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To: S. L. Murchie

From: L. M. Howser

Subject: Linearity Results for the CONTOUR Spectrograph

References: (1) L. M. Howser, "Measurements of the Attenuator for the CRISP Test Equipment," A1F(2)02-U-082, 29 October 2002.

(2) L. M. Howser, "Preliminary Linearity Results for the CONTOUR Spectrograph," A1F(2)02-U-020, 10 June 2002.

Summary

Preliminary linearity results for the CRISP instrument were reported in Reference (2). Recently, the integrating sphere and attenuators used in the linearity measurements were calibrated. These new calibration results for the test equipment have been used to update the measurement of the CRISP sensor linearity.

Introduction

The CONTOUR Remote Imager and Spectrograph (CRISP) is one of the instruments on the CONTOUR spacecraft. The IR spectrograph contains a 256x256 HgCdTe array. The array is illuminated through a slit that provides a one-dimensional spatial image. The spatial instantaneous field-of-view (IFOV) is 58.6 _rad/pixel, giving a field-of-view of about 0.86°. The other image dimension is spectral, from the dispersion of the spectrometer's grating. The spectrograph has a spectral pixel size of about 7 nm and measures the IR spectrum from 800 nm to 2500 nm. There are two spectral zones on the array, covered by fixed-mounted bandpass filters that block out-of-order light from the grating and thermal background from the instrument cavity.

During the calibration of the spectrograph, a series of measurements of an integrating sphere was collected in order to characterize the instrument linearity. The setup for these tests included a white integrating sphere with two inputs: a halogen lamp and a xenon lamp. Each lamp had a knife-edge attenuator between the lamp and the integrating sphere. Thus, each lamp was attenuated individually. During these tests, the attenuators were commanded from 255 (closed, "background" image) to 0 (open). When both lamps were used, the two attenuators were commanded to the same value. When only one lamp was used, the attenuator for the unused lamp was commanded to 255.

Data from the test sequence, 355_CSBML_WFR_02, were used in these analyses. These files are from calibration tests performed after the instrument's environmental tests. Three series of data were collected for this test: halogen lamp only, xenon lamp only, and both lamps. The attenuators were varied from Closed to Open for each test series.

The integrating sphere and attenuators were calibrated this past summer. Reference (1) has results from this calibration. These results were used in updating the preliminary linearity results reported in reference (2).

Linearity

Both the halogen-only and xenon-only data were used in this analysis. Figure 1 shows an example image of the halogen data. This image is from the 1 Hz data, collected with the attenuator set to 180. (During this series of tests, data were collected at 1, 3, and 5 Hz frame rates.) The transition between the ‘zone 1’ and ‘zone 2’ filters in the instrument is at about 1310 nm. This image shows that the sensor was near saturation at 1600 nm. The figure also shows that the top few rows (about 12) of the image are dark. These rows are not illuminated by the sphere. Signals in these rows change slightly with attenuator position, but don’t follow the pattern of the lower rows.

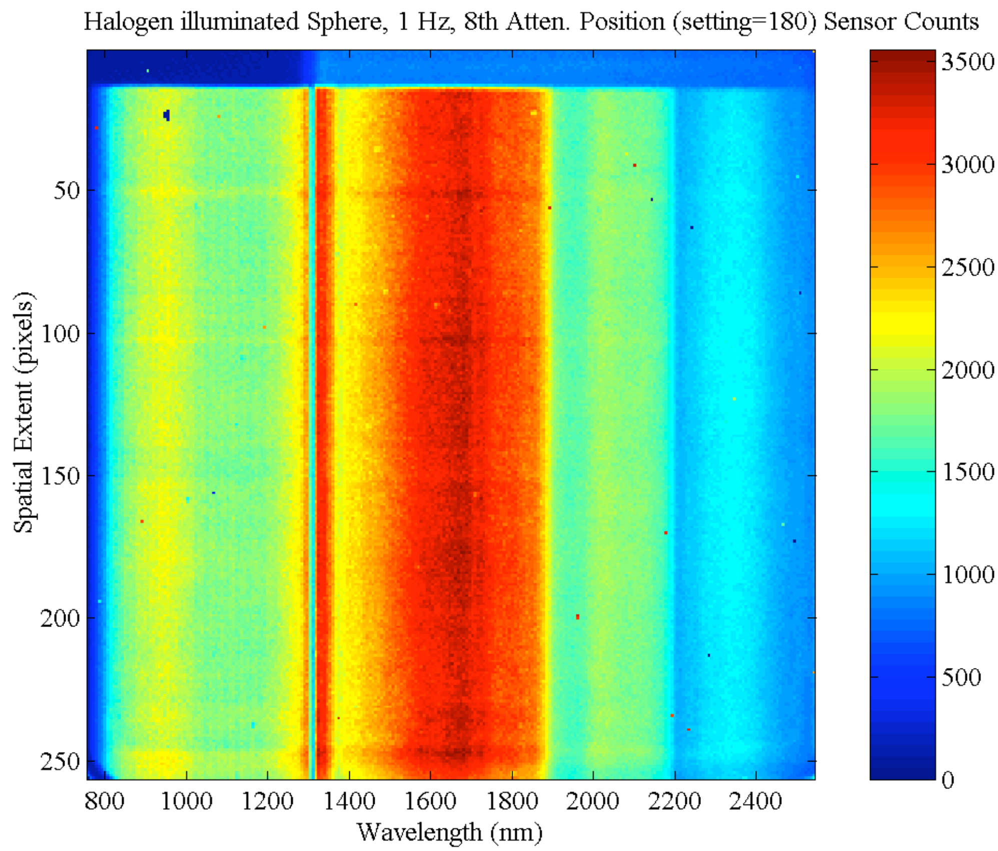

Figure 1: An example image from the halogen dataset. The division between the zone 1 and zone 2 data is visible at around 1310 nm.

The linearity analysis was started using the shorter wavelength data. These columns have little signal caused by the instrument background. For the shortest integration times, the sensor signal is close to the system bias. A slight signal (10-20 counts) was present after subtracting the bias. Thus, instead of subtracting the bias, the background image (image collected with attenuator closed) was subtracted from the data. This subtraction is only valid in the shorter wavelength region where the background is only a few counts above the bias.

To continue the analysis, three consecutive frames with the same attenuator setting were averaged to reduce image noise. An average was then performed down each column (excluding the top 30 rows and the bottom 15 rows) to obtain an average signal for each wavelength. This averaging was used to reduce noise effects.

The three plots in Figure 2 are from columns 10-60 (845 – 1188 nm) of the 1 Hz Halogen data. The top left plot shows the column-averaged sensor signal versus the attenuator position. (Positions 1 through 12 correspond to transmissions of 0 to 100%.) All of the columns (wavelengths) reached saturation (>3500 counts) at the highest attenuator settings. In this plot, each wavelength is plotted in a different color dot. The dots for a given attenuator setting form a vertical line. Two lines have been drawn to connect the dots from two different wavelengths.

Table 1 lists the attenuator positions used in the CRISP testing and in the sphere calibration. Sphere spectra were measured at 5 positions; 4 of the 5 positions were also used during the CRISP testing. The weakest spectrum was measured at the attenuator setting of 220. This spectrum was also very noisy. The sphere spectra for the attenuator positions from 230 – 255 would have been extrapolated from the measurement at position 220. Because of the weak signals at CRISP positions 1-3, and the extrapolated spectra, we decided to use data only from positions 4 through 12 (attenuator settings 220 through 0) for this linearity analysis.

Table 1 Attenuator Settings during Tests

CRISP Measurements		Sphere Calibration	
Position Number	Attenuator Setting	Position Number	Attenuator Setting
1	255 (CLOSED)	1	220
2	240	2	200
3	230	3	170
4	**220**	4	100
5	210	5	0 (OPEN)
6	**200**		
7	190		
8	180		
9	**170**		
10	150		
11	130		
12	**0 (OPEN)**		

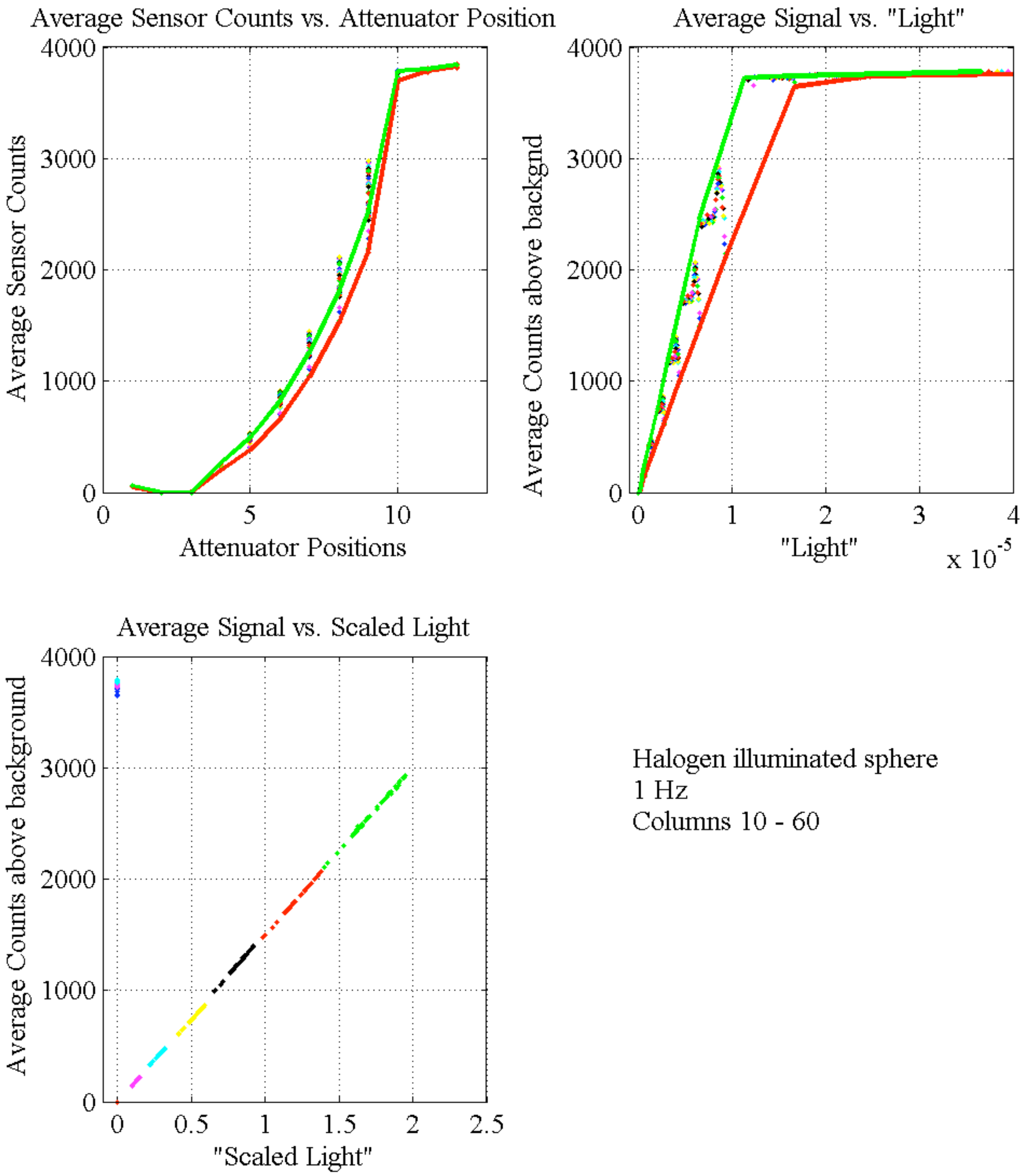

Figure 2: Results from the 1 Hz halogen data, columns 10 – 60. The top-left plot shows the column-averaged sensor signal versus attenuator position for these 51 columns. The same sensor data are shown in the top-right plot, except the x-axis is now the computed light. The bottom plot shows the same sensor data versus the scaled light. The scaling was performed to approximate the sensor responsivity. Plotted against the scaled light, all of the data up to the saturation point lie on a straight line. In the bottom plot, the colors represent different attenuator settings.

The top right plot of Figure 2 shows the same column-averaged signal minus the background signal (attenuator closed) versus the computed "light". Light was computed as:

light = r(l) * t_w(l) * t

where

l = wavelength,
r = the measured halogen spectrum at given attenuator positions (Ref. (1)),
t_w = window transmission, and
t = normalized integration time (integration time / max(integration time))

Thus, "light" is proportional to the input from the integrating sphere. It has not been corrected for the system responsivity. Normalizing by the maximum integration time allows the combination of the three data rates (integration times) onto a single plot.

Analysis of the halogen spectra measured this summer showed that the attenuation varied with wavelength. Because of this, the spectrum at each attenuation position was used in the calculation of "light," rather than simply applying an attenuation scale factor to the OPEN spectrum.

The results in this second plot are almost straight lines, excluding the saturated data. This top-right plot has the same format as the top-left plot; data from each wavelength are plotted in one color. The two lines connect the data from two wavelengths. Unfortunately, data were not collected near the knee of the curve close to saturation.

To estimate the relative responsivity of each wavelength, a second-order polynomial fit was computed using the unsaturated data from each column (wavelength) and the light as inputs to the fit function. This fit was then used to compute the light that would generate a signal of 1500 counts. A new x-axis was then computed:

scaled light = light / f(1500)

where f(1500) is the value from the polynomial fit. This new variable compensates for the system responsivity at each wavelength.

The bottom plot of the figure shows the resulting curves: average signal minus background versus "scaled light". With this approximation of relative responsivity scaling the input light, the data from all columns lie together on a curve. Because the background has been subtracted and only the lower wavelength data included, the curve goes through the origin. Saturated "scaled light" data were set to a negative value. Each color in this plot represents data from a different attenuator setting.

The halogen spectra measured during the sphere calibration were scaled to match the photometer readings collected during the CRISP testing. The data in Reference (1) shows that during the CRISP testing, the absolute signal received with the attenuator OPEN was less than _ of the signal measured during the sphere calibration. Thus, the spectra measured during the sphere calibration were scaled by the ratio of the photometer OPEN signals. In addition, the reference shows that the relative transmission of the attenuator positions varied between the CRISP testing and the sphere calibration. At some attenuator positions, the measured transmission varied by a factor of two. To match the conditions during the CRISP testing, the sphere spectra (at each attenuator position) were scaled by the ratio of the transmission during the CRISP testing and the transmission during the sphere calibration. Figure 3 shows a comparison of these results. The "scaled light" computed from the measured spectra (green dots) creates a curve that is erratic. However, when the data are scaled to match the transmission measured during the CRISP tests (red dots), they form a nearly linear curve. This curve shows the importance of having the test equipment calibrated under the same conditions as the instrument calibration measurements.

Figure 4 summarizes the results for the three sensor frame rates. The 1 Hz, 3 Hz, and 5 Hz data are plotted in red, green, and blue, respectively. The x-axis is the "scaled light," and the y-axis is the counts above the background. The black line shows the desired linear fit. On this line, the sensor counts should be a linear function of the scaled light. These curves show that data from all three rates lie close together and the data are nearly linear. The goal of this analysis is to find the function(s) that would make the sensor data match the straight line, i.e. that would transform the sensor data values to those that would be produced by a perfectly linearly responding detector. This plot shows that the data are nearly linear without any correction.

The original sensor data versus the (desired) linear data are plotted in Figure 5. The quadratic fit between the x- and y- axes are printed in the text. Because the background has been subtracted, the data should go through the origin. In these equations, the offset has been forced to 0. This figure shows the functions that convert the original data to the linear resulting data. The terms for the quadratic functions show that the original data are nearly linear.

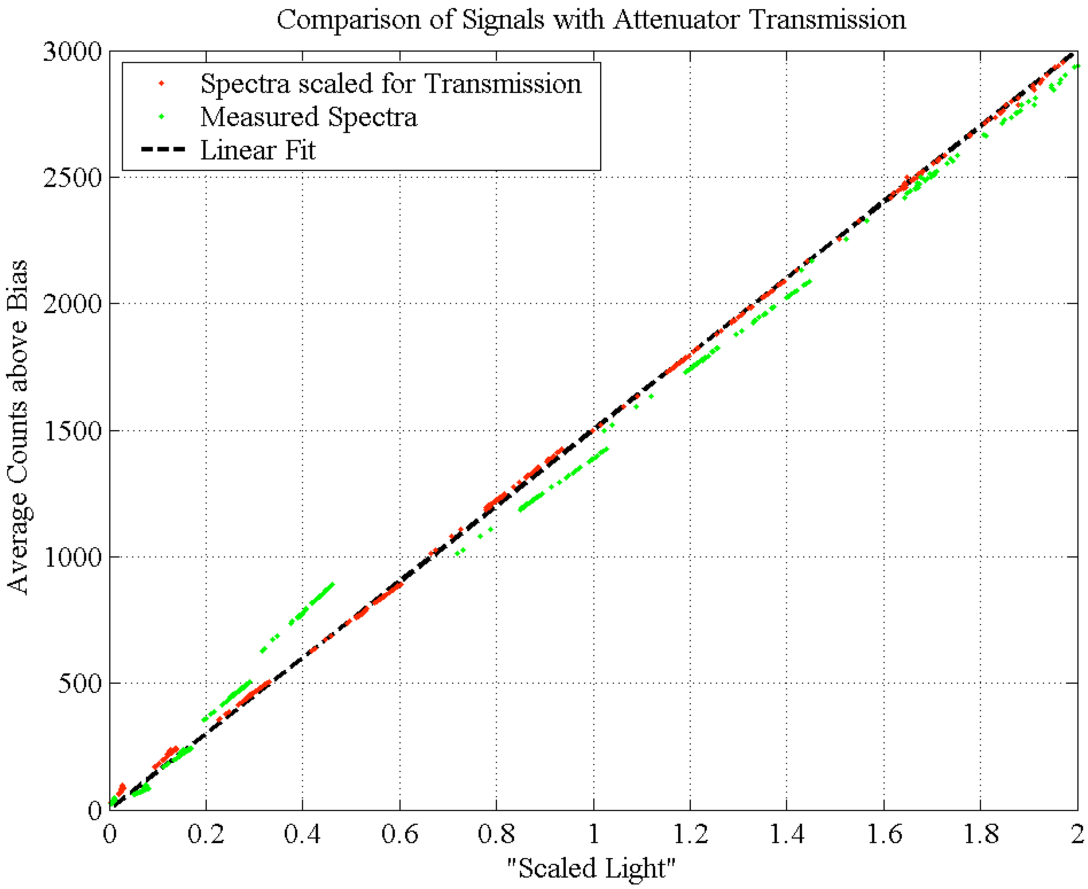

Figure 3: Illustration of the effect of adjusting the measured spectra by the transmission measured during CRISP tests. The x-axis is the product of the measured spectra, the window transmission, and an approximation of the responsivity. Sensor counts versus the calibration-measured spectra are plotted in green. The measured spectra were then scaled by the attenuator transmissions measured during the CRISP tests; these data are in red. The red points form a linear function (compare to the linear fit); the green points (uncorrected for attenuator transmission) are erratic.

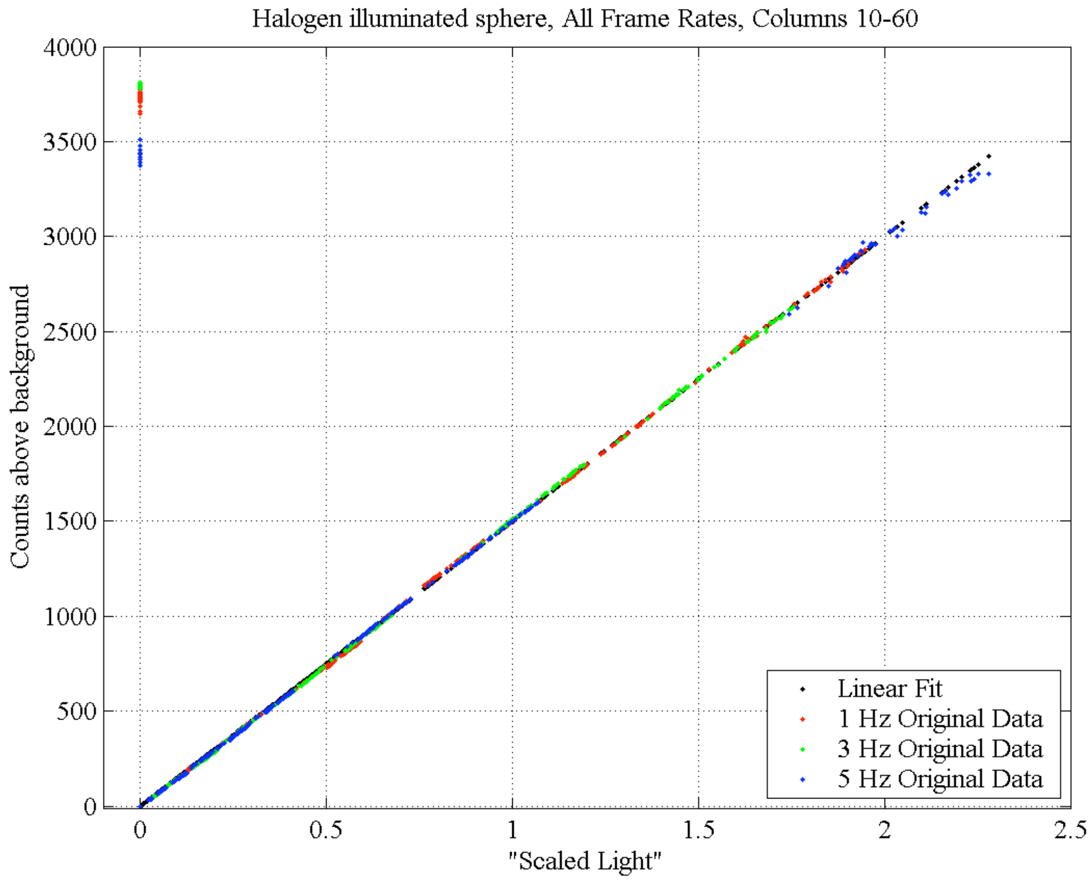

Figure 4: Summary of halogen low wavelength data for all three frame rates. The 5 Hz data have the best range, going from 0 counts up to saturation. The 1 Hz and 3 Hz data have a gap between about 3000 counts and saturation. Data from all three frame rates lie on the same curve.

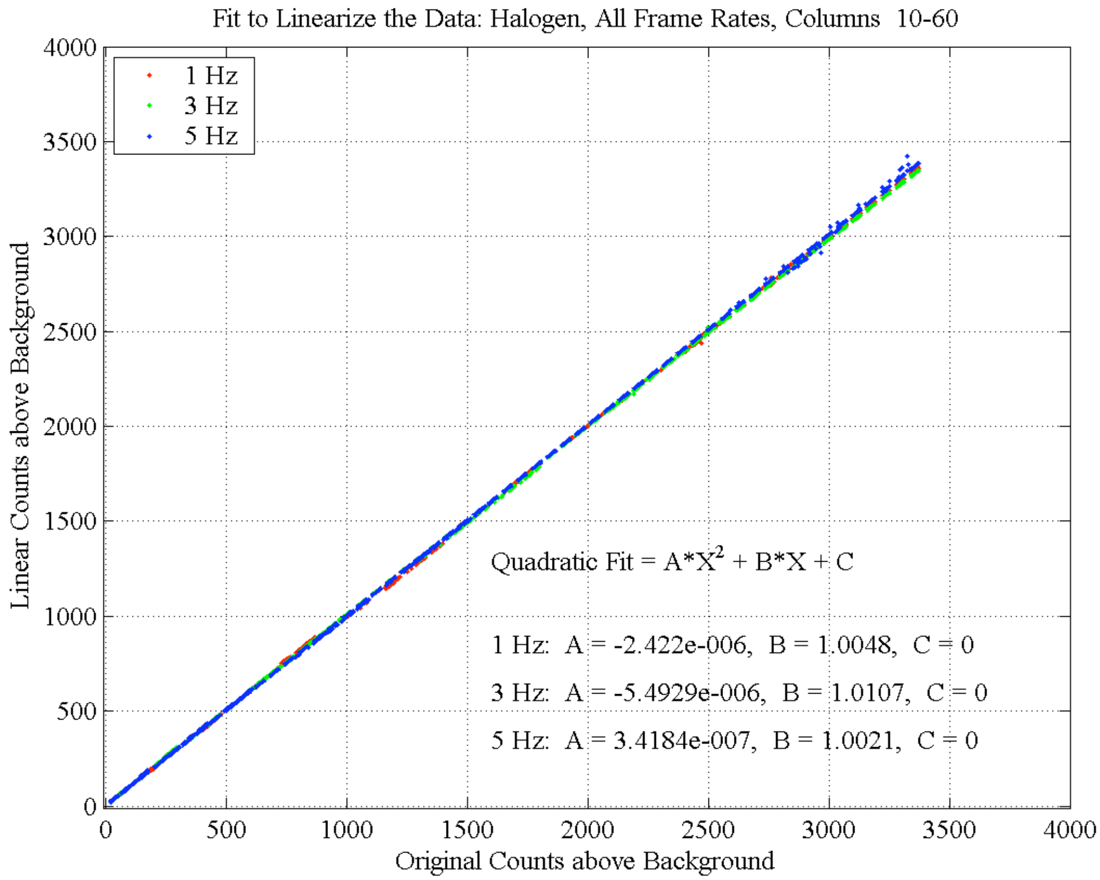

Figure 5: Original sensor counts versus linear counts for the halogen data. The data are plotted as dots; the fits to the data are plotted as dashed lines. The quadratic fits to the data are listed. The offset values ('C') were forced to be zero.

The same procedure was executed for the xenon-only sphere data. Figure 6 shows an example image from this dataset. Overall, the xenon data have much lower signals than the halogen data. (Because of the weaker signals, only data from attenuator position 6 and above were used in this analysis.) The results of the quadratic fit for the lower wavelength xenon data are shown in Figure 7. The results are similar to the halogen results, but not identical. The halogen data had many more data points out to saturation (3400 counts) than the xenon data. In comparison, the xenon image data values were mostly between 0 and 2000 counts. The larger range of the halogen data could explain the differences in the quadratic fits. Table 2 summarizes the results of the quadratic fits. The data are listed for the halogen and xenon data fits computed from the lower wavelength image data.

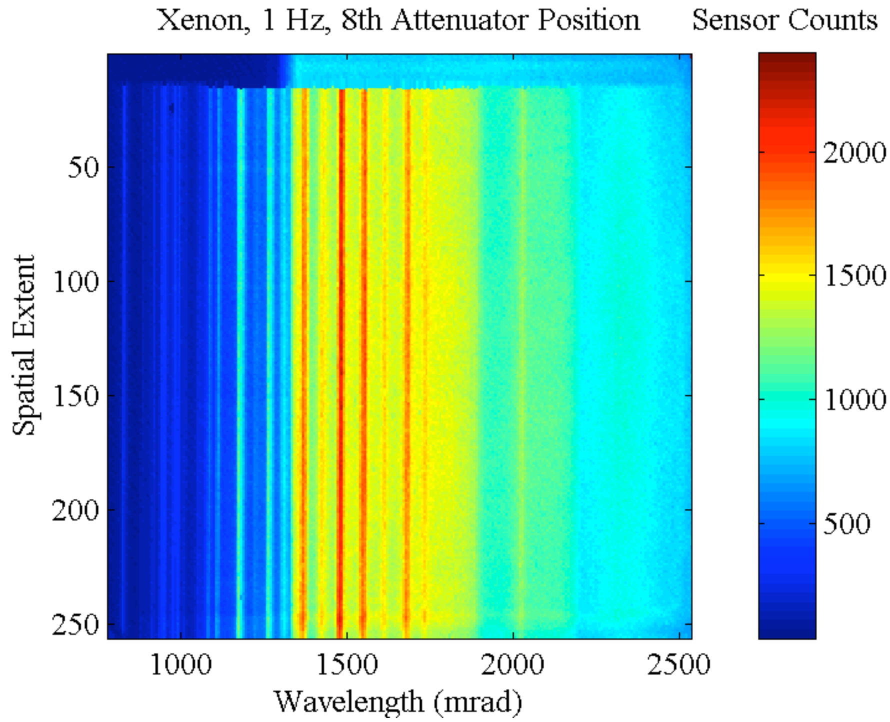

Figure 6: Example image from the xenon-only dataset. The signals from the xenon lamp are significantly lower than the signals from the halogen lamp.

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Table 2 Summary of Quadratic Fit Terms

	Halogen: $A * X^2 + B * X + C$			Xenon: $A * X^2 + B * X + C$		
Frame Rate	A	B	C	A	B	C
1	-2.422e-6	1.0048	0	9.091e-6	0.9840	0
3	-5.493e-6	1.0107	0	-2.536e-8	0.9996	0
5	3.418e-7	1.0021	0	6.654e-7	1.0002	0

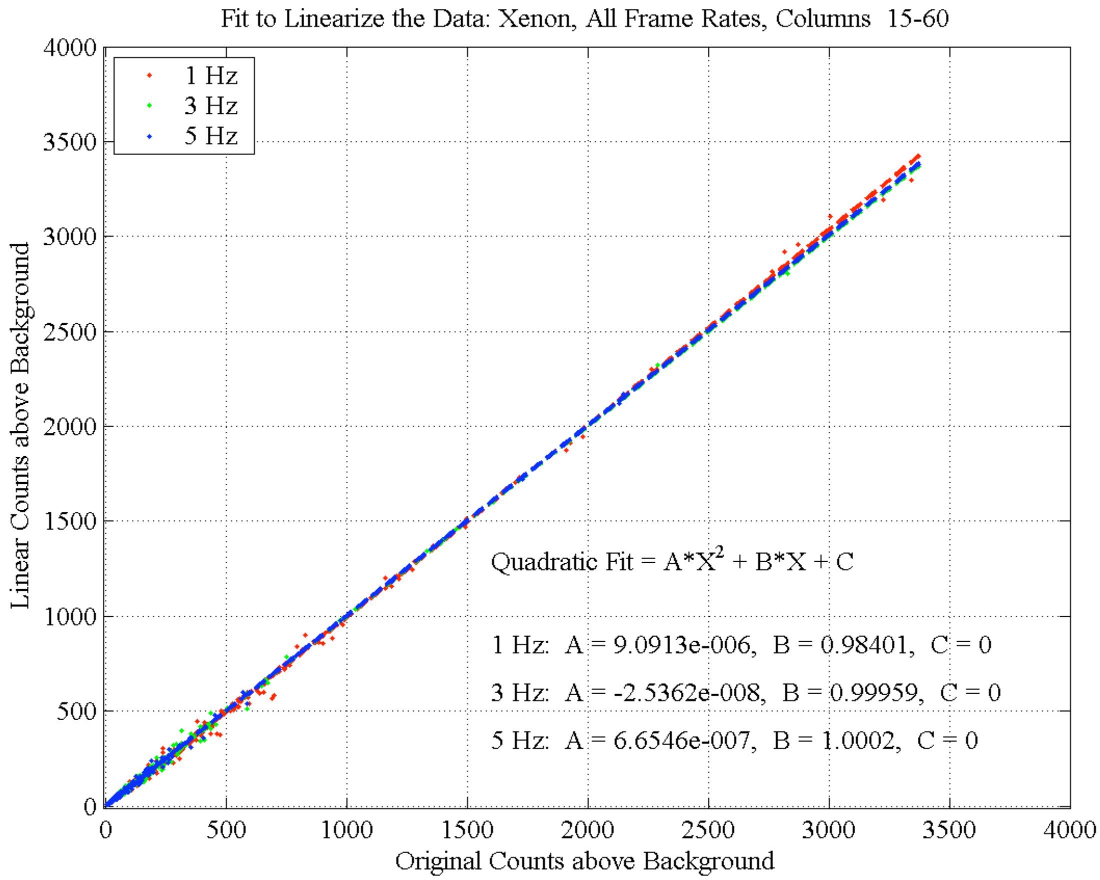

Figure 7: Quadratic fit results for the lower wavelength xenon-only data. Because of the weaker xenon lamp, most of the data for the x-axis are below 2000 counts; there are only a few points above 2000 counts. This may explain the difference in the quadratic fits between the halogen and xenon data.

The previous analysis used only the lower wavelength data to compute the quadratic terms required to make the image data linear with input light. To ensure the validity of the quadratic fits, these terms were then applied to the longer wavelength data.

A summary plot of the long wavelength halogen data is shown in Figure 8. This figure shows the average counts in the image versus the scaled light for the three frame rates. This plot is similar to Figure 4, except that the data from the three frame rates do not lie on the same curve. The three rates have a similar slope, but significantly different offsets.

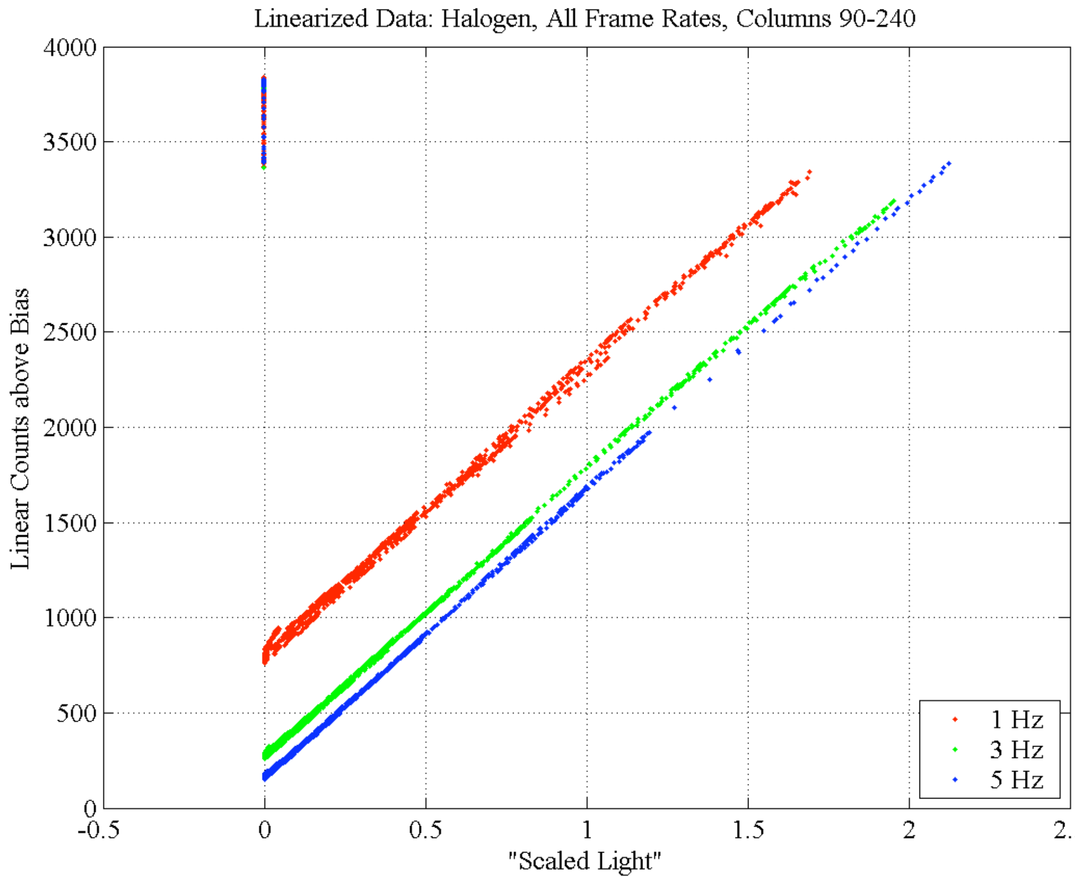

Figure 8: Summary of halogen long wavelength data. The average counts are plotted versus the scaled light. Data from the three frame rates are nearly linear, with similar slopes but with different offsets.

The quadratic terms for the halogen data from Table 2 were applied to the data in Figure 8. The results are shown in Figure 9. Very little effect is shown on the data.

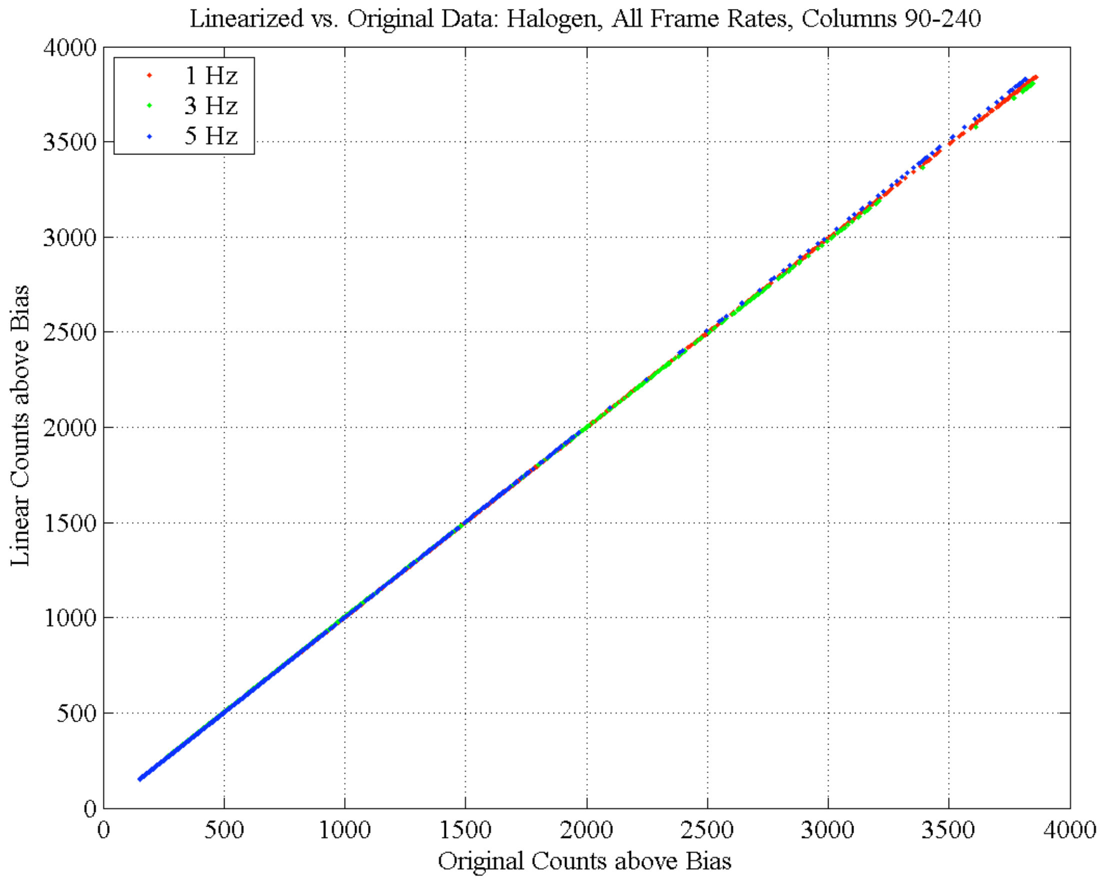

Figure 9: The results of applying the quadratic terms to the long wavelength halogen data.

Figure 10 shows the final result of this analysis. The quadratic terms were applied to the longer wavelength data. After linearization, the background image (attenuator closed) was subtracted from the remaining images. The results are plotted versus the scaled light. Since the estimated responsivity at 1500 counts was used to scale the light, the slope of the straight line is nearly 1500. Also, as expected, the intercept is approximately 0.

It appears that the original data from the CRISP sensor are nearly linear. A slight quadratic term is used to add a slight linear correction to the data. The plot in Figure 10 shows that after applying the quadratic terms and subtracting the background image, the data from the three frame rates lie on a straight line.

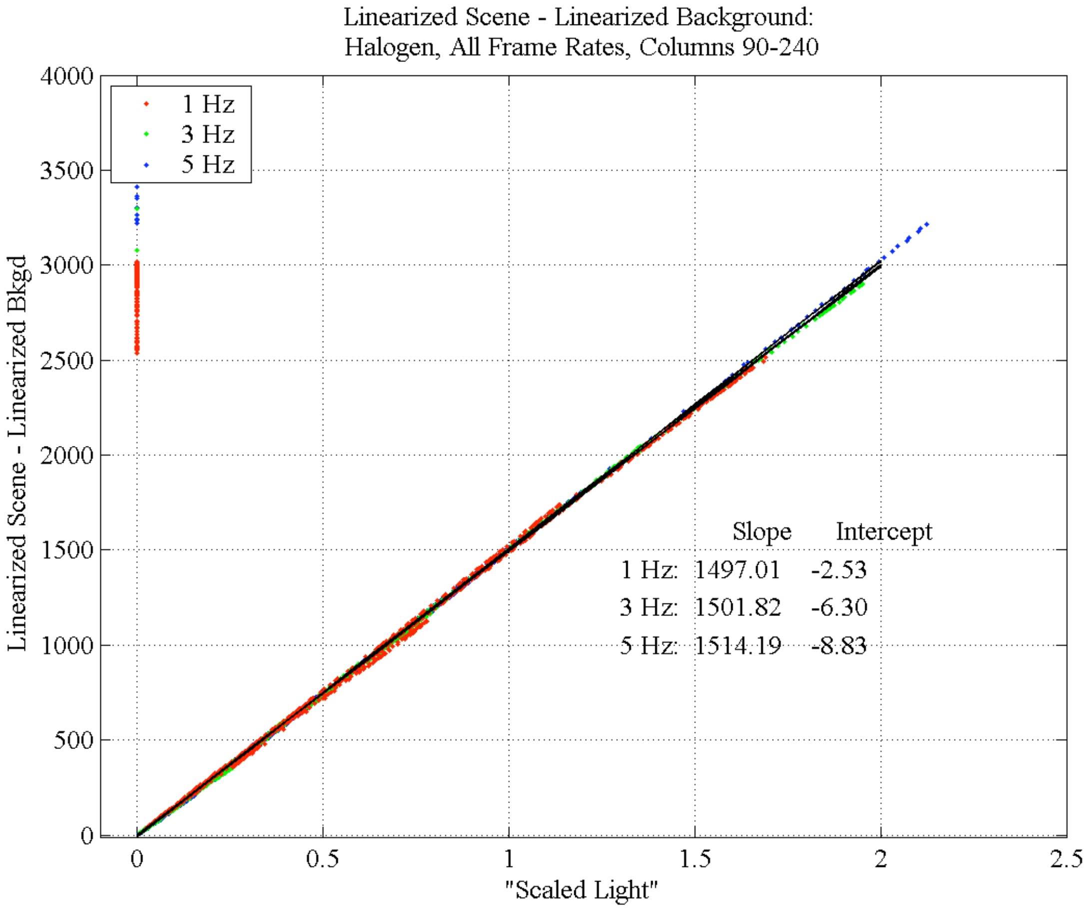

Figure 10: Linearized long wavelength halogen data versus scaled light. After subtracting the linearized background image, data from the three frame rates lie close together, and are linear with the input light.

Conclusions

Results from this analysis show that the original sensor data are nearly linear without any correction. The lower wavelength data from the halogen and xenon integrating sphere tests were used to generate quadratic fits between the input sensor data and output linearized data. These quadratic fits were applied to the longer wavelength data. After removing the background image, the linearized long wavelength data are linear with the scaled light.

These results used the halogen and xenon spectra measured this summer during the integrating sphere calibration. These spectra were measured at much higher resolution than the previous spectra. Also, the spectra measured with various attenuations showed that the attenuation varies with wavelength. Thus, a simple attenuation scale factor could not be used to compute the 'light' entering the sensor. Adjustments to the measured attenuations were also required to correctly compute the 'light.' These higher quality sphere spectra gave significantly improved linearity results over the original vendor-supplied lamp spectra.

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