Notas Técnicas do
Laboratório Nacional de Astrofísica

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LNA/NT/2015-11
June/2015

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2015, June 22

Abstract: The base mean level (bias) of images taken with CCD Andor Ikon 9867 is observed to significantly vary with time in a cyclic manner on time scales of a few minutes. This effect, if not taken into account may lead to erroneour interpretations of astronomical observations performed with the detector. This technical note contains a preliminary characterization of these bias variations.

Key words: Detectors – CCD cameras – Instrument characterization

1 Introduction

Using CCD Andor Ikon 9867 for time series astronomical observations at the Observatório do Pico dos Dias of the Laboratório Nacional de Astrofísica during 2014 and 2015, cyclic variations of the sky background were detected. These can be traced to variations of the base mean level (bias level) imposed upon the individual images. The technique used to reduce the astronomical images includes the subtraction of an average bias images from the object frames. For this purpose, a series of bias images is taken before or after the astronomical observations. If the bias is intrinsically variable, this variability is preserved in the individual images even after the subtraction of some average bias level. This translates into variations of the signal level in these images which mimick changes in the sky background.

This technical note is meant as a preliminary characterization of this effect.

2 Data

In order to characterize the bias variations, several series of bias images were taken on two days at different detector temperatures[1]. Details are given in Table 1. Each series consists of 2500 images, spanning a total time base of $\sim 18^{\mathrm{m}}$. The sequence of the three series taken on 2015, June 8, is such the detector temperature was increased between the individual series, while on 2015, June 12, the temperature was decreased. On 2015, June 8, the data were taken in the late afternoon, while on June 11 they were taken in the early morning right after the end of the observing night. In all cases the minimum exposure time of $0^{\mathrm{s}}.00001$ permitted by the data acquisition system was used, and the camara shutter remained permanently closed. Care was taken to permit the temperature to stabilize before inicitating the exposure sequences.

These series of bias images are too short to enable the characterization of bias variations over a time scale of several hours, the typical duration of astronomical time series obserations

[1]During the first of these days, the temperature was not recorded with high precision. The temperature values for these series, quoted in Table 1 are therefore reliable only to about $\pm 1^{o}$C.

Table 1: Bias data

Series No.	Date	Detector Temperature	Pre-amplifyer setting	Fractional amplitude variation
#1	2015 Jun 12	-72.8 ^{o}C	1×	$5.9\,10^{-3}$
#2	2015 Jun 12	-66.3 ^{o}C	1×	$5.2\,10^{-3}$
#3	2015 Jun 12	-50.7 ^{o}C	1×	$4.4\,10^{-3}$
#4	2015 Jun 12	-29.9 ^{o}C	1×	$6.5\,10^{-3}$
#5	2015 Jun 08	-41 ^{o}C	4×	$10.1\,10^{-3}$
#6	2015 Jun 08	-61 ^{o}C	4×	$11.4\,10^{-3}$
#7	2015 Jun 08	-72 ^{o}C	4×	$0.5\,10^{-3}$

Table 2: Sky background light curves

Light curve No.	Date	Detector Temperature	Pre-amplifyer setting	Time base
#1	2014 Jun 21	-70.8 ^{o}C	4×	$4^{\rm h}\ 28^{\rm m}$
#2	2015 Jun 09	-72.1 ^{o}C	4×	$4^{\rm h}\ 56^{\rm m}$
#3	2015 Jun 11	-52.8 ^{o}C	1×	$4^{\rm h}\ 20^{\rm m}$

performed by the author. To do so, I will investigate the sky background behaviour in observations of the same stellar field in stable atmospheric conditions, spanning some hours and sampled with a time resolution of $5^{\rm s} - 6^{\rm s}$. Variations in the sky background can then be regarded as a proxy for bias variations. Three series were selected which are detailed in Table 2.

In all cases an A/D rate of 3.0 MHz was used. For the time series measurements of the bias (Table 1), readout has been restricted to a small field of 258×258 pixels at the centre of the CCD (no binning). Instead, the field from which the light curves were obtained comprise 1024×1024 pixel (again, with no binning) on 2015 June 9 and 11, while on 2014, June 21 the entire CCD (field 2048×2048 pixels) was read, using a binning of 2 in both dimensions.

3 Results

3.1 Bias variations

The variations seen in the seven series of bias images are summarized in Fig. 1. The four frames at the left hand side show the temporal behaviour of average of all pixel values (somewhat loosely termed "count rate" here) in each bias frame as a function of time for the series taken on 2015, June 12. Detector temperature decreases from top to bottom. The frames at the right side show the same for the three series taken on 2015, June 8. Note that the vertical scale is the same for all frames, permitting a direct comparison of the amplitude of the variations. The following characteristics are obvious:

- Except for series #7 (lower right frame) in all cases strong systematic variations of the bias level are seen.
- The shape of the variations exhibits significant variations which aparently depend on the detector temperature (note, however, that it has not been investigated if the temperature dependence of these shapes can be reproduced at other epochs).

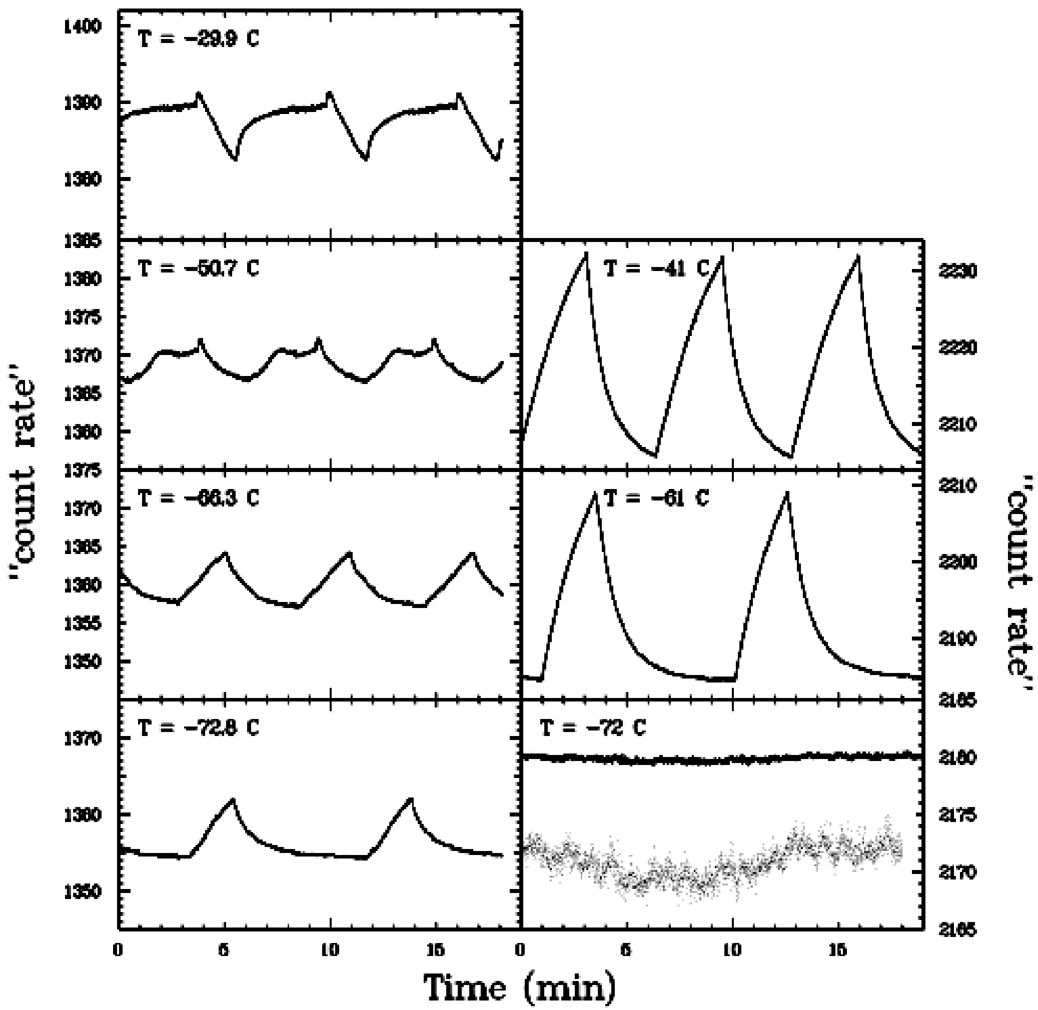

Figure 1: Temporal variations of the bias under different circumstances. See text for details.

- The time scales of the variations (I refrain from using the term "period"; see below) are not stable. The separation between individual peaks or minima vary significantly.
- On the 2015, Jun 12, the total amplitude of the variations is much smaller than on 2015, Jun 08 (except for series #7). At the same time, the average bias level is significantly reduced with respect to the level observed on 2015, Jun 12. This latter effect is due to the different pre-amplifyer settings on the two dates.
- The fractional amplitude variation (i.e., the difference between minimal and maximal bias level, divided by the average bias level) is quoted in Table 1. While no consistent variations with detector temperature is discernable, it increases significantly with the average bias level, being much larger on 2015, Jun 08, than on 2015, Jun 12 (again, with the expection of series #7).
- Most suprisingly, the behaviour of series #7 (lower right frame of Fig. 1) is drastically different from that of all other series. Here, the bias level (upper graph) is almost constant. The lower graph[2] shows the same data on an expanded vertical scale. Some small variations with time are still present (the total amplitude is just 1.18 counts), but they do no show the distinct pattern seen in the other series. Regarding the sky background variations of astronomical images as a proxy for the bias variations, this behaviour was never observed during dozens of observing nights in 2014 and 2015. Even observations taken just hours after obtaining series #7 at the same detector temperature exhibit the clear variability pattern of the other series.

3.2 Variability on time scales of hours

I will now investigate variations of the sky background in astronomical time series observations as a proxy of bias variations on the time scale of several hours.

As an example of a relatively well behaved case I first regard a sky background light curve observed during the night of 2014, June 21/22 (upper frame of Fig. 2). It shows a strong apparently periodic modulation with constant amplitude superposed on some much slower variations. The latter are probably due to real sky background fluctuations. During the following analysis they are removed by subtraction of a spline fit to the minima of the rapid variations from the original data.

The light curve was then subjected to a period analysis. Since the bias variations seen in Fig. 1 are far from sinusoidal, I refrain from using a Fourier analysis. Instead, I apply the analysis-of-variance (AoV) algorithm (Schwarzenberg-Czerny, 1989, MNRAS, 241, 153) which is better suited to find periods in non-sinusoidally varying signals. The AoV periodogram is shown in the second frame of Fig. 1. There is a strong peak at a frequency of $f = 10.8$/hour. The peaks at lower frequencies are all harmonics of this fundamental frequency. However, there is some structure around the princial maximum which indicates that the signal at frequency f is not pure.

This becomes also obvious when the light curve is folded on period $P = 1/f = 5\overset{\mathrm{m}}{.}56$, as shown in the lower frame of Fig. 1. While the mean waveform of the variations stands out clearly, a significant amount of data points do not follow the mean. This indicates either a variation of the period or of the phase of the variations.

A less well behaved case is shown in Fig. 3, which refers to the night of 2015, June 9. The data were treated in the same way as in the previous example. Instead of an (approximately) clean signal, the AoV periodogram now shows a broad distribution with two distinct peaks

[2] Note that the scale at the right hand side of the frame refers to the upper graph!

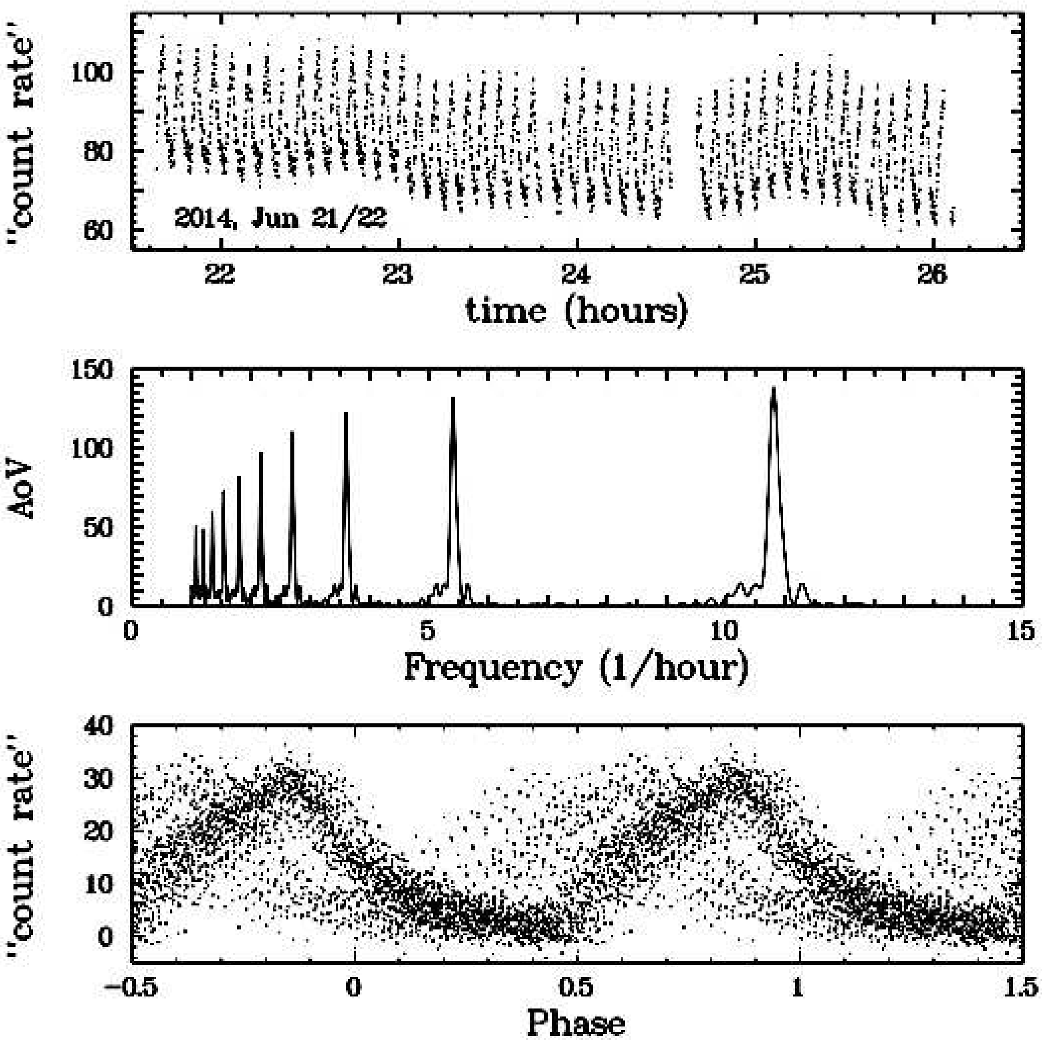

Figure 2: *Top:* Apparent sky background variations observed on 2014, June 21/22, induced by variations of the bias level. *Centre:* Analysis of Variance (AoV) periodogram of the sky background variations. *Bottom:* Sky background variations folded on the period correpond-ing to the main signal of the AoV periodogrom. See text for details.

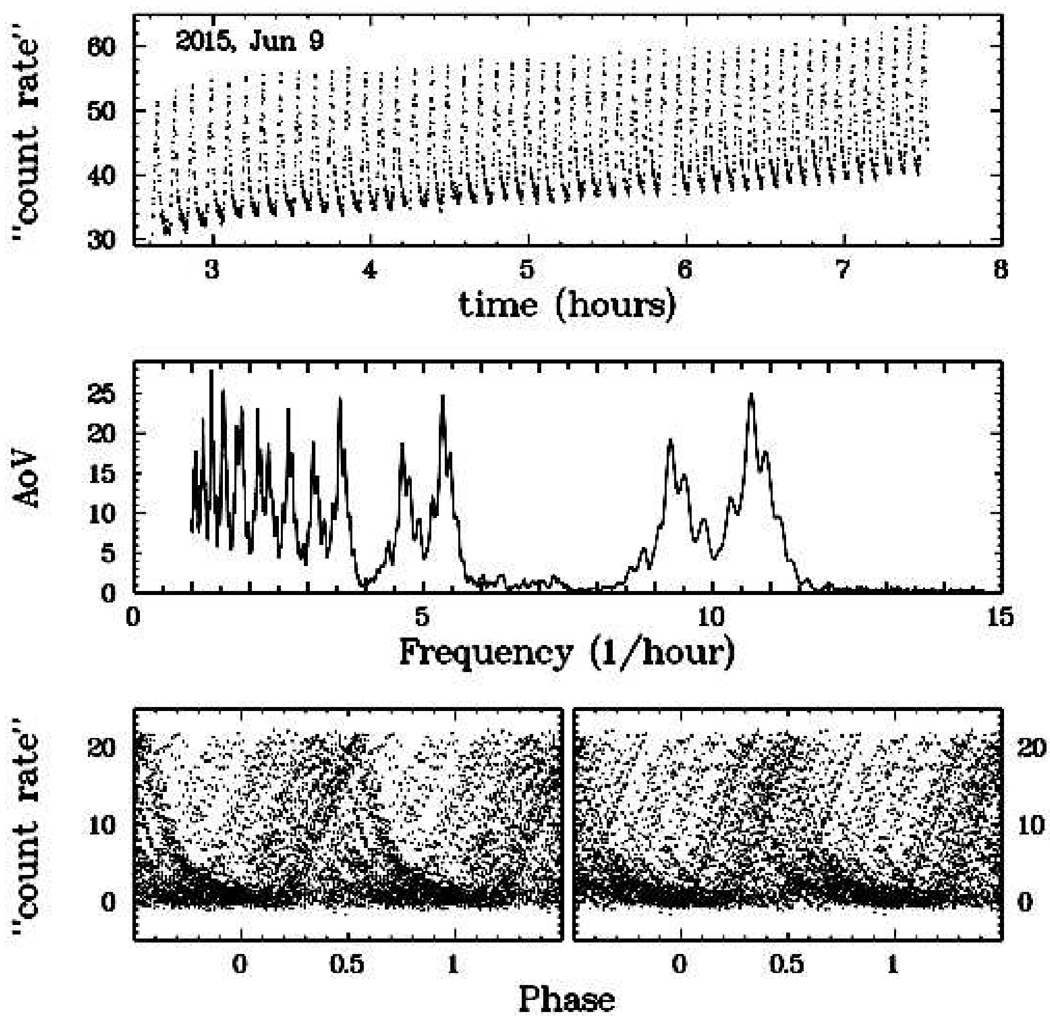

Figure 3: Same as Fig. 2 for the night of 2015, June 9. See text for details.

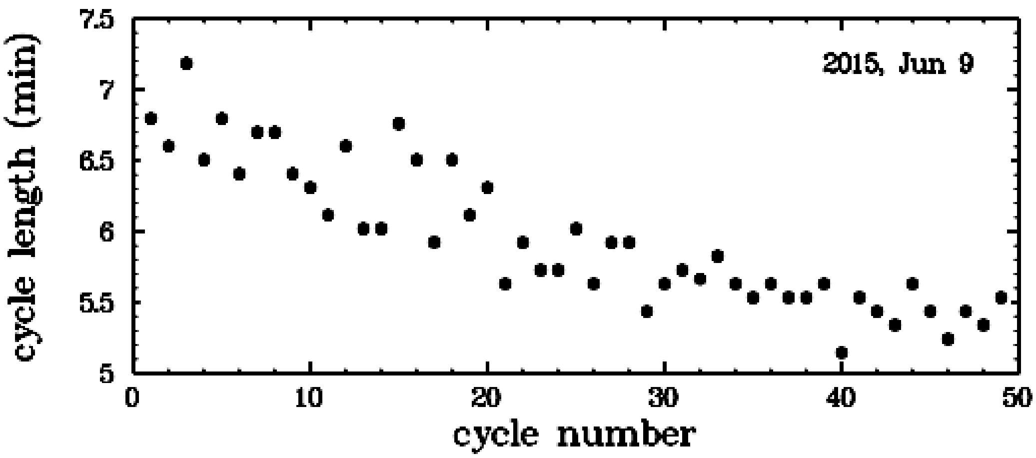

Figure 4: Intervals between the maxima observed in the sky background variations of 2015, Jun 9, as a function of cycle number. See text for details.

at $f_1 = 10.7$/hour and $f_2 = 9.3$/hour. Folding the light curve on the respective periods $P_1 = 1/f_1 = 5\overset{\rm m}{.}62$ and $P_2 = 1/f_2 = 6\overset{\rm m}{.}47$ (lower left and right frames of Fig. 3) does not yield a clear picuture of a dominant wave form.

This can be explained as follows: In Fig. 4 the time difference between subsequent peaks in the sky background light curve is shown as a function of the cycle number. It shows that the length of the cycles decreases systematically over the course of the light curve. Thus, the variations are not really periodic, but the apparent period decreases over time.

In Fig. 5 the unstable character of the bias variations is shown in still another way. Here, the sky background light curves of the three night mentioned in Table 2 are shown on the same scale in time and "count rate". On 2014, June 21, and 2015, June 9 (top and second frame of Fig. 5), both, the time scale of the variations and their waveform (the latter is better seen in the lower frame of Fig. 2) are similar, but the ampliude is significantly lower on 2015, Jun 9. In contrast, on 2015 June 11 (lower frame of Fig. 5, the time scale, waveform and amplitude are all drastically different. It is also obvious that the interval between the peaks is not constant.

4 Consequences for astronomical photometry

At first glance it might appear that the bias variations should not have an impact on the results of astronomical observations as long as the sky background is subtracted from the signal of the astronomical objects because the bias variations just mimick background variations. However, would only rigorously be true if the bias variations had a strictly linear influence. In praxis this is not so, and the reason is flatfielding.

In order to understand this, consider the astronomical image to be a simple exposure of a stellar field and the objects in the field are subjected to photometry. Let us assume that c^o is the intensity ("count rate") of an object at the moment when the instantaneous bias has a value $\bar{B}$ equal to that value which is used during the process of bias subtraction. At

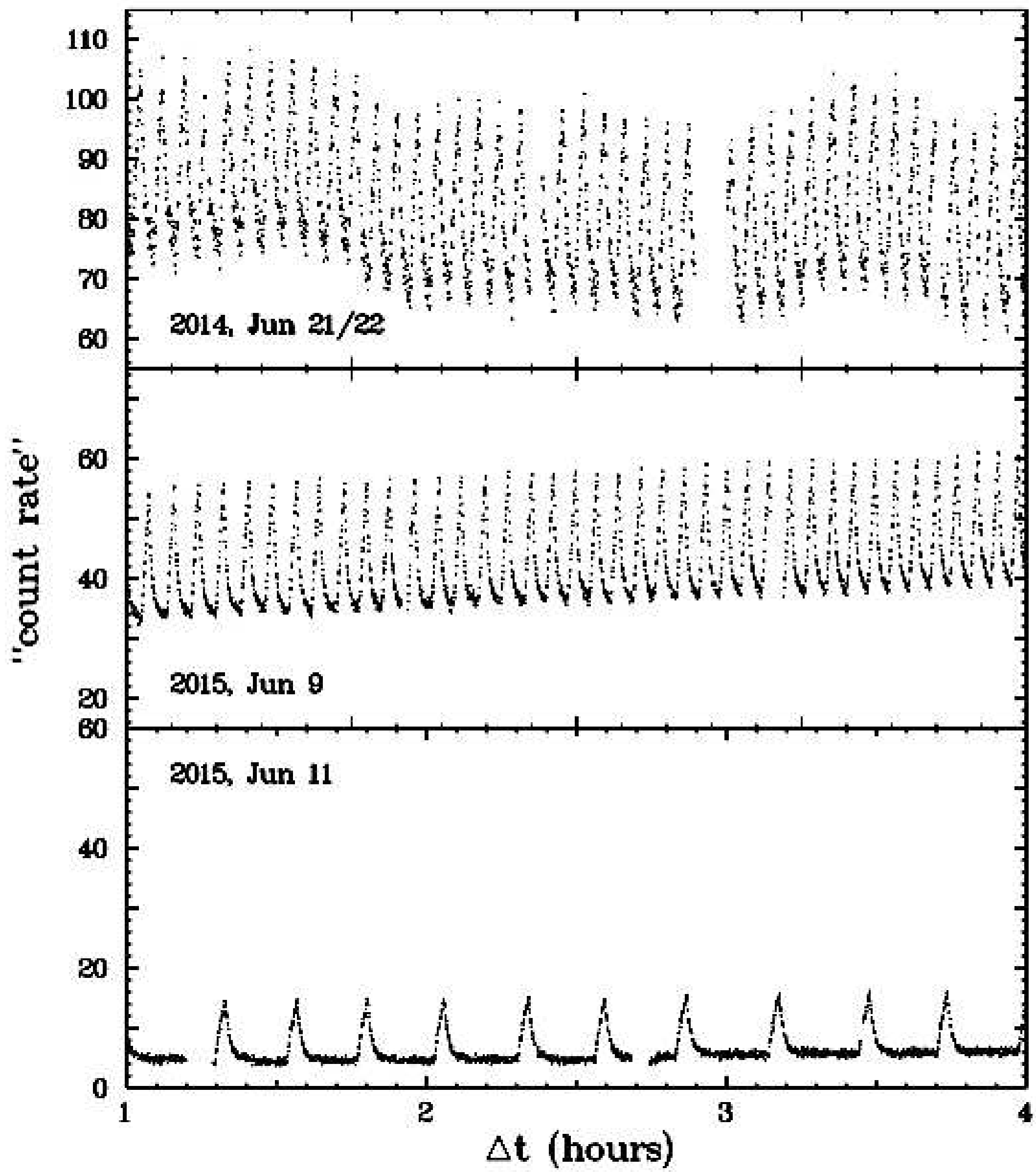

Figure 5: Sky background variations observed in three different nights plotted on the same scale in order to highlight the differences. See text for details.

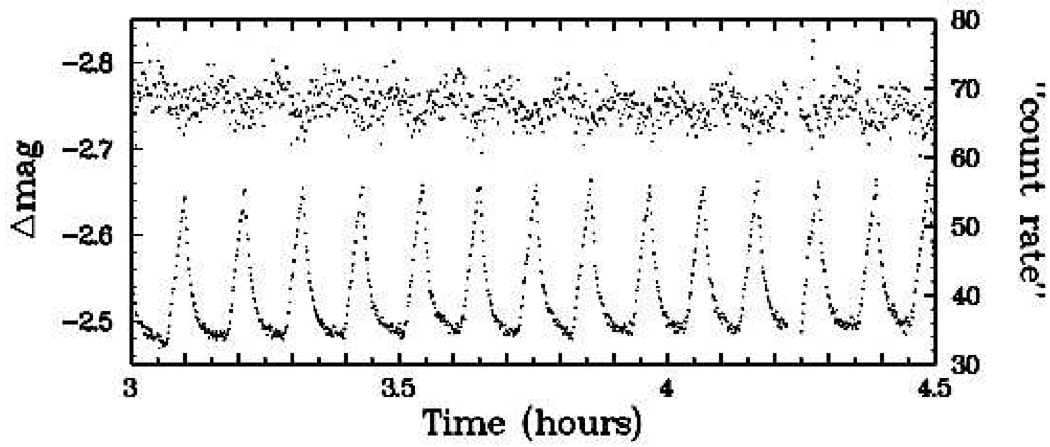

Figure 6: *Upper graph:* Magnitude difference between the a bright and a faint star observed on 2015, Jun 9, as a function of time. *Lower graph:* Simultaneously observed sky background variations. See text for details.

some time t the same object[3] will be observed at the instantaneous intensity

$$c = c^o + \Delta B$$

where $\Delta B = \Delta B(t)$ describes the bias variations as a function of time.

The first step during the image reduction procedure will now be the subtraction of the average bias image. This will yield

$$c' = c - \bar{B} = c^o + \Delta B - \bar{B}.$$

Next, the sensitivity variations between pixels will be removed by dividing the image by a normalized mean flat field image. This is equivalent to multiplying the observed signal by a factor F which depends on the location of the object within the image. Let us assume that at the object location $F = F_c$. Then:

$$c'' = c' F_c = \left(c^o + \Delta B - \bar{B}\right) \times F_c.$$

Finally, the sky background around the astronomical object will be determined and subtracted from the object signal. Denoting the background by the symbol s, it has undergone the same reductions steps as the object. Therefore, we may write:

$$s'' = s' F_s = \left(s^o + \Delta B - \bar{B}\right) \times F_s.$$

Subtracting the sky background from the object signal thus yields:

$$c''' = c'' - s'' = \left(c^o + \Delta B - \bar{B}\right) \times F_c - \left(s^o + \Delta B - \bar{B}\right) \times F_s$$

or

$$c''' = c^o F_c - s^o F_s - \left(\bar{B} - \Delta B\right)\left(F_c - F_s\right).$$

It can be seen that c''' is not constant due to the variability of ΔB as long as $F_c \neq F_s$.

[3]Assuming the object to be constant and that the instrumental setup has not changed.

In general, this effect will be so small as to be negligible (depending on the accuracy of the photometry which can be achieved!). It depends on the variations of the pixel sensitivity of the CCD (via $F_c - F_s$) and also strongly on the object intensity (c^o). Not surprisingly, on a relative scale weak objects are affected much more strongly than bright ones.

That the effect cannot be disregarded in all cases is shown in Fig. 6. Here, the measured magnitude difference between a bright and a faint star observed on 2015, June 9, is plotted versus time (upper graph; left hand scale). It clearly shows a consistent pattern of wiggles which the unsuspecting observer might interpret as oscillations in either of the two stars. The lower graph (right hand scale) shows the simultaneously observed sky background. There is a one-to-one correspondence between the minima in the differential light curves and the maxima of the sky background. This leaves no doubt that the wiggles are not due to some intrinsic variations of one of the stars but of the variations of the CCD bias level.

5 Concluding remarks

The present study cannot be regarded as an exaustive caracterization of the bias variations observed in CCD Andor Ikon 9867. In particular, it has not been investigated to which degree the variations can be reproduced using the same instrumental setup. Its dependence of several different setup parameters such as detector gain and readout speed has also not been studied systematically.

Therefore, I regard this study as preliminary. Its purpose is twofold: On the one hand it is meant to draw the attention of the astronomical user's of the CCD to an instrumental effect which is apt to induce erroneous interpretations of observations if not taken into accout. On the other hand is may help the engineering staff of the CCD manufacturer to identify the reasons for the bias variations.