COMMENTS ON “THE FIRST DETECTIONS OF THE EXTRAGALACTIC BACKGROUND LIGHT AT 3000, 5500, AND 8000 Å” BY BERNSTEIN, FREEDMAN AND MADORE

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Draft version February 15, 2022

ABSTRACT

A critical discussion is presented of the data analysis applied by Bernstein, Freedman, & Madore (2002a, b) in their measurement of the Extragalactic Background Light. There are questionable assumptions in the analysis of the ground-based observations of the Zodiacal Light. The modeling of the Diffuse Galactic Light is based on an underestimated value of the dust column density along the line of sight. Comparison with the previously presented results from the same observations reveals a puzzling situation: in spite of a large difference in the atmospheric scattered light corrections the derived Extragalactic Background Light values are exactly the same. The claim of the paper of a “detection of the Extragalactic Background Light” appears premature.

Subject headings: diffuse radiation – techniques: photometric – dust, extinction

1. INTRODUCTION

Bernstein, Freedman, & Madore (2002a, b), hereafter BFM02a, BFM02b, or BFM02 combined, have announced the first detection of the Extragalactic Background Light (EBL) from absolute photometry, with the mean values of 4.0(±2.5), 2.7(±1.4), and 2.2(±1.0) × 10^{-9} erg s^{-1} cm^{-2} sr^{-1} Å^{-1} at 3000, 5500, and 8000 Å, respectively. The errors quoted are 1σ uncertainties. Their method is based on the formula:

\[ I_{\text{EBL}} = I_{\text{tot}} - I_{\text{ZL}} - I_{\text{DGL}}, \]

where \( I_{\text{tot}} \) is the total sky surface brightness outside the atmosphere, \( I_{\text{ZL}} \) is the Zodiacal Light (ZL), and \( I_{\text{DGL}} \) is the Diffuse Galactic Light (DGL) surface brightness, all to be determined in the direction of the BFM02 target field at \( l = 206.6, b = -59.8 \) deg. Each one of the three components is derived in BFM02 with a different method. \( I_{\text{tot}} \) is measured above the atmosphere with the Hubble Space Telescope (HST) using broad-band CCD photometry; \( I_{\text{ZL}} \) is measured from the ground, with the 2.5-m du Pont telescope at the Las Campanas Observatory (LCO), using spectrophotometry; and \( I_{\text{DGL}} \) is estimated by using a model for the scattering of starlight by interstellar dust. A very demanding task for the BFM02 method is set by the requirement that, for each of the two telescopes with different properties and different observing methods, the measured flux, \( I_{\text{ZL}} \) or \( I_{\text{tot}} \), has to be separately calibrated to the same scale. \( I_{\text{EBL}} \) is only a small fraction, a few per cent at most, of \( I_{\text{tot}} \) and \( I_{\text{ZL}} \). Therefore, the BFM02 method crucially depends on whether or not the very high absolute accuracy, of \( \lesssim 1 \% \), needed in the measurement, calibration, and scattered light corrections for \( I_{\text{ZL}} \) and separately for \( I_{\text{tot}} \) is achieved.

In this paper a critical discussion will be presented of the calibration and the atmospheric corrections applied in BFM02b to the ground based measurement of the Zodiacal Light. The assumptions for estimating \( I_{\text{DGL}} \) are critically reviewed. In addition, I point out a puzzling situation which emerges from comparison between the results of BFM02 and of the widely cited previous presentations of the same observations.

2. GROUND BASED MEASUREMENT OF THE ZODIACAL LIGHT

Two atmospheric corrections have to be applied: (1) extinction, and (2) tropospheric scattered light. The observed night sky brightness, \( I_{\text{obs}}(\lambda, t, X) \), towards the target field is given by

\[ I_{\text{obs}}(\lambda, t, X) = I_{\text{ZL}}(\lambda)e^{-\tau(\lambda)X} + [I_{\text{EBL}} + I_{\text{DGL}}](\lambda)e^{-\tau(\lambda)X} + I_{\text{sca}}(\lambda, t, X) + I_{\text{agl}}(\lambda, t, X) \]

where \( \lambda \) is the wavelength, \( t \) the time of the observation, \( X \) the airmass, \( \tau(\lambda) \) the atmospheric extinction coefficient for unit airmass, \( I_{\text{sca}} \) the tropospheric scattered light, and \( I_{\text{agl}} \) the airglow as observed from the ground (including atmospheric attenuation and scattered airglow). The BFM02b method of separating the ZL from the airglow component is based on the assumptions that (1) the depths of the Fraunhofer lines in the spectrum of the Zodiacal Light are identical to those in the solar spectrum, and (2) the airglow spectrum is uncorrelated with the solar Fraunhofer spectrum.

The tropospheric scattered light, \( I_{\text{sca}}(\lambda, t, X) \), is the main obstacle in conducting accurate absolute diffuse sky photometry from the ground. Unlike the photometry of stars or small extended sources, no differential ON/OFF measurements are possible, and one must calculate the scattered light contribution coming from all the light sources above the horizon. The scattered light components which contribute to the “ZL-like” (Fraunhofer spectrum) signal are due to the all-sky distributions of the ZL itself, the Integrated Starlight (ISL), and the DGL. Each one of these components has the Rayleigh (R) and the Mie or aerosol (M) scattering part:

\[ I_{\text{sca}}(\lambda, t, X) = I_{\text{sca}}^{R}(\text{ZL}) + I_{\text{sca}}^{M}(\text{ZL}) + I_{\text{sca}}^{R}(\text{ISL}) + I_{\text{sca}}^{M}(\text{ISL}) + I_{\text{sca}}^{R}(\text{DGL}) + I_{\text{sca}}^{M}(\text{DGL}) \]
The results of BFM02 have been previously presented in in Bernstein (1998, 1999a,b, 2001), and distributed in a preprint form for some time (Bernstein, Freedman, & Madore 1999, 2000); in the following they are collectively referred to as BFM98-01. These results have been widely cited in the literature as the “EBL standard reference values”, see e.g. Barger et al. (2001); Hauser (2001); Jimenez & Kashlinsky (1999); Longair (2001); Madau & Pozzetti (2000); Pagel (2002); Peebles (2001); Pozzetti & Madau (2001); Primack et al. (1999); Renault et al. (2001); Wright (2001). It is therefore important to point out the following puzzling situation which results from the comparison between the BFM98-01 and BFM02 results:

In BFM98-01, the reduction method for the Zodiacal Light measurements differed in a fundamental way from that in BFM02b. Instead of Eq. (2), the following formula was applied:

\[ I_{\text{obs}}(\lambda, t, X) = I_{\text{ZL}}(\lambda) e^{-\tau(\lambda)X} + |I_{\text{EBL}}| + |I_{\text{DGL}}|(\lambda) e^{-\tau(\lambda)X} + I_{\text{agl}}(\lambda, t, X) \]  
\[ I_{\text{obs}}(\lambda, t, X) \]

i.e. the atmospheric scattered light term \( I_{\text{sca}}(\lambda, t, X) \) was completely omitted without explanation, thus neglecting this fundamental aspect of the diffuse night sky photometry. Only in BFM02b has an Appendix on scattered light corrections been added. The results of these calculations a lower limit to \( I_{\text{sca}} \) at 4500 Å can be estimated by adopting \( X = 1.1 \) for the airmass, i.e. a value at the lower end of the BFM02b airmass range. \( I_{\text{sca}} \) amounts to \( \sim18\% \) of \( I_{\text{ZL}} \). It consists of the Rayleigh (\( \sim10\% \) of \( I_{\text{ZL}} \)) and Mie (\( \sim4\% \) of \( I_{\text{ZL}} \)) components of scattered Zodiacal Light, as well as of a scattered ISL component with a “ZL-like” spectrum (\( \sim4\% \) of \( I_{\text{ZL}} \)) (see Sect. 4 and 5, and Figs. 20, 21, and 30 of BFM02b). This value translates, for the airmass of 1.1, to an outside-the-atmosphere value of \( \sim22\% \) of \( I_{\text{ZL}} \) which, for the BFM02b value of \( I_{\text{ZL}} = 109.4 \times 10^{-9}\text{erg s}^{-1}\text{cm}^{-2}\text{sr}^{-1}\text{Å}^{-1} \) at 4500 Å, corresponds to \( 24 \times 10^{-9}\text{erg s}^{-1}\text{cm}^{-2}\text{sr}^{-1}\text{Å}^{-1} \).

Since not subtracted, \( I_{\text{sca}} \) was erroneously included into the Zodiacal Light, \( I_{\text{ZL}} \), in the BFM98-01 analysis. Thus, the difference in the reduction methods necessarily should have resulted in a \( \sim22\% \) larger ZL value in BFM98-01 than in BFM02b. This \( \sim22\% \) difference in \( I_{\text{ZL}} \) is at least 7 times as large as the EBL value of BFM02 at 5500 and 8000 Å. However, in BFM98-01 the EBL intensities at 3000, 5500, and 8000 Å are identical to the values in BFM02 of 4.0, 2.7, and 2.2 \( \times 10^{-9}\text{erg s}^{-1}\text{cm}^{-2}\text{sr}^{-1}\text{Å}^{-1} \) to within \( \sim0.1 \times 10^{-9}\text{erg s}^{-1}\text{cm}^{-2}\text{sr}^{-1}\text{Å}^{-1} \). It is unclear how this puzzling situation should be understood.

4. SCATTERED LIGHT CORRECTIONS

In an Appendix of BFM02b model calculations for the atmospheric scattered light are now presented. However, the nature of the problem dictates that it is hardly possible to achieve an absolute accuracy of \( \leq 1 \times 10^{-9}\text{erg s}^{-1}\text{cm}^{-2}\text{sr}^{-1}\text{Å}^{-1} \) as required in the BFM02 method. Major problems are caused by e.g. the varying properties of the atmospheric aerosols and ground reflectance, as well as by the insufficiently known intensity distributions of the main light sources, the ZL, ISL, and DGL over the sky.

The Moon, if above or up to a few degrees below the horizon, will give rise to a substantial atmospheric scattered light component (Krischunas & Schaefer 1991). The observations at LCO, if carried out on 1995 November 27 and 29 as announced by BFM98-01 and BFM02b, would have included time slots when the Moon was above the horizon. In an erratum (Bernstein, Freedman, & Madore 2003) the authors have now removed this problem by stating that their published dates were incorrect, the correct dates of their observing nights being 1995 November 24/25 and November 26/27.

4.1. Aerosol scattering

BFM02b have adopted for the albedo of the aerosol particles a value of \( a = 0.59 \). This value, given in Staude (1975), was calculated for an ad hoc particle composition with a refractive index of \( m = 1.5 - 0.1i \). For a realistic aerosol composition, according to Garstang (1991) and McClatchey et al. (1978), the albedo is \( \sim0.94 \). This is a representative value over the whole wavelength range, 3900 - 5100 Å, of the BFM02b Zodiacal Light measurement and for a variety of different measured aerosol populations and conditions. The aerosol scattering composition, \( M^A_{\text{sca}} = M^A_{\text{sca}}(\text{ZL}) + M^A_{\text{sca}}(\text{ISL}) \), has to be corrected for the effect of increased albedo by multiplying it with the albedo ratio 0.94/0.59. In order to obtain the contribution to the extraterrestrial \( I_{\text{ZL}} \) value one has to multiply \( M^A_{\text{sca}} \) by the extinction correction factor \( e^{-\tau(\lambda)X} \).

According to BFM02b Appendix, \( M^A_{\text{sca}}(\text{ZL}) \) is 3.6 - 6.1% of \( I_{\text{ZL}} \) at their minimum airmass of 1.02 and 5.2 - 8.1% of \( I_{\text{ZL}} \) at their maximum airmass of 1.82. The lower value stands for \( \lambda = 4920 \) Å and the higher one for \( \lambda = 3960 \) Å. (Four selected wavelength slots at \( \sim3960, 4270, 4340, \) and 4920 Å were used by BFM02b to derive their final \( I_{\text{ZL}} \) value at 4650 Å.)

\( M^A_{\text{sca}}(\text{ISL}) \) is not explicitly given in BFM02b Appendix. It is only a small fraction of the total (Rayleigh + Mie) scattered ISL which they estimate to be \( \sim12 - 24 \times 10^{-9}\text{erg s}^{-1}\text{cm}^{-2}\text{sr}^{-1}\text{Å}^{-1} \). A rough estimate is obtained from

\[ f_{\text{sca}}(\text{ISL}) = a(1 - e^{-\tau(\lambda)X})I_{\text{ISL}}, \]

where \( \tau_M \) is the aerosol extinction per airmass and \( I_{\text{ISL}} = 4 \times 10^{-9}\text{erg s}^{-1}\text{cm}^{-2}\text{sr}^{-1}\text{Å}^{-1} \) is the ISL intensity in the direction of the target. For the wavelength and airmass range, and the albedo \( a = 0.59 \), as adopted by BFM02b, \( M^A_{\text{sca}}(\text{ISL}) \) \( \sim (0.9 - 2.4) \times 10^{-9}\text{erg s}^{-1}\text{cm}^{-2}\text{sr}^{-1}\text{Å}^{-1} \). A third of \( M^A_{\text{sca}}(\text{ISL}) \) is estimated to have a solar type Fraunhofer spectrum and thus adds \( \sim0.3 - 0.8 \% \) of \( I_{\text{ZL}} \) to the scattered ZL value.

The average of \( M^A_{\text{sca}}e^{-\tau(\lambda)X} \) for the 16 different airmasses and four wavelength slots of the BFM02b measurement gives an outside-the-atmosphere value of \( \sim7.6 \% \) of \( I_{\text{ZL}} \). With the aerosol albedo of 0.94 instead of 0.59, this value should be scaled up to \( \sim12.1 \% \) of \( I_{\text{ZL}} \). The difference of \( \sim4.5 \% \) of \( I_{\text{ZL}} \) corresponds to \( 4.9 \times 10^{-9}\text{erg s}^{-1}\text{cm}^{-2}\text{sr}^{-1}\text{Å}^{-1} \) at 4650 Å which, when not subtracted, will artificially increase the \( I_{\text{ZL}} \) value (see Table 1).
4.2. Ground reflection

BFM02b have neglected the reflection from the ground. Light reflected from the ground is scattered a second time by the molecules in the atmosphere, back into the observer’s line of sight. Because of the strongly forward scattering phase function of the aerosols, only the Rayleigh scattering by molecules is important here. The influence of the ground reflection on the Rayleigh scattered light intensity can be estimated using the tables of Ashburn (1954). The ground reflectance value obtained from the intensity can be estimated using the tables of Ashburn (1954). The ground reflectance value obtained from the NASA MODIS/Terra Surface Reflectance database is \( \approx 8\% \). This value is for a \( 100 \times 100 \text{ km}^2 \) area centered at the Las Campanas Observatory, for the same season of the year (November-December 2000 and 2001) as the BFM02b observations, and for a wavelength band (4590 - 4790 Å, MODIS/Terra band 3) which closely matches the one used in BFM02b. According to the Ashburn (1954) tables the Rayleigh scattered light intensity, for the extinction range of BFM02b, has to be increased by 7.2% relative to the case of zero ground reflectance.

According to BFM02b Appendix, \( I_{\text{sc}}^{R} \) (ZL) is 8-18% of \( I_{\text{ZL}} \) at their minimum airmass of 1.02 and 15-32% of \( I_{\text{ZL}} \) at their maximum airmass of 1.82. The lower value stands for \( \lambda = 4920 \text{ Å} \) and the higher one for \( \lambda = 3960 \text{ Å} \). The value of \( I_{\text{sc}}^{R} \) (ISL) is not explicitly given in BFM02b, but it can be estimated using the total (Rayleigh + Mie) scattered ISL which BFM02b estimate to be \( \sim 12 - 24 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1} \). After subtracting \( I_{\text{sc}}^{M} \) (ISL) according to Sect. 4.1 and adding \( I_{\text{sc}}^{R} \) (DGL) according to Sect. 4.3 one obtains the range \( I_{\text{sc}}^{R} \) (ISL) = \( (14 - 27) \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1} \). A third of it is estimated to have a solar type Fraunhofer spectrum and thus adds \( \sim 4.6 - 8.3\% \) of \( I_{\text{ZL}} \) to the scattered ZL value.

The average of the ground reflection correction referred to outside-the-atmosphere, \( \Delta I_{\text{sc}}^{R} e^{-\tau X} \), at the 16 different airmasses and four wavelength slots of the BFM02b measurement, gives a value of \( \sim 2.1\% \) of \( I_{\text{ZL}} \). This corresponds to \( 2.3 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1} \) at 4650 Å which, when not subtracted, will artificially increase the \( I_{\text{ZL}} \) value (see Table 1).

4.3. Diffuse Galactic Light as source

BFM02b have constructed an approximate model for the intensity distribution and spectrum of the ISL. They find that their averaged intensities are within 10% of the star count integrations of Roach & Megill (1961). However, the ISL is only a part of the Galactic radiation field which contributes to the trospheric scattered light, with the other part being the DGL. The contribution of the DGL to the total Galactic radiation field can be estimated using the tabulation of the ratios \( I_{\text{DGL}}/I_{\text{ISL}} \). These data are based on the Pioneer 10 measurements at 4400 Å by Toller (1981) and are reproduced in Table 39 of Leinert et al. (1998). The \( I_{\text{DGL}}/I_{\text{ISL}} \) ratio varies as a function of galactic latitude, from \(-0.25-0.34\) at low galactic latitudes to \(-0.12\) at high latitudes. There is no pronounced dependence of this ratio on the galactic longitude. To estimate the total contribution of the DGL to the Galactic radiation field a weighted mean value of the ratio over the galactic latitude range was formed. The overall ratio is 0.24, i.e. the pure ISL sky brightness used by BFM02b as the Galactic illumination source has to be increased by 24%. This 24% correction should be applied to the Rayleigh scattering component only. Because of strong forward scattering, the Mie (aerosol) component couples to the DGL in the viewing direction at high galactic latitudes where \( I_{\text{DGL}}/I_{\text{ISL}} \approx 0.12 \).

According to BFM02b, the scattered (Rayleigh + Mie) ISL is \( 12 - 24 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1} \) over their airmass range of 1.02 to 1.82. The Mie component has been estimated in Sect. 4.1 to be \( I_{\text{sc}}^{M} \) (ISL) \( \approx (0.9 - 2.4) \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1} \). Thus, the Rayleigh component is \( I_{\text{sc}}^{R} \) (ISL) \( \approx (11 - 22) \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1} \). The atmospheric scattered DGL component is 24% of it, i.e. \( I_{\text{sc}}^{R} \) (DGL) \( \approx (2.6 - 5.2) \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1} \). However, as discussed in BFM02b, it is not the total scattered flux which is important, but rather the strength of the Fraunhofer spectral features which are in common with the Sun. According to BFM02b, the strengths of the spectral features they use in their analysis are approximately 1.5 to 3.8 times weaker in the DGL than in the ZL spectrum. To obtain a reasonable lower-end estimate for the “ZL-like” component I use here a factor of 3.0, leading to a range of \( (0.9 - 1.8) \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1} \).

The average of \( I_{\text{sc}}^{R} \) (DGL)\( e^{-\tau X} \) at the 16 different airmasses and four wavelength slots of the BFM02b measurement gives an outside-the-atmosphere value of \( \sim 1.6 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1} \) at 4650 Å which, when not subtracted, will artificially increase the \( I_{\text{ZL}} \) value (see Table 1).

5. CALIBRATION OF THE ZODIACAL LIGHT MEASUREMENTS: APERTURE CORRECTION

As stated in BFM02a,b the calibration of extended uniform surface brightness photometry differs in an essential way from point source photometry. The following two standard issues are in common with point source and surface photometry:

(1) Point source calibration (including the atmospheric extinction effects); and (2) Calibration of the fiducial standard star system.

However, in the calibration of extended uniform surface brightness photometry one requires knowledge of two additional aspects:

(3) The solid angle subtended by the spectrometer or photometer aperture or CCD detector pixel; and (4) The aperture correction factor which accounts for the loss of flux of the standard star outside the spectrometer or photometer aperture.

Because of scattering by micro-roughness and dust particle contamination on the optics, and atmospheric small-angle scattering, the point spread function of a telescope extends beyond the aperture size of 1-20 arcsec normally used in point source photometry. The aperture correction factor, \( T(A) \), is the fraction of the flux from a point source that is contained within the aperture. The fraction \( 1 - T(A) \) of the point source flux is lost outside the aperture. In the measurement of a uniform extended source the situation is different: the flux which is lost from the

\[ 1 \text{ Available at http://modis-land.gsfc.nasa.gov/mod09/} \]
solid angle defined by the focal plane aperture is compensated for by the flux which is scattered and diffracted into the aperture from the sky outside of the solid angle of the aperture. Therefore, the intensity in units of erg s$^{-1}$cm$^{-2}$sr$^{-1}$Å$^{-1}$ of an extended uniform source is given by

$$I(\lambda) = \frac{S(\lambda) T(A)}{\Omega} C(\lambda), \quad (5)$$

where $C(\lambda)$ is the signal in instrumental units (DN s$^{-1}$), $\Omega$ the solid angle of the aperture in steradians, and $S(\lambda)$ the sensitivity function in units of erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$/DN s$^{-1}$ determined from the standard star observations.

The aperture correction is an additional factor specific to the absolute surface photometry of extended uniform sources. It does not appear in point source photometry, nor in the photometry of small extended sources where the sky background can be measured next to the object. The aperture correction factor is not “automatically” taken care of by simply using in the standard star observations the same measuring arrangement as was used in generating the standard star system.

The accuracy of the EBL measurement of BFM02 crucially depends on how consistently the surface brightnesses for the HST and du Pont telescope can be calibrated to the same scale in spite of the different properties of the two telescopes. In practice, as also pointed out by BFM02, the majority of error in calibrating a uniform surface brightness source comes from the accuracy with which the large-angle PSF is determined. In fact, the two telescopes differ strongly with respect to the aperture correction factor.

The surface (spectro)photometry of BFM02b at LCO was calibrated by standard stars which were observed through a slit of 10.8 arcsec width. In order to compensate for the light lost outside of the slit, BFM02b measured the PSF up to a radius of ~60 arcsec. They found that the aperture correction factor for a uniform-surface-brightness, aperture-filling source is $T = 0.963$. However, in their analysis, BFM02b did not take into account that, in order to include 100% of encircled energy into the star image, the integration must be extended far beyond 60 arcsec from the axis.

A widely used compilation of data for the profile of a star image was presented by King (1971). Outside the central disk of ~10 arcsec radius, the image shows a more slowly declining halo or aureole which is well represented by an inverse-square law of intensity over a factor of 1000 in angular distance. Between 1 and 100 arcmin the aureole contains about 5% and between 1 arcmin and 5 deg about 6% of the star’s flux. Later work by e.g. Capaccioli & de Vaucouleurs (1983) (McDonald 0.9-m and 2-m telescopes), Surma, Seifert, & Bender (1990) (Calar Alto 1.23-m), Racine (1996) (CTIO 4-m), Mackie (1992) (KPGO 0.6-m Burrel Schmidt), Middlemass, Clegg & Walsh (1989) (La Palma I NG 2.5-m), Piccirillo (1975) (Goethe Link 16-inch and McDonald 2-m), and Uson, Boughn, & Kuhn (1991) (KPGO No, 1 0.9-m) has demonstrated that very similar functional dependences (i.e. inverse square law), but in some cases substantially higher aureole energy fractions, are obtained for other telescopes equipped with photometric photometers, CCD cameras or spectrographs. For example, Capaccioli & de Vaucouleurs (1983) find an integrated aureole contribution of ~10% between 30 arcsec and 1.5 deg. Furthermore, in Uson, Boughn, & Kuhn (1991), the aureole stray radiation level is ~1.5 times higher than in King (1971). The probable reason for the aureole is light scattering by the imperfections of the telescope optics, such as microripples and dust on the mirrors (Beckers 1995; Roddier 1995).

Although no stellar image aureole measurements were available in BFM02b or BFM98-01 for the du Pont telescope, there are good reasons to assume that its characteristics are similar to the telescopes mentioned above. Including the aureole contribution to the stellar PSF, the aperture correction factor of BFM02b should be decreased by 5 - 10%, from $T = 0.963$ to 0.86 - 0.91. The resulting outside-the-atmosphere ZL value should thus be reduced by 5 - 10%, corresponding to $5.5 - 11 \times 10^{-9}$ erg s$^{-1}$ cm$^{-2}$ sr$^{-1}$ Å$^{-1}$ at 4650 Å (see Table 1).

For their HST measurement BFM02a used the WFPC2 default calibration and adopted the standard aperture corrections as given in Holtzman et al. (1995). For their filters used, they applied an aperture correction factor of 90% in moving from a 0.5' radius aperture to an “infinite” aperture (600' radius). Large angle scattering measurements by Krist & Burrows (1994) at 20'-60' have shown that the scattered light level in HST/WFPC2 is much below the aureole levels of the ground-based telescopes as listed above. Uson, Boughn, & Kuhn (1991) and Surma, Seifert, & Bender (1990) give at 60' a stray radiation value of 15.8 mag arcsec$^{-2}$ (normalisation to a 0th mag star), corresponding to $4.8 \times 10^{-7}$ arcsec$^{-2}$ (normalisation to stellar flux = 1), while the HST/WFPC2 value is $7 \times 10^{-8}$ arcsec$^{-2}$, i.e. a factor of ~7 lower. This is as expected since the HST optics are known to have extremely small microroughness and are practically dust-free. Therefore, it is unlikely that any additional large-angle aureole correction to the HST aperture correction factor is needed beyond the 90% correction applied by BFM02a. In any case it would be much smaller than the correction for the ground-based du Pont telescope. Thus, when taking the difference $I_{tot} - I_{SL}$, the error in the aperture correction factor for $I_{SL}$ (du Pont telescope) is not compensated for by a similar error in $I_{tot}$ (HST).

6. MODEL ESTIMATES OF THE DIFFUSE GALACTIC LIGHT

The BFM02a estimation of the DGL intensity is based on the 100 µm surface brightness, $I_{100}$, as extracted from the IRAS Sky Survey Atlas (ISSA). This Atlas gives the very low value of 0.4 MJy sr$^{-1}$ for their target position. The authors have apparently not paid attention to the fact that the ISSA surface brightnesses cannot be utilised for absolute surface photometry; see The Explanatory Supplement to the IRAS Sky Survey Atlas, Wheelock et al. (1994), p. 1-6. From their $I_{100}$ estimate BFM02a derived the values $N(H) = 0.47 \times 10^{20}$ cm$^{-2}$ and $A_V = 0.028$ mag. However, the value of $N(H)$ can be directly extracted from the Hartmann & Burton (1997) Atlas, carefully corrected for stray radiation effects. It gives for the BFM02 target $N(H) = 1.78 \times 10^{20}$ cm$^{-2}$ corresponding to $A_V = 0.106$ mag, i.e. 3.8 times as large as the value adopted in BFM02a. Using the COBE/DIRBE surface photometry to fix the zero point for the IRAS 100 µm data, Schlegel, Finkbeiner, & Davis (1998) produced an all-sky Galactic 100 µm emission and optical extinction.
atlas. The values derived for the BFM02 target direction are $I_{100} = 0.8 \text{ MJy sr}^{-1}$ and $A_V = 0.054 \text{ mag}$, i.e. twice as large as the value adopted by BFM02. From these two determinations, one obtains an average correction factor of 2.9 ± 0.9 by which the BFM02a dust column density and DGL intensity estimates have to be multiplied. The resulting DGL intensities then become 2.9, 2.3, and $3 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$ at 3000, 5500, and 8000 Å, respectively. These are to be compared with the $I_{\text{DGL}}$ values of 1.0, 0.8, and $0.8 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$ as given in BFM02a at the three wavelengths. Thus, the DGL intensity is substantially larger than estimated by BFM02a and about equal to their EBL intensities.

Because the DGL has a similar spectrum as the ZL, part of the DGL has been included into the ZL measurement and therefore has been subtracted from $I_{\text{tot}}$ together with the ZL. According to BFM02, this part is ∼35%. Therefore, the remaining DGL correction, to be subtracted from $I_{\text{EBL}}$ as given in BFM02a, amounts to $\sim 1 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$.

7. THE RESULTING EBL ESTIMATES AND THEIR ERRORS

My analysis above has revealed several, in part serious problems in the BFM02b treatment of the ground-based Zodiacal Light observations.

(1) There is a major puzzle resulting from the comparison of the BFM02b and BFM98-01 treatment of atmospheric scattered light: in spite of a large difference in the scattered light corrections applied, $I_{\text{sca}} = 0$ in BFM98-01 vs. $I_{\text{sca}} \approx 24 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$ in BFM02b, the derived EBL values are exactly the same to within $0.1 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$.

(2) The systematic errors in calibration and atmospheric scattering, discussed in Sections 4.1-4.3 and 5, influence the derived ZL value in the same direction (see Table 1); the corrected $I_{\text{ZL}}$ value at 4650 Å is smaller than the estimate given in BFM02b by $\sim 14.3-19.8 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$.

(3) BFM02a have based their estimation of the DGL intensity on too low a dust column density. The error caused by this is $\sim 1 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$, and is to be subtracted from the BFM02 $I_{\text{EBL}}$ values. This correction is small compared with the scattered light and calibration corrections described above and does not suffice to compensate for them (see Table 1).

(4) The corrected EBL estimates will be increased to $\sim 7.4-9.1$, $\sim 15.4-20.7$, and $\sim 10.6-14.3 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$ at 3000, 5500, and 8000 Å, respectively. These values are 2 to 7 times as high as the original BFM02 estimates. Clearly, such high EBL values are in conflict with the upper limits of $\sim 4.5-9 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$ as derived by Dube, Wickes, & Wilkinson (1979), Toller (1983), and Mattila (1990) at 4000-5100 Å.

(5) BFM02 give for their mean EBL intensities the 1σ combined statistical and systematic uncertainties of ±2.5, ±1.4, and $\pm 1.0 \times 10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$ at 3000, 5500, and 8000 Å, respectively. However, the systematic effects discussed in Sect. 3 - 6 of this paper have not been adequately dealt with in BFM02. The corrections as listed in Table 1 are to be considered as systematic errors which are not included in the BFM02 error analysis. They can be seen to substantially exceed the BFM02 1σ combined statistical and systematic error estimates.

In summary, I have presented arguments indicating that systematic errors of the BFM02 measurement have been underestimated. The claim of the paper of a “detection of the EBL” appears premature.

| Correction                              | BFM02    | This paper | $\Delta I_0^a$ | Applies to | $\Delta I_{\text{EBL}}^b$ |
|------------------------------------------|----------|------------|---------------|------------|-------------------------|
| 1. Aerosol albedo                        | 0.59     | 0.94       | -4.9 $ZL @ 4650$ Å | +1.5 $+0.7$ | +1.5 $+2.2$ |
| 2. Ground reflectance                    | neglected| 8%         | -2.3 $ZL @ 4650$ Å | +0.7       | +2.2       |
| 3. DGL as source of atmospheric scattering| neglected| included    | -1.6 $ZL @ 4650$ Å | +0.5       | +1.5       |
| 4. ZL calibration, aperture correction factor | 0.963    | 0.86-0.91 | -5.5to-11 $ZL @ 4650$ Å | +1.7-3.4  | +3.6-7.3  |
| 5. DGL modeling, line-of-sight $A_V$     | $0^\circ 028$ | $0^\circ 081 \pm 0^\circ 025$ | +1.5to+1.9 $DGL @ all \lambda$ | -1        | -1        |

| $I_{\text{EBL}}$ (BFM02) | $I_{\text{EBL}}$ (this paper) |
|--------------------------|-------------------------------|
| $4.0 \pm 2.5$            | $4.0 \pm 2.5$                 |
| $2.7 \pm 1.4$            | $2.7 \pm 1.4$                 |
| $2.2 \pm 1.0$            | $2.2 \pm 1.0$                 |

| $\sigma$ | $\Delta I_{\text{EBL}}$ |
|----------|-------------------------|
| 3000 Å   | $+0.8 \pm 0.7$          |
| 5500 Å   | $+2.2 \pm 2.2$          |
| 8000 Å   | $+10.6-14.3$            |

$^a$ in units of $10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$

$^b$ Corrections in units of $10^{-9} \text{erg s}^{-1} \text{cm}^{-2} \text{sr}^{-1} \text{Å}^{-1}$ to be applied to the BFM02 $I_{\text{EBL}}$ values
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