ULTRAVIOLET EXTINCTION AT HIGH GALACTIC LATITUDES II: THE ULTRAVIOLET EXTINCTION FUNCTION

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ABSTRACT

We present a dust-column–dependent extinction curve parameters for ultraviolet wavelengths at high Galactic latitudes. This extinction function diverges from previous work in that it takes into account the results of Peek & Schiminovich (2013; Paper I), which demonstrated that there is more reddening in the GALEX bands than would be otherwise expected for $E(B-V) < 0.2$. We also test the biases in the Planck and Schlegel et al. (1998; SFD) extinction maps, and find that the SFD extinction maps are significantly biased at $E(B-V) < 0.2$. We find that while an extinction function that takes into account a varying $R_{FUV}$ with $E(B-V)$ dramatically improves our estimation of $FUV - NUV$ colors, a fit that also includes H$\alpha$ column density dependence is superior. The ultraviolet extinction function we present here follows the model of Fitzpatrick (1999), varying only the amplitude of the $FUV$ rise parameter to be consistent with the data.

Subject headings: ISM: dust, extinction, Galaxy: local interstellar matter

1. INTRODUCTION

In this era of precision extragalactic observations, we must develop equally precise corrections for the effects of Galactic extinction. The Galactic interstellar medium (ISM) is full of small solid particles called dust, which scatter and absorb light across the electromagnetic spectrum, distorting our view of the cosmos (for a review of dust see Draine 2003). While the effects of this extinction and reddening are strongest in the Galactic plane, the high latitude sky is especially important to parameterize accurately, as we often examine large groups of extragalactic objects in these areas.

There are two pieces of data needed to correct for the effects of extinction at high latitude. The first is a map of the overall amplitude of extinction across the sky. Since its publication, this has largely been done using the maps of Schlegel et al. (1998; SFD). SFD uses far infrared (FIR) emission from dust grains supplied by IRAS, a temperature correction derived from DIRBE, along with an assumption of a single distribution of grain sizes and compositions to predict the overall dust extinction. Using similar methods, new data from the Planck satellite (Collaboration et al. 2013) has also been used to create an extinction map (Planck Collaboration, in prep). The newer Planck dust map seems to be more accurate in dusty regions at small scales, owing in part to the fact that the dust temperature correction used is higher resolution than the DIRBE maps employed in SFD (Schlafly in prep). The second piece of information needed is the reddening curve (or law); the functional dependence of extinction on wavelength, from the infrared to the ultraviolet. Many reddening laws have been devised, though for Milky Way dust the most often used are Cardelli et al. (1989; CCM), O’Donnell (1994; OD94), and Fitzpatrick (1999; F99). The essential assumption of this decomposition is that extinction at a given wavelength is linearly dependent upon the dust column density.

The advent of large-area surveys with precision photometry has both necessitated and provided higher precision in our extinction maps. Large photometric surveys, chiefly the Sloan Digital Sky Survey (York et al. 2000; SDSS), but also the Galaxy Evolution Explorer (GALEX) All-Sky Survey Martin et al. (2005; AIS) and the Wide-field Infrared Explorer (WISE) All-Sky Data Release (Wright et al. 2010), have allowed the construction of databases of “standard crayons” — objects whose intrinsic colors can be calibrated, such the foreground extinction can be probed. Peek & Graves (2010; PG10) used quiescent galaxies to probe spatial errors in the SFD maps, while Schlafly & Finkbeiner (2011; SF11) used spectroscopically observed stars to test reddening laws, and look for overall scaling errors in SFD. Jones et al. (2011; JWF11) used M-dwarfs to probe extinction in three dimensions, as well as examine variations in the reddening parameter $R_V$. While reddening laws have always been calibrated against stars at much lower latitudes ($A_V > 1$), these investigations have generally shown that at in the optical wavelengths these reddening laws are rather accurate even at low extinctions. Specifically, SF11 showed that at intermediate latitude the F99 reddening law is more consistent with the data than CCM or OD94 laws. While some variation in the ratio of extinction to reddening, $R_V \equiv A_V/E(B-V)$, has been seen (e.g. JWF11), the standard assumption of $R_V = 3.1$ has been shown to be a rather good assumption (e.g. in SF11).

In Peek & Schiminovich (2013; Paper I) we used galaxies selected from WISE and GALEX data to investigate extinction in the ultraviolet at high Galactic latitudes, and found large, significant discrepancy with the standard UV reddening laws at high Galactic latitude. Specifically, Paper I showed that extinction in the NUV band was somewhat higher than expected, and the extinction in the FUV was much higher than expected, and that neither of these could be accounted for with any standard extinction curve, using any value of $R_V$. This discrepancy was demonstrated for $E_{SFD} < 0.2$, or about 2/3 of the sky. Paper I also reported significant variations in $FUV - NUV$ color across the high latitude
sky in large regions. In this work we extend the analysis of Paper I to build an extinction-dependent reddening law, or “reddening function”, consistent with observations and as minimally modified from existing laws. To do this accurately we also compare the SFD extinction map to the \textit{Planck} extinction map, and investigate which is less biased at high latitudes, and thus which is a better calibration for an extinction curve. We use the standard nomenclature to describe the total dust column using its optical reddening, \( E(B-V) \), but it may simpler for the reader to interpret this value as the extinction measure \( E(B-V) = A_V/3.1 \). We refer to the estimation of each of these values by the two FIR maps as \( E_{\text{SFD}} \) and \( E_{\text{Planck}} \).

This paper is laid out as follows. In §2 we describe the data sets used in our analysis. In §3.1 we investigate the biases in SFD and \textit{Planck} extinction maps using the PG10 galaxy sample, and confirm our results in §3.2 with the \textit{GALEX-WISE} sample from Paper I. We confirm the variation of \( R_{\text{FUV}} \) seen in Paper I using \( E_{\text{Planck}} \) in §3.3, and determine its dependency on \( \text{H}_i \) column in §3.4. We parameterize the ultraviolet extinction function in §4. We discuss the implication of our results in §5 and conclude in §6.

2. DATA SETS

In this work we rely on two types of data sets. The first type consists of maps of foreground extinction, which predict the overall extinction in a given direction of sky. In particular we rely on the SFD map and \textit{Planck} map, each of which directly report measures of \( E(B-V) \) as inferred from emission in the FIR. We also rely on the \( \text{H}_i \) map from the Leiden-Argentina-Bonn (LAB) survey (Kalberla et al. 2005). This is a velocity resolved, strayradiation corrected map of the Galactic \( \text{H}_i \) sky in the 21-cm line of neutral hydrogen at 36° resolution. While it is much lower resolution than the FIR maps, it has been shown that combining \( \text{H}_i \) and FIR maps is often a better predictor of extinction at high Galactic latitude (Peek 2013; Peek13). We use this map to construct an \( \text{H}_i \) column density map of the sky, integrating along Galactic velocities.

The second type of data set consists of collections of distant galaxies that act as color standards, or standard crayons. The first of these is the PG10 galaxy sample, largely to-wards the northern Galactic cap, to what is predicted in each map. We use here the \( g-r \) colors of the galaxies, as it is the most precise color from PG10 in the estimation of \( E(B-V) \). PG10 showed there were significant discrepancies, up to 45 mmags, in patches of the northern Galactic cap area of the SFD map, though most regions showed deviations of order a few to 10 mmags. In this work, we are instead concerned with the bias of the errors in the reddening maps as a function of \( E(B-V) \); any such trends will manifest themselves as errors in \( R_X = A_X/E(B-V) \).

In Figure 1 we show the median color of the PG10 galaxies, after having corrected for each of the extinction maps, against overall \( E(B-V) \). We only examine the range \( E(B-V) < 0.1 \), as the PG10 area is quite incomplete toward higher extinction. Since we are examining the reddening in a relatively low signal-to-noise area of the maps, we must avoid significant covariance between the independent and dependent variables in our analysis – such covariance can induce spurious correlations. To do this we chart the residual colors of the PG10 galaxies after correcting with the SFD map against the \textit{Planck} map and vice-versa.

We find that the SFD-corrected galaxies have a distinct color trend over the range \( 0.2 < E(B-V) < 0.1 \) that is absent in the \textit{Planck}-corrected galaxies. This under-prediction of \( E(B-V) \) is consistent with a variation in \( E_{\text{SFD}} \) needed to induce the variation in \( R_{\text{NUV}} \) seen in Paper I (dotted line in Figure 1). We note that SF11 found the opposite trend: SFD \textit{overpredicts} extinction by \( 15\% \), but this result largely applies to \( E(B-V) > 0.2 \), and thus is not in contradiction to our finding. Indeed, the standardized spectroscopic stars of SF11 show a similar trend over the range \( 0.2 < E(B-V) < 0.2 \) as we found above. We find consistent results when charting \( E_{\text{Planck}} \) and \( E_{\text{Planck}} \) against \( \text{H}_i \) column density. This result is consistent with the recent work by Liszt (2013), who and equation 3, which describes the variation in color of the sample as dim galaxies are extinguished out of it.

3. ANALYSIS

3.1. Bias in SFD and \textit{Planck} maps at high Galactic latitudes

It is not the aim of this work to provide a final and broad judgement on the relative value of the SFD and \textit{Planck} extinction maps. Not only does such a review go beyond the scope of this work, but it is not at all clear that a single map would be preferable in all contexts. Furthermore, with large new data sets from \textit{Planck}, \textit{WISE} and AKARI (Murakami et al. 2007) in the infrared, as well as GASS (McClure-Griffiths et al. 2009) and EBHIS (Winkel et al. 2010) in neutral hydrogen, a new, higher resolution map incorporating all these data will likely soon supersede either map we discuss in this work. In this analysis we limit ourselves to a discussion of the bias in each data set at high latitudes, roughly bounded by \( E(B-V) < 0.2 \), where Paper I found significant discrepancy in UV extinction, inconsistent with the literature values. Any bias in this area of sky will modify the overall scaling of any reddening curve we construct, and thus is a critical to investigate and constrain.

To do this analysis, we compare the median color observed in the PG10 standard crayon objects, largely towards the northern Galactic cap, to what is predicted in each map. We use here the \( g-r \) colors of the galaxies, as it is the most precise color from PG10 in the estimation of \( E(B-V) \). PG10 showed there were significant discrepancies, up to 45 mmags, in patches of the northern Galactic cap area of the SFD map, though most regions showed deviations of order a few to 10 mmags. In this work, we are instead concerned with the bias of the errors in the reddening maps as a function of \( E(B-V) \); any such trends will manifest themselves as errors in \( R_X = A_X/E(B-V) \).
showed that the observed value of $N(H\text{I})/E(B-V)$ for $E(B-V) < 0.1$ is in significant excess of the standard canonical value when using $E_{\text{SFD}}$. The excess found in that work is consistent with the bias in $E_{\text{SFD}}$ we find here.

3.2. NUV extinction with Planck

We note that the SDSS DR7 spectroscopic footprint covers very little sky $E(B-V) > 0.1$, while the data used to generate the UV extinctions measured in Paper I extend over the entire AIS, a much larger area of sky that includes the Galactic southern hemisphere, and most of the sky where $E(B-V) < 0.2$. As a further check we replicate the Paper I analysis of the NUV extinction, using the Planck map. Simply put, we take a comparison sample of galaxies at where $0.02 < E(B-V) < 0.03$ and measure their number density. We then artificially extinct the galaxies, removing galaxies too dim to meet the $NUV < 20$ selection criterion, and match the number density of galaxies observed as a function of $E(B-V)$. We then fit the resulting $R_{\text{NUV}}$ with a second-order polynomial, and find confidence intervals. The details of this method can be found in Paper I, §4.1: the results are shown in Figure 2. This seems to confirm the result found in the optical: the bulk of the trend detected in the variation in $R_{\text{NUV}}$ is an effect of biases in $E_{\text{SFD}}$, rather than a change in grain properties at high Galactic latitude. We marginally detect a much weaker trend in $R_{\text{NUV}}$, although this trend could easily be generated by small biases in the Planck map for $0.1 < E(B-V) < 0.2$. Since these results are largely consistent with the predictions from the O'D94, CCM and F99 reddening laws, we make the conservative assumption that the reddening laws are accurate in these regions of low extinction in NUV.

3.3. FUV-NUV reddening with Planck

We also reexamine the detection of variation in $R_{\text{FUV}} - R_{\text{NUV}}$ with $E(B-V)$ found in Paper I. The details of the method are discussed in Paper I §4.1, but in essence we find the median color of the GALEX-WISE galaxies binned by $E(B-V)$, and fit the resulting data with a second-order polynomial. One important subtlety is that we must compensate for color variation in the underlying population as we go to higher extinction regions and dim objects leave the sample, an effect we
Fig. 3.— The change in the median FUV − NUV color of background galaxies with E(B − V), for both Planck (black) and SFD (red) extinction maps. The top panel shows the median color of GALEX-WISE galaxies in bins of 0.002 in E(B − V), with error bars. The bottom panel shows the fit value of (R_{FUV} − R_{NUV}) E(B − V) for each extinction map. Also shown is the expected trends from CCM and F99 reddening curves, very clearly inconsistent with the UV reddening trends seen against either extinction map.

called population reddening in Paper I. When we repeat this method using the Planck map as our extinction estimator we find very similar results to Paper I (Figure 3). Indeed, the results are essentially identical, except for the subtle rescaling of the E(B − V) axis. Since the standard expectation from extinction studies previous to Paper I is that R_{FUV} − R_{NUV} ≍ 0, no value of E(B − V) should produce any variation in the galaxy color. Thus, any rescaling of E(B − V) cannot induce the observed color shift. Fitting for the population reddening-corrected color of the galaxies is equivalent to fitting for R_{FUV} − R_{NUV} (see equation 5 in Paper I), and we find a best fit value of

\[
R_{FUV} − R_{NUV} = (1.72 ± 0.07) + (−4.75 ± 0.48) E_{Planck}. \tag{1}
\]

3.4. The dependence of FUV-NUV reddening on HI

HI has long been known to be a good proxy for dust extinction at high latitude, as originally codified by Burstein & Heiles (1978). It was demonstrated more recently in Peek13 that at high Galactic latitudes a combination of FIR and HI extinction prescriptions are significantly superior to either alone. In light of this fact we explore how HI can help predict FUV extinction. Our median binning of UV color against E_{Planck} used in §3.3 is not a sufficient method to explore the dependence on two parameters simultaneously, as N_HI and E_{Planck} are not allowed to vary independently. Instead, we separate the GALEX AIS sky into 16 deg² regions in a zenith equal area projection, as described in Paper I. In each region we sample the median E_{Planck}, HI column at the galaxy positions, and the median FUV − NUV color, which we call E_{Planck}, N_HI, and C_{FUV−NUV}, respectively. We determine the error in the median UV color using a bootstrap analysis, to properly take into account the effects of FUV non-detections. We then fit C_{FUV−NUV} (corrected for population reddening), with a first-order polynomial in N_HI and E_{Planck}, for a total of 4 parameters, accounting for the N_{HI} × E_{Planck} cross term. As in §3.3 the overall, unextinguished color of the galaxies is a nuisance parameter, leaving us with a 3 parameter fit for R_{FUV} − R_{NUV}:

\[
R_{FUV} − R_{NUV} = \begin{align*}
−1.01 ± 0.003 & + (2.69 ± 0.12) \frac{N_{HI}}{6.2 \times 10^{21} \text{cm}^{-2}} E_{Planck}^{−1} + \\
−4.03 ± 0.87 & \frac{N_{HI}}{6.2 \times 10^{21} \text{cm}^{-2}}.
\end{align*} \tag{2}
\]

We have normalized the HI column here by the typical ratio of N_{HI}/E(B − V) = 6.2 × 10^{21} cm^{-2} we find for E_{Planck} < 0.1, thus this equation is very similar to Equation 1 for typical values of N_{HI}/E_{Planck}. We can assess the effectiveness of this fit, and the importance of a dependency on HI, by measuring a χ² per degree of freedom (dog). Just using the mean R_{FUV} − R_{NUV} for the whole E_{Planck} < 0.2 sky, with no dependence on N_{HI} or E(B − V), yields χ²/dof = 16.6: clearly a bad fit to the data. To compare an E_{Planck}-only fit to Equation 2 on even footing, we fit C_{FUV−NUV} with a third-order polynomial in E_{Planck}, which yields χ²/dof = 5.38. The fit in Equation 2 yields χ²/dof = 4.55. Thus, while none of these fits fully encompass the variation of R_{FUV} − R_{NUV} across the high-latitude sky, a method making use of both the HI and FIR maps does the best job.

4. RESULTS: THE UV EXTINCTION FUNCTION

We have shown in §3 that while the NUV extinction at high Galactic latitudes is largely consistent with the literature when using the Planck reddening map, there remains a strong and significant variation in R_{FUV} − R_{NUV}, very similar to that shown in Paper I, albeit reduced in amplitude by ~20%. To capture this variation in a reddening law, we must have a reddening curve that varies with E(B − V). This is equivalent to saying that at low values of E(B − V), FUV extinction has a non-linear dependence on E(B − V), and thus is not simply described by a single curve. To highlight this distinction we call our parameterization of extinction in the UV an “extinction function”, rather than an extinction curve. We note here that we have not shown E_{Planck} to be bias-free in the regime 0.1 < E_{Planck} < 0.2, such that some of the non-linear dependence on reddening could be due to further biases in E_{Planck}. This being said, the steep
trends in color we see at lower extinction are clearly real and cannot be due to biases in \( E_{\text{Planck}} \).

We construct an ultraviolet extinction function that is minimally modified from existing curves, but that is consistent with the observed variation we see in \( R_{\text{FUV}} \). We base our approach here on the extinction parameterization developed in Fitzpatrick & Massa (1988), and discussed further in Fitzpatrick & Massa (1990) and F99. There are two advantages of this particular parameterization of the extinction. First, it is the basis of the F99 extinction curve shown by SF11 to be a better fit in the optical to the high latitude sky than the CCM / OD94 reddening parameterization. Second, it is separated into six variables, such that we can leave the extinction curve as untouched as possible at wavelengths where the observed extinction is consistent with the curve and modify it only in the FUV region. In this formulation the UV extinction curve is written as

\[
k(\lambda - V) = \frac{E(\lambda - V)}{E(B - V)}.
\]

Using the standard notation of \( x \equiv \lambda^{-1} \), the complete parameterization is written as

\[
k(x - V) = c_1 + c_2 x + c_3 D(x; \gamma, x_0) + c_4 F(x)
\]

where \( D \) is the Drude profile

\[
D(x; \gamma, x_0) = \frac{x^2}{(x^2 - x_0^2)^2 + x^2 \gamma^2}
\]

and \( F \) is the far-UV rise term

\[
F(x) = \begin{cases} 
0.5392 (x - 5.9)^2 + 0.05644 (x - 5.9)^3, & \text{for } x \geq 5.9 \mu m^{-1} \\
0, & \text{for } x < 5.9 \mu m^{-1}.
\end{cases}
\]

Thus, the UV extinction curve is parameterized by the six coefficients \( c_1, c_2, c_3, c_4, x_0, \) and \( \gamma \). F99 gives specific values for these coefficients; \( c_1 \) and \( c_2 \) as functions of the observed \( R_V \), and the other four fixed, for typical sight lines. We base our extinction curve on these values with the assumption of \( R_V = 3.1 \). Since we do not have evidence for the modification of the NUV extinction, we leave \( c_3, x_0, \) and \( \gamma \) fixed, as they apply only to the amplitude, position, and width of the 2175 Å bump, which occurs only in the NUV GALEX channel (see Figure 4). \( c_1 \) and \( c_2 \) modify the extinction in both the NUV and FUV channels, and there does indeed exist a family of values of these parameters that leave NUV extinction fixed while modifying FUV extinction. While we cannot rule this modification out, we find it unlikely that \( c_1 \) and \( c_2 \) would dramatically depart from their observed relationship with \( R_V \) at high latitudes and also conspire to leave NUV extinction fixed. This then leaves us with the single variable parameter \( c_4 \), the amplitude of the far-UV rise term \( F(x) \).

To accurately determine the dependence of \( c_4 \) on \( E(B - V) \) at high latitude, we use the sample of 4000 UV spectral energy distributions from Paper I that are consistent with the selection criteria of the GALEX-WISE galaxy sample. We then weight the GALEX NUV and WISE extinction data.

**DISCUSSION**

The first result from this work in §3.1 and corroborated in §3.2 is that \( R_{\text{NUV}} \) does not significantly depart from the expected value, when measured against \( E_{\text{Planck}} \). The parameterization of \( R_{\text{NUV}} \) discussed in Paper I still holds against \( E_{\text{Planck}} \), but we no longer expect \( E_{\text{SFD}} \) to be an unbiased measure of extinction at \( E_{\text{SFD}} < 0.2 \). Conveniently, none of the qualitative conclusions of Paper I depend on a physical interpretation of a varying \( R_{\text{NUV}} \). It is worth pointing out that we since we see only an overall increase in \( R_{\text{FUV}} \) at high latitude, it is likely that whatever grain type causes this effect only contributes to extinction in the FUV. This is consistent with the general sense that \( c_4 \) is only weakly correlated with the other extinction coefficients at lower
latitude (e.g. Fitzpatrick & Massa 1988), and that the FUV-rise stems from a resonance line similar to the 2175 A bump (Johlin et al. 1992, Li & Draine 2001).

We note that the extinction functions derived in §4 are, at least naively, not consistent with the literature. As an example, Valencic et al. (2004) provides extinction curves toward 417 stars, and parameterizes them with the F99 method (Equation 4). While these stars all have \( E(B-V) \geq 0.2 \), and are thus not in the parameter range over which we fit our extinction functions, 84 stars have \( E(B-V) < 0.3 \) and these stars do not show any clear trend toward higher \( c_4 \) values consistent with §4. Rather than posit some very sharp turnover at \( E(B-V) = 0.2 \) (which is not supported by the few GALEX-WISE objects we have toward higher extinctions), we suggest that this discrepancy is due to the fact that the Galactic stars are measured at low latitudes, and thus the bulk of the obscuration may stem from denser gas. It is, after all, not the overall column density of the gas that is important, but rather the physical state of the gas, likely largely determined by its volume density and history (e.g. Wakker & Mathis 2000, Fitzpatrick 1996). Thus, we recommend against using the extinction functions provided in §4 for Galactic objects unless they are expected to be well into the halo, and rather refer the reader to the standard F99 UV extinction curves. It is unclear whether these equations can be extrapolated to extragalactic objects toward \( E(B-V) > 0.2 \); we do not have enough data at higher extinctions to constrain these functions in this regime. There is certainly no evidence that one should extrapolate these functions to values where \( c_4 < 0.41 \), the standard F99 value, which occurs for \( E(B-V) > 0.36 \) in Equation 1. We also note that while the standard far-UV rise term, \( F(x) \), is the most reasonable parameterization of the variation in FUV extinction we measure, we have not reported direct evidence for extinction beyond the GALEX FUV band, which drops off abruptly shortward of 1350Å.

Equation 2 may lend some insight into how grains evolve in the diffuse ISM. As H\textsubscript{i} becomes molecular, or so dense and cold that it becomes optically thick, the ratio of H\textsubscript{i} to FIR tends to decrease, typically for \( E_{\text{Planck}} > 0.1 \) (Reach et al. 1994, Douglas & Taylor 2007). The large, positive coefficient to the \( N_{HI}/E_{\text{Planck}} \) term indicates that there is more relative extinction in the FUV in regimes where H\textsubscript{i} is not at higher densities. This is qualitatively consistent with the interpretation that the grains responsible for the Far-UV rise are plentiful in low density environments, and in higher density environments they tend to be destroyed or agglomerate onto larger grains.

6. CONCLUSIONS

We present in this work a new ultraviolet extinction function at high Galactic latitude. To summarize our findings:

1. While the dependence on \( R_{NUV} \) on \( E_{SFD} \) found in Paper I holds, we find that \( E_{SFD} \) is a biased measure of \( E(B-V) \) for \( E(B-V) < 0.1 \), while \( E_{\text{Planck}} \) is relatively bias-free in this regime.

2. \( R_{NUV} \) derived against \( E_{\text{Planck}} \) is indeed largely consistent with the canonical results from the literature.

3. \( R_{FUV} - R_{NUV} \) when measured against \( E_{\text{Planck}} \) is still found to be in gross inconsistency with the the literature values, and is qualitatively consistent with what was found in Paper I.

4. A non-linear fit in \( E_{\text{Planck}} \) to \( R_{FUV} - R_{NUV} \) can reproduce much of the variation seen in the data (Equation 1), though a similar fit incorporating a dependence on \( N_{HI} \) is superior (Equation 2).

5. A standard F99 extinction curve can reproduce the variation we see in \( R_{FUV} - R_{NUV} \) if the \( c_4 \) parameter is allowed to vary with \( E_{\text{Planck}} \) (Equation 7), or with both \( E_{\text{Planck}} \) and \( N_{HI} \) (Equation 8).

To fully understand the variation and origin of the FUV-rise at high Galactic latitude spectroscopic observations of halo stars are needed. Without this spectroscopic information we do not know whether the UV color variation shown in Paper I and this work can truly be encompassed by strong variation in the \( c_4 \) parameter or are wholly different in character.

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