pointing camera calibrations and initial reductions

Aaron Meisner, Behzad Abareshi, Arjun Dey

background info

- Everything currently in this document refers to the “El Nino” pointing camera
  - “pointing camera” is the term I use, but other terms I’ve seen on-list or in DocDB are “top ring imager” and “Mayall startracker”
- Behzad is setting up a second pointing camera called “La Nina”, planning to have both operational in the future
- El Nino has two operating modes
  - Video mode - useful visual tool for OA’s and observers
  - Astrometry mode - longer exposures typically saved unbinned
- We have 20,000+ archival El Nino astrometry mode pointing camera images (3/2019-3/2020), which I have been using as a testbed data set for analysis scripting, calibration studies, and GFA comparisons
- Goals include monitoring transparency and sky brightness throughout the DESI field of view
  - Potentially also flagging satellite streaks during DESI exposures

background info

components summary from David Schlegel's [desi-commiss 655]

Allied Vision Prosilica GT3300 4/3" Monochrome CCD Camera F-Mount Model Number GT 3300 B
Edmund Stock Number: 87-089
Zeiss 135mm f/2 Milvus ZF.2 Lens for Nikon F Mount DSLR Cameras Manufacturer Number: 2111-635
Zeiss 77mm Carl Zeiss T* UV Filter MFR # 1933-986

- pixel size: 5.5 μm x 5.5 μm
- max frame rate: 14.7 fps
- max exposure time: 26.8 seconds

see also Behzad's DESI-3709

exptime (ms)	# exp	# nights
1	1	1
20	6	1
100	6	2
200	41	5
250	38	3
300	31	2
400	532	23
500	276	4
600	1	1
750	29	1
800	504	10
1000	8817	18
1500	4465	2
2000	96	2
3000	5009	8
5000	238	14
10000	106	18
15000	16	7
20000	35	15
25000	2	2
26000	221	16

example raw El Nino astrometry mode image

7.9º x 5.9º field of view
3296 x 2472 pixels
8.65” pixels

20190328; observers B. Abareshi, A. Dey, D. Schlegel; 20 seconds; M44

calibrations summary

- We have one “bias” (1 ms, which is the minimum exposure time)
- We have another 3 dark images from that same night (20190519)
- This allowed me to make per quadrant measurements of the “bias” offsets, read noise, and dark current rates (no knowledge of temperature dependence, no investigation of spatial structure)
- Darks also allowed me to make a hot pixel mask
- Details of these initial non-sky calibration analyses are in the Appendix of this document

pixel-level detrending

- Raw astrometry mode images are already quite cosmetically clean to begin with
- Currently
  - subtract per-quadrant scalar offset representing the bias
  - subtract per-quadrant scalar offset representing the dark current
  - interpolate over hot pixels
- Possible future enhancements
  - account for spatial structure in bias and dark current
  - flat fielding

additional per-exposure analysis

- Centroid refinement of Gaia stars expected to be of sufficiently high S/N

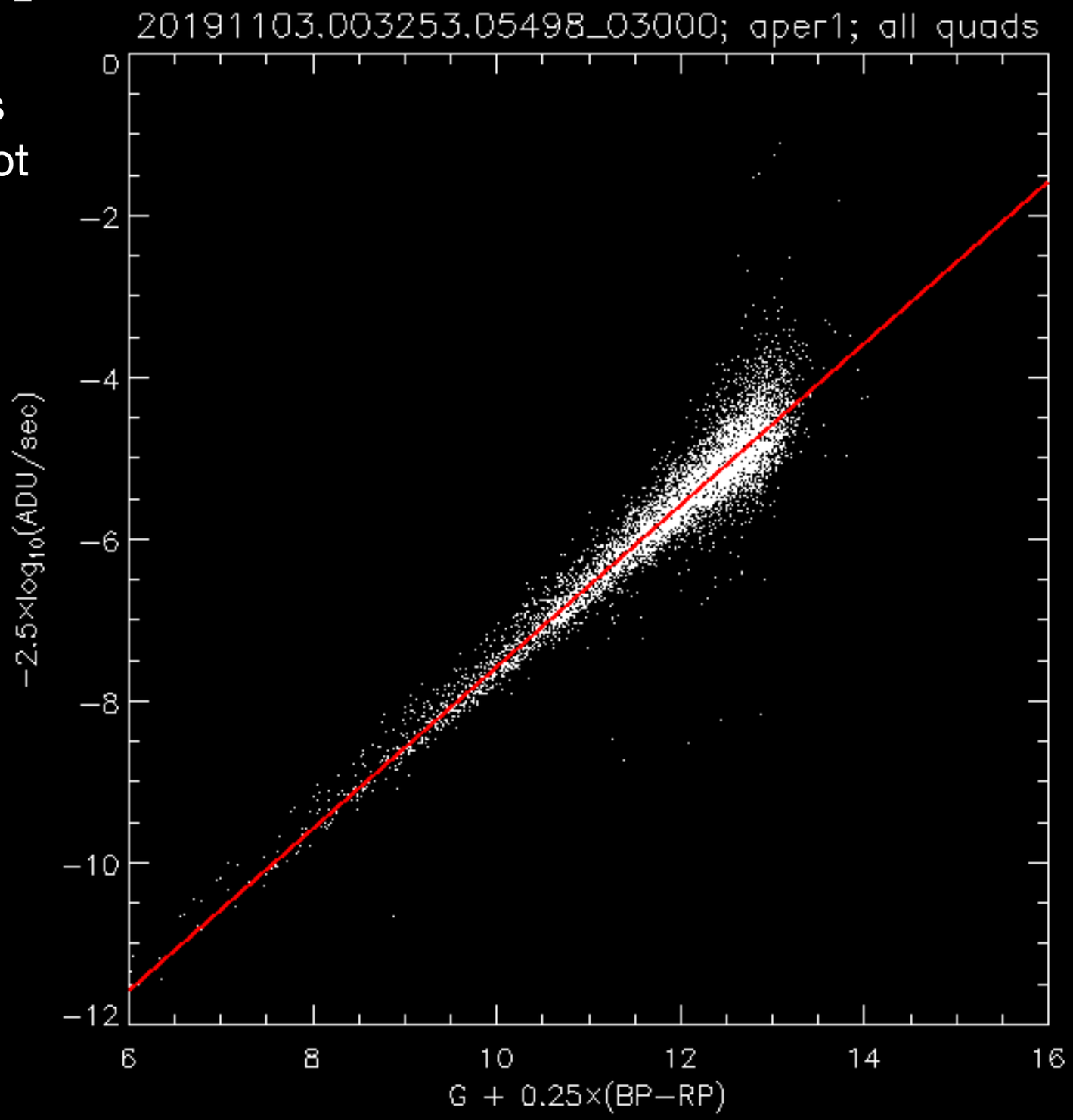
- Aperture photometry
    - Default aperture has 2.5 pixel radius (~21.6” radius)

- Full frame and per quadrant zeropoints, for seven different aperture size (2, 2.5, …, 5 pixel radii)

- Full frame and per quadrant sky levels currently based on simple median of pixel values after detrending

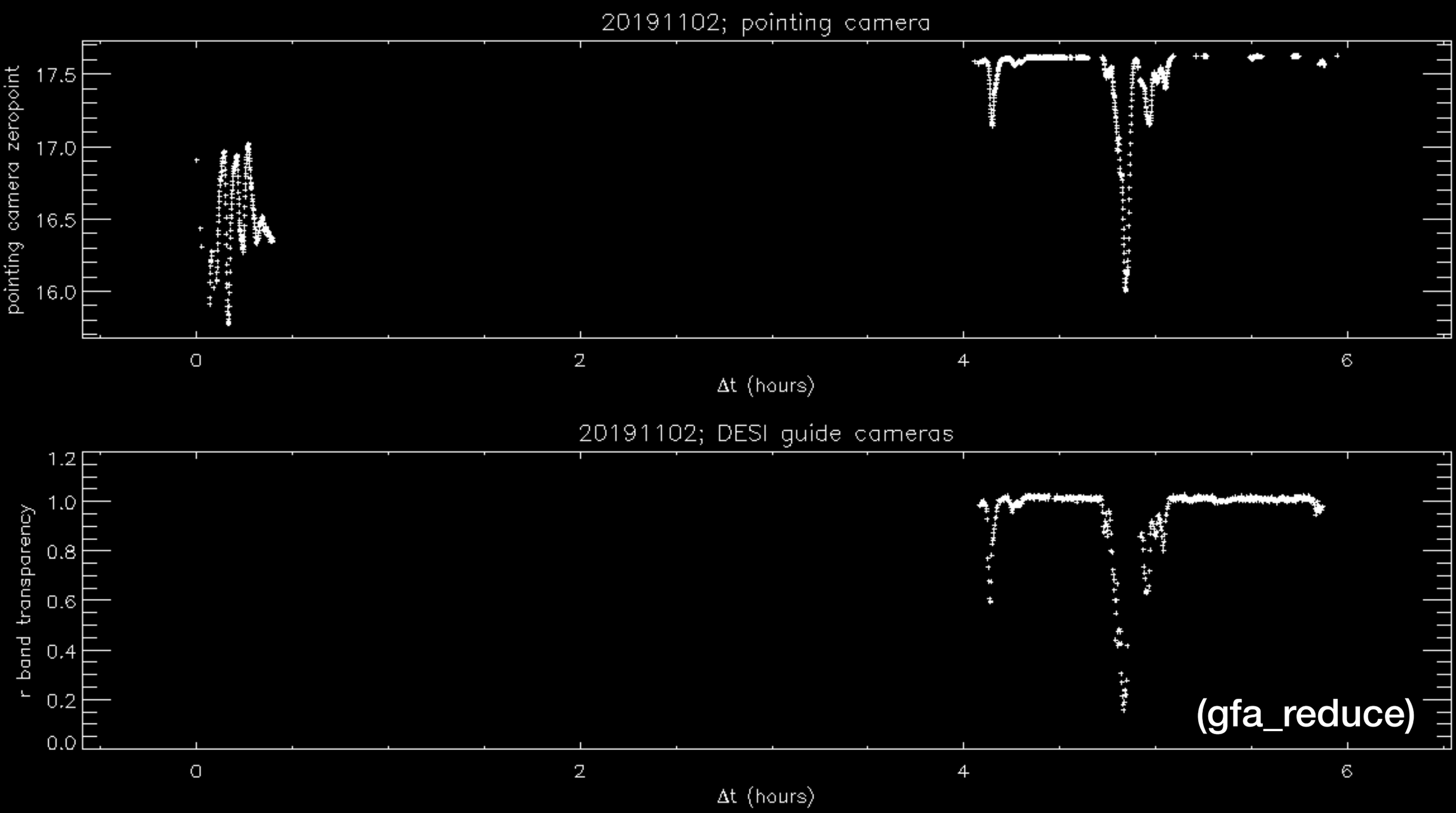
zeropoint measurement

pipeline produces
one such check plot
per exposure

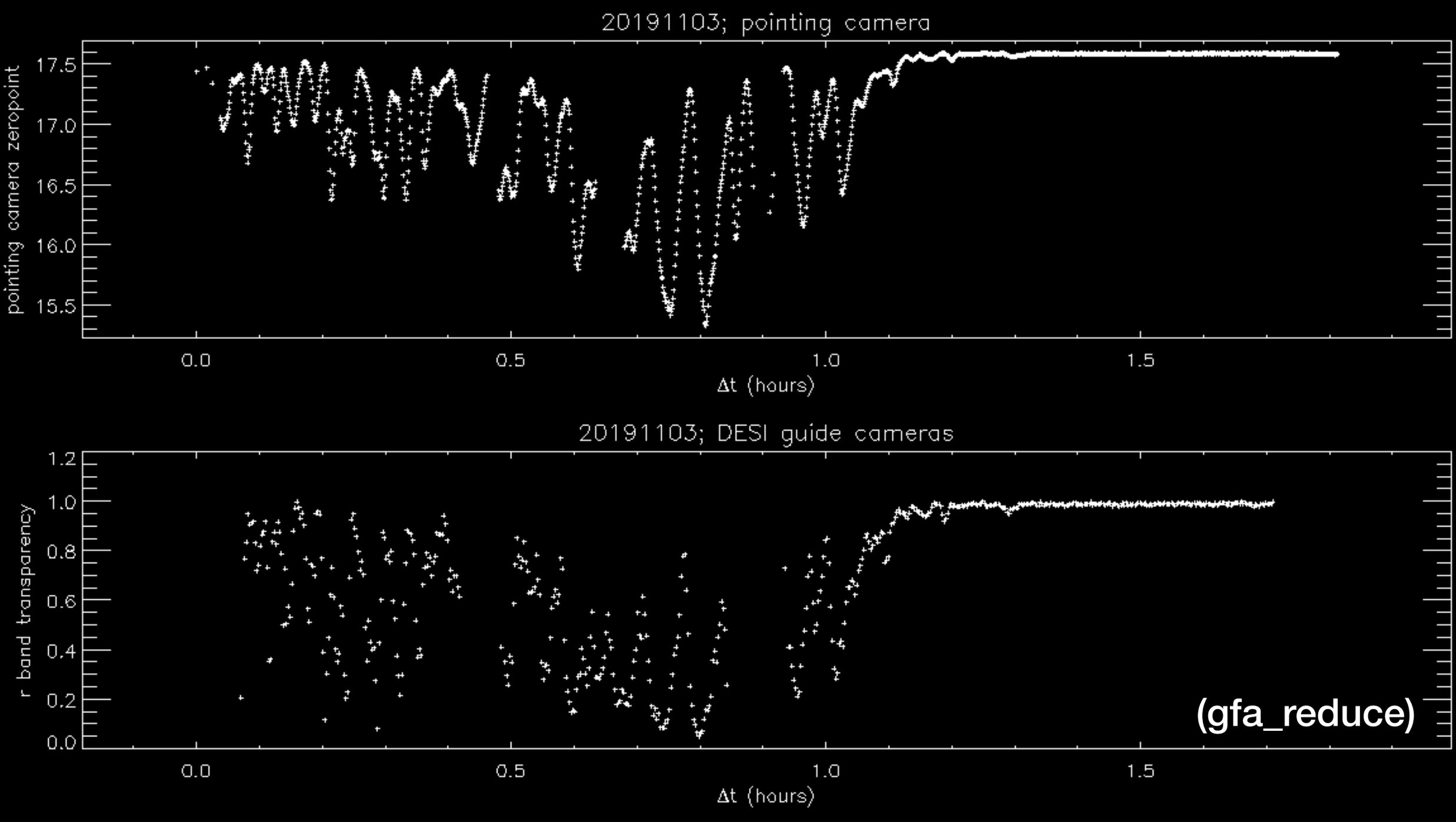


cf. David Schlegel's [desi-commiss 655]

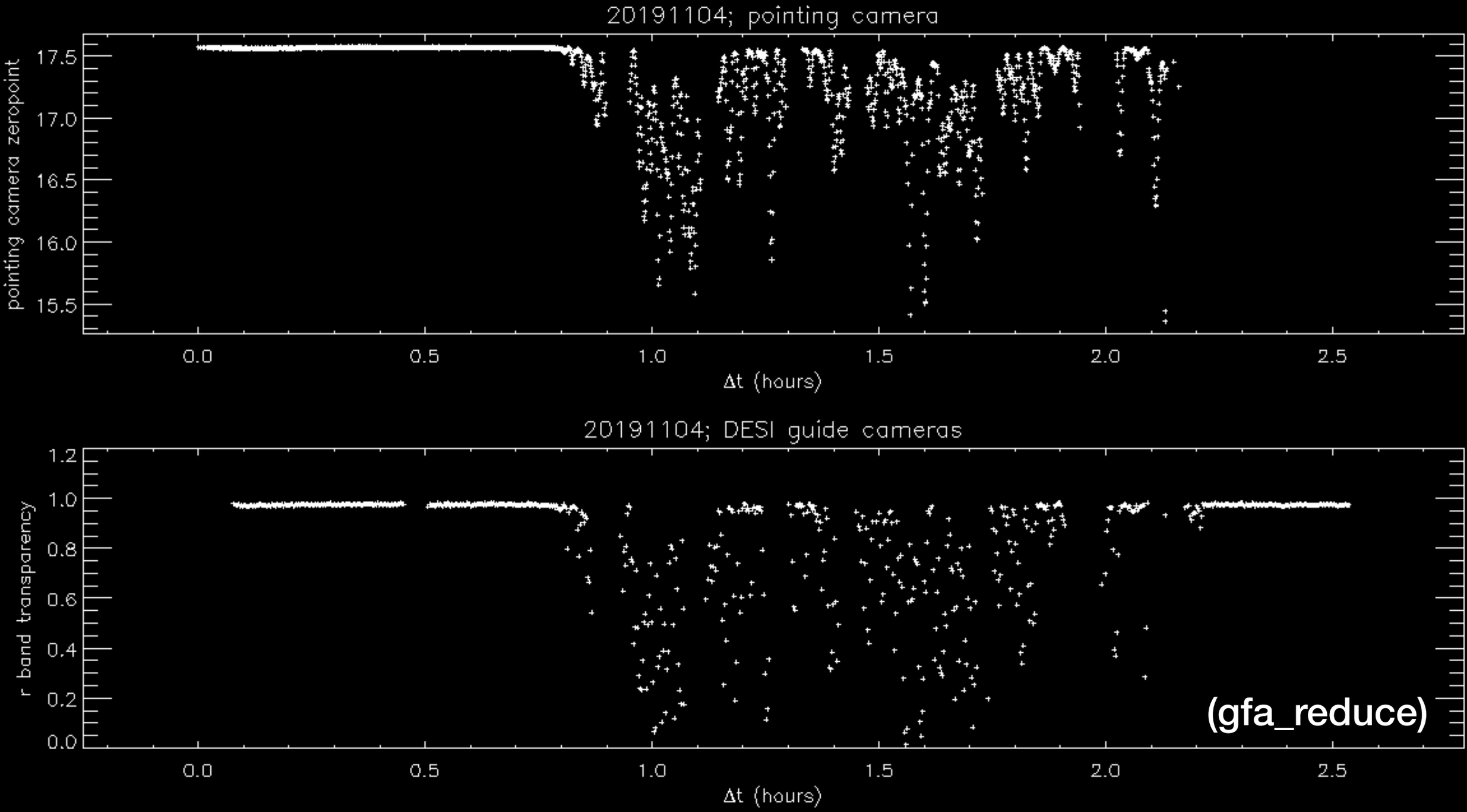
zeropoints/transparency ("good" examples)



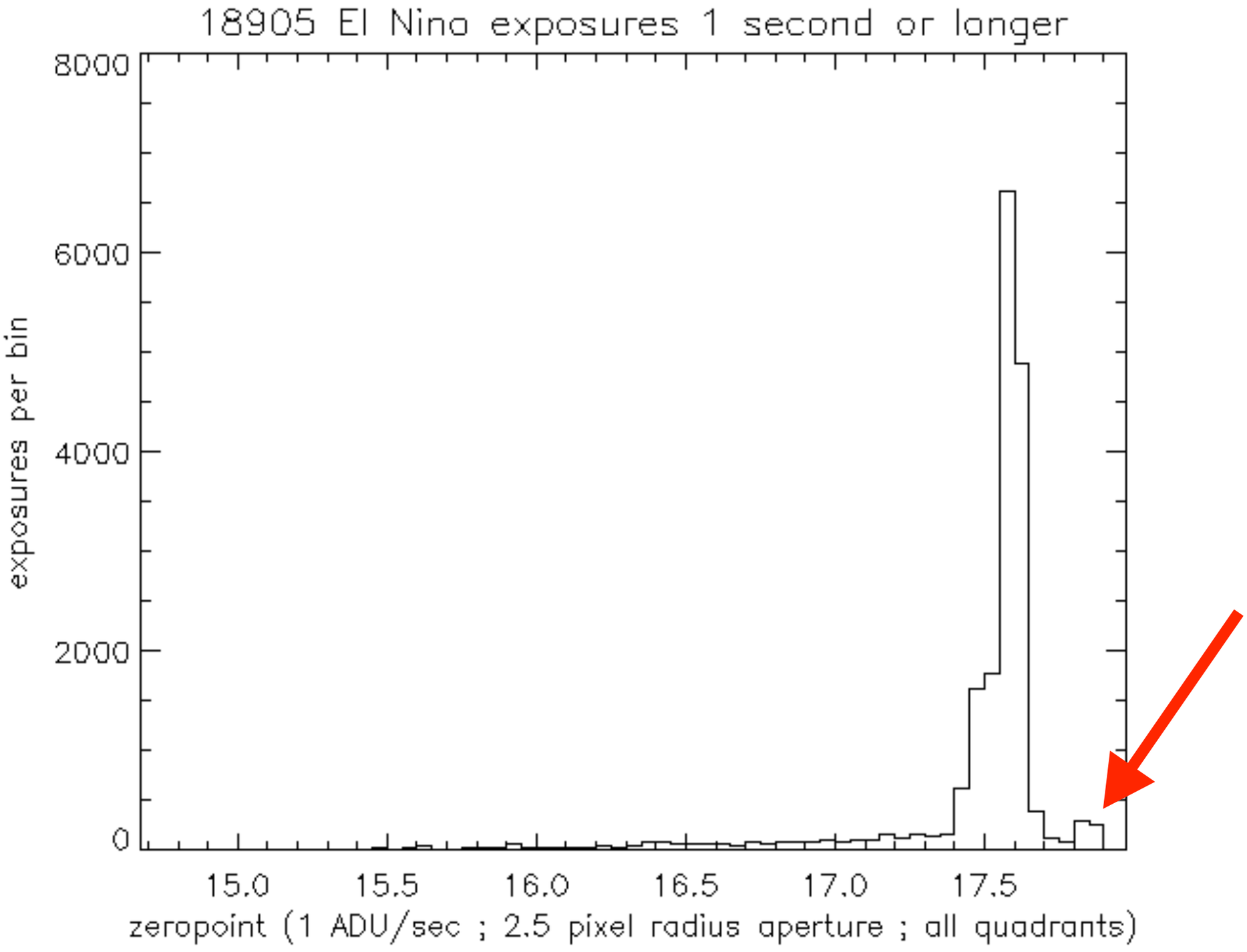
zeropoints/transparency ("good" examples)



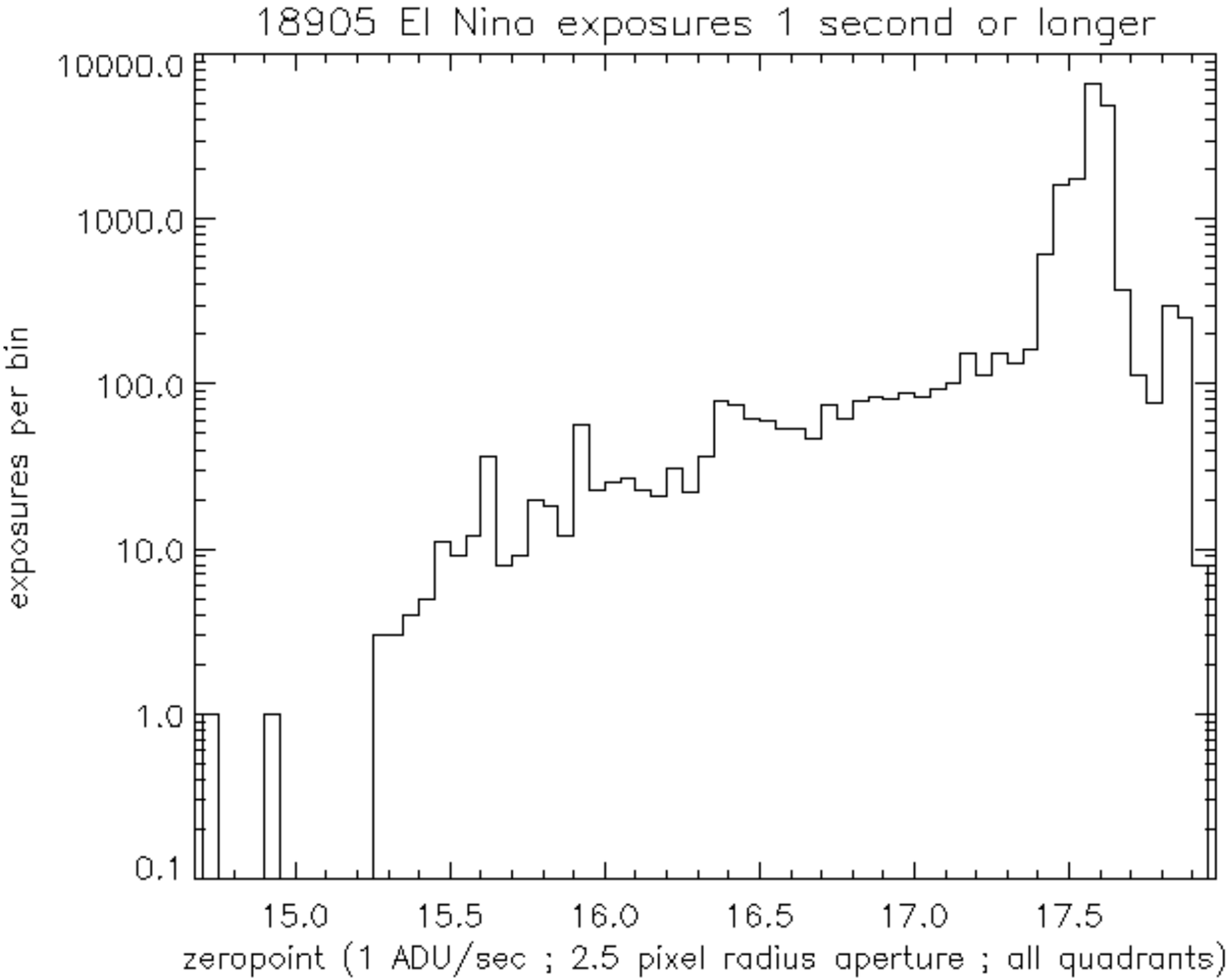
zeropoints/transparency ("good" examples)



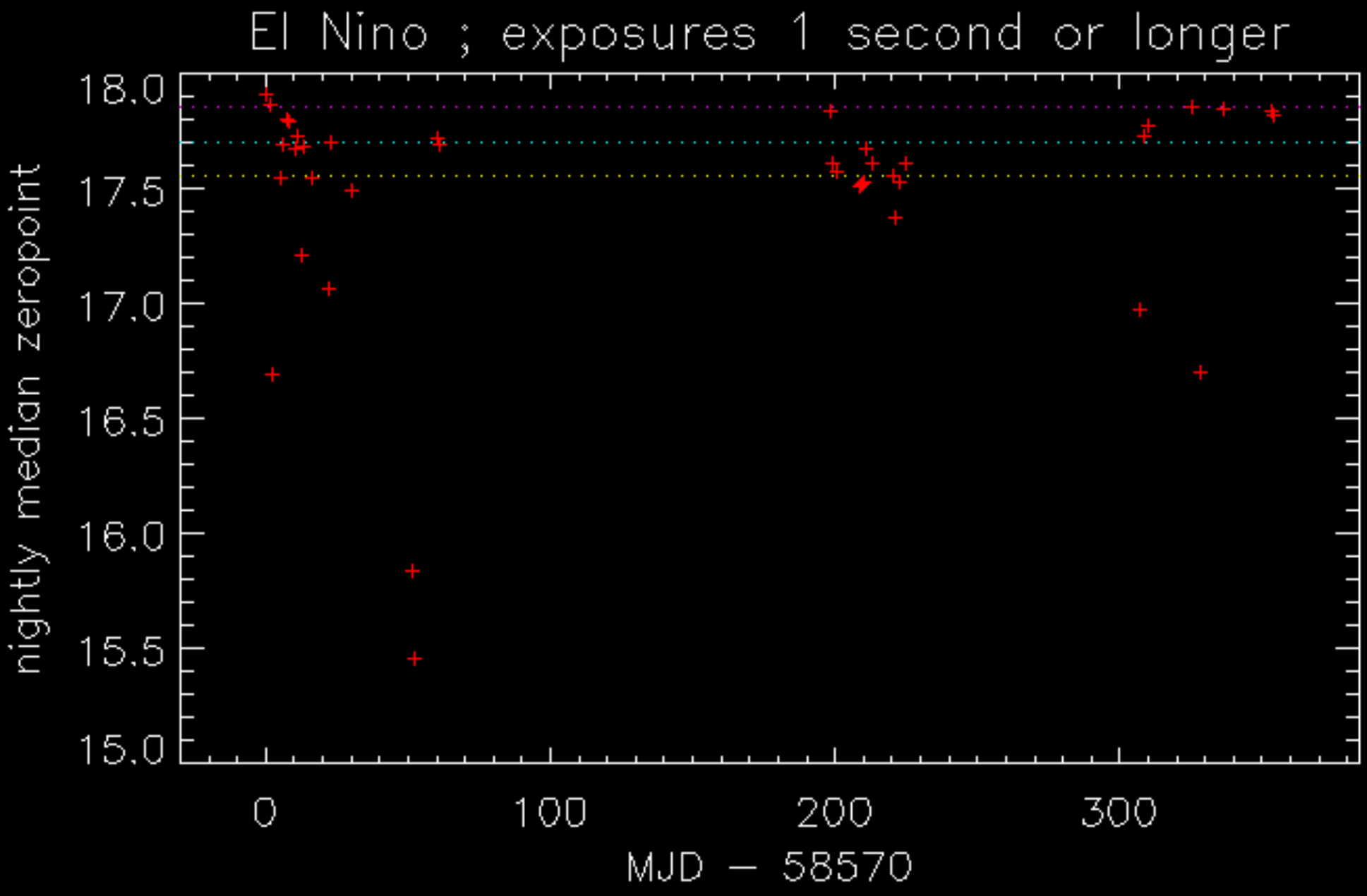
Variation of the zeropoint?



Variation of the zeropoint?

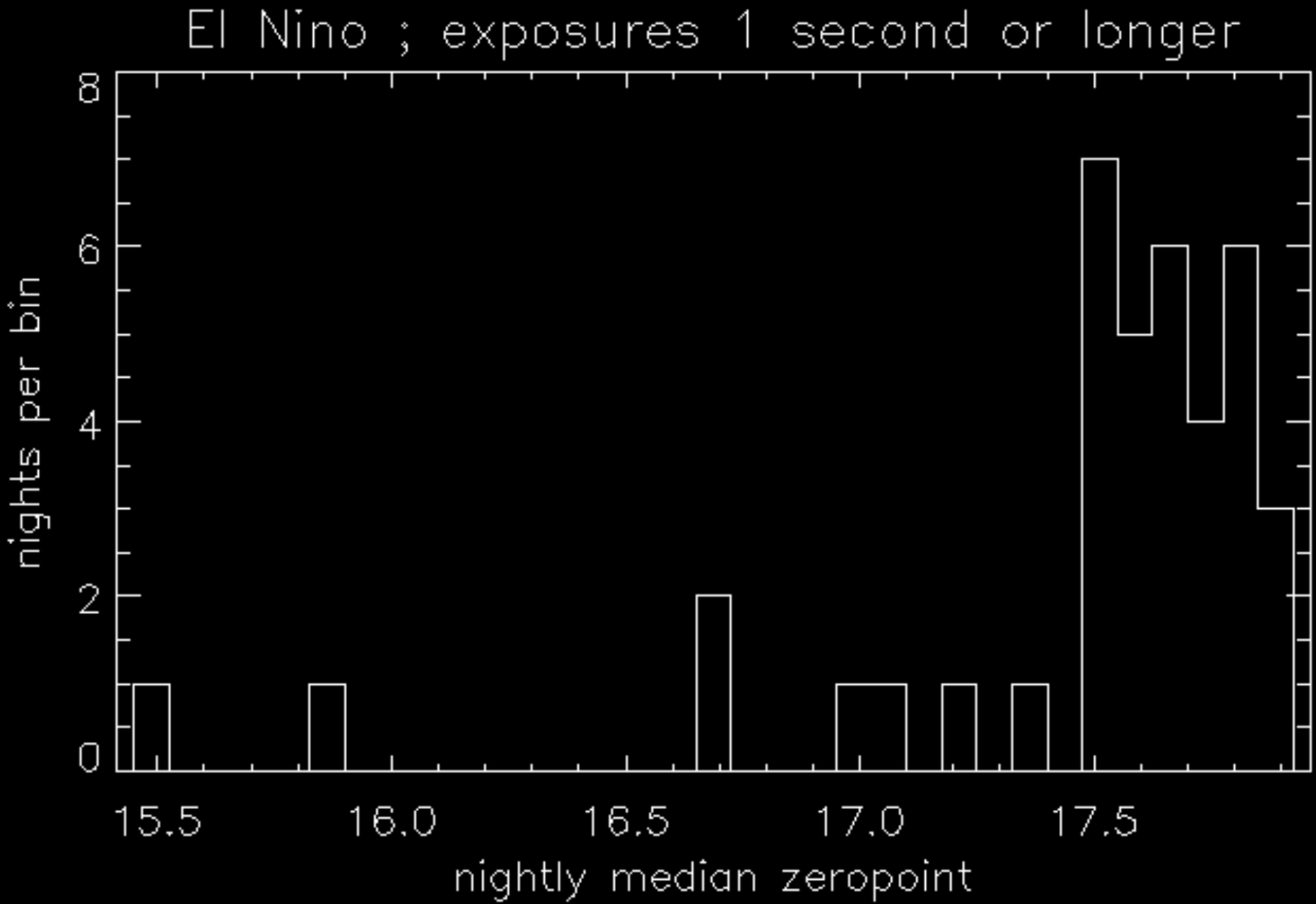


Variation of the zeropoint?



nightly median zero point

Variation of the zeropoint?



20191102

pointing camera sky brightness

−1.6
−1.8
−2.0
−2.2
−2.4
−2.6
−2.8

−0.1
0.0
0.1
0.2
0.3

Δt (hours)

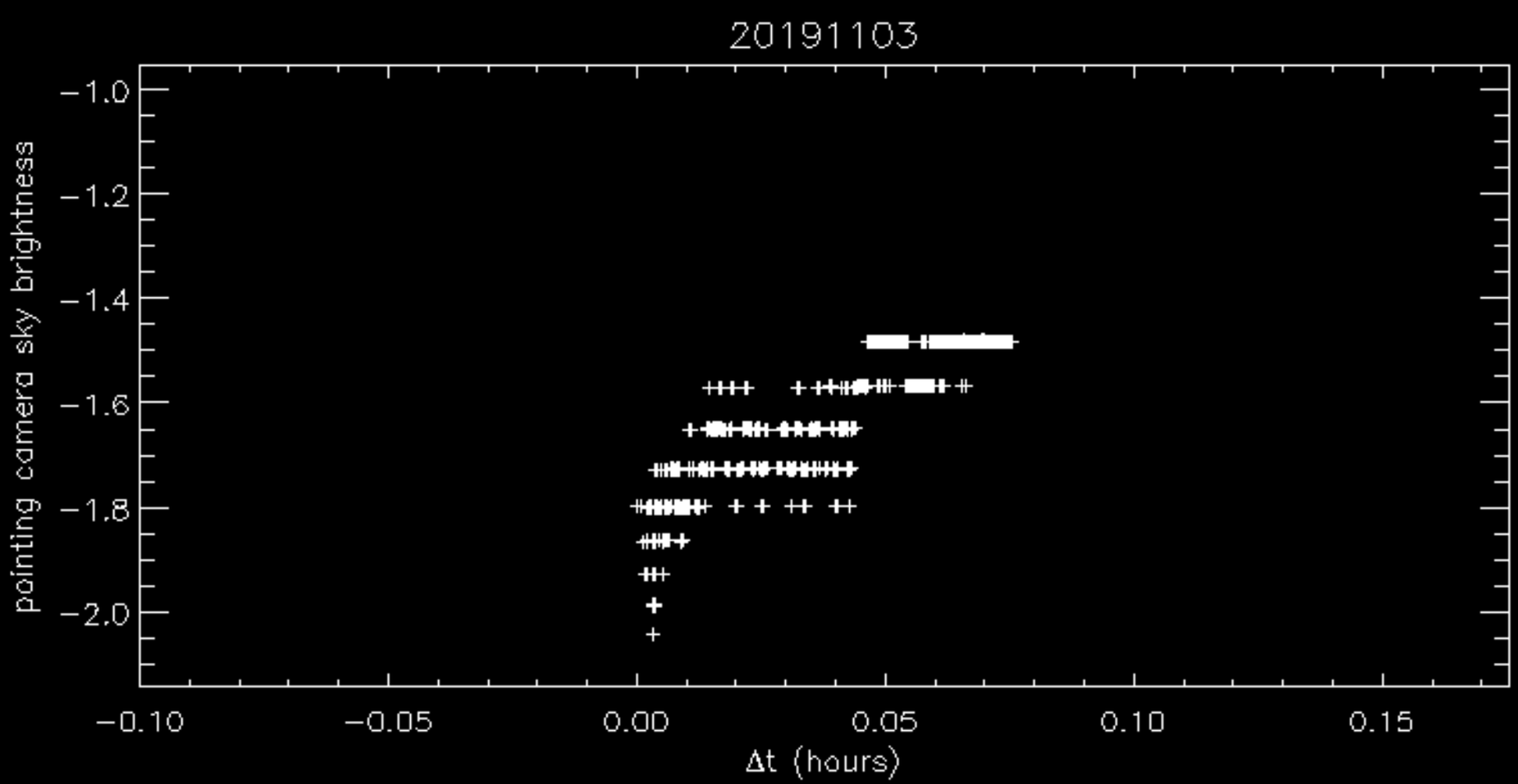
sky brightness
(gfa_reduce)

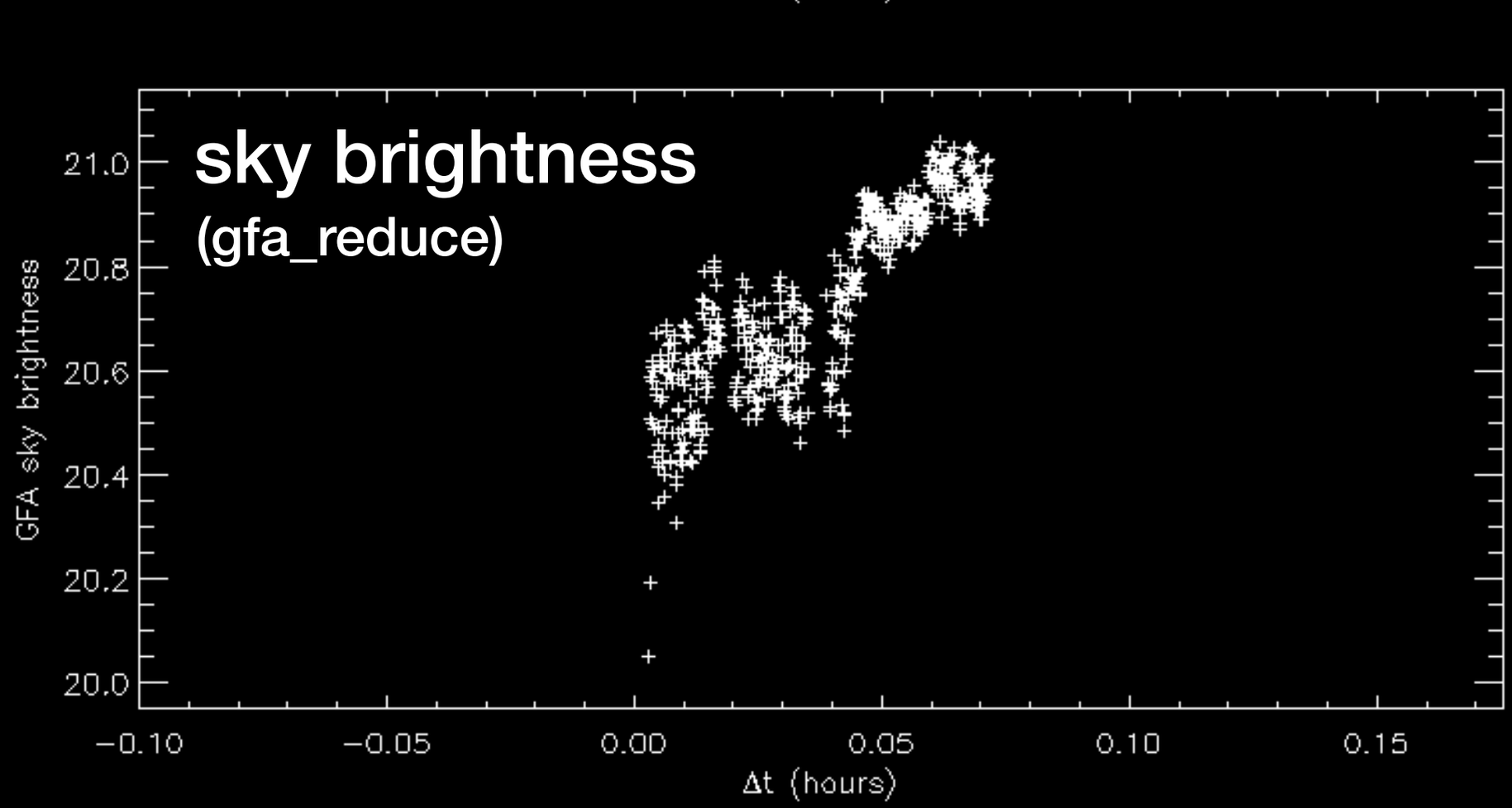
GFA sky brightness

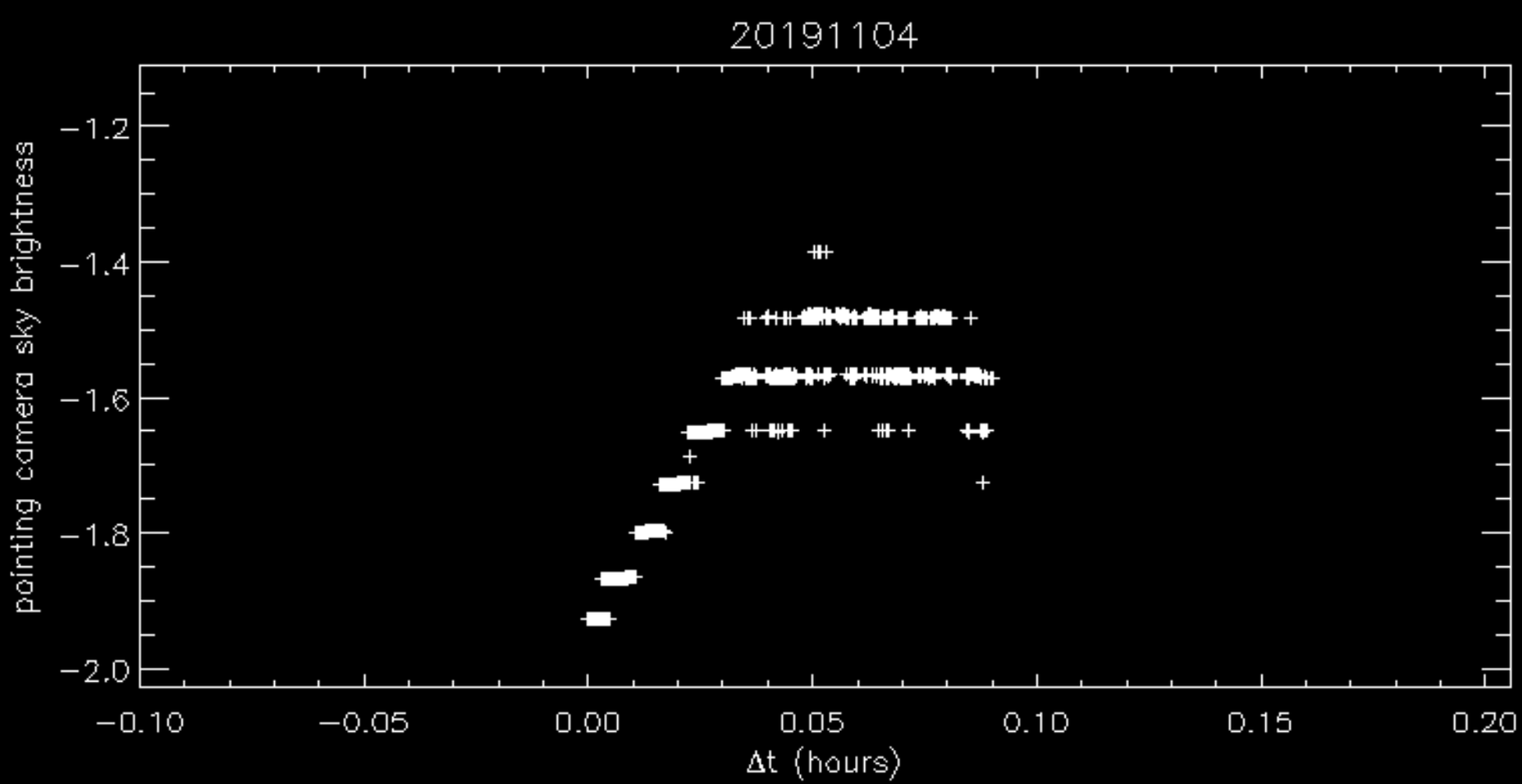
21.4
21.2
21.0
20.8
20.6
20.4

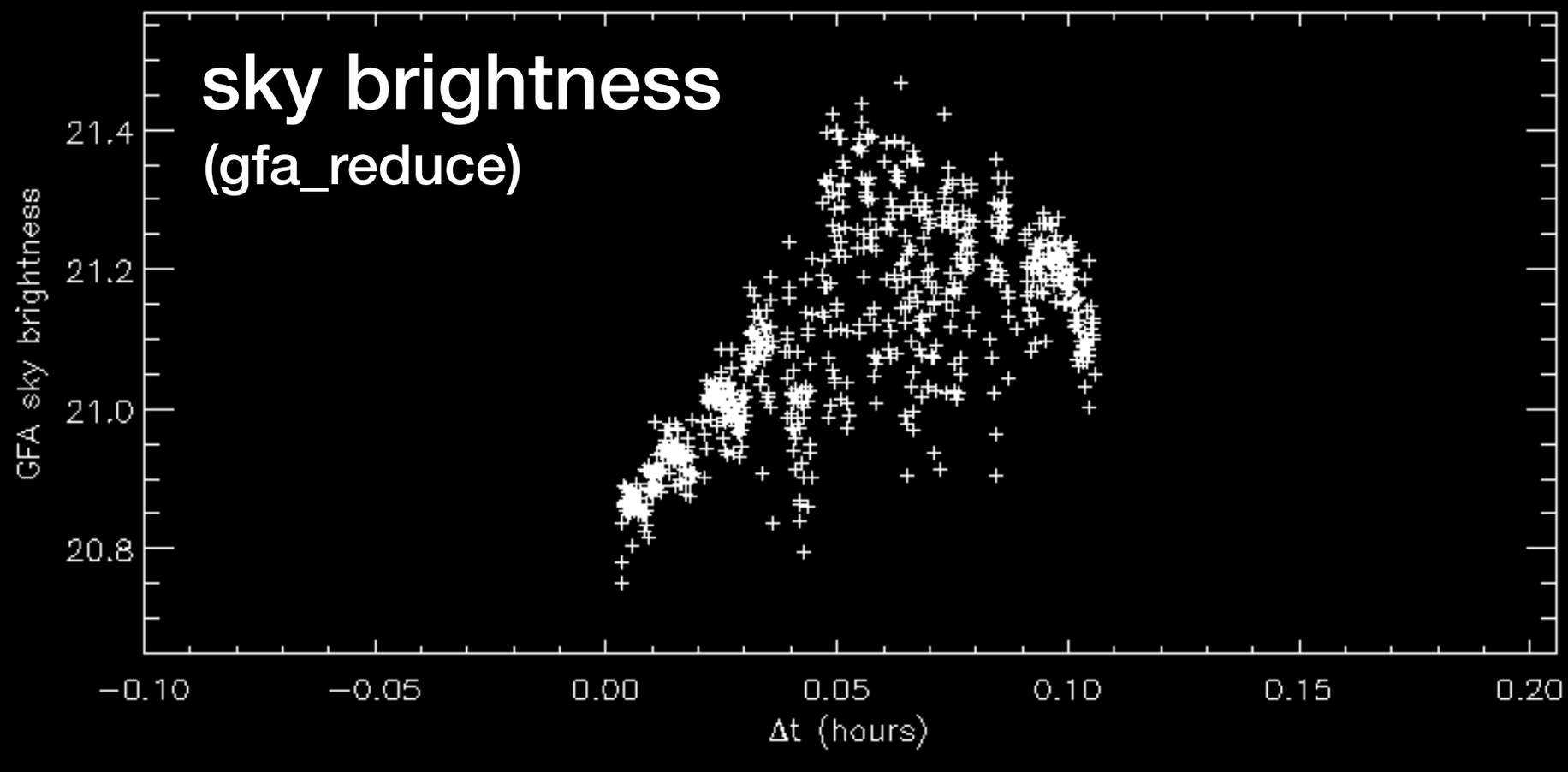
−0.1
0.0
0.1
0.2
0.3

Δt (hours)

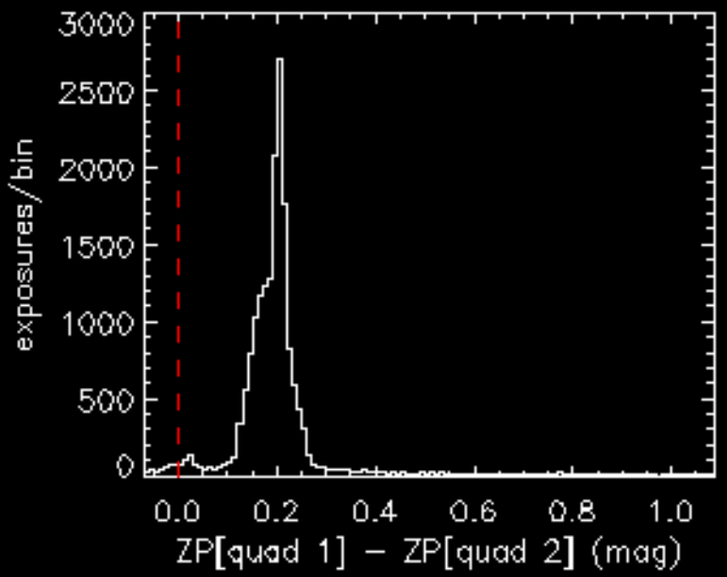

20191103
pointing camera sky brightness
−1.0
−1.2
−1.4
−1.6
−1.8
−2.0
−0.10
−0.05
0.00
0.05
0.10
0.15
Δt (hours)

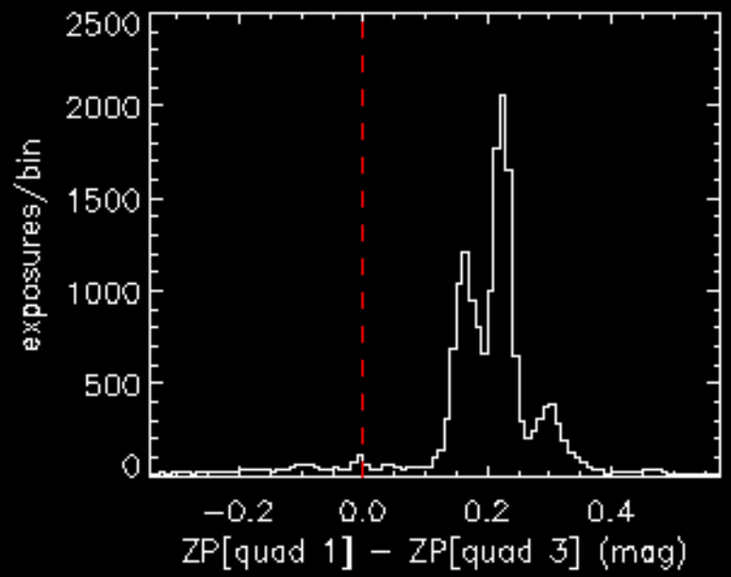

sky brightness
(gfa_reduce)
GFA sky brightness
21.0
20.8
20.6
20.4
20.2
20.0
−0.10
−0.05
0.00
0.05
0.10
0.15
Δt (hours)

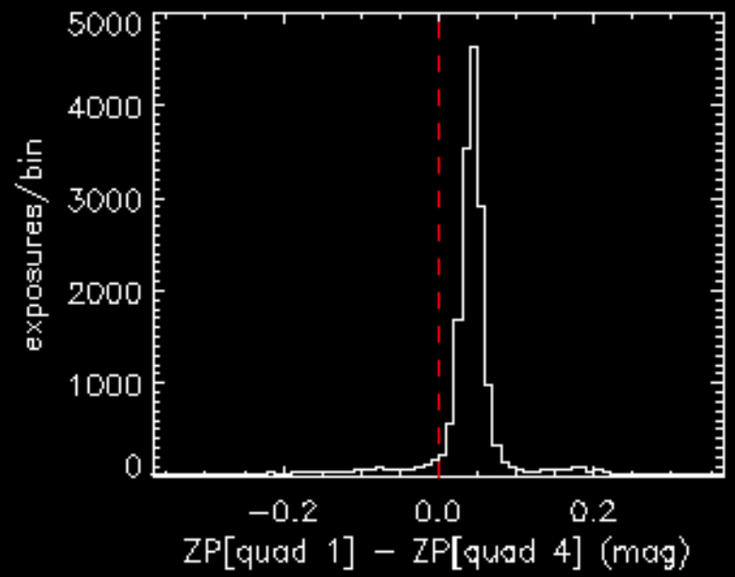

20191104
pointing camera sky brightness
−1.2
−1.4
−1.6
−1.8
−2.0
−0.10
−0.05
0.00
0.05
0.10
0.15
0.20
Δt (hours)

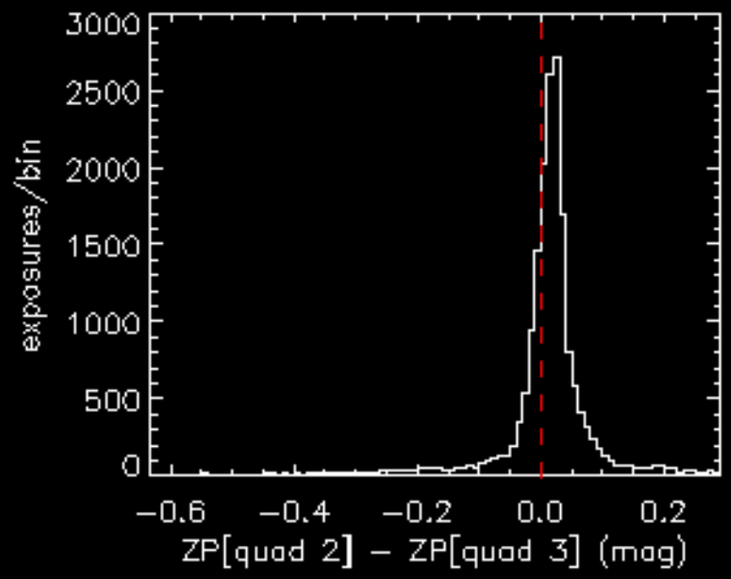

sky brightness
(gfa_reduce)
GFA sky brightness
21.4
21.2
21.0
20.8
−0.10
−0.05
0.00
0.05
0.10
0.15
0.20
Δt (hours)

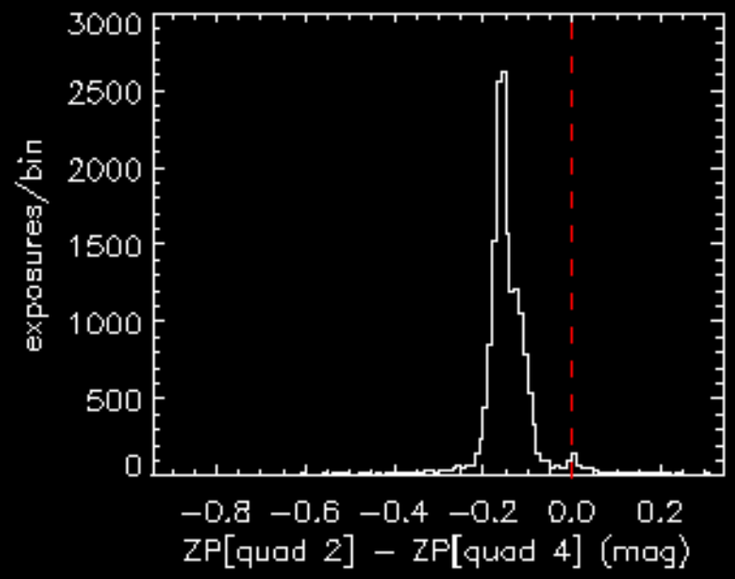
quadrant comparison: zeropoints

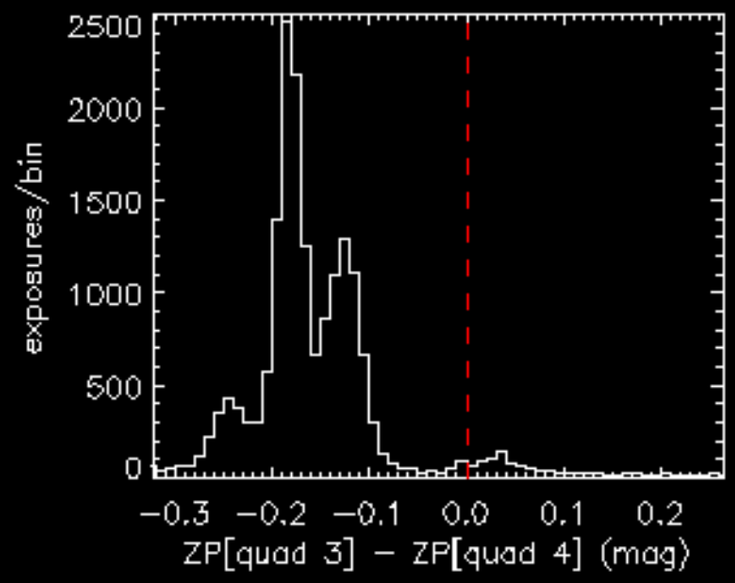


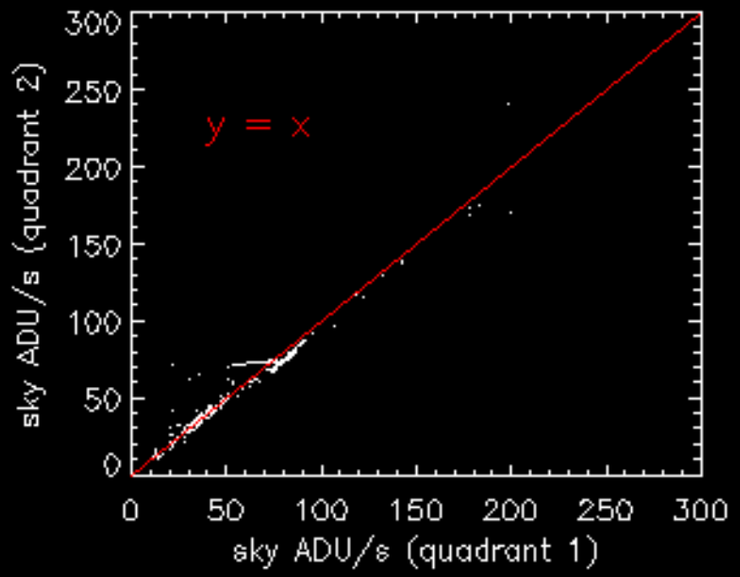


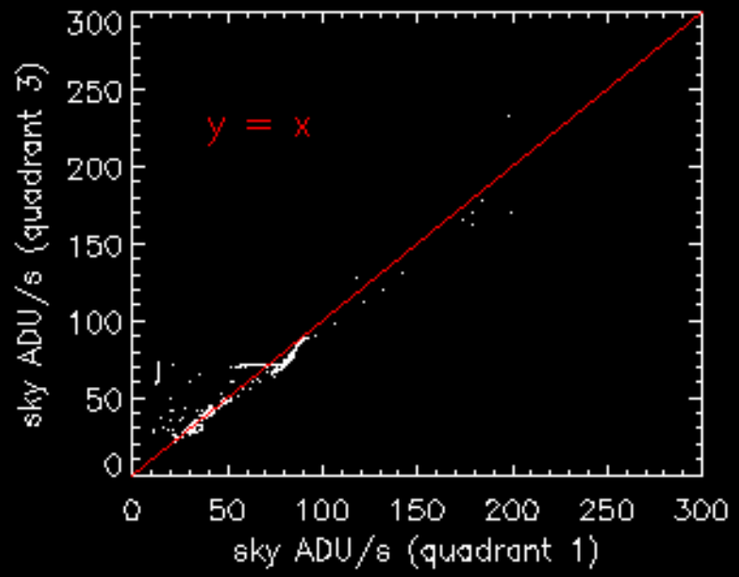


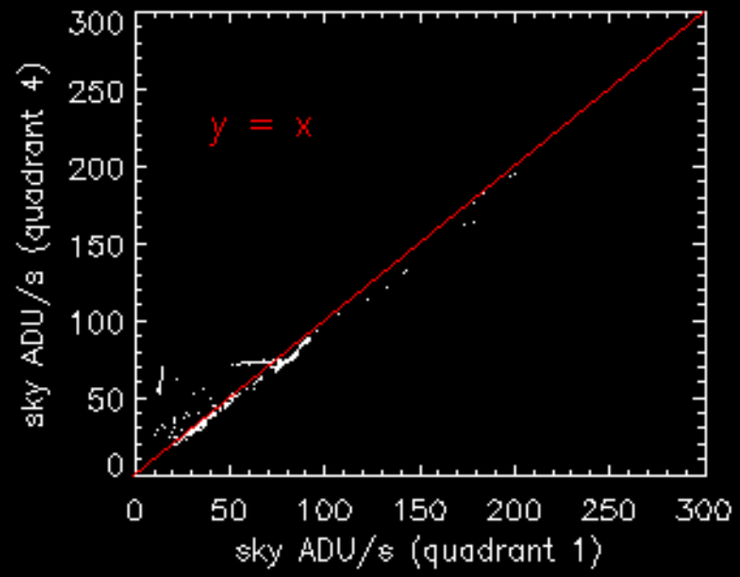


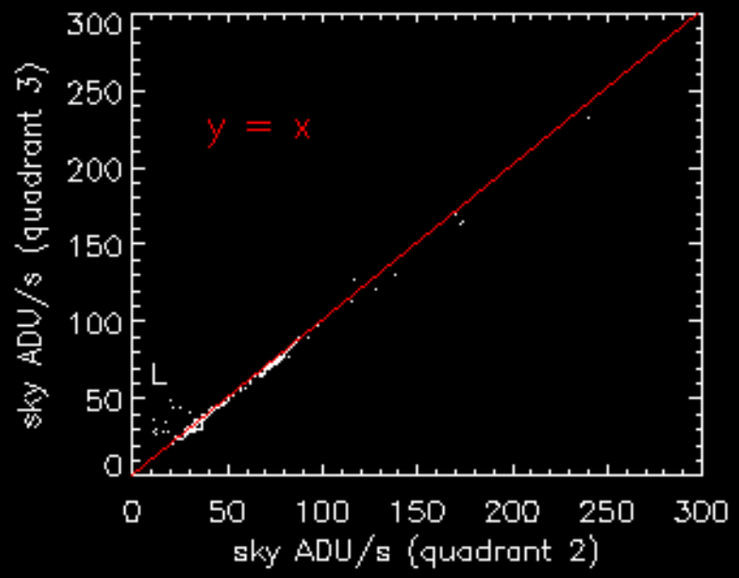


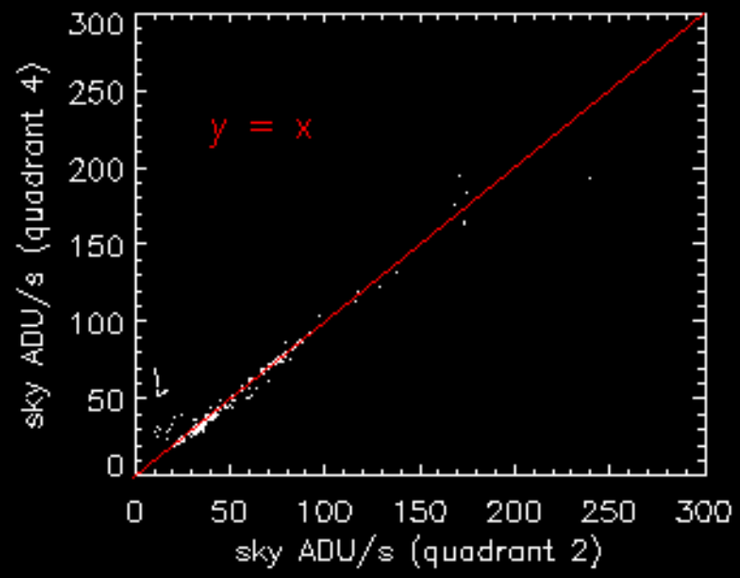




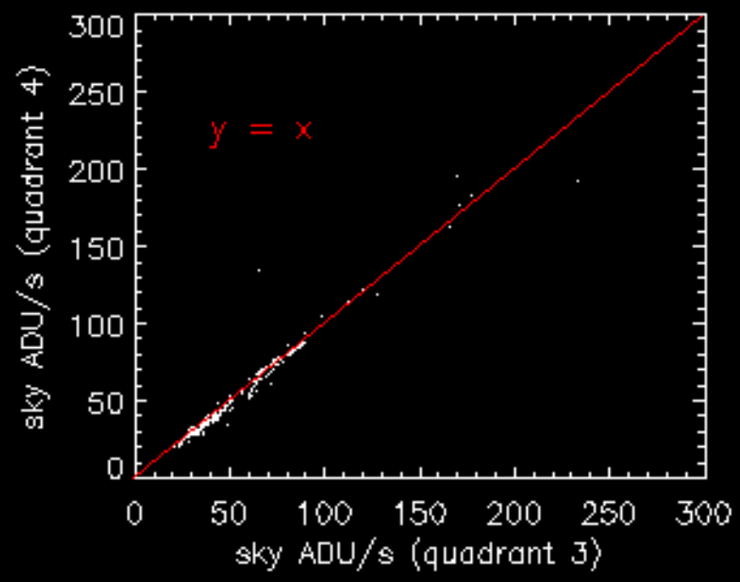


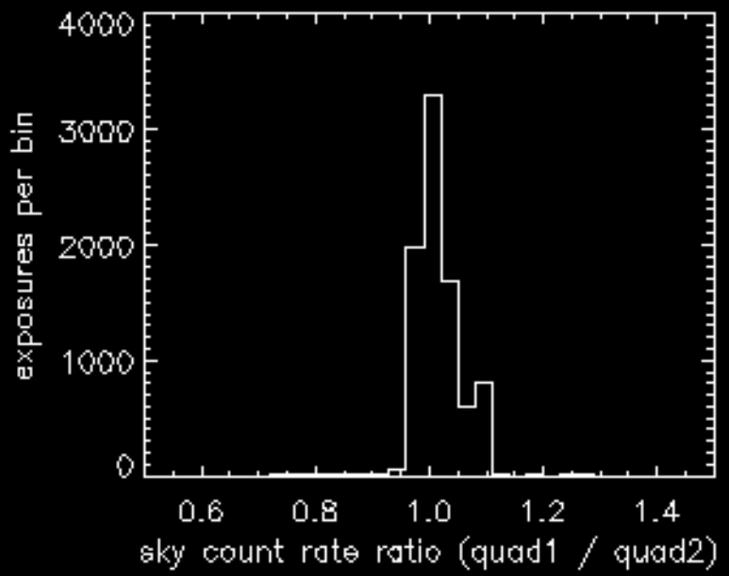


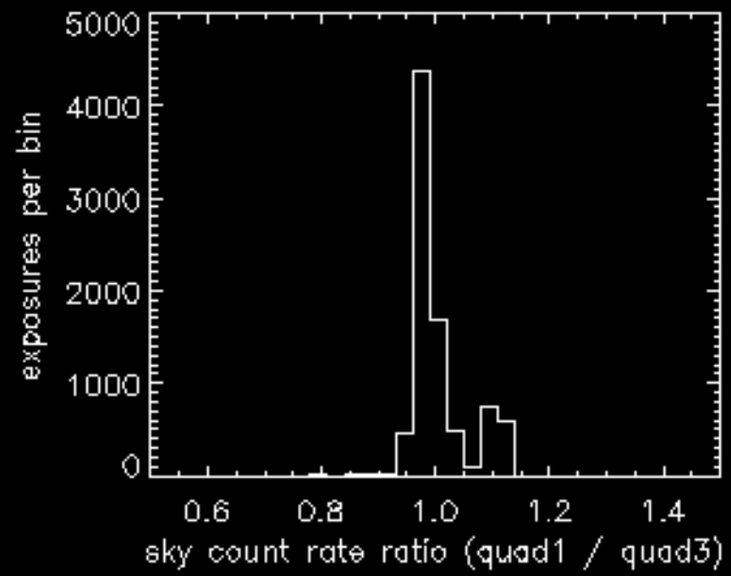


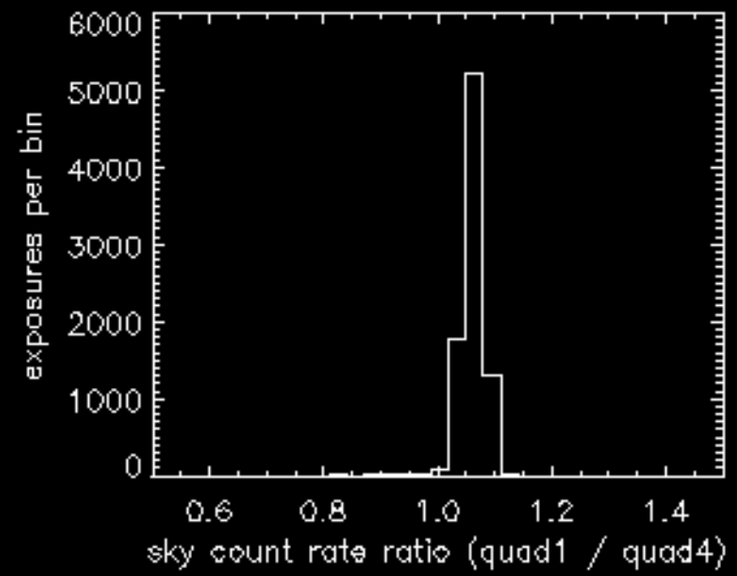


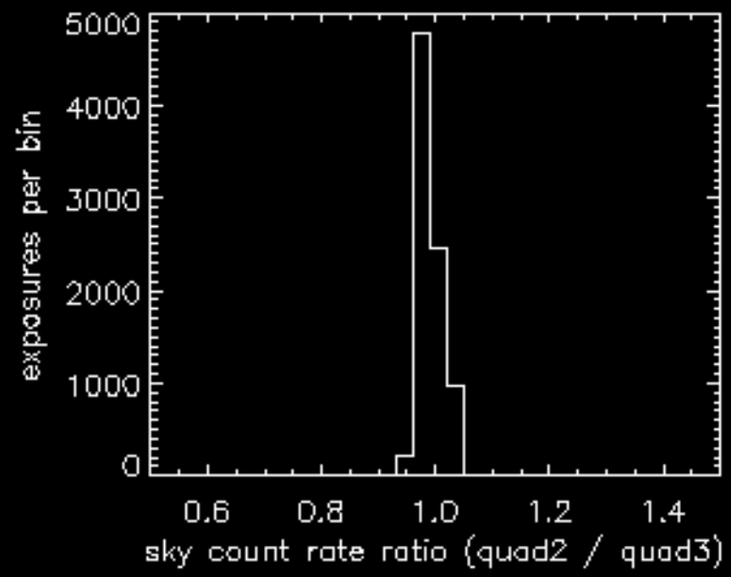
quadrant comparison: sky count rates

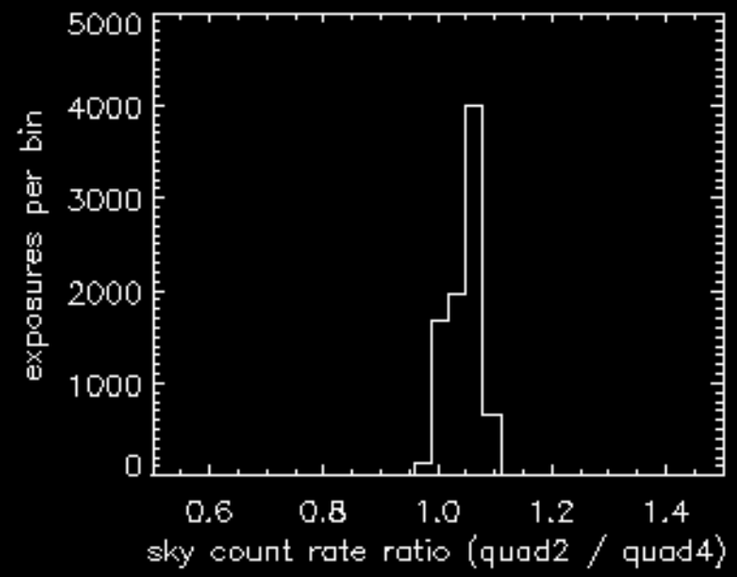




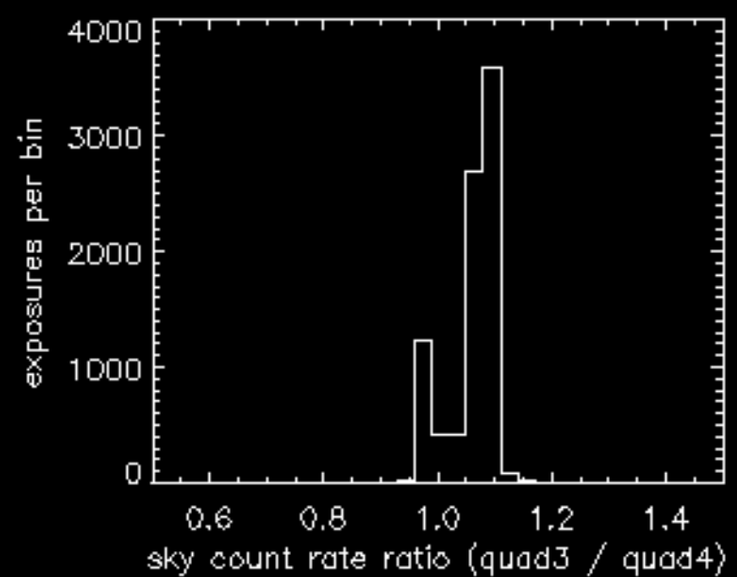




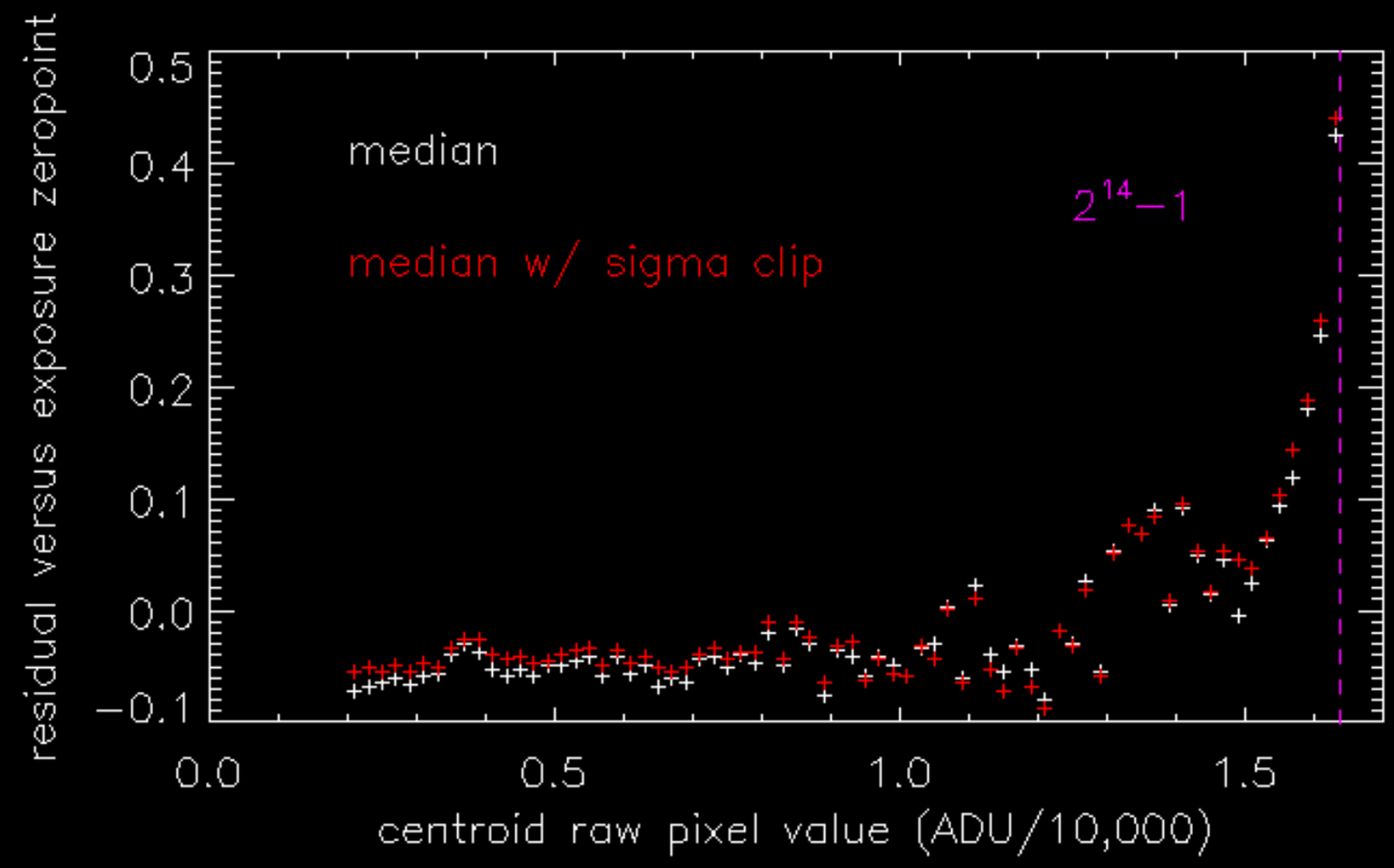


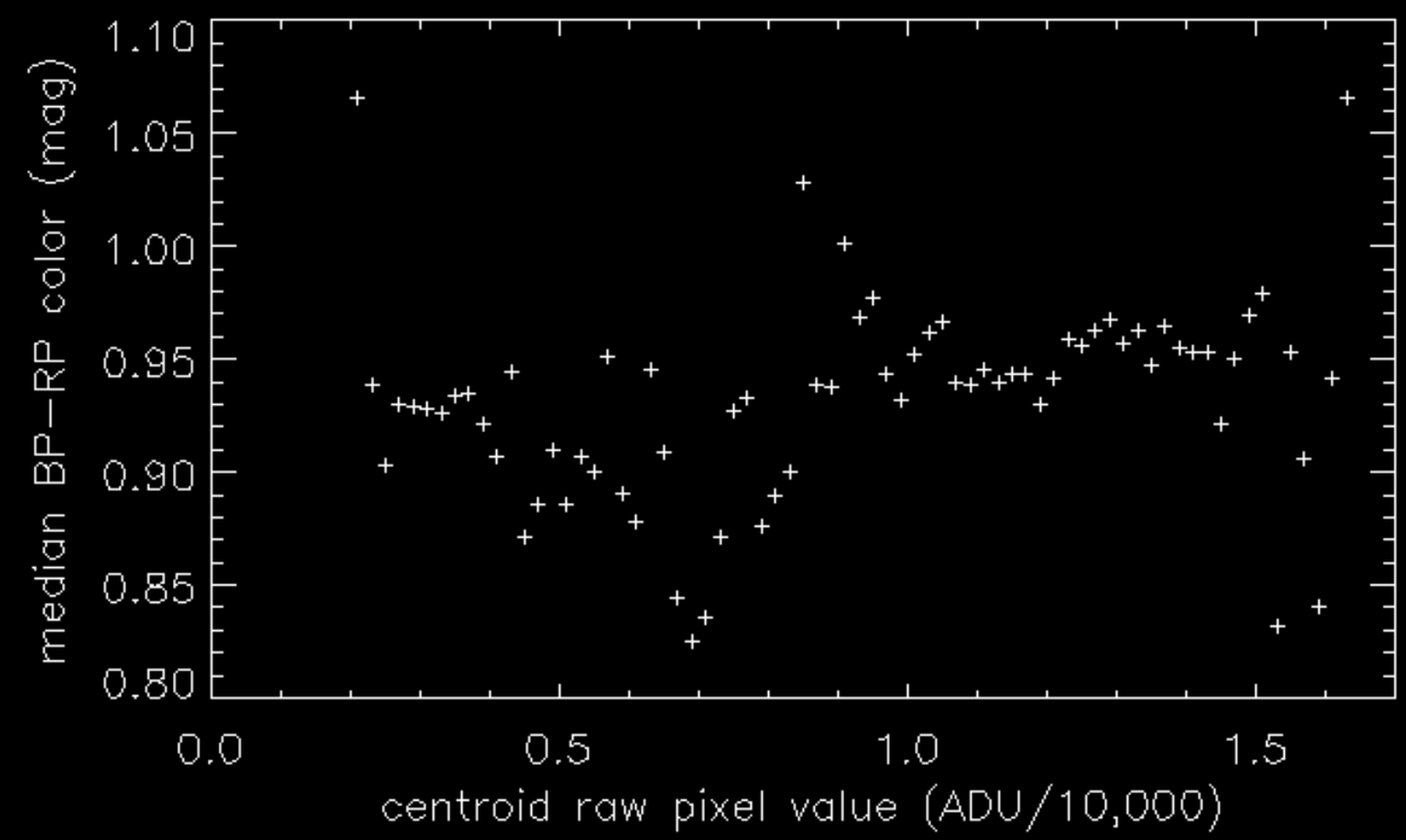


quadrant comparison: sky count rates

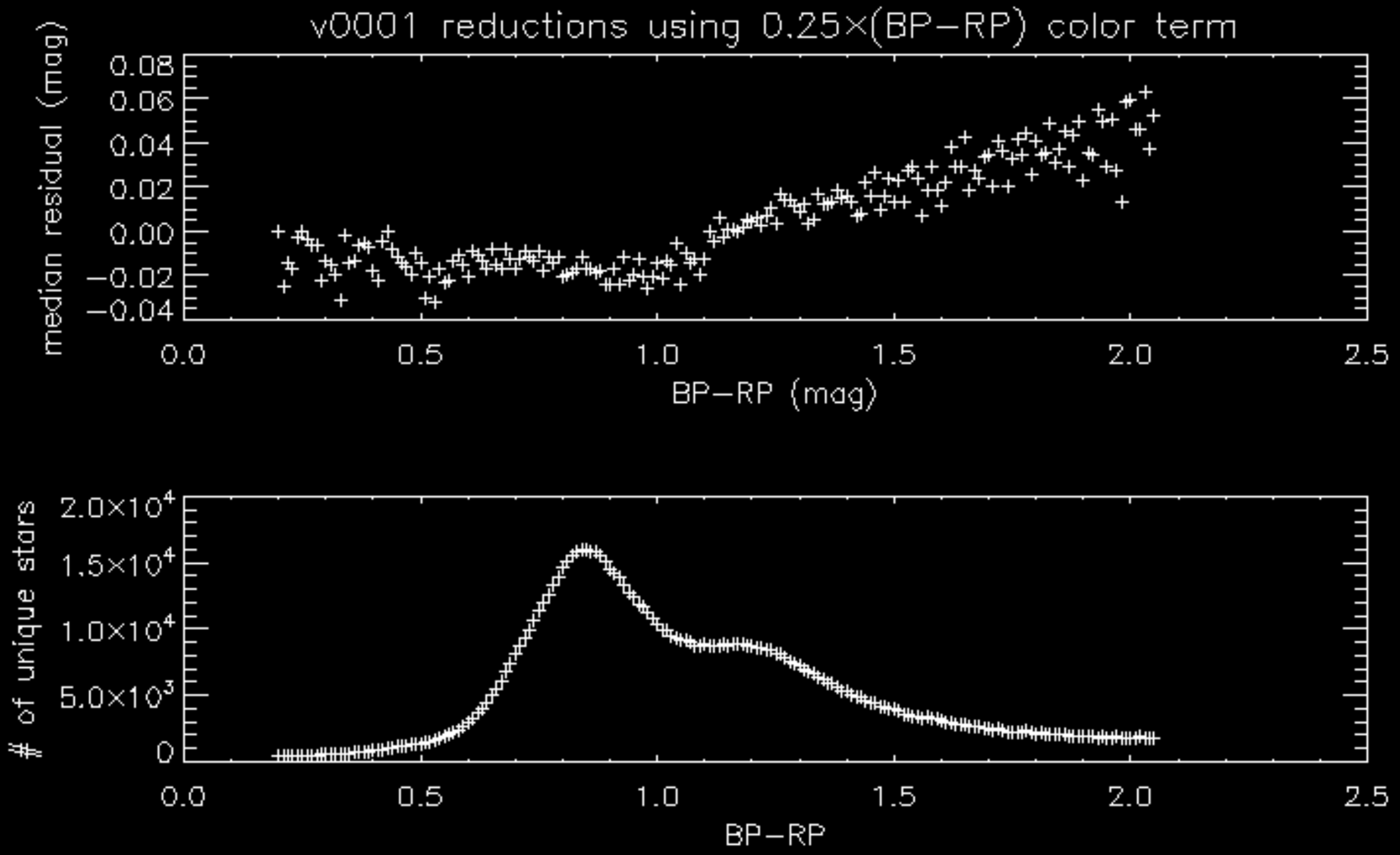


linearity


residual versus exposure zeropoint
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
median
median w/ sigma clip
$2^{14}-1$
0.0
0.5
1.0
1.5
centroid raw pixel value (ADU/10,000)


median BP−RP color (mag)
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.0
0.5
1.0
1.5
centroid raw pixel value (ADU/10,000)

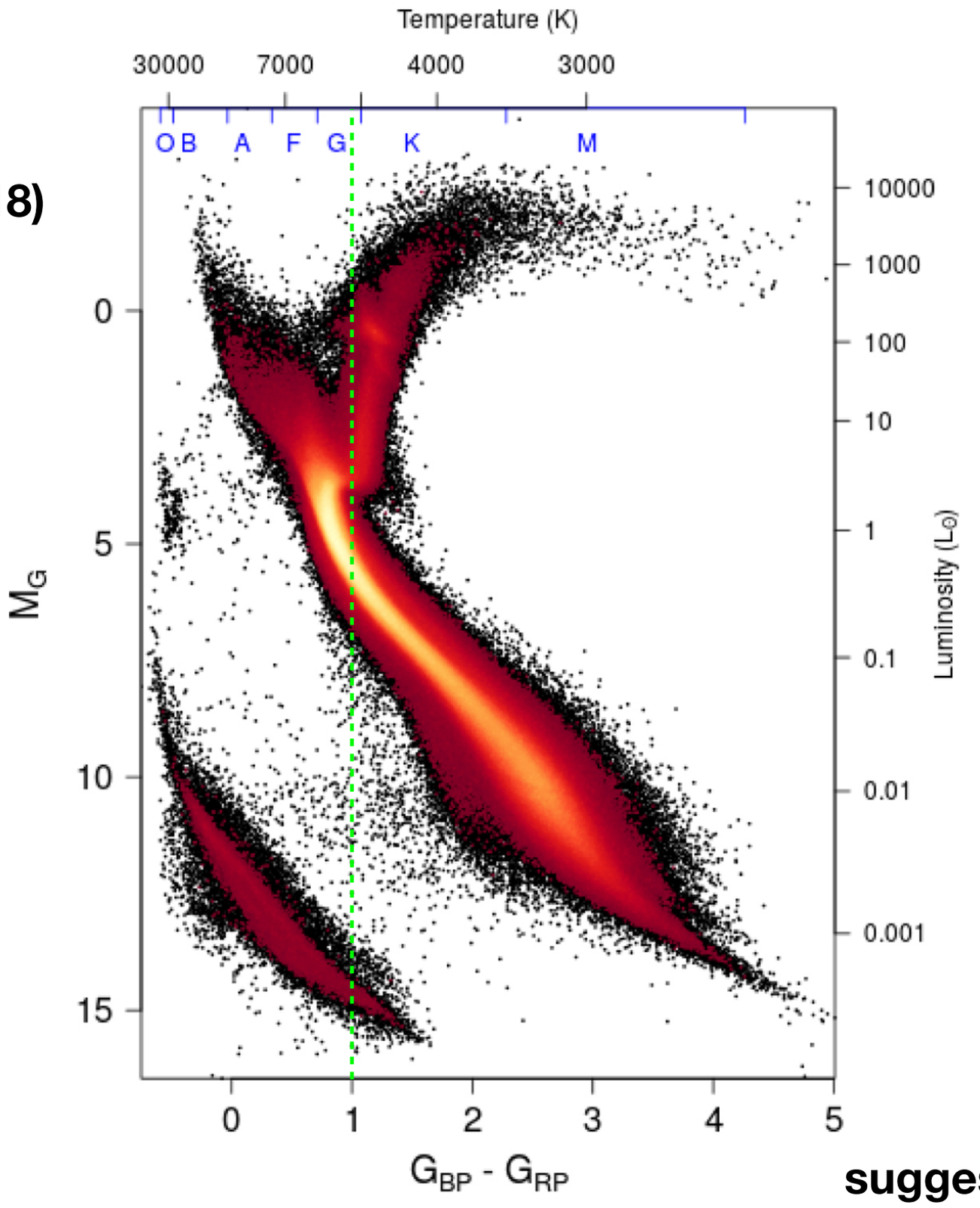
residuals versus Gaia color



current color term of 0.25×(BP-RP) suggested by David Schlegel (desi-commiss 655)

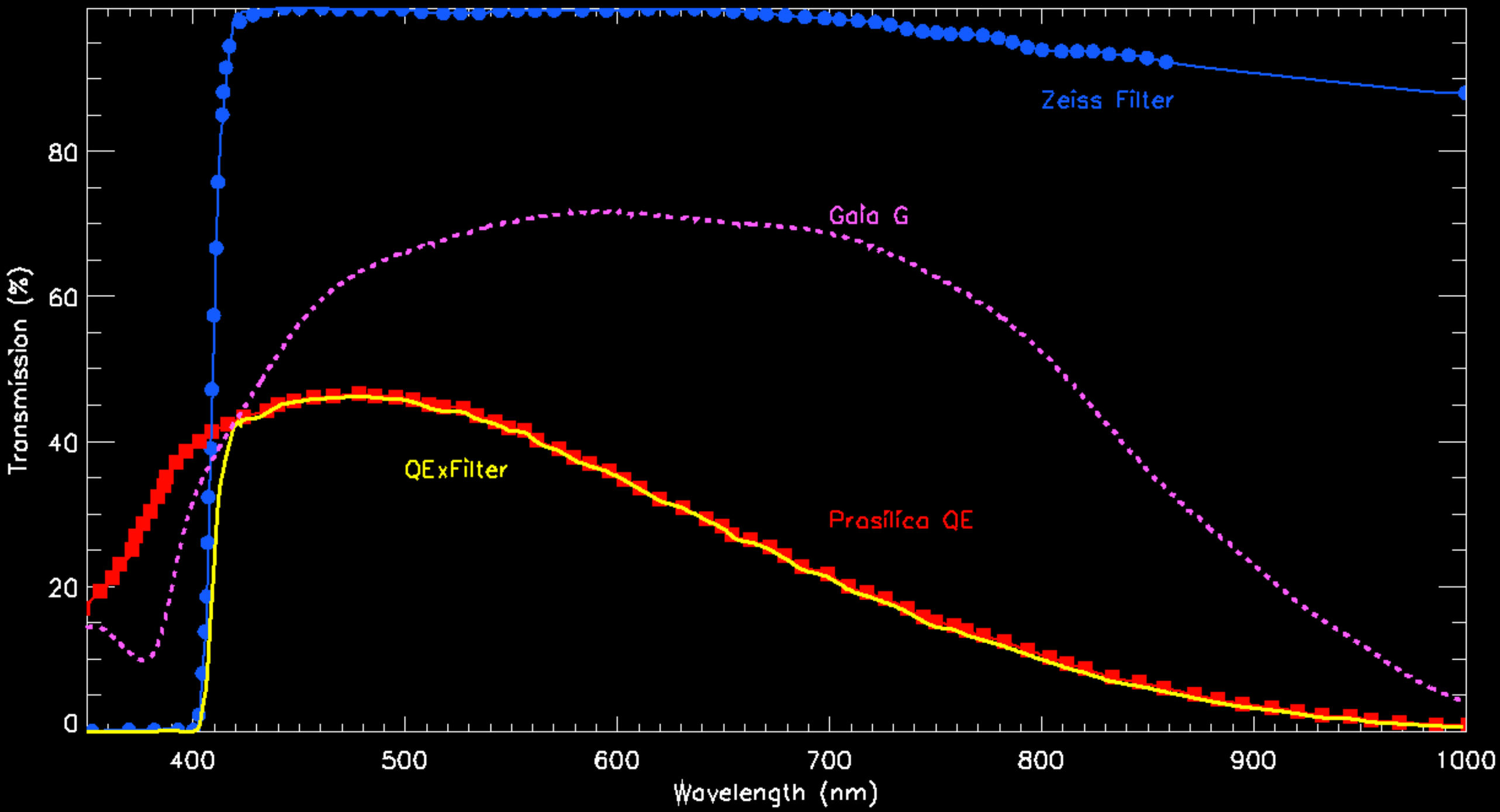
potential explanation of color-dependent residual trend

Babusiaux et al. (2018)



suggested by Arjun

progress on throughput curve



plot/analysis courtesy of Arjun Dey

future/ongoing work

- Understand apparent zeropoint variations
- Better tested, more robust Python analysis pipeline
- Try swapping in Tycho V instead of Gaia
- Add streak detection
- Requests for more metadata in raw pointing camera image headers, e.g. camera temperature
- Running in real-time at the mountain

future/ongoing work

- Finish constructing expected El Nino throughput curve as a function of wavelength

- More non-sky calibration data (“zeros”, darks)

  - Currently planning to try this during the upcoming dark time (lens cap is not on)

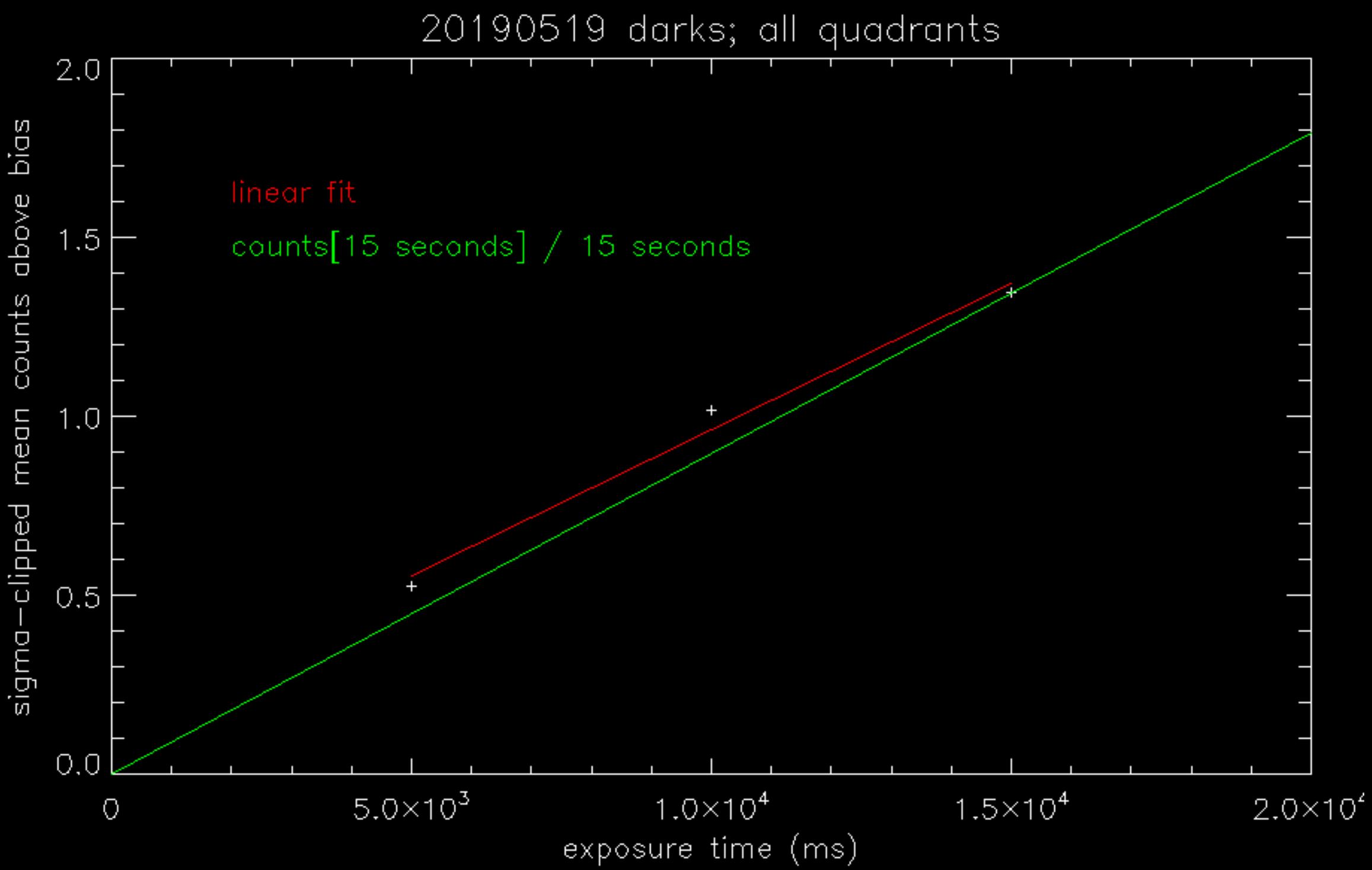
- More on-sky calibrations/tests

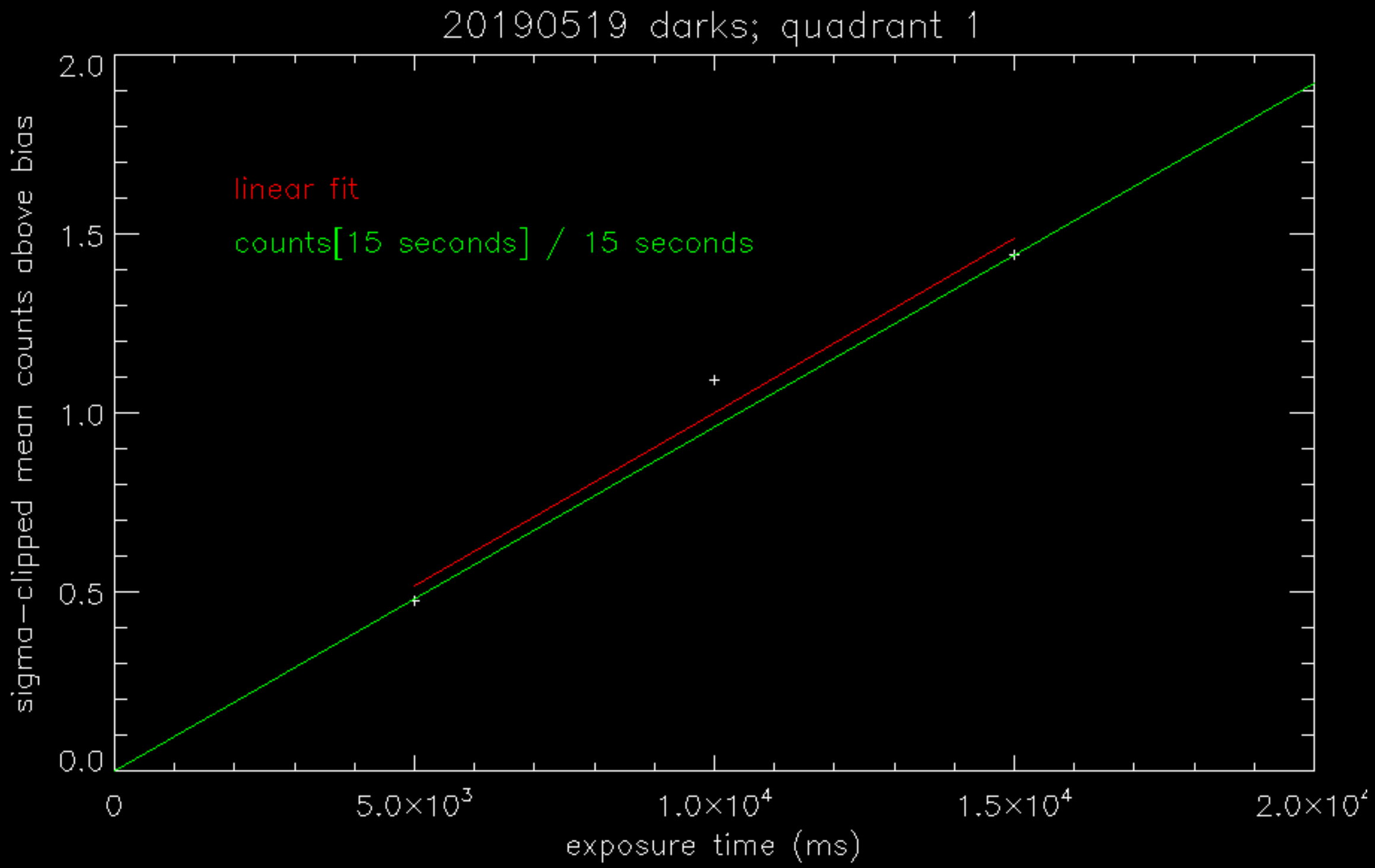
  - e.g., twilight flats

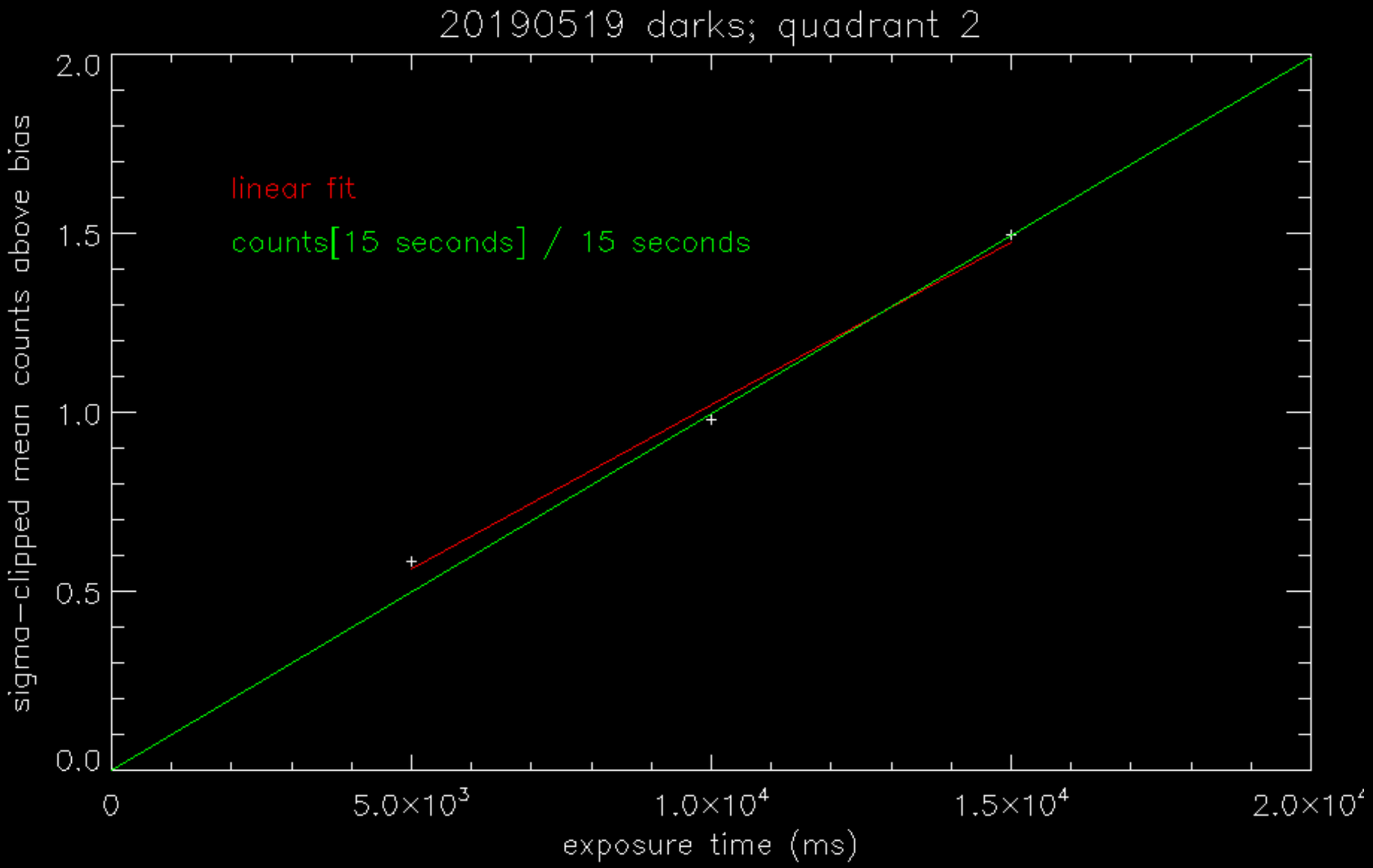
  - running pointing camera in astrometry mode simultaneously with DESI guide sequences more often in the future

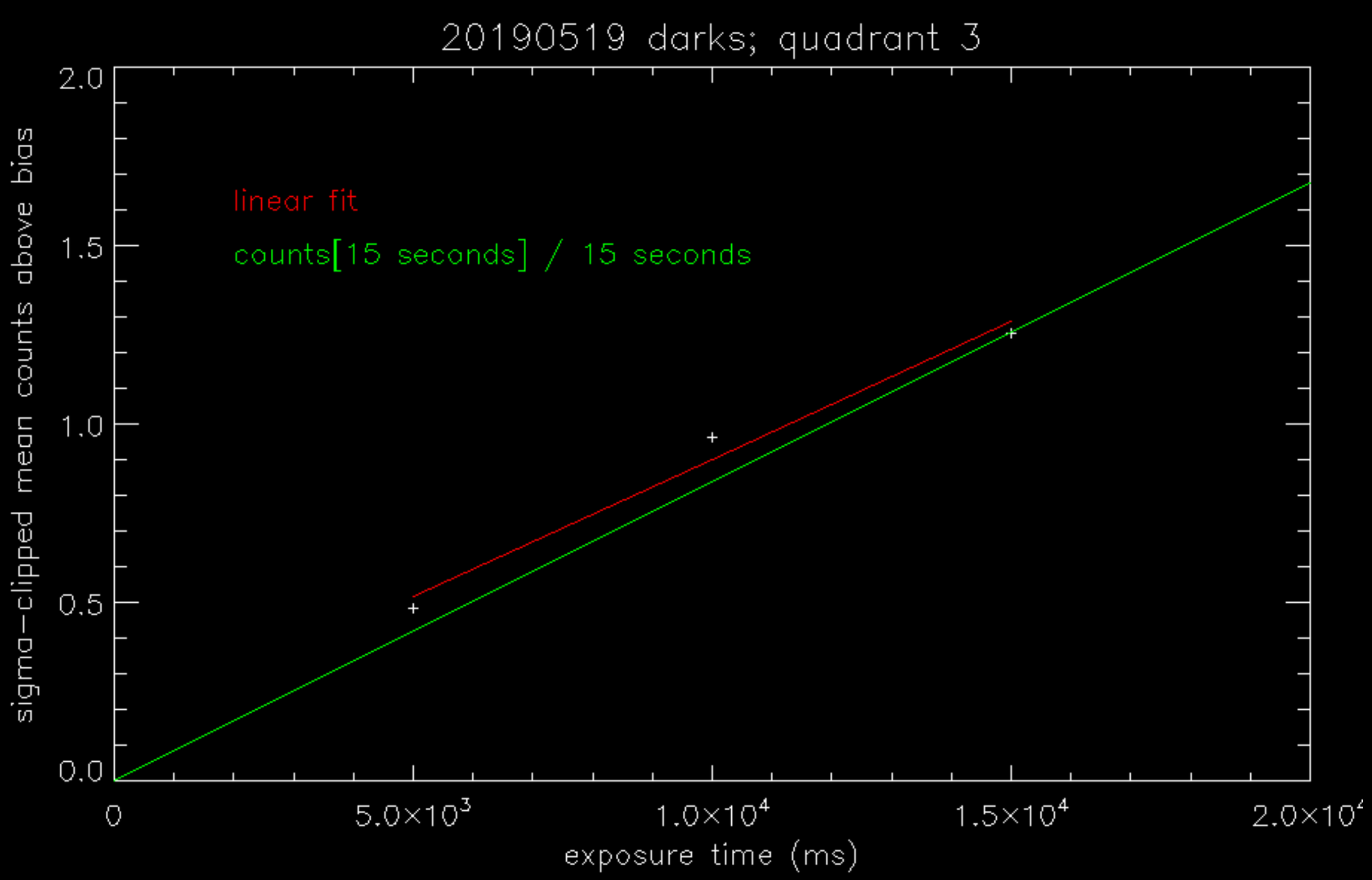
- Adapt pipeline to work for both El Nino and La Nina

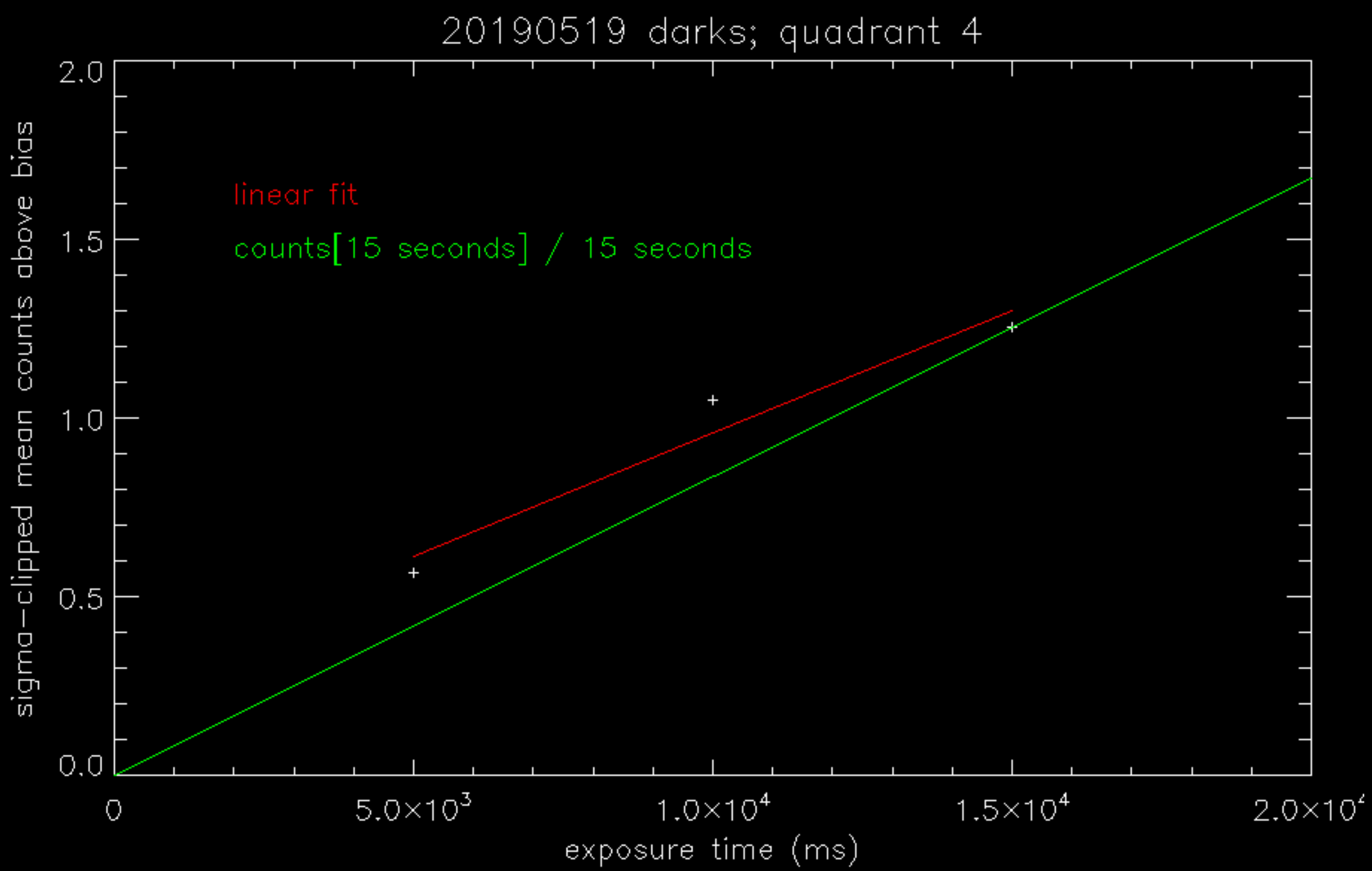
Appendix: Details about Non-sky Calibrations


20190519 darks; all quadrants
linear fit
counts[15 seconds] / 15 seconds
sigma-clipped mean counts above bias
2.0
1.5
1.0
0.5
0.0
0
5.0×10³
1.0×10⁴
1.5×10⁴
2.0×10⁴
exposure time (ms)


20190519 darks; quadrant 1
linear fit
counts[15 seconds] / 15 seconds
sigma-clipped mean counts above bias
2.0
1.5
1.0
0.5
0.0
0
5.0×10^3
1.0×10^4
1.5×10^4
2.0×10^4
exposure time (ms)


20190519 darks; quadrant 2
linear fit
counts[15 seconds] / 15 seconds
sigma-clipped mean counts above bias
2.0
1.5
1.0
0.5
0.0
0
5.0×10³
1.0×10⁴
1.5×10⁴
2.0×10⁴
exposure time (ms)


20190519 darks; quadrant 3
linear fit
counts[15 seconds] / 15 seconds
sigma-clipped mean counts above bias
2.0
1.5
1.0
0.5
0.0
0
5.0×10³
1.0×10⁴
1.5×10⁴
2.0×10⁴
exposure time (ms)


20190519 darks; quadrant 4
linear fit
counts[15 seconds] / 15 seconds
sigma-clipped mean counts above bias
2.0
1.5
1.0
0.5
0.0
0
5.0×10³
1.0×10⁴
1.5×10⁴
2.0×10⁴
exposure time (ms)

dark current rates

quadrant	counts[15 s] / 15 s	m	b
all	0.0897	0.0820	0.143
1	0.0961	0.0968	0.033
2	0.0997	0.0912	0.107
3	0.0837	0.0772	0.129
4	0.0836	0.0689	0.268

- m (slope) and b (y intercept) come from linear fit of counts/pix versus integration time (red line in each plot).
- All values except b are in counts/pix/second ; b is in counts/pix

other per-quadrant quantities

quadrant	readnoise (ADU/pix)	median bias (ADU/pix)
1	12.54	87
2	13.05	152
3	12.78	118
4	12.65	110

Gaia G cut as a function of exposure time