Report on Analysis of WFCAM Commissioning Data

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Abstract

This report details our analysis of WFCAM commissioning data taken during November & December 2004. The aim of this work has been to establish whether the performance of WFCAM meets the criteria imposed by the science goals of UKIDSS. We provide a summary of our findings with currently unresolved issues that must be addressed before design of the UKIDSS observations can be completed.

1 Data Analysis

The sub-sections here follow the WFCAM on-sky characterisation check-list found at:
www.jach.hawaii.edu/UKIRT/instruments/wfcam/commissioning/on_sky_tests.html

1.1 Detector noise

Read noise

- Correlated double sampling (CDS) read mode results in a read noise of 19e$^-$ but the effect of 'banding' (see below in 'Dark current stability') effectively increases this to 21e$^-$. Due to a bug in the data acquisition software, it is not presently clear whether the read noise in non-destructive read (NDR) mode can be measured from current commissioning data. Measurement of NDR read noise is crucial to determine whether UKIDSS will achieve background limited data in the Z & Y filters (see 'Background limit' below).

Cross talk

- Not measured

Bad pixel stability

- Not measured

Dark current stability

- 'Banding' is present in all darks with a standard deviation of 11e$^-$. An example is seen in Figure 1 which shows the difference image of two consecutive 1s darks (image IDs are 00017 subtracted from 00018; data from 8/11/04). Figure 2 shows the cross section of the top left quadrant in this plot, averaged over 50 rows. The plot on the right shows a magnified version of the cross section. Both plots show that the banding appears to consist of a larger scale random fluctuation and a regular small scale signal.
- Darks taken immediately after a science observation are not useful due to array persistence after being exposed to unfiltered sky during movement of the filter assembly to the dark filter. Darks are only useful after 3 or 4 have been taken and this seems to be independent of the dark exposure length. This is demonstrated in Figure 3 which shows the following four noticable artifacts die away as subseqent darks are taken: 1) A 'flare' in the bottom right corner of array

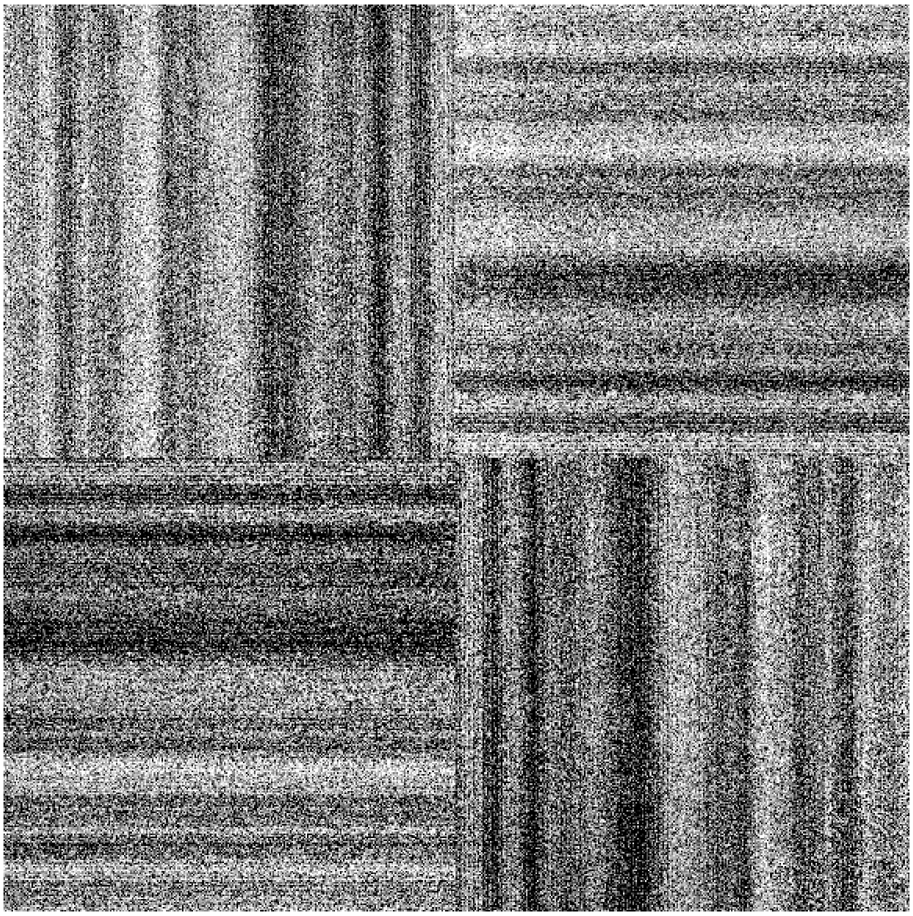

Figure 1: Image banding (array 2 shown). This frame is the difference between two consecutive 1s darks.

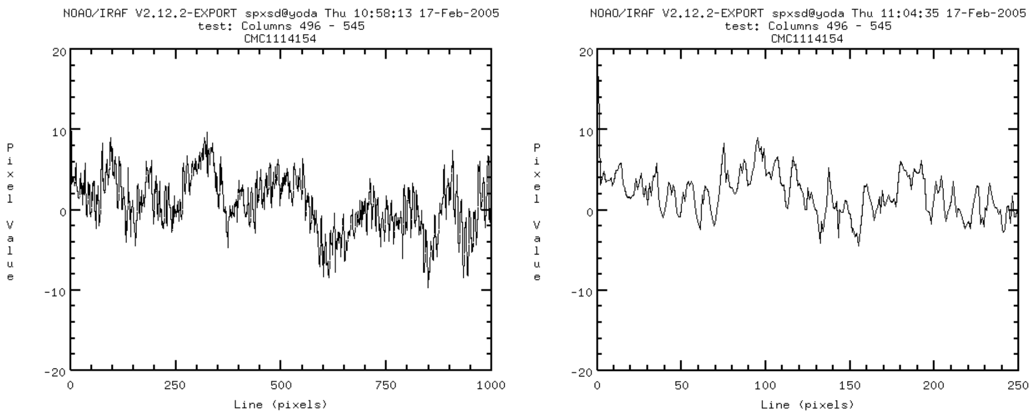

Figure 2: *Left*: Cross section through top-left quadrant of Figure 1 averaged over 50 rows in centre. *Right*: Plot on left zoomed in by $\times 4$ to show the regular small scale structure.

1. 2) Large-scale brightening in bottom left corner of array 3. 3) A dark spot near centre of array 3. 4) A bright line about 100 pix into array 4 from the middle right hand edge. The decay of these features seems to be independent of the dark integration time.

- Discrepancies were found in counts in darks taken before and after telescope movement in one particular case. Figure 4 shows dark levels averaged over a central 200×200 pixel area for a selection of 1s dark frames taken at the beginning of the run on 8/11/04. There is a gap of 2.5 hours and a telescope slew of (+3h,0°) between darks 5 & 6 (image IDs 00009 & 00017) yet the counts are consistent. However, darks 13 & 14 (image IDs 00024 & 00025) were taken consecutively and are separated by only 4 minutes during which time the telescope slewed by (-3h,-20°). As the figure shows, the central dark levels made an abrupt change, especially in array 4 (the reset anomaly also differs markedly between these two frames, the most significant difference again in array 4).
- Longer darks (ie. > 5s) that are taken 3 or 4 readouts after a filter change (see reset anomaly below) are fairly consistent throughout the night although array 4 exhibits noticably more variation.
- Dark counts (again in central 200×200 pixel region in all arrays) were found to be independent of integration time (darks tested were integrated for 10s, 20s, 30s & 40s).

Reset anomaly

- The reset anomaly is not properly subtracted from science frames of $\sim 1-2$s, despite matching dark and science frame integration times.
- Variation in the shape of the reset anomaly throughout a given night is usually within the total read noise so long as images are > 5s and are not taken immediately after a filter change. However, differences between the reset anomaly in the dark (taken with identical NEXP and EXP_TIME), and the data have been seen. For example, in the data of 9/11/04, (NEXP=5, EXP_TIME 10s, K band, count level ∼6000), subtracting an average dark formed using the three frames 00335-00337 from the science observation 00338 leaves a reset anomaly visible at a level of 10% of sky in array 1. The 3 darks show reasonable agreement between each other with regard to reset anomaly. This affects flatfielding by self-flats (see 'Flatfield/Scattered Light' below).

1.2 Microstepping

Not assessed yet.

1.3 Sky Emission

Not assessed yet.

1.4 Fringing

No fringing seen in any of the filters at any scale. Fringing is at the level of $<< 1\%$ of background.

1.5 Sensitivity

Not assessed but the zero points determined by CASU are consistent with the UKIDSS survey limits set out in the science proposal.

1.6 Background limit

The proposed observing strategy for the shallow surveys is to use a standard exposure time of 5s, building the 40s per field with two 2×2 microstep sequences. With such a strategy, observations in the Y & Z filters will be far from background limited. In Y, 5s gives a background level of about 400e$^-$ so that the CDS read noise of $\sim$20e$^-$ effectively increases the sky noise by 40%. The meaning of 'background limited' needs to be defined, but anything worse than the read noise contributing 10% to the sky noise shouldn't be tolerated. For the Y band and the current CDS read noise, this amounts to an integration time of 25s, 5 times too long ! (ie. the background level would be 2000e$^-$ with the read noise contributing an extra $1 - \sqrt{(20 \times 20 + 2000)/2000} = 10\%$). The situation in the Z band is even worse.
The purpose of having 8 frames per 40s integration is for the improved sampling given by the microstepping and so that two independent array pixels contribute to every image pixel in the final interlaced frame to better eliminate bad pixels. This is vital in a huge survey that searches for rare objects, to minimise the amount of spurious data. It appears that a different strategy might be needed, e.g. not use microstepping in Y and Z and use a different read mode. Currently very little is known about the possible gains of using non-destructive read.

1.7 Cosmic Rays

Not assessed yet.

1.8 Persistence

- Dark current stability strongly affected by persistence effects (see above).
- Persistence of bright point sources clearly seen but a very preliminary analysis indicates that the decay isn't a power law (a more thorough investigation is needed).

1.9 Flatfield/Scattered Light

Flatfields created three different ways were analysed:
1. 'Linear twilight flats': For each pixel, the linear minimum χ^2 fit to pixel counts versus average frame counts for a set of frames where the sky is brightening is computed. The fit provides the Poisson error on the slope and hence the flatfield error. The range of frame counts is limited to the dark sky count level up to approx twice this value. The principle (employed by 2MASS) is similar to the lamp-on minus lamp-off method. Any constant term (e.g. thermal emission from dust spots) does not affect the fit.
2. 'Linear object flats': The same as linear twilight flats, but using dark sky frames in a long sequence, sufficient that the sky counts vary. These flats are as good as linear twilight flats for avoiding the effect of thermal emission, but limited in accuracy by the smaller variation in sky counts.
3. 'Self flats': Formed by taking a set of dark-subtracted dark-sky object frames, scaling to the mode and filtering out objects.
The three types of flats are were compared between each other, across different nights, and between filters. The main points are as follows:

- Flat fielding by the linear twilight or linear object flats demonstrates that there is significant thermal emission and/or scattered light from dust on the field lens, where a substantial fraction of the area is affected. The effect is as large as 15% in K. Figure 5 shows examples of this additive component. If this is typical of the state of cleanliness of the field lens, it is a serious problem for self flats. If the field lens will be very much cleaner in normal use, this problem (which causes errors in photometry of objects but doesn't create false objects) might not be serious. However, because this is intermittent, if the flat field and data are taken at different times, false objects or sky holes can appear. This would be a problem if considered typical of operating conditions. Finally, the dust changes, albeit slowly, with time although this isn't expected to pose a significant problem. There is no signature of dust that looks very different ie. that might be assoicated with the cryostat window, so perhaps this is very clean, or very out of focus.
- As described above in 'Reset Anomaly', in at least one dataset, we see a large difference between the reset anomaly in the dark and the data. After subtracting an average dark, the reset anomaly is visible at the level of 10% of sky. Self flats in this case would therefore create 10% errors in the photometry. Furthermore, because the sky level varies by 15% across the K sequence, the background will not be flat after flatfielding by up to 1.5% of sky, with jumps between quadrants.
- Linear object flats are not really an option because the variation in sky count is too small, so the Poisson error for a typical MSB is too large. They are, however, useful as checks.
- Linear twilight flats, for the range in counts used ie. dark sky to twice dark sky, give a flat field accuracy of about 0.4%. A 10s K-band image (DXS and UDS may use 10s integrations) would have about 30,000 photons per pixel, or a Poisson error of 0.6%. So the linear twilight sky flat makes a significant contribution to the noise: A number of nights worth of data must be averaged if the proposed scheme is to flatfield and subtract a constant. However, provided the sky level doesn't vary too rapidly, this accuracy could be sufficient under the alternative scheme of dividing by a linear twilight flat, then creating some sort of average 'sky' frame (scaling or offsetting, it doesn't matter which if sky variation is small), and subtract. Sky subtraction (and thermal dust subtraction in the K band) will be near perfect, and the flat field is certainly accurate enough for the photometry of the objects that remain. The accuracy of this scheme is essentially flat-field error times fractional sky variation and should be sufficient if the latter is a few percent.
- Each array typically has $\sim 0.1\%$ of pixels that are identifiably 'bad'. A significant fraction of these appear to be associated with the banding, ie. solving the banding would solve the bad pixels. In the meantime they are a worse problem than cosmic rays, but ought to be quite identifiable, being very bright, and confined to a pixel.

1.10 Astrometry

Not assessed yet.

1.11 Guiding

Not assessed yet.

1.12 Photometry

Not assessed yet.

2 Summary

- The fact that the reset anomaly in short, 1-2s integrations typically differs between the data and the darks may prove a concern for calibration observations.
- Three or four ‘dummy integrations’ are likely to be needed after changing filter, to allow persistence of unfiltered array exposure to sky to decay sufficiently.
- Are the reported sudden changes in dark levels seen after a telescope slew cause for concern? What is the likely cause?
- The issue of not reaching the background limit in the Y & Z filters with current MSB design philosophy and the CDS read mode must be resolved. What improvement can be expected with NDR reads?
- Currently the reset anomaly, in exhibiting occasional differences between darks and data, appears to dictate that self flats are not viable. This conclusion is based on only a small dataset.
- Currently the dirty field lens causes significant problems at all wavelengths and *has* to be solved.
- Linear twilight flats could deal with the reset anomaly problem, provided the reset anomaly is fairly constant over the object sequence (the problem is the difference between darks and objects), and provided an average ’sky’ frame is created after flat fielding that is then subtracted.
- A scheme for identifying bright anomalous bad pixels, and giving them zero confidence, is necessary.

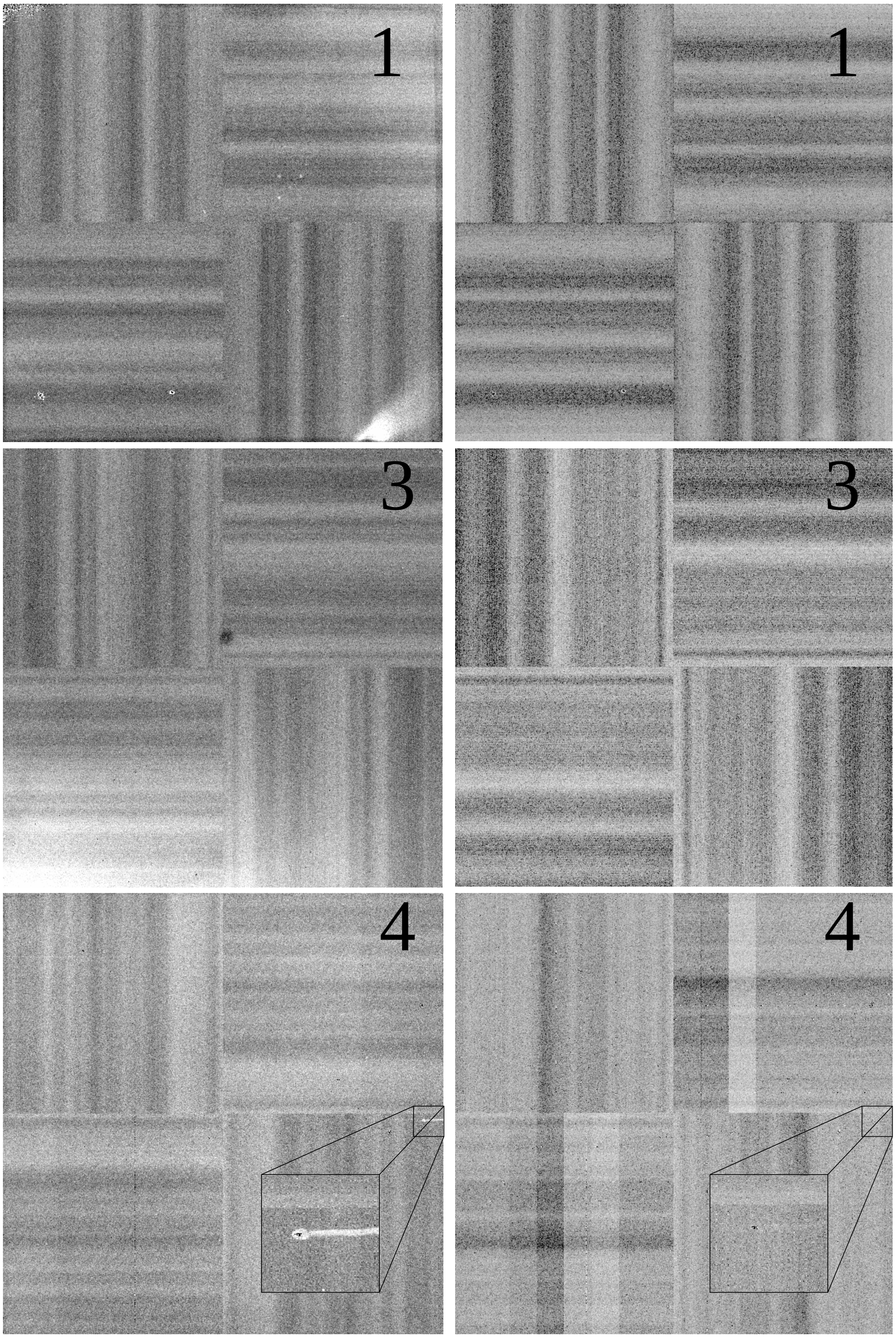

Figure 3: Effects of persistence on darks. Shown here are image pairs created from three 10s darks (image IDs 00335-00337 from 9/11/04) taken immediately after a science observation. Left column shows (dark1-dark3) and right column shows (dark2-dark3), where darks were observed in order dark1, dark2, dark3. Rows correspond to arrays 1, 3 & 4 as labelled. The four features identified in the text decay noticeably between dark1 and dark2, but do not decay to an insignificant level until ∼dark 4.

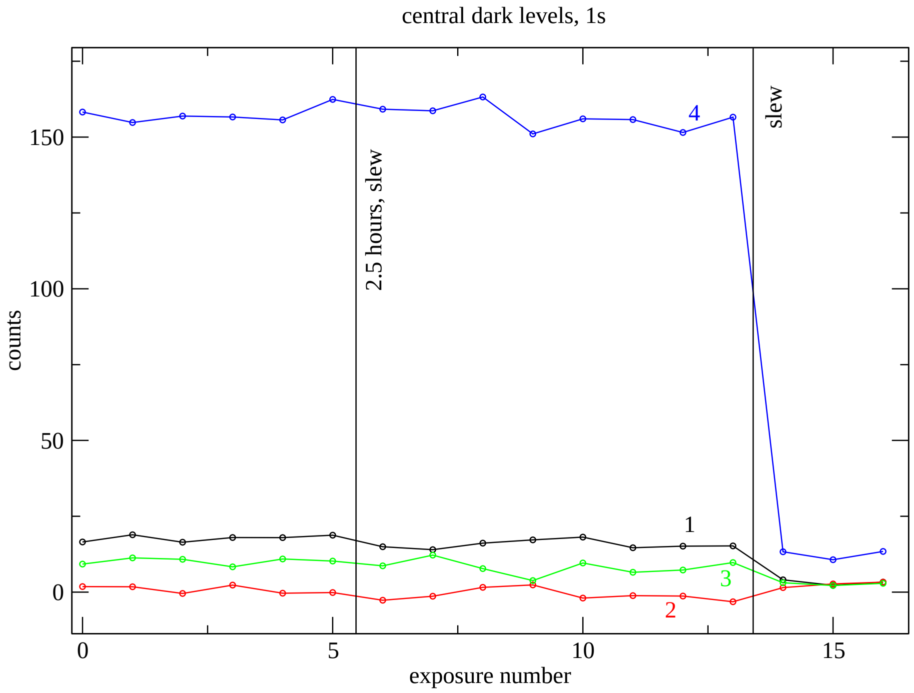

Figure 4: Variation of levels in central 200 × 200 pixel region of 1s darks for all arrays as labelled. A gap of 2.5 hours exists between darks 5 & 6 together with a telescope slew. The sudden change in levels seen between consecutive darks 13 & 14 occurs after a telescope slew and a pause of only 4 minutes.

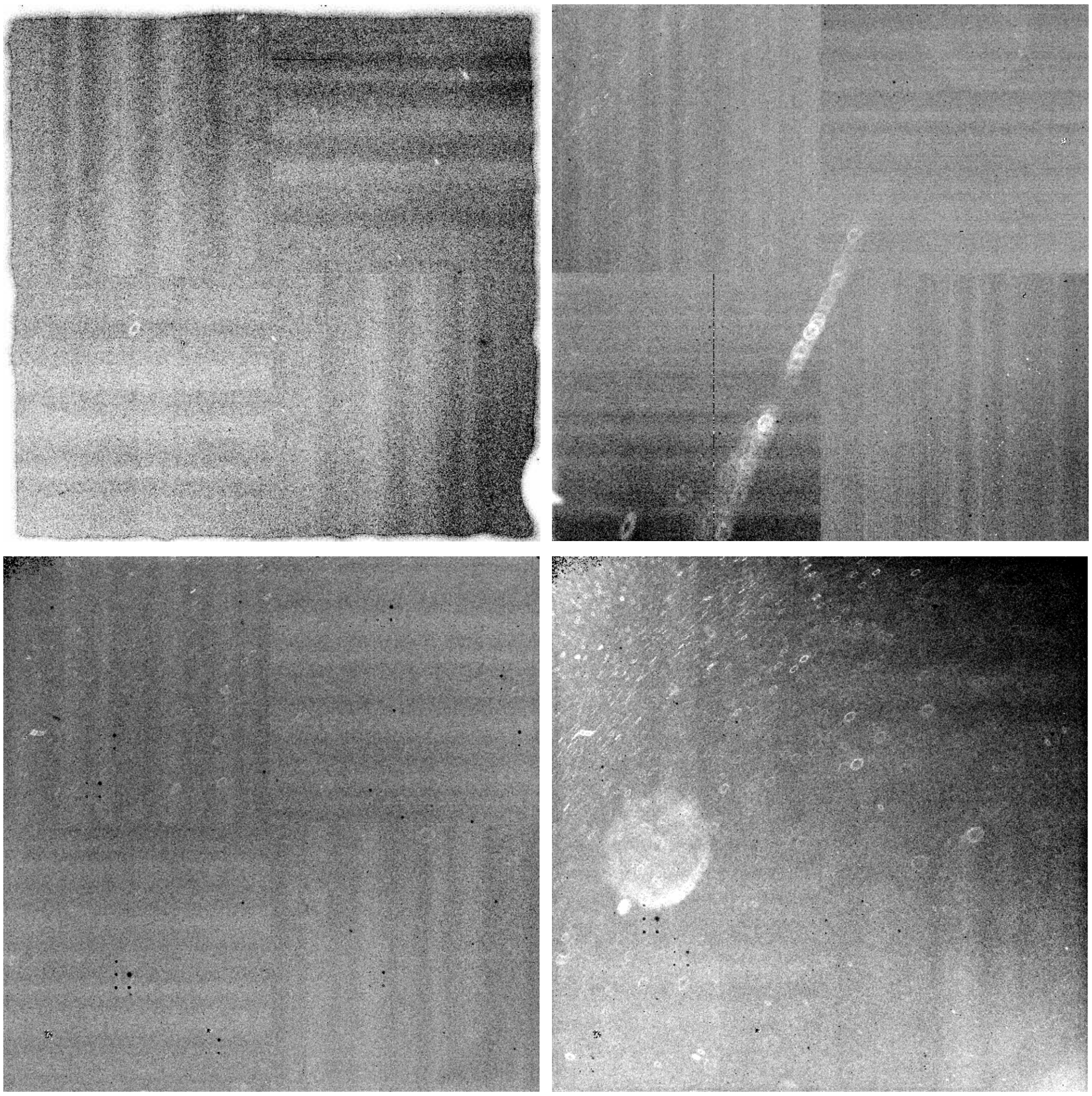

Figure 5: Four examples of additive components seen in flatfields in Y band array 2 (top left), J band array 4 (top right), H band array 1 (bottom left) and K band array 1 (bottom right).