A SEARCH FOR SMALL SCALE STRUCTURES IN THE ZODIACAL LIGHT

S. S. Hong*, N. Y. Misconi, M. H. H. van Dijk[1],
J. L. Weinberg, and G. N. Toller
Space Astronomy Laboratory, University of Florida
1810 NW 6th Street, Gainesville, Florida 32609, USA
[1]Free University, Amsterdam, the Netherlands

ABSTRACT. Gegenschein observations from Pioneer 10 were found to have brightness structures with an amplitude of about 10% and a period of several to ten degrees in elongation. A search is made for such structures in high angular resolution ground-based observations from Mt. Haleakala, Hawaii. A new empirical method is used to correct for atmosphere-originated radiation. Background starlight is subtracted using Pioneer 10 observations from beyond the asteroid belt. Preliminary analysis of the ground data also indicates the presence of small amplitude structures in the brightness distribution.

This is a first report on our search for small scale structures in the zodiacal light brightness. By structures we mean small amplitude spatial fluctuations in the brightness distribution. Such structures might be expected from inhomogeneities in the spatial distribution of the zodiacal dust and/or structure in the scattering phase function. There have been a number of observational hints for the existence of such structures. Ground-based observations of zodiacal light brightness by Weinberg (1963) show an enhancement at elongation 135°, which also has a counterpart in the polarized brightness (Weinberg, 1964; Frey, et al., 1974). Other space and ground-based observations of zodiacal light have also shown irregularities in the brightness distribution (Sparrow and Ney, 1972; Dumont and Sánchez, 1975). Despite these observational indications, structures in the zodiacal light have generally been ignored for two reasons. First, there was a lack of detailed information on the distribution of background starlight over the sky. Second, for ground observations it is difficult to determine the airglow continuum and to correct for airglow and astronomical diffuse background that is scattered into the telescope's field of view by the Earth's atmosphere.

Figure 1 shows Pioneer 10 near-Earth observations of zodiacal light brightness as a function of differential ecliptic longitude $\lambda-\lambda_\odot$ for various ecliptic latitudes. Connection of the points in Figure 1

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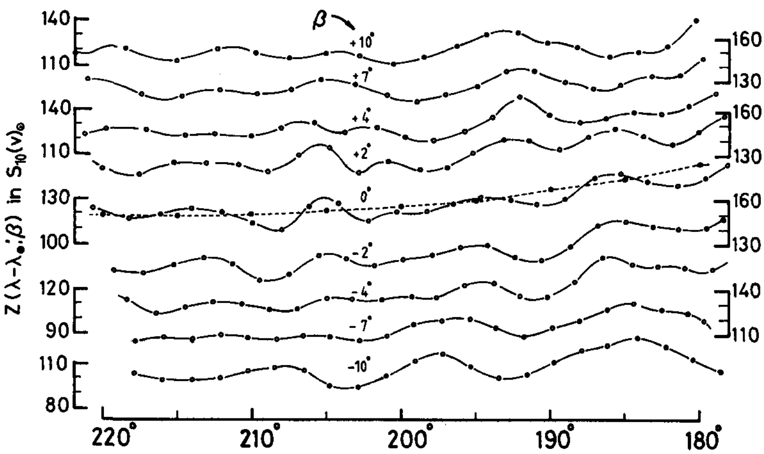

Figure 1. Zodiacal light brightness distribution near anti-solar point as seen from Pioneer 10 on March 14, 1972 at 1.011 AU from the sun. Abscissa represents differential ecliptic longitude $\lambda-\lambda_\odot$ and ecliptic latitude β is given to each curve.

reveals a persistent pattern of fluctuations having 10% amplitude 7 to 10 degree period. When the fluctuations are smoothed out, the underlying average distribution has the same differential ecliptic longitude dependence as Dumont's ground observations (Levasseur-Regourd and Dumont, 1980); the filled circles connected by dashes are their ecliptic values multiplied by a constant factor 0.86. Because the amplitude of the structure is not much greater than the noise level of the observations and the Pioneer's instantaneous field of view is approximately 2.3° by 2.3° , we decided to examine selected higher angular resolution ground-based observations obtained by Weinberg and Mann.

One night's observations, 21/22 August 1968 at Mt. Haleakala, Hawaii, are particularly well-suited for this investigation. The sky was scanned repeatedly over the entire range (360°) of azimuth at elevations 10°(05)45° using a 1.7°-radius field of view. Eleven such groups of scans were made at each of wavelengths 5080 Å and 5300 Å. Observations at 5080 Å are analyzed here.

Because the same sky positions were observed at different times through different air masses, the following correction scheme for atmosphere-originated radiation was devised specifically for this body of data. The observed brightness (B) of a sky position includes the zodiacal light (ZL), background starlight (BS), resolved starlight (ST), airglow emission (AG), and the airglow and astronomical radiation diffusely scattered into the field of view (SCT). Putting the airglow emitting layer outside the scattering atmosphere and denoting the optical path length of the atmosphere at elevation h by t(h), we have

$$B = (ZL+BS+ST)\exp[-t(h)] + AG(h)\exp[-t(h)] + SCT(h). \quad (1)$$

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Similarly, when the same sky position is viewed at h´, we have

$$B' = (ZL+BS+ST)\exp[-t(h')] + AG(h')\exp[-t(h')] + SCT(h'). \quad (2)$$

$X(h) \equiv AG(h) + SCT(h)\exp[t(h)]$ is the amount of airglow emission and total scattered light which must be removed to obtain ZL+BS+ST. From equations (1) and (2) we obtain

$$X(h) - X(h') = B\exp[t(h)] - B'\exp[t(h')]. \quad (3)$$

Figure 2 illustrates how X(h) increases with increasing atmospheric extinction exp [t(h)]. Values on the left ordinate represent the excess brightness of X(h) over X(45°) in $S_{10}(V)_{\odot}$ units. Because the Haleakala Observatory is located at latitude 20.7 degrees north, the elevation 20 degree scans include the north celestial pole, enabling us to determine X(45°) and giving an absolute scale for X(h) as shown on the right ordinate. Spreads of the data points shown by vertical bars in Figure 2 are clear indications of spatial and temporal variations of the atmosphere-originated radiation. To minimize the azimuthal dependence of X(h) due to spatial variations of astronomical background, we only include regions more than 30° away from the galactic plane.

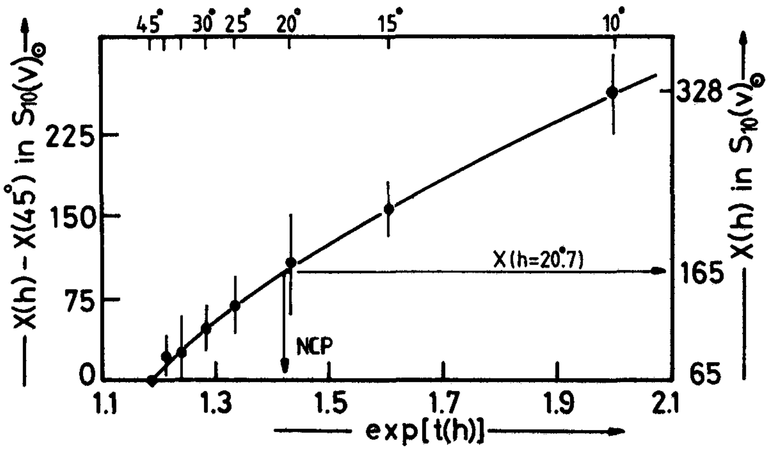

Figure 2. Elevation dependence of the atmospheric correction term X(h). To set up an absolute scale for X(h), 64 and 73 $S_{10}(V)_{\odot}$ were used for the brightnesses of background starlight at the north celestial pole and zodiacal light there at the time of observation, respectively.

The zodiacal light is determined by using X(h) (the solid line in Figure 2) to correct for airglow continuum emission and atmospheric scattering, by subtracting Pioneer 10 determinations of background starlight BS (Toller, 1981), and by subtracting the contribution ST by stars brighter than visual magnitude 6.5 from Bexp[t(h)]. The resulting brightness distribution is shown, in Figure 3, as a function of $\lambda-\lambda_{\odot}$

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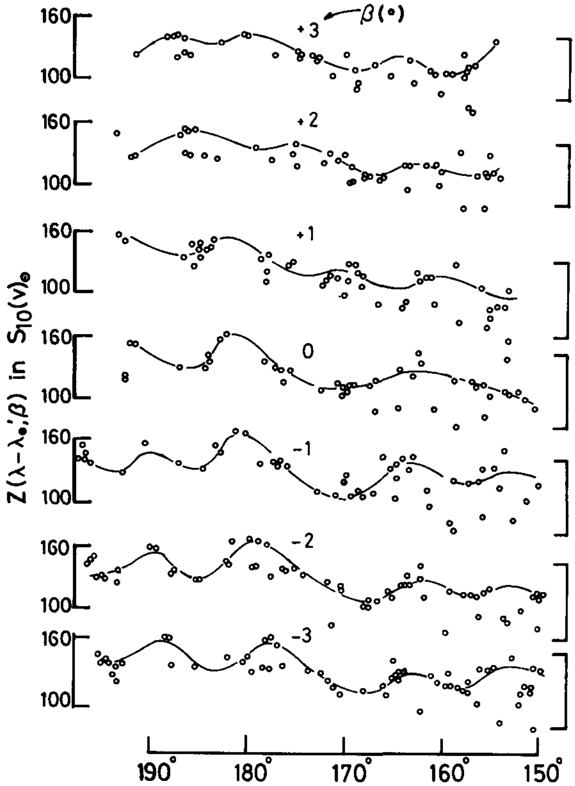

Figure 3. Zodiacal light brightness distribution near anti-solar point as observed from Mt. Haleakala, Hawaii on 21/22 August, 1968. Abscissa represents the differential ecliptic longitude and ecliptic latitude β is given to each curve.

for various ecliptic latitudes. A 10% amplitude and 10 degree periodicity of the structures are evident in the ground-based observations, and the structures persist at different latitudes. In order to confirm the structures seen in this preliminary study, we intend to refine the absolute calibrations, examine polarization observations, and extend coverage in elongation, wavelength and season. Nevertheless, the consistency in overall characteristics of the structures that has emerged from both the space and ground-based observations strongly suggests that the zodiacal light has fine structure which could provide new information on the spatial distribution and/or optical properties of the interplanetary dust particles.

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DISCUSSIONS

Dumont: The patchy and sometimes rapidly evolutive distribution of the airglow continuum is known to be a main difficulty in ground-based zodiacal light observations. Part of the structure that you report in the Gegenschein could be ascribed to these airglow fluctuations. To what extent can your reduction method take into accound such telluric effects?

Hong: As scatter in Figures 2 and 3 indicates, airglow is certainly a problem. But, for the following reasons, we do not think the structure seen in this study is due to airglow variation. The pattern of structures persists at widely different ecliptic latitudes. The structure seen in the Pioneer data is consistent, at least in overall characteristics, with the one seen in the ground data. All night monitoring of brightness at the north celestial pole at Mt. Haleakala typically does not show rapid changes at 5080 Å and 5300 Å, which is in agreement with the 5000 Å result from the balloon-borne observations by Frey, et al. (1974). From extensive multicolor observations of celestial pole brightness we hope to derive a time-dependent correction for the atmospheric term, thereby reducing the scatter in Figure 3.