Physics, Chemistry, and Dynamics of Interplanetary Dust
ASP Conference Series, Vol. 104, 1996
Bo A. S. Gustafson and Martha S. Hanner (eds.)

Clementine Photographs of the Inner Zodiacal Light

B. L. Cooper[1], H. A. Zook[2], and A. E. Potter[2]
[1]*B. Cooper & Associates, Houston Texas*
[2]*NASA Johnson Space Center, Houston, Texas*

Abstract. Over 700 photographs of the inner zodiacal light were taken from the Clementine spacecraft while it was in orbit around the Moon. These exposures were taken with the 28° x 43° field-of-view Star Tracker camera and the 4.2° x 5.6° field-of-view UV/Vis camera. The images were made while the Clementine spacecraft was on the dark side of the Moon such that the Sun was occulted. Most of the photos were taken at the highest possible sensitivity and longest exposure time (0.7 sec) in order to detect an expected weak lunar horizon glow. Consequently, many of the photos are over exposed where the zodiacal light is the brightest. However, a subset of photos were purposefully taken with a range of exposure times to reveal the entire inner zodiacal light structure, both in latitude and longitude, to within 1° of the Sun. These Star Tracker images show the lenticular shape of the inner zodiacal light. When work to correct the images to absolute photometry is concluded, the detailed structure of the entire inner zodiacal light will be derived.

1. Introduction

The Clementine spacecraft was built and flown by the Naval Research Lab, under the direction of the U.S. Dept. of Defense. Its principal purpose was to determine the survivability of its instrumentation in the space environment; doing so in near-lunar space permitted the collection of useful data in the process.

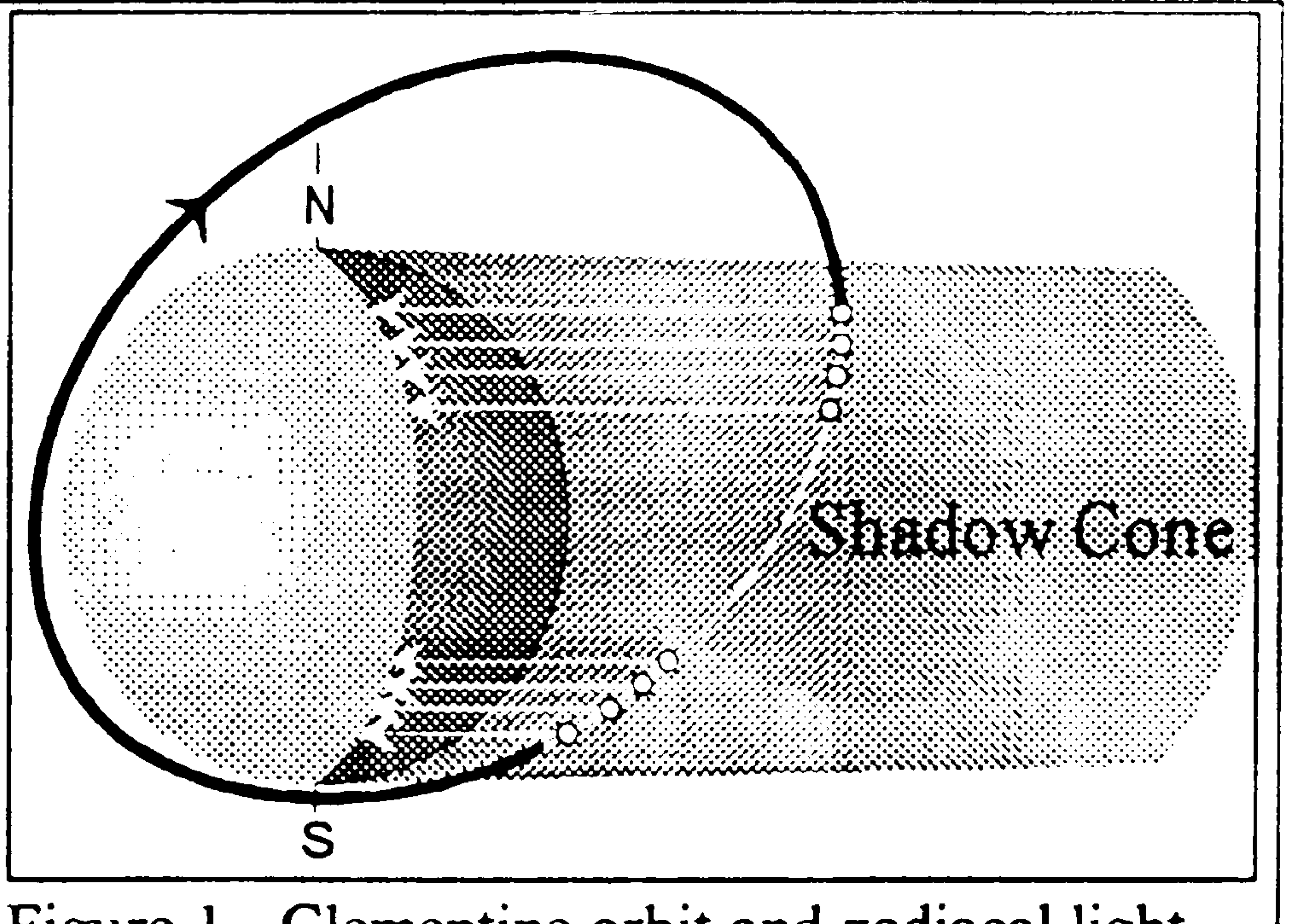

Figure 1. Clementine orbit and zodiacal light data collection points.

Clementine's Star Tracker camera was originally intended to be used only for guidance, but its wide field of view and light gathering capacity made it useful for other purposes as well. The camera has no filters and thus has a wide bandpass, gathering light in the range from 3000 to 10000Å. It imaged the zodiacal light while the spacecraft was in the shadow of the Moon. Fig. 1 shows the orbital geometry of the spacecraft during the lunar mapping phase of the mission.

2. Observations and Preliminary Analysis

The raw data were very dark, with pixel brightnesses at low levels above the thermal background. Exposures ranged from 50 to 700 milliseconds. In order to view the images it was usually necessary to stretch the contrast. All of the Star Tracker images have a streak going through them, which is caused by the lack of a shutter on the camera. While the pixels are being read out, the charge-coupled device (CCD), upon which the image was recorded, continues to record information.

We have developed two procedures to remove the streak: a matrix inversion method and a block subtraction method. The exposure settings and viewing geometry of each image determine the method to be used.

If there is a bright region in the image, then pixels at column positions to the right and left of the bright spot record not only their own image brightness for the primary exposure time T, but each element is also exposed to the bright region for a lesser time, τ, the time required for each row of the image to be read out of the CCD. The matrix inversion method involves solving 576 simultaneous equations (the length of an image column in pixels) to determine the amount of added brightness caused by the bright object on each pixel over time τ.

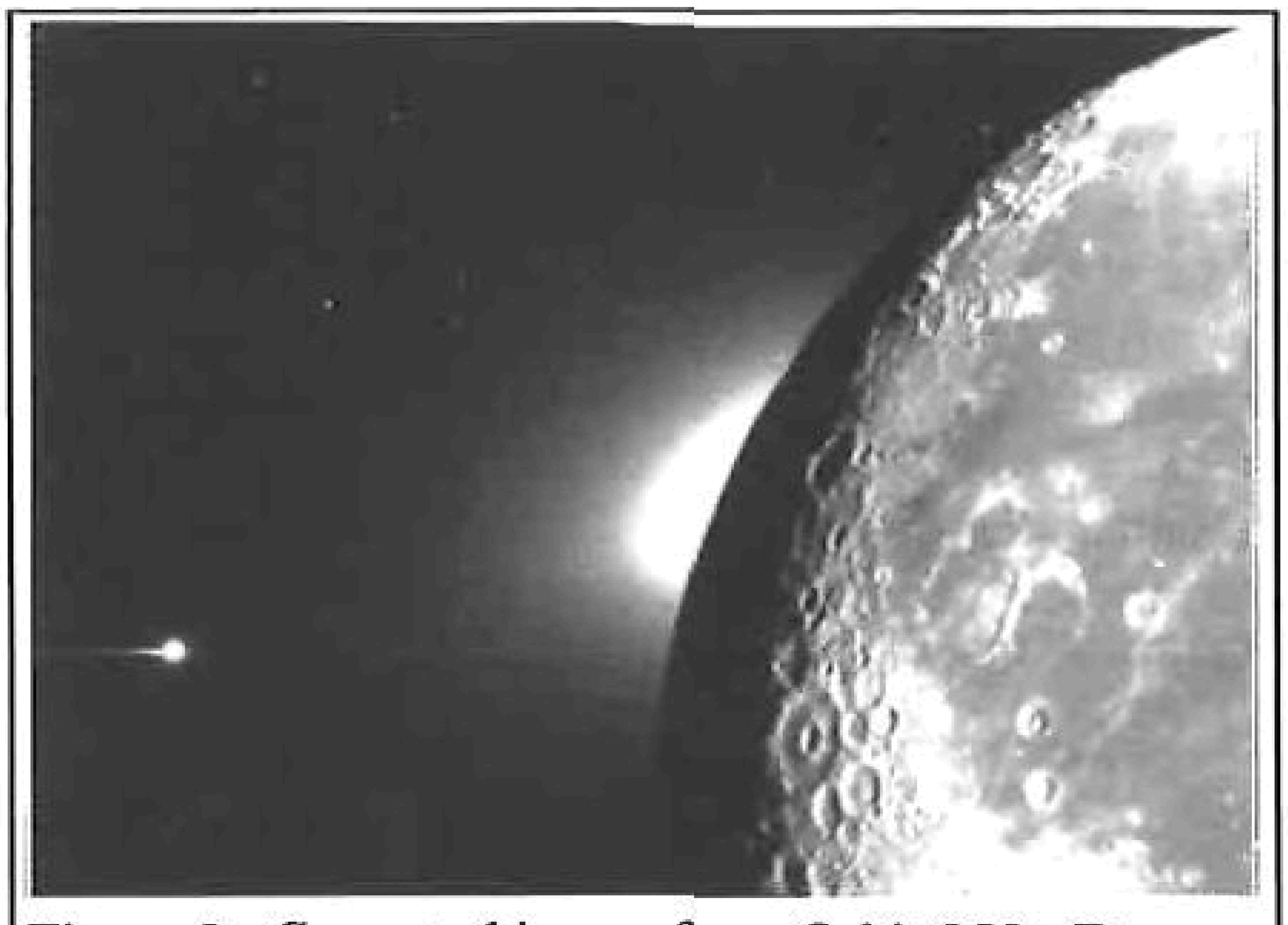

Figure 2. Corrected image from Orbit 253. Depression angle[1] is 3.8°, exposure is 400 ms. Venus, the bright object to the left, has a solar elongation[2] of approximately 21°. The illuminated Moon is due to Earthshine. The "up" direction is approximately ecliptic North in all figures.

This procedure was used to obtain Fig. 2. The method only works when image pixels are not saturated. Saturation occurs when the integrated brightness of the image exceeds 256 digital units. Each digital unit corresponds to about 75 electrons (analogous to about 300 photons) when the camera is operated in the most sensitive mode, which is usually the case for the Zodiacal Light images.

When the image is saturated, the "block subtraction" method is used instead. This procedure was used on Fig. 3 to obtain Fig. 4. We obtain an average background matrix for an area of the image in which the dark moon covers several vertical columns. For the dark Moon, thermal electrons result in digital numbers near 40. This average is subtracted, line by line, from the entire image.

We determined which stars and planets were visible in each image, and their

---

[1] Depression angle: The angular distance of a heavenly body below the horizon.
[2] Elongation: The angle between two celestial bodies as seen from the Earth.

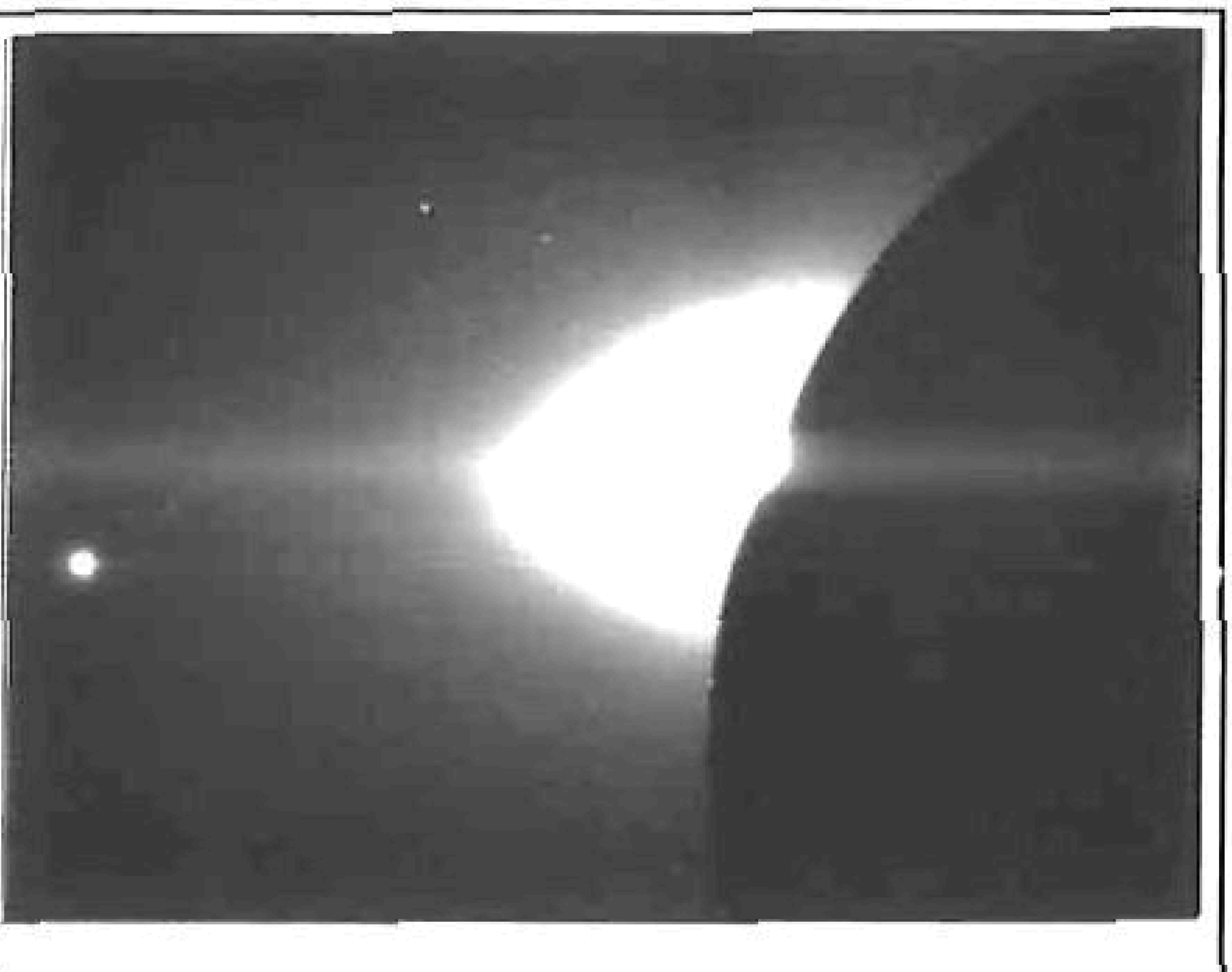

Figure 3. Orbit 273, image #24, uncorrected. Depression angle = 0.57°, exposure duration = 700 ms.

Figure 4. Corrected (streak removed) version of image shown in Figure 5.

approximate location relative to the camera boresight (the center of the image). We also calculated the approximate solar depression angle using information given in the image headers.

In Figs. 3 and 4, for example, Venus is about 22 degrees from the Sun; the Sun is just barely below the lunar limb, at a depression angle of 0.57°. Using all of the images, we have unsaturated information about the zodiacal light from about 1° to 22° solar elongation along the long axis of symmetry, and for about 14° above and below the picture's long axis. In comparison to Fig. 3, Fig. 2 has a solar depression angle of 3.8°, as well as a lower exposure duration--400 milliseconds versus 700 milliseconds. We can glean information about the brighter part of the zodiacal light in the lower-exposure images, because the bright areas are then less likely to be saturated.

3. Discussion

Calibration of the brightness of each image consists of locating stars that are similar in spectral characteristics to the Sun in the many images. We can then compare their brightness to that of the zodiacal light.

The dynamic range of the data can be estimated by the fact that images were made with exposure durations of 50, 100, 200, 400, and 700 milliseconds, and each exposure has a brightness range of 256 gray levels. This gives a dynamic range[3] of about 3500. The corresponding brightness range is roughly from 3×10^{-13} $B_\odot$ to 10^{-9} $B_\odot$. Further work will refine these numbers.

[3] Dynamic range: the ratio of the highest measure (in whatever units) to the lowest measure (in the same units).

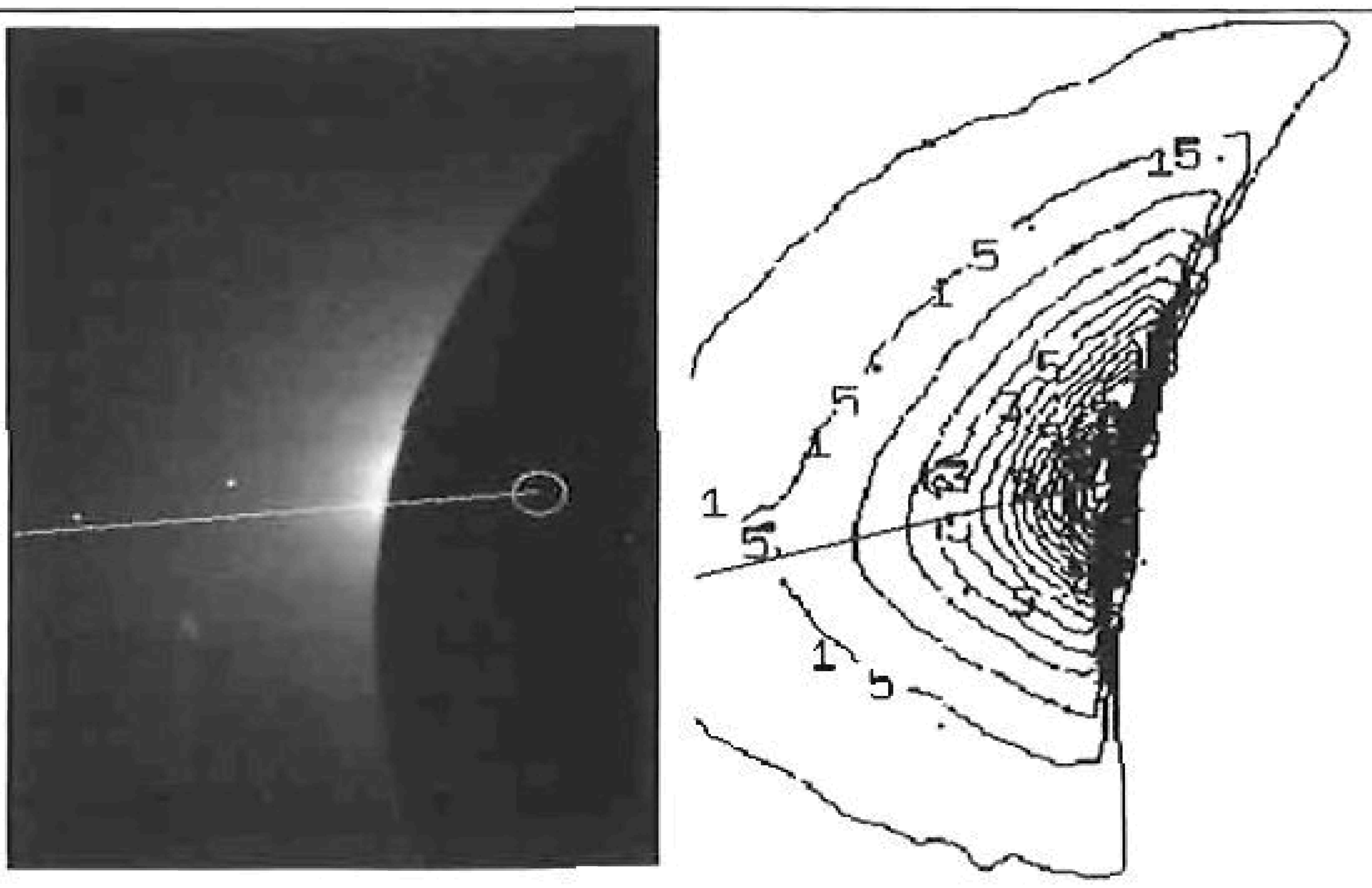

Figure 5. (Left) Image #18 from orbit 66, with a line showing the plane of the ecliptic. Note the planets Mars and Saturn, respectively, from left to right, and near the ecliptic. (Right) Isophote contour plot of the image, with a line showing the plane of symmetry of the zodiacal light.

We can estimate the degree of tilt of the plane of symmetry away from the plane of the ecliptic by comparing an image upon which the plane of the ecliptic has been plotted (Fig. 5, left) with an isophote plot of the zodiacal light (Figure 5, right). In the isophote plot, a straight line has been drawn at the plane of symmetry of the zodiacal light. Visual inspection shows that the line of the plane of the ecliptic is not tilted by the same amount as the line of symmetry of the zodiacal light. From this comparison we can estimate that there is at least 2° difference between the two planes, and possibly as much as 7°. We will compare as many images as possible with their corresponding isophote plots to refine our estimate.

4. Conclusions

The Clementine data set of approximately 700 images of zodiacal light offers a new opportunity to study interplanetary dust in the region from 1° to 22° solar elongation[4]. This is a region that has been difficult to study from Earth or from other spacecraft. These data offer us the opportunity to establish the absolute brightness of the zodiacal light in this region, and to determine, by visual methods, the degree of tilt of the plane of symmetry of the zodiacal light. Future reports will detail our progress in this study.

5. Acknowledgments

Many people helped to plan and take these images. Besides the Naval Research Laboratory, we would particularly like to thank Eugene Shoemaker, Don Horan, Trevor Sorensen, Hye-Sook Park, Eric Eliason, Mike Corson, Bill Collins, and Barry Geldzahler. Thanks also to Mark Cintala for a careful review of this paper.

---

[4] The Clementine data are publicly accessible. Contact the NSSDC request office at request@nssdca.gsfc.nasa.gov, phone number (301) 286-6695.