The Diffuse Ultraviolet Background Close to the Galactic Plane

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ABSTRACT
We have used Voyager and GALEX observations to map the diffuse Galactic light near the Galactic equator. We find that most of the observations are relatively faint with surface brightnesses of less than 5,000 photon units. This is important because many ultraviolet telescopes have not observed at low Galactic latitudes because of the fear of a bright diffuse emission. Our data are consistent with emission from interstellar dust grains with albedo (\(a\)) of 0.2 – 0.3 and phase function (\(g\)) < 0.7 at 1100 Å; 0.2 < \(a\) < 0.5; \(g\) < 0.8 at 1500 Å; and 0.4 < \(a\) < 0.6; \(g\) < 0.4 at 2300 Å.

Key words: dust, extinction – ISM: general – local interstellar matter – diffuse radiation – ultraviolet: ISM

1 INTRODUCTION
The diffuse Galactic light (DGL) in the ultraviolet (UV) is comprised of many different components whose relative contributions vary across the sky. Stellar radiation scattered from interstellar dust dominates the DGL at low Galactic latitudes (Murthy 2016) with extragalactic radiation being more important near the poles where there is little dust (Akshaya et al. 2018, 2019). Molecular hydrogen fluorescence contributes even at high latitudes (Akshaya et al. 2019) and may contribute more at low latitudes where there are more molecular clouds. Unfortunately most missions capable of observing the diffuse radiation in the UV avoided the Galactic plane because of the fear of damaging the detectors due to the intense radiation expected (Martin et al. 2005) and there are few observations of the DGL at low latitudes.

One of the first observations in the Galactic plane was made using the Voyager ultraviolet spectrometer (UVS) in the vicinity of the Coalsack Nebula where Murthy et al. (1994) found intense radiation at 1100 Å, which they attributed to the scattering of the light from 3 of the 5 brightest UV stars in the sky from a thin layer of foreground dust. Further studies with both Voyager and the Far Ultraviolet Spectroscopic Explorer (FUSE) by Murthy & Sahnow (2004) showed a patchy distribution at low latitudes with dark regions even in the Galactic Plane. The DGL in the UV is due to the light from stars scattered by nearby dust within a few hundred parsecs of the Sun and is therefore concentrated near bright stars.

We will look at the DGL using both Voyager and GALEX data. Because these are archival observations made with long inoperative instruments, we have incomplete coverage and have a limited ability to confirm uncertain observations. Nevertheless, they provide valuable input on the sources of the diffuse light in the Galactic Plane.

2 DATA
2.1 Voyager
The two Voyager spacecraft were launched in 1977 with the primary mission objective of visiting the Jovian planets. However, during their cruise phase and after the last

Table 1. Exclusion dates for Voyager planetary encounters.

| Voyager |  |
|---------|---|
| 1       |  |
| 1979 – 1979.29 | Jupiter |
| 1980.64 - 1981 | Saturn |
| 2       |  |
| 1979.3 – 1979.9 | Jupiter |
| 1981.4 – 1981.8 | Saturn |
| 1985.8 – 1986.2 | Uranus |
| 1989.4 – 1989.8 | Neptune |

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of their planetary encounters, the two spacecraft observed many astrophysical targets with their ultraviolet spectrometers (UVS). The two UVS are identical Wadsworth-mounted objective grating spectrometers which cover the spectral range between 500 and 1700 Å (with maximum sensitivity for λ < 1200Å) with a field of view of 0°.1×0°.87 (Broadfoot et al. 1977). Murthy et al. (1999, 2012) reprocessed the entire Voyager database of several thousand observations and tabulated the diffuse observations, from which we have extracted those within 10° of the Galactic equator. Note that we have excluded several of the brightest points from Murthy et al. (2012) which, upon further examination, were found to be near planetary encounters (Table 1). They were flagged as observations of the blank sky but cluster around the planetary encounters and are probably observations of the planetary environment.

There were 292 background observations within 10° of the Galactic plane and we have plotted these in Fig. 1 where the size of the symbol is dependent on the mean surface brightness between 1070 and 1130 Å. The distribution of the observed brightness is plotted in Fig. 2. We emphasize that, even though these are observations near the Galactic Plane, most (206) of them have a surface brightness of less than 5000 photon units and only 47 with a surface brightness of more than 10,000 photon units.

Some of these were very bright observations in the Voyager targets in the Galactic Plane (Table 2). All are consistent with an interstellar diffuse source (see Murthy et al. 2012) but exist in isolation; that is, there is no plausible source in optical maps of the region. A few even overlap with the GALEX data but, again, with no evidence for such a bright source. Given the passage of time since the Voyager observations, we have not included them in this work and have left out a few others where the background subtraction was unreliable. This left 282 of the original 292 observations. The spectra for all Voyager diffuse observations, including those left out of this work, may be obtained from Murthy et al. (2012).

### 2.2 GALEX

The GALEX mission was launched in 2003 and continued to take observations until 2013 (Martin et al. 2005; Morrissey et al. 2007). There were two imagers on board: the far ultraviolet (FUV: 1516 Å), which failed in 2007, and the near ultraviolet (NUV: 2316 Å). Observations of the Galactic plane were barred for much of the mission under the mistaken belief that the diffuse radiation was intense, as would have predicted from a cosecant law (Murthy et al. 2010), and only started near the end of the mission. Each GALEX observation is an image of a 1.2° field in the sky with a spatial resolution of 5′. The typical observation length was 100 seconds but could be much longer in a few fields. Murthy (2014) used the original GALEX data, removed the stars, subtracted the foreground airglow and zodiacal light (Murthy 2014), and binned the data to produce a map of the diffuse radiation over the entire sky with a bin size of 6′. We have extracted the FUV and NUV observations within 10° of the plane from these data (Fig. 4).

As discussed above, the Galactic plane was only observed near the end of the GALEX mission and only 125 of the Voyager targets are covered by NUV observations with 19 covered by FUV observations. There is a reasonable correlation between the Voyager DGL observations at 1100 Å and the GALEX FUV and NUV observations (Fig. 5), with the outliers already discussed (Table 2).

### 3 MODELING & ANALYSIS

Murthy (2015, 2016) developed a Monte Carlo model in which they used:

- The stellar positions, spectral types, magnitudes and positions from the Hipparcos catalog (Perryman et al. 1997).
- Stellar spectra from Castelli & Kurucz (2004).
- A 3-dimensional dust model using dust maps from Schlegel et al. (1998) with an exponential drop off from the Galactic plane.
- A scattering phase function from Henyey & Greenstein (1941) with the albedo (a) and phase function asymmetry factor (g = cos θ >) as free parameters.

This model tracked the observed emission well at high Galactic latitudes but did increasingly poorly at lower latitudes as the dust column density increased. The dust cross-section at 100 μm is much less than that in the UV and the 100 μm emission from the Infrared Astronomy Satellite (IRAS: Neugebauer et al. 1984) samples a much longer line of sight than would be the case in the UV where the DGL comes primarily from dust within a few hundred parsecs of the Sun (Murthy 2016). We have therefore replaced the 2-dimensional dust map from Schlegel et al. (1998) with the 3-d map of Green et al. (2015), as described by Akshaya et al. (2019).

We have fit our observations with our models at 1100, 1500, and 2300 Å as a function of the optical constants (a and g) and have drawn pseudo-confidence contours in Fig. 6 to find limits on the optical constants (Table 3). Our models are time consuming and we have only run them over a limited grid of optical parameters with a spacing of 0.1 on both a and g. Nevertheless, we find limits that are consistent with others (Draine 2003; Akshaya et al. 2018).

The observations have been plotted against the models...
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Figure 1. Locations of Voyager observations with the size of the symbol dependent on the observed surface brightness in photon units.

Figure 2. Histogram of observed surface brightness in photon units.

Figure 3. Three brightest Voyager observations in the Galactic plane.

4 CONCLUSIONS

We have used archival observations from Voyager and GALEX to study the DGL near the Galactic plane. Although there are a few particularly bright regions for which we have no explanation, most of the observations are a few thousand photon units from 1100 Å to 2300 Å. We will examine the bright regions further in a future work but expect that it will be difficult to find a plausible explanation without further observations.

We have compared a model for dust scattering in the Galaxy (Murthy 2016) to the observations finding a reason-
Figure 4. FUV (top) and NUV (bottom) images of the Galactic plane from GALEX. The scale in both is linear with a maximum of 2000 photon units in the FUV and 5000 photon units in the NUV. The Galactic origin is at the center of the plot with longitude intervals every 60° and latitude intervals at 10°. Voyager observations are shown as plus signs.

Figure 5. Voyager UVS observations at 1100 Å versus GALEX FUV (red circles) and NUV (plus signs) surface brightness. The two lines represent \( x = y \) (dark line) and \( y = 0 \).

Figure 6. Allowed regions for optical constants of dust at 1100 Å (black solid line), 1500 Å (red solid line) and 2300 Å (blue dashed line).

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Figure 7. Data from Voyager (1100 Å) GALEX FUV (1500 Å) and NUV (2300 Å) versus model predictions. The line has a slope of 1 and is shown to guide the eye.

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APPENDIX A: SOME EXTRA MATERIAL

If you want to present additional material which would interrupt the flow of the main paper, it can be placed in an Appendix which appears after the list of references.

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