Calibration of the CCDs at Piszkéstető

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1 Calibration of the Wright CCD

Basic parameters of the camera

This is the calibration documentation of the Wright CCD camera EEV CCD05-20, which was in use on the 1m RCC telescope from 1993 till June of 1998 at the Piszkéstető Mountain Station of Konkoly Observatory. The camera has a Peltier cooling system and a 15-bit A/D converter. The dimensions of the chip are $770H \times 1152V$ pixels, $22.5\mu m$ each. The focal length of the telescope is $13.6m$, ie. the scale is $0.352''$pixels, yielding a FOV (field of view) of approximately $270'' \times 405''$. Typical saturation level is 120000e$^-$/pixel (approximately 12000 ADU for G=1 setting and 48000 ADU for G=2.5 setting). There are two CCD camera manuals, one of them at Konkoly Observatory's library, the other one at Piszkéstető.

"G=1"	High readout	Low readout	'G=4"	High readout	Low readout
Gain(e^-/ADU)	10.2	10.0		2.55	2.5
Rdnoise (e^-)	11.3	4.3		11.3	4.3

Table 1: Basic parameters of Wright CCD camera

The bias structure

There is no significant bias structure in the X dimension ("horizontally"), thus overscan correction is usually sufficient. There is a slight decrease in the bias level with decreasing Y, however this effect must be fully corrected by overscan trimming. In most cases the second order polynomial fit to the overscan vector is fair enough. You can view the bias level dependence in the Y direction on Figure 1 (G=4 setting). Several formats of readout were in use on the camera. In the case of the images retrievable from the web version of this page, the bias section was $[6 : 23, 22 : 1100]$, the trim section was $[30 : 790, 22 : 1100]$. Figure 2 shows the bias section of an uncalibrated flatfield image.

The dark structure of the chip

Dark structure of the chip was investigated several times, and seemed to vary in time. There are certainly some warm pixels, but the effect almost absolutely disapeared by 1998. If you see these pixels to be anomalously high on your images, you can try masking them with superdark images available on the web-site of this manual. You can either interpolate across the bad pixels, or simply set the pixels to large negative values (eg. STSDAS/imcalc task).

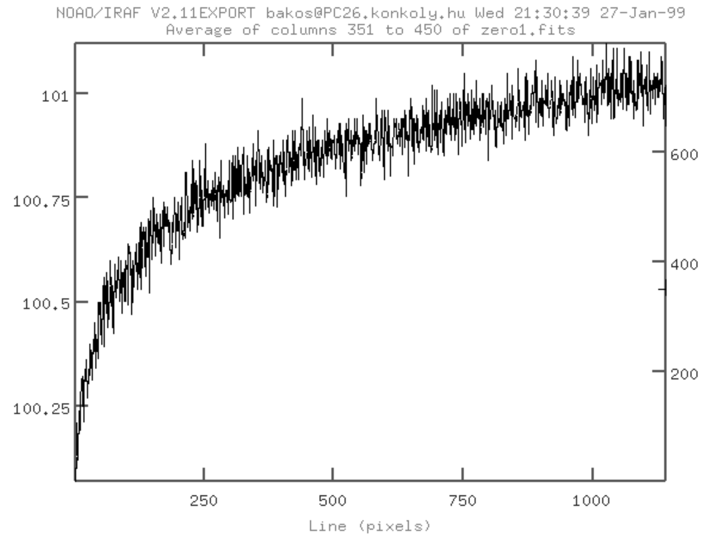

Figure 1: The Y direction dependence of the bias level at the Wright camera.

The flat structure

Johnson UBV and Cousins R,I filters are available in the filter wheel. Dirt on the filters might cause flatfielding errors, because the precision of the filter wheel (when changing filters) might be not sufficient, and a small-scale residual flat structure can alias photometric data. The persistent dirt on the camera-window is relatively stable, and well corrected by the flatfield images. A white flatfield board and illumination is available for your convenience, in case skyflat images could not be taken. The horizontal (Y) split on the flat images is the pure flatfield itself (due to different sensitivity of the pixels), while the circular-shaped objects are the results of dirt on the camera-window (usu. the smaller ones), the filters, and the optical system as a whole. It is also quite usual that the flatfield images change during the night (due to the close-by power station and it's air pollution), so it is recommended to use different flatfields for the evening and morning images. You can retrieve sample flatfields from the web version of this document.

Linearity of the chip

The almost negligible nonlinearity of the chip can be corrected (raw images!) if someone desires to push the precision to the limits. A simple C program (NONLIN.C, written by R. Szabó, modified by G. Bakos) can be retrieved from the corresponding website.

Image processing

Simply done with your favourite program, for example IRAF/NOAO.IMRED.CCDRED. It should be noted that the exposure time in the headers of the raw images (when using the standard AT1 CCD controll software[1]) has a special format (with a comma in it), which should be changed with a script (eg. EXP.CL available on the homepage of this document). Comments

[1] AT1 Operators guide, Version 3.00, cf. references section

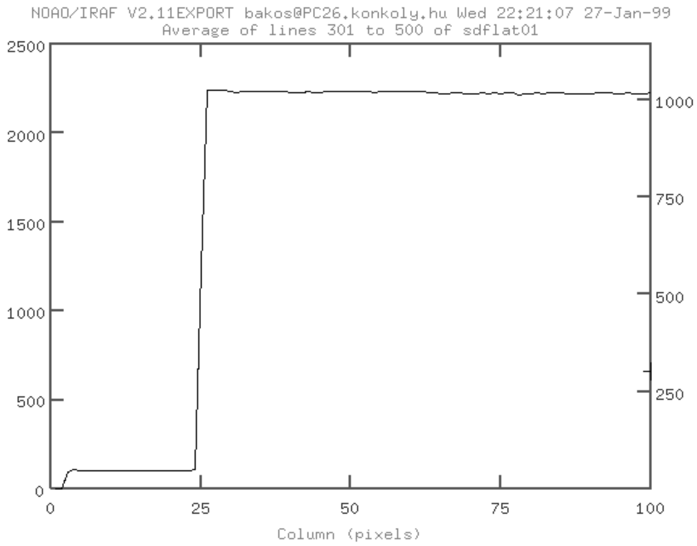

Figure 2: The bias section of an uncalibrated flatfield image at the Wright camera.

on the usage of this script are found in its first (commented) lines. Hopefully a new, Linux OS-based driver will be implemented soon, which will handle image formats properly.

Before data reduction of the frames under Linux, Unix or VMS, the bytes of the integers have to be swapped. This can be done with the Unix based "DD" task, or the "SWAB" script.

Other features of the Wright camera can be easily set with the IRAF/FILRENAME.CL script written by G. Bakos, which should be slightly modified conforming to the actual situation. This script encodes the filtername in the filename, sets the gain=2.5, rdnoise=1.075 (ADU), adds the appropriate "subset" header keywords to the header. The NOAO.IMRED package should be loaded before running the script! You can add the declination, right ascension and HJD keywords to the header by slightly modifying the script.

The "obsdb.dat" at Konkoly Observatory includes the parameters of the Piszkéstető Mountain Station. To check whether your IRAF is using this file, type
"grep piszkes /iraf/iraf/noao/lib/obsdb.dat".
If grep returns with some lines, you are probably using the good version. A sample obsdb.dat can be found at the webpage of this document.

Other effects

Dark glow of the camera window might affect the dark level of your images, especially when cosmic-ray impact rate is high. The effect was not detected. Secondary cosmic rays which might have originated in the camera-window were also not detected.
Bias jumps of the camera might occur, but they are extremely rare. The bias level is spatially split into two parts with slightly different mean values. Maybe the only reason for taking bias images during the night is to detect such a phenomenon, and check the cables, and camera head if this effect occurs.
Residual images have not been detected, but this might be due to the lack of calibration.
Stray light in the camera was an extended problem, but eventually it was eliminated with

some inner diaphragms. Stray light can be detected on your flat images, and you can try to mask it with a "stray-light mask" fit to every image.
Contamination rates of the CCD might affect your UV photometry, such as Johnson U band magnitudes, if the camera is cooled for a very long period. As the system is switched off every day, this effect should not cause any serious error in the data.
Charge transfer efficiency tests were not carried out, according to the manual CTE is less than 1% diagonally.
Long versus short anomaly was not detected.
Geometric distortion of the system concerning photometry is negligible, but of course, astrometric equations have to be solved for every field using reference stars. Usually linear equations of the form

$$\begin{aligned} X_{ref} &= a + cX_i + eY_i \\ Y_{ref} &= b + dX_i + dY_i \end{aligned}$$

where a,b,c,d,e,f are constants, are sufficient.
Digitization noise: The gain of 2.5 e-/ADU, is larger than the read noise of the chip. As a result, digitization can be a source of noise in the images. This effect is particularly pernicious when attempting to determine low sky values, because the measured values tend to cluster about a few integer values (dark subtraction and flatfielding cause the values to differ by slightly non-integer amounts). A more subtle effect is that some statistics programs assume Gaussian noise characteristics when computing properties such as the median and mode.
Special note - new camera driver : A new Linux ascii kernel driver is upcoming, which will allow sophisticated controll-features for the users. The camera parameters will slightly change (in a good sense).

2 Calibration of the Photometrics CCD on the Schmidt telescope

Basic parameters of the camera

The Photometrics KAF-1600 CCD camera is in use on the 90/60/180cm Schmidt telescope at the Piszkéstető Mountain Station of Konkoly Observatory. The camera has a Peltier plus liquid cooling system, normally operating at T = $-40°$C. The dimensions of the chip are 1024H $\times$ 1536Vpixels, 9μm each. The scale is 1.03″/pixel. Typical saturation level is 81000e$^-$/pixel ($\sim$15000 ADU for G=1 setting, $\sim$ 63000 ADU for G=4 setting). Nominal dark current value is 0.009 electrons per pixel per second. Readout speed is 200kHz. There are two CCD camera manuals and two PMIS software guides, one of them at Konkoly Observatory's library, the other one at Piszkéstető[2]. Nominal values for readout noise and gain are:

	"G=1" setting	"G=4" setting
Gain(e^-/ADU)	5.35	1.28
Readout noise (e^-)	14.6	13.5

Table 2: Nominal parameters of the chip.

The bias structure of the camera

No significant structure is detected on the average of several bias images. The bias level is approximately 98 ADU at G=1 setting. It is possible to use an artificial overscan region (eg. the first 31 pixels). The mean of the overscan and the bias level is not the same, but they correlate pretty well - within 0.1 ADU. This is of utmost importance as the bias level is strongly time-dependent (cf. Fig. 3). The mean shift between the trim and the overscan is 18.311 ADU (this value might change over longer periods, but seems to be rather stable within a single night).

The dark structure of the camera

Tests were carried out in April, 1999. The dark current is almost negligible, and no definite dark structure was detected.

The flat structure of the optical system

Johnson UBV and Cousins R, I filters are available in the filter wheel. Dirt on the filters might cause flatfielding errors, because the precision of the filter wheel (when changing filters) might be not sufficient, and a small-scale residual flat structure can alias photometric data. The persistent dirt on the camera-window is relatively stable, and well corrected by the flatfield images. A white flatfield board and illumination is available for your convenience, in case skyflat images couldn't be taken. It is also quite usual that the flatfield images change during

[2] PMIS$_{TM}$ Image Processing Software, Version 3.5, User's Manual

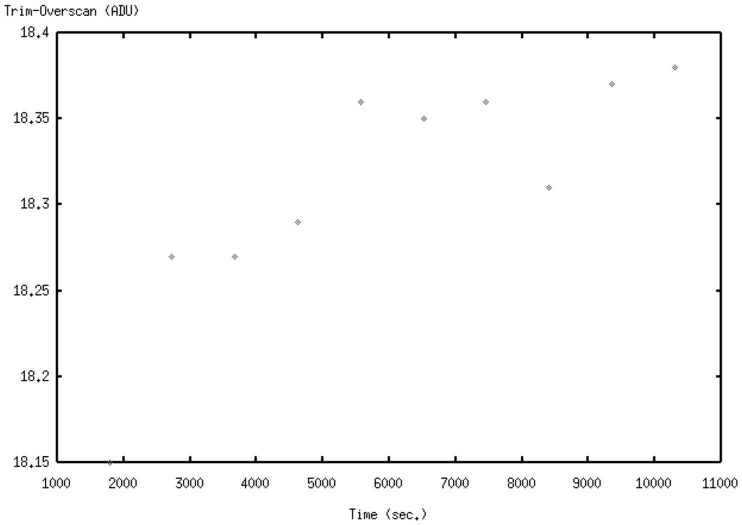

Figure 3: The time dependence of the bias level (Photometrics camera on the Schmidt telescope).

the night (due to the close-by power station and it's air pollution), so it is recommended to use different flatfields for the evening and morning images.

Linearity of the chip

Nominal value for the error is 0.1%. Further tests are not yet available.

Other image anomalies

Dark glow of the camera window might affect the dark level of your images, especially when cosmic-ray impact rate is high.
Bias jumps of the camera might occur, but they are extremely rare. The bias level is spatially split into two parts with slightly different mean values.
Residual images - no tests available.
Stray light in the camera: not yet detected.
Stray light from stars: some really bright stars in a few arcminutes distance from the center of FOV cause illuminated patterns.

Other photometric corrections

Contamination rates of the CCD might affect your UV photometry, such as Johnson U band magnitudes, if the camera is cooled for a very long period. As the system is usually switched off every day, this effect shouldn't cause any serious error in the data.
Charge transfer efficiency - no tests available.
Long versus short anomaly - no tests available.
Digitization noise - as gain values are much smaller than the readout noise there is no serious effect of digitization noise.

Geometric distortion

The plate-constants of the telescope were determined from 12 stars in the middle of the field by L. Kiss (JATE). The difference in declination and right ascension between the calculated positions and USNO catalogue reference positions were calculated for other 129 stars scattered across the chip. The differences in declination (calculated from plate-constants minus reference) are plotted in the left panel of Fig. 4. The same results are shown for right ascension in the right panel. The absolute differences ($\sqrt{((\delta \mathrm{DEC})^2 + (\delta \mathrm{RA})^2)}$) are shown on the corresponding web-page. The conclusion is that the chip is not perfectly aligned with the optical axis of the system, and it is in a slightly tilted position. All astrometric observations should take this into account.

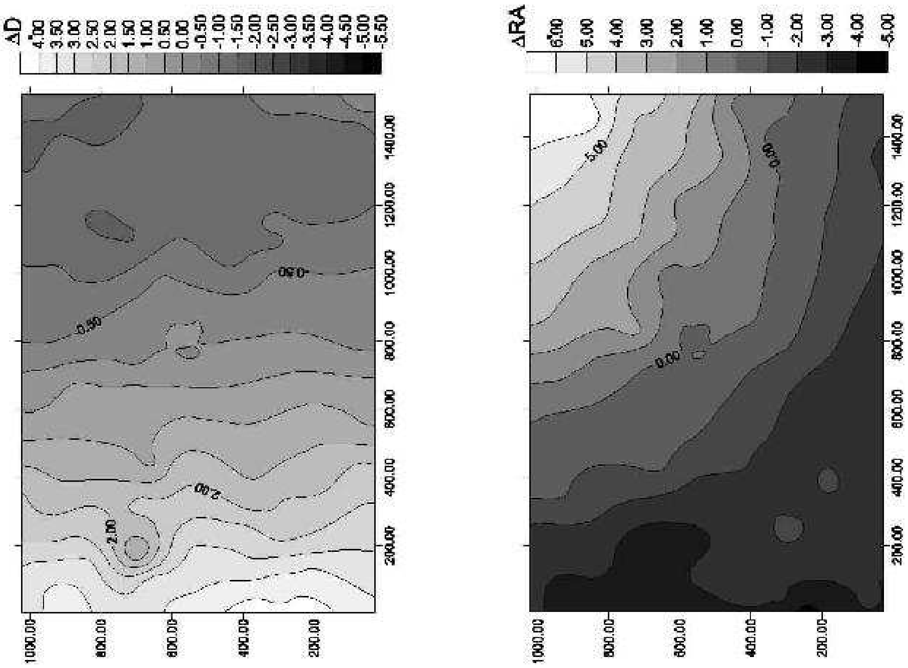

Figure 4: The differences in declination (calculated from plate-constants minus reference) and in right ascension (Schmidt telescope).

3 Calibration of the Photometrics CCD on the RCC telescope

Basic parameters of the camera

This section deals with the calibration Photometrics TH7896M UV-coated CCD camera, which is in use on the 1m RCC telescope at the Piszkéstető Mountain Station of Konkoly Observatory. The camera has a Peltier plus liquid cooling system, normally operating at T = −40°C, and a 16-bit A/D converter. The dimensions of the chip are 1024H × 1024V pixels, 19μm each. The focal length of the telescope is 13.6m, ie. the scale is 0.288”/pixel. Typical saturation level is 375000 e^-/pixel ($\sim$ 68000 ADU for G=1 setting, $\sim$ 270000 ADU for G=4 setting). Nominal dark current value is 0.4 electrons per pixel per second. Readout speed is 40kHz, but there is a great difference between the net readout time (including writing file to disk) of “G=1” (31s) and “G=4” (57s) settings. For further details on the programing environment confer the camera manuals and the PMIS software guides. Linearity error is nominally smaller than 0.07%.

	“G=1” setting	“G=4” setting
Gain(e^-/ADU)	5.5	1.4
Readout noise (e^-)	5.8	4.5

Table 3: Nominal values for readout noise and gain.

	“G=1” setting	“G=4” setting
Gain(e^-/ADU)	5.56 ± 0.01	1.4 ± 0.1
Readout noise (e^-)	5.7 ± 0.2	5.0 ± 0.2

Table 4: Measurements from March 1999.

The bias structure of the camera

The time-dependence of the bias level

Tests were carried out in February, 1999, showing that the bias level for both gain settings were reasonably stable. The temperature was held at −40°C with an error of 0.2°C. This issue is of utmost importance because there is no overscan area on the chip, thus the bias level has to be determined from interpolation of bias images. The negative feedback of the cooling system results in periods of slow cooling and slow heating, which might (electronically, but not due to temperature changes!) cause the following anomalies.

For ”G=1” setting the bias level is approximately 480.9 ADU, the minimum to maximum difference is 0.6 ADU, which means approximately 0.1% relative deviation. The statistical scatter of the dataset is much smaller. You can check the bias level’s time dependence graph for 04/02/1999 and 05/02/1999 on Fig. 5 and Fig. 6, respectively.

For ”G=4” setting the situation is more complex.. Each time rebooting the system, or initializing the camera again (eg. switching between different gain values), the bias level gets anomalously high and then decreases to a rather stable value. The bias level is approximately 452ADU , minimum to maximum scatter in 3 hours is $\sim$ 0.6ADU, which is approx. 0.1%. You

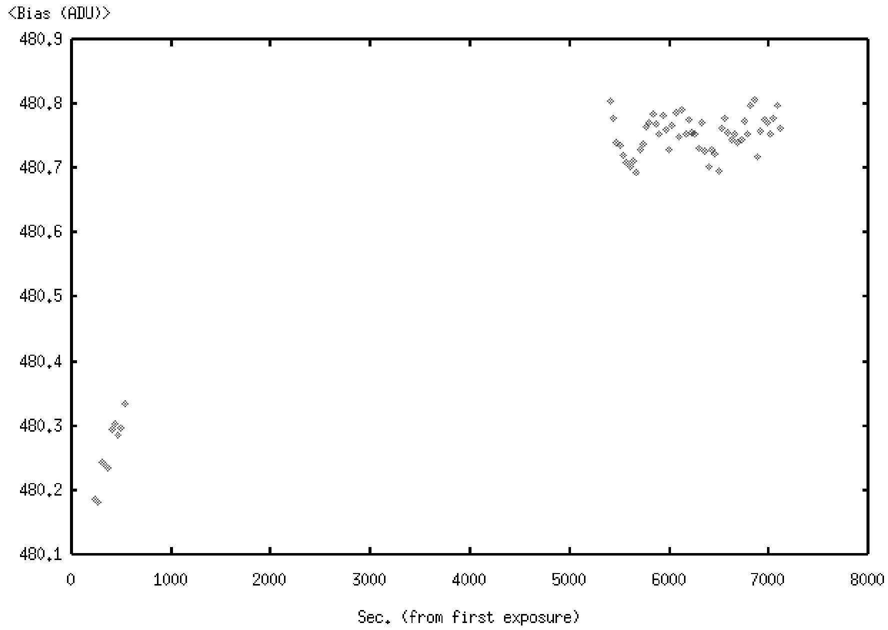

Figure 5: Time dependence of the bias level for 04/02/1999 at the Photometrics camera attached to the 1m telescope (G=1).

can check the bias level's time dependence graph for 04/02/1999 and 05/02/1999 on Figs. 7 and 8.

Average parameters of the bias images

The mean value for "G=1" setting ($T = -40°C$) is $\sim$ 480.9ADU, standard deviation is $\sim$ 1ADU. For "G=4" mean is 452ADU, standard deviation is $\sim$ 3.5ADU.

Structure of the bias images

Due to slow readout, and relatively high readout noise (this is not a N_2 -cooled camera) the bias images are seriously affected by the dark current of the chip. Generally speaking, the pixels with small Y have smaller bias values (read out before the higher ones). This slope is well represented in Figs. 9 and 10. As it is expected, the slope of this dependence for "G=4" setting is much higher, due to longer readout time.

Other features are also well visible on the averaged bias images, such as bright streaks resulting from warm pixels with anomalously high dark current, and dark streaks from charge traps.

Histogram of bias images

In a normal case for "G=1" setting there are no pixels with higher values than 700ADU, and no higher pixels than 1500 for "G=4". The histogram of the biases is quite normal, showing no sign of constant electric disturbances (Fig. 11: histogram for "G=1", Fig. 12 histogram for "G=4")

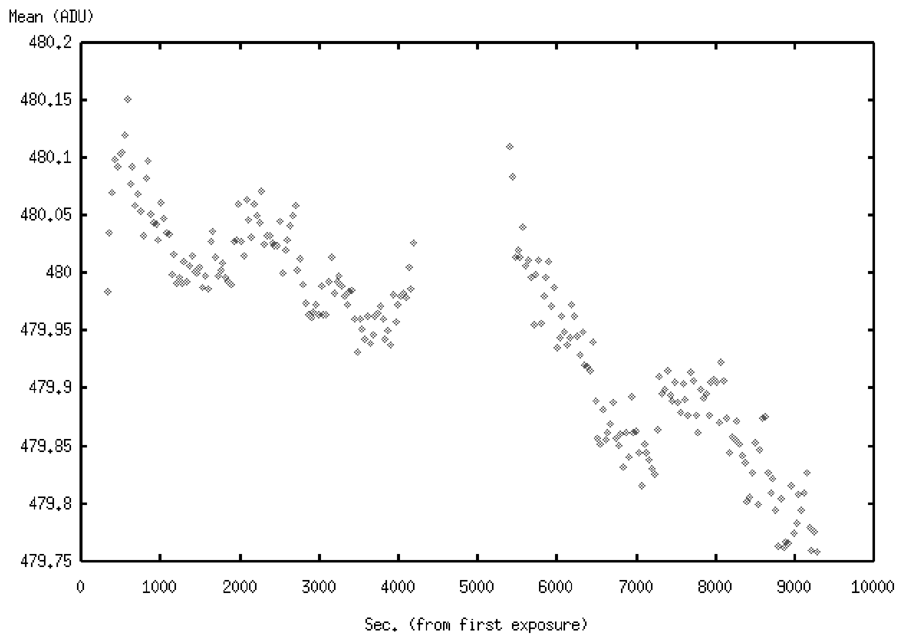

Figure 6: Time dependence of the bias level for 05/02/1999 at the Photometrics camera attached to the 1m telescope (G=1).

The temperature-dependence of the bias images

The bias level depends slightly on the temperature of the chip. The temperature of the chip was assumed to be the one shown on the digital display of the cooler, however the precision of the cooler's thermometer should need further investigation. In a range of 15 Celsius degrees the average bias level changes $\sim$ 6ADUs, which corresponds to bigger than 0.01 slope (Fig. 13), which is far too big for a photometric camera. However, due to the dark current, this is not the true bias level. The average of the first 100 rows is plotted against the temperature shows that the true bias-level dependence is approx. 0.006 (just acceptable).

Bias errors

Bias jumps were not observed out of more than a thousand bias images. Unfortunately, the camera was connected to the same electric circuit as the other electronic devices in the dome till late Spring of 1999. Switching off/on any device in the dome seriously affected the images during readout (maybe not only then).

Dark structure of the camera

Tests investigating the dark structure of the camera were carried out in February, 1999, on 3 subsequent days. The average dark image of several dozens of frames shows no definite structure, rather a notable scatter with warm pixels and charge traps. There are at least three regions where slight clustering of the warm pixels is noticeable.

The linearity of the dark current was measured with taking series of (bias, dark) frames, interpolating the bias level versus time, and correcting the dark images for the actual bias

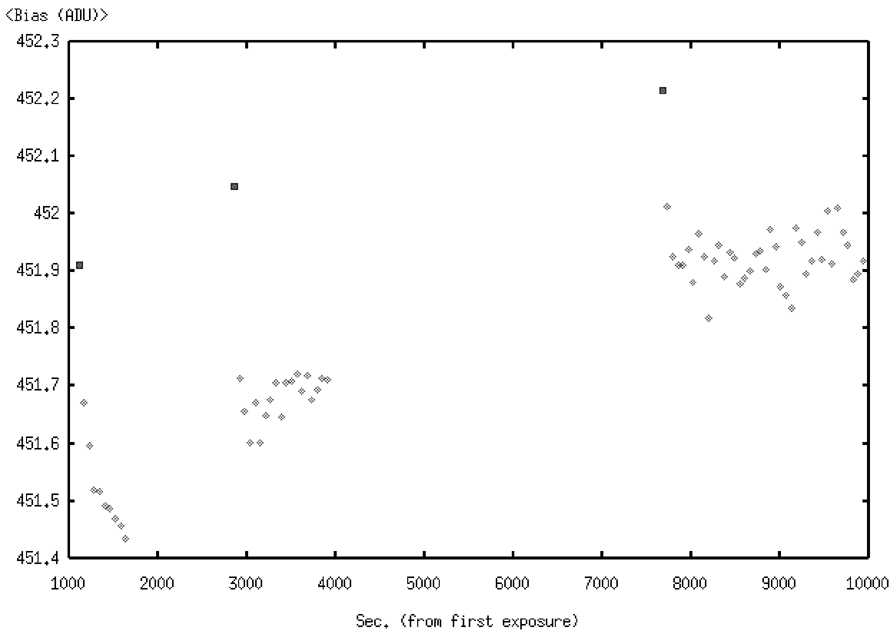

Figure 7: Time dependence of the bias level for 04/02/1999 at the Photometrics camera attached to the 1m telescope (G=4).

levels. Almost all light was excluded in the dome, and the shutter was closed. For "G=1" setting the dark current is perfectly linear, and it can be well approximated by 0.0297ADU/sec, For "G=4" the dark current is quite linear, unfortunately the bias level was rapidly changing at the beginning of the observation. The linear part is well fitted by 0.117ADU/sec, which indicates that the gain ratio GR = G4/G1 = 3.94 ± 0.04.

The standard deviation of the dark current for "G=1" is STDEV = $0.0363 * T_{exp} + 4.8$(ADU), the same quantity for "G=4" is STDEV = $0.122 * T_{exp} + 27$, which indicates a similar gain ratio, but with much higher uncertainty, and not taking the digitization noise into account.

As concerns photometry, dark current can be approximated to be linear as a function of time, and dark correction cannot be skipped. Moreover, it is recommended to take several dark images during daytime and create a masterdark, because the images quoted on this page might change in time. For "G=1" setting the 1% linearity approximately ends at MAXDATA = 63500ADU signal (+bias), and theoretically this quantity is independent of the gain.

The anomalously low pixel values at the lower Y edge ($Y <= 30$) of the images were investigated. There seems to be a dichotomy between integration times shorter and longer than 10000 milliseconds, respectively, ie. the effect is absent if the integration time is shorter than 10000 milliseconds. There is not trace of transition between the two states; the pixel values suddenly become lower if the exposure time is 10001 milliseconds! In case you are doing photometry on this region with integration times longer than 10.0 seconds, you might want to correct for this anomaly. Figure 14 shows the effect on a dark image with T=10.001s exposure time.

The dark structure of the camera was revisited in March 1999. There seems to be a large-scale structure on the dark images with a vertical streak at Y=809 splitting the chip into two separate parts.

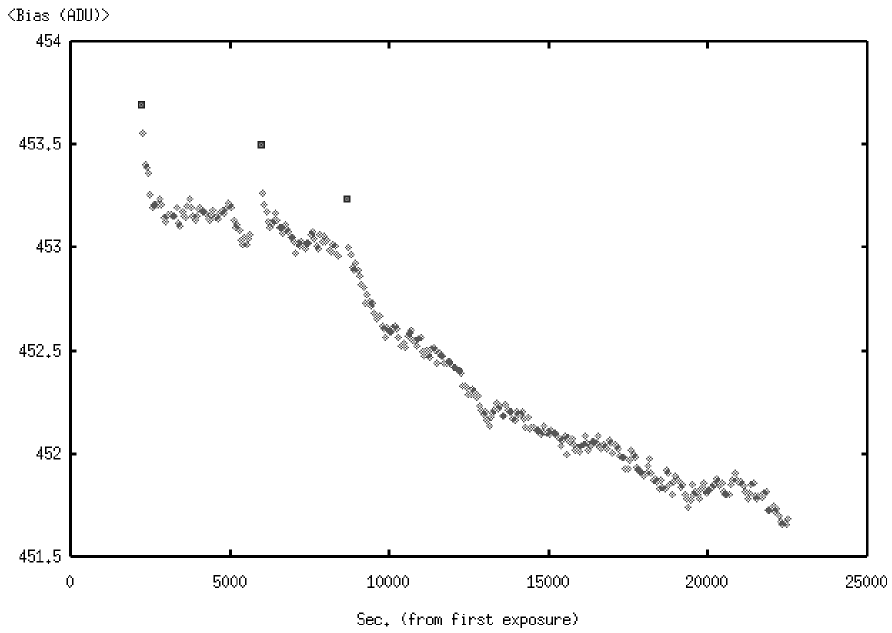

Figure 8: Time dependence of the bias level for 05/02/1999 at the Photometrics camera attached to the 1m telescope (G=4).

Linearity of the chip

Linearity measurements were carried out in February, 1999, with domeflat images lit by a voltage-stabilizer aided lamp, and several bias images to fit the background level. The overall results are shown on Figure 15.

For "G=1" the data points were fitted with a linear expression (after fitting a high order polynomial to the bias level, and subtracting it), and the standard deviation of the points from the fitted line within the [10000:50000] ADU range was $\sim$ 16ADU, which means that the chip is linear to 0.16% precision in worst case (this value is rather smaller, $\sim$ 0.05%). Should this affect your photometry, you might want to make more precise measurements in the range of interest.

Similar method was carried out for "G=4", where the errors in the linear range were in the order of maximum 0.3%.

Using the fitted curves, the gain ratio turned out to be GR = 3.98, which is consistent with the previous results.

For "G=1" setting the 1% linearity approximately ends at MAXDATA=63500 ADU signal (+bias), and theoretically this quantity is independent of the gain (for "G=4" the measurements gave MAXDATA=63300 ADU).

Flatfield structure of the optical system

See section at the calibration of the Wright CCD.

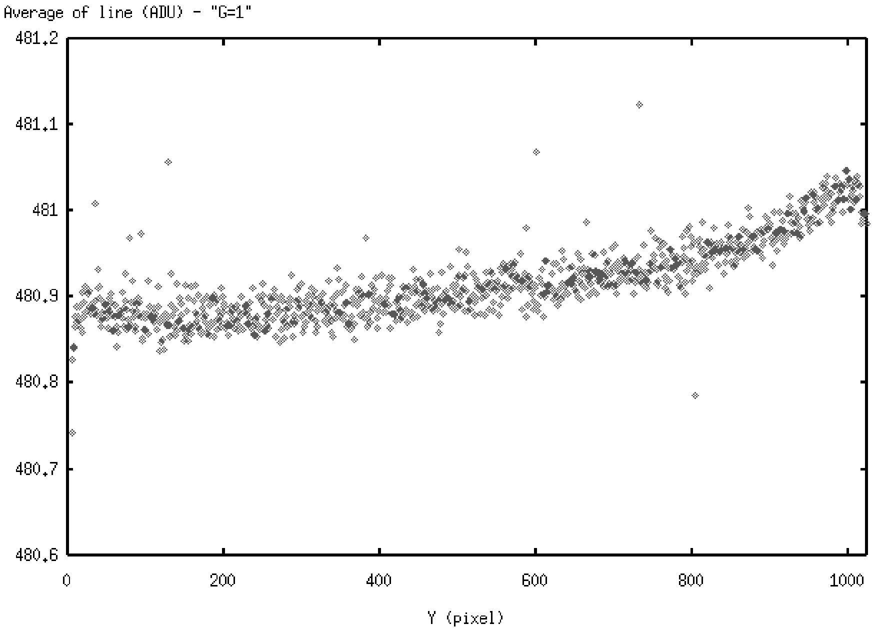

Figure 9: Pixels with small Y have smaller bias values at the Photometrics camera attached to the 1m telescope (G=1).

Shutter effects

The shutter is nominally able to take exposures as short as 0.01 seconds. However, if the illumination of the blades is high (thus short exposures are required) shutter effects must be taken into account. The effect becomes quite serious with exposures shorter than 5 seconds.

References

PMIS$_{TM}$ Image Processing Software, Version 3.5, User's Manual
AT1 operators guide, Version 3.00
CCD camera manual (For Wright Instruments Peltier cooled CCD cameras)
This document on the www: `http://www.konkoly.hu/konkoly/telescopes/calibration/index.html`

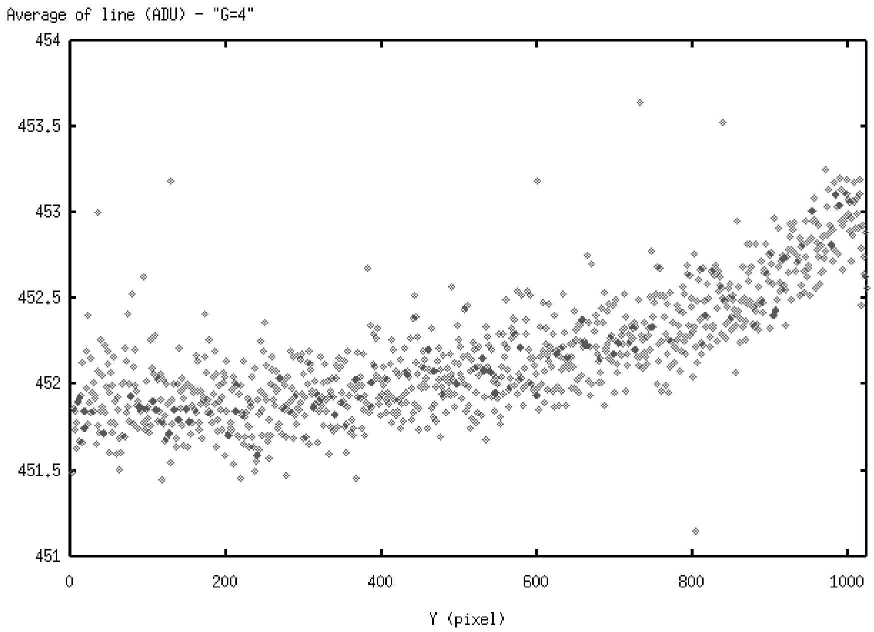

Figure 10: Pixels with small Y have smaller bias values at the Photometrics camera attached to the 1m telescope (G=4).

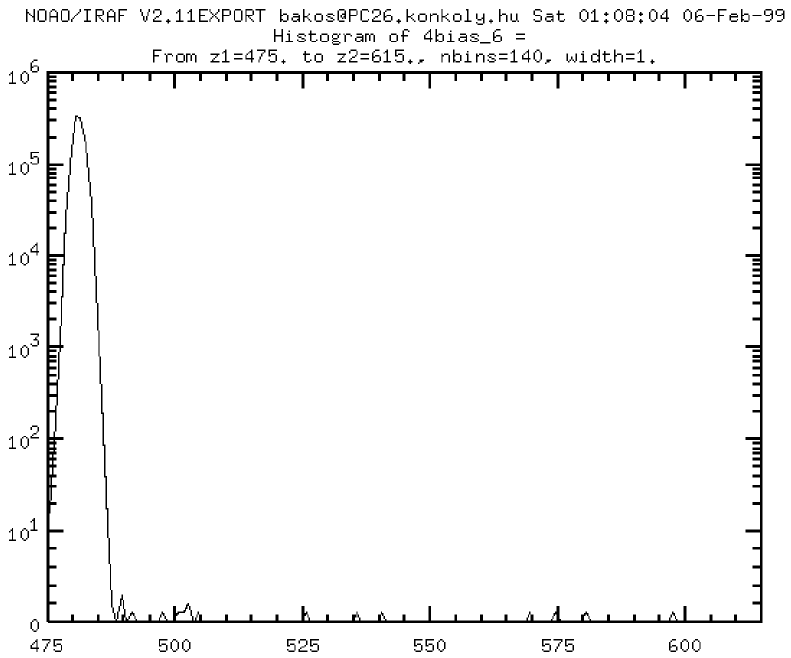

Figure 11: Histogram of the bias image at the Photometrics camera attached to the 1m telescope (G=1).

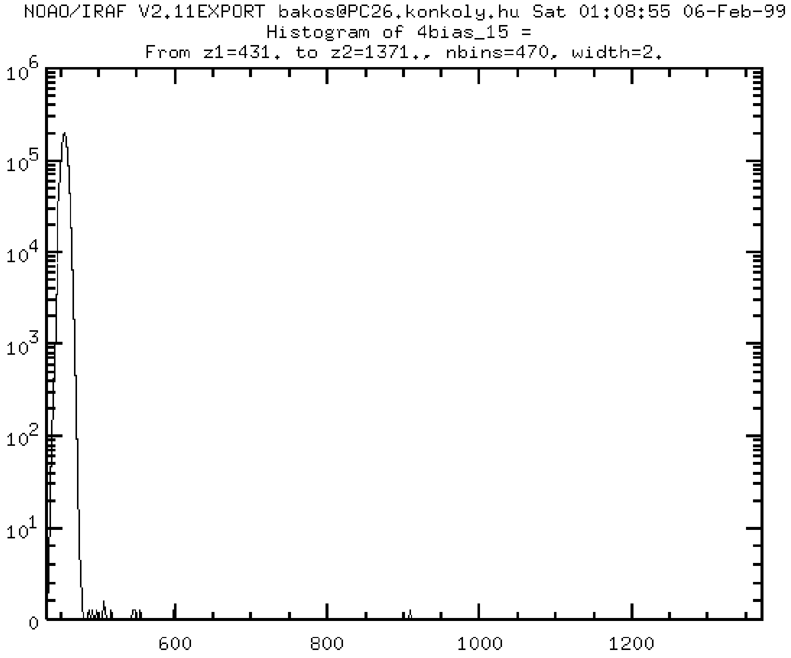

Figure 12: Histogram of the bias image for G=4.

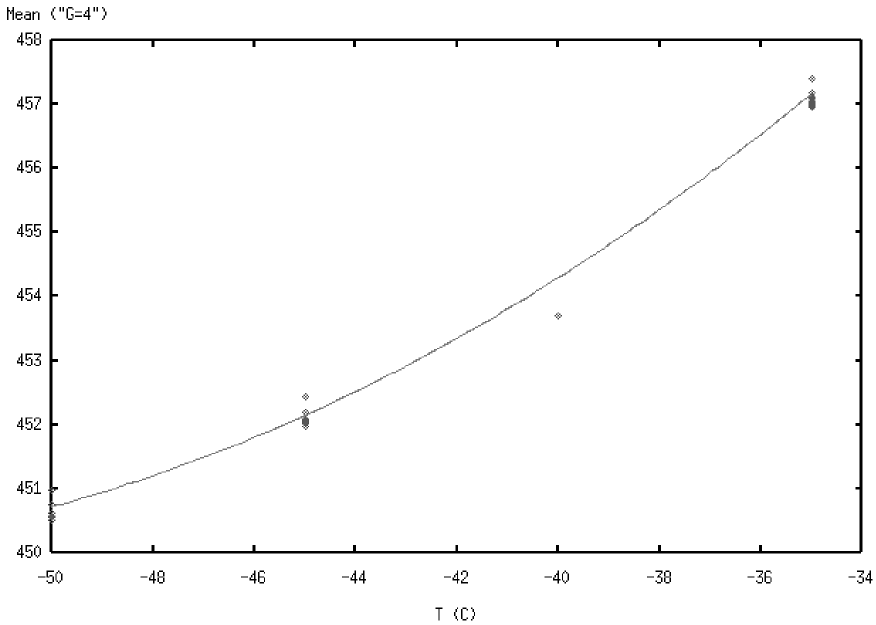

Figure 13: Temperature dependence of the bias level.

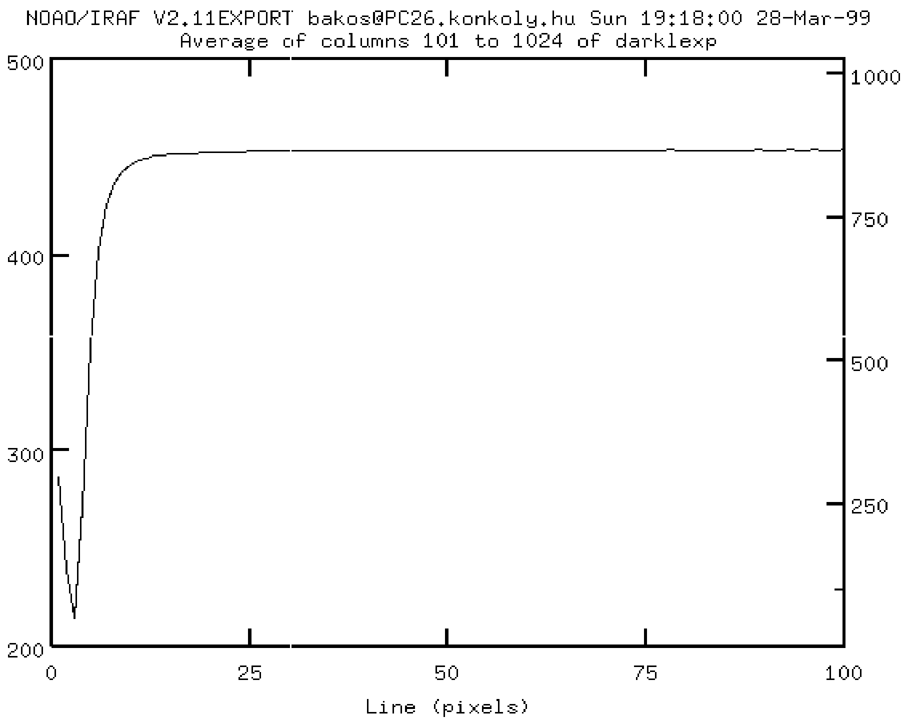

Figure 14: Anomalously low pixel values at the lower Y edge for exposure times longer that 10000 milliseconds (Photometrics camera on the 1m telescope).

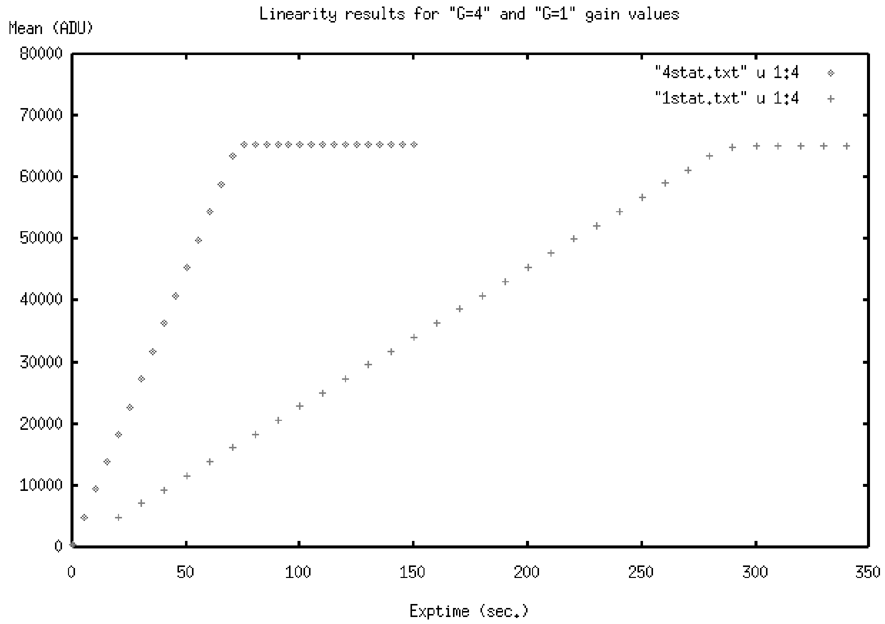

Figure 15: Results of the linearity measurements (Photometrics camera on the 1m telescope).