SXT Calibration Note # 41
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Correcting Yohkoh/SXT X-ray Images for White Light Contamination

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1 Introduction

The Yohkoh spacecraft was launched on August 30, 1991. One year later, on November 13, 1992, a portion of the front entrance filters on the Soft X-ray Telescope (SXT) failed allowing white light into the instrument. The white light leaks through pinholes etc. in the analysis filters contaminating the X-ray observations. The X-ray images are corrected for this problem using terminator images which are obtained as the Sun is seen through the Earth's atmosphere from Yohkoh's vantage point. Under these conditions, the solar X-rays are blocked by the atmosphere, but the white light is not. These images allow us to correct for the white light contamination caused by the failure of the front entrance filters.

Until recently, this correction has been carried out by selecting the closest terminator image for each data image and subtracting the white light contamination. In this algorithm, the closest terminator image is defined as the image closest in time and spacecraft pointing since the which light contamination, particularly through pinholes in the analysis filters, is a function of spacecraft pointing (i.e. the angle of the incoming solar whit light with respect to the SXT axis) and the apparent solar radius.

Terminator images were collected at every opportunity to get good coverage over a range of spacecraft pointings and time. Periodically over the course of the Yohkoh mission, further failures of the front entrance filters have occurred. Over each of the so-called epochs, defined as the intervals between entrance filter failures, a set of terminator images is collected with as complete a coverage of pointing and solar radius as possible. However, the

Figure 1: Example of a thin aluminum filter terminator image for epoch 1 (logarithmically scaled).

epochs are typically a few months to a year in duration, so the coverage is necessarily incomplete.

While the correction of the white light leak is adequate in many cases, there are instances where the nearest terminator image is not sufficiently close in pointing and solar radius and the correction is not good enough for quantitative analysis of the corrected data images. Hence, we have derived a new algorithm which interpolates the available terminator images to give an improved correction of the white light leak and to extend the correction to a much wider range of spacecraft pointings and solar radii.

This new correction is done on an epoch by epoch basis. It was developed as part of the effort to create the new SXT science composite database which contains composite images using data from two different exposures to increase the dynamic range of the SXT images. This database will supercede the familiar SDC database and will use the best corrections available to the SXT team.

2 The Terminator Images

The white light contamination corrections must be done over several epochs corresponding to successive failures of the front entrance filters. Table 1 details the epochs. Throughout each epoch, terminator images are obtained as often as possible. However, it takes considerable effort to obtain good coverage of terminator images over a reasonable range of spacecraft pointings apparent solar radius. Further, each analysis filter requires its own set of terminator images. Hence, the longer epochs have better coverage.

Not all terminator images are suitable for correcting the X-ray images. There is only a narrow range of times at the end of an orbit which can be used to remove the X-rays from the image. Furthermore, images taken at the time of an SAA or image taken when the CCD is too warm are not suitable.

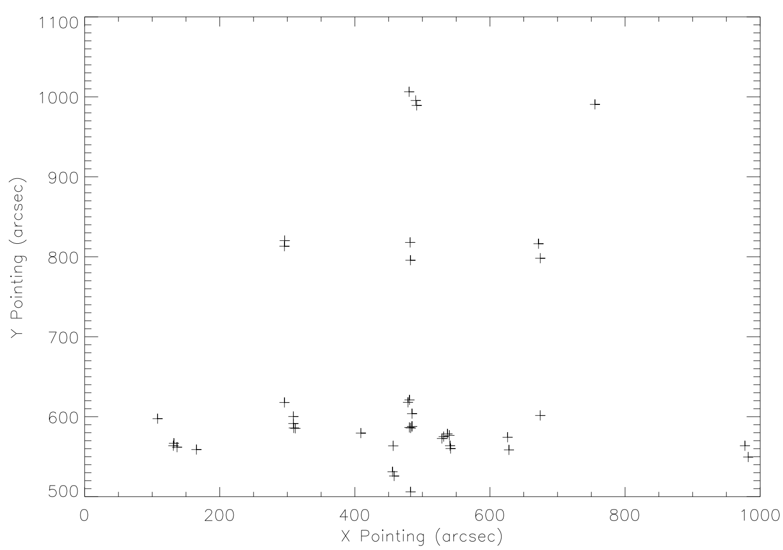

Figure 2: Terminator coverage for epoch 1 vs. pointing.

As an example, Figure 2 shows the coverage of terminator images for epoch 1 (13-NOV-92 to 16-AUG-95) for the thin aluminum filter. This figure highlights the problem with the old correction algorithm: the number of terminator images obtained is often insufficient to allow a good enough correction from the closest terminator to a particular data image: interpolation is required.

Table 1: Dates of the leak epochs.

Epoch	Start Date	Comment
	30-AUG-91 10:30:00	Launch
1	13-NOV-92 18:00:00	First filter failure
2	16-AUG-95 08:04:20	
3	24-AUG-96 07:00:00	
4	24-JAN-98 00:00:00	
5	30-JAN-99 23:17:00	
6	12-MAR-99 02:00:00	
7	20-APR-99 19:02:00	
	14-DEC-01 21:12:16	Spacecraft failure

3 Interpolation of Terminator Images

The interpolation of the terminator images is done for the Al.1 and AlMg SXT filters on a pixel-bypixel basis using a quadratic fit (including crossterms) to the set of terminator images for each epoch with independent variables x, y, and r:

$$S_i = a_{0i} + a_{1i}x + a_{2i}y + a_{3i}r + a_{4i}x^2 + a_{5i}y^2 + a_{6i}r^2 + a_{7i}xy + a_{8i}xr + a_{9i}yr \quad (1)$$

where i ranges over all the pixels in the terminator image, S is the synthetic terminator image, x is the spacecraft pointing in the east-west direction, y is the spacecraft pointing in the north-south direction, r is the apparent solar radius viewed from the spacecraft, and the a_{ji} are the coefficients of the fit to the actual termintor images.

The terminator images outside of a box defined by pointing coordinates x:450″-600″ and y:550″-600″ are not used in the fit. Restricting the fit to this subset of terminator images avoids problems with extrapolation rather than interpolation. The terminator images outside the box result from infrequent offpoints of the Yohkoh satellite for special observing sequences. There is insufficient terminator data in these outlying regions to make a reasonable interpolation. Further these special observations are treated on a case-by-case basis.

The multi-dimensional fit used in the interpolation is done on a pixel by

Table 2: Example Coeffients for Epoch 1, Al.1, Pixel (171,108)

a_0	70.2540
a_1	-0.0261938
a_2	-0.0217165
a_3	-0.116499
a_4	6.08895e-06
a_5	8.51783e-05
a_6	8.12281e-05
a_7	-5.99966e-06
a_8	2.22588e-05
a_9	-8.32286e-05

pixel basis; each pixel (i) is fit over the acceptable set of terminator images independently from every other pixel. Neglecting pixel by pixel correlations was deemed the most efficient method for the interpolation since the alternative, modeling features in the images such as the pinhole in the lower left quadrant, would be difficult and unreliable since we do not yet have a good physical model of the exact nature of the front entrance filter failures.

4 Application of the Interpolation Algorithm

We have tested the interpolated terminator images by fitting our model to to individual terminator images by interpolating to generate a terminator at the same coordinates as the actual terminator. The results are shown in Figure 3 as the ratio of the mean difference between the synthetic terminator and the actual termintor scaled to the brightness of the synthetic terminator. This analysis demonstrates that the synthetic method is sound. The scatter in the figure is indicative of the natural variation of the terminator images. This variation is in the form of an overall scale factor and does not affect the morphology of the leak pattern. The source of this variation is not known, however it is corrected using the "second order leak correction" which adjusts the overall scale of the leak or synthetic leak to a particular X-ray data image until the lower left corner of the data image is consistent with the expected scattered light from the solar disk.

Figures 4 and 5 show the application of the interpolated terminator data

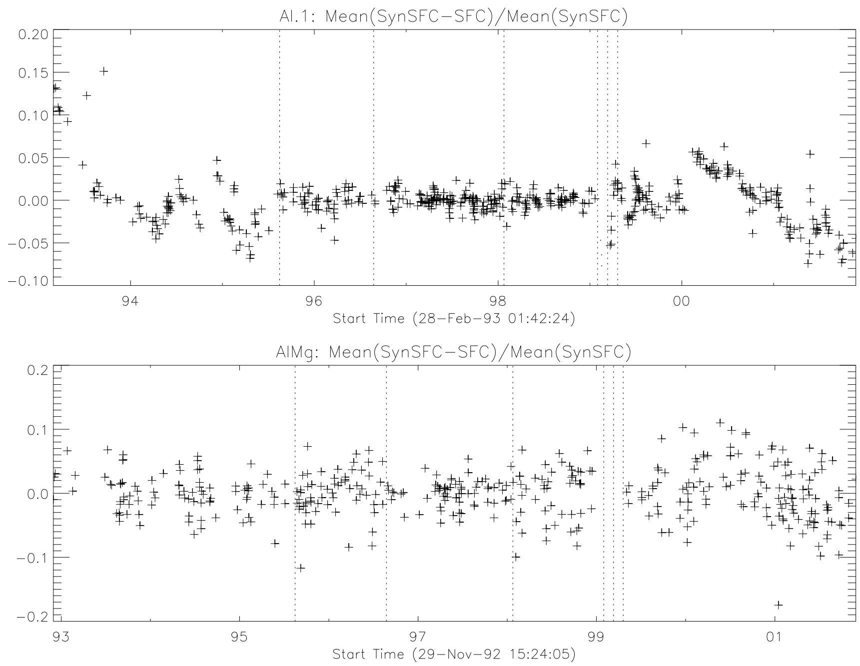

Figure 3: Accuracy of the interpolation algorithm produced by generating interpolated images at the same pointing etc. as a real terminator image. The vertical lines indicate the times of entrace filter failures.

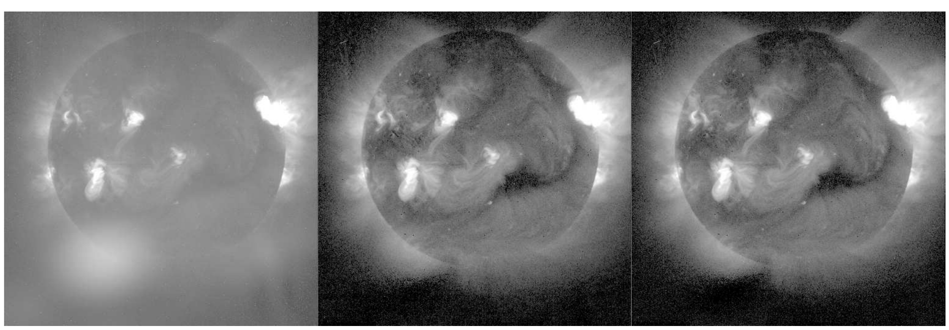

Figure 4: Demonstration of leak correction for an SXT image from 15-MAY-93 12:39:31. Left: Raw image. Center: Leak correction from closest terminator. Right: Leak correction from synthetic algorithm. All images are logarithmically scaled.

to an SXT full frame image. The first panel shows the raw SXT data uncorrected for the white light leak. The second frame shows the image corrected

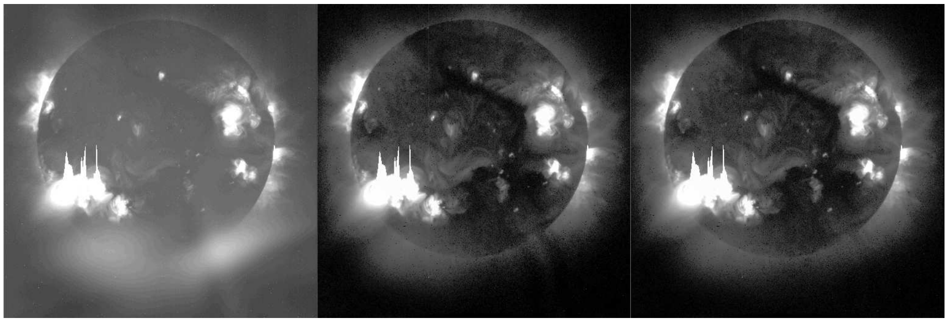

Figure 5: Demonstration of leak correction for an SXT image from 25-AUG-01 14:46:29. Left: Raw image. Center: Leak correction from closest terminator. Right: Leak correction from synthetic algorithm. All images are compressed.

using the old, nearest terminator algorithm, and the third panel shows the image corrected using the interpolated terminator. At the level of detail visible in these images, both algorithms are properly correcting the X-ray images.

A close look at the second and third panels reveal some interesting features. While neither algorithm makes a perfect correction, it is clear that the interpolated image gives a much superior correction. Notice particularly, that the dark coronal areas in the image corrected with the interpolated image are considerably darker than the same features in the image corrected with the nearest terminator. This implies that the interpolated terminator is doing a much better job of correcting for the large-scale white light contamination. Note also that the leak features, such as the pinhole feature in the upper right and the linear feature cutting diagonally across the image are better corrected with the interpolated terminator. The large pinhole feature in the lower right is not fully corrected with either algorithm, but the interpolated terminator does yield a clearly better correction.

5 Discussion and Summary

We have developed a new algorithm for correcting the X-ray images for white light contamination. This new algorithm has proved to be quite robust and yields superior X-ray images. This correction is particularly important for studies of the faint X-ray corona as the white light contamination can be a considerable fraction of the intensity of the total image intensity in these regions.