Mapping and Removal of Bright Pixels in UVIS Data

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UVIS

The ultraviolet infra-red spectrometer (UVIS) is a scientific imaging device on the ExoMars Trace Gas Orbiter that will be used to look for the presence of trace gases in the martian atmosphere. The ExoMars Trace Gas Orbiter contains 4 scientific instrument packages, with UVIS being housed in the Nadir and Occultation for Mars Discovery (NOMAD) package.The UVIS channel captures data using a charge-coupled device (CCD) which creates a 2D array of pixels. This 2D array is then flattened into a 1D spectrum that can be analysed by the spectrometer.

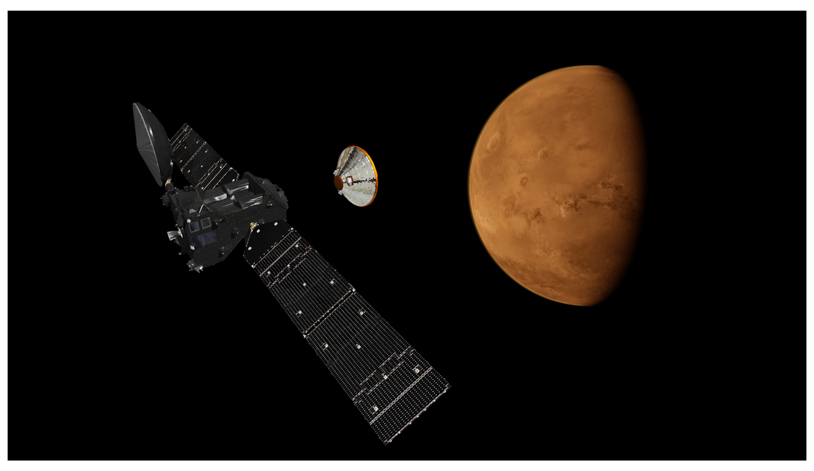

Figure 1: Artists Impression of the Trace Gas Orbiter at the EDM separation above Mars

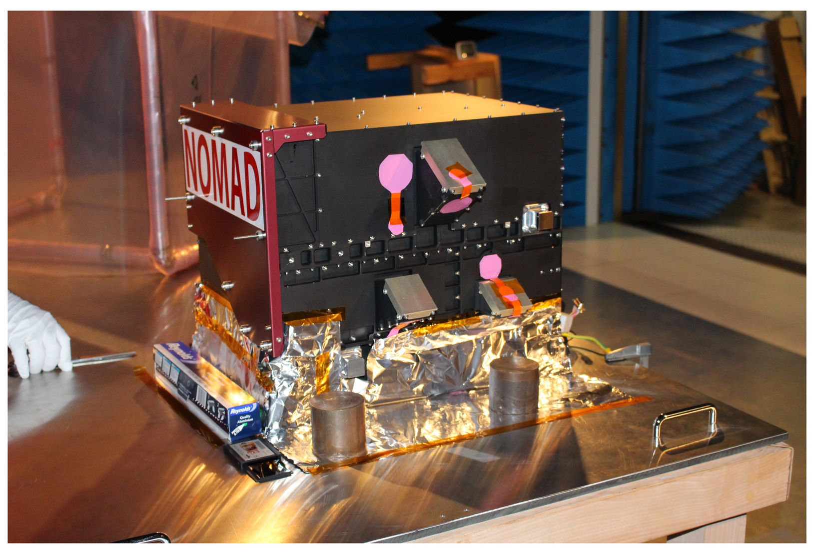

Figure 2: Photograph of the Nadir and Occultation for Mars Discovery (NOMAD) package

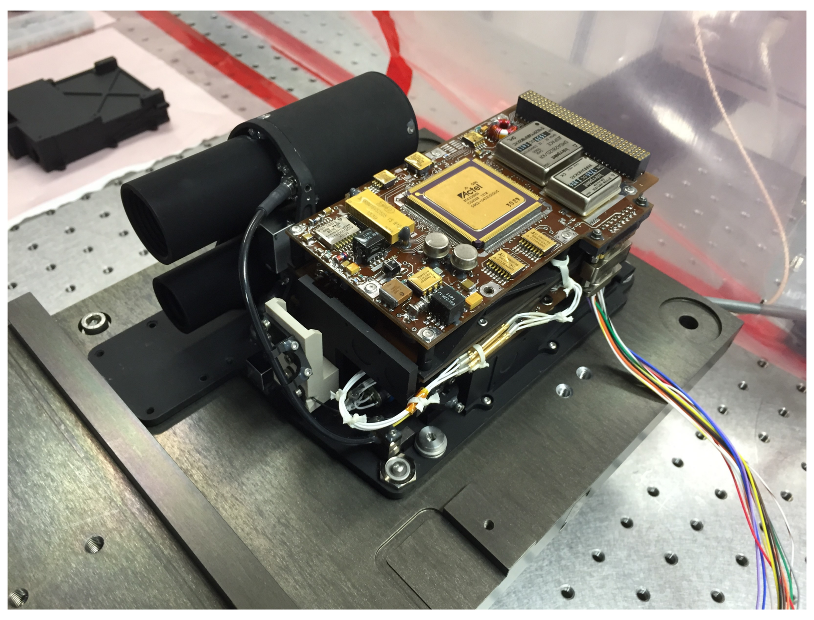

Figure 3: Photograph of the Ultra Violet Infra-red Spectrometer (UVIS)

Bright Pixel Problem

When the ExoMars Trace-Gas Orbiter reaches its full scientific orbit early next year the UVIS channel will produce many observations in each of the 13 orbits completed every day. Each observation contains a varying amount of frames which are the 2D images created by the CCD. Figure 4 shows a frame produced earlier this year in MCO-2 (Mars capture orbit-2) which was a calibration test to check that the UVIS channel was still working. This image contains many white pixels, these pixels are called bright pixels and are caused by errors in the CCD. These errors can be caused by radiation and cosmic rays damaging individual pixels. The bright pixels reduce the SNR of the data and reduce the sensitivity of the detector to ozone in the atmosphere so need to be mapped and replaced.

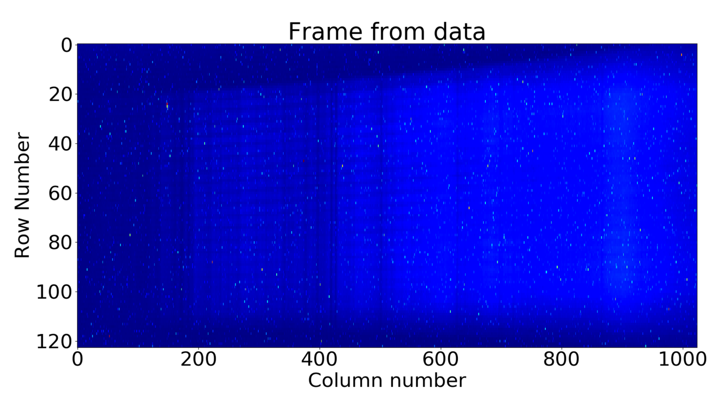

Figure 4: 2D frame from Mars Capture Orbit-2

Bright Pixel Mapping

To map the locations of bright pixels dark frames (where the CCD is blocked by a shutter) and night-side frames are used as these have very low illumination which makes mapping the true locations of bright pixels more accurate than using day-side frames. The mapping is done over multiple frames and a pixel is marked as bright if it is bright in all the frames. A new bright pixel map is made for each mission stage. I have found that the best way to map the locations of bright pixels in an individual frame is to create a grid of 13 x 13 pixels centred on the pixel being checked. The mean and standard deviation of the intensity of pixels in this grid is then calculated and if the pixel being checked has an intensity more than 3 standard deviations from the mean it is marked as bright. This is repeated for each pixel and an initial bright pixel map is created. After this 1st iteration all the pixels marked as bright are now replaced with NaN and the scan is done again. This is repeated 6 times to ensure all bright pixels are found. This method finds 99.9% of all bright pixels. Figure 5 shows why the grid size, SD limit, and iteration number have been chosen to take these values. Figure 6 shows an example of a bright pixel map. This map was made from the MCO-2 mission stage.

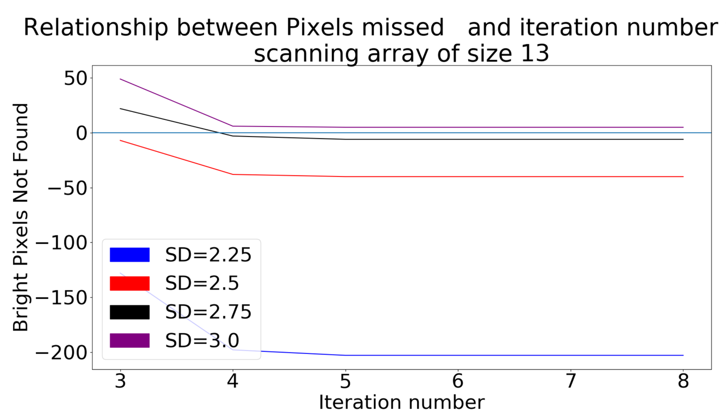

Figure 5: Graph showing the number bright pixels missed (out of 6000) against iteration number for different standard deviation limits using a 13x13 scanning grid size. For SD=3 only 8 bright pixels are missed.

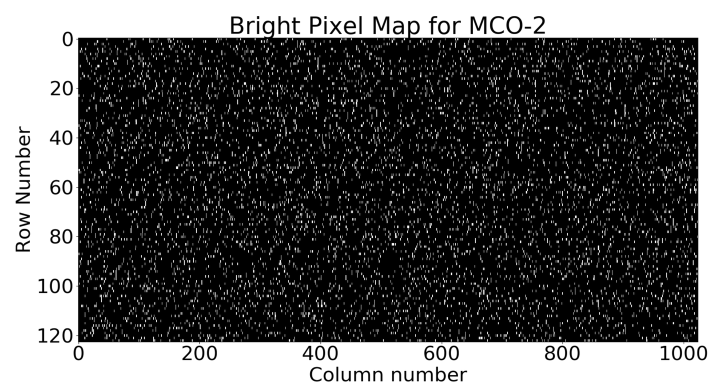

Figure 6: Bright pixel map for MCO-2, white pixels represent locations of bright pixels.There are 7374 bright pixels in this map.

Bright Pixel Removal

After mapping the locations of bright pixels in a mission stage the bright pixels in both day-side and night-side frames need to be replaced with appropriate values. For both day-side and night-side frames I have found that using a 2D linear interpolation method is the most appropriate way to replace the bright pixels. This uses a linear function to interpolate the bright pixels using data from the full 2D array (ignoring bright pixels). This removal method replaces bright pixels to a value within 0.1% of what the intensity of the pixels should be. Figures 7 and 8 show a day-side frame before bright pixels are replaced and a day-side frame after bright pixels are removed respectively. Figures 9 and 10 shows the 1D binned spectra from a night-side frame before and after bright pixels are replaced respectively.

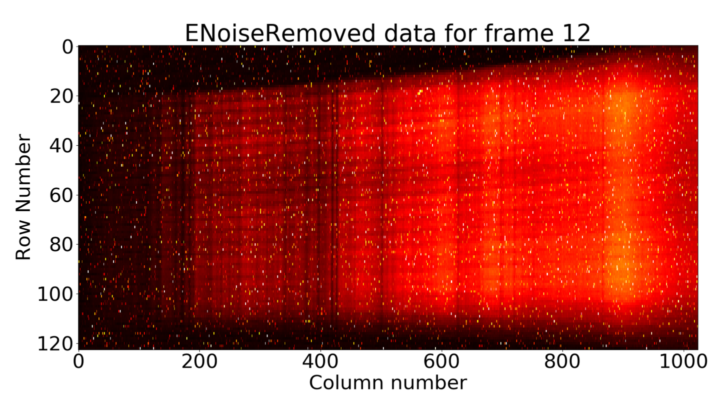

Figure 7: 2D raw data for frame 12 from MCO-2. Many bright pixels are visible in this image.

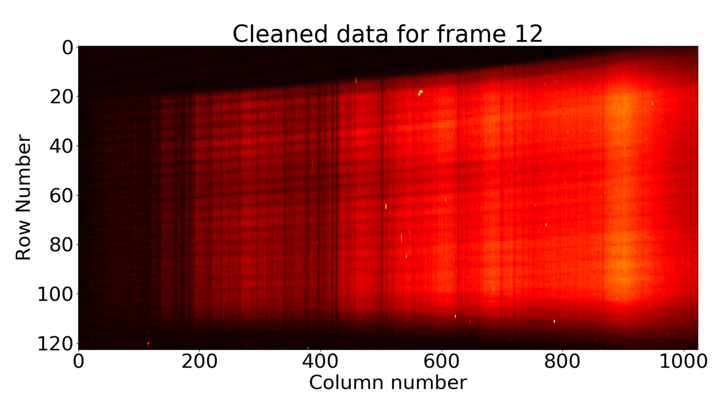

Figure 8: Cleaned data for frame 12 from MCO-2 . This shows that all bright pixels have been replaced by more consistent values.

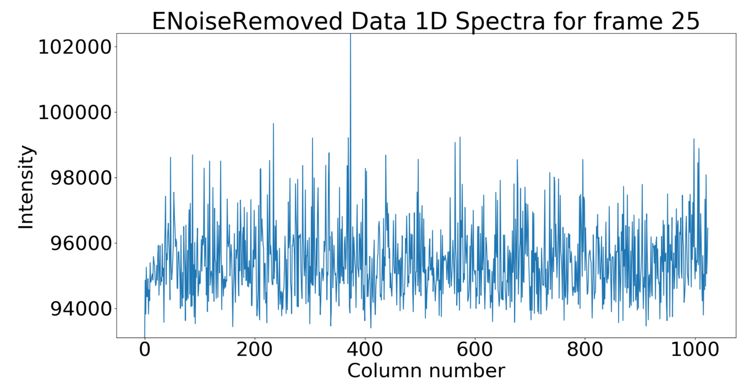

Figure 9: Raw 1D binned spectra for frame 25 (dark frame) from MCO-2.

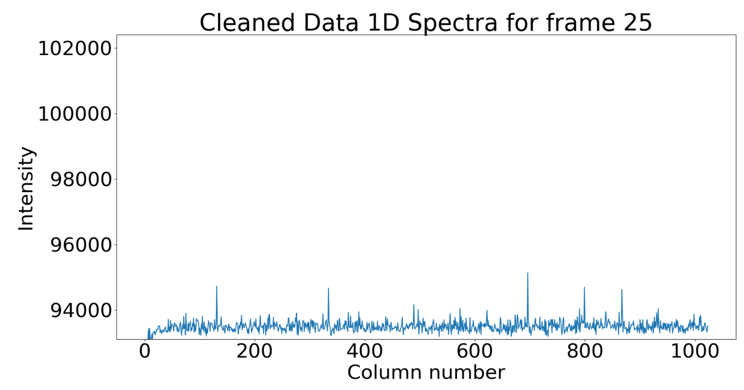

Figure 10: Cleaned 1D binned spectra for frame 25 (dark frame) from MCO-2. This shows how much the noise has been reduced by.

Results

To calculate the quantitative improvement of the signal through the mapping and replacement method I have calculated the signal to noise ratio (SNR) of the signal before and after replacement of bright pixels. SNR was calculated using the following formula:

$$SNR(i) = S(i)/N(i)$$

where S(i) is the signal of an individual pixel and N(i) is the noise of that individual pixel.The improvement in SNR is shown in figure 11.

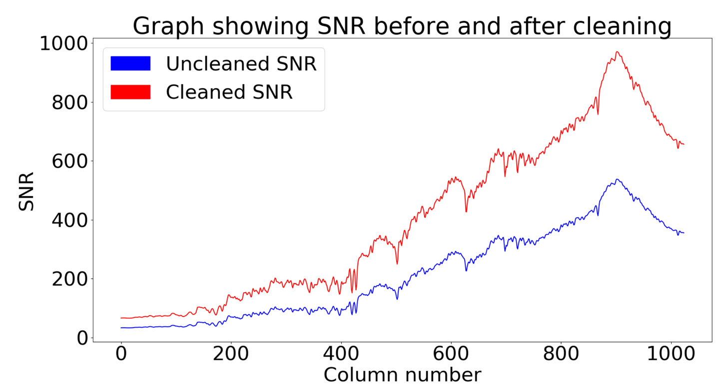

Figure 11: Graph showing SNR improvement. The blue line is before bright pixels are replaced and the red line is after the bright pixels are replaced.

Conclusion

In conclusion I have found that using a scanning grid of size 13x13 with a standard deviation limit of 3 and looping through 6 iterations is the best mapping method. I have found that using a 2D linear interpolation method is the most accurate way to replace bright pixels in the data. When this is applied to frames we see a significant SNR increase which will improve the quality of science and allow for the detection of ozone in Mars' atmosphere. The mapping and removal methods will be applied to all data collected by UVIS when it begins scientific measurements early next year.

References

[1] Patel, Manish R et al. (2017) NOMAD spectrometer on the ExoMars trace gas orbiter mission: part 2design, manufacturing, and testing of the ultraviolet and visible channel. Applied Optics, 56(10) pp. 27712782
[2] Ann C. Vandaele et al. (2015) Optical and radiometric models of the NOMAD instrument part I: the UVIS channel. Optics Express, 23

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