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DIRBE OBSERVATIONS OF THE GALACTIC BULGE

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ABSTRACT

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Near-infrared observations of the Galactic bulge from the Diffuse Infrared Background Experiment (DIRBE) on-board NASA's Cosmic Background Explorer (COBE) satellite are discussed. Emphasis is placed on preliminary analysis of asymmetries in the brightness distribution of the bulge, and the implications for the presence of a stellar bar in the bulge region.

1. INTRODUCTION

Since interstellar extinction obscures a substantial fraction of the Galactic bulge from observation at optical wavelengths, the morphology of the bulge is more easily studied in the near-infrared. The bulge is evident in near-infrared wavelengths as a roughly elliptically-shaped distribution of stars and interstellar material centered within the flatter disk of the Galaxy.

Recently, Blitz & Spergel (1991) have used asymmetries in the bulge brightness distribution at 2.2 μm to infer the presence of a stellar bar at the center of the Galaxy, which is oriented at an angle to the observer in the plane, and possibly also tilted out of the plane by a few degrees. The presence of a bar has been postulated by others based on velocity data (e.g. de Vaucouleurs 1964, Lizst & Burton 1980) and IRAS late-type stellar population distributions (e.g. Weinberg 1992, Whitelock & Catchpole 1992).

We discuss evidence for asymmetries in the bulge structure as seen in data from the Diffuse Infrared Background Experiment (DIRBE), and the implications of our results for the stellar bar model of Blitz & Spergel (1991).

2. THE DIRBE INSTRUMENT AND OBSERVATIONS

The DIRBE instrument is a 10 spectral band absolute photometer with wavelength coverage from 1 to 240 μm (Hauser *et al.* 1991). The DIRBE has surveyed the entire sky with a 0.7° square field of view, systematically sampling each pixel at solar elongation angles between 64° and 124°. The DIRBE data have shown excellent relative photometric stability. A more complete description of the DIRBE instrument and COBE mission is given by Boggess *et al.* (1992).

Using DIRBE observations spanning a 6 month interval, maps of the sky interpolated to a solar elongation of 90° were created. An empirical fitting func-

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tion (Hauser 1993) was used to remove foreground contamination from zodiacal dust from these maps. Estimated inaccuracies in this foreground removal for $\lambda \leq 3.5\mu m$ are $\leq 1-2\%$ of the median brightness of the bulge in the inner Galaxy region.

The Galactic bulge is clearly visible in the 1.25 to 4.9 μm DIRBE maps, within $|l| < 15°$ and $|b| < 10°$. In the 1.25 μm map, there is obvious evidence of a dust extinction lane running along the Galactic plane. The 2.2 μm map shows intensity levels and morphology similar to those observed by Matsumoto *et al.* (1982).

Longitudinal asymmetries in the near-infrared bulge brightness distribution at 1.25, 2.2, 3.5 and 4.9 μm can be discerned by 'folding' the intensity contours about $l = 0°$. At a fixed Galactic latitude, contours of the same intensity level for $l = 345°$ to $360°$ lie systematically inside those for 15° to 0°, indicating asymmetry.

3. CORRECTION FOR EXTINCTION AT 2.2 μm

Extinction within the Galactic plane is still significant in the near-infrared, although considerably reduced compared to that at optical wavelengths. It is possible that some of the brightness asymmetries seen in the DIRBE data could be caused by patchy extinction, rather than by the underlying source distribution. Since the DIRBE data provide the first multi-wavelength near-infrared maps of the full Galactic plane, direct compensation for the effect of extinction can be made. As an example, we have performed the correction for the 2.2 μm DIRBE map.

The optical depth at 2.2 μm is estimated from the DIRBE data by two methods: 1) deriving the optical depth at 2.2 μm from the near-infrared DIRBE data as per Arendt *et al.* (1993), and 2) scaling the optical depth at 240 μm as determined by Sodroski *et al.* (1993) to 2.2 μm. The region within $|b| \leq 3°$ is excluded from analysis since the stellar light from the Galactic center region is too heavily attenuated to correct accurately. Both correction methods are in good agreement for $|b| > 3°$, yielding estimates for the 2.2 μm optical depth $\tau \lesssim 0.5$ in this region.

Even after an extinction correction is applied to the DIRBE data, some longitudinal asymmetries in the bulge brightness distribution remain. There are, however, structural differences in the appearance of the bulge between the corrected and uncorrected maps. In particular, extinction is chiefly responsible for the presence of the pronounced "peanut-shape" waist located near $l = 1°$, $b = 5°$ in the uncorrected DIRBE maps of the bulge at 1.25 μm and 2.2 μm. In the extinction-corrected maps, the pronounced "waist" disappears. This structure correlates strongly with features in the 2.2 μm optical depth map, and the near-infrared polarization (Arendt *et al.* 1993).

4. FRACTIONAL BRIGHTNESS DIFFERENCES AT 2.2 μm

A more quantitative way to characterize the asymmetries in the DIRBE maps is to compute difference maps between two halves folded either about $l = 0°$ or $b = 0°$ 'symmetry' planes. Following Blitz & Spergel (1991), we define the following fractional brightness differences:

about $l = 0°$: $\Delta I_l = [I(l,b) - I(-l,b)]/I(l,b)$
about $b = 0°$: $\Delta I_b = [I(l,b) - I(l,-b)]/I(l,b)$

DIRBE 2.2 μm fractional brightness differences about $l = 0°$ for data before and after extinction correction both show negative differences near $l = 0°$, become increasingly positive with increasing longitude out to 15°, and then decrease. The difference map created with data uncorrected for extinction possesses structure which is correlated with extinction: a highly negative feature appears near $l = 1°$, $b = 5°$, which we associated in the previous section with an extinction feature. Fractional differences about $l = 0°$ for extinction-corrected data are smoother and more latitudinally symmetric than the uncorrected data. Longitudinal asymmetries persist regardless of where the longitudinal symmetry plane is placed.

Difference maps created about $b = 0°$ show a general lack of structure beyond an overall latitudinal brightness displacement which is apparently the same for both the Galactic disk and bulge. Tests show that this gradient in brightness can be removed if the latitudinal symmetry plane is located not at $b = 0°$, but near $b = -0.16°$. This value is consistent with the assumption that the Sun is located roughly 10-20 pc above the Galactic plane (*e.g.* Djorgovsky & Sosin 1989, Freudenreich *et al.* 1993).

5. IMPLICATIONS FOR A STELLAR BAR

The emission from a triaxial stellar bar at the Galactic center may be modelled by parametrizing the stellar density distribution and choosing a geometrical orientation with respect to the observer. In the table below, the model predictions of Blitz & Spergel (1991) are compared with our findings for the observations at 2.2 μm:

Prediction	Verified by DIRBE?
If the bar is tilted so that the nearer half is in the positive longitude hemisphere, then the fractional brightness differences about $l = 0°$ should show an increasingly positive gradient as a function of longitude. The positive excess should be present at all latitudes.	*Yes*, although the gradient peaks and then drops off, presumably because light from the disk starts to dominate observed intensity.
Close to $l = 0°$, there should be a sign change in the fractional brightness differences about $l = 0°$.	*Yes.*
The near side of the bar should show a larger angular scale height. (Angular scale heights are computed assuming an exponential brightness distribution as a function of Galactic latitude).	*Yes.* Within $\|l\| < 7°$, scale heights at positive longitudes are larger than those at their corresponding co-longitudes.

Therefore, the DIRBE data are consistent with the signatures of a stellar bar with its near end in the first quadrant. It has been additionally suggested that the proposed stellar bar is tilted a few degrees out of the Galactic plane (Blitz & Spergel 1991, Liszt & Burton 1980). In this case, the fractional bright-

ness difference maps are expected to show latitudinal asymmetries which are longitude dependent. There is no evidence for this effect in the extinction-corrected 2.2 μm DIRBE data.

6. SUMMARY

DIRBE data at 1.25, 2.2, 3.5 and 4.9 μm show longitudinal asymmetries in the Galactic bulge brightness distribution. The multi-wavelength nature of the DIRBE observations permits correction for extinction effects: even after correction, longitudinal asymmetries persist. However, extinction is responsible for some of the structure seen in the DIRBE near-infrared maps: in particular, the pronounced "peanut-shaped" waist in the northern part of the bulge.

The DIRBE fractional brightness differences and larger angular scale heights at positive longitudes are consistent with the signatures of a stellar bar with its near end in the first quadrant. This orientation is in agreement with the findings of previous studies (e.g. Liszt & Burton 1980, Blitz & Spergel 1991, Whitelock & Catchpole 1992). However, the extinction-corrected DIRBE data do not show the latitudinal asymmetries necessary to support the proposal that the stellar bar is also tilted a few degrees out of the Galactic plane.

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