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Does the UVI on Polar detect cosmic snowballs?

G. Parks,[1] M. Brittnacher,[1] L. J. Chen,[1] R. Elsen,[1] M. McCarthy,[1] G. Germany,[2] and J. Spann,[3]

Abstract. If 20 to 40 ton cosmic snowballs pelt Earth as claimed by *Frank and Sigwarth* [1997a], dark pixels will be produced in the 130.4 nm images of dayglow obtained by the Ultraviolet Imager (UVI) on the Polar spacecraft. Examination of the UVI images has revealed that dayglow images are indeed spotted with single and multiple dark pixels. But is a snowball the only explanation for these dark pixels? To learn more about the dark pixels, we have examined the calibration images obtained from the same camera just before the instrument was launched. We find that dark pixels similar to those in dayglow images also exist in calibration images. This strongly indicates that the source of the dark pixels is instrumental. For further verification, a statistical analysis found the dark pixels from dayglow and calibration images have nearly identically shaped occurrence patterns. We have also looked for evidence of spacecraft "wobble" which demonstrates that the source of a bright or dark feature in the images is external to the camera, but found none for dark pixels. Finally, we studied the bright streaks that frequently appear in UVI images, sometimes comet-like in appearance. These trails are ionization tracks produced by cosmic rays or other penetrating energetic particles interacting with our camera. We conclude that the source of the dark pixels in dayglow images is internal to the camera system and there is no scientific evidence from UVI that snowballs pelt Earth.

Introduction

The recent papers by *Frank and Sigwarth* [1997a,b] have rekindled the discussion of the observations and meaning of the dark pixels first observed in dayglow imaged from space [*Frank et al.*, 1986a]. *Frank et al.* [1986b] interpreted these dark pixels as arising from the absorption of the 130.4 emissions by water between the altitude where the dayglow emissions occur and the point of observation. They suggested that Earth is continually bombarded by 20 to 40 ton "cometesimals". Because these dark pixels were single pixel events, their observations and interpretations have been disputed and questioned [*Dessler*, 1991]. *Frank and Sigwarth* [1997a] now report that the VIS Earth sensor on the Polar spacecraft also detects dark pixels in dayglow images. The new observations include events with multiple pixels and they argue that these multiple pixel events cannot be due to random instrument noise.

The Ultraviolet Imager (UVI) [*Torr et al.*, 1995] sits on the same despun platform as VIS. The UVI incorporates a narrow-band filter that detects emissions at 130.4 ± 4.0 nm. Polar spins with a period of 6 seconds, but the despun platform can be oriented along one axis, permitting staring at specific regions of Earth for up to several hours. The UVI has an 8° field of view (FOV) and a pixel resolution of approximately 0.04°. The ultraviolet photons that pass through the optics impinge on a MgF entrance window of an image intensifier whose inside surface is coated with a thin film of nichrome. Transmitted photons interact with the photocathode (CsI deposited on the front surface of the first channel plate) and the photoelectrons are multiplied by a pair of microchannel plates. The electrons that exit the other end are accelerated by a 4 kV potential and proximity focused to a P31 phosphor screen. The light from the phosphor screen is then coupled by means of fiber optics to a charge-coupled device (CCD) imaging array of 200 by 228 pixels.

After Polar was launched, it was discovered that the despun platform has an unresolved 0.4° wobble in one direction which degrades the UVI pixel resolution to approximately 1×10 pixels. However, this wobble turns out to be serendipitous for the purpose of studying the dark pixels because an external source reaching the UVI will now be modulated by the wobble. We can look for this signature to determine if the source of the dark pixels is internal or external to the instrument.

The main purpose of this article is to answer: (1) Does the UVI on Polar detect dark pixels in dayglow images? (2) If so, what are they?

Observations

The UVI imaged the dayglow with the 130.4 nm filter for about two hours, obtaining 67 images from a geocentric distance of approximately 4 R_E. The UVI operated in the 9 second (instead of the normal 36 second) accumulation mode to better resolve moving objects. The phosphor afterglow contributions were minimized

[1]Geophysics Program, University of Washington, Seattle, WA
[2]University of Alabama in Huntsville, Huntsville, AL
[3]NASA Marshall Space Flight Center, Huntsville, AL

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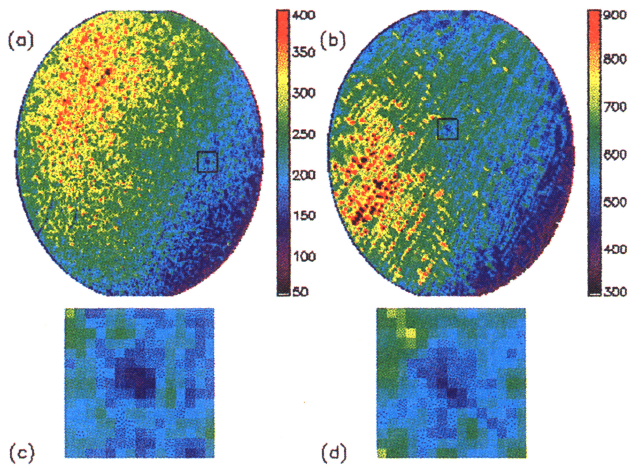

Figure 1. An example of uncorrected images acquired with the 130.4 nm filter (a) of Earth's dayglow and (b) of a diffused source during laboratory calibration, and high resolution details of the boxed regions in the (c) dayglow and (d) calibration images.

by closing the shutter between images acquired every 73.4 seconds. An example of a false color dayglow image exposed beginning at 2334:05 UT on April 12, 1996 is shown in Figure 1a.

A calibration image taken with the same 130.4 nm filter, obtained by a combination of calibrated ultraviolet light sources and a diffuser that uniformly filled the aperture of the camera, is shown in Figure 1b. This is a 36 second image produced with a slightly lower image-intensifier gain than the dayglow image. No corrections have been applied for optical distortions or the nonuniform response of the pixels in either image.

Figures 1c and 1d show expanded views of dark pixel clusters in dayglow and calibration images (boxed area of Figures 1a and 1b). Note that the count rate for the calibration image is 2 times greater than the dayglow. The images before and after, at 2333:38 UT and 2336:05 UT, do not show dark pixels at these pixel locations (not shown). Thus these clusters are transient. The transient dark pixels are now examined systematically.

Occurrence Distribution of Darkened Pixel Events

Two procedures were used to identify the dark pixels. The first examines a small portion of the imaging plane, a 21×21 pixel submatrix, which is about 1% of the total number of pixels in an image. Let C_j represent the counts in each of the pixels of this submatrix, M the mean, and σ the standard deviation. Any pixel in this matrix whose count was diminished below the mean by more than $p\sigma$ (p = 1.5, 1.8, 2.0 and 2.2) is designated as a dark pixel, that is, $M - C_j \geq p\sigma$ for all $C_j < M$. The matrix was sequentially advanced one pixel column (row) at a time, and thus every pixel was scrutinized. Computing a moving mean from a small portion of the imaging plane minimizes the biasing effects of uneven counting statistics over the image.

The occurrence distributions of the dark pixels are constructed by sorting the dark pixels clusters according to their size. The top panel of Figure 2 shows the distributions for dayglow and calibration images for various standard deviations. The abscissa represents the number of adjoining dark pixels in each event, and the ordinate the occurrence frequency of each type of event. The triangles indicate the dayglow (averaged over the 67 images) and the diamonds the laboratory calibration data (averaged over 5 images). The laboratory distributions from solar filter (>190.0 nm) images are shown because they were obtained at the same gain setting as the dayglow images. Calibration data indicate that the dark pixel occurrence distribution changes with the image-intensifier gain (not shown).

The distributions of the dark pixels in dayglow and calibration are nearly identical. Note, however, the day-

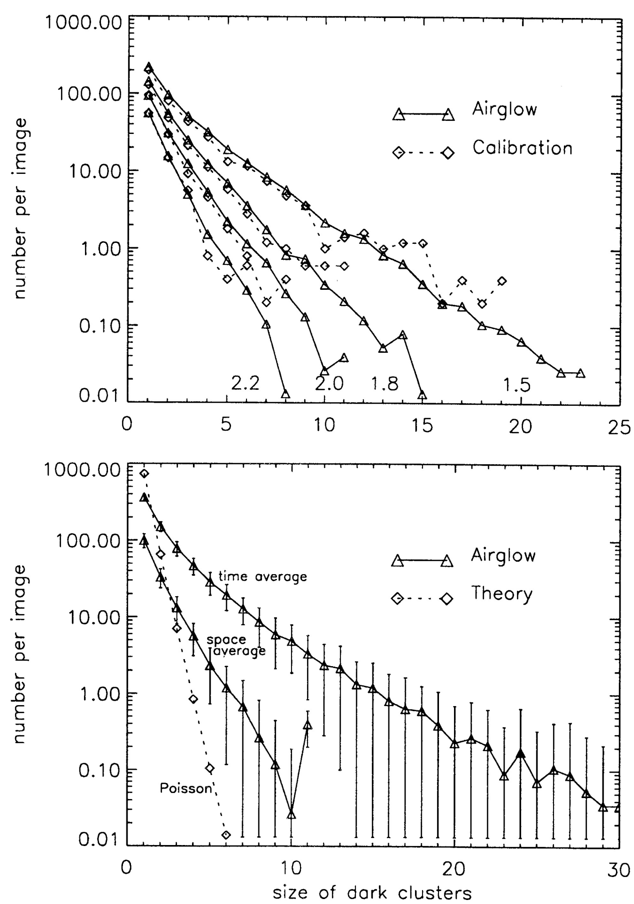

Figure 2. (Top) The occurrence distributions of the dark pixels, identified by the spatial averaging method for various values of σ, in images of dayglow using the 130.4 nm filter and laboratory calibration images taken with a >190.0 nm filter at the same gain level. (Bottom) A comparison of the occurrence distributions for the time and space averaging methods along with the predicted distribution based on independent Poisson events.

glow distributions extend to larger clusters than the calibration images. For the 2σ distribution, for example, the calibration images did not include any clusters of 9 or more adjoining pixels. Furthermore, the large clusters in dayglow appear to belong to the same population as the smaller ones, indicating the source is the same. These distributions predict that every 130.4 nm image will include, on average, about one cluster with 5 or more pixels (2σ criterion) whether it is of the dayglow or a calibration image.

The second procedure examines time variations of the dayglow intensity of each pixel on the image plane during the course of the two hour interval. The spacecraft motion contributed a slow factor of two variation in the dayglow intensities during the two hours of observations (not shown). This variation was removed by computing a running average for each pixel over 11 images and subtracting the number of counts from the mean. Pixel values more than 2σ below the mean were considered dark. The occurrence distribution constructed using the time average is shown in Figure 2 (bottom panel). For comparison, the curves from space averaging (for 2σ) and the occurrence frequency predicted by a Poisson distribution are included. The time average procedure has revealed a larger number of dark cluster events than the spatial averaging procedure. Both curves depart from the Poisson distribution. This is an important result that indicates that the adjacent pixels are not independent but correlated.

145 / 0.5	136 / -0.1	133 / -0.3	118 / -1.3	110 / -1.9	115 / -1.5	121 / -1.0
148 / 0.7	133 / -0.4	133 / -0.3	121 / -1.2	106 / -2.2	106 / -2.2	128 / -0.6
130 / -0.6	125 / -1.0	122 / -1.1	110 / -1.9	104 / -2.3	106 / -2.2	124 / -0.9
110 / -2.0	114 / -1.7	121 / -1.2	116 / -1.5	102 / -2.4	111 / -1.8	119 / -1.2
117 / -1.6	118 / -1.5	124 / -1.0	123 / -1.1	114 / -1.6	107 / -2.1	110 / -1.8
136 / -0.3	133 / -0.4	135 / -0.3	133 / -0.4	133 / -0.3	127 / -0.7	124 / -0.9
150 / 0.7	149 / 0.7	150 / 0.8	156 / 1.2	157 / 1.3	151 / 1.0	149 / 0.8
143 / 0.3	159 / 1.4	151 / 0.9	162 / 1.7	163 / 1.8	154 / 1.2	142 / 0.4
143 / 0.3	162 / 1.6	149 / 0.7	146 / 0.6	151 / 0.9	140 / 0.2	133 / -0.3
144 / 0.3	156 / 1.2	151 / 0.8	144 / 0.4	151 / 0.9	152 / 1.0	142 / 0.3
149 / 0.6	151 / 0.8	151 / 0.8	142 / 0.2	150 / 0.8	158 / 1.4	143 / 0.4
153 / 0.8	148 / 0.5	140 / 0.0	144 / 0.3	144 / 0.3	160 / 1.5	149 / 0.7
155 / 1.0	132 / -0.7	123 / -1.3	136 / -0.3	144 / 0.3	150 / 0.7	145 / 0.4
160 / 1.3	111 / -2.3	110 / -2.3	138 / -0.2	144 / 0.2	147 / 0.5	145 / 0.4
150 / 0.5	111 / -2.4	109 / -2.5	143 / 0.1	149 / 0.6	142 / 0.1	139 / -0.1
142 / -0.1	118 / -1.9	117 / -2.0	138 / -0.3	134 / -0.6	131 / -0.8	123 / -1.3
138 / -0.4	128 / -1.1	117 / -2.0	126 / -1.2	135 / -0.5	147 / 0.5	127 / -1.0
144 / 0.0	141 / -0.2	121 / -1.6	133 / -0.6	156 / 1.1	156 / 1.1	146 / 0.5

Figure 4. Pixel map of a portion of an image showing two clusters of 6 dark pixels separated by a little more than the wobble amplitude. The instrument counts (upper left) and deviations from the mean in units of standard deviation (lower right) are shown for each pixel.

Search for Wobble Modulation

One clear determination whether a dark pixel is of geophysical origin is the evidence of spacecraft wobble. The image of a small source originating external to the UVI appears as a dual-peaked function (dumbell shape) with about a ten-pixel spread in the direction of the wobble motion. Figure 3 shows a wobble signature for the star ν CEN (HD120307) imaged by the UVI. Any small source with a duration longer than 6 seconds evidences the characteristic dual-peaked function. If the point source is in motion perpendicular to the wobble then the image appears as a sinusoidal function. The signature of motions in oblique directions is more complex but predictable.

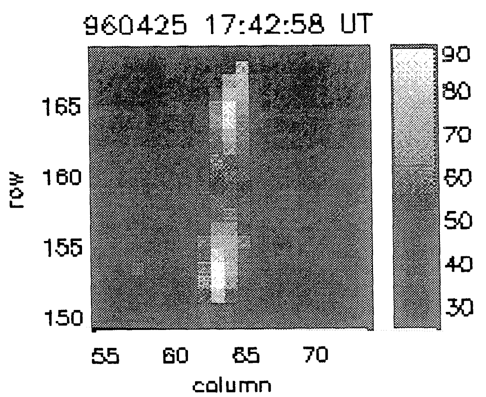

Figure 3. An uncorrected 36 second image of an ultraviolet star imaged by the UVI camera. The vertical distortion is produced by motion of the camera during several periods of spacecraft wobble.

We sought evidence of the wobble in the dark pixels, identified by the two procedures discussed above, by searching for pairs of clusters with five or more dark pixels that were located within a radius of 14 pixels. The wobble motion is aligned within 2.5° of the vertical and has an amplitude of about 10 pixels. Spacecraft orbital motion during image acquisition introduces image blurring perpendicular to the wobble direction by about one pixel. An automated search of 67 images for pairs of dark pixel clusters, identified by space averaging, found only three candidates. For two of these candidates the clusters were aligned nearly perpendicular to the wobble direction and could clearly be dismissed as coincident noise events. A pixel map from a portion of an image acquired on April 12, 1996 at 2356:10 UT reveals the third candidate (Figure 4). Two clusters of six dark pixels whose centers are separated by about 12 pixels are aligned at about 13 degrees from the vertical. The dark clusters are located farther apart than can be accounted for by spacecraft wobble motion. It is also important to note that a true wobble would only pro-

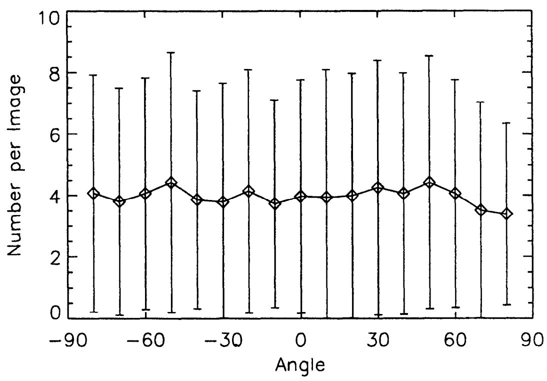

Figure 5. Angular distribution of cluster pairs. The wobble is along 0°.

duce counts below the local mean (negative values in units of the standard deviation) between the two clusters. Instead, counts significantly above the local mean were recorded. We conclude that the two clusters are independent dark events occurring in one image.

A similar search for evidence of the wobble in the clusters identified as dark by time averaging method for the 67 images found many more events. However, as shown in Figure 5, they are distributed uniformly in angle and no preference was observed in the wobble direction. The absence of dark cluster pairs aligned in the wobble direction strongly indicates that the source of the dark pixels is internal to the instrument.

Search for Comet Albedo

It is possible that solar ultraviolet scattering from neutral oxygen released during comet breakup might produce a bright trail in a 130.4 nm image, especially when viewing above the limb of Earth where the background is dark. Numerous patterns of bright pixels are found in the images. Some bright pixels appear noisy and random, others are structured, usually forming an elongated streak. Many pixels have count-rates too high to be explained as random variations. A statistical analysis of these pixels has not been performed.

One known source of structured bright streaks is cosmic ray noise. Cosmic rays lose energy as they propagate through the camera system. The ionization tracks they produce frequently appear in the UVI images as bright spots, long and short streaks and other complex shapes. We can distinguish between real comets and penetrating radiation because the former is wobble modulated and the latter is not, owing to a very short interaction time. After examining numerous bright streaks in UVI images, we conclude that virtually all of them can be explained as ionization tracks due to cosmic rays and other types of penetrating radiation.

Discussion and Conclusion

Our search has revealed that dark pixels do exist in dayglow images. But we have also found similar dark pixel events in the calibration images. A systematic statistical analysis of the two data sets reveals that the two distributions are nearly identical. Another laboratory result shows that the occurrence frequency of the dark pixel events changes in a complicated way as the high voltage gain of the image intensifier is changed. At low gains, some of the same pixels repeatedly show up as dark.

These results have led us to conclude that the dark pixels observed in dayglow images are instrumental and produced in the complex intensifier–CCD assembly. The UVI data show that it is highly improbable that the dark pixel events (single or cluster) in dayglow images are of geophysical origin, and we do not support the conclusions of *Frank and Sigwarth* [1997a].

Note added in proof: After the submission of this paper we received one hour of VIS data that was concurrent with the UVI images analyzed in this report. These VIS images are being analyzed by the same statistical methods described above. The findings of that study and a comparison with the UVI results presented here will be submitted to Geophysical Research Letters.

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G. Parks, M. Brittnacher, L. J. Chen, R. Elsen, and M. McCarthy, Geophysics Program, Box 351650, University of Washington, Seattle, WA 98195 (E-mail: parks@geophys.washington.edu)

G. Germany, CSPAR, University of Alabama in Huntsville, Huntsville, AL 35899

J. Spann, Space Sciences Laboratory, NASA Marshall Space Flight Center, Huntsville, AL 35812

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