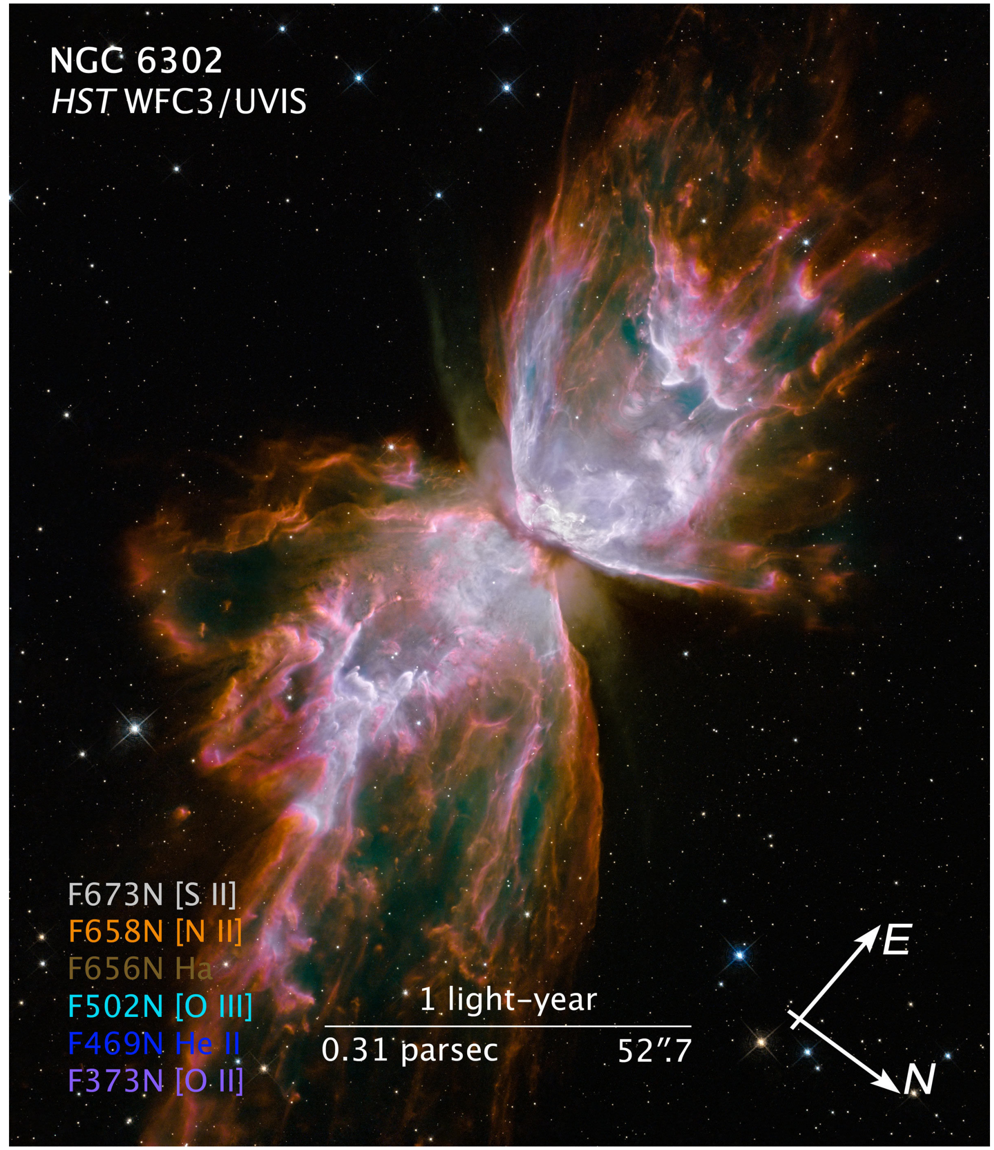
The UVIS Channel and Its Detector

- Focal plane is a pair of 2K x 4K backside-thinned CCD43 arrays (15um pixels) from e2v
- UV-optimized backside treatment and AR coating
- Covers 200-1000nm, FOV of 160 x 160 arcsec at 0.039 arcsec/pixel
- Gap between CCDs is ~35 pixels or 1.4 arcsec
- Operates at -83C with 4-stage TEC
- Full frame readout is through 4 amps; subarray, binning available
- Charge injection capability for mitigating CTE degradation with radiation damage

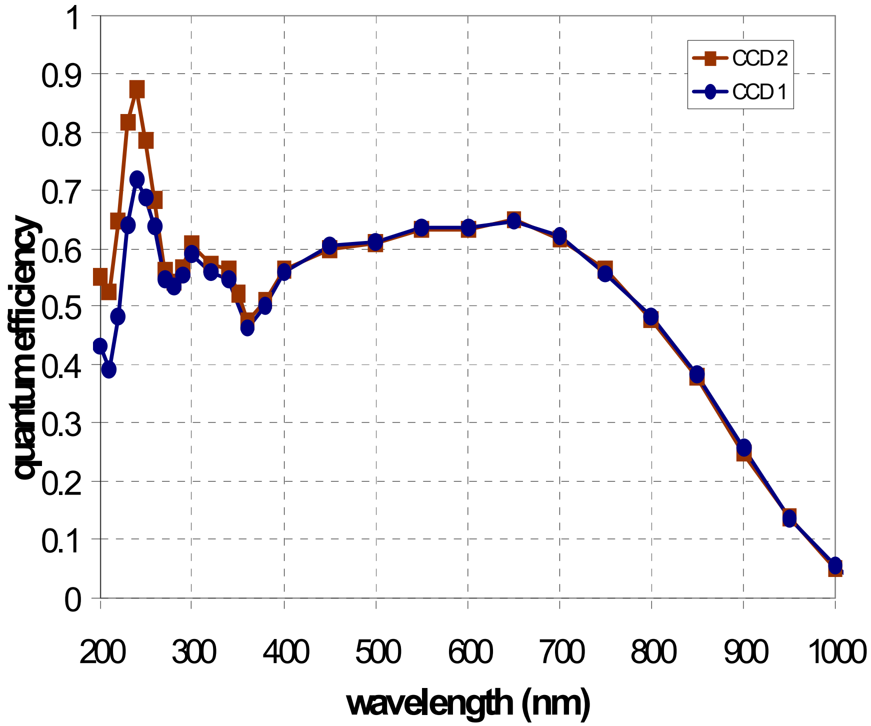


UVIS Science Capabilities

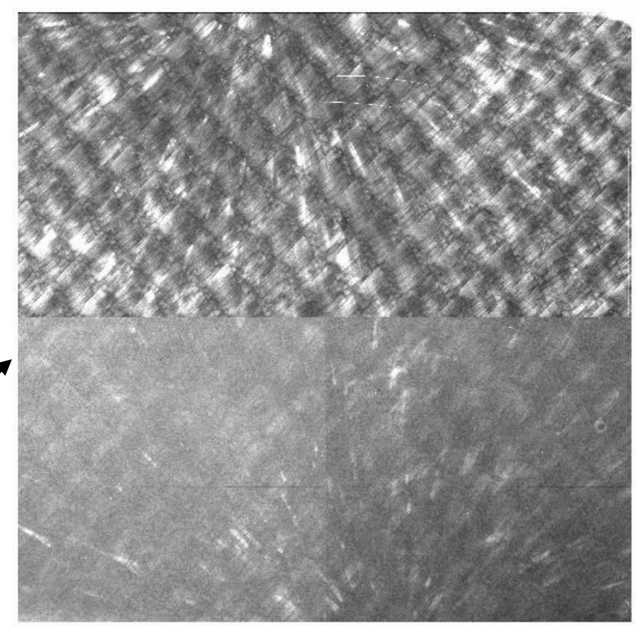
- Beautifully complementary to I-band-optimized ACS/WFC
- Unique capability in NUV (200-400nm)
  - 10-100x the survey speed of WFPC2 or ACS/HRC
- Rich complement of narrow-band filters (as in Early Release image at right)
- Fine backup to ACS/WFC for red broadband imaging, with finer sampling



QE and Flat-Field



- Thin-chip QE curve with good UV response
- Curve not corrected for quantum gain, but we found that to be small



336 nm Flat Field

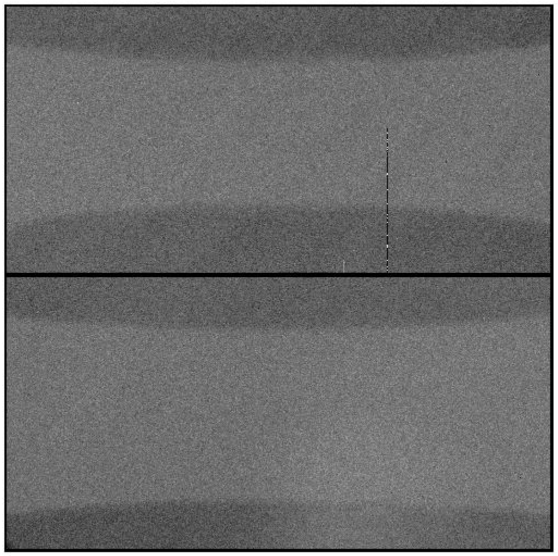
- UV flat field shows characteristic e2v structure
- Visible flat very smooth

UVIS Detector Has Low Read Noise and Dark Current

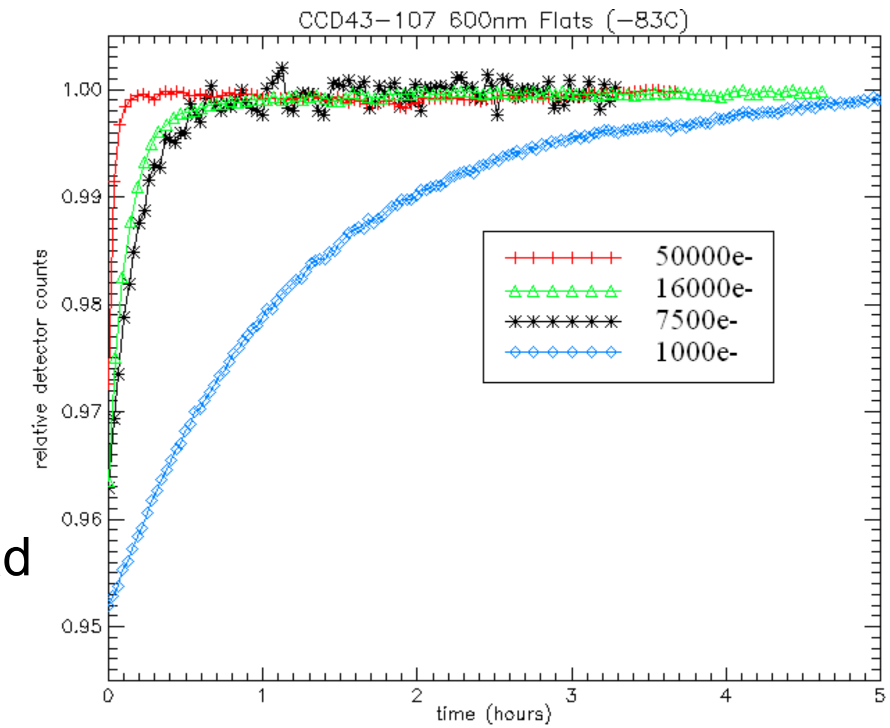
- Read noise is ~3.1 e- rms for all four readout amps
- Median dark current 1.6-1.7 e-/pixel/hr
  - Higher than ground test by 1-1.3 e-/pixel/hr (window glow? effect of pinning exposures?) but still negligible
  - Hot pixel tail slowly growing with radiation damage

- *These low values are particularly valuable for WFC3 with its fine sampling (0.039”/pixel) and its emphasis on UV and narrowband observing → low sky counts*

The “Bowtie” Effect:
A Manifestation of QE Hysteresis



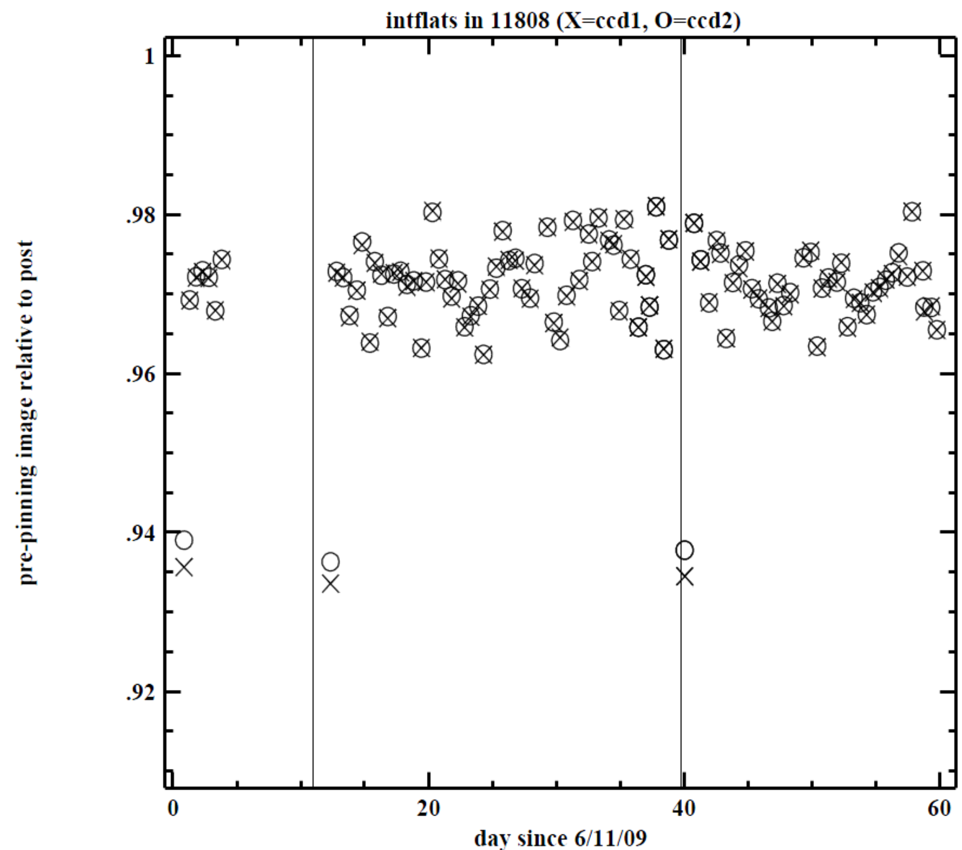
- Peculiar bowtie morphology observed occasionally in flats during ground test
- Morphology never clearly explained
- But behavior turned out to be a symptom of a general QE hysteresis behavior



- When CCD cooled in the dark, QE starts low by 3-5% -- not just in UV!
- Successive flats asymptotically pin response – integrated deficit of ~2000 e-/pixel
- Can pin with one saturated flat instead
- <u>Visible flat pins all wavelengths</u>

Successful QE Pinning in Flight

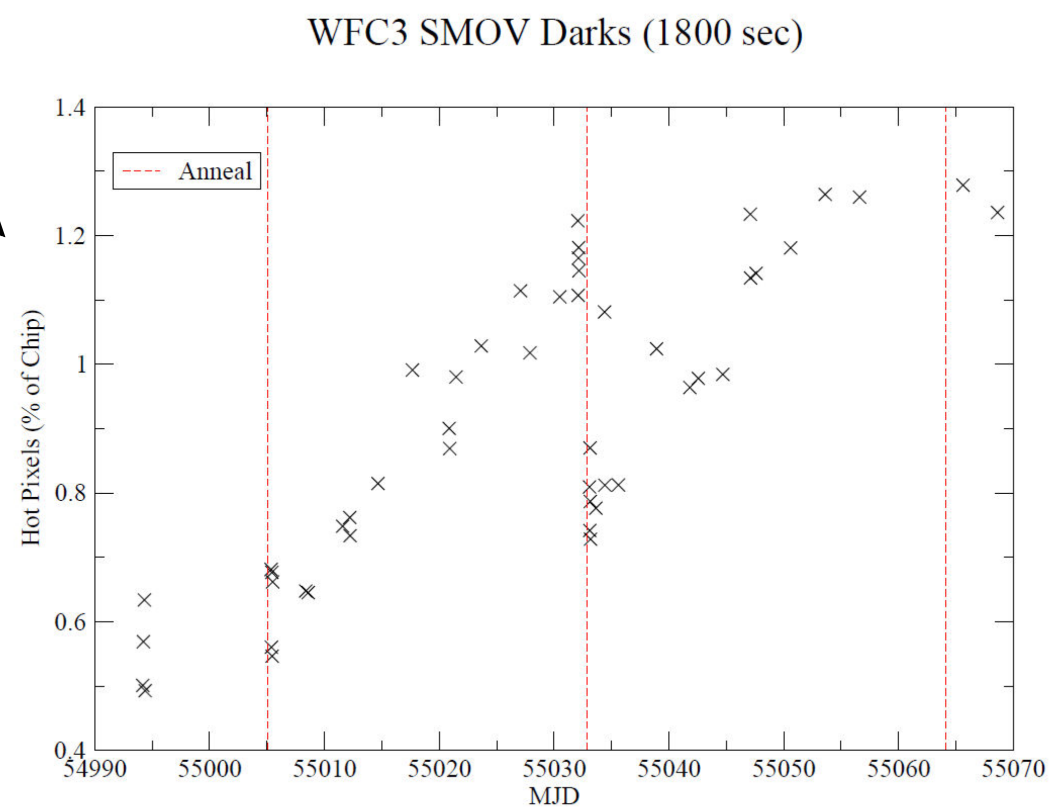
- Ground testing of spares showed that un-pinning has very long time constant
  - ~0.1% QE drop in 10 days
- Flight protocol developed for sequence of 3 exposures:
  1. Low level flat
  2. Pinning flat (500,000 e-)
  3. Low level flat to check
- Only see difference between 1st and 3rd after anneal and dark cooldown



- <u>Afterwards stable, confirmed by standard stars</u>
- No bowtie morphologies seen

Initial Radiation Damage Assessment

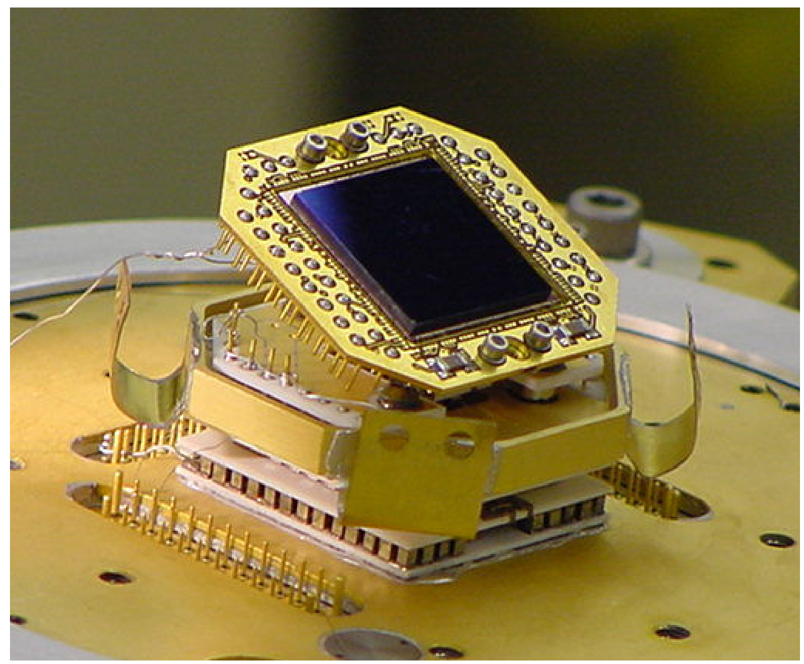
- Growth in hot pixels as expected; significant benefit from monthly anneal to 20C (~70%)
- Initial assessment of CTE degradation: very similar to ACS
- Greater impact with our generally lower sky background (UV, narrow-band, finer sampling)



- Charge injection available in later years – 10ke- injection with a penalty of 15e- rms noise

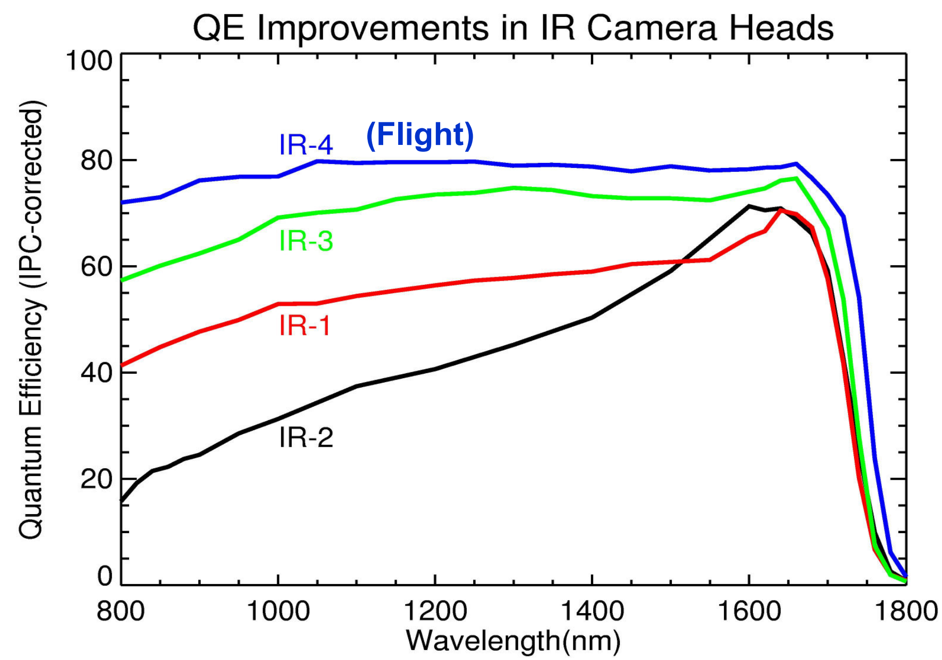
The IR Channel and Its Detector

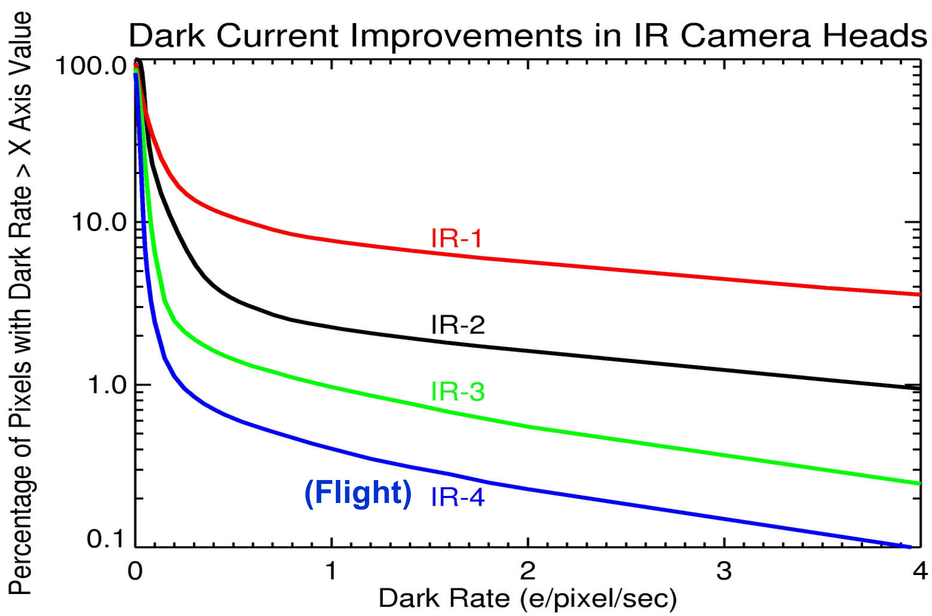
- Focal plane array is a hybrid HgCdTe device by Teledyne Imaging Sensors (formerly Rockwell Scientific)
- 1.7µm cutoff HgCdTe on a Hawaii-1R mux, 1024x1024 pixels (18x18 µm), 1014x1014 active, with peripheral reference pixels to correct thermal and/or electrical drifts
- Substrate-removed to eliminate radiation-induced luminescence
- Range: 800-1700 nm; FOV: 123”x136”
- FPA, filters, and cold stop inside cold enclosure
- Operates at 145K via TECs and passive radiator (no cryogen)
- No shutter, exposures controlled electronically
- Multiaccum readout, up to 16 non-destructive reads, via 4 amps



Successful Development of 1.7μm HgCdTe Arrays

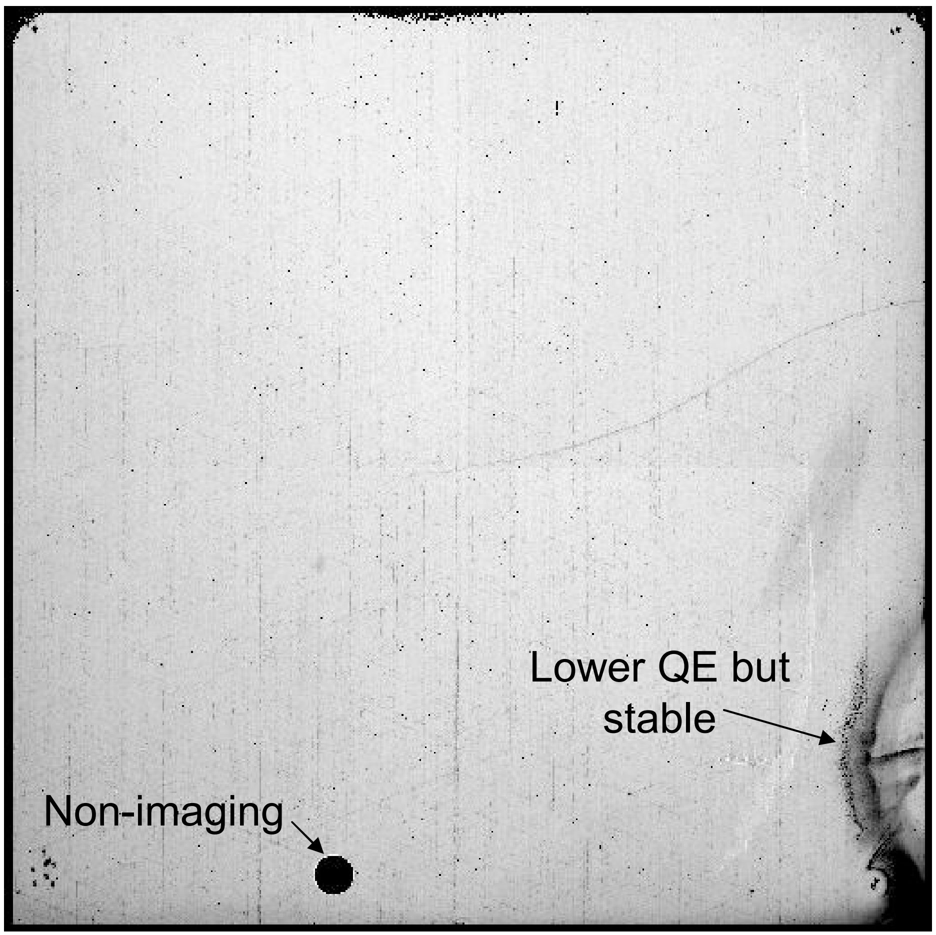
- HgCdTe arrays with 1.7μm cutoff was a custom development for WFC3
- Turned out to be quite challenging





- But enormous improvements were achieved over course of program (packaged camera heads IR-2, IR-1, IR-3, IR-4)
- Culminating in outstanding performance of IR-4, FPA165

Introduction to Flight FPA165



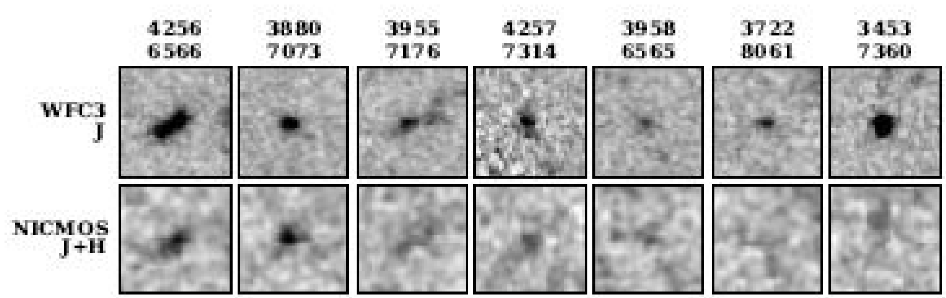
F140W Ground Test Flat Field

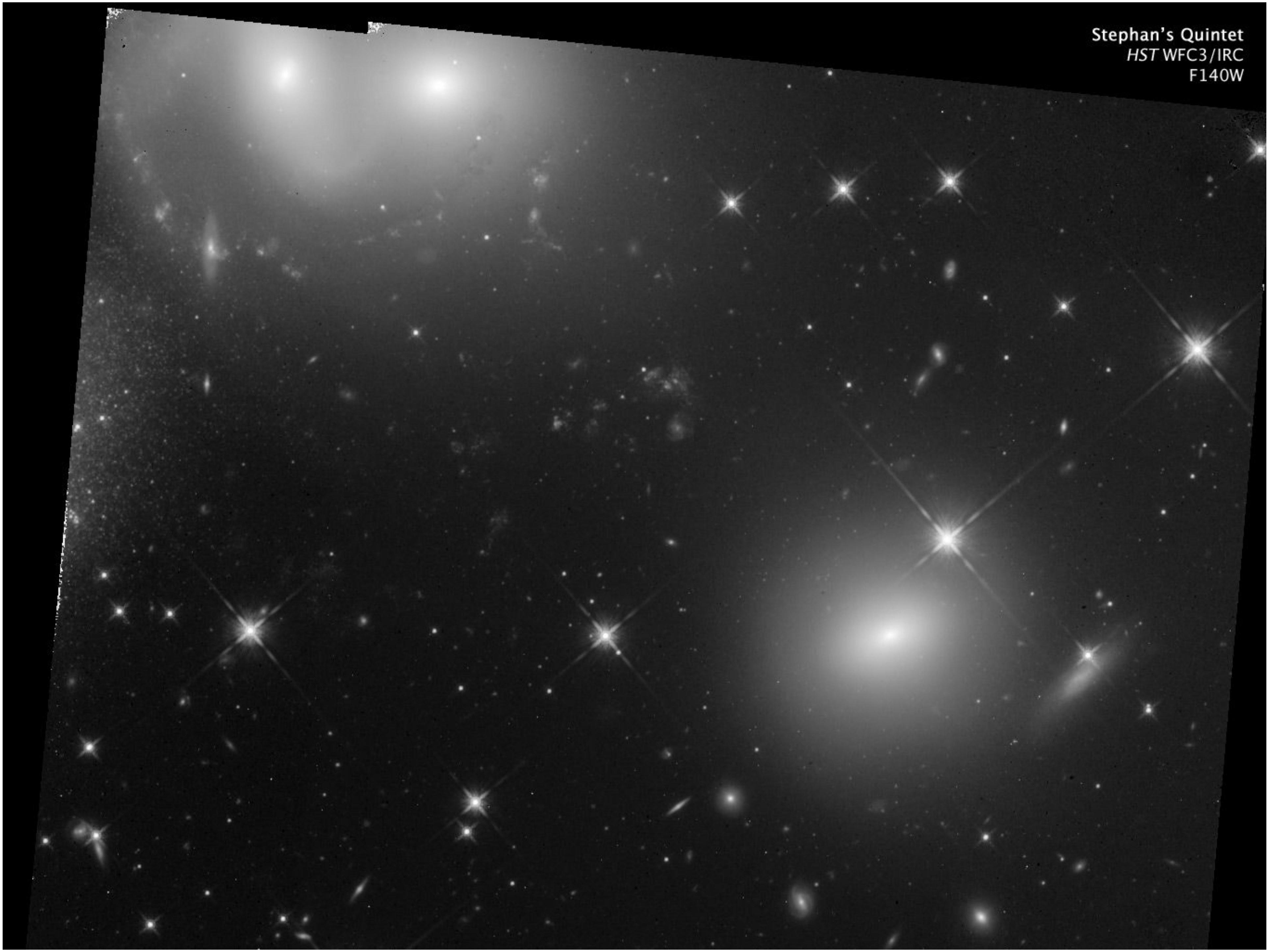
- Overall best performer – best combination of QE, dark current, read noise
- 96% of pixels within 10% of median QE
- Cosmetic defects are minor and stable
- With fairly tight data quality criteria, 1.8% of pixels are flagged as bad
  - High dark current
  - Low QE
  - Unstable ramp to ramp
- Readily overcome with a few dither positions

Early IR Science Performance Very Exciting

- Higher throughput and 6.4x field vs. NICMOS, 130 vs. 200 mas pixels, predicted large gains in IR surveys
  - WFC3 requirement was 10x NICMOS survey capability
  - Pre-launch prediction was >20x
- Early science programs confirm and exceed predictions
  - Illingworth's program imaging HUDF has obtained deepest NIR image ever in 60 orbits
    - high-*z* galaxy discovery rate increased 40-50x
  - Cepheid program of Adam Riess (private comm) progressing 40x faster

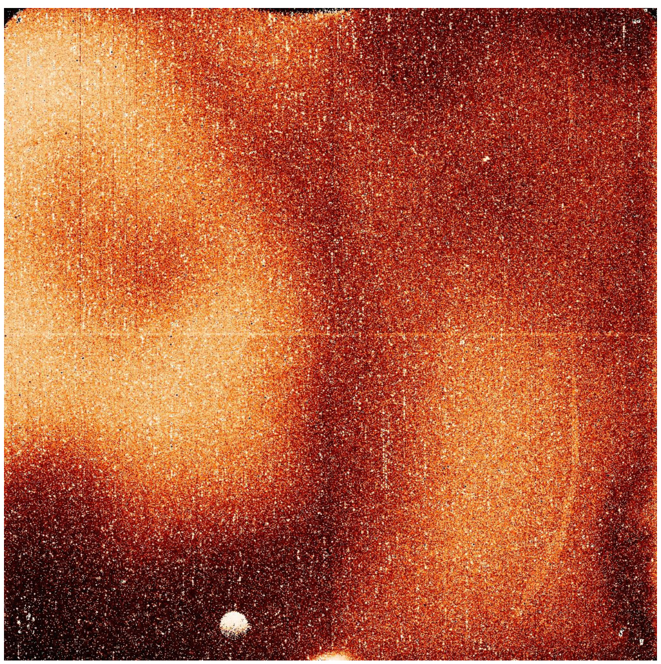
$z \sim 7$ candidates (Y_{105} dropouts) from Oesch et al. 2009; WFC3 and NICMOS observations of same candidates



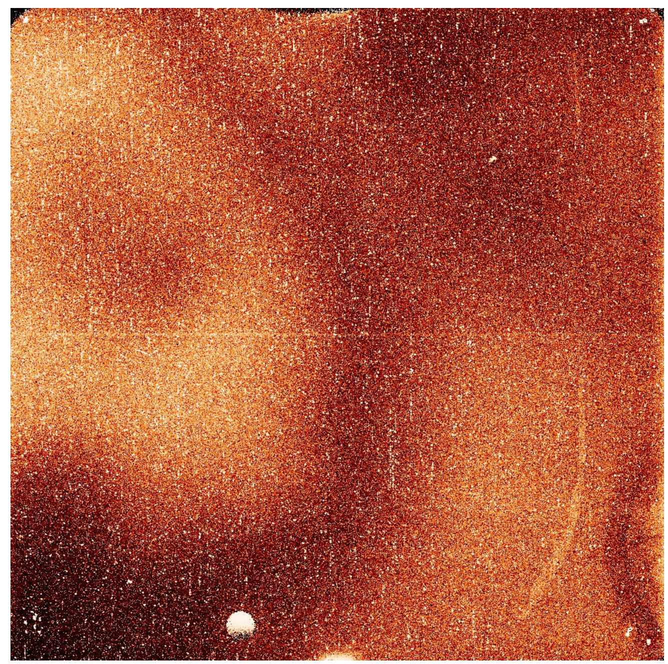

Stephan's Quintet
HST WFC3/IRC
F140W

Dark Current Similar to Ground Test

- Dark current levels and spatial morphology are very similar to ground test -- both at 145K
- Median rates: 0.048 e-/pix/s in flight, 0.057 e-/pix/s in T-V
- Only 0.6% of pixels above spec of 0.4 e-/pix/s



Flight



Thermal-Vac

Read Noise Improved vs. Ground Test

- CDS read noise is 20-22 e- rms (varies with quadrant); same as ground result; noise in RAPID reads also similar to T-V result
- Effective noise reading up the ramp is actually a bit lower in flight than in thermal-vac for long exposures: (average of the 4 quadrants shown)

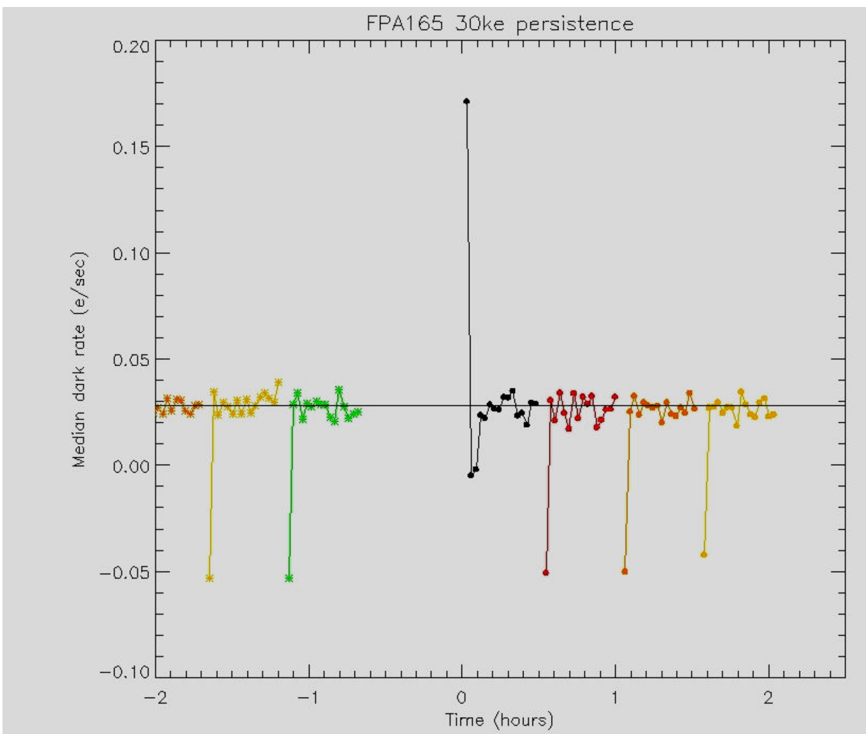
# of Reads	3	8	15
Effective noise (e- rms; SMOV)	19.6	16.0	12.4
Effective noise (e- rms; thermal-vac)	20.8	17.8	14.6

For SPARS200 sample sequence

- *Combined with excellent dark current, very well satisfies goal of being zodiacal-background-limited for long exposures in broad bands (zodi rates from a few tenths to >1 e-/pix/s)*

After-Image Effects: Persistence

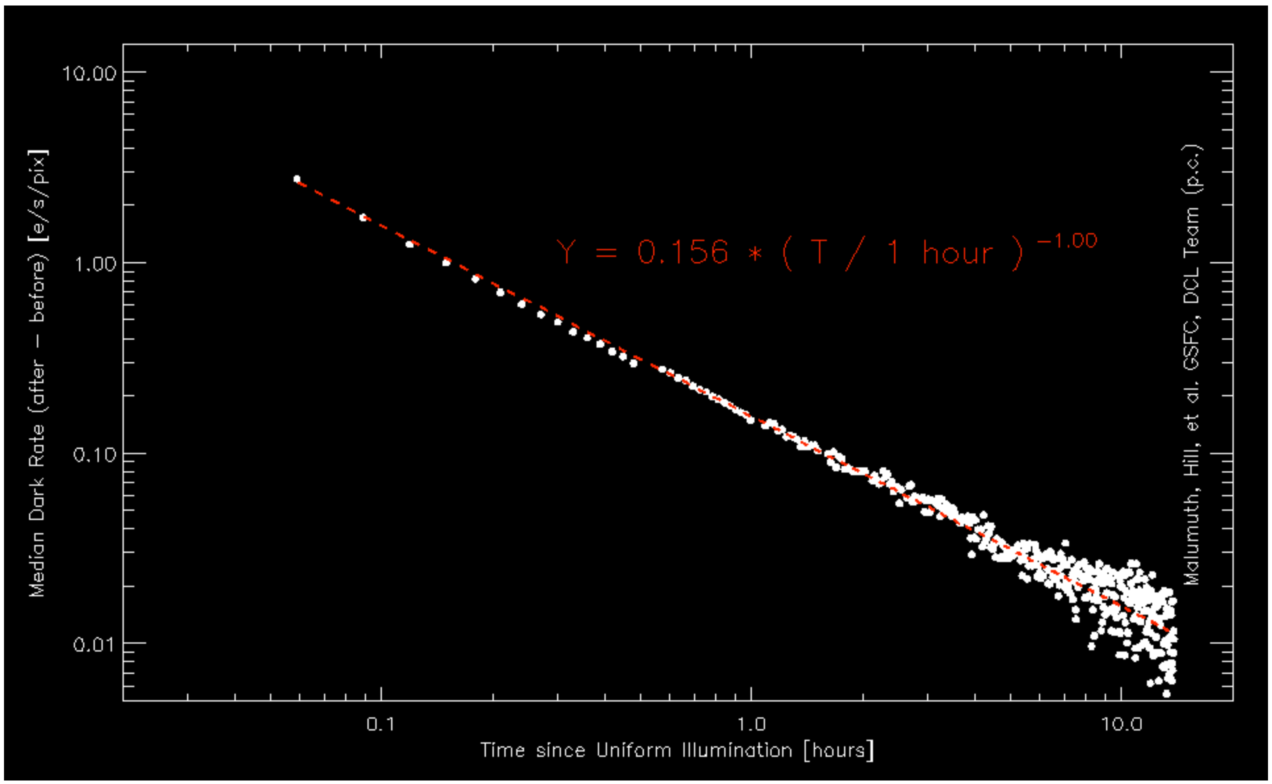
- Persistence is a well-known feature of HgCdTe devices; has been particularly prevalent in the development of the 1.7μm material
- Our H-1R does not have global reset capability whose persistence benefits Gert Finger showed – our inter-exposure idle mode is continuous row by row reset



Persistence response to sub-full-well signals (here 30,000 e-/pixel) recovers to baseline within 15-20 minutes

Persistence (2)

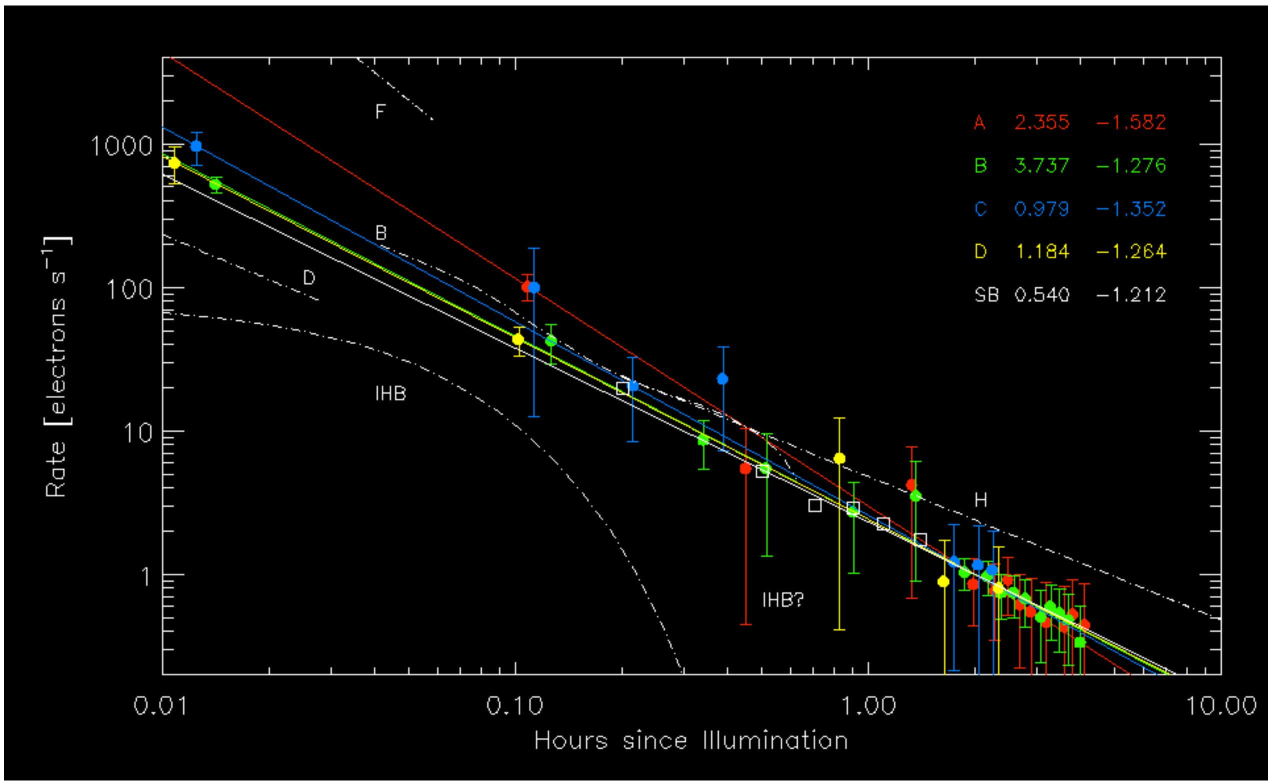
- Strongly saturated images, however, generate persistence effects that last for hours



Persistence response to 100x FW flat-field in DCL characterization; power-law falloff as time$^{-1.0}$; still detectable above baseline rate after 10 hours.

Persistence (3)

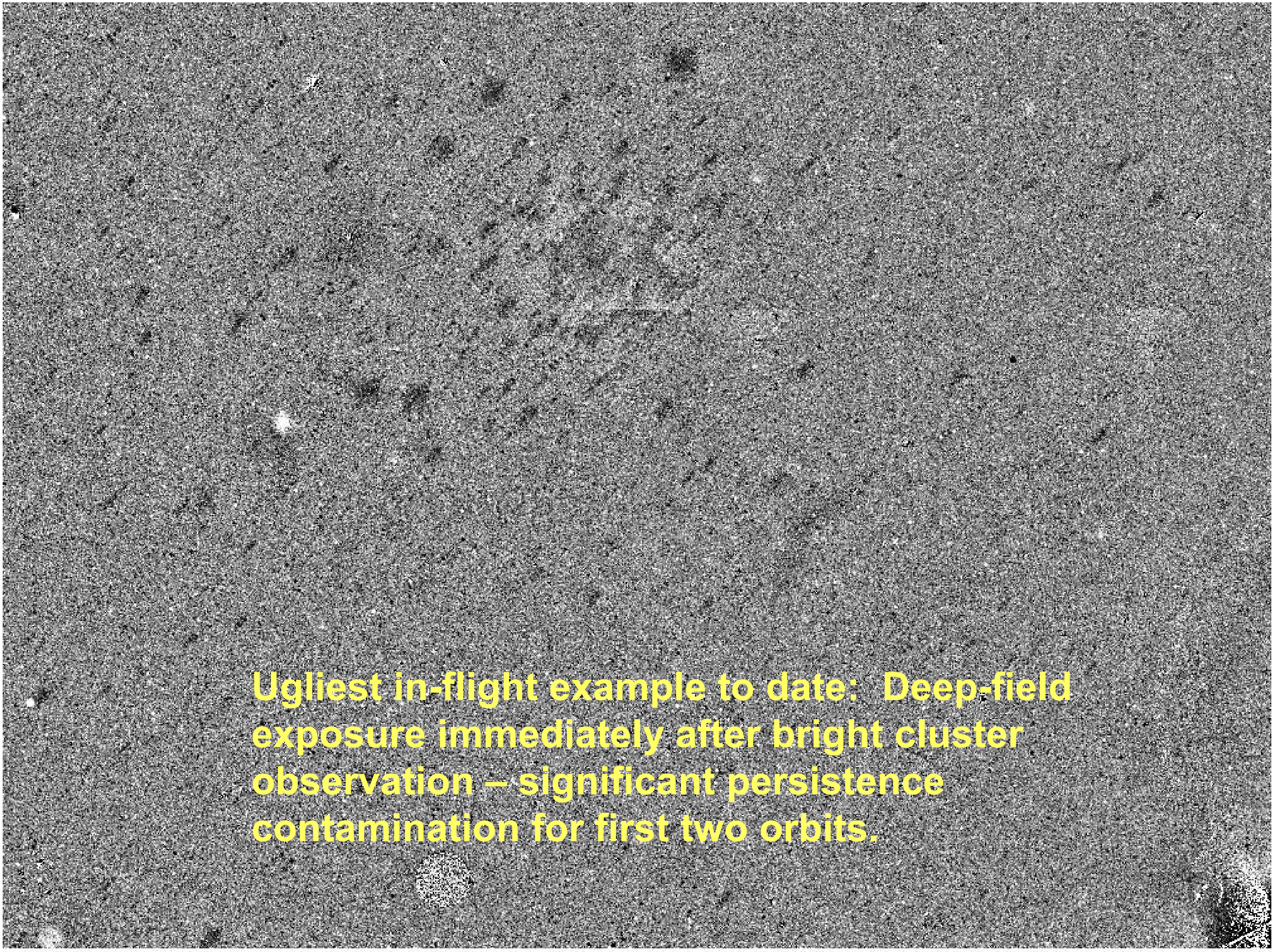
- Persistence response to small spots, observed in thermal-vac, appears to have a slightly steeper decline with time than the response to flats, but can still generate effects lasting hours

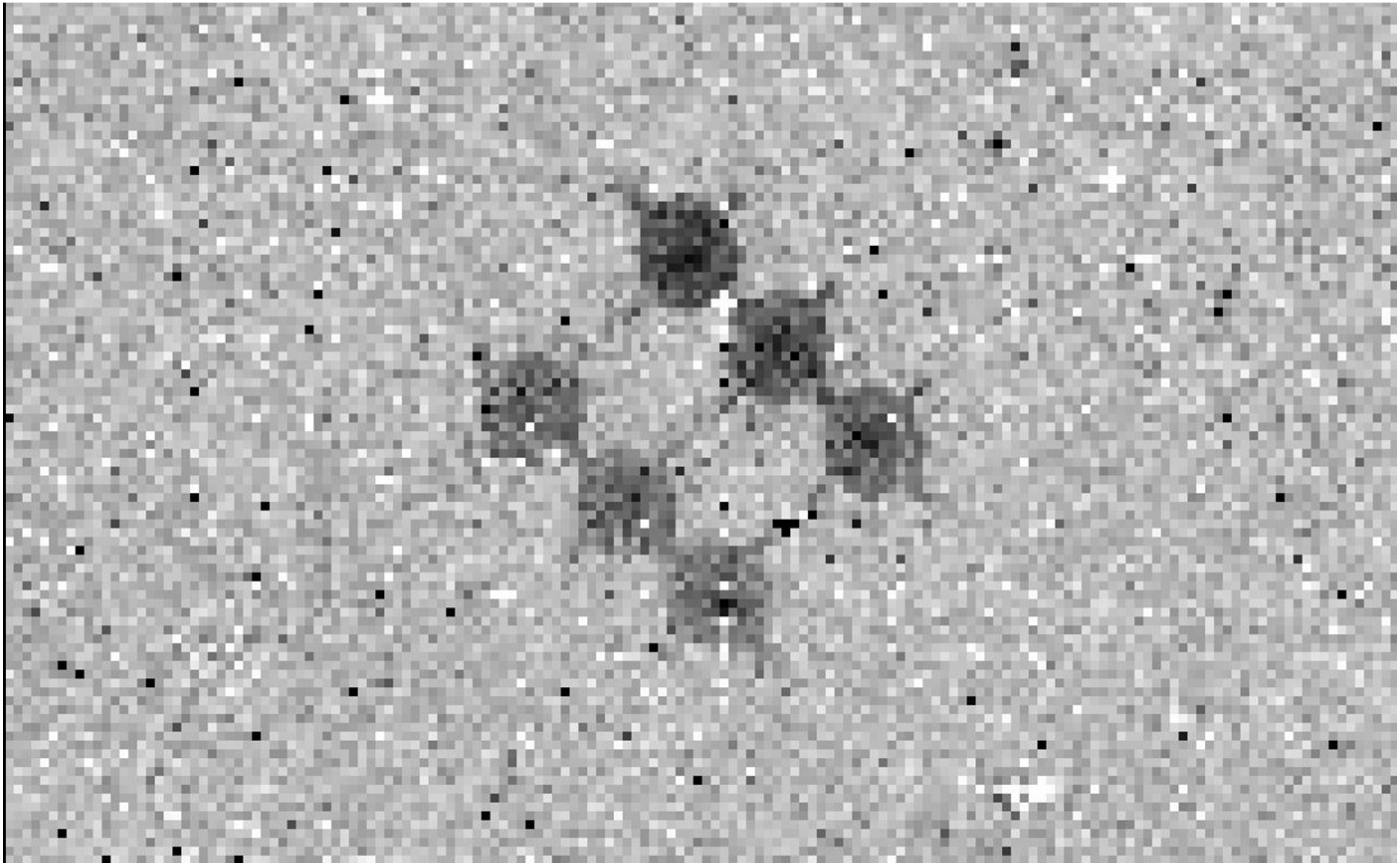


Ignore absolute scaling (which is per spot, not per pixel), but note general power-law drop with time.

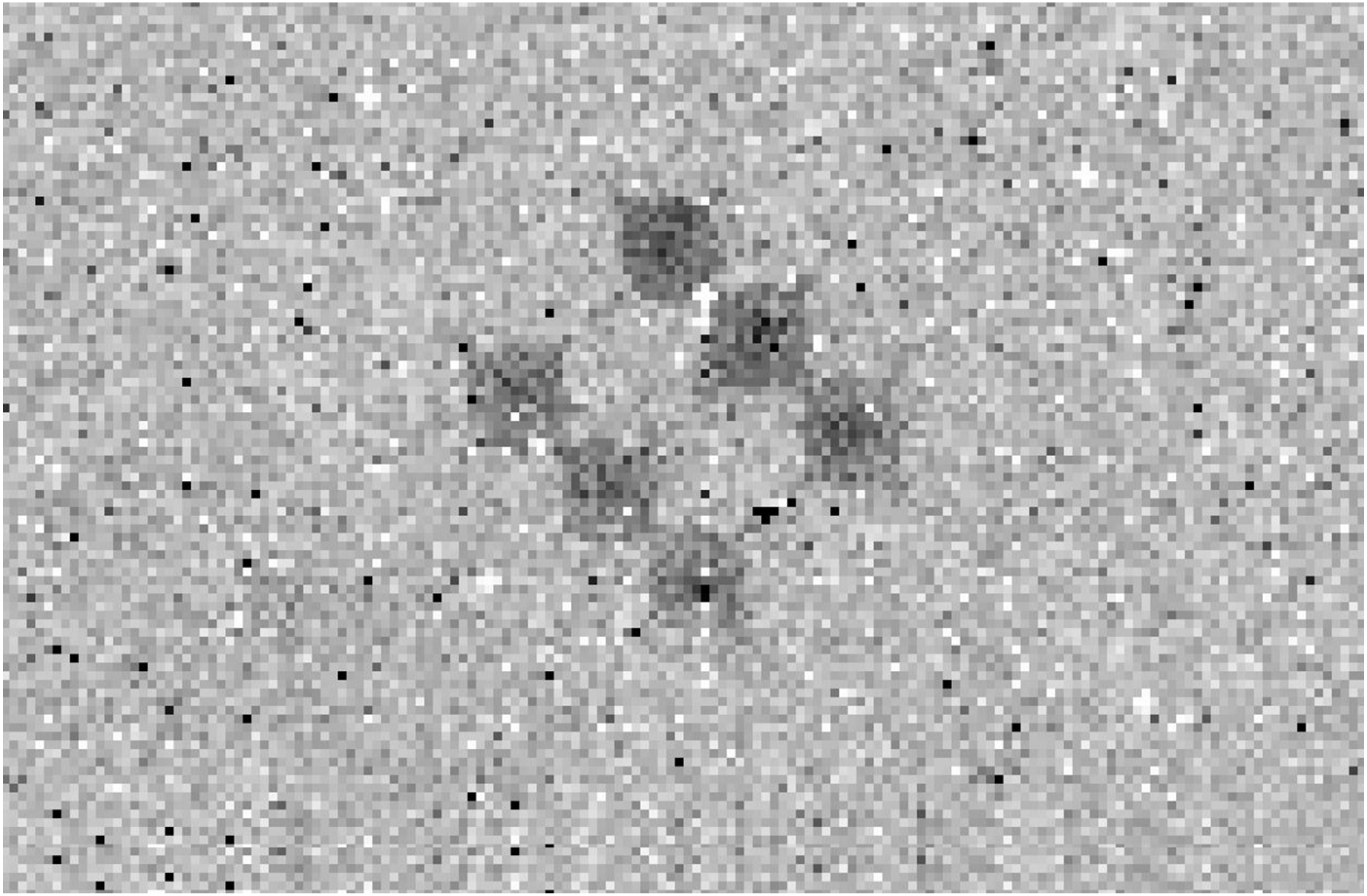
Saturated spot persistence rate is reasonably well approximated by:

0.15 e/pix/s x t(hrs)$^{-1.25}$

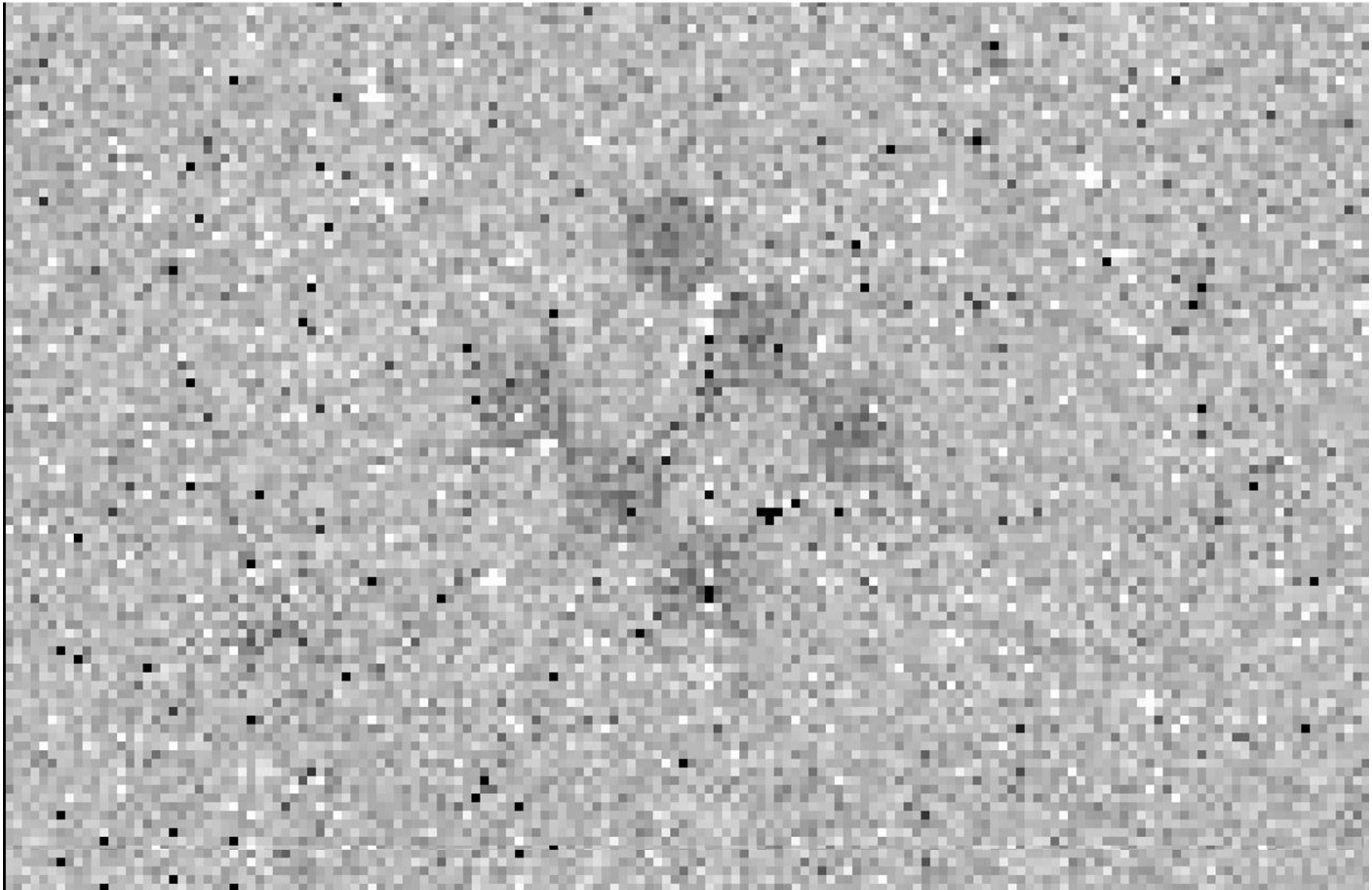

Ugliest in-flight example to date: Deep-field
exposure immediately after bright cluster
observation – significant persistence
contamination for first two orbits.



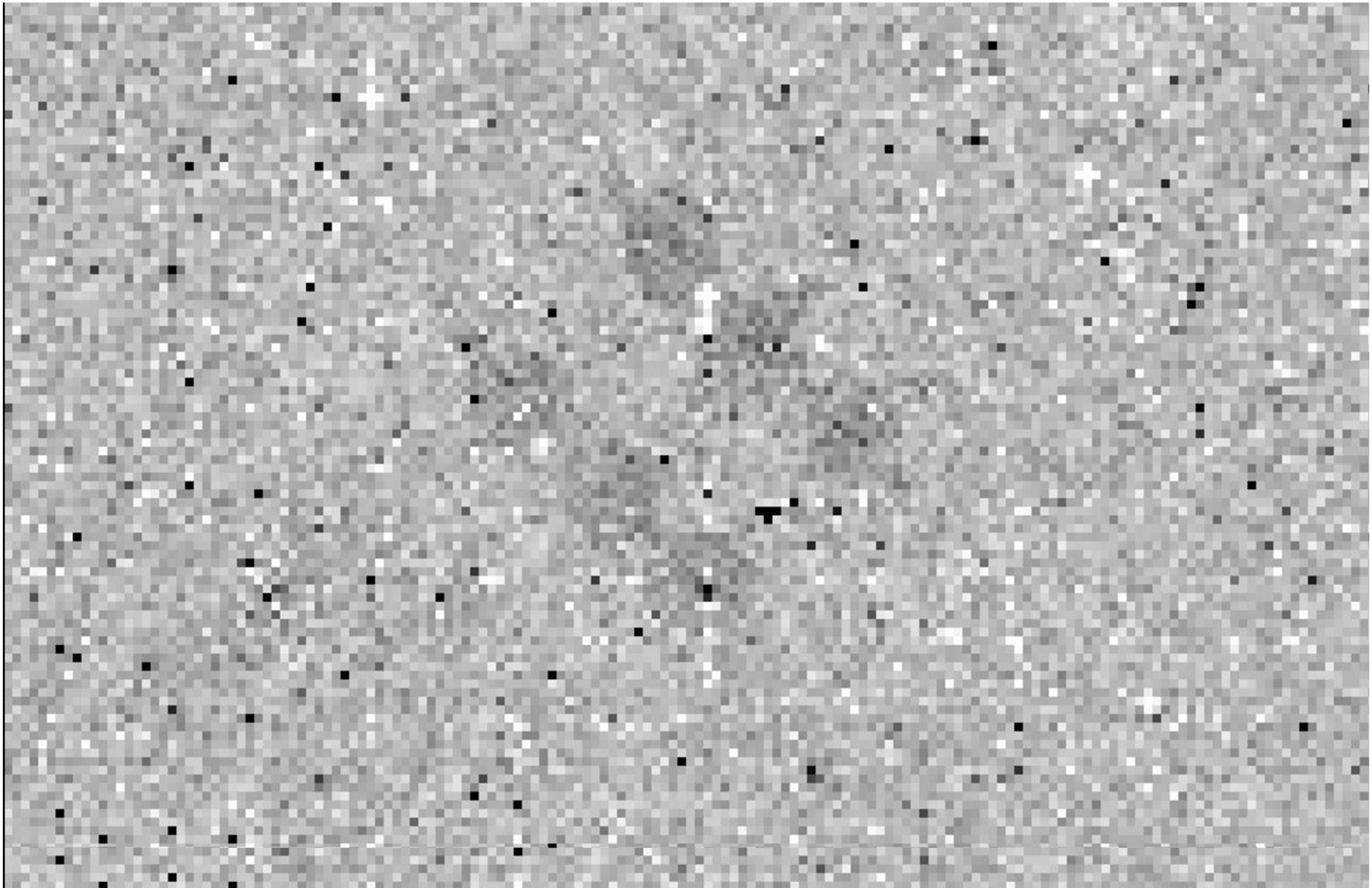
Latent star images



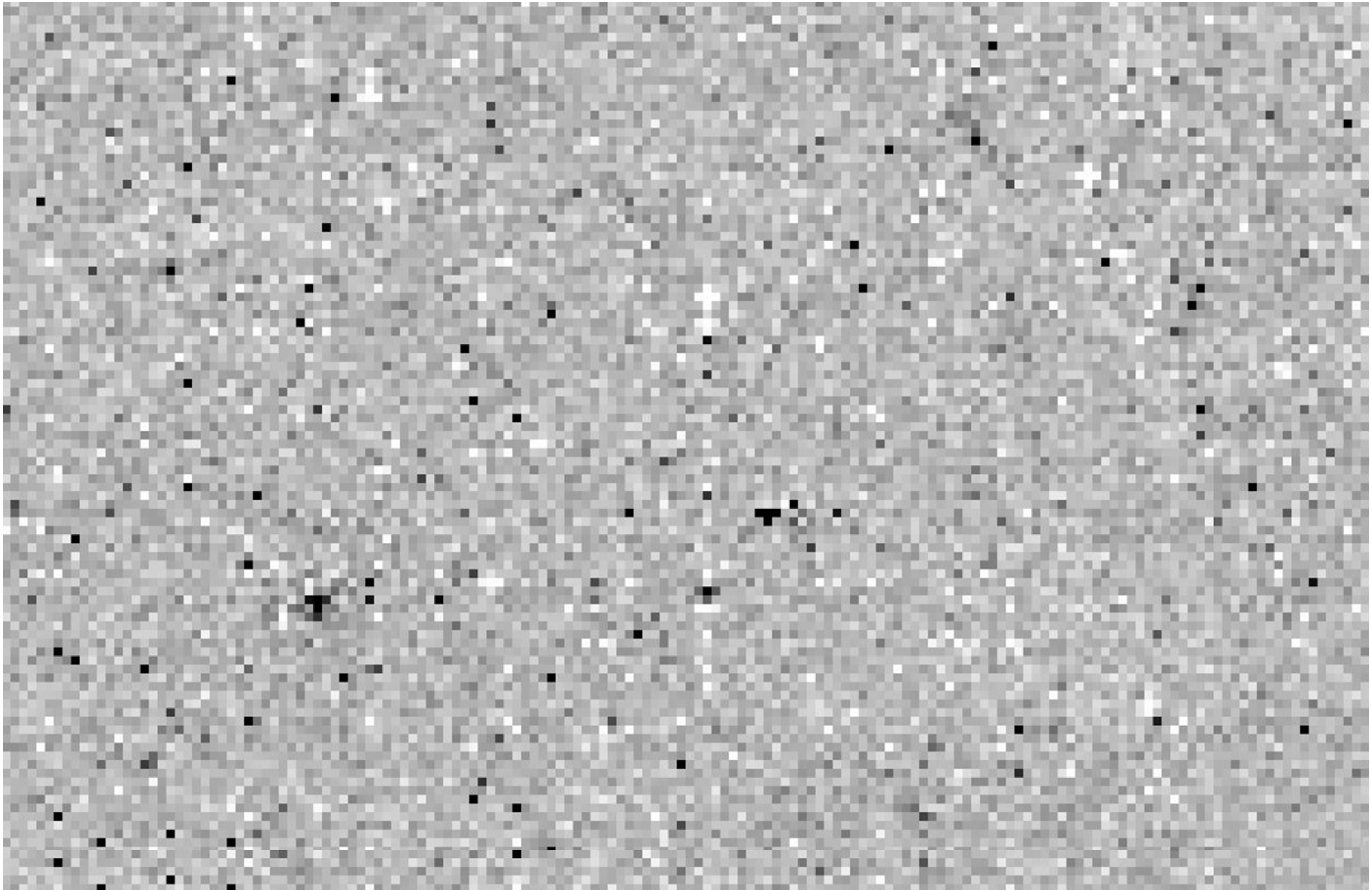
Latent star images



Latent star images



Latent star images



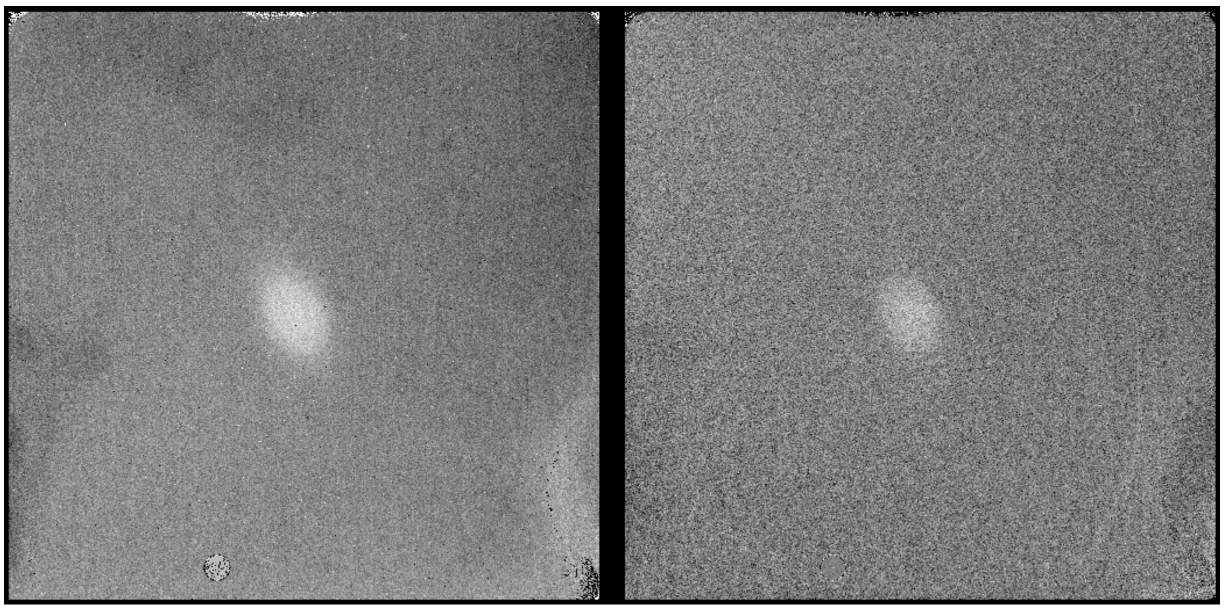
Next Visit…

Persistence (conclusion)

- Image persistence likely to be the biggest complication in the use of the WFC3 IR channel
  - Cycle 17 calibration program will better quantify in-flight behavior
  - Careful planning of one's own observations will help to mitigate the effects
    - Dithering is extremely important for separating effects that are fixed in detector space from real signal (and beneficial for cosmetics too)
    - More darks for tracking state of detector might be useful – within data storage/transmission limits of the telescope
- STScI has screened Cycle 17 proposals with POSS & 2MASS BOT
  - Over 50% have targets >10x full well (general screen impractical)
  - ~10 worst cases identified and being manually scheduled
- Started effort to consider means of information transfer between observations
- Additional complication: FPA exposure not equal to Exptime
  - Consequence of not having a shutter

After-Image Effects: QEH+ (?)

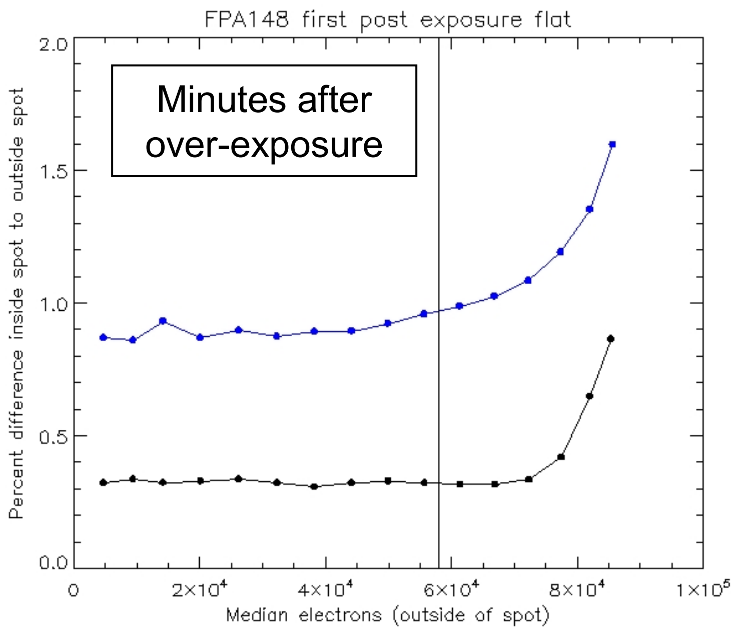
- ~30 minutes after bright galaxy exposure, flat-field exposures showed enhanced signal in saturated region of the earlier exposure; *excess too large to be accounted for by the expected additive persistence*

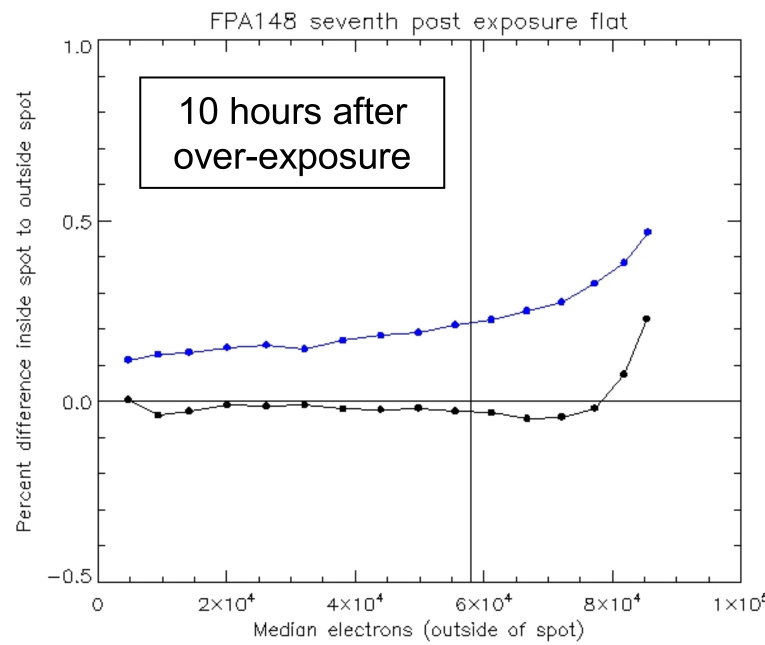


- Further examination: the strongest enhancement (2.5%) seen only in the last saturated reads of the flat-field ramps
- Below nominal full-well, contrast is still present but significantly smaller (0.6-0.8%)

QEH+ (2)

- DCL measurements on flight spares confirm the same basic behavior (plots track after-effects of 20xFW and 2xFW spots)

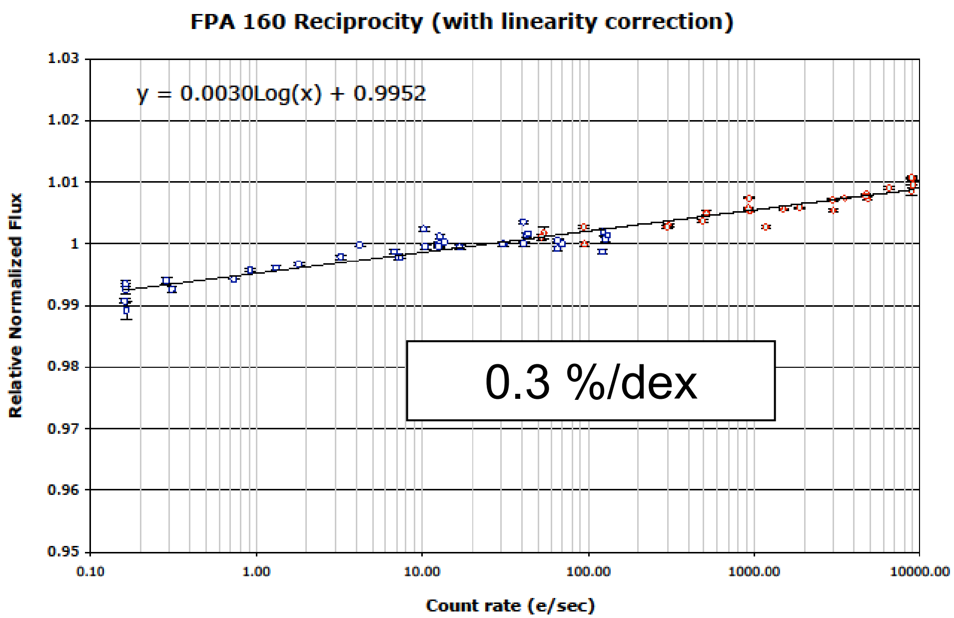


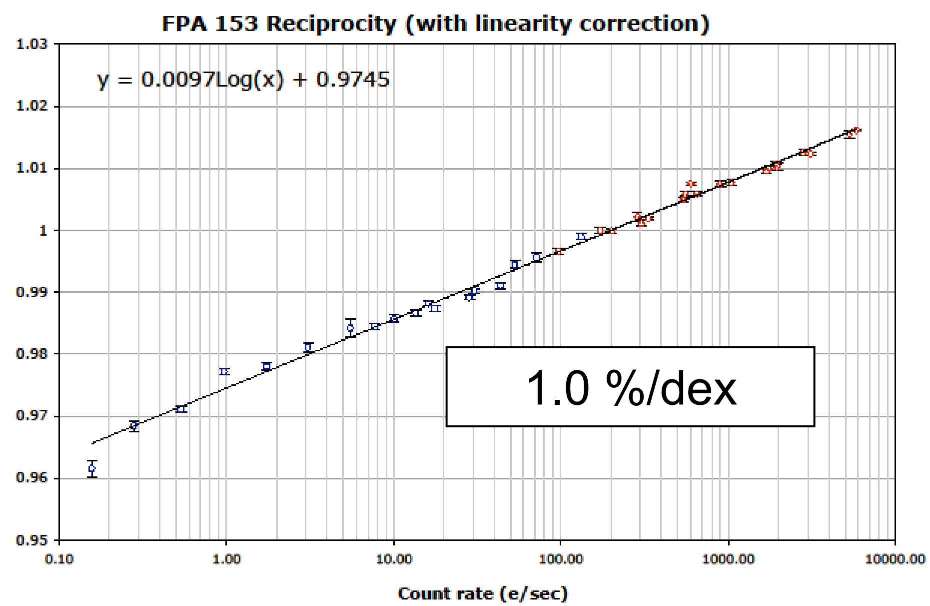


- Again, sub-1% effects below full well, rising above full well
- After persistence correction, initial additional excess is ~0.5%
- Excess response/change in linearity lasts for hours

Rate-Dependent Non-Linearity

- Have been investigating the issue of rate-dependent non-linearity, aka reciprocity failure
- For NICMOS, effect is 3-6 %/dex decline in response at lower count rates, with the steeper behavior at shorter wavelengths
- WFC3 flight spares measured at 0.3, 0.4, 1.0 %/dex





Rate-Dependent Non-Linearity (2)

- Adam Riess has done a very preliminary analysis of this behavior in the flight array
- Compares WFC3 photometry to NIC2 photometry on same fields
  - Relatively limited dynamic range and color range
- *Assuming that the NIC2 non-linearity calibration is accurate:*
- Yields ~1.1 %/dex for WFC3 flight array
- Will attempt to calibrate WFC3 independently in Cycle 17 by doing repeat photometry of the same sources with varying background

Snowballs

- JWST program identified a class of detector events with sudden large signals (FW, >>10^5 e- total) and circular morphologies that they dubbed "snowballs" – hypothesized source is radioactivity in detector structure
- WFC3 devices show analogous events, typically with smaller diameter, at a generally lower rate than the JWST arrays
- FPA165 snowball rate was <u>0.4-0.7 events/hr</u> on the ground over the full 1Mpixel array
- <u>Flight rate appears slightly enhanced</u>; have seen excursions to 2.5-3 events/hr; no obvious trend with time – recent weeks have been back at 0.7 events/hr
- Will continue to track trend in flight
- Note that radiation test parts (2) from this lot showed no enhancement in snowball rate after 5 yr dose of 60 MeV protons
  - Those test devices had lower than typical snowball rates to start

Summary

- WFC3's science program is off to a very exciting start, in large part due to the fine performance of its flight detectors
  - e.g. high-z galaxy detection, Cepheid calibration at 40x previously achievable rate, studies of star formation in the nearby universe
- Nonetheless, we need to continue to learn how to deal with the subtleties of the detector behaviors, particularly in the IR channel, both operationally and in data analysis, to extract the most accurate quantitative results
- Continued work with the Servicing Mission Orbital Verification data, as well as the Cycle 17 Calibration Program, will support that goal
- Follow STScI's WFC3 web site: www.stsci.edu/hst/wfc3 for news and Instrument Science Reports on these topics