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# Linearity Correction methodology for array spectroradiometers

## 1 Introduction

The measurements of linearity performed with the ATLAS setup and described in ATLAS\_TD2.2.pdf are used to establish a linearity correction methodology for correcting the linearity of array spectroradiometers.

## 2 Linearity Correction

Array Spectroradiometers can exhibit two kinds of nonlinearities:

- 1) Nonlinearities related to the number of photons per second incoming on the CCD detector. This nonlinearity component is related to changes in intensity of the incoming radiation.
- 2) Nonlinearities of the data acquisition system for constant intensity. This nonlinearity component is related to the electronics used to convert the charge of the analog detection device (CCD detector) to digital counts. The changes in counts are obtained by a change in the integration time.

## 3 Nonlinearity I – Intensity (photons/sec)

The Nonlinearity with respect to intensity changes determined on the two systems are shown in Figure 2 and 3 below. They are obtained by measuring the line-spread function at a single wavelength for varying intensities, obtained by setting the attenuation through the filter wheel. Figure 1 shows measurements at different intensity settings for the Phaeton system at 320 nm.

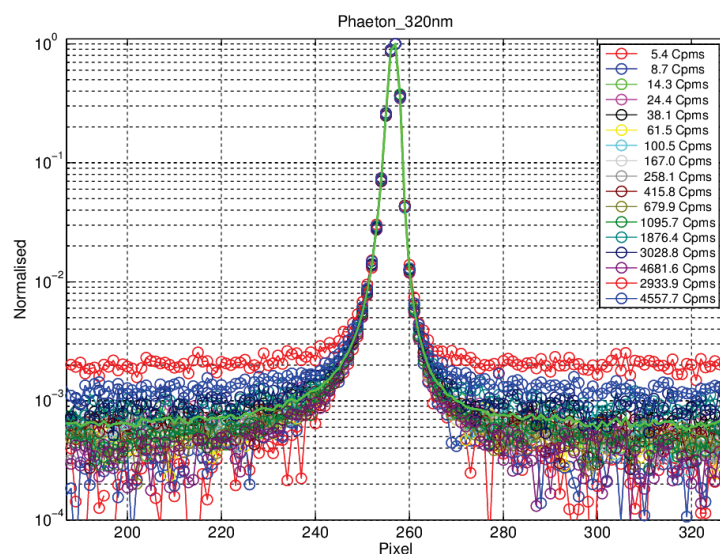
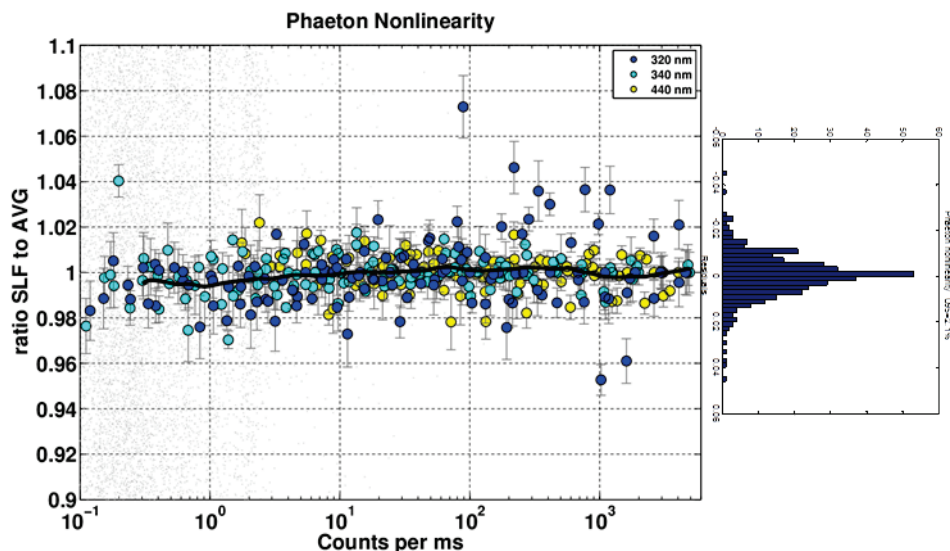


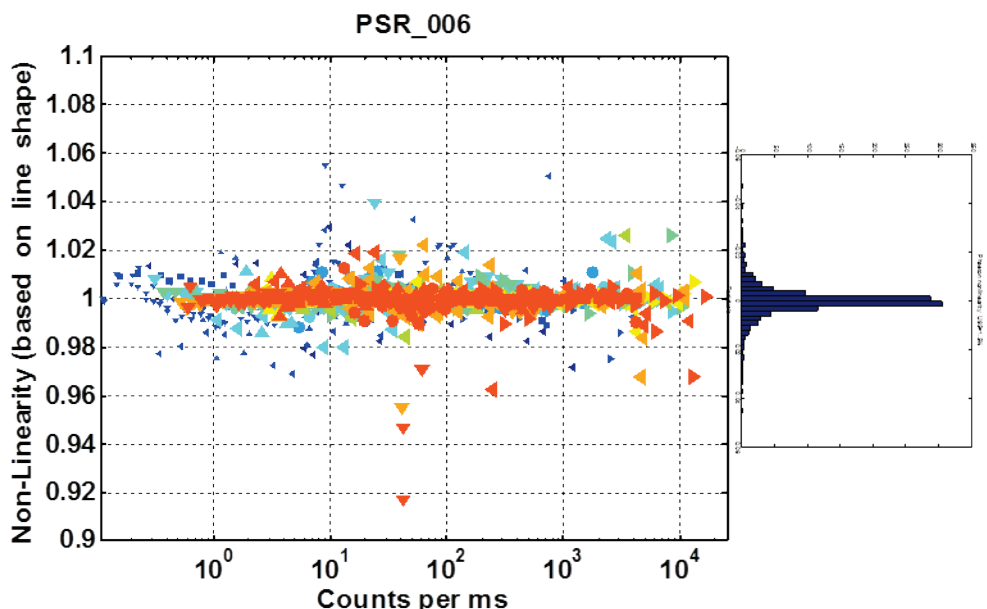
Figure 1 Line-spread function measurements at 320 nm for different intensity levels of the incoming laser beam.

These measurements are converted to counts per millisecond by normalising each measurement with the appropriate integration time. The deviation of each line-spread function from the average line-spread-function represents the nonlinearity of the system. Figure 2 shows the combined measurements for different attenuation settings and different wavelengths.



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**Figure 2 Nonlinearity of the Phaeton System with respect to changes in intensity, shown as a relative change of counts per millisecond at three wavelengths, 320 nm, 340 nm, and 440 nm.**



**Figure 3 Nonlinearity of the PSR006 with respect to changes in intensity, shown as a relative change of counts per millisecond at 400 nm.**

As can be seen in the figures, the two systems are perfectly linear with respect to changes in intensity. The phaeton system can be assumed to be linear with respect to changes in intensity over 4 orders of magnitude to

better than 2.1% (95% confidence level, assuming a normal distribution of the residuals). The PSR006 is linear to better than 1.5% over 5 orders of magnitude.

Similar results were obtained in previous investigations (Nevas et al., 2014), confirming that the intensity range in which the detectors are used in these array spectroradiometers do not exhibit any nonlinearity with respect to intensity changes and can therefore be assumed linear in this parameter. Therefore no correction for this parameter needs to be applied to the measurements.

## 4 Nonlinearity II – Count range (DAQ)

The second nonlinearity might come from the data acquisition system and the analog to digital conversion. In that case, the nonlinearity depends on the amount of charge accumulated during a measurement, which is mainly depending on the integration time used. The nonlinearity is determined by varying the integration time for constant intensity to sample the dynamic range of the system. In the case of the Phaeton system it is  $2^{16}$  bits, e.g. 65536 counts, while for PSR006 it is  $2^{18}$  or 262144 counts. The results for the two systems are shown in Figures 4 and 5 respectively for Phaeton and PSR006.

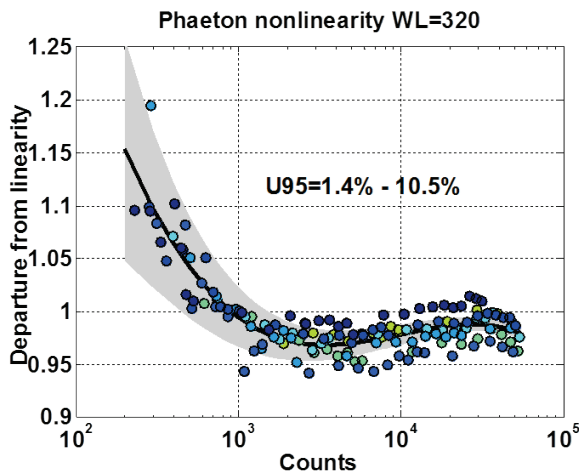


Figure 4 Nonlinearity component in function of total counts for the Phaeton system at 320 nm.

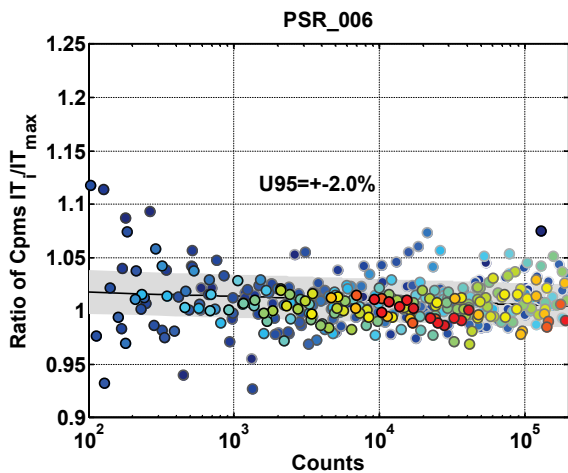


Figure 5 Nonlinearity component as a function of total counts for PSR006.

As can be seen in Figure 4, the Phaeton DAQ has a significant nonlinearity at low counts below 1000. This nonlinearity of up to 15% can be taken into account by applying a correction function to the total measured counts. This correction function is indicated by the thick black line in the figure. The uncertainty of this correction of up to 10% is rather large, mainly due to the low count range and the corresponding uncertainty arising from the dark count correction applied to the measurements. Similar nonlinearities in count space have

been found also in a previous study (Nevas et al., 2014) with instruments from the same manufacturer, indicating that the electronics used in these systems need to be corrected.

As shown in Figure 5 for PSR006 no departure from linearity could be determined.

## 5 Data archive

The measured data is archived in matlab format on the PMOD/WRC server, at <\\ad.pmodwrc.ch\Institute\Projects\ATLAS\characterisations>

## 6 References

Nevas, S., P. Blattner, O. El Gawhary, T. Pulli, P. Kärhä, L. Egli, and J. Gröbner, Characterisation of nonlinearities of array spectroradiometers in use for measurements of the terrestrial solar UV irradiance, UVNews 10, 9-11, 2014, <http://metrology.hut.fi/uvnet/reports.htm>.

### *The Dokumenten History*

| Version | Freigabedatum | Freigabe | Änderungen                |
|---------|---------------|----------|---------------------------|
| 1.0     | 13.7.2016     | JG       | First Version of document |
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