MAOP-702

CCD 47 Characterization

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Revision History

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1. Applicable Documents

[RD1] e2V CCD47-10 AIMO Technical Specifications.
[RD2] Scimeasure Little Joe SN 41044 Test Data 2010-05-28

2. Acronyms and Abbreviations

AOS	Adaptive Optics System
ASM	Adaptive Secondary Mirror
MagAO	Magellan Adaptive Optics
TBC	To Be Confirmed
TBD	To Be Determined
TBR	To Be Reviewed
VisAO	The MagAO Visible wavelength science camera
W-Unit	Wavefront Sensing Unit

3. Introduction

The Magellan AO (MagAO) CCD 47 is the system acquisition camera and the main sensor of the visible wavelength science camera (VisAO). Here we document the laboratory characterization of the CCD 47 installed on the MagAO W-Unit, and its Little Joe controller.

4. Laboratory Gain and Readout Noise Measurements

Gain and read-out noise (RON) were measured in the Magellan AO lab at Steward Observatory in February 2010, prior to being mounted on the W-Unit board. For these measurements the CCD head was wrapped in Al foil, place in a cardboard box, and had liquid cooling applied. The cardboard box had a hole cut in it, a paper placed over the hole to provide a somewhat flat illumination, and an LED flashlight was used as the source.

The lab thermostat was set to minimum to provide a cool ambient temperature to minimize the impact of dark current. For these tests the Little Joe case temperature was 20C. CCD47 Head temperature was -36C, except in the 64x64 and 32x32 modes when it rose to -33C due to the high frame rate.

At each pixel rate and gain setting we took 2 darks and 2 flats, which were then analyzed using the findgain task in IRAF. Two sets of data were taken at each setting, and typical variations between these sets was 0.01 for gain and 0.02 ADU for RON. The 64x64 and 32x32 modes had larger variations, and the numbers presented are the average of the two sets.

The results are presented in Table 1. The values provided by Scimeasure for the MagAO hardware from RD2 are included in the table for comparison.

		Measured		**Scimeasure (RD2)**	
Mode	Gain Setting	Gain (e/ADU)	RON (e)	Gain (e/ADU)	RON (e)
2500 kHz 1024x1024 Bin 1x1 3.53 fps	High	0.53	9.7	0.55	10.2
	Med High	1.93	9.55	1.97	9.83
	Med Low	3.58	10.74	3.62	10.4
	Low	13.23	15.47	13.3	15.3
2500 kHz 64x64 Bin 1x1 31.48 fps	High	0.54	9.62	-	-
	Med High	1.93	9.58	-	-
	Med Low	3.58	10.86	-	-
	Low	13.14	15.49	-	-
250 kHz 1024x1024 Bin 1x1 0.44 fps	High	0.47	4.52	0.49	5.81
	Med High[1]	1.77	4.67	1.71	5.66
	Med Low[2]	3.34	5.28	3.29	6.59
	Low[1]	12.3	11.11	12.1	10.8
80 kHz[3] 1024x1024 Bin 1x1 0.143 fps	High	0.48	7.35 / 3.54	0.48	3.37
	Med High	1.78	6.3 / 3.69	1.79	3.53
	Med Low[1]	3.33	6.23 / 4.38	3.31	4.28
	Low[1]	12.43	12.35 / 11.02	12.2	10.3
80 kHz 1024x1024 Bin 2x2 0.551 fps	High	0.48	5.69 / 3.62	0.48	3.28
	Med High	1.74	5.98 / 3.72	1.79	3.61
	Med Low[1]	3.27	6.18 / 4.43	3.31	3.29
	Low	11.08	12.1 / 9.68	12.2	10.3
80 kHz 1024x1024 Bin 16x16 10.42 fps	High[4]	0.47	9.76 / 6.85	0.46	3.62
	Med High[4]	1.76	10.07 / 7.31	1.74	3.95
	Med Low[4]	3.25	10.42 / 7.43	3.31	4.63
	Low[4]	12.38	14.43 / 12.13	11.6	10.3
2500 kHz 512x512 Bin 1x11 6.70 fps	High	0.53	9.59	-	-
	Med High	1.93	9.54	-	-
	Med Low	3.57	10.71	-	-
	Low	13.26	15.55	-	-
2500 kHz 32x32	High	0.54	9.46	-	-
	Med High	1.88	9.57	-	-

		Measured		Scimeasure (RD2)	
Mode	Gain Setting	Gain (e/ADU)	RON (e)	Gain (e/ADU)	RON (e)
Bin 1x1 42.78 fps	Med Low	3.5	10.59	-	-
	Low	12.61	14.51	-	-
250 kHz 512x512 Bin 1x1 1.49 fps	High	0.48	3.84	-	-
	Med High	1.77	4.25	-	-
	Med Low	3.32	4.88	-	-
	Low	12.36	10.52	-	-
80 kHz 512x512 Bin 1x1 0.535 fps	High[5]	0.47	9.06 / 8.66	-	-
	Med High	1.74	4.13 / 3.36	-	-
	Med Low	3.32	4.82 / 4.24	-	-
	Low	12.46	10.94 / 10.58	-	-

Table 1: CCD 47 Gain and RON measurements.

Notes: (1) Used 1 pass of 5 sigma-clipping
(2) One bad dark frame here gives odd results. Ignored.
(3) The 80kHz RON measurements require special handling due to excess frame-transfer dark current. The 2nd number is from the alternate 100 frame method described below.
(4) The bad results here are explainable by the excess dark current. Taking into account both the decreased frame time and the larger number of pixels in each bin, there is ~3.5 as much dark current per pixel in these images.
(5) This mode appears to be genuinely out of spec. We had to adjust black levels in this mode (a consequence of low Joe temperature) but it would be surprising if this affects RON.

5. The 80 kHz Frame-transfer Dark current

As noted in Table 1, the raw 80kHz RON was significantly worse than expected. The number one suspect is dark current since we did not measure RON with 0 exposure time. Upon investigating, we found that a dark current is the likely culprit, however it appears that it is not simply a dark current which scales with exposure time.

To start our investigation we took 100 dark frames (cap on) at 80 kHz. Figure 1 shows the median of these frames. We next took the standard deviation of the 100 frames on a pixel by pixel basis, shown in Figure 2. It appears that the signal shown in Figure 1 is a source of Poisson noise, which is at the same level as expected to explain the high RON results. This dark signal is much higher than expected based on the E2V specifications for our CCD47.

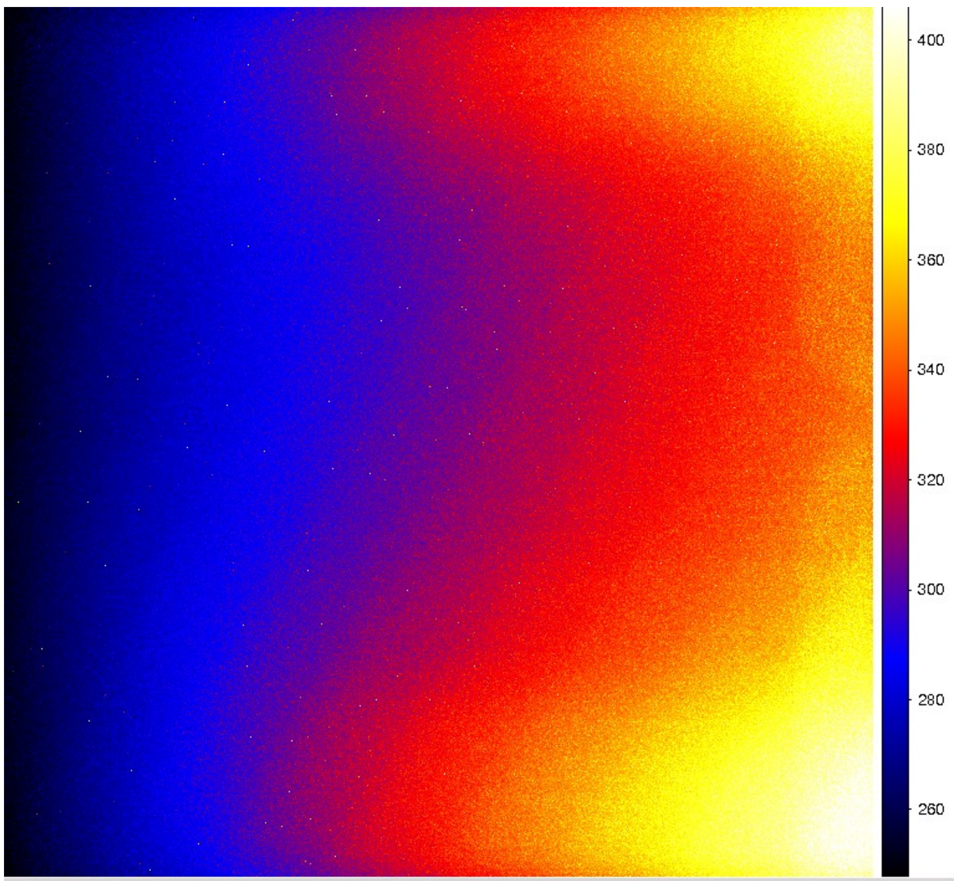

Figure 1: This is the median of 100 6.944sec (80kHz) dark frames

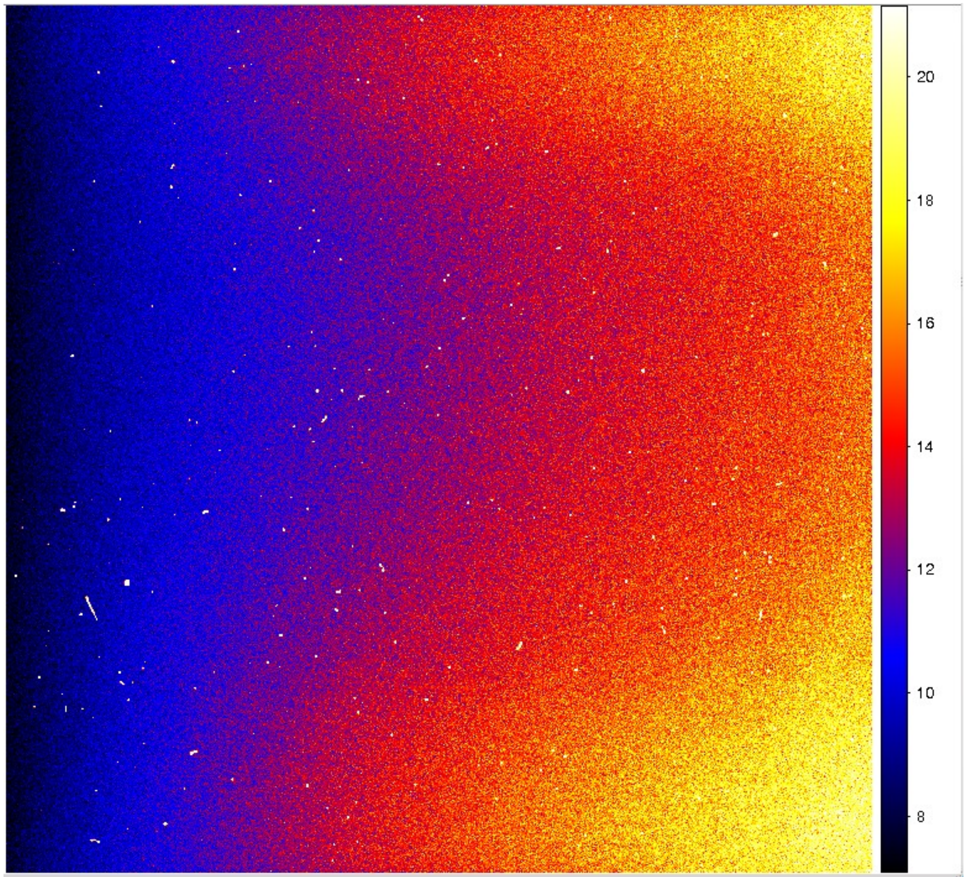

Figure 2: What is this.

In Figure 3 we show the median of 50 41 second dark frames. Here we see the first hint that the dark signal in Figure 1 is not scaling with time. A separate pattern is now becoming visible. In Figure 4 we show the median dark current, which was calculated by subtracting a 6.9 second exposure from a 94 second exposure. The short exposure was not scaled, so we see that the dark signal in Figure 1 is indeed not scaling with time, and once it is subtracted a dark signal more in line with that expected is evident.

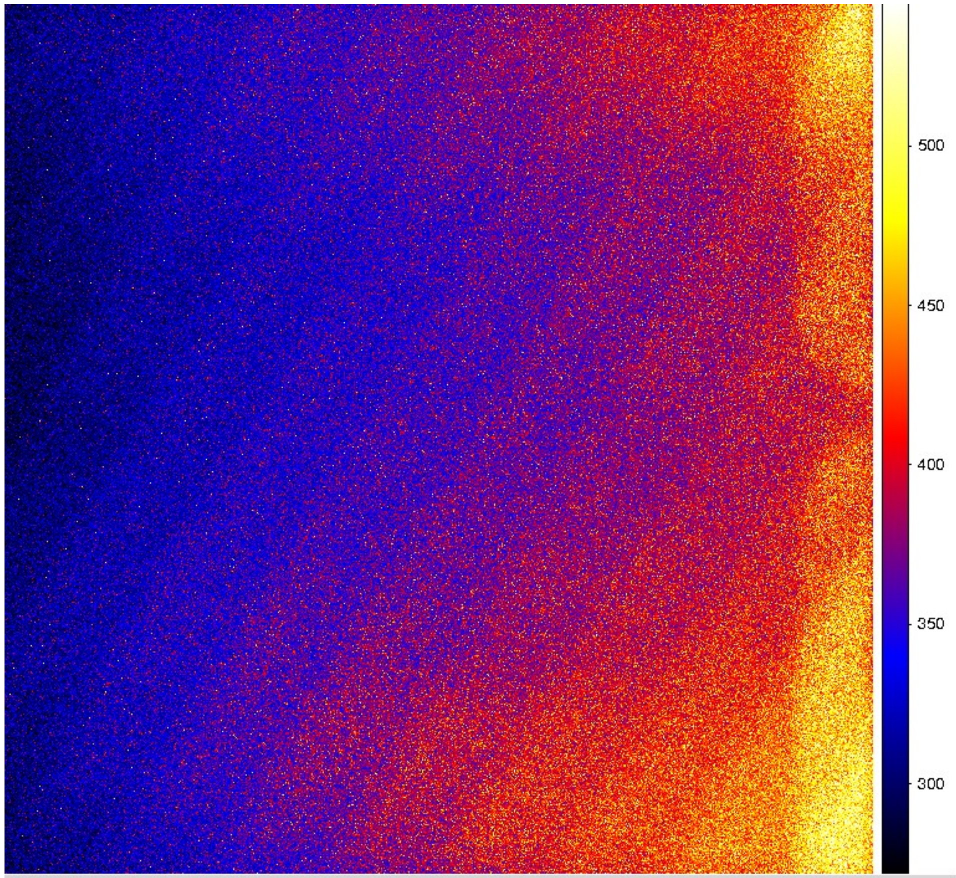

Figure 3: This is the median of 50 41 sec (80kHz) dark frames. Note the structure from Figure 1 is still visible, but the two “pads” are starting to show up. Also note the waves are now visible.

Figure 4: This is the dark current, calculated by subtracting a 6.9 second frame from a 94 second frame (80kHz) and dividing by exposure time. Note that the structure in the first image has almost completely subtracted out, but the “pads” and the “waves” are clearly visible.

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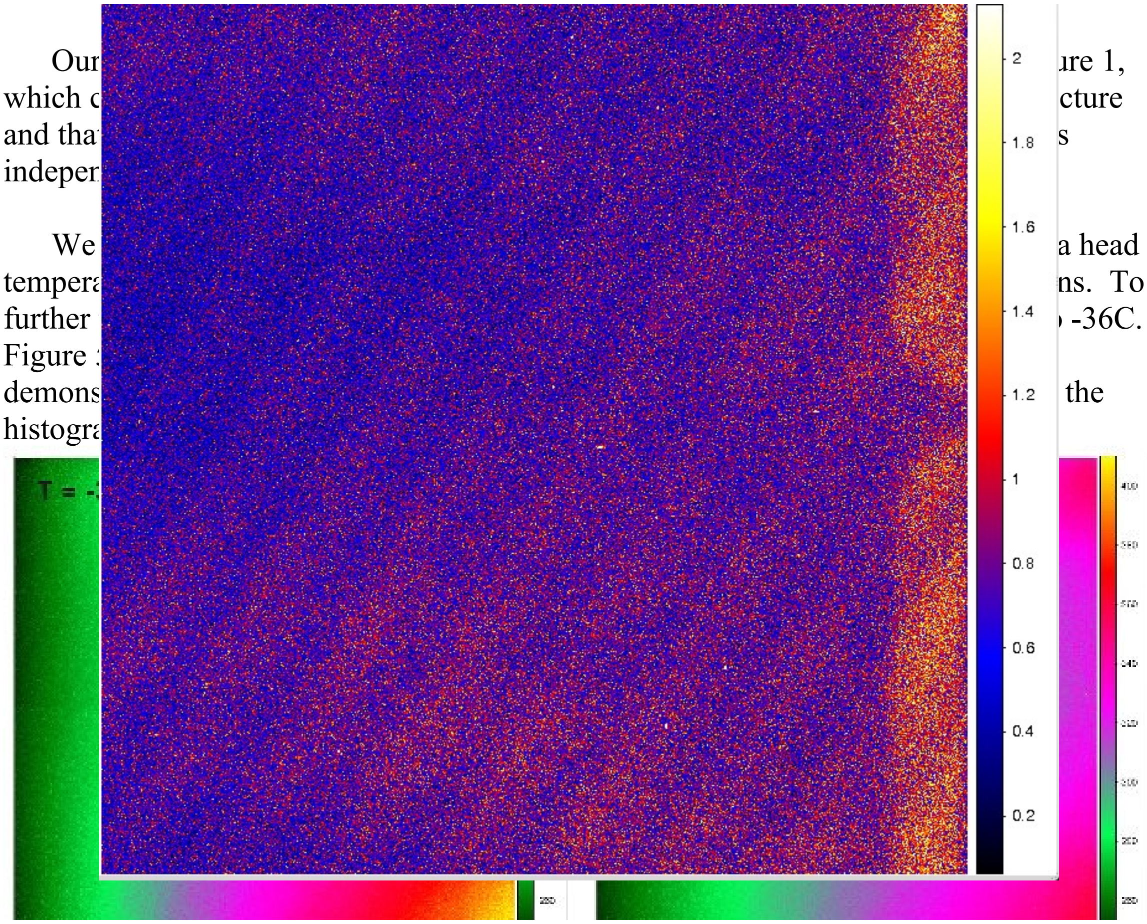

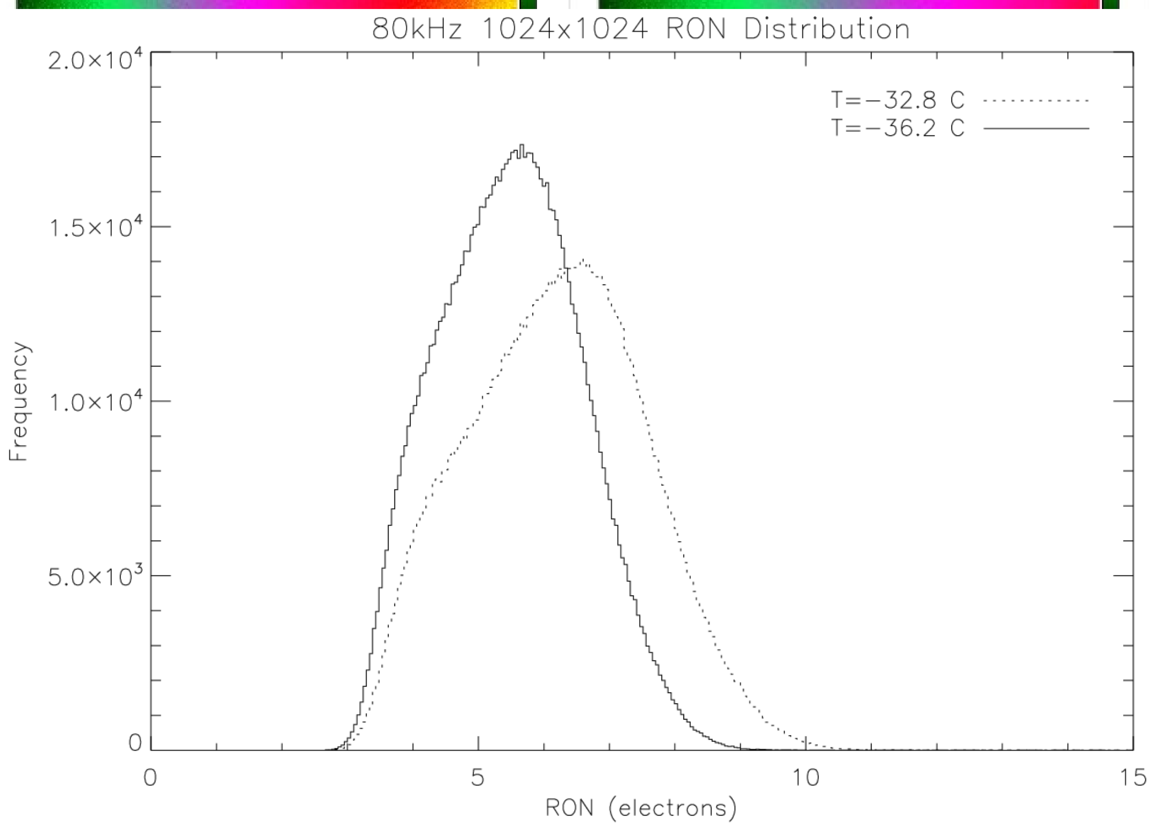

Figure 6: Histogram of RON, calculated per-pixel using 100 6.9 second frames at 80kHz. Mean RON at -32.8C is 6.32e, and at -36.2 it is 5.60e. There is a marked improvement as temperature is reduced.

In Figure 7 we plot the column standard deviation, at -32C and -36C. We see that the signal is lowest at column 0, so we assume that this is the first column read out and column 1023 is the last column read out. We also show the signal we can expect if we achieve a -50C head temperature – which is expected at the telescope with a 0-10C ambient temperature. Linear extrapolation predicts that we will achieve the expected value of 3.37 electrons.

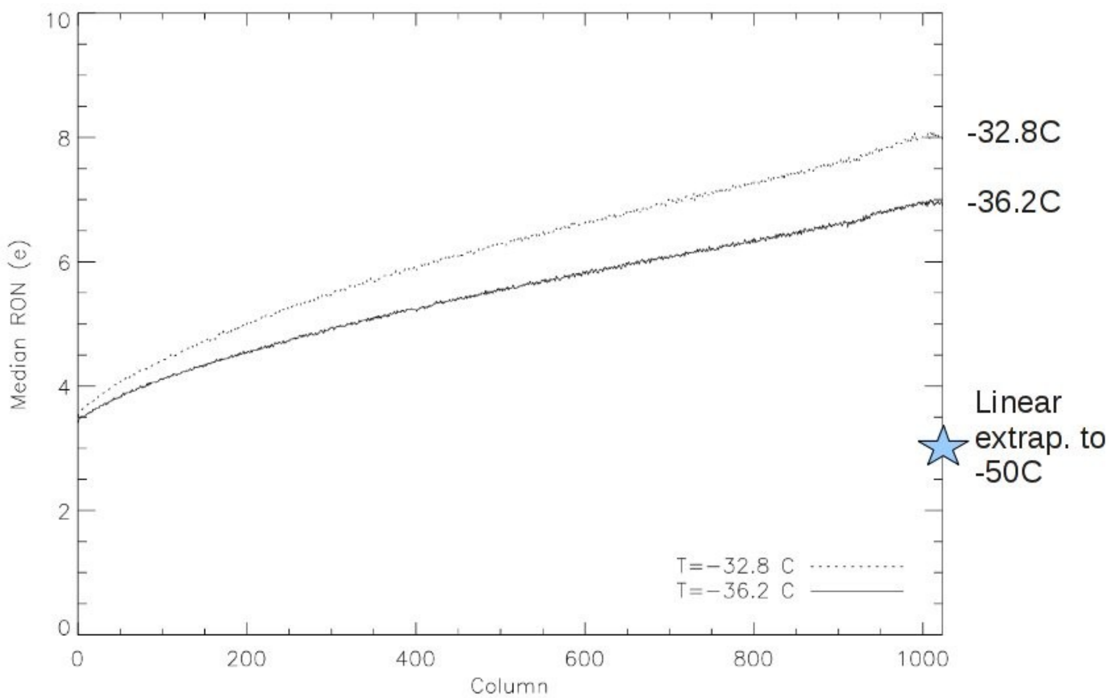

Figure 7: The median of each column, shown for two different temperatures. Note that column 0 is only weakly effected. We estimate the RON at -50C by linear extrapolation to be ~3 e. The expected value is 3.43 e.

Finally, to provide an estimate of our true RON measured in the lab, we calculate the value of the column 0 standard deviation by fitting a line to the first 100 columns and taking its intercept, which is 3.54 electrons in this case. This technique provides the second numbers in the 80kHz sections of Table 1.

6. Linearity

We measured the linearity of our CCD 47 using a white light and varying the exposure time, in the 2500 kHz full frame mode. This was done only in the high gain setting, as the lower gains will all digitally saturate before reaching non-linearity. Figure 8 shows the results in ADU, and Figure 9 shows the results in electrons. Note that so as to measure the lower part of the curve the flux was not high enough to actually achieve strong non-linearity. Further work is required to document when non-linearity and bleeding become significant. Most pixels read around 9000 ADU in this mode when saturated.

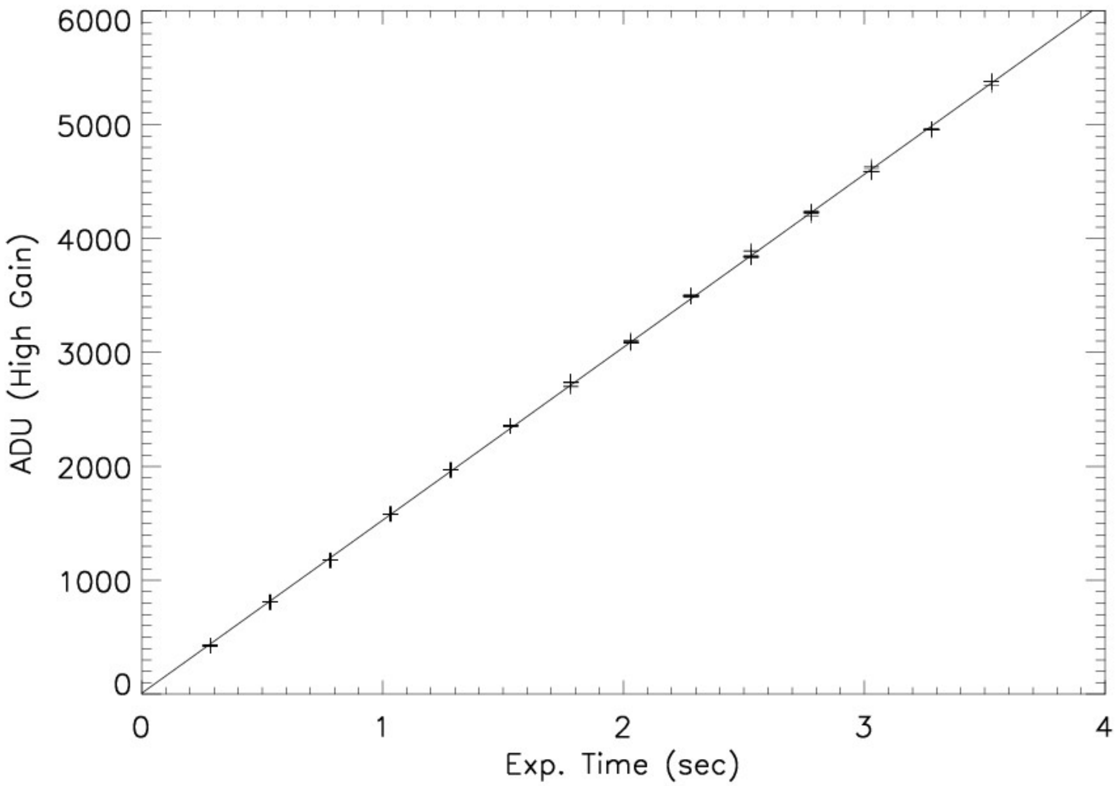

Figure 8: Mean array flux vs. exposure time for a flat white light field.

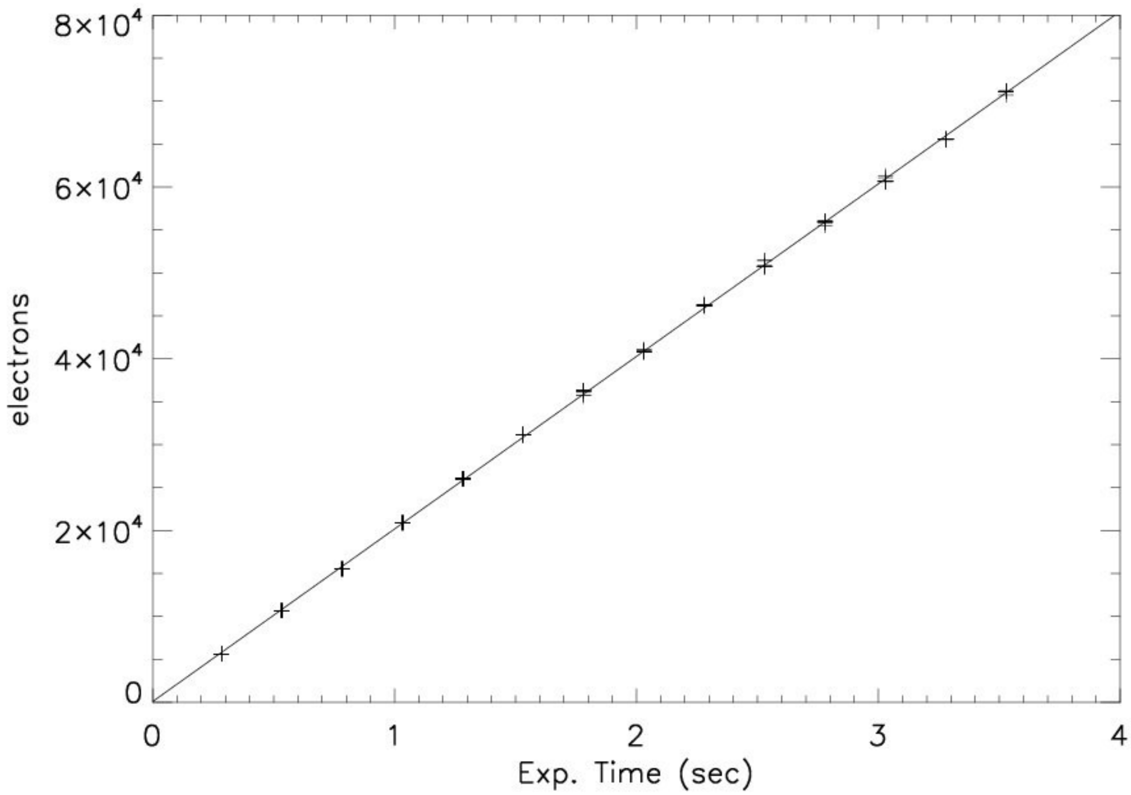

Figure 9: Same as Figure 8, but in electrons. Full well depth is 100,000 electrons.

7. Scaling Factors

It is sometimes useful to convert from ADU to electrons per second when comparing images taken with different exposure times. To convert we calculate the scaling factor (SF) to multiply each pixel by. The formula is:

SF = (10^ND) / EXPTIME * GAIN

Where:
SF = scale factor which converts ADU to electrons/second

ND = value of the neutral density filter, if used.

EXPTIME = the exposure time of the image, in older VisAO fits headers this is the value of V47EXPTM. In newer headers it is the standard EXPTIME.

GAIN = the gain factor, in electrons/ADU. This depends on the gain setting (LOW, MLOW, MHIGH, HIGH) which is given in the fits header as V47GAIN, and the pixel rate which is V47PIXRT, and very weakly on the window size and binning. See Table 1 for measured gains.

8. Spectral Response

In Figure 10 we show the CCD 47 spectral response, taken from RD 1. The MagAO CCD 47 has the Near-IR coating.

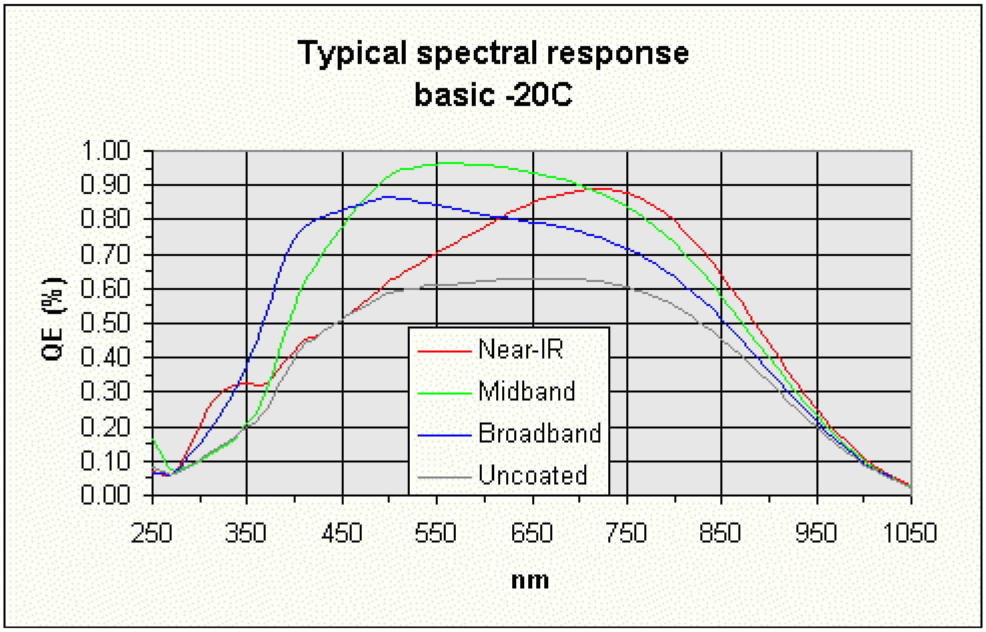

Figure 10: CCD 47 Spectral Response taken from RD1. The MagAO CCD 47 has the Near-IR coating.