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ASTRONOMICAL STATION VIDOJEVICA: IN SITU TEST OF THE ALTA APOGEE U42 CCD CAMERA

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SUMMARY: Currently, the CCD camera most used by observers of the Astronomical Observatory of Belgrade is the ALTA Apogee U42. It is used for both photometric and astrometric observations. Therefore, it is very important to know different measurable parameters which describe the condition of the camera - linearity, gain, readout noise etc. In this paper, we present a thorough test of this camera.

Key words. instrumentation: detectors – methods: data analysis

1. INTRODUCTION

Charge Couple Device (CCD) is an electronic device which has considerably changed the observation in the previous century not just in astronomy but in many different scientific areas. It consists of an array of pixels arranged on a very thin silicon layer. Incident photons are converted to electrons which can be moved around and read out by a controller. The controller converts the electrons in each pixel to digital counts (analogue-to-digital units or ADUs). The conversion factor, expressed in electrons per ADU, is called a conversion factor or simply gain.

Linearity is the most important characteristics of a CCD. Correction of a CCD images for non-linearity is important whenever a differential photometry is made. We might need for instance to setup a long exposure time to obtain a good signal-to-noise ratio for the comparison star which will push our variable star into the non-linear part of the camera's range and eventually saturate it. A 10% difference between the measured and expected light level due to the non-linear response would make the variable star 0.11 magnitude fainter then it truly is, in this paper, we test our camera for non-linearity.

If one would like to express a result measured on a raw image in electrons rather than in ADUs, one must measure the gain. This parameter is usually given by the manufacturer in the camera's specifications. However, this is not always the case. Besides, if the camera is frequently used, the gain rapidly changes with time. Therefore, it should be redetermined from time to time depending on how often the camera is being used. In this paper, we determine the gain too.

Most commercial cameras are equipped with shutter, which enable us to take exposures of a finite duration in the most efficient way. However, there are many side effects due to the shutter that should be taken into account. We deal with a different kind of shutter effects in this paper.

Readout noise of the camera is also very important parameter worth to know. Taking this parameter into account can save us a lot of observing time. For instance, many observers take dozens of dark images in order to correct raw images for thermal electrons. However, it is useless to do that if the thermal noise is dominant over the readout noise. Instead, one should determine the readout noise of the camera and determine what is the minimal exposure time when the thermal noise becomes larger then the readout noise for a given CCD temperature.

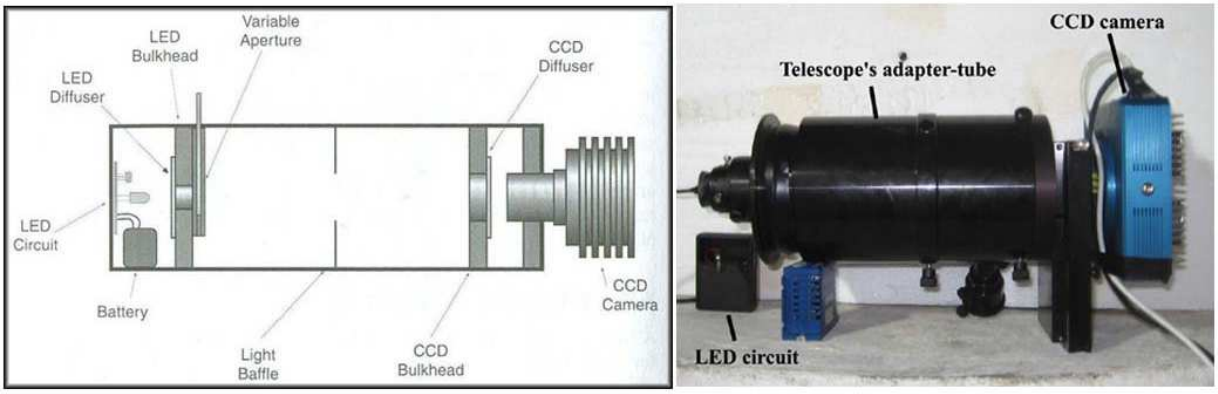


Fig. 1. *Left: Scheme of the equipment according to which we built our device for the non-linearity test. Right: Our improvised device for the non-linearity test.*

The dark current is also determined. Along with the readout noise, this parameter is important when we calculate the theoretical (or expected) signal to noise ratio for the camera in use.

Bias images can tell us a lot about the condition of a camera. Therefore, it is important to do a thorough examination of a bias images for different parameters. We report on this in the paper too.

The paper is organized as follows: the CCD camera and the device used for the test are described in the first section. The linearity is tested in the second section. The transfer curve is determined in the third section. Thorough bias analysis is performed in the fourth section. Bad pixel map is determined in the fifth section. The shutter's side effects is quantified in the sixth section. The conclusion is given in the last section.

2. THE CCD CAMERA AND THE ELECTRONIC DEVICE FOR THE CAMERA TEST

Because of light pollution in Belgrade, AOB terminated the majority of observational projects in 1980s and started to search for location for a new observatory. After more than 30 years, a new observatory was built in southern Serbia on the mountain Vidojevica - Astronomical Station Vidojevica (ASV). Several CCD cameras for various observational projects were purchased by the AOB in the meantime. The most used one is the ALTA Apogee U42, which we test for non-linearity in this paper. Some basic parameters of the camera are: 2048 x 2048 array with 13 μm pixel-size, 27.6 x 27.6 mm imaging size, peak quantum efficiency $> 90\%$ at 550 nm, and dark current of 1 e-/pixel/sec at - 25 °C.

Our electronic device for measuring the linearity and the transfer curve of the CCD was made according to the scheme found in Berry and Burnell (2000). In Fig. 1 left image is taken from their book (Fig. 6.3 therein) and shows the scheme of the equipment. Here we quote their description of how to make the device using this scheme: it should be a light-box (made of heavy cardboard or light plywood) which consist of a faint source of light on the left (circuit-stabilized LED in their case) and CCD camera on the right side of the box. They put two light diffusers into the device - one in front of the camera and the other after the light source (they recommend using an opal-glass or milk plastic as a diffuser). The light-source intensity is varied by changing several slides (made also of heavy cardboard or light plywood) with drilled holes of different size. The light baffle in the middle of the device serves to reduce the scattered light from its inner wall.

Fig. 1 right panel shows our improvised device. The light-box in our case is actually the adapter for the 60cm telescope. As given on the scheme, the camera and the light source are attached to the adapter on the right and left side, respectively. We used semi-transparent paper as a light-diffuser.

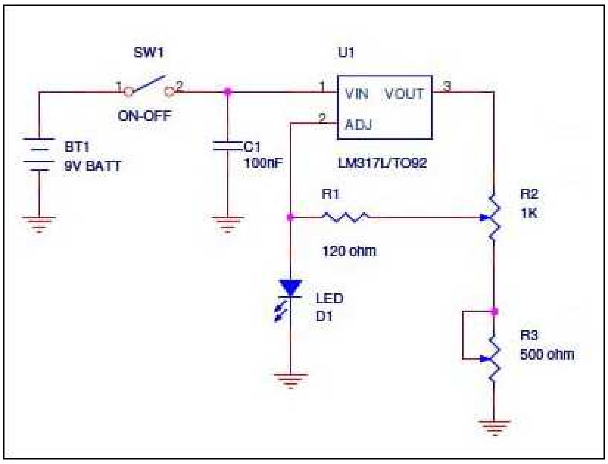


Fig. 2. *The design of the electronic circuit that we used to make a stable light source.*

In our case, the stable light-source is a stabilized LED. Fig. 2 shows the design of the electronic circuit according to which we built the LED-device[1]. The main parts of the design are: BT1 - 9 volt battery, which is used as a power supply, SW1 - on-off switcher, R1 - a maximum current limiting resistor, R2 - potentiometer, which enables adjustment of the LED brightness, R3 - trimming potentiometer which avoids unused main potentiometer range between 0 and 1.6 volt where typical LED starts conducting, and LED. This is different circuit then that given by Berry and Burnell (2000). In our case, it is possible to adjust the light level, which makes it easier to setup the range of the exposure times for the linearity test. The LED-device is simple but, in a similar manner, can be used for multiple purposes (e.g. for measuring shutter effect, making bad pixel map, measuring transfer curve, etc.)

3. THE LINEARITY TEST

As already mentioned, the linearity is the most important characteristics of a CCD camera - it is defined as a dynamical range of the camera where it responds linearly to the incident light. There will certainly be large non-linearity near the saturation level. This effect is a result of unguided transfer of electrons from saturated to adjacent pixels on the camera. Most CCD cameras respond non-linearly at low light level too. This effect is a result of charge traps in the image (or in the shift register) and is sometimes referred to as deferred charge. Finally, the camera may have smaller but still significant non-linear response in the whole dynamic range.

In general, the number of electrons we read out from a CCD (N) is proportional to integration time (t) times the intensity of the light reaching CCD (I), that is:

$$N \sim g \cdot t \cdot I, \tag{1}$$

where g is the gain. Assuming that we have an extremely stable light source (I is constant), we can measure the intensity of the light source as a function of exposure time and then plot level per unit time versus level. For linear camera this function should be constant. This is the most simple and direct way to measure the non-linearity of a CCD and is sometimes referred to as direct method. We use this method to test our camera for linearity.

Specifically, we use the so called Bracketed Exposure method. This method involves taking images with varying exposure time which are bracketed with images with constant exposure time (see Gilliland et al. 1993 for example). For instance, in a sequence 5s, 2s, 5s, 7s, 5s, 10s, 5s, 13s, 5s, 17s, 5s, 20s, the images with increasing exposure time are bracketed with 5s exposures. The constant exposures (5s in this example) are used to check and to correct images for variation of lamp intensity (lamp drift) if it exists.

We use MaxIm DL imaging software to run the CCD camera. Visual Basic Script (VBS), which can be run from MaxImDL, is used to automatize the test. We use a data sequence of 36 exposures with 18 increasing exposure times from 1.5 to 52 seconds, with 3 seconds of exposure increments followed by the same number of exposures from 52 to 1.5 seconds with 3 seconds decreasing exposure. For better statistics, we make 2 sets of data sequences. Before each data set, the VB script takes 10 bias frames which are averaged into single master bias frame. Thereafter, the script takes 10 dark frames with at least 5 times longer exposure time then the longest exposure time in the sequence in order to make a single scalable master dark frame. Master bias and dark frames are used to calibrate the images.

By default the VB script analyzes the FITS images on the fly. Before any measurement, the images are automatically corrected for master bias and master dark frames. Then the average level is measured in the central 200x200 pixels where the shutter effect is minimal.

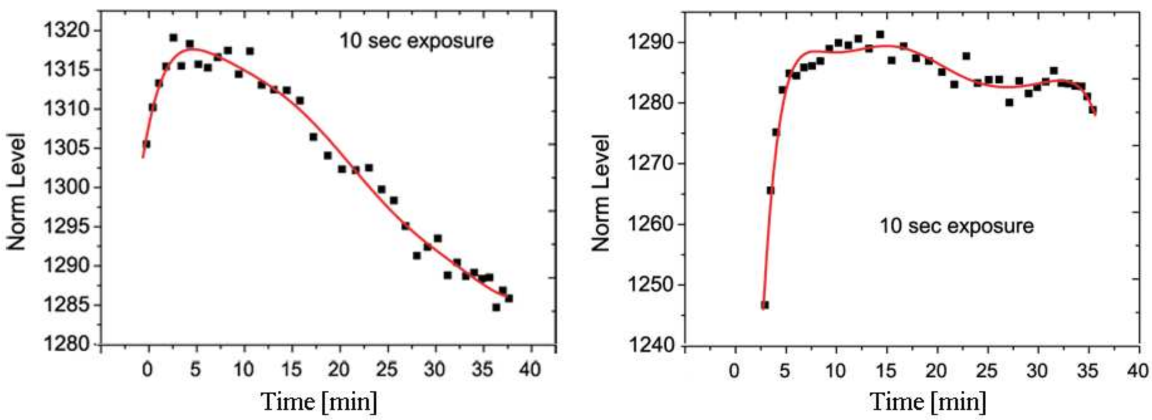


Fig. 3. *Light variation with time for the two data-sets are presented on the left and right hand side respectively. The time scale is expressed in minutes.*

[1]We thank Viktor Cosic for the design as well as for making the electronic device.

In Fig. 3 we show the light variation with time for images with 10 second exposure time for the two data sets on the left and right hand panels, respectively. As can be seen, there is about 2.5% and 3.3% change in the light intensity with time in the two data-sets. Correction of the data for this effect will be described later.

As an example of how the intensity variation of the lamp affects the data, the left hand panel of the Fig. 4 shows the average level per unit time versus level for both data sets, which are denoted with different symbols as explained in the figure's legend. There are two things worth noting at this point. First, the level per unit time versus level is expected to be constant for a linear camera. In our case, besides an expected non-linearity close to the saturation level (around 60 000 ADU), there is a non-linearity over the whole dynamic range of the camera. The non-linearity and correction for this effect will be explained in the next section.

Second, there is a large discrepancy between data obtained in direct and reverse order in both data sets. This is caused by the variation of the lamp intensity with time as illustrated in Fig. 3. Because of this, we correct data for this effect in the following way: The correction starts with fitting the data in Fig. 3 with 7^{th} and 9^{th} order polynomial function in the case of the first and second data-sets, respectively. Best fits are shown with solid line in Fig. 3. Arbitrary value 1290 for the Level/Time in both data-sets is taken as a reference value and all the data are corrected against this value according to formula:

$$Lc = Lm - (Lp - 1290) \cdot t, \qquad (2)$$

where Lc are the corrected data, Lm are the measured data, Lp are the calibrated data i.e. data returned by the polynomial, and 1290 is the reference value. The expression in the parentheses is multiplied by time, t, because the polynomial functions are fitted to the normalized data (see Fig. 3). right hand panel in Fig. 4 shows the average light level per unit time versus average level after the correction for lamp drift. The figure clearly indicates that the data are properly corrected for this effect.

A useful information for observation with a particular camera is the light level when the pixels start to saturate and the camera becomes non-linear. Fig. 5 left, shows the light level (corrected for lamp drift) versus exposure time. Data from both data sets are joined together for this plot. Solid line is a linear fit to data in a range where the camera is linear, i.e. from 7000 to 30000 ADUs in our case. Coefficients of linear fits are given in the legend. Therefore, the values returned by the linear fit are the expected values, that is, the light level that we expect to measure if the camera were linear. Fig. 5 right, shows the difference between measured light level Lm and expected light level Le as a function of average level. We can note several things:

(i) A large difference can be noticed at low light level (around 2.7% for the first point where the light level is around 2000 ADU after the bias and dark correction). This effect is a result of charge traps in the image or in the shift register and is sometime referred to as deferred charge. Most CCDs respond non-linearly in this range. Besides deferred charge, the exposure times for the first images in both sets were 1.5 seconds where the shutter effect may have some influence. The large difference we have for the first point is probably a combination of the two effects.

(ii) The difference between measured and expected light level is below 1% up to around 46 000 ADU after the bias and dark corrections. Therefore, if we need observation with photometric accuracy better than 1%, we must observe in range from 2000 ADU to 46 000 ADU after the bias and dark correction. Since the average bias level is around 1400 ADU, and the bias level is dominant over the dark level even for the longest exposure time, this means that we must observe between 3400 ADU and 47 400 ADU measured on raw images.

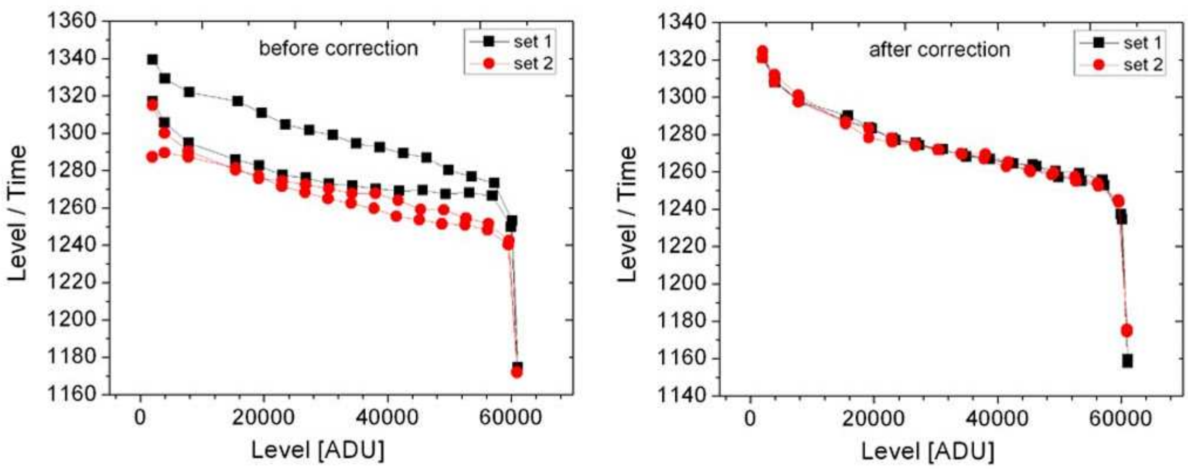


Fig. 4. *Average level per unit time versus level before (left panel) and after lamp-drift correction (right panel).*

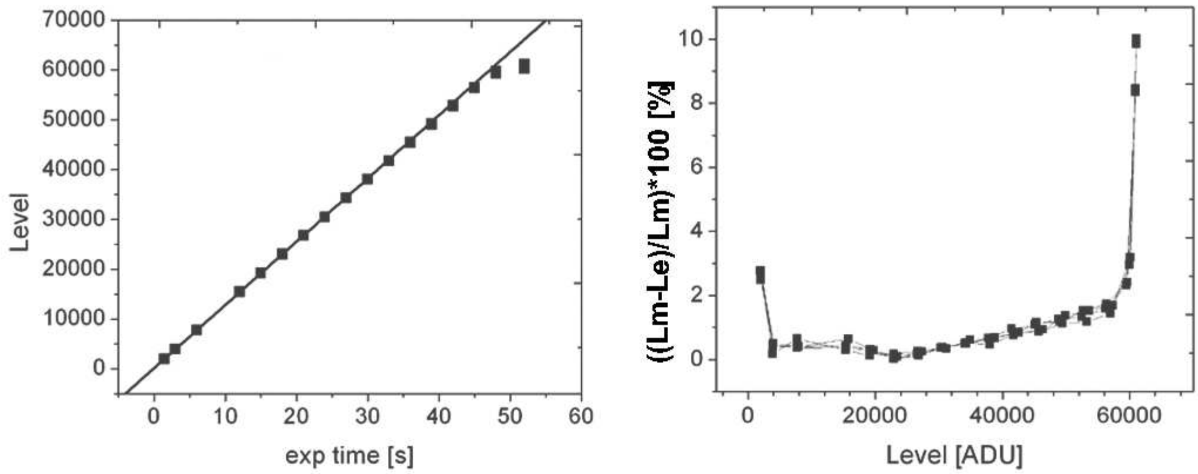


Fig. 5. *Left: light level versus exposure time. Right: difference between measured and expected light level (in percent) as a function of light level.*

(iii) The camera is highly non-linear above 58 000 ADU where the difference between the measured and the expected level is larger then 2%. Generally, this range should be avoided when observing or the data should be corrected for non-linearity as will be described later.

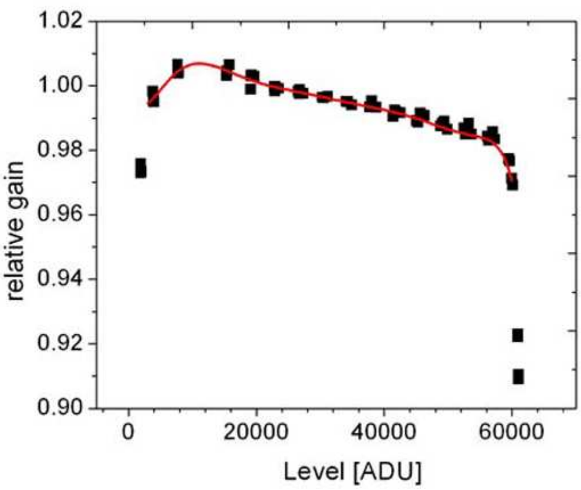


Fig. 6. *Relative gain (measured level per expected level) as a function of measured level.*

At this point, we want to know how to correct data for non-linearity when this CCD camera is used for observation. Fig. 6 shows the relative gain (measured level per expected level) as a function of measured level. Solid line is a 9^{th} order polynomial fitted from 3000 ADU to 60 000 ADU. Points bellow the lower cut correspond to images with 1.5 second exposure time, thus the motivation to eject this point is the mentioned shutter effect. We also reject points above 60 000 ADU because it is hard to find an analytical function which describes the data sufficiently well when these points are kept. Because of this, regions below and above these cuts should be avoided when observing because the given polynomial will not be able to correct the data for the non-linearity effect. In order to convert data to expected values, that is, to correct data for non-linearity, we should divide the measured counts by the relative gain. The coefficients of the polynomial, along with the coefficient of multiple determination, R2[2], are given in Table 1.

Table 1. Coefficients of the 9^{th} order polynomial and the coefficient of multiple determination, R2. The polynomial is of this form: $Y = A9 * x^9 + A8 * x^8 + A7 * x^7 + A6 * x^6 + A5 * x^5 + A4 * x^4 + A3 * x^3 + A2 * x^2 + A1 * x + A9$.

Coefficients and parameters	Values
A9	-1.25098E-41
A8	3.5107E-36
A7	-4.19141E-31
A6	2.77159E-26
A5	-1.10523E-21
A4	2.70221E-17
A3	-3.90456E-13
A2	2.95918E-09
A1	-8.40986E-06
A0	1.00174
R2	0.97796542

[2] R2 is a ratio of the regression sum of squares (which is a portion of the variation that is explained by the regression model) to the residual sum of squares (which is a portion that is not explained by the regression model). Clearly, the ratio of these two parameters can be used as one measure of the quality of the regression model - the closer to one the better the model is.

4. THE TRANSFER CURVE

The transfer curve is a plot of the square of the noise (variance) in an image versus the mean intensity level. It is used for measuring the camera's conversion factor (gain) in electrons/ADU. The final equation describing the transfer curve is given by (Christian 1991):

$$\sigma_A^2 = \frac{1}{g} I_A + \frac{1}{g^2}\sigma_r^2 \,, \tag{3}$$

where σ_r^2 is the readout noise in electrons, I_A intensity level, σ_A^2 variance of the signal in ADU, and g is the gain. Therefore, the gain is equal to the inverse of the slope obtained from linear plot.

To generate the transfer curve, images with different exposure time (in the increasing order for example) must be taken, and the variance must be measured at each exposure. The most direct way to do this is to take a pair of images with the same integration time for each exposure, subtract one from the other, and divide by two. In practice, one should have a stable light source, and to take a pair of images for each exposure time.

In our case, we use the same equipment that was used for the linearity test to generate the transfer curve. It provides a relatively stable light source and a convenience in work. The measurement is also automatized by a VB script and with a similar algorithm as in the case of the linearity test with the only difference that each exposure is repeated twice. Each exposure pair is also bracketed with the 10 sec exposure in order to check and correct for the lamp drift if exists. Before the measurement, the images are corrected for bias and dark counts.

Fig. 7 left shows the variance as a function of mean intensity after correction of data for lamp drift. The solid line is the best linear fit to data with coefficients 666.4 and 0.8 for the intercept and slope respectively. From this result, we can conclude that the gain for our camera is 1.25 electrons/ADU.

5. THE BIAS AND DARK IMAGES

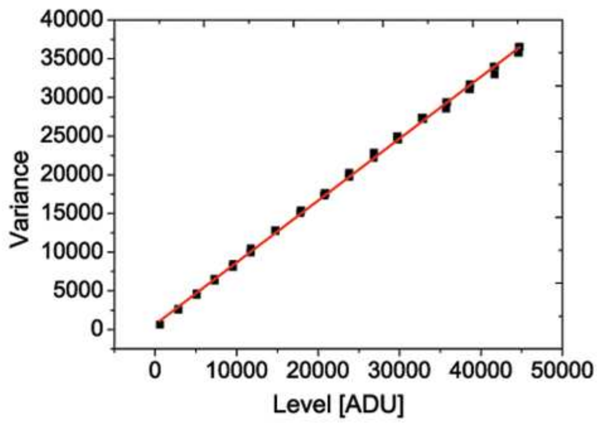
Careful examination of bias frames may also provide many useful information about a CCD camera and its condition. Results of some of the standard tests will be reported in this section. For this purpose we use a set of 10 bias frames.

a) *The mean and standard deviation.* The mean and standard deviation of dozens of bias frames should tell us how stable the bias level is. For a good camera, both values should be within 1 ADU of the same value for every frame. Our result shows that the standard deviation, which is a measure of the readout noise of the camera, is around 10 ADU/pixel and that this parameter is essentially the same for each bias frame. The mean, on the other hand, vary within 4 ADU around 1452 ADU.

We have also measured the mean and standard deviation for 3 sets of 10 bias images taken with the camera cooled down to 3 different temperatures, that is, 0, -10, and -15 °C. Fig. 8 left shows the result indicating that the mean level and the corresponding standard deviation decrease with temperature. Since there are not so many points in the plot, we can give the mean and standard deviations here too: the mean is 1606, 1424 and 1408 ADU for 0, -10 and -15 °C respectively; standard deviation is 9, 4 and 3 ADU in the same temperature order. This result should warn us not to use bias frames from one observational night to correct images taken on some other night unless the camera is cooled down to the same temperature.

b) *The histogram of a single bias frame.* This plot should be normal indicating that the noise follows the Gaussian distribution.

Fig. 8 right shows a histogram of one bias frame on a log-normal plot. All pixels are included in the plot. Tails on both side of the parabola indicate that there are some pixels which do not follow the normal distribution. However, number of these pixels is very small, that is, about 0.05%. Careful examination of the image shows that the large bump on the right side of the distribution originates from the first column of the frame.



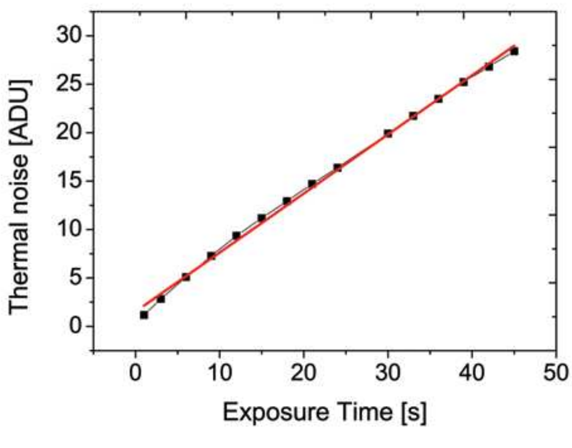
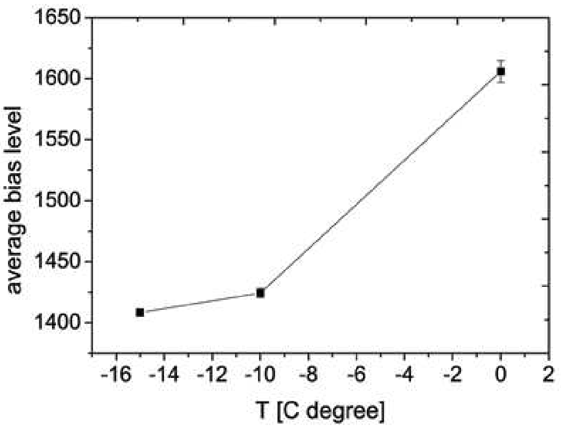


Fig. 7. *Left: Variance versus mean intensity level. Right: Thermal noise versus exposure time. Solid lines on both plots are the best linear fit to the plots.*



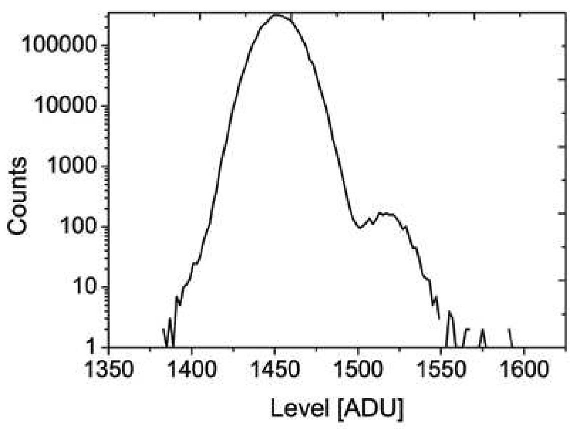


Fig. 8. *Left: Bias versus camera's temperature. Right: Histogram of a single bias frame.*

c) *The median of the bias frames.* Median of dozens of bias frames is also very useful to analyze because all the patterns identical for each row are clearly brought out in this way. For example, coherent interference patterns due to nearby electronics could be detected and their source could be removed.

d) *The dark current.* The dark current of the CCD is also useful parameter to know. It can be easily determined from the plot of thermal noise versus exposure time. To do this, we take 10 bias frames and 15 dark frames with different exposure times ranging from 1 to 45 seconds with step of 3 seconds. Biases were averaged into a single master bias frame and all the dark frames were corrected for it in order to get the thermal noise in the images. Central 200x200 pixels were used to measure the average thermal noise in the frames.

Fig. 7 right shows the thermal noise as a function of exposure time. As expected, the plot is linear and the solid line is the best linear fit to the data. The slope of the plot is the dark current and in our case it is equal to 0.61 ADU/s or, using gain, 0.76 electrons/s. This information is useful when we want to calculate the theoretical signal to noise ratio of our camera. We may also use this plot to calculate the exposure time when the readout noise becomes dominant over thermal noise for faint objects where the photon noise is small. We note that this result is valid for a particular CCD temperature which is -15 °C for this plot.

6. THE BAD PIXEL MAP

It is very important to qualify and quantify pixels on a CCD frame that do not respond linearly to the light. This can easily be done by using two flat field images with different light levels. Ratio of two flat fields removes all features which would normally flat field properly and only pixels which are not corrected by flat fielding remain. The resulting image is called a bad pixel mask and it is directly used to correct raw images for bad pixels.

To generate bad pixel masks for our camera, we make 10 bias frames, 10 low-level flat fields with around 2700 ADU and 10 high-level flats with about 14000 ADU. First we make a single master bias frame by averaging all biases. Thereafter, flat fields are corrected for the bias level. Master low- and high-level flat fields are obtained by averaging the corresponding flats and the ratio is calculated. The bad pixel mask is calculated in the IRAF image reduction package using CCDMASK task (see the official IRAF site for the description of the task). Raw images are easily corrected for bad pixels in the IRAF package using the FIXPIX task, so those who aim to correct images for this effect are welcome to ask the author for the generated mask.

Table 2. Number of bad pixels (in percent) for different sigma factors.

Sigma Factor	Bad Pixels [%]
10 σ	0.002
5 σ	0.2
4 σ	0.7
3 σ	5
2 σ	24
1 σ	84

The CCDMASK task in IRAF basically makes a pixel mask from pixels deviating by a specified statistical amount (defined by positive sigma factors) from the local median level. Table 2. shows the number of bad pixels in percent (second column) for different sigma factors (first column).

7. THE SHUTTER

There are two effects that an observer should have in mind when working with a CCD camera with shutter. One is the shutter latency and the second is the shutter effect.

The shutter latency is simply the intrinsic delay that occurs between the instant of issuing the command on the keyboard to start the exposure and the instant at which the shutter opens. This difference is important when we observe some phenomena where the precise timing is important (for instance for detection of the third body in the eclipsing binary systems using the minima in the light curve).

For some cameras this delay can be quite significant. For instance, we have measured this effect for our ALTA Apogee E47 camera and it is equal to 0.43 seconds on average and it is quite repeatable and stable. This fact was actually the motivation to check the shutter latency for this camera too.

We use MaxImDL to drive the camera and to measure the latency effect. There is a nice tool in this software for this purpose. The CCD camera should be equipped with a short-focus lens to be able to take a sharp image of the PC monitor which is used as it is shown in Fig. 11. How the experiment works is most clearly explained in the MaxImDL's help and the most important part of the description will be simply quoted here: "The latency window will immediately show a dynamic display with a single white block, moving every 1/100th of a second to the next location in succession. One white digit in each of the top two rows is also illuminated at any given instant; this shows the time in seconds and tenths of seconds since the camera was commanded to take the exposure. The display continues updating as long as the camera is exposing".

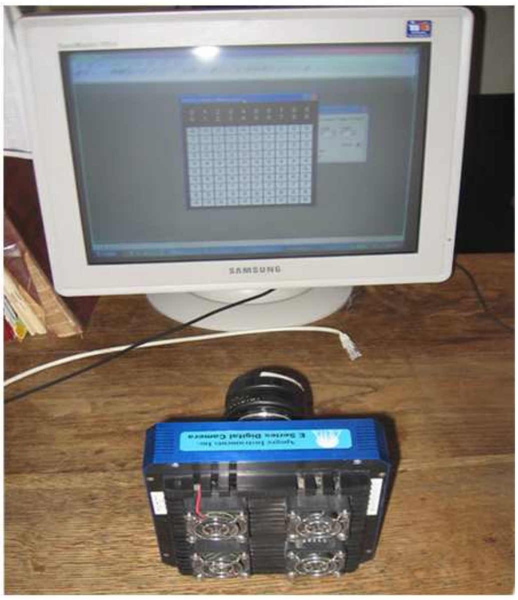


Fig. 9. *The experimental setup for the shutter delay measurement.*

For better statistics, we made 3 sets of 10 images with different exposure times: 0.01, 0.1 and 0.5 sec. From the analysis of all images, we may conclude that the shutter is in good condition and has no delay in opening and also no significant delay in closing (0.01 seconds on average).

The second effect that we have mentioned is the shutter effect. When making an image, the shutter must be accelerated two times - during its opening and closing. Because of the finite time to do this, some parts of the detector receive more light then others. Iris shutter, for example, opens from the center outward so stars close to the center are exposed first and covered last. This effect is called the shutter effect.

The shutter effect is larger for shorter exposure time. A 0.5 second exposure time difference for some stars in the field causes a 0.005 magnitude error for 100 sec exposure time but this error is 0.75 of a magnitude for 1 sec exposure, for example, which is significant even for the ground-based differential photometry.

There are several ways to take into account the shutter effect. One is to quantify the limit when the shutter effect is negligible for our purpose and to avoid shorter exposure times. Sometimes the flat field images are taken with short exposure times when the shutter effect is significant. In this case, if it is possible, we should take images with the same exposure time so the effect will be corrected automatically by flat-fielding. The most common way to deal with shutter effect is to make a shutter map and to correct images for the effect. For the shutter map one should provide a stable light source and to take a set of images with long and short exposure times (see Zissel 2000, for example). This is done on dome flat-field screen.

Since it has a stable light source, we have tried to use our improvised device for the linearity test to make a shutter map. Interestingly, we didn't obtain any shutter pattern which is expected for short exposure time probably because of the 2 diffusers in the device where one is quite close to the CCD receiver.

To quantify the shutter effect in this paper, we find the exposure time when the effect for our camera disappears. To do this, we take a set of 10 bias images, and 5 sets of 5 flat-field images with different exposure times, that is, 0.05, 1, 3, 5, and 10 seconds. Flats are taken on twilight sky. A single master bias frame is obtained by averaging biases, then, all flats are calibrated to the bias level and, finally, the flats with the same exposure time are stacked.

The ALTA Apogee U42 has an Iris shutter, whose blades open from the center outward, so the shutter effect leaves a characteristic pattern on the flat-field images similar to that shown in Fig. 10. The central part of the image is the least affected by the shutter effect since it receives light first and last when opening and closing, respectively. Because of this we normalize the stacked flats to the central 50x50 pixels. In order to get a qualitative result, we find ratio of the 10 second flat and flats with shorter exposure times. The result is presented in Fig. 10. Numbers at the bottom left corner of each panel show which stacked flat is divided by the 10 second exposure flat. As we can see, the shutter effect is most

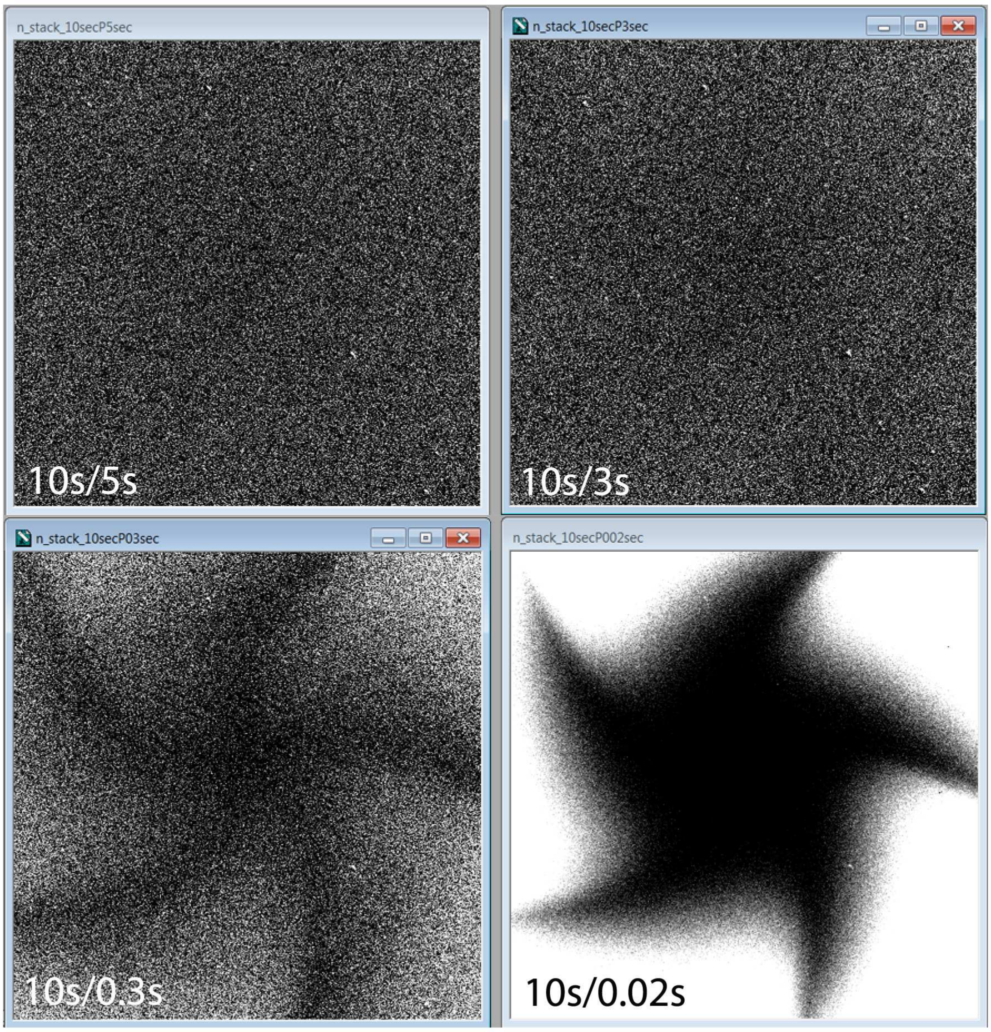


Fig. 10. *Qualitative result of the shutter effect (see the text for details).*

pronounced on an image with shortest exposure time and gets smaller as the exposure time increases. Based on this images, we can state that the shutter effect is still present at the 3 second exposure time.

A more qualitative result can be determined from the distribution of pixel values in flat ratios. Since we have normalized the flats for the average level in the center of their images, the histogram of their ratio is expected to be normal with the mean equal to one if there is no shutter effect. Then, any deviation from the normal distribution can be used as a relative measure of the shutter effect. In our case, the mean of the Gaussian function that we fit to these distributions deviate from one by 19, 2.3, 0.3 and 0.002 percent for 10sec/0.02sec, 10sec/0.02sec, 10sec/0.02sec, and 10sec/0.02sec flat ratios, respectively. We note that these numbers only tell us the percentage of the shutter effect presence in the image relative to the image without this effect and do not describe the effect in absolute terms as in the case of the shutter map.

8. CONCLUSION

In this paper, we test Apogee ALTA U42 CCD camera in terms of different parameters which describe the condition of the camera. For some tests we have built a device with a stabilized-LED which gives us a constant light. In this way we could determine the non-linearity and the gain of the camera but unfortunately we failed to get the shutter map. Anyway, the results can be summarized as follows:

(1.) The camera is tested for non-linearity. It is linear within 1% between 3400 ADU and 47 400 ADU measured on the raw image.

(2.) The gain for the camera is 1.25 electrons/ADU. This is used to convert the intensity level measured directly on the CCD image in ADU into electrons. It is also useful if one wants to compare some tested parameters of the camera with the ones given in the camera's specification which are mostly expressed in electrons.

(3.) The readout noise of the camera is 10 ADU/pixel or, using the gain to convert, 12.5 electrons/pixel.
(4.) The mean and standard deviation of 10 bias images shows that both parameters are stable within one observing set. About 0.05% of all pixels in the bias image do not follow the normal distribution.
(5.) Both, the mean and standard deviation of the bias images decrease with camera's temperature telling us that we should not use bias frames from one observational night to correct images taken on some other night unless the camera is cooled down to the same temperature.
(6.) The median stack of the bias images brings out all fixed patterns that will be subtracted from the raw data in the bias calibration.
(7.) The linear dependence of the thermal noise as a function of exposure time is tested. The dark current is 0.76 electrons/s from this plot for the camera cooled down to -15C degrees.
(8.) We also calculate a number of bad pixels for different sigma factors. By doing photometry and astrometry, one should not risk by not correcting their raw for bad pixels since in both cases they can introduce large deviations in the measured parameters if they overlap with a particular object.
(9.) We also analyze the shutter of our camera. It has a negligible delay while opening and shutting. One should always check his/her camera for delay if the timing is important for an observation because, for some cameras, it can be quite long.
(10.) We also check our camera for shutter effect. Unfortunately, we may provide only a qualitative result in this paper which tels us that one should correct images with shutter map if the exposure time is less than 5 seconds or just avoid exposures bellow this limit if the shutter map is unavailable.

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АСТРОНОМСКА СТАНИЦА ВИДОЈЕВИЦА: ОДРЕЂИВАЊЕ НЕЛИНЕАРНОСТИ ALTA APOGEE CCD КАМЕРЕ

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Стручни чланак

Најкоришћенија CCD камера која се тренутно употребљава за посматрања на Астрономској станици Видојевица од стране посматрача запослених на Астрономској опсерваторији у Београду је ALTA Apogee U42. Ова камера се користи за фотометријска и астрометријска мерења. У овом раду ће се одредити разни параметри који описују и карактеришу камеру као што су линеарност, gain, шум ишчитавања итд.