Clio linearity calibration

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Abstract

Here I report linearity measurements, fitting a linearity curve, and correcting raw Clio data for linearity. This is important to get right, as it impacts all high-contrast photometry. This document refers to the original Clio detector (the one also used at MMT), in Clio during Comm1 and Comm2 commissioning of the MagAO system in Nov-Dec 2012 and Mar-Apr 2013. Result: With the linearity correction calibrated here, counts up to ∼45,000 DN in the raw frames can be corrected for linearity. Clio users should avoid raw counts above this threshold. Users must apply the linearity calibration to pixels with raw counts above ∼27,000 DN.

1 Method

We (Vanessa Bailey and I) observed the background through the 3.4 um filter with the rectangle field stop in the wide camera on 2013 March 30th, UT (when we were still on the CRO and not opening the dome at night). This illuminated most of the right half of the detector. We took 5 images at each integration time (1 coadd), and stepped up the integration time as follows, in milliseconds: [43, 100, 150, 200, 300, 400, 500, 750, 1000, 1250, 1500, 1750]. Data are saved as "linearity*.fit" in "n130330/". The IDL data analysis session is saved as a journal file in journals/20130330_06-14-57.txt, 20130408_02-34-14.txt, and .

The median counts within the illuminated rectangle were recorded for each raw frame. I then took the average of the 5 frames per integration time as the "counts" value. This value, counts (a.k.a. DN = data numbers), is plotted in Fig. 1 as a function of integration time in milliseconds. The count rate was extrememly stable over each set of 5 images, as shown by the 5-standard-deviation error bars in the plot (the black vertical bars on top of the data points), varying from 0.1 to 0.5%.

2 Fitting the data

The goal of the linearity test is to find the true count rate as a function of the measured count rate, in order to linearize photometry. So first we try fitting a line to the linearity data, as shown in Fig. 2. I ignored the measurements below 500 ms, because they were noisier due to a higher proportion of dark current. I stayed in the strictly linear regime by only choosing the data up to 1500 ms.

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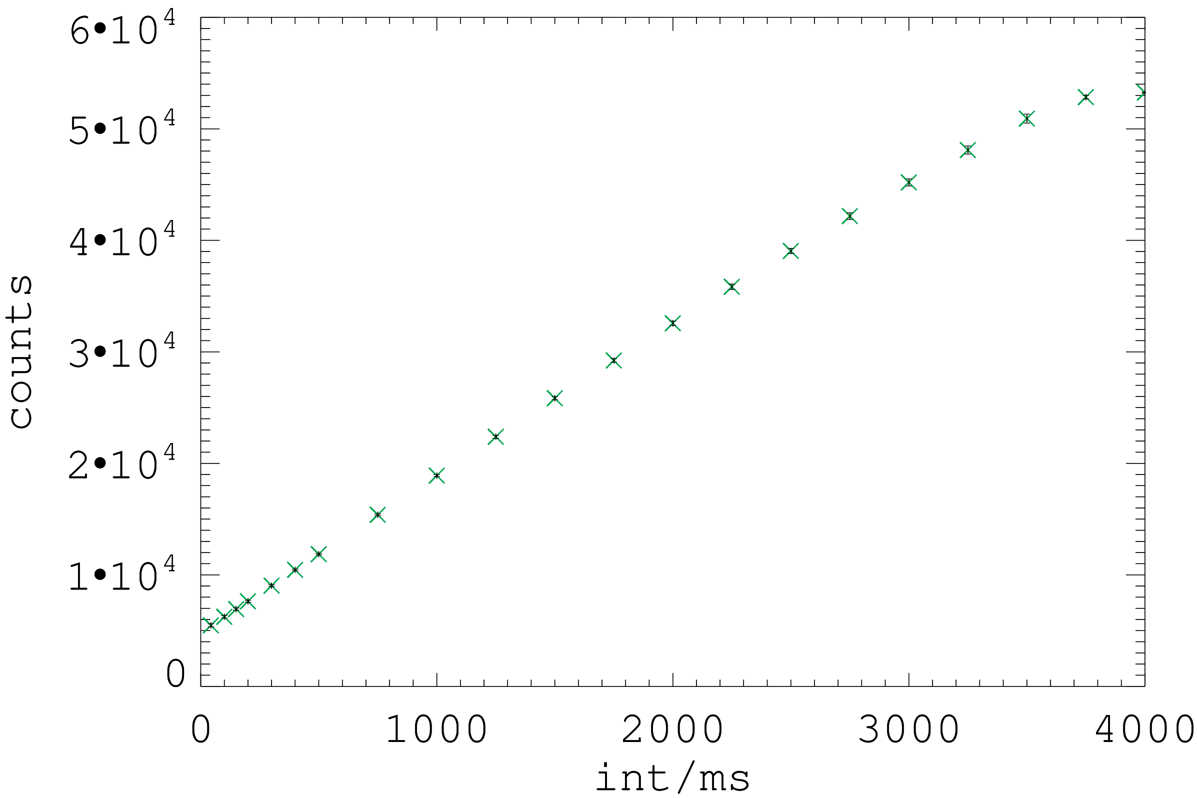

Figure 1: Counts in DN as a function of integration time in milliseconds. The green X's mark the data points, and the tiny black bars show the 5-sigma error in the count rate.

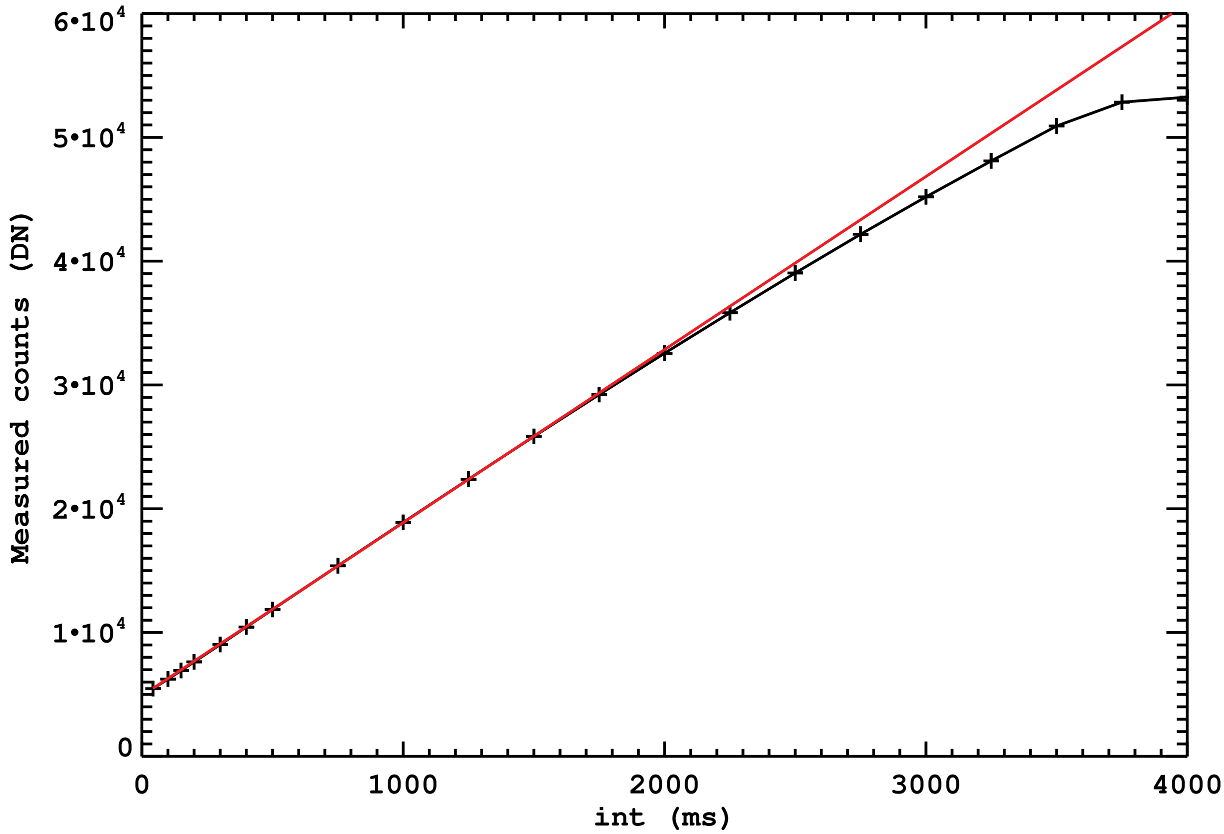

Figure 2: Best-fit line to the linearity measurements. The detector is only strictly linear up to ∼27,000–30,000 DN. A linearity correction must be applied above this threshold.

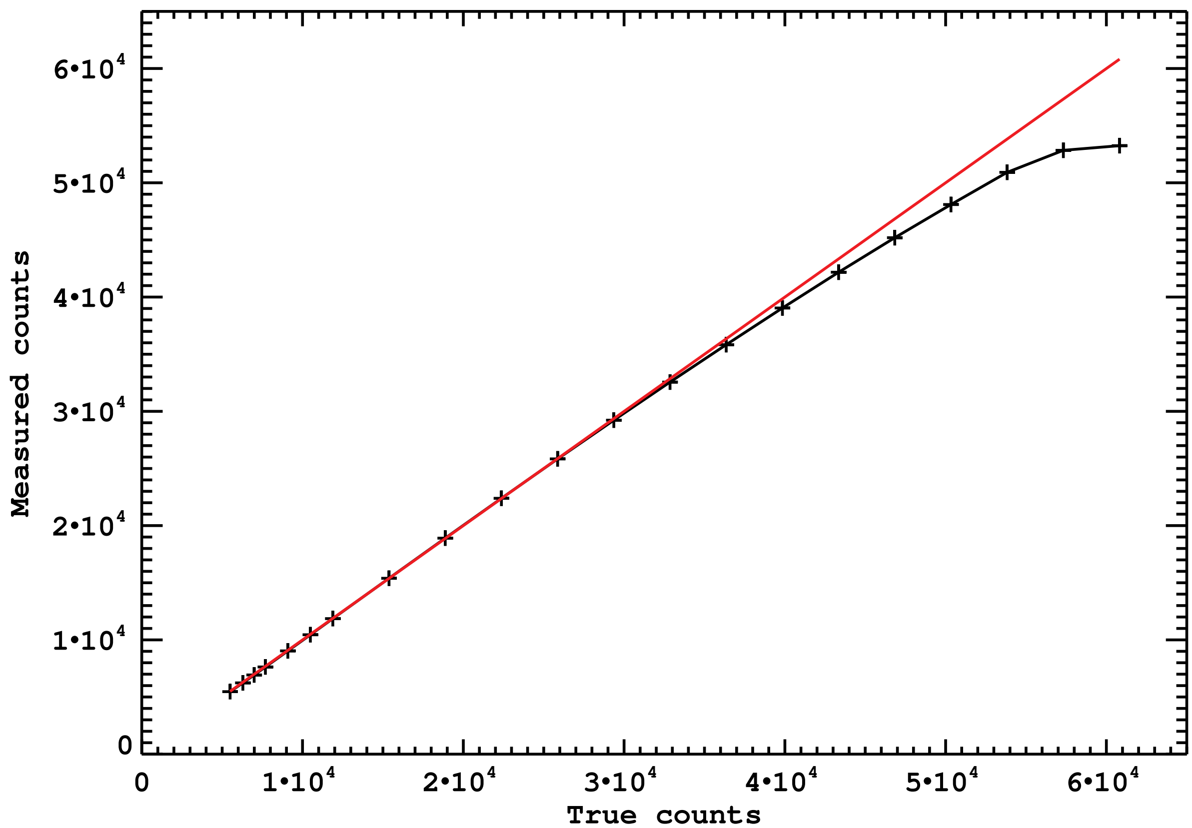

Figure 3: True counts vs. measured counts, based on a line fit to the data between 500 and 1500 ms (black line). The red line shows the assumed linear relationship used to generate the fit and determine the "true" counts: true counts=measured counts.

The result of fitting the data within the linear regime, using the count rate measured at 500, 750, 1000, 1250, and 1500 ms, was a line of slope 13.9820 DN/ms and y-intercept 4892.02 DN, where the x-axis is ints in ms and the y-axis is measured counts in DN.

Therefore, the measured counts of [5470.80, 6239.40, 6931.00, 7630.10, 9034.70, 10446.9, 11858.9, 15388.0, 18899.9, 22385.8, 25837.5, 29225.3, 32558.6, 35832.9, 39044.7, 42172.1, 45193.2, 48096.0, 50914.0, 52842.4, 53251.4] DN by the linear fit should be true counts of [5493.25, 6290.22, 6989.32, 7688.42, 9086.62, 10484.8, 11883.0, 15378.5, 18874.0, 22369.5, 25865.0, 29360.5, 32856.0, 36351.5, 39847.0, 43342.5, 46838.0, 50333.5, 53829.0, 57324.5, 60820.0] DN. These values are plotted in Fig. 3, showing the best-fit "true" counts vs. measured counts.

3 Finding a function for linearity correction

I tried fitting second, third, and fourth-order polynomials to the measured counts to come up with a function to convert data to true counts. This is the function that best fits the data (black line) in Fig. 3.

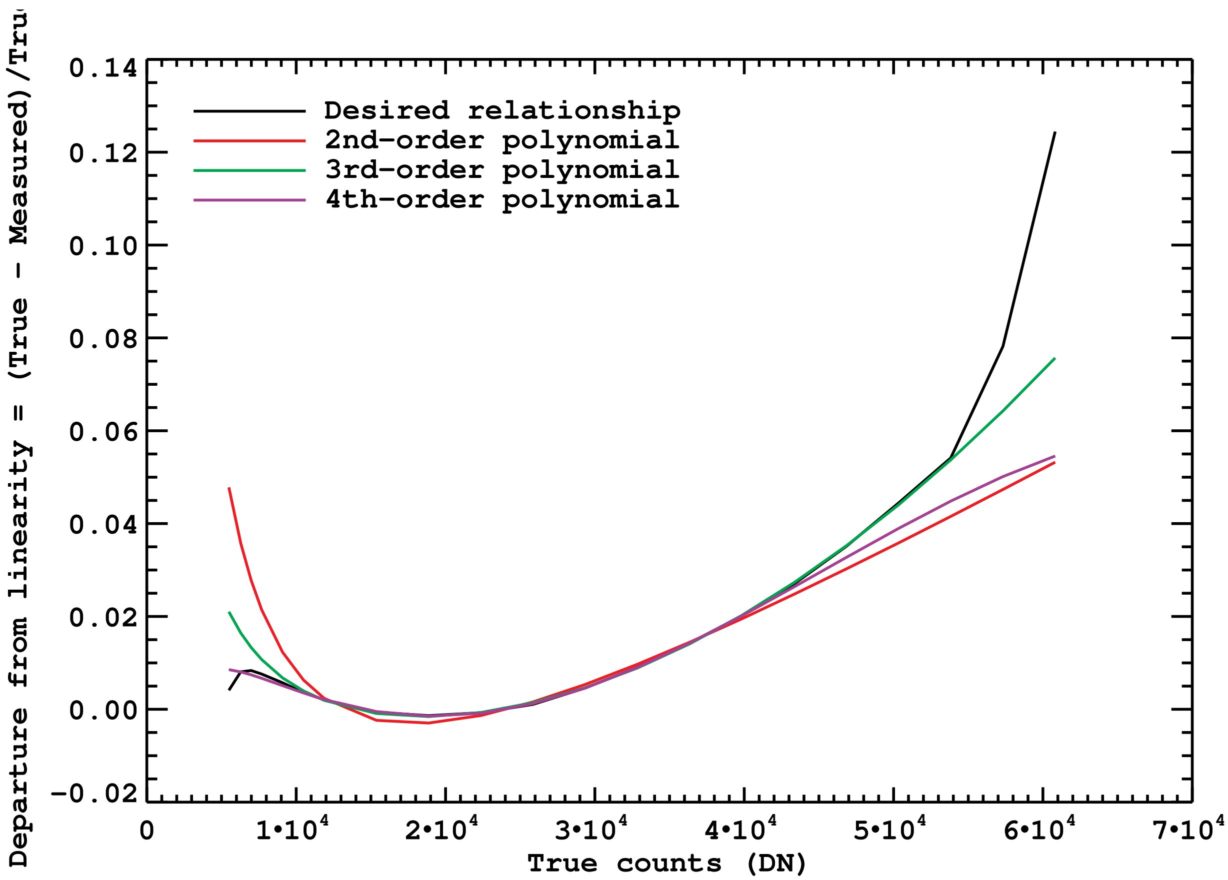

Figure 4: Best fit functions of 2nd (red), 3rd (green), and 4th (purple) order to the linearity data (black). The y-axis is a metric for linearity which is equal to the difference of true counts and measured counts, divided by true counts. The best fit is the 3rd-order polynomial (green), which can be applied to raw images for pixels above a count rate of 27,000 counts.

In order to see small differences in the functions, I now plot a kind of fractional linearity as the y-axis metric, as seen in Fig. 4.

Therefore, I find that the best-fit function to the data is a third-order polynomial, determined uisng the IDL function poly_fit, giving:

$$y = A + Bx + Cx^2 + Dx^3 \tag{1}$$

and the coefficients are given as

- A = 112.575
- B = 1.00273
- C = -1.40776e-06
- D = 4.59015e-11

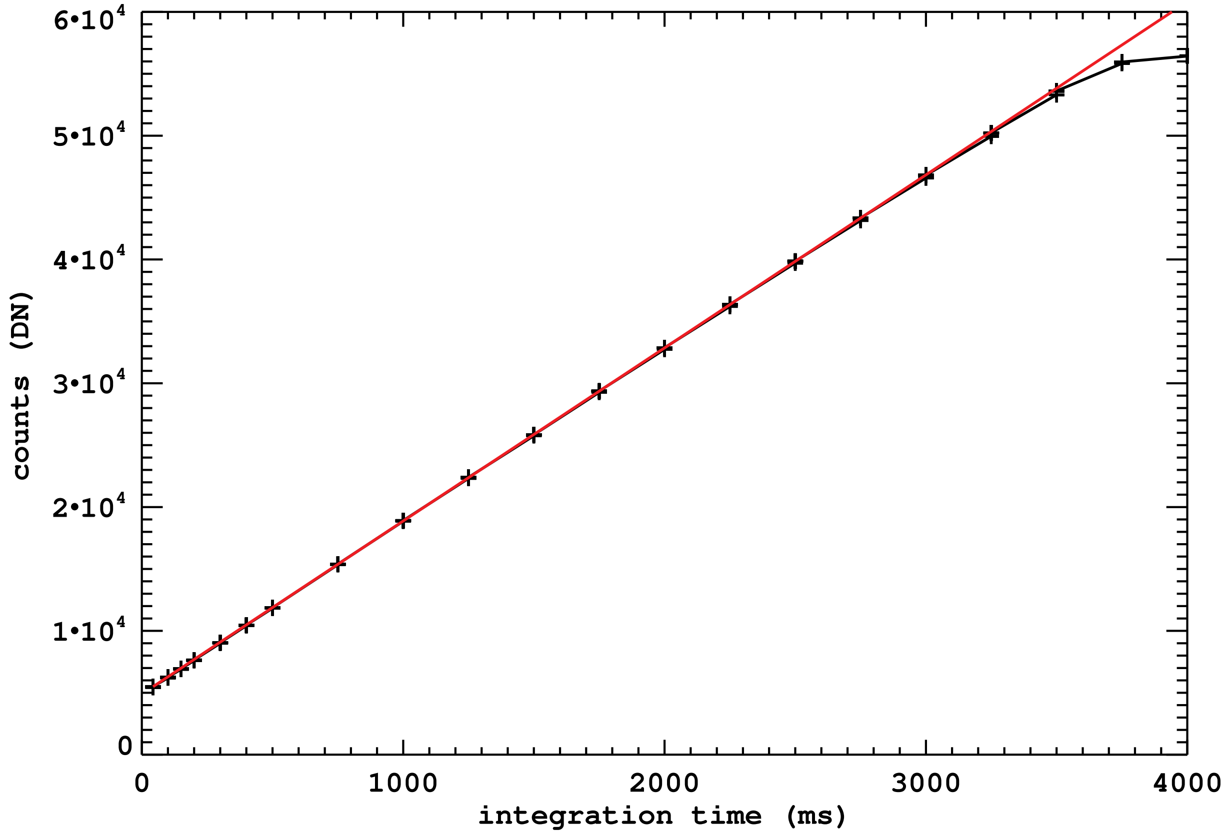

Figure 5: Linearity-corrected data using Eqtn. 1 applied to pixels above 27,000 raw DN. Counts up to ∼45,000 DN in the raw frames (which is ∼46,000 DN, corrected) can be corrected for linearity; avoid raw counts above this threshold.

and where y is the true counts and x is the measured counts. This function can be used to correct the linearity of raw Clio data, only for pixels above ∼27,000 DN in the raw frame. (FITS files with coadded data should first be divided by the number of coadds). I created the IDL function "linearize_clio2.pro" for this calculation, used as "corrected_image = linearize_clio2(raw_image)".

4 Testing the linearity correction

Just to check this function and make sure I got it right, I applied the linearity correction to the original data of the background imaged through the rectangle field stop at 3.4um. The result is shown in Fig. 5, where pixels above 27,000 DN in the raw frames have been corrected to make their counts linear. With the linearity correction, raw Clio data is useable (un-saturated; aka. linearity-correctable) up to ∼45,000 DN; raw counts above this threshold should be considered saturated.