Deep Survey Dead Spot III
Correction Algorithm

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To: Science Team, DASS, Guest Observers

Abstract

Deep Survey count rates are attenuated by up to 75% by the DS Dead Spot. A sensitivity map of the DS detector is constructed from Moon observations and is used for count rate corrections. Two correction algorithms are developed and applied to a 170 000s dithered white dwarf observation. Under certain conditions, countrates are restored to $\pm 15\%$ of their expected value. Products and software are made available for general use.

I. Introduction

The Deep Survey (DS) dead spot was first described in MMS/EUVE/0171/93 after the 50 000s HZ 43 observation of February 1993. The peak countrate was 66 ct/s, and resulted in a loss of sensitivity on boresight. Analysis of Moon eclipse data of November, 1993 were presented in MMS/EUVE/0025/94. Additional Moon data have now been combined in an effort to create a "flat field" image. This report further quantifies the characteristics of the dead zone, and outlines a corrective algorithm. The limitations of the existing data and algorithm are stated, and recommendations on the future use of the DS are proposed.

II. Calibration Data

Moon observations obtained on 1993 June 30, 1993 Nov. 29, and 1994 March 29 are combined into a single image with values ranging from zero to ten counts per pixel. The region centered on the bore sight is shown as Figure 1. Black represents zero counts. The size of the affected region is about 25 pixels across.

III. Analysis

Figure 1 clearly shows many pixels with zero counts both in, and far from, the dead spot. Histograms showing counts per pixel in a square region (25 by 25 px) are presented for the dead spot, and for a normal region (far from the dead spot) as Figure 2. The simple fact that there are pixels with value zero makes the Moon image useless

as a flat field. The histograms also show that it is impossible to say whether or not the dead spot is truly dead, or just suffers from decreased sensitivity. However, long exposure pointed observations of the white dwarf LB01919 indicate that the dead spot is at $\approx 5\%$ the normal DS sensitivity.

In order to estimate the effect of the dead spot on source count rates as a function of imaging position, the Moon image is normalized by dividing by a smoothed (64 channel) version of itself (after first patching the dead region with a mean normal value). Then, the normalized Moon image is convolved with a DS trilobate PSF made from pre HZ 43 DS observations (shown to scale as an inset in Figure 3). The resulting image is a sensitivity map of the DS detector where each pixel represents the fraction of normal flux that will be detected when a source is centered on a particular pixel. This map is shown as Figure 3, while Figure 4 presents an enlargement of these data as a contour plot. The minimum value of the map at $X = 1030$, $Y = 1023$ is about 25% of normal, and the width at the 85% level is 32 pixels, or 1.8 arcmin. The combination of intrinsic detector variability and the low counts of the Moon data leads to the 20% variation about the normal value of 1 far from the dead spot. It must be emphasized that the sensitivity map is *not* a flat field; erroneous countrates will result if it is used as such.

IV. Correction Algorithm

a) Basic Approach

The concept is quite simple. First, determine the centroid of a DS observation in detector coordinates, and then divide by the corresponding correction factor from the sensitivity map based on the centroid. The difficulty arises in obtaining reliable centroids since the dead spot drastically alters the shape of the DS PSF (typically, one of the DS PSF lobes is missing). Standard centroiding techniques such as Gaussian fits, or convolving with an expected PSF are inappropriate, since the resulting centroids are shifted towards the brighter lobes of the affected PSF (*i.e.* away from the dead spot). A robust approach is required that is sensitive to the spatial distribution of photon events, but not the density of events. In other words, the measured centroid of a DS image should be unaffected by differential attenuation of the three PSF lobes. Several methods were investigated. The first was to find the minimum in the summed squared differences between a standard PSF and the affected data. Centroid shifts by this method towards the brighter lobes are manifest, so it was rejected. The second method is similar to the first, except the absolute value of the differences, rather than the square is calculated. The centroid is defined as the pixel (i, j) where the image χ is minimum

$$\chi(i,j) = \sum |Data_{ij} - PSF|$$

where PSF is the expected point spread function, and $Data_{ij}$ is a sub–image of the affected data with the same dimensions as PSF, centered at pixel (i, j). Provided that the data and PSF are normalized by their respective maximum values, the centroids are unaffected by more than a pixel, even when one lobe of the DS data is entirely missing.

One other method was briefly explored; cross correlation. In this case, the maximum of the sum of the products of the data and PSF is determined (after first subtracting the mean value of each image from itself). Similar results were obtained, but whether this method is superior to the one above has not been determined.

Utilizing the long observation of the white dwarf LB01919 in which the pointing direction was altered randomly (dithered) every EUVE orbit, the second centroiding technique is shown to be reliable. However, when the source is imaged less than 13 pixels (1 arcmin) from the dead spot center, the PSF may show attenuation in more than one lobe, and large errors in the centroid become apparent. It is unlikely that any centroiding scheme can deal with a DS PSF where two thirds of it are missing. Thus, the basic correction algorithm is good to within 15% only for pointings 1 arcmin or more from boresight. At smaller distances, the correction factors are systematically underestimated due to centroid shifts away from the dead spot, and thus, corrected countrates are only good to within 25–50%

b) Refinement to Correction Algorithm

If a target is imaged at dozen or more positions on the detector, better corrections than those outlined above are possible by utilizing the spacecraft aspect and the target's known RA and Dec coordinates. Essentially, one performs an *ad hoc* boresight determination specific to the star in question. (P. Jelinsky is the author of the boresight code. He has created a modified version that determines off axis angles for a given target in a given time interval. He and M. Sirk are the only folks who know how run it at present). First, XY centroids are determined for each pointing as in the basic approach (throwing out any points within 10 pixels of boresight). Then, corresponding off–axis angles θ_x and θ_y with respect to boresight are determined from the aspect Euler angles. The parameters that relate X and Y to θ_x and θ_y in the coordinate transformation equations

$$x = x_0 + S(\ \ \theta_x \cos\alpha + \theta_y \sin\alpha)$$
$$y = y_0 + S(-\theta_x \sin\alpha + \theta_y \cos\alpha)$$

are determined by least squares where x_0 and y_0 are constant offsets, S is a scale factor, and α the rotation angle between the two coordinate systems. Once the parameters are found, the equations are used to generate a set of expected XY centroids based on the spacecraft aspect. This technique greatly reduces the effect of the dead spot on individual centroids since it takes advantage of both the empirically derived centroids, and the spacecraft aspect information simultaneously.

The method is applied to the LB01919 observation. Figure 5 shows the raw and corrected countrates plotted against radial distance from the dead spot. The corrections are good, being nearly flat down to about 7 pixels from the dead spot center. The results are quantified in the next section.

V. Errors and Limitations

Analysis of the scatter in the corrected count rates allows one to judge in a quantifiable manner the success of the correction algorithm. Immediately apparent are the large discrepancies between the corrected and expected countrates short-ward of 7 pixels from the dead spot center; here the corrections are systematically underestimated. Also, one point at $R = 12.7$ px obviously has an incorrect centroid. Excluding these seven bad points, the mean corrected countrate is $2.13 \pm .024$ with a scatter of 0.21 ct/sec, while the mean count rate for just the points far from the dead spot ($R > 22$ px) is $2.20 \pm .043$ ct/sec, with a scatter of 0.19. The difference is not significant. However, a straight line fit of count rate *vs* R does yield a significant slope at the 2σ level, indicating that there is a small residual systematic error ($< 10\%$) that underestimates the counts as one approaches the dead spot.

The source of error must arise from uncertainties in the sensitivity map, and from the expected centroids derived from the spacecraft aspect. An uncertainty in position of just 1 pixel can result in a change of 10% in the sensitivity map; the scatter in the corrected countrates depicted in Figure 5 is also 10%.

VI. Conclusions and Recommendations

Count rates compromised by the DS dead spot are shown to be correctable to within 15%, provided that certain conditions are met. First, for each correction interval, several hundred photons are required to adequately sample the PSF, and the observatory must not slew during the interval. Second, to utilize the aspect information, a dozen or more pointings are necessary. Third, targets should be imaged such that they never fall within 8 pixels of the dead spot center where the sensitivity gradient is maximum (*i.e.* the dithering table should be confined to an annulus 8 to 26 px from the dead spot).

For a single pointing one is forced to use the basic approach. The error in the count rate will be due to the uncertainty in the centroid and will range from 15 to 50% depending on the distance from the dead spot. For target distances > 13 px (1 arcmin) from the dead spot, the basic algorithm provides count rates good to within 15%. Targets that are expected to show no flux in the medium and long wavelength spectrometers (*e.g.* magnetic CVs) may be moved far off boresight since the short wavelength spectrometer has no collimator. The effect of the dead spot is then completely eliminated, and, if the target is moved off axis in the +X direction, scattered light at the shortest wavelengths is also reduced.

Further improvements in dead spot corrections may be realized by combining additional Moon and daytime observations to reduce the noise in the sensitivity map. However, a true flat field image would require 30 such observations to ensure > 100 ct/px in the center of the dead spot. As more dithered observations of white dwarfs become available, an independent sensitivity map may be assembled by comparing the observed and expected countrates as a function of imaging position.

VII. On Line Products

Copies of this memo in PS and TEXforms are available via the World Wide Web along with FITS images of the Sensitivity Map, the raw Moon data, and the Deep Survey PSF at

http://cea-ftp.cea.berkeley.edu/Archive/Local/EuveTechnicalMemos/deepsurvey/Dead_spot/dead.html

Examples (written in IDL) of centroiding techniques, and other software are also included.

Figure Captions

Figure 1. Raw Moon image centered on the DS dead Spot. Counts per pixel range from 0 to 8.

Figure 2. Counts per pixel histograms for a 25 by 25 px square region about the dead spot (top) and far from it (bottom). The Poisson statistics are inadequate to say whether or not the dead spot is truly dead.

Figure 3. Moon data normalized by a smoothed (64 channel) version of itself, and then convolved with a pre dead spot DS PSF (inset). This image is referred to as the Sensitivity Map, and represents the fractional sensitivity of the the DS instrument when a source is centered at a given pixel.

Figure 4. Contour plot of Sensitivity Map of Figure 3. Minimum value at the core of the dead spot ($X = 1030,\ Y = 1023$) is 0.25.

Figure 5. Observed and Corrected count rates for 87 EUVE orbits of the WD LB01919 plotted as a function of distance from the dead spot. Corrected values are nearly flat down to within 7 px of the center.