Is there ERE in diffuse galactic light at high latitude?

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Abstract. Up until recently most optical observations of nebulae were explained by scattering of starlight. Since the 1970s, authors have believed optical observations of interstellar matter couldn’t be accounted for by extinction effects only. To join observations and models they required an additional broad band emission in the $R$ and $I$ band range. This emission, called ERE (extended red emission), is attributed to luminescence of some molecule of the interstellar medium which hasn’t been identified yet.

In 1998 Gordon, Witt and Friedmann wrote of detection of ERE in diffuse galactic light at high latitudes. The comparison of diffuse galactic light and starlight over a few regions of the sky cannot, according to the authors, be fully explained by extinction of starlight.

Different aspects of Gordon et al.’s data reduction work, and of the model which supports their assertion, will be considered here. IRAS images show that the scattering medium in which diffuse galactic light originates is misrepresented when using their model. The quantity of matter on the stars’ line of sight, used to calculate the $R$ magnitude of the stars, is in many cases underestimated, leading to a color of starlight bluer than the exact one. Finally, the search for ERE could have been simplified by the comparison of starlight and Pioneer colors, which are equal within the error bars.

Analysis of the 100 $\mu$m emission of the regions Gordon et al. have studied will prove that the color of the diffuse galactic light is explained by scattering of the background starlight by dust embedded in nearby cirrus.

ERE may not be present in diffuse galactic light, and, more generally, in interstellar space.

Key words: ISRF, ERE, DGL
1. Introduction

To study the optical properties of interstellar grains two types of approaches are usually followed. The first is to compare the strength of a nebula surface brightness to the value of the source radiation field at the cloud position. More frequently the color of the cloud is compared to that of the illuminating source.

Both methods have led some authors (Lynds 1962, Guhathakurta & Cutri 1994, Gordon, Witt and Friedmann 1998 and references therein) to conclude that not all interstellar cloud emission can be accounted for solely by the scattering of starlight. According to these authors, comparison of nebula and source emissions cannot explain the strength of the emission in the $R$ and $I$ bands, and the red color emission of some, if not most, interstellar clouds. Hence, the clouds must be emitting themselves, which implies the presence of a particular class of dust grain, assumed to absorb UV ambient radiation and to re-emit in the red. The phenomenon is called ERE (Extended Red Emission). Unfortunately, all the attempts to identify ERE carriers have failed.

The directions where ERE is found, which for many years consisted of only one direction (the Red Rectangle), now cover nearly the entire sky. The phenomenon is thought to be so important that up to 50% of interstellar red emission is attributed to ERE (Gordon, Witt and Friedmann 1998, hereafter GWF). ERE appears in a wide range of different environments and astrophysical objects, including cirrus, nebulae, planetary nebulae, HII regions, novae, and other galaxies. Complete references can be found in the introduction of GWF.

Diffuse galactic light (DGL) was identified at the beginning of the century (Struve & Elvey 1936) as diffuse interstellar radiation which remains after the subtraction of direct starlight and the light of solar and terrestrial origins. It was attributed to starlight scattered by interstellar grains. Toller (1981) has found that the visible surface brightness of the DGL in high latitude directions and the HI column density are roughly proportional.

The GWF paper is devoted to detecting ERE in DGL and is divided into two parts.

The first part of the GWF paper describes the method the authors have followed to estimate the $B$ and $R$ surface brightnesses of direct starlight in different directions of the galaxy. In two high galactic latitude regions, region (a) and region (b), the result is substracted from the $B$ and $R$ Pioneer satellite measurements to yield an estimate of the DGL.

The second part of the GWF paper (§ 4 on), in which the authors attempt to demonstrate the existence of ERE in the diffuse interstellar medium, is constructed on the following idea: if we have a reliable model of the starlight scattered from the diffuse interstellar medium, and if the observed DGL is in excess of this estimate, the difference must arise from a non-scattering emission process.
To estimate the scattered part of DGL, GWF use the Witt-Petersen model (‘WP’ model hereafter) of the galaxy. From HI data, the model sets up a vast three dimensional representation of the galaxy which GWF use to calculate the amount of scattered-DGL received from any direction.

The large grains responsible for the scattered optical DGL also have a thermal 100 $\mu$m emission. Following Toller’s search for an HI counterpart to the DGL, IRAS images are a powerful tool to visualize the medium in which the DGL originates. For the regions of the sky in which GWF have separated DGL from starlight, IRAS images can be used to check the pertinence and accuracy of the WP model. In both regions, the medium has a complicated structure. It is impossible for the WP model, or any other model, to approach the three dimensional structure of these mediums with the necessary precision solely from an estimate of the HI column density. It is surprising that the large differences between the results of the model and the observations are attributed either to variations of the properties of interstellar grains with longitude when the $B$ band is concerned, or to ERE for the $R$ band.

Is it even possible, or furthermore necessary, to model the part of the DGL which comes from the scattering of starlight? Since the interstellar grains are forward scattering light (Henyey & Greenstein 1941), DGL in one direction must arise from the scattering of the light of stars in close proximity to this direction. Evaluation of the scattered part of the DGL can be restricted to a local estimate of the radiative transfer of the background direct starlight through the interstellar medium. The radiative transfer does not need to be calculated for the entire galaxy. Existence of ERE could have been probed through a direct and local comparison of DGL and direct starlight. Such a comparison (section 5) is more reliable since it will use GWF data only.

IRAS images help to understand the variation of the DGL and the starlight surface brightnesses in fields (a) and (b), in relation to the interstellar medium structure. There are clear correlations between IRAS 100 $\mu$m images and the variations of DGL and direct starlight in the two regions where it was isolated by GWF. These correlations will be discussed in section 6.

The data presented in the GWF paper are reviewed in section 2. The difficulties which arise when considering the GWF method and the WP model are detailed in section 3 and section 4. An alternative explanation of the GWF data, supported by the IRAS images of fields (a) and (b), is proposed from section 5 to section 6.

To conclude, all of GWF data will be explained by scattering of background starlight by the nearby interstellar cirrus. The relative colors of Pioneer observations, the direct starlight and the DGL can be explained with the absence of ERE.
Fig. 1. GWF figure 12. Caption: ‘Red and blue intensities for the Pioneer measurements and integrated star/galaxy light (ISGL) are plotted as functions of Galactic latitude for cuts in Galactic longitude between 0° and 5° (a) and 95° and 100° (b). Each point corresponds to a 5°×5° region. The Pioneer error bars were computed using the algorithm described in §2.1. The ISGL error bars were assumed to be a conservative 5% (see §3.2).’

Fig. 2. GWF figure 13. Caption: ‘Red and blue intensities for the light from the diffuse ISM are plotted for cuts in Galactic longitude between 0° and 5° (a) and 95° and 100° (b). The diffuse ISM intensities were computed by subtracting the ISGL from the Pioneer measurements.’

Fig. 3. GWF figure 14. Caption: ‘Red/blue ratio for the Pioneer measurements, the ISGL, and the diffuse ISM. The first plot (a) displays the cut in Galactic longitude between 0° and 5° and the second plot (b), the cut between 95° and 100°.’
2. Data

To compare the color of DGL and of direct starlight, GWF have determined the absolute emissions in the $B$ and $R$ bands in two regions of the sky and calculated the $R/B$ ratio of the emissions. This method is difficult to apply to ground-based observations since it requires the subtraction of all foreground (zodiacal light and scattering in the earth’s atmosphere, see Leinert et al. [1998] for a review) sky emissions. The difficulty is increased by the low level of emission of the diffuse interstellar medium at high galactic latitude. Any such attempt should use space observations and subtract the direct emission of the stars, which can be evaluated from star catalogs. Toller [1981, see also Leinart et al.] did this work in 192 regions of the sky using Pioneer measurements.

In boxes $5^\circ \times 5^\circ$ large, and along two cuts at galactic longitude, $l = 0$ and $l = 100$ (region (a) and region (b), figure 3), GWF have separated the respective $B$ and $R$ emissions of bright stars, stars with mag $> 6$, and the DGL.

Bright stars with $m_V < 6.5$ were removed during the Pioneer data reduction. The remaining emission, comprising stars of $m_V > 6.5$, galaxies, and DGL, corresponds to the Pioneer curves of the figures 1, 2 and 3.

The ISGL curves correspond to the expected emission of stars and galaxies with magnitude greater than 6.5. They are calculated from the GWF ‘Master Catalog’ which is a compilation of different star catalogs.

Not all stars have a $B$ and an $R$ measured magnitude. To determine the $R$ and $B$ magnitudes of a star with only a $V$ measurement, GWF use an estimate of the $A_V$ value in the star direction. Determination of $A_V$ assumes a reddening proportional to the star distance.

Figure 1 gives the Pioneer surface brightnesses $P_B$ and $P_R$, and the ISGL integrated intensities per unit solid angle, $isgl_B$ and $isgl_R$, as measured from earth, for the $B$ and $R$ bands, along cuts (a) and (b).

3. The GWF’s argumentation

3.1. The GWF analysis of figures 1, 2 and 3

GWF’s analysis of the curves, figures 1, 2 and 3, is short enough to be reproduced here: “From Figure 14, it is obvious that the diffuse ISM is redder (larger $PR/PB$ ratio) than either the Pioneer measurements or the ISGL. As the scattered component of the diffuse ISM (DGL) is bluer (see § 4.1) than Pioneer measurements, this requires that the nonscattered component is present in the red diffuse ISM intensity. (GWF, p.531)”
Fig. 4. IRAS 100 µm images of GWF fields (a), left, and (b), right. The brightest regions (saturated) of field (a) have surface brightnesses between 25 and 30 MJy/sr. The surface brightness decreases to 11 MJy/sr at 40°. It is of respectively ∼ 3 MJy/sr and ∼ 1 MJy/sr in the brightest and darkest parts above 45°. The brightest regions in field (b) have ∼ 8 MJy/sr surface brightness. The surface brightness falls to 5 MJy/sr in regions where emission is still discernable and 1.5 MJy/sr in the darkest parts. Both fields can be seen
It is difficult to accept GWF’s premise at face value. Why should the scattered component of the diffuse ISM (DGL) be bluer than Pioneer measurements or than the ISGL? Where in GWF has it been proven that DGL must be bluer than Pioneer measurements?

In GWF’s introduction it is ascerted that: “The DGL will have a bluer color than the integrated starlight because scattering is more efficient at shorter wavelengths [in the blue than in the red] (GWF p.523)”. The following sentence states: “So, if the diffuse ISM color (red/blue ratio) is as red as or redder than the integrated starlight and other sources of excess red light can be positively excluded, ERE is present (GWF p.523)”.

Note that the first of these GWF assumptions is evidently restricted to low column density mediums since an increase of column density will see all blue starlight absorbed before red light and the scattered light color turn to the red. If GWF had related the two sentences to suggest that the source of the scattered light in one direction is the background starlight in that direction, I would fully agree with this assumption since interstellar grains are known to scatter light preferentially in the forward direction. The elimination of the contribution of the bright stars (mag < 6.5) may not modify the ISGL color enough to invalidate the calculations. This is justified, for instance, if the brightest stars are close to the sun or by the small number of bright stars at high latitude.

GWF don’t seem to make this connection between DGL and background starlight. Their approach of the problem is to calculate what should be the scattered starlight in each direction, taking into account the transfer of starlight from all directions and throughout the whole galaxy.

3.2. The ‘WP’ model
3.2.1. Description of the WP model

§ 4.1 of GWF - where the reader is supposed to find the demonstration that the scattered-DGL should have a bluer color than Pioneer’s and ISGL’s- is dedicated to the comparison of the Witt-Petersson ('WP') model with the data. According to GWF, the WP model represents the galaxy as a ‘gigantic reflection nebula’. Calculation of the radiative transfer through the nebula will give a model of the scattered light. This scattered-DGL model will be compared to the observations.

In order to compute the radiative transfer of starlight through the ‘gigantic nebula’ the structure of the medium in which light is scattered and the radiation field at each position of the galaxy need to be defined. The result given by the simulation of the radiative transfer through the WP model gives an expected radiation field for all directions of the galaxy.

The WP model of the galaxy is constructed from HI surveys. For each direction of space, the HI column density is converted into dust optical depth for the $B$ and $R$ bands by multiplication with an appropriate factor. The total column density is also divided into interstellar clouds with a spectrum of sizes and optical depths given by Witt et al. (1997).

The radiation field GWF use is deduced from Pioneer data, with the bright stars re-integrated. It comprises the DGL.

3.2.2. Results

Concerning field (a), the model can hardly fit the data in the $B$ band, where scattering is supposed to be the only process involved. For field (b), whatever grain parameters are chosen, the model is a factor of 2 to 4 above the data, which GWF interpret as changes in grain properties with longitude.

Despite the fact that the WP model does not fit the data when it should, the conclusion of GWF is that the $PR/PB$ ratio is a factor of 2 over the WP model expectation. Since $PB$ contains starlight and scattered starlight, it is concluded that additional red emission must arise in the diffuse interstellar medium.

4. Some problems with the GWF argument

4.1. Remarks on the ‘WP’ model

Not surprisingly, GWF’s model does not concur with the observations and as such the following questions arise:

What if the ‘WP model’ is an inappropriate one on which to model the galaxy?
Can the WP model give a representation of the galaxy with enough accuracy to justify the radiative transfer calculations? When the GWF model doesn’t fit the data, why is the discrepancy attributed to the variations of grain properties and not to the inadequacy of the model?

Why is it necessary to have a representation of the whole galaxy to model the DGL in two limited regions? Why isn’t the model restricted to fields (a) and (b)? Grains are known to strongly forward scatter starlight, which implies that most of the DGL we receive from one direction originates from the scattering of the light of the stars close to that direction.

The radiation field which GWF use in their Monte Carlo simulation of the radiative transfer through the Witt representation of the galaxy includes DGL which should be the result of the simulation. Why isn’t direct starlight, which GWF have estimated in their ‘Master Catalog’ the input radiation field of the simulation?

GWF never proved that the observed DGL should be bluer than the ISGL. Only Monte Carlo simulations with the WP model as a representation of the galaxy and an arbitrary radiation field give a theoretical color of the scattered starlight bluer than that of the ISGL.

Is it necessary to introduce any model at all? The search for ERE can be restricted to a comparison of the observed color of the ISGL (corrected for reddening) and of the DGL in each of the 5° × 5° areas.

In regard to the method and the uncertainties which accompany this model one can at best find GWF conclusions doubtful.

4.2. Is the DGL redder than the ISGL?

The high values of $S_R/S_B$ in figure 14 in GWF, are due to the considerable amplification of the error by the successive subtractions and divisions which led to the calculation of the DGL color.

The problem introduced by the amplification of the error through these operations can be overcome if it is remarked that $S_R/S_B > isgl_R/isgl_B$ is equivalent to $P_R/P_B > isgl_R/isgl_B$ since $P_R = S_R + isgl_R$ and $P_B = S_B + isgl_B$. Hence, comparison of the DGL color and the ISGL color can be reduced to a comparison of the Pioneer and the ISGL colors, which can be done with much better accuracy.

In both fields the 2 curves $P_R/P_B$ and $isgl_R/isgl_B$ are very close to each other.

Concerning field (b), we have within the error margin: $P_R/P_B = isgl_R/isgl_B$, which would yield:

$$P_R/P_B = isgl_R/isgl_B = S_R/S_B$$ (1)
Except for the two lower latitude points, the same remark applies to field (a). The redder color of the Pioneer data at the two low latitude points will be interpreted in section 3.

5. Relations between the colors of DGL, ISGL and Pioneer

5.1. IRAS data

5.1.1. The diffuse interstellar medium and IRAS images

Because grains scatter starlight in the forward direction, it will be considered that DGL in one direction is the light of background stars in the same direction scattered by foreground dust. This is also justified by the large areas which GWF have considered.

It is a wide-spread idea that the diffuse galactic scattered light is due to a diffuse interstellar medium, which the WP model attempts to represent. But the large grains which scatter starlight in the visible have a thermal emission, and, considering the importance of the scattering, must be detected on the IRAS images. Therefore, the diffuse medium which, according to GWF, is responsible for the DGL in fields (a) and (b) can be identified to the infrared cirrus shown in figure 3. The GWF areas are in approximate correspondence with the $5^\circ \times 5^\circ$ rectangles in each of the images.

These areas sample a medium with evident structure. It is this medium that the WP model pretends to reconstruct from its HI emission.

5.1.2. IRAS images of fields (a) and (b)

In all probability the mediums which compose the cirrus of field (b) (figure 3, right) has similar properties in each of the GWF areas. The decrease of the $100 \mu m$ surface brightness with absolute latitude in field (b) is associated with the decrease of the radiation field. At high absolute latitude, the IRAS surface brightness varies from 5 MJy/sr to 1.5 MJy/sr. With an $100 \mu m$ to visible extinction ratio $I_{100}/A_V$ of 18 MJy/sr/mag (Boulanger & Pérault 1988), $A_V$ is less than 0.2 on the average.

The areas of field (a) with $b > 45^\circ$ have similar properties as field (b). They have a low $100 \mu m$ surface brightness, a small $A_V$ (on average), and a clear small scale structure. These areas are the outermost parts of the HI loop at the edge of the Scorpio Centaurus region.

The (a) areas at lower latitude are in the densest parts of the HI loop and have high surface brightnesses. Zeta Oph ($m_V = 2.6$), a few degrees apart, may contribute to the heating of the region and to the enhancement, up to 30 MJy/sr, of its infrared emission. In the low latitude areas there is an increase of the average HI column density (de Geus 1988), hence of the visible extinction. CO is detected at the brightest IRAS positions (Laureijs et al. 1995).
GWF data can be separated in two. The field (b) and the high latitude regions of field (a) have a low column density and a low visible extinction on average. The low latitude points of field (a) are clearly a different kind of medium with much higher column density and visible extinction.

5.2. The color of the ISGL

In regions where there is interstellar matter, the direct starlight is reddened. In these regions the color of the direct starlight, \( \text{isgl}_R/\text{isgl}_B \), is redder than \( \sigma_R/\sigma_B \), where \( \sigma_R \) and \( \sigma_B \) are the surface brightnesses of direct starlight corrected for interstellar reddening.

Let \( f \) be the filling factor of interstellar matter in one of the areas GWF have considered. Assume that the ‘diffuse interstellar matter’ has an average low \( A_V \sim \tau_V \) value. This is true in region (b) and in the high latitude regions of (a).

We have for the regions with low 100 \( \mu \)m emission:

\[
\text{isgl}_R = (1-f)\sigma_R + (1-\tau_R)f\sigma_R \\
= \sigma_R(1-f\tau_R) \tag{2}
\]

\[
\text{isgl}_B = \sigma_B(1-f\tau_B), \tag{3}
\]

and

\[
\frac{\text{isgl}_R}{\text{isgl}_B} = \frac{\sigma_R}{\sigma_B} \frac{1-f\tau_R}{1-f\tau_B} \\
\sim \frac{\sigma_R}{\sigma_B} (1+f(\tau_B-\tau_R)) \tag{4}
\]

Expressed as a function of \( A_V \) (Cardelli et al. [1989]), equation 4 takes the simple form:

\[
\frac{\text{isgl}_R}{\text{isgl}_B} = \frac{\sigma_R}{\sigma_B} (1 + 0.6fA_V) \tag{5}
\]

The measured color of the stars is of course redder than \( \sigma_R/\sigma_B \), but the change of color will not be important. The reddening of direct starlight, \( 1 + 0.6fA_V \), for a medium of \( I_{100} \sim 2 \text{ MJy/sr} \) and \( A_V \sim 0.1 \) will be of order \( 1 + 0.05f \). Within the margin of error estimated by GWF for the ISGL, \( \sim 0.1 \), we can adopt \( \text{isgl}_R/\text{isgl}_B = \sigma_R/\sigma_B \).

Local increases of column density, due to the small scale structure of the medium, will not modify this approximation. The high resolution images of MCLD123.5+24.9 presented in Zagury et al. [1999] shows the presence of high density clumps with a small surface coverage (\( \sim 5' \times 5' \)). In field (b) and for the (a)-field regions where \( b > 40^\circ \), high density clumps must occupy only a small fraction of the surface. In such clumps the number of stars diminishes with \( A_V \) and the color of ISGL in the lower column density medium, which probably occupies most of the volume in regions (a) and (b), will determine the ISGL color of the 5\(^\circ\) \( \times \) 5\(^\circ\) areas.
The result does not hold for the low latitude points of field (a). There is a net increase of the average column density which can be evaluated by:

\[
\frac{\text{isgl}_R}{\text{isgl}_B} = \frac{\sigma_R e^{\tau_B - \tau_R}}{\sigma_B} = \frac{\sigma_R e^{0.5 A_V}}{\sigma_B}
\]  

(6)

While the reddening is, as seen before, small for small \(A_V\) values, for \(A_V = 0.5\) the ISGL is 1.3 times redder than the stars’ color.

The latter remarks also show that GWF’s estimate of the \(B\) and \(R\) magnitudes of the stars may have been biased when the \(A_V\) value of the stars were used to construct the ‘Master Catalog’. To estimate \(A_V\), GWF assume an average extinction of 0.6 mag/kpc. This approximation applies only if the interstellar matter in the star direction has a low column density. In the case of larger column densities, the GWF estimate of the color of starlight will be bluer than it is in reality.

The distance to the cirrus of field (a) should be 200 pc at most, since it belongs to the Scorpio Centaurus region. For an \(A_V\)-value of 0.5 for instance, the extinction of all stars at closer distance than 300 pc will be underestimated. The effect increases with column density and will be more pronounced in the low latitude regions of field (a). It will affect the \(B\) band more than the \(R\) band since the \(E(B-V)/A_V\) coefficient used by GWF is twice \(E(V-R)/A_V\). The color of the ISGL estimated by GWF from the Master catalog will be bluer than it should. It may explain the drop of the ISGL color of the lowest latitude point of field (a), figure 3.

5.3. The Pioneer color

The Pioneer surface brightness comprises the ISGL \((\text{isgl} \sim \sigma)\) and the DGL.

If the scattering volume is a medium of low optical depth \(\tau_B\) in the \(B\) band, the DGL surface brightness will be at most: \(\omega \tau_B\), where \(\omega\) is the albedo, assumed to be constant \((\sim 0.6)\) at optical wavelengths. Use of equations 2 and 3 gives:

\[
P_R = \sigma_R (1 - f(1 - \omega)\tau_R)
\]

(7)

\[
P_B = \sigma_B (1 - f(1 - \omega)\tau_B)
\]

(8)

Then:

\[
\frac{P_R}{P_B} = \frac{\sigma_R (1 - f(1 - \omega)\tau_R)}{\sigma_B (1 - f(1 - \omega)\tau_B)}
\]

\[
= \frac{\sigma_R}{\sigma_B} (1 + f(1 - \omega)(\tau_B - \tau_R))
\]

(9)

\[
\frac{P_R}{P_B} = \frac{\text{isgl}_R}{\text{isgl}_B} (1 - \omega(\tau_B - \tau_R))
\]

(10)
The Pioneer color is in between the ISGL and the DGL colors. Equation 9 can be simplified with $\omega \sim 0.6$ and Cardelli, Clayton and Mathis (1989) relations:

$$
\frac{P_R}{P_B} = \frac{\sigma_R}{\sigma_B} (1 + 0.3 f_A V) \quad (11)
$$

$$
\frac{P_R}{P_B} = \frac{isgl_R}{isgl_B} (1 - 0.15 f_A V) \quad (12)
$$

Equations 11 and 12 show that within GWF error margin equality between $P_R/P_B$, $isgl_R/isgl_B$, $\sigma_R/\sigma_B$ and $dgl_R/dgl_B$, will be satisfied for mediums of low column density.

5.4. Effect of the cirrus small scale structure on the observed colors

Small scale structure affects the surface brightness of starlight. Stars with no interstellar matter on their line of sight will have little or no reddening, while stars behind a cirrus are reddened. The clumpiness of the regions GWF have chosen, revealed by the IRAS images, will certainly affect the evaluation of the starlight surface brightness since GWF have considered an average reddening by unit distance (section 4) for all stars, regardless of the increase of interstellar matter in some directions. As pointed out in section 5.2, the color of direct starlight may be redder than estimated by GWF.

Small scale structure also modifies the color of the DGL since small clumps of different $A_V$ can be mixed in the beam. Even if the optical depth averaged over the beam of the observations is small, the existence of clumps of higher $A_V$ than average cannot be discarded. These clumps will redden the color of the DGL from the color of a low column density medium. Regions of higher than average $A_V$, such as the low latitude areas of field (a), are more likely to show this effect.

These effects of the small scale structure of the interstellar medium on GWF data cannot be totally leaved over. Each of the GWF areas is large compared to the size at which the interstellar medium is structured. IRAS images show that this size is less than a few arcminutes. Higher resolution observations (Falgarone et al. 1998, Zagury et al. 1999) give sizes of a few arcseconds at most for the entities which compose the interstellar medium.

5.5. The comparison of Pioneer and ISGL colors

The preceding sections show that a precise comparison of Pioneer and direct starlight data will sharply depend on the reliability of the GWF master catalog and on the cirrus structure.

For the GWF regions of low average optical depth, plot 3 is in accordance, within the error margin given by GWF, with equality 1.

Concerning the two lower latitude point of the field (a) different reasons may explain the drop in ISGL color. These points are different from the others since the region has
a much higher $A_V$ and cannot be considered as a ‘diffuse medium’. This was not taken into account by GWF for the estimate of the direct starlight $B$ and $R$ magnitudes. The medium also contains regions with more extinction which may modify the DGL color and redden the Pioneer color.

6. A qualitative comparison of IRAS image and the GWF data

A remarkable difference between fields (a) and (b) can be seen in figure 1. In field (b), $isgl_R$ and $isgl_B$ decrease with increasing (absolute) latitude, as is expected. The $B$ surface brightness follows a $\sim 1/\sin|b|$ law from $b = -28$ to $b = -55$, with a higher value than expected at $b = -22$. It is slightly under but close to the prediction of the Besançon Galactic Model (figure 5). The $R/B$ color closely follows the model.

In field (a) the ISGL is nearly constant and $isgl_R$ and $isgl_B$ have parallel variations. Low latitude points in (a) have lower ISGL than in (b) and what is predicted ($\sim 75 S_{10}(V)_G$) by the Besançon Galactic Model, figure 5, while higher latitude points ($|b| > 45^\circ$) have the same values at both longitudes. The ratio of the DGL to the total Pioneer emission in the $R$ band, $S_R/P_R$ (calculated from figure 1 and figure 2) is between 0.45 and 0.5 for the 3 lowest latitude points in (a), while for the higher latitudes points and for all points in (b), it is between 0.2 and 0.3.

The lower than expected starlight emission for field (a) low latitude points, along with the relative increase of DGL $R$ emission, are easily interpreted as extinction effects due to the average increase of interstellar matter along the line of sight (section 5.1). The increase of the column density increases the extinction of starlight.

Corresponding to this extinction of starlight, there is a sharp rise in the DGL emission between the 3 (a) points at latitude 42.5, 37.5 and 32.5, figure 2. The $R$ emission between latitudes 37.5 and 32.5 reaches a ceiling which corresponds to a decrease of $B$ emission, $S_B$. This can also be understood by the average increase of column density: absorption starts to dominate scattering in the $B$ band and the $R$ surface brightness is increased.

For the two low latitude points of field (a) in figure 3 departure from relation 1 seems certain. In this region we are clearly outside the low column density approximation, supposed by GWF, hence outside the framework of their study. The understanding of the ISGL color in this region deserves further investigations but two reasons may contribute to the blue color of the ISGL. One reason is the GWF method to estimate the ISGL magnitude which applies to low column density mediums only (section 5.2). The second reason is if Zeta Oph, a few degrees apart, participates in the illumination of the region. Note that illumination by Zeta Oph ($m_V = 2.6$) on such a large scale may be difficult to justify.
The correlation between the IRAS images of both fields (figure 3) and the DGL $R$ emission (figure 2) makes it likely that most of the emission measured by Pioneer comes from the infrared cirrus. In the visible, the cirrus scatter the light of background stars. The relation between the color of the radiation field due to the stars and the color of the DGL is given by equation 3.

The DGL optical emission at low latitude in field (a) may in part be due to illumination by the star Zeta Oph, a few degrees apart.

7. Conclusion

GWF have compared the color of the diffuse galactic light at high galactic latitude, deduced from observations of the Pioneer satellite, to the color of the light scattered by a diffuse medium with a certain cloud size distribution. GWF conclude that ERE is required to explain the amount of diffuse galactic emission at high latitude and can represent up to 50% of this emission.

In GWF it is said that, “An accurate calculation of the DGL should include the effects of multiple scattering, the cloudiness of the interstellar medium, and the observed anisotropy of the illuminating radiation field.” It should also include a reliable description of the interstellar medium. It would be very surprising if the WP model or any other, as sophisticated as it might be, can deduce from the measure of the HI emission in one direction the organisation of the interstellar matter in that direction. It is also surprising that when the WP model does not match the data it is supposed to match, changes in the properties of the interstellar grains are invoked rather than the validity of the model. It seems more plausible that observations do not agree with the WP model because this model does not properly describe the reality of the interstellar medium.

The exact structure of the interstellar medium the WP model should reproduce is shown at a scale of $2'$ by the IRAS 100 $\mu$m images. These images reveal the thermal emission of the same large grains responsible for the scattering of background starlight in the visible. They would have been a better basis to model the interstellar medium than the HI emission used in GWF. This medium may be of low column density on the average but is extremely structured and may have local column density enhancements. Some regions, the lower latitude points of field (a), have a clear increase of their average column density. It is very unlikely that the WP model reproduces this medium with the accuracy necessary to justify their conclusions.

The uncertainty of the DGL color as calculated in GWF is extremely large compared to the errors on Pioneer integrated light color or on the direct starlight color. Comparison of the DGL and the starlight colors should be replaced by a comparison of the starlight to the Pioneer colors, both of which are determined with less relative error.
Within the error margin given in GWF, there is equality between the color of the integrated starlight and the color given by the Pioneer measurements. It implies equality with the color of the DGL. There may be a tendency for the starlight surface brightness calculated by GWF to be slightly bluer than Pioneer integrated light. This tendency correlates with mediums of higher $A_V$ and can be attributed to two effects. Starlight is redder than estimated by GWF who assume a low and equal reddening in all directions. It modifies the GWF estimation of the $R$ and/or $B$ magnitude of the stars. Small scale structure will redden the color of DGL and of Pioneer from the color of a low column density medium.

A better understanding of the optical emission in the high latitude directions comes from the consideration that the DGL in these directions is the light of background stars scattered by the nearby infrared cirrus. For the GWF fields (a) and (b), there are relations between the cirrus observed on the 100 $\mu$m IRAS image, the visible emission of background stars, and the DGL. The IRAS 100 $\mu$m emission in the GWF field (b) and the high latitude regions of field (a) attests to low column densities in the average. The corresponding DGL surface brightness is low. Increase of the column density of dust in the low latitude areas of field (a) attenuates starlight and increases the $R$ surface brightness of the DGL, while the increase in the $B$ surface brightness is limited because of absorption.

ERE is not needed to explain the DGL at high galactic latitude (this paper) or in bright nebulae (Zagury, ‘Is there ERE in bright nebulae?’; submitted). Nor is it needed to explain the emission in the Red Rectangle (Zagury, in preparation), the milestone of ERE. There might be no ERE at all in interstellar space, which can be inferred from present day observations.

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