WHIRC Report I – Detector Performance Jan 2008

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Introduction

This is a report of a number of tests of detector performance for WHIRC which we have carried out during January 2008. Rather than send out several short reports, I decided to concatenate all of the results into a single document.

The data were obtained on three separate occasions in January 2008; one of these was during the T&E run on WIYN, the other two afterwards, when WHIRC was still on the telescope and being monitored for filter wheel function and hold time. All were run using a custom script written by Charles Corson, which would take data at increasing integration times under (assumed) constant flux. After each set of 4 or 5 frames, the shortest time integration would be repeated to provide a "check" of the illumination flux stability. The datasets are:

- 18 Jan 2008 J filter ~ 800 ADU/s
- 25 Jan 2008 J filter ~1250 ADU/s
- 31 Jan 2008 Ks filter ~ 100 ADU/s

All were taken using the "row reset" mode of operation, with a bias voltage of 1.0 v. The purpose of the different flux levels was to investigate whether the observed linearity properties were a function of integration time or signal level.

In addition, I plot up some data obtained by Bezawada & Ives on one of the VIRGO detectors used for the VISTA project to compare the linearity properties with the WHIRC array.

18 January 2008

During the afternoon of 18 January 2008, we obtained a set of mean-variance (or PTC) data with WHIRC installed on WIYN, pointed at the White Spot. Since only the J filter could be used, we illuminated the screen with the flatfield lamps. Using a specialized script written by Charles Corson, we obtained data for 30 different integration times ranging from 3.3 to 86 s. Five frames were obtained at each integration time, and a sixth "check" frame was taken at 3.3 s to serve as an indicator of the flatfield lamp stability. The flux was on the order of 500 – 750 ADU/s, depending on field position.

Mean-Variance

The mean-variance statistics were obtained in the usual manner, using the IRAF imcomb task to obtain 'mean' and 'sigma' images. It was obvious in examining the statistics of the raw frames that the illumination was in fact not constant, and the "check" frames corroborated this suspicion (Fig. 1). It appears that the flatfield intensity can jump between two or three discrete values. The effect on the PTC data is more insidious, since such transitions can occur one or more times during a given exposure, resulting in a random mean value.

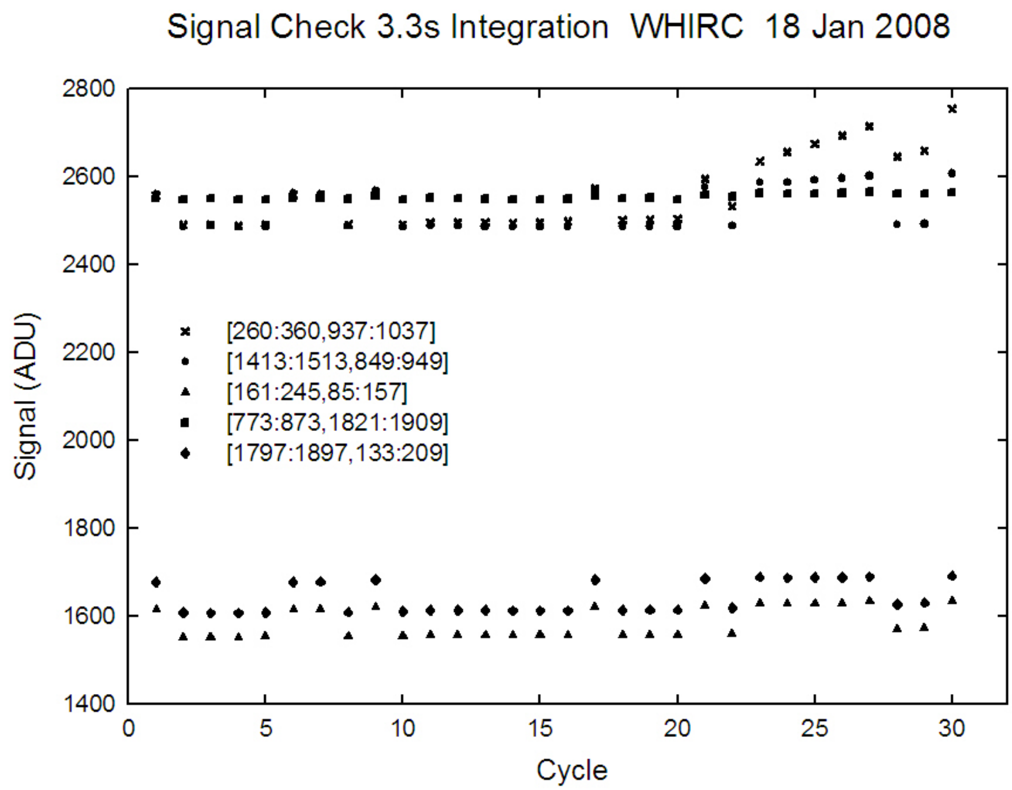


Figure 1: Signal values for five subregions within the "check" frames for the 30 different integration times used in the PTC experiment.

This plot will receive further attention in the section on linearity analysis. The odd behavior of the [260:360,937:1037] subregion near the end of the experiment (high signals in the PTC exposures) will also be discussed.

To make a reasonable attempt at extracting the system gain from the data, the frames were scaled within imexam, using the mean value of a 500 x 500 pixel region near the center of the array. This is not an intellectually satisfying solution, but is the only way to salvage a result, since the variance would otherwise be dominated by the variations due to the changing flux. The statistics were then calculated for five subregions within the array (the same used on the "check" frames in Fig. 1) which were apparently free of defects or hot pixels and spatially scattered to provide some variation in flux. The result is shown in Fig. 2.

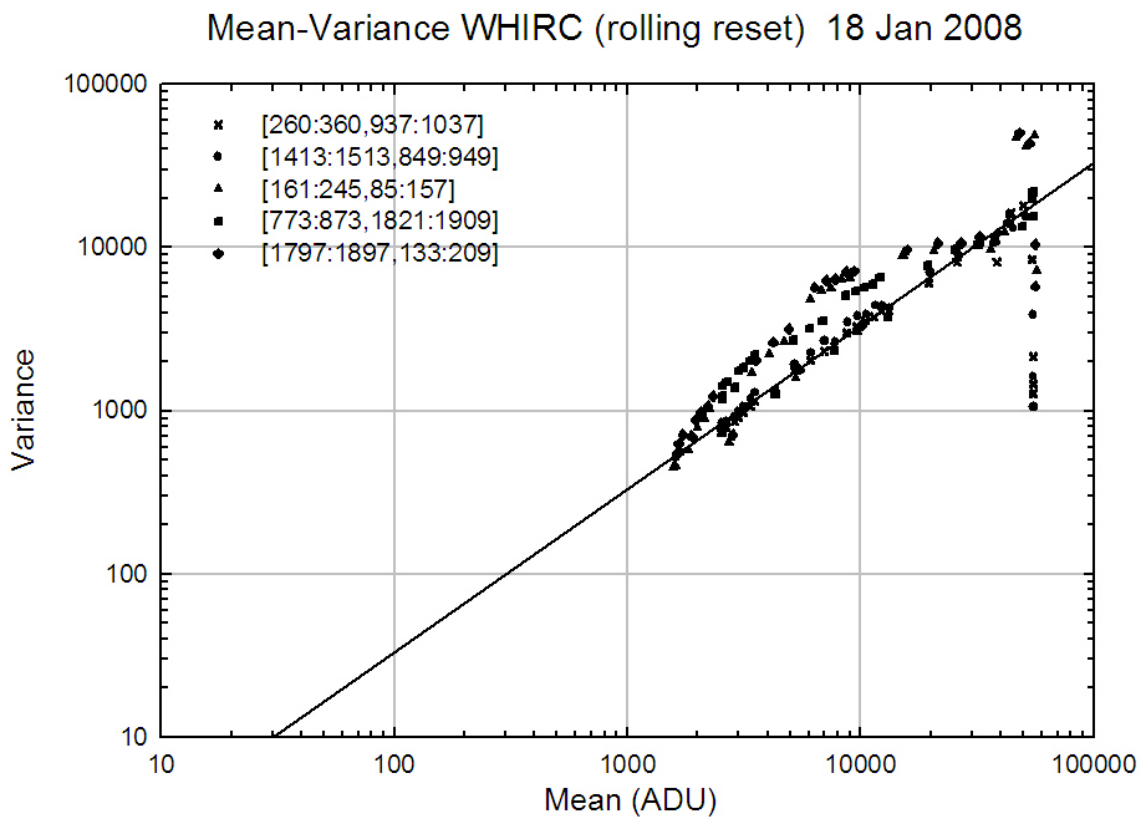


Figure 2: Mean-variance plot for five subregions within the PTC frames. All data were taken at DA4, F1. The read noise from a series of dark frames was 9.6 ADU. The read noise variance of 92 has been subtracted from the variance of the PTC frames. The straight line represents a gain of 3.0.

These results are not entirely satisfying. While the gain of 3.0 is consistent with earlier measurements of the rolling reset mode, there is a lot of scatter in the data. It is tempting to argue that the strategy of normalizing the frames within a set may not eliminate non-statistical noise, because of the discrete jumps in the flatfield flux, and thus the lower boundary of the variance represents the statistical value. For one thing, this gives the anticipated answer. However, some subregions of the array, particularly those at the bottom of the array where the signal is lower, also appear to have consistently larger noise. These subregions also differ in their linearity properties, as discussed below.

Linearity

Because of the known instability of the flatfield illumination, determining the linearity properties is problematic. However, the "check" frames suggest that the nature of the instability was jumping between two or three values, rather than a long-term increase or decrease in the flux. We attempted to correct for the source variability by making the simplistic assumption that the value of the "check" frame signal was representative of the flatfield illumination for the previous set of frames in the PTC data, so we normalized the mean for a given integration time by the ratio of the first check frame to that taken immediately after the PTC series for that integration time. Figures 3 and 4 show the linearity (mean signal vs integration time) for uncorrected and corrected data. The five subsections used for the mean-variance analysis were also used for the linearity. The data are plotted on a log-log scale to illustrate the behavior at short integration times.

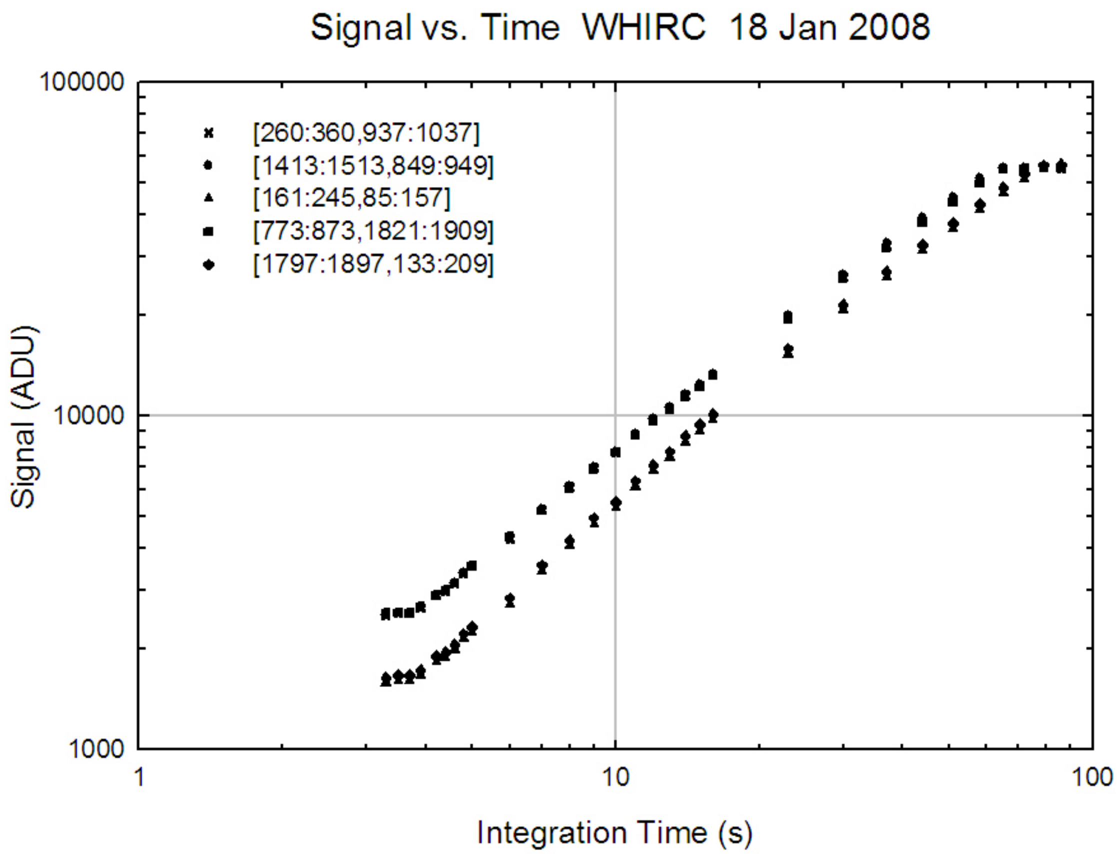


Figure 3: Plot of signal vs integration time for the five subregions used in the mean-variance analysis. The flattening of the curve at short integration times is unexpected.

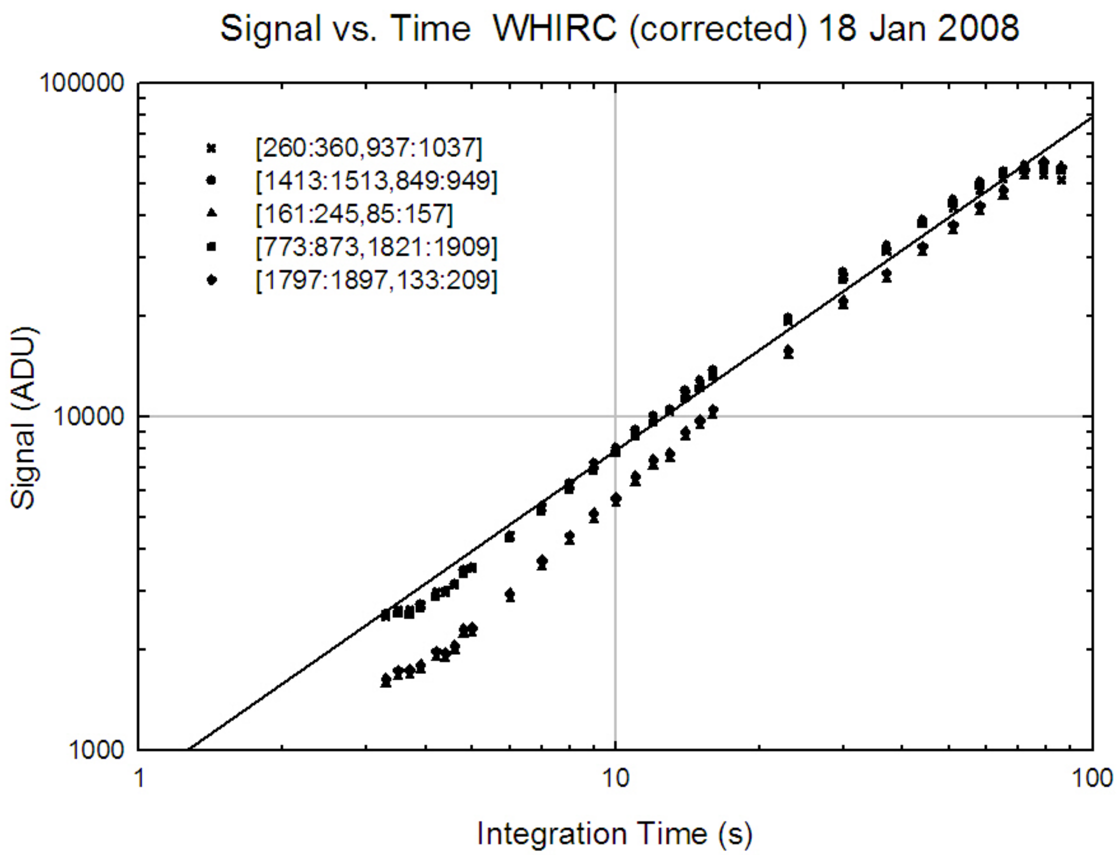


Figure 4: Same as Fig. 3, but with the mean signal values corrected for the estimated variation in flux as determined from the "check" images. The flattening off at short integration times is not as apparent as in Fig. 3, but is still present. The line represents a linear fit (slope=1) through the value for 10 s for the three "high" subregions.

Linearity Analysis

Although any conclusions with regard to the linearity of the WHIRC detector are tentative, due to the known instability of the light source, the general behavior is similar to that which was seen during earlier PTC experiments taken with the rolling reset mode. Typical infrared detectors are quite linear at low flux values, becoming sublinear (rolling off) at higher signal levels as the potential well fills up. The WHIRC behavior seems to show an initial sublinear (almost constant signal over a range of integration times) behavior, followed by superlinearity (slope > 1) up to ~ 10000 ADU and a fairly linear response until saturation begins at about 50000 ADU. This is difficult to understand physically. Moreover, the two subregions in the lower part of the array which appear to be less sensitive to light seem to show an even larger slope in the mid-flux regions.

One possible, although unlikely, explanation for the relatively constant signal over a range (3.3 – 3.9 s) of integration times is that the actual interval between the initial and final readouts is not the expected value. A constant offset in the integration time will also produce this type of behavior, but a quick attempt to model this required an unlikely large (3 s) offset.

The variation across the array was confirmed by taking the ratio of two images, one the mean of 30 s, the other the mean of 6 s. While the variation in flux level would explain a numerical value different from 5.0, the actual ratio frame (Fig. 5) has a significant variation, up to 8.0, particularly in the lower ~250 rows of the array. One can infer this from Fig. 4, where the linearity curve for the lower portion of the array is much closer to that for the upper portion at 30 s than at 6 s. The transition to the more pathological lower region of the array occurs near the same row (285) as the PED, but this could be coincidental.

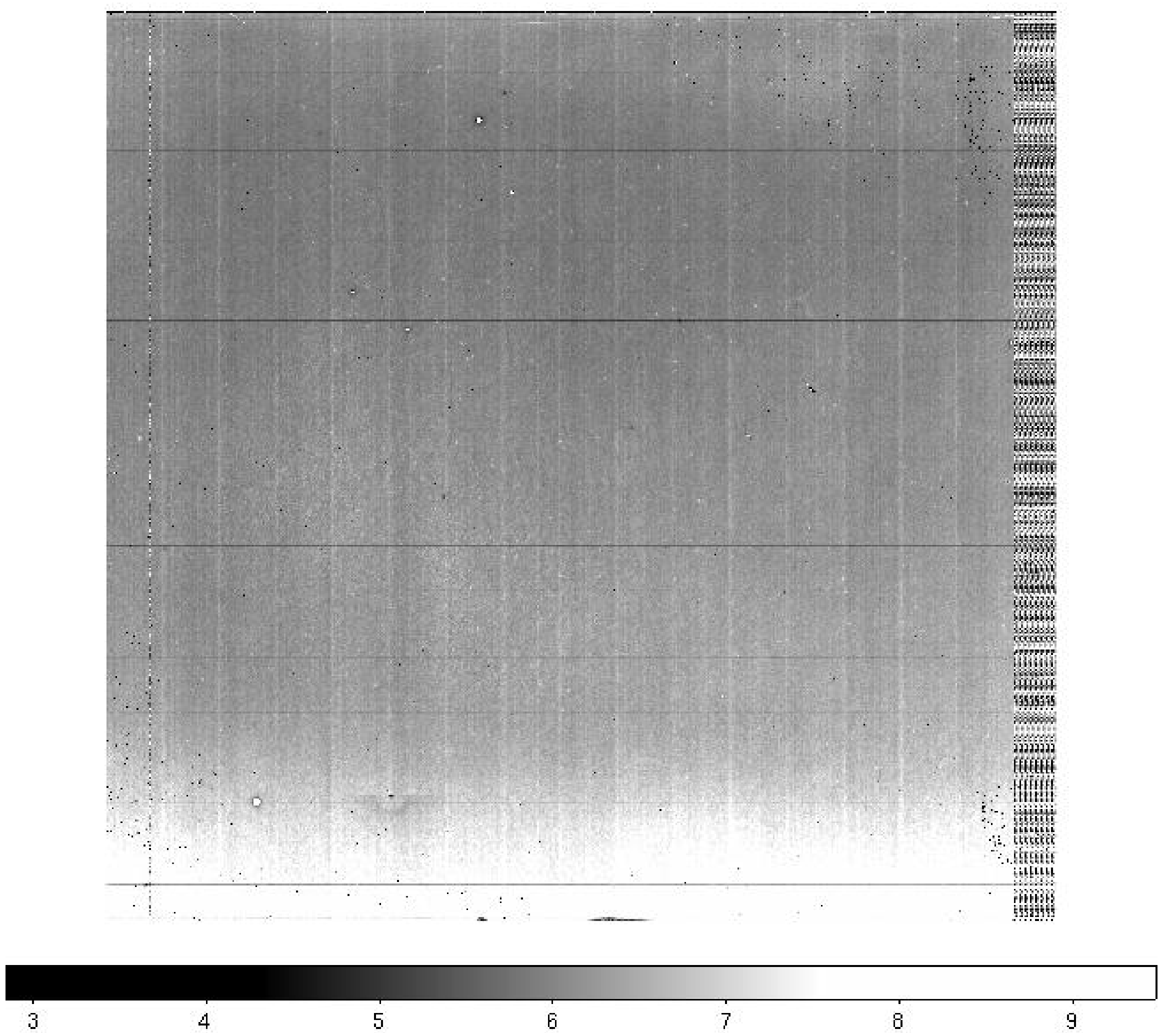


Figure 5: Image of the ratio of the flatfields for 30.0 and 6.0 s. The value in the upper 80% of the array is between 5.5 and 6.4, increasing to near 8.0 at the bottom of the array. The PED artifact [641:285] is weakly visible.

Returning to Fig. 1, the unusual behavior of the "check" signal level for the [260:360,937:1037] subarray was deduced by taking the ratio of "check" frames near the end and beginning of the PTC experiment. The ratio frame clearly showed the "palmprint" due to the PED as a bright (ratio > 1.0) feature, even though the ratio was of two frames of the same integration time. The difference is that the numerator frame was taken following a series of long integration time PTC frames which filled the wells nearly to capacity

Conclusions

1. Both the mean-variance and linearity analysis have an element of uncertainty because the flatfield lights did not produce a constant flux. The "check" frames showed that the lamp illumination jumped between two or three discrete values. The signal instability appeared to be larger for the two subregions in the lower part of the array for presently unknown reasons.

2. Within the uncertainty set by the known instability of the light source, the mean-variance analysis is consistent with the gain value of 3.0 e/ADU determined in earlier experiments. The two subregions in the lower part of the array are not well-behaved in this analysis.

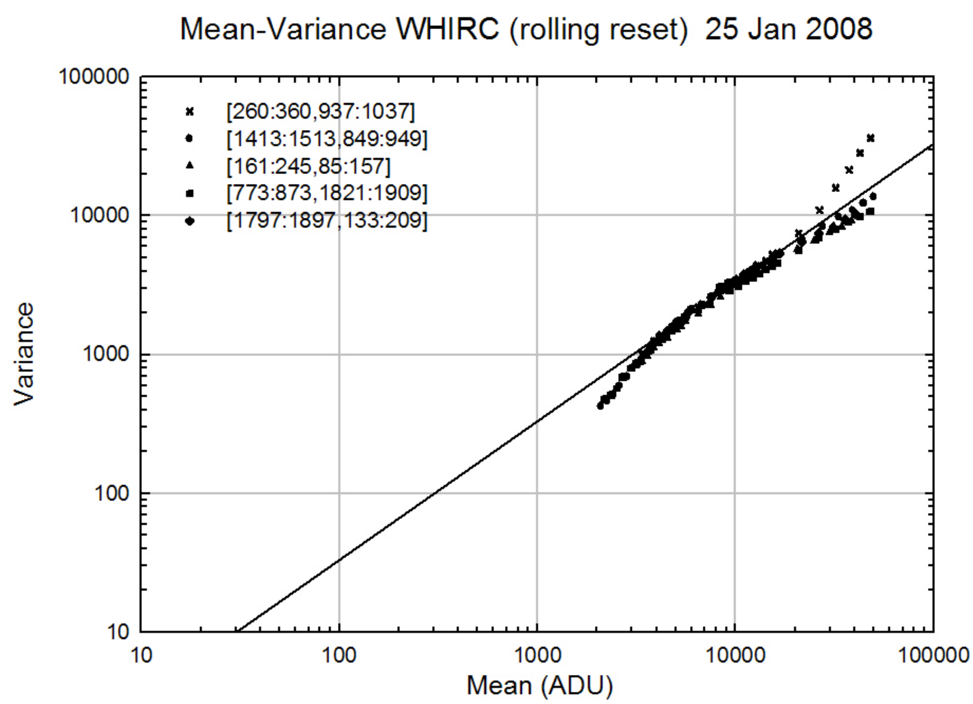
3. The linearity of the array is not well understood. The light source fluctuations make a quantitative analysis difficult, but the general behavior was seen in earlier tests using the rolling reset mode. This is characterized by a relatively low slope at short integration times followed by a region where the slope > 1, up to the point where well saturation begins. The array appeared to saturate fairly uniformly at about 50000 ADU. This behavior appears more extreme for regions in the lower 250 rows of the array. Unfortunately, the inability to change filters (and background flux) made it impossible to test whether the transition points in the linearity curve were a function of integration time or signal level. This needs to be retested under known constant flux conditions at two or more flux levels. Perhaps the science observations of clusters will provide this information. Concerns would be: 1) an error or offset in the actual frame time; 2) a change in the capacitance of the potential well with charge which causes the gain (e/ADU) to *decrease* and thus explain the "superlinear" behavior.

4. Although the PED is no longer obviously visible in images taken in the rolling reset mode, it is still there. Long dark frames show the "palmprint" associated with the PED emission (which look similar to those which were taken in global reset mode). The check frame experiment produced the interesting result that a short frame taken after a long (or high-flux) frame shows a residual PED artifact. This should also be investigated to see if the effect is a function of integration time or incident flux level, since residual effects of this sort may affect science observations which employ both long and short exposure times.

25 January 2008

Another set of PTC data were obtained on 25 January 2008 under slightly higher lamp settings which appeared to give a much more stable lamp behavior. The data mode was DA1F1, which will give significantly higher read noise than the DA4F1 mode used on 18 January. No "check" frames were obtained, but a quick look at the statistics of the individual frames for a given integration time suggested that the light was reasonably stable.

The data were reduced in the same way as for the 18 January 2008 data, except that the read noise was calculated for each of the five subregions in the array. We plotted the mean-variance curve both with and without subtraction of the read noise variance (Figure 6). Although there is no physical justification for the second plot, the fit to the g = 3.0 e/ADU line seems better, although there is more scatter in the data.



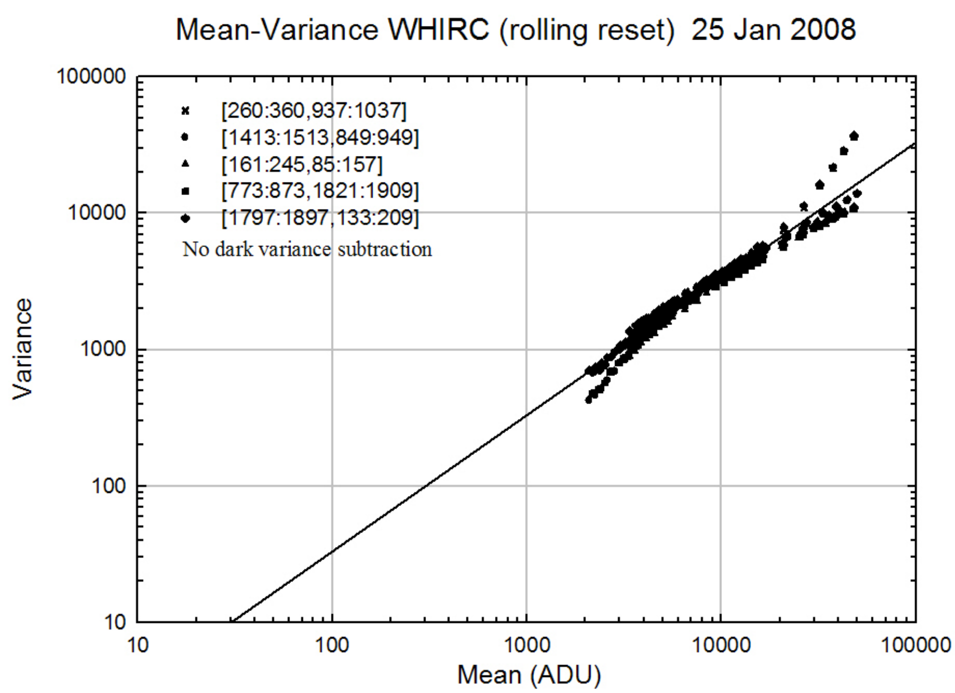


Figure 6: Mean-variance plot for data of 25 January 2008, for the same 5 subregions used in the 18 January 2008 analysis. The data are plotted with and without subtraction of the read noise variance (top and bottom panels, respectively). The line represents a gain of 3.0.

The linearity (signal vs integration time) plot is shown in Figure 7. The data do not appear to show the "flattening out" at short integration times seen in Fig. 3 (some of which may have been a result of the changing lamp flux), but still have the "superlinear" behavior which is difficult to understand.

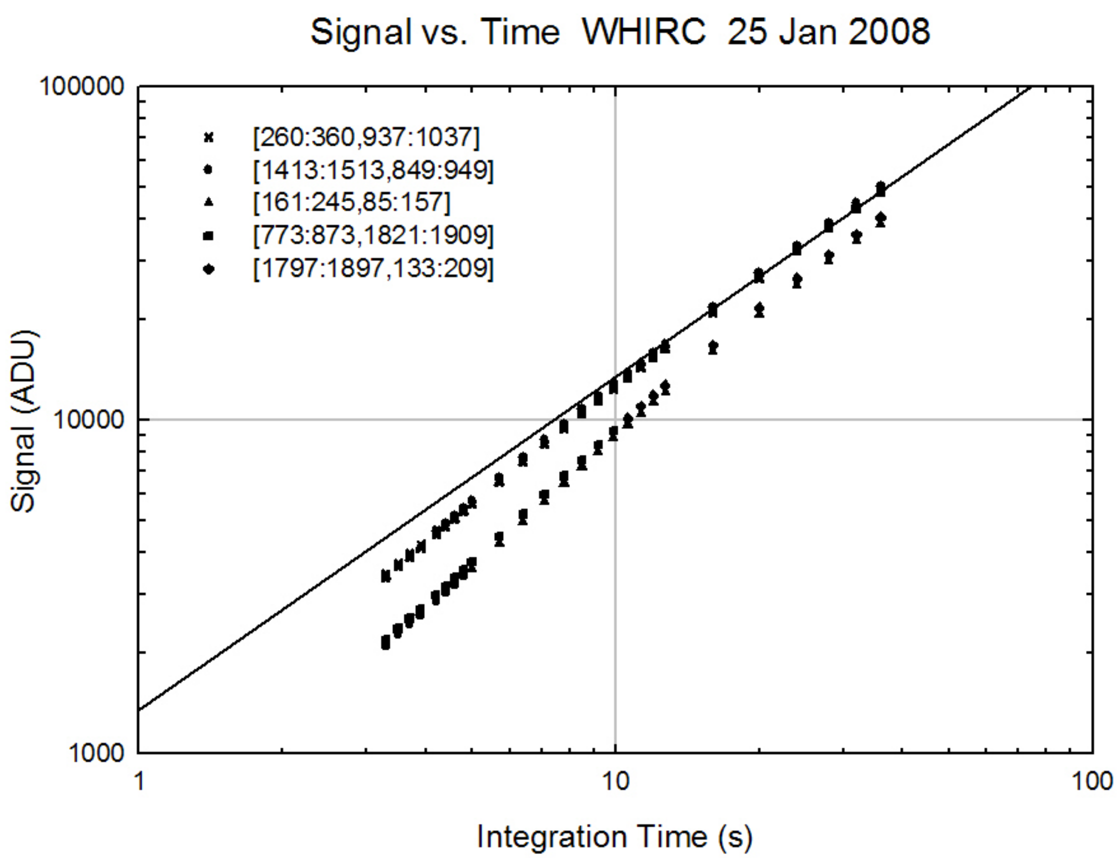


Figure 7: Plot of signal vs. integration time for the data of 25 January 2008. The line represents a slope of 1.0 fit to the data above 20000 ADU.

Conclusions

The new data are still consistent with a gain of 3.0, although the fit is still not particularly satisfying, especially for regions in the bottom 250 pixels of the array. The "superlinear" behavior is still present at about the same magnitude as for the 18 January 2008 data, although without the flattening at short integration times. Although the lamp flux was higher than in the 18 January experiment, the difference was not sufficient to determine if the linearity behavior is a function of signal or integration time. This will be critical in evaluating the system for science observations.

31 January 2008

This is another set of PTC data obtained using the Ks filter under much lower flux conditions. The current analysis is only of the linearity, to evaluate whether the unusual behavior seen in the earlier data could be a function of integration time (which would suggest a timing error) or of the well depth. The results are plotted in Fig. 8. Unlike the previous analyses, this used the mean statistics for the entire array rather than smaller subregions, but the general trend is very similar to that in Fig. 7, suggesting that the nonlinear behavior is tied to the signal level rather than the integration time.

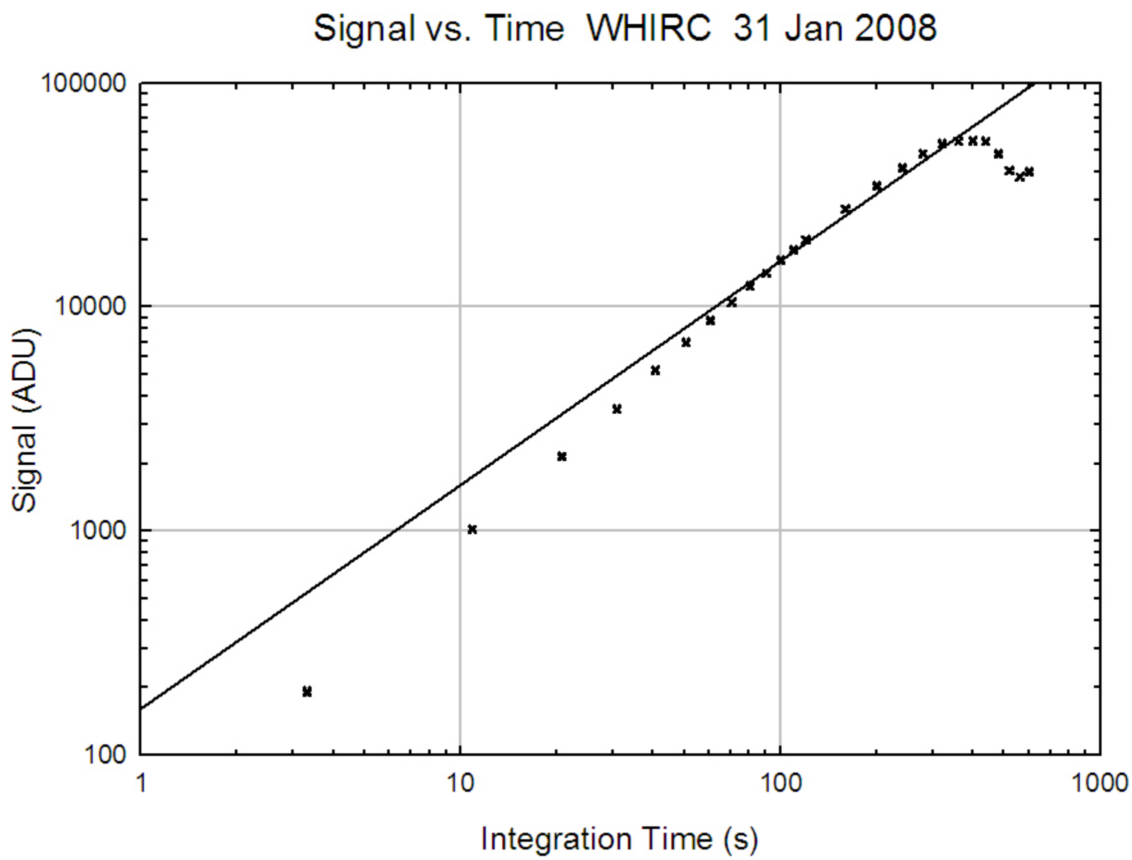


Figure 8: Plot of signal vs. integration time for the data of 31 January 2008. The line represents a slope of 1.0 fit to the data above 20000 ADU. The statistics are for the entire array rather than small subregions.

VISTA Data

A paper by Bezawada & Ives (*Scientific Detectors for Astronomy 2005,* J. Beletic *et al.* (eds), pp 499-506) describes some performance tests of some of the Raytheon VIRGO arrays for the VISTA project. Among the data were a PTC curve and a transimpedance conversion gain plot as a function of signal level of one of the arrays. The PTC curve suggested a gain of 6.25 e/ADU at a signal level of 10000 ADU; combined with the transimpedance conversion plot, this suggested an A/D step of 22.5 μv/ADU. It is not clear why the authors did not simply note this in the paper. Using the behavior of the transimpedance conversion gain with signal, one can generate a linearity plot similar to those presented for the WHIRC data. Fig. 9 plots the expected signal vs. integration time for a flux generating 1000 e/s.

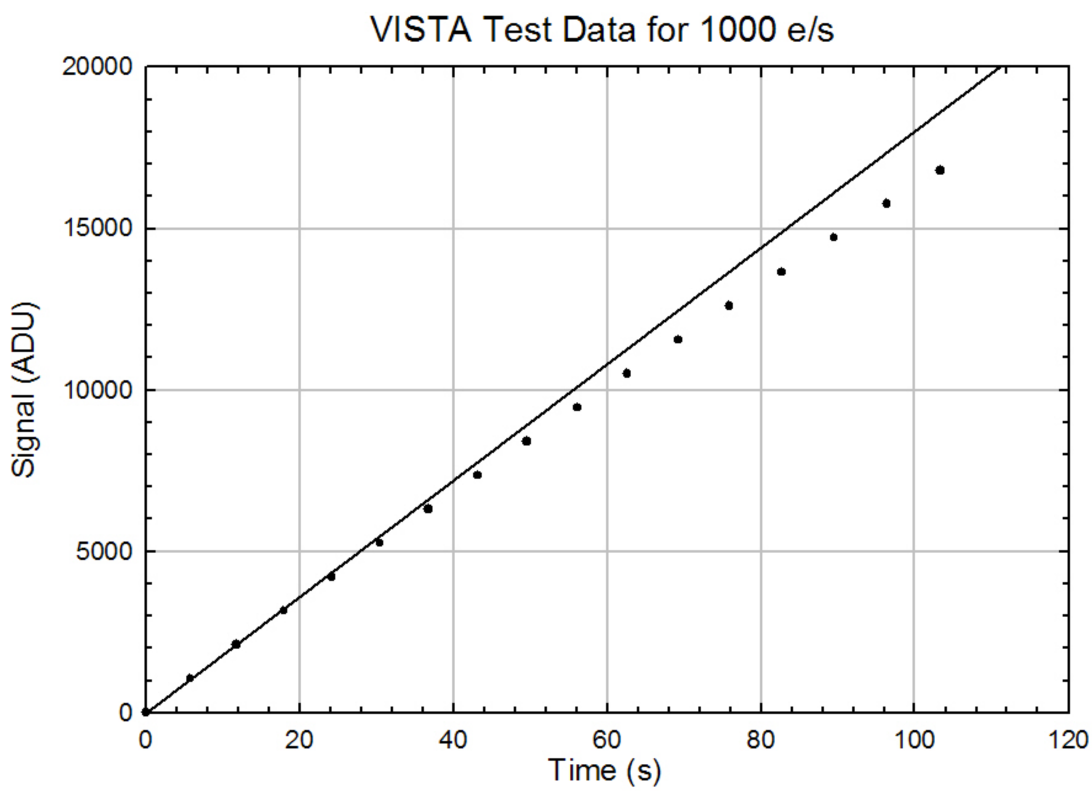


Figure 9: Simulated linearity plot for VISTA array SCA-45 at 1000 e/s using the measured transimpedance conversion gain plot.

The mean-variance data are plotted in Fig. 10.

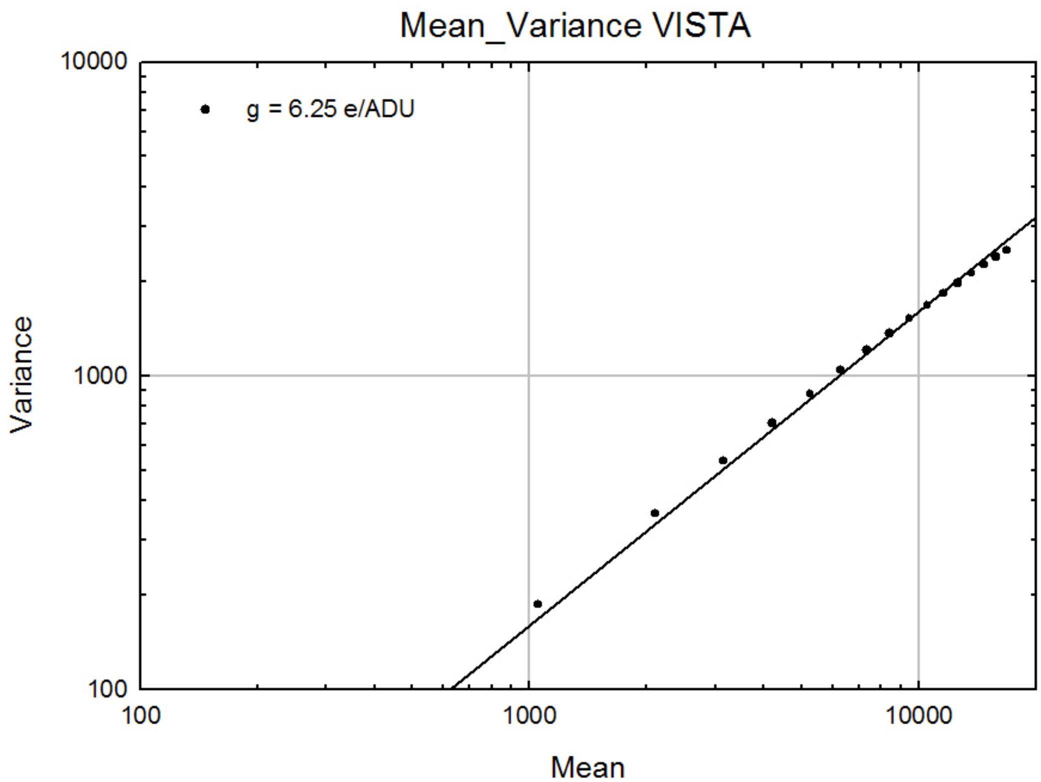


Figure 10: Mean-variance data from Bezawada & Ives for VISTA array SCA-45, plotted on a log-log plot for comparison with the other figures in this report. The line represents a gain of 6.25 e/ADU.

Conclusions

The VISTA data are quite revealing in that they suggest a nonlinear behavior similar to that which has been seen with other detectors, in which the sensitivity decreases with signal level (sublinear behavior). This is expected on physical grounds, since the capacitance of the detector junction will increase as the well fills up, requiring more electrons to give a given voltage change on the capacitor. The authors state in their paper that both global reset and row reset can be tested, but did not note which mode was used for their published plots.

The strange behavior of the WHIRC array remains unexplained. Since the data from August 2007 using the global reset mode suggest a linearity curve more like that seen with the VISTA array, the use of the row reset mode may be a factor. Unfortunately, the global reset mode does not appear to bias the array to the proper voltage and results in a much smaller well depth than does the row reset mode. The best course of action may be to see if the linearity behavior of the WHIRC detector is stable and amenable to compensation in the data reduction process.

Thanks to Charles and Heidi for providing a copy of the paper.