THE DIFFUSE GALACTIC FAR-ULTRAVIOLET SKY

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ABSTRACT

We present an all-sky map of the diffuse Galactic far ultraviolet (1344–1786 Å) background using Galaxy Evolution Explorer data, covering 65% of the sky with 11.79 arcmin² pixels. We investigate the dependence of the background on Galactic coordinates, finding that a standard cosecant model of intensity is not a valid fit. Furthermore, we compare our map to Galactic all-sky maps of 100 µm emission, N_H, column, and Hα intensity. We measure a consistent low level far-UV (FUV) intensity at zero points for other Galactic quantities, indicating a 300 photons cm⁻² s⁻¹ sr⁻¹ Å⁻¹ non-scattered isotropic component to the diffuse FUV. There is also a linear relationship between FUV and 100 µm emission below 100 µm values of 8 MJy sr⁻¹. We find a similar linear relationship between FUV and N_H below 10²¹ cm⁻². The relationship between FUV and Hα intensity has no such constant cutoff. For all Galactic quantities, the slope of the linear portion of the relationship decreases with Galactic latitude. A modified cosecant model, taking into account dust scattering asymmetry and albedo, is able to accurately fit the diffuse FUV at latitudes above 20°. The best fit model indicates an albedo, a, of 0.62 ± 0.04 and a scattering asymmetry function, g, of 0.78 ± 0.05. Deviations from the model fit may indicate regions of excess FUV emission from fluorescence or shock fronts, while low latitude regions with depressed FUV emission are likely the result of self-shielding dusty clouds.

Key words: ISM: general – scattering – ultraviolet: ISM

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1. INTRODUCTION

Dust scattering of starlight by UV bright stars in our own Milky Way is now known to explain the majority of the diffuse far-ultraviolet (FUV: ~1300–1800 Å) background. However, interest in the diffuse FUV background began not with a focus on Galactic dust but with a search for a cosmologically significant signal from the intergalactic medium (IGM) in order to quantify the total amount of mass and energy in the universe. Kurt & Sunyaev (1970) theorized that high energy photons emitted from dense hydrogen and helium in the IGM could be redshifted into the FUV and detected as a diffuse isotropic continuum background. A hot Galactic halo had also been proposed by Spitzer (1956) as a source of diffuse FUV line emission. It is now well understood that these components do exist, although with lower surface brightness than initially theorized.

Among the early observations of the diffuse background were measurements by Morgan et al. (1976), Paresce et al. (1980), Jakobsen et al. (1984), Fix et al. (1989), Hurwitz et al. (1991), Perault et al. (1991), and Murthy et al. (1999). While still incomplete in sky coverage, these observations hinted at a correlation between diffuse FUV intensity and Galactic neutral hydrogen column density. This pointed to a Galactic source for the FUV—specifically, scattering of UV star light by dust grains. The Galactic origin of the diffuse FUV was more clearly determined with observations showing the correlation between diffuse FUV intensity and the infrared background at 100 µm as measured by the Infrared Astronomical Satellite (IRAS; Jakobsen et al. 1987; Perault et al. 1991; Sasseen & Deharveng 1996). These results were further confirmed and expanded upon by recent missions with better sky coverage and angular resolution. Schiminovich et al. (2001) observed one quarter of the sky in FUV with the Narrow-band Ultraviolet Imaging Experiment for Wide-field Surveys (NUVIEWS) rocket, compared it to the N_H and 100 µm column, and found a linear relationship at high latitudes. Spectroscopic UV observations of parts of the diffuse sky have also been made by the Far-ultraviolet Imaging Spectrograph (FIMS/SPEAR; Edelstein et al. 2006) and the Far Ultraviolet Spectroscopic Explorer (FUSE; Moos et al. 2000). Seon et al. (2011a) used FIMS/SPEAR data and found correlations between FUV and 100 µm, N_H, and Hα. Murthy et al. (2010) used low resolution Galaxy Evolution Explorer (GALEX) all-sky data, with bright objects removed, and also found a strong correlation between FUV and 100 µm emission.

While the correlation between diffuse FUV and dust column is now broadly accepted, deviations from this correlation are significant (Seon et al. 2011a; Murthy et al. 2010; Schiminovich et al. 2001). Murthy & Sahnow (2004) found a weak correlation between FUV and 100 µm intensity using FUSE data, potentially due to differences in the local radiation field at low latitudes. On physical scales corresponding to molecular clouds, there can be significant deviations in the relationship between FUV and dust. Observations in Aquila with FIMS/SPEAR (Park et al. 2012) found that FUV intensity correlates well with the dust column for low extinction sight lines, while there is no correlation in regions with a higher dust column. Similarly, in the Draco Cloud, Sujatha et al. (2010) found substantial variations in the relationship between diffuse FUV and 100 µm intensity using GALEX data. The UV/IR ratio varied by a factor of 10 across the cloud. Such divergent behaviors indicate that dust column is not the sole predictor of diffuse FUV intensity. Seon (2013) and Seon et al. (2011a) explain large variations in the UV/IR ratio as a result of a turbulent interstellar medium (ISM) represented as a lognormal function where the standard deviation of a quantity increases with the mean value.

In the low density ISM, light from UV-bright stars (mostly near the plane of the Galaxy) is scattered off of dust grains,
resulting in a low level diffuse FUV brightness that is correlated with dust content. Above a certain threshold density, regions of the ISM may not reflect as much, as thicker clumps of dust attenuate FUV radiation. Witt et al. (2008) and Seon et al. (2011a) find that this shielding begins at 100 μm intensities of > 8 MJy sr⁻¹, but at a range of FUV values. Additionally, deviations from the FUV-dust correlation may indicate regions of especially high FUV radiation from nearby stars, a region of dust with unusual scattering properties, or even regions where molecular hydrogen is able to form and fluoresce.

Here we present a nearly all-sky survey (AIS) of the diffuse Galactic FUV background and compare the FUV intensity to 100 μm emission, N_H, observations, and He intensity maps. We employ a masking and mosaicking technique to remove FUV bright sources from AIS images and create a composite map of the GALEX diffuse FUV sky. This map provides unprecedented, wide, and deep coverage compared to results from previous missions.

We use this all-sky data to investigate the precise nature of the relationship between the FUV and tracers of cold Galactic dust and gas across the sky, focusing on how the relationship changes with both Galactic latitude and proximity to various Galactic plane associations. The minimum FUV in these relations is also examined to determine if it reveals a significant isotropic extragalactic component, an unmodeled Galactic component, or another source. The scatter in the relationships, both on large scales and within a single cloud, provide insight into the physical properties of the dust, including scattering asymmetry and albedo. A clear picture of the FUV behavior and what drives it can also allow for the modeling and removal of the Galactic UV foreground.

In Section 2, we describe the data products used and any further analysis. In Section 2.1, we describe the image mosaicking procedure and initial analysis of the GALEX data set in detail. In Section 3, we describe all-sky trends and spatial distributions. We discuss, in particular, the relationship between diffuse FUV, 100 μm emission (Section 3.4), and He intensity (Section 3.5). In Section 4, we discuss the implications of our results.

2. DATA

GALEX, a 0.5 m modified Ritchey-Chrétien telescope, operated for 10 yr after its launch in 2003 (Martin & GALEX Science Team 2003; Martin et al. 2005). GALEX observes in two UV channels—FUV (1344–1786 Å) and near-UV (NUV, 1771–2831 Å)—and has an angular resolution of 4.2'(FWHM) in the FUV and 5.3'(FWHM) in the NUV. In this paper, we use data from the AIS, covering more than 25,000 deg² on the sky, with a typical exposure time of 100 s and reaching a limiting magnitude (m_{AB}) of 19.9 (5σ AB; Morrissey et al. 2007). Each pointing center was chosen to minimize the gaps between adjacent fields. While GALEX avoided bright stars in the Galactic plane and other regions, there is good coverage at higher latitudes. We use images from the sixth GALEX data release (GR6), which contains a total of 34,551 individual AIS pointings. GR6 contains nearly all AIS FUV data taken during the GALEX mission.

Maps of the whole sky at 100 μm were taken from Schlegel et al. (1998). This map of the sky and the corresponding E(B−V) dust extinction maps were made by combining Cosmic Background Explorer/Diffuse Infrared Background Experiment data with IRAS Sky Survey Atlas maps in such a way as to accurately measure 100 μm emission (without a zero-point offset), which was then also used to derive a column density of dust. This technique is able to estimate the dust at all but the lowest Galactic latitudes and densest clouds to 10% precision. N_H data of the whole sky was taken from NASA’s Legacy Archive for Microwave Background Data (LAMBDA) data service. The all-sky neutral hydrogen column density information is an interpolation of two maps from Hartmann & Burton (1997) and Dickey & Lockman (1990). The Hartmann & Burton (1997) map is a velocity-integrated (−450 km s⁻¹ < V_{lsr} < +400 km s⁻¹) N_H brightness temperature map sampled every 0.5 and converted to N_H. The Dickey & Lockman (1990) map is a composite of several surveys averaged into 1° bins in Galactic coordinates with emission from −250 km s⁻¹ < V_{lsr} < +250 km s⁻¹. Hα data is taken from Finkbeiner (2003) and has a 6'(FWHM) resolution. It is a composite of the Virginia Tech Spectral-Line Survey in the northern hemisphere (Dennison et al. 1998) and the Southern H-Alpha Sky Survey Atlas in the southern hemisphere (Dennison et al. 1998). The Wisconsin H-Alpha Mapper (WHAM; Reynolds et al. 2002) provides a stable zero point at a 1° scale.

2.1. Image Mosaicking

In order to observe the diffuse background intensity, we create high resolution FUV images with known point and resolved sources removed. To create these mosaics, we use the GALEX data products described in Morrissey et al. (2007) along with the Montage software package (Berriman et al. 2003; Laity et al. 2005).

In our analysis, we use four main maps to generate FUV background images: cnt (counts per pixel), rrhr (relative response or effective exposure time per pixel), sky (estimated sky background), and mask (detected objects). The sky background file is created by the GALEX pipeline and is an estimate of the smoothed background after resolved and point sources are removed from each image (Morrissey et al. 2007). The mask file provides the locations of pixels that contain UV-detected objects, which are removed for background estimation. The flagged pixels in this pipeline mask file—also called a segmentation file by the Sextractor object-detection software used to perform photometry on GALEX images—only contains contiguous pixels from objects that are well detected above background and may not include the extended faint light (or optical ghosts, etc.) associated with an object.

Our mosaicking procedure involves several steps. First, we use the mask and cnt files to remove resolved sources from each file to be mosaicked. The mask file is smoothed using a boxcar of width 10 × 10 pixels to place an extra 15° border around the objects being masked. This is done to more effectively block light from bright stars and galaxies, which can extend beyond the unsmoothed masked area. Even with this extra border a fraction of the light from an object will remain unmasked. Encircled energy curves for the GALEX FUV point-spread function indicate that 5% of the light extends beyond our typical minimum masked radius of 20" (Morrissey et al. 2007). The object mask will be larger for bright objects, thereby reducing this fraction.

For display purposes, the flagged areas on the smoothed mask are then excised from the cnt files and replaced with the corresponding section of the sky file, which was generated by the pipeline as an estimation of the background in that region. Given the AIS source density, this background replacement has only a small impact on the overall noise in the images. The sky file is in units of counts per second, so we multiply the sky file by the corresponding regions of the rrhr file to maintain the...
The sensitivity of the points, due to the avoidance of the Galactic plane and other background from the masking. Regions covered by the mask have been replaced by the estimated sky. Each point was taken from a nested Hierarchical Equal Area centered on 12,288 equally spaced points covering the whole field with dimmer point sources. Bottom right: image of the same field after masking. Bottom left: close up image of an unmasked field with bright stars remain after masking. Figure 1 shows two different GALEX images before and after this procedure.

The next step was to create a set of GALEX FUV mosaics centered on 12,288 equally spaced points covering the whole sky. Each point was taken from a nested Hierarchical Equal Area isoLatitude Pixelization (HEALPix) ordering to evenly cover the sky (Górski et al. 2005) with Nside = 32. Each mosaicked image contains all GALEX AIS fields within a 3° radius from the center of the pointing, with some overlap between neighboring images. Using Montage, the rrhr and masked cnt files are reprojected so all images to be mosaicked lie in the same plane. The overall size of the cnt file is also trimmed to remove the edges. Reprojected files are then mosaicked into large rrhr and cnt files. The final step is to divide the mosaicked cnt file by the mosaicked rrhr file, creating a finished mosaic with units of counts per second.

\[ \text{cnt}_{\text{masked},i,j} = \text{mask}_{i,j} \ast \text{sky}_{i,j} \ast \text{rrhr}_{i,j} + (1 - \text{mask}_{i,j}) \ast \text{cnt}_{i,j}, \]

where mask_{i,j} = 1 for detected objects. The overall size of the cnt file is also trimmed to remove the edges. Reprojected files are then mosaicked into large rrhr and cnt files. The final step is to divide the mosaicked cnt file by the mosaicked rrhr file, creating a finished mosaic with units of counts per second.

\[ I_{\text{cnts/sec}} = \frac{\text{cnt}_{\text{masked},\text{mosaicked}}}{\text{rrhr}_{\text{mosaicked}}}. \]

The image units of cnts s\(^{-1}\) are then converted to photons cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\) Å\(^{-1}\), hereafter referred to as continuum units (CUs). The conversion from counts s\(^{-1}\) to flux is 1.40 \(\times\) 10\(^{-15}\) for FUV, with appropriate conversions from erg cm\(^{-2}\) to photons sr\(^{-1}\). The unit-converted mosaic is then compared to the all-sky maps described above.

\[ GALEX \text{ FUV data was not available for a fraction of these points, due to the avoidance of the Galactic plane and other bright objects. The sensitivity of the GALEX detector limited the maximum count rate for FUV AIS observations to 5000 counts s\(^{-1}\) (Morrissey et al. 2007). Of the 12,288 points, 10,019 had GALEX AIS fields within the 3° radius, using a total of 28,938 individual GALEX fields. Figure 2 shows the percentage of the sky covered by our maps for a given Galactic latitude. The lowest latitude regions (|b| < 25°) have coverage below 75%. There is a slight asymmetry between north and south hemispheres in this plot, due to the location of the Orion OB association below the Galactic plane.}

Our final step was to create an all-sky map, with each image described above sampled onto lower resolution pixels. A total of 12,582,912 pixels cover the whole sky in a nested HEALPix ordering (Górski et al. 2005) with each pixel covering 11.79 arcmin\(^2\) and Nside = 1024.

Assuming Poisson errors, with a signal-to-noise ratio (S/N) equal to the square root of the signal, we find a typical AIS image (with 100 s exposure) will yield an S/N of \(\sim 16\) per HEALPix pixel. Using regions of the sky with more than one GALEX AIS pointing, overlapping the edges of pointings, and averaging over larger areas will all yield greater S/N values. The all-sky map is shown in Figure 3. The map contains 65% of the sky, as compared to 25% from Schiminovich et al. (2001), 75% from Murthy et al. (2010), and 80% from Seon et al. (2011a).

3. THE DIFFUSE FUV SKY

Here we present the GALEX diffuse FUV all-sky map. Figure 3 shows the composite map in log scale. At high latitudes, FUV intensity is low, reaching a lower limit of a few hundred CU. At lower latitudes closer to the Galactic plane, the intensity increases to several thousand CU. The growing intensity toward the plane follows a rough cosecant trend with latitude, as discussed below. The highest intensities are found at the edges of known OB associations near dense molecular clouds: Ophiuchus (l = 355°, b = 18°), the Tau-Per-Aur Complex (l = 170°, b = −15°), and the Orion A and B complex (l = 200–220°, b = −17°; Dame et al. 2001).

Seon et al. (2011a) and Schiminovich et al. (2001) both note a “significant depression” in the FUV maps at latitudes above b > 20° between l = 20° and l = 60°. Overall, we find the intensity at mid to high latitudes here is mostly consistent with intensity at similar latitude regions in other parts of the sky. Regions of the sky with unusually high intensity (>5000 CU) can be linked to the OB associations mentioned above and
Figure 3. Log of diffuse FUV intensity (CU) across the sky. The lowest FUV intensity (a few hundred CU) is at the highest latitudes, while the highest FUV intensity (a few thousand CU) is found nearest to the Galactic plane. The highest intensity observed is at the edges of known OB associations, near dense molecular clouds. Overall intensity is best fit as a modified cosecant with latitude, as discussed in Section 3.1.

(A color version of this figure is available in the online journal.)

Figure 4. Log of diffuse FUV intensity (CU) across the sky, with locations of TD-1 bright stars overplotted. The diameter of the points is proportional to the log of the FUV flux. The coordinates are the same as Figure 3.

(A color version of this figure is available in the online journal.)

Figure 5. Left: plot of FUV vs. Galactic longitude. Blue dots indicate median FUV intensity in 5° bins. Median FUV intensity (800–1000 CU) is relatively constant across longitudes. Right: plot of FUV vs. Galactic latitude. Blue dots indicate median FUV intensity in 3° bins. The lowest latitudes have fewer points since GALEX has not observed the entire Galactic plane.

(A color version of this figure is available in the online journal.)

3.1. Galactic Trends

FUV intensity versus Galactic latitude and longitude are shown in Figure 5. The left panel shows diffuse FUV intensity versus Galactic longitude. Overall, we find this matches well with the diffuse FUV intensity from SPEAR/FIMS described in Seon et al. (2011a). The right panel shows FUV intensity versus Galactic latitude. FUV intensity increases with decreasing absolute value of the latitude and appears to be relatively symmetric between northern and southern Galactic hemispheres. The avoidance by GALEX of UV-bright regions will bias the latitude-averaged intensity at the lowest latitudes (|b| < 20), evident when compared to Seon et al. (2011a), which reaches values of 10,000 CU in the plane.

Certain Galactic quantities, including column densities and absorption, have been known to follow a cosecant shape with latitude, derived by Parenago (1940) to model Galactic reddening. This model has been expanded and refined, but the basic principle remains the same. Following Milne & Aller (1980) and Sturch (1966), Galactic extinction can be modeled as

\[
C = \int_{r=0}^{d} k_\alpha(z)dz = k_\alpha \csc |b| \times \int_{0}^{z} \xi(z)dz, \tag{3}
\]

where \(k_\alpha\) is reddening in the plane, \(z\) is height above the plane, and \(\xi(z)\) is a function that describes how reddening changes with \(z\). Using simple trigonometry, we replace a radial distance with \(z = \sin |b| \times r\). The resulting cosecant dependence is shown in the right-hand side of Equation (3). Several functions have been suggested for \(\xi(z)\), including exponential with a scale height (Milne & Aller 1980), although the exact form is not relevant here. If \(C\) traces the amount of obscuring dust and the scattered FUV is proportional to the dust column, then one can relate the two by a scale factor, \(k_{\text{scatter}}\).

\[
I_{\text{FUV}} = k_{\text{scatter}} \times C. \tag{4}
\]

With a latitude-dependent extinction model, we can reasonably expect a latitude-dependent FUV intensity. This model has been fit by Perault et al. (1991) and others.

The cosecant dependence of FUV is shown in the left panel of Figure 6 which plots FUV sin|b| versus sin|b|. Including all points, the median FUV sin|b| is 451 CU, slightly lower than the value from Seon et al. (2011a) of 525.4 CU. We ascribe this difference to unobserved high intensity regions, as discussed previously. While the unobserved regions are concentrated in the plane, high intensity areas at all latitudes are not included in
our data. Thus an overall lower median for our all-sky data is to be expected. The deviation from a constant value with \( \sin |b| \) at the lowest latitudes is probably due to the fact that the line of sight is no longer optically thin. At higher latitudes, the behavior is roughly flat—consistent with a cosecant form—with a slight decrease above \( \sin |b| = 0.8 \).

Fitting a function of the form of Equation (4) corresponds to a horizontal line on this plot. If we assume \( \text{FUV} = A/\sin |b| \), we find \( A = 495 \). This is the dashed line in the plot, compared to \( 412.3 \pm 10.3 \) (dotted line) from Seon et al. (2011a). This is not a good fit to our data at any latitude. Adding an additional constant term and fitting a function of the form \( I = A/\sin |b| + B \), with green fitting points above \( |b| = 25^\circ \) and red for all points. The cyan line is the two-parameter fit from Seon et al. (2011a). Right: two-dimensional histogram of the same data as the top plots, but with a 300 CU offset removed. The black dashed line is the median for all points, while the green line is a two-parameter fit for \( |b| > 25^\circ \).

(A color version of this figure is available in the online journal.)

Figure 6. Plot of FUV \( \sin |b| \) vs. \( \sin |b| \). Left: two-dimensional histogram of FUV \( \sin |b| \) as a function of Galactic latitude. The black dashed line is the single parameter fit to FUV \( \sin |b| \) at all points, 495 CU. The black dotted line is the single parameter fit from Seon et al. (2011a), 412 CU. The green and red lines are best fits for a function of the form \( I = A/\sin |b| + B \), with green fitting points above \( |b| = 25^\circ \) and red for all points. The cyan line is the two-parameter fit from Seon et al. (2011a). Right: two-dimensional histogram of the same data as the top plots, but with a 300 CU offset removed. The black dashed line is the median for all points, while the green line is a two-parameter fit for \( |b| > 25^\circ \).

3.2. Relationship with other Galactic Properties

The diffuse FUV intensity at high latitudes is determined by the distributions and intensities of both FUV emission from bright stars throughout the disk and the dust which scatters that emission. Here we investigate the relationship between FUV intensity and other Galactic quantities that trace dust and gas. In this section, all-sky maps of 100 \( \mu \)m emission, \( H_\alpha \) intensity, and \( N_{HI} \) column density are each compared to the diffuse FUV data. While there are overall correlations, we also explore how scattering may provide information about the distribution and properties of the dust and illuminating sources. We note here that the resolution of the \( N_{HI} \) column density map is significantly lower than the other maps used. We expect this will increase the scatter in our correlation between FUV and \( N_{HI} \) column, but will not change the overall result.

Two-dimensional histograms are plotted for FUV emission versus each Galactic quantity in log–log space in Figure 7. All three graphs show strong correlation between the FUV intensity and the other measured quantities (correlation values calculated using the linear Pearson method are shown). As found by Seon et al. (2011a), all three quantities are well correlated with FUV emission but include a large amount of scatter. The strongest correlation is between FUV emission and 100 \( \mu \)m intensity, with \( r = 0.80 \). The correlation between FUV emission and \( N_{HI} \) is also quite high, with \( r = 0.78 \). The weakest correlation is between FUV emission and \( H_\alpha \) intensity, with \( r = 0.73 \).

In all three plots of Figure 7, we find a low level minimum FUV. The FUV intensity has a minimum at around a few hundred CU, flattening below \( 2 \times 10^{20} \text{ cm}^{-2} \) for \( N_{HI} \), 1 MJy sr\(^{-1} \) for 100 \( \mu \)m, and 0.5 Rayleighs (R) for \( H_\alpha \). The plots of \( N_{HI} \) and 100 \( \mu \)m also have a significant flattening of FUV intensity at large values. The FUV median remains constant above \( 10 \times 10^{20} \text{ cm}^{-2} \) for \( N_{HI} \) and 8 MJy sr\(^{-1} \) for 100 \( \mu \)m. The plot of FUV versus \( H_\alpha \), however, continues to be linear at high values of both (also seen by Seon et al. 2011b). Some flattening at
large values of 100 μm and N_H. was also observed by Seon et al. (2011a) with SPEAR/FIMS data. The GALEX avoidance of bright regions of the sky could make this more pronounced in our data.

As noted above, any quantity which has a plane-parallel distribution with respect to the Galactic plane will vary with latitude roughly as the cosecant of latitude. By removing the cosecant dependence, we can verify that deviations from a plane-parallel distribution are also correlated between two different Galactic quantities. As such, we replotted Figure 7 with a factor of sin|b|, shown in Figure 8. The correlation coefficient is again calculated using the linear Pearson method and is weaker after the cosecant correction. The scatter in all plots is increased compared to Figure 7. The correlation between 100 μm emission and diffuse FUV remains the strongest and is discussed further in Section 3.4. The correlation between Hα and diffuse FUV is still the weakest of the three; we examine it in more detail in Section 3.5. Seon et al. (2011a) noted that 100 μm emission and N_H corresponded well to a plane-parallel model, whereas Hα and FUV emission did not. As a simple plane-parallel model only crudely represents the true three-dimensional distribution of any Galactic component (Witt & Petersohn 1994 and discussed above), it is not surprising that we find these weak correlations. A more detailed model is required to fully interpret this result.

A comparison of the quantities is shown in Figure 9 to highlight behavior at low intensities where the relationship is primarily linear. Seon et al. (2011a) calculated best-fit lines (in red) for b > 25°, whereas our lines include data from all latitudes. The fits are similar for all but 100 μm. Restricting our data to b > 25° yields a closer fit for FUV versus 100 μm. Table 1 shows slopes and intercepts for the calculated best-fit lines.

Because the correlation with dust (and other properties) is nearly linear at low intensities, it is conventional to use the fit to this relation to determine the value of the constant FUV offset,
which presumably includes components that are not associated with dust-scattered light. Most analyses have assumed that this component is nearly isotropic and we do the same here. FUV versus 100 μm emission shows a pronounced flattening at low 100 μm values (<1 MJy sr⁻¹, as seen in the log–log plot of Figure 7). Furthermore, there is an FUV offset in the plots in Figure 9 at zero values of the abscissa. This minimum appears to be 200–300 CU. This offset has also been noted as a positive offset at N_H = 0 cm⁻² of 200–300 CU by Martin et al. (1991), who suggested that it may be partially due to an undetected dust component.

In the top right panel of Figure 9, we note the break in the FUV intensity at 100 μm > 8 MJy sr⁻¹, with a median FUV intensity of 2400 CU. This saturation in the FUV intensity has been previously noted (Seon et al. 2011a; Witt et al. 2008); it appears to occur along lines of sight with an optical depth high enough to both self-shield emission from within the cloud and block scattered FUV light from behind the cloud, thus decreasing the overall FUV intensity from that region. At high 100 μm we also observe a large scatter in FUV intensity. Along some sight lines, the presence of nearby FUV-bright stars can enhance the overall FUV intensity above that predicted under the assumption of a uniform radiation field. A more detailed analysis of UV self-shielding and illumination of these sight lines is discussed in a forthcoming paper.

We find a similar break in the correlation of FUV versus N_H, at N_H ~ 12 × 10¹⁹ cm⁻². There is a break in the plot of FUV intensity versus Hα intensity at 4 R, as found by Seon et al. (2011a), although this is a more gradual transition than for the other two quantities. In all plots, there is increased scatter as the abscissa values increase. If the FUV intensity is lognormal, as described in Seon (2013), this is a natural property of lognormal distributions. However, the plot of FUV versus Galactic latitude shows this occurs primarily at the lowest latitudes. Cutting out intensity from points with |b| < 25° decreases this scatter and it’s likely the strong interstellar radiation field (ISRF) at low latitudes contributes significantly to the scatter.

### 3.3. Correlations versus Galactic Latitude

We have already noted above that it is difficult to compare our results to previous works because derived correlations will depend on the Galactic footprint of the data used and, in particular, the range in latitude. In order to understand the magnitude and physical origin of these effects, it is useful to divide our large data set into Galactic latitude cuts. In doing so, we note that regions of high scatter are generally confined to the lowest latitudes, while the FUV emission adheres to a linear fit at higher latitudes.

Figure 10 shows contour plots of FUV versus 100 μm for latitude bins of 15°, combining the northern and southern hemispheres. Above 8 MJy sr⁻¹ in latitude bins from 0°–15° and from 30°–45°, there is a flattening in the FUV profile with the median constant at around 2500 CU. This flattening is not as clear in the latitude cut from 15°–30°, but this is likely due to very high FUV emission around the Ophiuchus and Orion OB associations.

At high latitudes (|b| > 45°), few points have 100 μm values above 8 MJy sr⁻¹, leaving the low intensity linear relationship. The slope of the linear portion does appear to change with latitude, with the low latitude cuts having a larger slope than at higher latitudes. Line fits below 8 MJy sr⁻¹ are plotted in red, as described in Table 1.

Some of the scatter from the linear relation can be directly traced to specific objects or regions in the Galaxy. For example, in the latitude cut 45°–60° there is a region of low 100 μm emission, but very high FUV (>2500 CU), which stands out compared to the rest of the high latitude region. This appears to come primarily from the region directly around Spica (α Vir, at l = 316°, b = 51°; Park et al. 2012), which is a spectroscopic binary with two B-type stars. The FUV intensity here is high, while the dust emission is more consistent with the rest of the latitude. This area also appears in Figures 11 and 12 at similarly low values for the abscissa.

At very high latitudes, where there appears to be only a weak relationship between dust and FUV intensity, increased relative scatter may be masking any correlation. This is reflected in the Pearson r value for the fits, which is generally observed to decrease with latitude. For example, while the overall correlation between FUV and 100 μm is quite high (r = .80 for all points in log-log space, r = .64 after removing the cosecant dependence), at high latitudes the linear Pearson r value drops to 0.14 (for |b| > 75°, with or without the cosecant dependence). The FUV intensity in these regions is quite low and the scatter is large enough to give the appearance of high latitude FUV intensity that is only weakly sensitive to the 100 μm emission.

Figure 11 shows contour plots of FUV versus N_H column for |b| cuts of 15°. As with Figure 10, there is a flattening of the FUV emission at high values of N_H. This appears to occur at 12 × 10²⁰ cm⁻², which is consistent with the behavior found by Hurwitz et al. (1991) and, more recently, Seon et al. (2011a).
Figure 10. Two-dimensional histograms of FUV intensity vs. 100 μm emission for latitude cuts of 15°, N and S combined. Blue dots are the median for bins of 0.5 MJy sr$^{-1}$, with blue lines indicating one standard deviation. The red line is the best fit line to the median below 8 MJy sr$^{-1}$. At low latitudes, there is significant scatter in the relationship, due to both FUV bright stars and obscuring dust. There is a turnover in FUV intensity at $\sim 8$ MJy sr$^{-1}$, above which the median FUV value remains constant. The slope of the linear relationship decreases systematically with increasing latitude, becoming smaller at the highest latitude cut. (A color version of this figure is available in the online journal.)

Figure 11. Two-dimensional histogram of FUV intensity vs. $N_{HI}$ column. Blue and red lines as in Figure 10. There is a turnover in FUV intensity at $\sim 10^{21}$ cm$^{-2}$. (A color version of this figure is available in the online journal.)

3.4. FUV versus 100 μm

The relationship between diffuse FUV intensity and 100 μm emission is often expressed as a slope with units of CU MJy$^{-1}$ sr$^{-1}$. Previous work shows a wide range of slopes. Perault et al. (1991) measured 244 CU MJy$^{-1}$ sr$^{-1}$ in the northern hemisphere and 214 CU MJy$^{-1}$ sr$^{-1}$ in the southern hemisphere using data from the ELZ spectrophotometer on DB2-AURA. Hurwitz et al. (1991) found $\sim 294$ CU MJy$^{-1}$ sr$^{-1}$ using data from the Berkeley UVX spectrometer. Wright (1992) obtained 203 CU MJy$^{-1}$ sr$^{-1}$ using data from Fix et al. (1989). Haikala et al. (1995) used FAUST data to observe Galactic cirrus near the north Galactic pole, finding 128 CU MJy$^{-1}$ sr$^{-1}$. Sasseen & Deharveng (1996) found a range of slopes from $-49$ to 255 CU MJy$^{-1}$ sr$^{-1}$ in 13 regions using data from FAUST. Sujatha et al. (2010) found slopes between 50 and 480 CU MJy$^{-1}$ sr$^{-1}$ using data from GALEX in part of the Draco Nebula. Murthy et al. (2010) found an average slope of 302 CU MJy$^{-1}$ sr$^{-1}$ using smoothed GALEX data from the whole sky. Seon et al. (2011a) found a slope of 158 CU MJy$^{-1}$ sr$^{-1}$ from SPEAR data. In our all-sky GALEX data, we find an average slope of 280 CU MJy$^{-1}$ sr$^{-1}$.

Clearly, the behavior of FUV intensity and 100 μm emission can vary significantly from region to region and even within the same cloud complex. We show a contour plot of ratios (FUV/IR) for the whole sky in Figure 13. The isotropic
diffuse FUV offset of 300 CU is removed. There are two large regions with high ratios, one in the northern hemisphere above $b > 30^\circ$ ($l = 60^\circ$ and $180^\circ$) and one in the southern hemisphere below $b < -45^\circ$ ($l = 0^\circ$ and $240^\circ$). These features correspond to regions of particularly low IR emission, with a $100 \mu m$ intensity of less than 1 MJy sr$^{-1}$ and often lower than 0.5 MJy sr$^{-1}$. In their original dust map, Schlegel et al. (1998) note these extremely low emission windows as good regions for observations requiring minimum dust contamination.

Very low ratios ($<100$ CU MJy$^{-1}$ sr$^{-1}$) are found near the Galactic plane, reflecting the high dust content in these regions. There are some low latitude areas with high ratios from excess FUV intensity due to proximity of nearby OB associations, particularly Orion ($l = 200^\circ$), the Gum nebula ($l = 260^\circ$, $b = -2^\circ$), and Ophiuchus ($l = 355^\circ$, $b = 18^\circ$).

In Figure 14, showing the FUV/IR ratio versus Galactic latitude, the ratio is nearly constant. With the 300 CU offset removed, as in the bottom panels, the ratio begins to decline at latitudes above $|b| = 30^\circ$—the same behavior as the slopes in Figure 10. This is likely driven by decreasing FUV intensity at high latitudes, rather than increasing IR intensity. In both panels, there is significant scatter at all latitudes.

The origin of this scatter becomes more clear in Figure 15, which shows the ratio of FUV/IR versus Galactic longitude for different latitude cuts. The high ratio regions centered around $l = 90^\circ$ in the northern hemisphere and at $b < -45^\circ$, $350 < l < 250^\circ$ in the southern hemisphere, are the same regions that have
been noted previously. Otherwise, elevated ratios at low latitudes indicate higher than expected FUV intensity. In particular, the Orion OB complex, the Gum nebula, and regions in between have excess FUV intensity concentrated in the Galactic plane. There is little leakage of this to higher latitudes, as evidenced by the generally flat profile in the top two panels of Figure 15. High slopes in the southern hemisphere below this region could point to leakage of FUV photons, but that may also be the result of the low IR emission region discussed above. The region of high slopes near $b > 45^\circ$ at $l = 310^\circ$ is again due to excess FUV intensity from Spica.

### 3.5. FUV versus Hα

The relationship between diffuse FUV intensity and diffuse Hα intensity has not been as well studied as other Galactic quantities. The common assumption was that most Galactic Hα originated in ionized H II regions, with significant leakage of Lyman continuum photons responsible for any Hα intensity observed at high latitudes. This high latitude Hα intensity traces the diffuse warm ionized medium (WIM). Recent work by Witt et al. (2010), Seon et al. (2011b), and Dong & Draine (2011) have argued that a significant percent of Hα intensity observed outside of H II regions is scattered by dust and can be shown to correlate with the diffuse FUV intensity.

Scattering percentages for Hα in the WIM have been calculated to be as low as 5%–20% (Wood & Reynolds 1999), 20% (Dong & Draine 2011), and as high as 37% (Seon et al. 2011b) using varied techniques. Brandt & Draine (2012) have recently measured the visible spectrum of diffuse Galactic light (DGL) and found that scattering accounts for around 19% ± 4% of Hα intensity for $|b| > 60^\circ$.

As shown in Figures 8 and 7, there is a correlation between the diffuse FUV and Hα intensity, although it is not as tightly correlated as 100 μm and $N_{\rm HI}$, with $r = 0.73$ (log–log) overall and $r = 0.45$ after the latitude dependence is removed. Still, this indicates that there is some shared dependence between FUV and Hα, as discussed above. Our data set mainly encompasses the diffuse WIM due to the avoidance of the Galactic plane and bright regions.

Figure 16 shows an all-sky map of Hα/FUV in units of R/10^3 CU, following Seon et al. (2011b). An offset of 300 CU has been subtracted from the FUV data. There is clear structure, including especially high ratios around the Gum Nebula and Orion complex. These are all likely due to bright Hα regions, but in general the ratio is nearly constant. Unlike for FUV/100 μm (Figure 14), the plot of Hα/FUV versus Galactic latitude does not appear significantly changed by the removal
of the FUV offset. Potentially this is because the Hα intensity is the result of a wide range of processes, not just scattering, so the correlation is low to begin with (as noted in Figure 8). The range of ratios becomes larger at high latitudes; however, the median remains roughly constant below \( \sin |b| = 0.8 \) and rises slightly after.

Figure 18 shows the ratio of Hα/FUV as a function of Galactic longitude for different latitude cuts, with the 300 CU FUV offset removed. Like its counterpart for 100 \( \mu \)m emission shown in Figure 15, the ratio varies by an order of magnitude across the sky. At the highest latitude cuts, the standard deviation is 2 R/10³ CU, but the mean is relatively stable with longitude. At latitudes closer to the Galactic plane, the standard deviation decreases, but the variation in ratio can be more than a factor of two between different longitudes. Some of this variation is seen in multiple latitude cuts, with high Hα/FUV ratios appearing in the same longitude range. Of particular note is the peak at \( l = 200^\circ \), potentially associated with the Orion OB association, which appears at all latitude cuts. This peak is the result of high Hα intensity and recalls a similarly placed peak in Figure 15. In some cases, excess Hα intensity may be caused by significant Lyman continuum photon leakage into high latitudes. This may be related to the broad features of Hα excess found near the Gum nebula and Orion.

4. DISCUSSION

The dust content of the Galaxy provides a common origin for both the diffuse FUV and 100 \( \mu \)m emission. Cold dust emits at IR wavelengths and efficiently scatters FUV starlight. In general, these two quantities vary proportionately. Here we consider two different simplified models of the observed FUV intensity. The first assumes that it can be modeled as a linear function of 100 \( \mu \)m emission. A second refined model fits FUV as a function of Galactic latitude, albedo, and scattering asymmetry using a modified cosecant fit to overcome the deficiencies described in Section 3.1.

4.1. Linear Fit between FUV and 100 \( \mu \)m

Linearity between FUV intensity and 100 \( \mu \)m emission is found for points with 100 \( \mu \)m emission less than \( \sim 8 \) MJy sr\(^{-1}\). Line fits and other evidence discussed in Section 3.2 also indicate an FUV offset at the 100 \( \mu \)m zero-point. The slope and offset of the linear fit between FUV intensity and 100 \( \mu \)m emission are discussed in further detail.

4.1.1. FUV Offset

An FUV offset in the linear relationship with other tracers of the cold Galactic ISM has been observed previously and in our work appears to be \( \sim 300 \) CU. This offset is assumed to result from a local source of diffuse isotropic background, an extragalactic background, or an isotropic Galactic source not yet considered. As discussed above in Section 2, some contribution may also come from incomplete masking of known resolved objects.
As the FUV background shows low-level variability over the course of an orbital night, some contribution is likely to originate from O I (1356 Å, 1304 Å) airglow and/or geocoronal Lyα (1216 Å) lines, which have night-sky intensities of 1.0, 10, and 3000 R, respectively. O I 1356 Å falls within the FUV bandpass (at 35% peak efficiency) resulting in a count rate at the detector corresponding to ∼150 CU FUV continuum background. GALEX included a blue edge filter which is expected to attenuate the contribution from O I 1304 Å and Lyα below these levels. During orbital night, we observe a variation in the background intensity of ±50 CU. Observations of an identical target throughout the year show a similar 50 CU scatter, presumably due to seasonal variation in orbit geometry and airglow intensity. Murthy (2013) also calculated the expected contribution to the GALEX FUV channel from airglow as a function of both time from local midnight and angle between the Sun and the observed target. From this work, airglow was estimated to be 200 ± 100 CU at local midnight, comparable to our assessment, with a similar variation versus local midnight. As the low level of variation is not likely to impact our analysis, we have left more detailed modeling (and subtraction) of the variable airglow component to a subsequent paper. It is worth noting that Seon et al. (2011b) found a similar offset using FIMS/SPEAR data while excluding the O I airglow line. The contribution from Zodiacal light is sufficiently low for the FUV band that we do not attempt to remove it (Leinert et al. 1998). Inspection of FUV intensity versus ecliptic latitude shows no evidence for zodiacal contamination.

Another possible source of low level intensity is unresolved or incompletely masked FUV objects. There are at least three potential contributors here: unmasked scattered light or ghosts from bright stars, unresolved and/or undetected light from faint stars or extragalactic objects that have not been masked, and unmasked light from the other masked objects in the field. The GALEX pipeline mask, which is used to remove bright objects (see Section 2.1), could potentially have missed faint stars. Furthermore, unmasked reflections and ghosts around bright stars are visible in the data. These can contribute to the overall scatter, aside from any contribution to the offset. In general, GALEX avoided observing bright stars with \( m_{FUV} \sim 9.5 \), which have sufficient flux to produce a local count rate exceeding 5000 counts per second. If we conservatively assume that 1% of the light from the brightest observable star filled an 11 arcmin\(^2\) pixel, then we would anticipate a diffuse contribution of \(<6000 \text{ CU}\) at that location on the sky. The source density of stars just below the avoidance limit (e.g., with \(9.5 < m_{FUV} < 12\)) is low, much less than one per square degree over the AIS region, suggesting that fewer than 0.1% of all pixels may be contaminated by unmasked bright starlight. Additionally, our object detection software treats most bright stars as extended sources, creating a larger masked area than for fainter unresolved objects.

Extragalactic diffuse FUV intensity is believed to contribute only a few tens to 100 CU. Xu et al. (2005) calculated the contribution to the GALEX data from both resolved and unresolved galaxies to be \(1.03 \pm 0.15 \text{ nW m}^{-2} \text{ sr}^{-1}\), or about 51.5 ± 7.5 CU. Voyer et al. (2011) found that the integrated light from field galaxies contributes flux at the level of 65–82 CU to the extragalactic background. Seon et al. (2011a) also calculated that the cumulative effect of unmasked and unresolved FUV stars and galaxies is probably not significant. These same results suggest that unmasked light from the objects below the AIS detection limit will be negligible.

Additional components could come from other sources of FUV intensity, including molecular hydrogen fluorescence and line emission such as C iv. It seems unlikely that there is enough evenly distributed molecular hydrogen at these high latitudes to contribute significantly to the continuum offset. Ryu et al. (2006, 2008) report band-averaged \( I(H_2)/I_{\text{cont}} \) ratios of \(<0.15\) in molecular-rich star-forming regions; the ratios in diffuse gas are likely to be lower (e.g., Martin et al. 1990; Lee et al. 2006, 2008). Ryu et al. (2008) also suggest that the band-averaged contribution from C iv is even lower. As significant concentrations of molecular gas are present closer to the disk, \(H_2\) fluorescence may contribute to the large scatter for \(|\beta| < 25^\circ\).

A last concern is whether a possible systematic zero-point offset exists in the comparison data sets. We can investigate this possibility by comparing the relationship between different tracers of the Galactic ISM, provided that they are uncorrelated. More recent data sets, such as the Planck map of cold Galactic dust, could provide new measures of the lowest dust column densities. However, a preliminary inspection of the 2013 Planck data indicates the low dust regions are still present at the previously observed levels (Planck Collaboration et al. 2013). The offset calculated using these data did not change.

He provides a different view of the ISM which is indeed suggested in the correlations we observe. The presence of \(H\) regions will introduce additional scatter and the intercepts of the fits in these regions are typically a few hundred CU above the value used here. However, at high latitudes where star-forming regions are not present, the offset decreases to ∼400 CU, which is similar to the offset obtained using other Galactic quantities.

### 4.1.2. FUV–IR Slope

With the offset removed, the slope of the FUV versus 100 \(\mu\)m relation is variable across the sky, as seen in Figures 13 and 14. There are two regimes in the behavior of the FUV. In the optically thin regime, typically where 100 \(\mu\)m is less than 8 MJy sr\(^{-1}\), the FUV and 100 \(\mu\)m emission are correlated. In the optically thick regime, FUV saturates and the correlation disappears. In the discussion below, we only refer to the optically thin regime. At mid and high latitudes there are very few regions that deviate from a linear relationship due to an absence of optically thick dust.

A very simple model—assuming isotropic scattering, an average cosecant dust column relation and a constant scale height—predicts a uniform relation between 100 \(\mu\)m and FUV emission across the sky. Instead, the slope declines with increasing latitudes. This change in slope for optically thin clouds between mid and high latitudes indicates that a simple scattering picture may not be valid. The emission at 100 \(\mu\)m decreases at high latitudes, following the cosecant relation, with the simple model suggesting that the FUV intensity should decrease proportionally. Our results, as in Seon et al. (2011a), show that the FUV intensity is decreasing faster than expected, leading to a smaller typical value for the slope at high latitudes.

### 4.2. Modified Cosecant fit and Scattering Properties

The changing slope between FUV intensity and 100 \(\mu\)m emission at high latitudes is related to the deviations from a cosecant dependence (Figure 6). As discussed in Section 3.1, a function of the form \(I = A/\sin|\beta|\) for FUV intensity, with the offset removed, is not able to fully describe the observed intensity. Adding an extra term to the function, so that...
and $\pm$ optical depths of less than one, where Hurwitz et al. (1991). An overlay of the fit on the data is shown in the best fit model is similar to the 5800 CU scaling used by

Figure 19. Two-dimensional histograms of FUV intensity vs. Galactic latitude, with 300 CU offset removed. Left plot: FUV intensity vs. Galactic latitude, $|b|$. Right plot: FUV $\sin(b)$ vs. $\sin(b)$. Blue dots are the median for bins of 1°, above $|b| = 20°$, with blue lines indicating the standard deviation. The red line is the best fit of Equation (5) for FUV intensity. Values of $0.62 \pm 0.04$, $0.78 \pm 0.05$, and $6260 \pm 400$ are used, for $a$, $g$, and $S_o$, respectively.

(A color version of this figure is available in the online journal.)

$I = A/\sin|b| + D$, yields better fits for $|b| > 25°$ (see also Seon et al. 2011a). However, under the assumption that all isotropic components have been accounted for and removed, there is no physical basis for the inclusion of the constant $D$.

The simple cosecant fit does not include parameters for non-isotropic dust scattering; instead, it assumes that the dust scattering scale factor is constant with latitude. Jura (1979) proposed that the surface brightness of a cloud at various latitudes is a function of not only the ISRF but also the scattering function for the dust, assuming all illumination originates in the plane. With the inclusion of optical depth by Wright (1992), the dust scattered intensity, $S$, can be expressed as

$$S = S_o \tau a(1 - 1.1g\sqrt{\sin|b|}). \quad (5)$$

This approximation is valid for $|b| > 10°$, $g < 0.85$, and optical depths of less than one, where $S_o$ is the peak scattered ISRF. To calculate optical depth, we used $E(B-V)$ values from Schlegel et al. (1998) and a standard optical depth calculation:

$$\tau = \frac{R_v}{1.086} \times E(B-V). \quad (6)$$

We then use Equation (5) and fit for values of $a$, $g$, and $S_o$. We compare predicted intensity to FUV intensity (with 300 CU offset removed) and find that the best fit values are $0.62 \pm 0.04$ and $0.78 \pm 0.05$, for $a$ and $g$ respectively, with $S_o = 6260 \pm 400$ CU for $\sin|b| > 0.3$, or $|b| > 20°$. Here, a nonlinear least squares fit was applied to the median of FUV intensity in bins of $|b| = 1°$. There is some degeneracy between the choice of peak intensity, $S_o$, and albedo, $a$. The albedo value we predict is related in part to the selection of $S_o$. Larger values of $S_o$ allow for a smaller $a$. If we force $S_o = 5000$, the best fit model predicts an albedo of $0.75 \pm 0.04$, while $g$ remains unchanged. The value of $S_o$ in the best fit model is similar to the 5800 CU scaling used by Hurwitz et al. (1991). An overlay of the fit on the data is shown in Figure 19.

As with the cosecant fit, this modified fit is not valid at low latitudes. The best fit we find is similar to the two part cosecant fit described in Section 3.1 but is able to capture the effect of asymmetrical scattering more accurately.

The values we derive for $a$ and $g$ are slightly higher but within the limits of previous measurements. Draine (2003), in a review of previous work, reported a range of modeled values for DGL plus values predicted from dust models: $a$ varied between 0.2 and 0.6 in the FUV, while $g$ varied between 0.0 and 0.8. Albedo from the dust models of Weingartner & Draine (2001) was $a \approx 0.4$, with a predicted scattering asymmetry of $g \approx 0.7$. Witt & Petersohn (1994) found $a = 0.5$ and $g = 0.9$. Schiminovich et al. (2001) fit for values of $a = 0.45 \pm 0.05$ and $g = 0.77 \pm 0.1$. Murthy & Conn Henry (2011) found limits on $g$ between $0.58 \pm 0.12$, based on scattering angles around individual stars. Lee et al. (2008) found an albedo of $a = 0.36 \pm 0.20$ and $g = 0.52 \pm 0.22$. Reported values for $a$ and $g$ for individual regions or clouds have lower values than those of the DGL. For example, Lim et al. (2013) found $a = 0.42 \pm 0.05$ and $g = 0.47 \pm 0.12$, for the Taurus-Auriga-Pereus complex (see Draine (2003) for additional clouds and reflection nebulae.) The range of values for $a$ and $g$ in individual regions partly reflects the ambiguity of geometry in these clouds. Values for $g$, in particular, can vary if the dust is placed behind the illuminating stars or between the stars and the observer.

### 4.3. Deviations in FUV Intensity

After accounting for the FUV offset and the scattering asymmetry of Galactic dust grains, there remain two high latitude regions of the sky that are worth further consideration. These two regions, one in the northern hemisphere and one in the southern hemisphere, have high FUV/IR ratios ($\sim 600$ CU MJy$^{-1}$ sr$^{-1}$) compared to ratios found in areas at the same latitude ($\sim 200$ CU MJy$^{-1}$ sr$^{-1}$).

As shown in Figure 13, the regions above $b = 30°$ and between $60° < l < 120°$ in the northern hemisphere and below $b = -30°$ and between $240° < l < 300°$ in the southern hemisphere have somewhat elevated FUV intensity given the dust content, even with the offset removal. These regions do partially coincide with structures in the halo (high latitude Galactic clouds) and some Galactic satellites, including the Magellanic clouds and stream, but it is unlikely that excess FUV from these objects is being detected. Uniformly increasing the offset to require that these regions of the sky have zero FUV intensity (as the low levels of $N_{1}$ and $100 \mu m$ emission might require) ultimately causes other higher latitude regions of the sky to have negative FUV intensities. Thus, we do not think that the excess FUV intensity in these regions is a result of underestimating the offset.

Instead, we can consider two explanations for the excess FUV intensity. The first possibility is that these regions contain additional FUV intensity that is unrelated to the dust content. There are well known super bubble regions which contain FUV line emission from ionized gas and other sources. However, known super bubbles are not coincident with the regions of interest; instead, they are adjacent (Orion-Eridanus in the south and Ophiuchus in the north) and likely unrelated to the FUV emission found in these regions. The known line emission in super bubble regions is estimated at around 32700 LU (in the case of Orion-Eridanus; Jo et al. 2011; Kregenow et al. 2006), which translates to 87 CU in the GALEX FUV band. We cannot rule out the possibility that some additional line emission is contributing to the slight FUV excess in these regions, potentially excited by scattering or remnant shocks from the super bubble.

It might be more natural to consider a second possibility that infers a causal link between the low dust content and enhanced FUV intensity. One explanation for this may be that these regions are the remnants of old super bubbles. Such a remnant would have a low dust content as the super bubble cleared out the dusty ISM in the region, although a significant
population of older UV-bright stars might remain to illuminate
the surrounding area. This scenario is loosely suggested by the
distribution of OB and A stars from TD-1, as shown in
Figure 15 of Seon et al. (2011a), and the lower ratios of
Hα/FUV, which may indicate the presence of a softer local
radiation field with fewer ionizing photons. Furthermore, the
presence of holes or chimneys in these directions is also
suggested by observations of the three-dimensional distribution
of the Local Bubble (Lallement et al. 2003) and the link to
the EUV/soft-X-ray background. Nearby nebular regions in the
disk (e.g., the Gum Nebula) remain poorly understood and have
been shown to contain expanding gas and clouds (Woermann et al. 2001) that may also trace successive generations of star
formation. We note that while star formation rate (e.g., FUV
starlight) and molecular gas are globally correlated in external
galaxy disks, on smaller physical scales less than 1 kpc they
show considerable scatter (e.g., Schruba et al. 2010; Leroy et al.
2013).

5. SUMMARY

We have used GALEX FUV AIS data to construct an all-sky
map of diffuse Galactic FUV intensity covering 65% of the
sky. We have compared our map to other maps of the diffuse
FUV sky and to maps of complementary Galactic quantities. We
find the FUV intensity is highly dependent on a combination of
100 μm emission, Galactic latitude, and proximity to UV-bright
stars and OB associations.

Our main conclusions are as follows.

1. FUV intensity is highest near the Galactic plane and around
known OB associations and lowest at high latitudes.

2. There is a ~300 CU FUV isotropic offset which is likely
due to a combination of air glow (probably the domi-
nant contributor), a small extragalactic background compo-
nent including continuum light from unresolved galaxies,
and/or a Galactic component not traced by other indicators.

3. FUV intensity and 100 μm emission show a linear correla-
tion below 8 MJy sr⁻¹ of 100 μm.

4. FUV intensity and N_H1 show a linear correlation below
1.2 × 10²¹ cm⁻².

5. FUV intensity follows a modified cosecant shape as a func-
tion of Galactic latitude with low intensity at high
latitudes due to strongly forward-scattering dust grains.

6. We calculate a best fit value of \( a = 0.78 \pm 0.05 \) for the
scattering asymmetry, \( a = 0.62 \pm 0.04 \) for albedo, and a
peak scattering intensity of \( S_0 = 6260 \pm 400 \) CU for all
points with \(| \theta | > 20°\).

The direct linear variation of FUV intensity at low 100 μm
emission can be explained by scattered starlight off of low-
optical-depth dust. As 100 μm emission increases, the FUV
intensity increases until it reaches a plateau where the dust
begins to self shield. This plateau occurs at around 8 MJy sr⁻¹
and appears to be constant across the sky. The exact ratio of FUV
to 100 μm emission appears to depend on Galactic latitude,
with starlight more effectively scattered at lower latitudes. The scatter
in diffuse FUV intensity across a single latitude is primarily
caused by anisotropies in the ISRF, including the scale heights
of different stellar components and geometrical effects caused
by the exact structure of individual dust clouds. Variations in
the type of dust present, and the properties of that dust, are less
important but still a component of the scatter.

Of further interest are individual, small regions (less than 1°
across) where FUV intensity deviates from the expected linear
relationship with 100 μm intensity and modified cosecant model
with Galactic latitude. These regions are typically individual
dusty clouds or groups of clouds with high 100 μm emission.
While only 10% of our data covers points with 100 μm emission
above 8 MJy sr⁻¹, this still contains numerous regions with flat
or even inverse relationships between FUV and 100 μm. In a
future paper, we will discuss in detail individual clouds that
deviate from the models described above, some of which show
evidence for FUV obscuration or excess FUV intensity.

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