OBSERVATIONS OF THE EXTRAGALACTIC BACKGROUND LIGHT

K. Mattila
Helsinki University Observatory
Tähtitorninmäki
SF-00130 Helsinki, Finland

ABSTRACT. We present a review of the presently available observations of the extragalactic background light (EBL) obtained by means of night sky photometry. The EBL is a quantity of great cosmological importance; areas which are directly affected include galaxy formation and evolution, the appropriateness of different cosmological models, and the local luminosity density due to galaxies and other matter in intergalactic space. The basic problem in measuring the EBL is its separation from other, much stronger components of the light of the night sky. None of the different observational techniques have succeeded in providing a generally accepted measurement of the EBL. After a review of available methods, we present new results from an experiment by Mattila and Schnur (1989) utilizing the dark cloud technique in the area of L1642, a high-latitude dark nebula in the galactic anticentre direction.

1. INTRODUCTION

The great cosmological importance of an isotropic background radiation component was already recognized in theoretical contemplations by Halley (1721), Loys de Chéseaux (1744) and Olbers (1823; for a review see Harrison 1987, and 1989, this volume). The absence of a (very) bright background light, expected as the accumulation effect of more and more distant shells of stars in an infinite universe, is generally known as Olbers's Paradox. In spite of the long history of this problem in the optical, the background radiation was first detected in the microwave, radio, and X-ray bands. The background radiation components in the conventional optical and neighbouring infrared and ultraviolet wavebands have consistently defeated attempts to detect them.

The intensity of the background radiation due to galaxies (or other luminous matter) in the Friedmann models with a zero cosmological constant (see, e.g., Partridge and Peebles 1967) depends on the local luminosity density in the Universe, the galaxy evolution, and the cosmological model.

The principal interest for the EBL during the past 20 years stems from the prospect of using it as a probe of galaxy formation and evolution. In a pioneering investigation, Partridge and Peebles (1967) pointed out that the redshifted radiation from very young galaxies could be observable as a background light component, especially if the forming galaxies went through a bright outburst phase during which some 20% of primordial hydrogen was converted into helium. It is now generally believed that most of the helium was synthesized in the very early universe, before the galaxy formation. However, the concept of an initial star formation burst with accompanying strong ultraviolet (UV) radiation is nonetheless important for the EBL predictions and was analyzed by Tinsley (1973) in extensive model calculations that included realistic galaxy evolution assumptions.

It has been often suggested that the integrated background light due to galaxies could be used as a test to discriminate between different cosmological models (see, e.g., McVittie and Wyatt, 1959; Whitrow and Yallop, 1963; Partridge and Peebles, 1967). Calculations by

S. Bowyer and C. Leinert (eds.), The Galactic and Extragalactic Background Radiation, 257–268.
© 1990 *IAU. Printed in the Netherlands.*

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

Sandage and Tammann (1965) for models with no galaxy evolution show that, for different values of the deceleration parameter q_0, the background at optical wavelengths is about 1×10^{-9} erg cm^{-2} s^{-1} sr^{-1} Å^{-1} and decreases only about 30% when q_0 changes from −1 to +2.5. Tinsley (1973) found larger differences between the cosmological models with different q_0, especially when evolution was included. These differences are masked by the much larger uncertainties due to our incomplete knowledge of galaxy evolution. In a recent paper Yoshii and Takahara (1988) have found similar effects of q_0 on the predicted EBL. Stabell and Wesson (1980) and Wesson, Valle, and Stabell (1987) have reemphasized the fact, first pointed out by Harrison (1964), that the specific cosmological model—even if expanding or nonexpanding—is of less importance than the effect of the finite lifetime of galaxies.

Arp (1965) pointed out that there may exist large numbers of hitherto unknown galaxies which, either because of their small angular extension or their low surface brightness, are not detectable with present observing techniques. Shectman (1974), analyzing the small-scale anisotropy of the EBL has found, however, that if the luminous matter is distributed in the same way as galaxies, the observed fluctuations are in accord with the conventional value of the local luminosity density. If the EBL is due totally to galaxies, then the galaxy clustering will produce an anisotropy to the spatial distribution of EBL that is of the order of ~20–30% at scale lengths of a few arc minutes. This anisotropy may be the most efficient means of detecting the component due to galaxies of the EBL (see Shectman, 1973, 1974; Martin and Bowyer 1989). However, there may be other components of the EBL which do not follow the galaxy clustering. Thus the detection of the isotropic EBL level is still of the greatest interest.

Besides galaxies, intergalactic clusters, and stars, the intergalactic gas may also contribute to the EBL (see, e.g., Weyman, 1967; Hogan and Rees, 1979; and Sherman and Silk, 1979).

2. BASIC OBSERVATIONAL CONSIDERATIONS: THE COMPONENTS OF THE LIGHT OF THE NIGHT SKY

Observations of the EBL are hampered by the much stronger foreground components of the light of the night sky (LONS). Typical minimum values of these components in the blue spectral region are given in Table 1. Unlike the other components, the EBL is isotropic, which, in combination with its weakness, complicates its separation. For ground-based observations, one has the additional problem of irregular and relatively rapid time variations due to the airglow.

The situation in the optical is very different from the microwave band, where the extragalactic component (2.7 K) is roughly equal to the atmospheric component (~2.3 K; Penzias and Wilson, 1965), and both the solar system and galactic component off the Milky Way are negligible.

The basic approach when trying to measure the EBL is to use either the differences in the spatial distributions or the differences in the spectra of the different LONS components. Since both these methods have difficulties, one should try to eliminate or minimize as many of the unwanted foreground components as possible by a suitable selection of the observing site and of the observing technique.

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

TABLE 1. Components of the Light of the Night Sky at λ = 4000 Å.
(Unit is $1 \cdot 10^{-9}$ erg cm^{-2} s^{-1} sr^{-1} Å^{-1} which at 4000 Å corresponds to ~ 0.5 S_{10})

Extragalactic background light	1–10
Integrated galactic starlight (b=90°, m>8^m)	30
Diffuse galactic light (b=90°)	0–10
Zodiacal light (β=90°)	60
Airglow (zenith)	60
Atmospheric scattered light (zenith)	20
Total	171–190

3. EBL SEPARATION USING ITS DEPENDENCE UPON GALACTIC LATITUDE

The first attempt to measure the EBL intensity photometrically was by Roach and Smith (1968). The separation of the EBL was based on the assumption that its observed intensity decreases towards the galactic plane in accordance to the cosecant-law. However, the two galactic components, the integrated starlight (ISL), and the diffuse galactic light (DGL), also show a dependence on b and, being much stronger components, completely overwhelm the EBL.

Roach and Smith (1968) derived from their analysis of a large data base of zenith sky observations an upper limit of 5 S_{10} to the EBL at λ = 5300 Å. This upper limit is, however, too stringent since the analysis did not account for the indirect EBL component that is scattered by the galactic equator, analogous to the diffuse galactic light. The scattered EBL component is strongest towards the galactic equator and decreases towards the poles. The radiation transfer problem to be solved here is a plane parallel disk of dust embedded in an isotropic incident radiation field. For the observationally determined albedo values for dust, $a \approx 0.60$ (e.g. Mattila, 1970), about half of the extinction is compensated for. Thus the Roach and Smith (1968) upper limit is transformed to $I_{EBL} \leq 10\, S_{10}$. It appears that this method does not have much promise for an actual measurement of the EBL.

4. THE METHOD OF DUBE ET AL.

Dube, Wickes, and Wilkinson (1977, 1979) have carried out very thorough ground-based photometry of the night sky where each of the individual foreground components is dealt with in a different way. The experiment used a relatively large field of view (diameter 16′), containing typically several hundred stars brighter than 20^m. However, the stars were blocked with specific *star masks*, placed in the focal plane of the telescope and prefabricated with the help of the Palomar Sky Survey plates for each one of the eleven selected high-latitude fields in the range b =46°–89°.

The zodiacal light was separated on the basis of its solarlike spectrum. The depth of the strong MgI doublet at 5175 Å was measured using a combination of a narrow and broad filter. Finally, the airglow and the tropospheric scattered light were measured by assuming that they are proportional to sec z. The measuring fields were tracked across the sky over a wide range of sec z-values, and the temporal variations of the airglow were modeled with a polynomial. The residuals in this fitting procedure contributed most of the error in the final result.

After each of the foreground components had been eliminated with an accuracy approaching 1%, the remaining sky brightness contained only the EBL and DGL. These values with

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

their error bars are plotted in Figure 1 as a function of galactic latitude. As can be seen, the individual values typically have errors of ±5 S_{10}. Dube et al. obtained 1.0±1.2 S_{10} as a mean value of all the data. Because it was not possible to estimate the DGL contribution, the result was interpreted as an upper limit on the EBL of 3.4 S_{10} or 5.1 × 10^{-9} erg cm^{-2} s^{-1} sr^{-1} $Å^{-1}$ at the 90% confidence level.

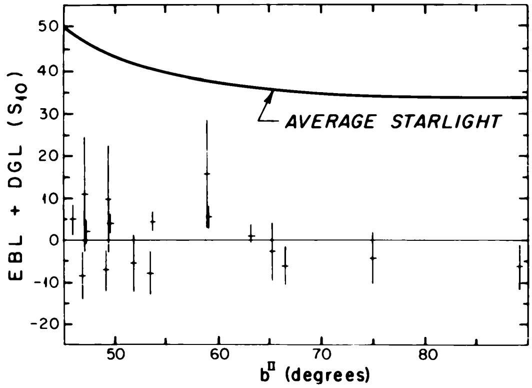

Figure 1. Results of Dube et al. (1979) for DGL+EBL vs. galactic latitude. The continuous curve indicates the average starlight.

A basic problem of this method is that it starts with the total brightness of the night sky which is a factor of ~100 brighter than the EBL. Thus, a very accurate elimination of the absolute amounts of the zodiacal light and airglow is required. Furthermore, the method does not differentiate between the EBL and DGL. The DGL, which will also have a strong MgI absorption line in its spectrum, is entangled in an unaccountable way with the zodiacal light.

5. MEASURING THE EBL BEYOND THE AIRGLOW AND THE ZODIACAL LIGHT

An unprecedented favorable opportunity for the EBL measurement was offered by the Pioneer 10 spacecraft as it passed the asteroid belt, and the zodiacal light intensity dropped beyond 3 AU to vanishingly small values. The only remaining LONS components at this observing site were the ISL, the DGL and the EBL. Because of the crude spatial resolution (2°) of the Pioneer 10 photometer experiment, starlight unavoidably dominated the signal. Toller (1983) analyzed the Pioneer 10 blue photometric data for 17 high galactic latitude areas using the Roach and Megill (1961) and Sharov and Lipaeva (1973) star count data to subtract the ISL component. Toller estimated the DGL value in these high-latitude fields to 2.0±0.4 S_{10} and derived an upper limit to the EBL of 3.9 $S_{10}(V)_{G2V}$ or 4.5 × 10^{-9} erg cm^{-2} s^{-1} sr^{-1} $Å^{-1}$ at the 2σ limit.

Because of the relatively large uncertainties in both the Pioneer photometry (±4 S_{10} or ±8%) and in the star count data (15%), an actual determination of the EBL appears not to be possible from these data. However, a larger optical telescope ($\phi \leq 50$ cm) sent above or beyond the zodiacal dust cloud has great promise for a clean measurement of the EBL and its spectrum. Equipped with an accurate photometer with ~2′ field of view, such a telescope could look *between* the stars down to ~20^m, rendering the starlight contribution negligible for the high galactic latitude areas.

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

6. THE DARK CLOUD METHOD

6.1. Description of the Method

We have been developing for several years a method for the measurement of the EBL which utilizes the screening effect of a dark nebula on the background light (Mattila, 1976; Schnur, 1980; Mattila and Schnur, 1983, 1988). A differential measurement of the night-sky brightness in the direction of a high galactic latitude dark cloud and its surrounding area, which is (almost) free of obscuring dust, provides a signal that is due to two components only: the extragalactic background light and the diffusely scattered starlight from interstellar dust.

All the large foreground components, i.e., the zodiacal light, the airglow, and the atmospheric scattered light, are completely eliminated (see Figure 2a). The direct starlight down to ~21 mag can be eliminated by selecting the measuring areas on a deep Schmidt plate. At high galactic latitudes ($|b| > 30°$), the star density is sufficiently low to allow blank fields of ~2′ diameter to be easily found. Galaxy models show that the contribution from unresolved stars beyond this limiting magnitude is of minor importance. If the scattered light from the interstellar dust were zero (i.e., the albedo of the interstellar grains $a = 0$), then the difference in surface brightness between a transparent comparison area and the dark nebula would be due to the EBL only, and an opaque nebula would be darker by the amount of the EBL intensity (dashed line in Figure 2c).

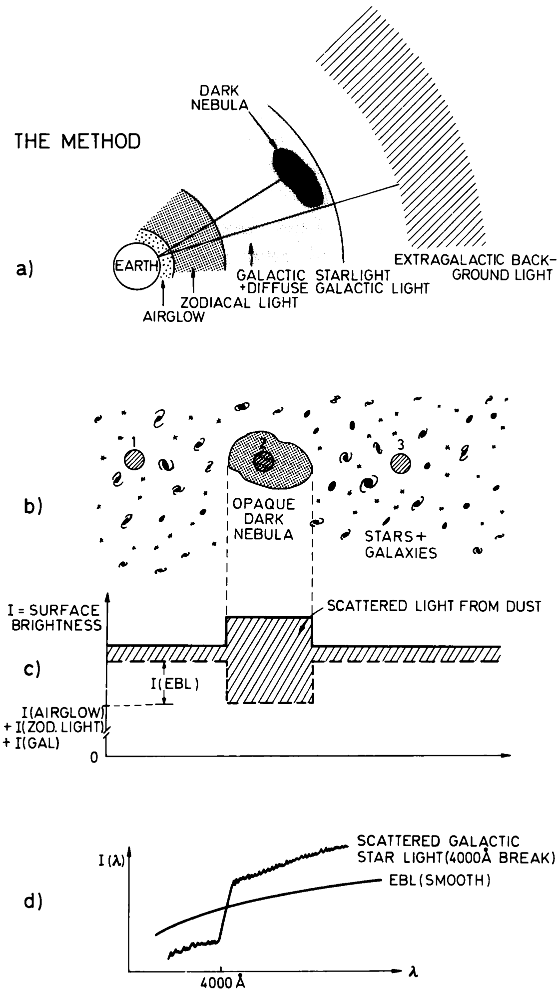

Figure 2. (a) Principle of the dark cloud method for EBL measurement. (b) Opaque dark nebula is shown in front of a high galactic latitude background of stars and galaxies. Measuring positions within the nebula (#2) and outside (#1 and 3) are indicated. (c) Schematic presentation of the surface brightness distribution across the dark nebula. (d) The difference in spectral distributions of the galactic starlight and the EBL.

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

Unfortunately, however, the scattered light is not zero. A dark nebula in the interstellar space is always exposed to the radiation field of the integrated galactic starlight, which gives rise to a diffuse scattered light (shaded area in Figure 2c). Because the intensity of this scattered starlight in the dark nebula is expected to be equal to or larger than the EBL, its separation will be the main problem in the present method.

The separation method utilizes the difference in the shape of the spectral energy distributions of the EBL and the galactic light around the wavelength $\lambda = 4000$ Å (see Figure 2d). The spectrum of the integrated starlight can be synthesized by using the known spectra of stars representing the different spectral types, as well as by using data on the space density and distribution in the z-direction of stars and dust. Synthetic spectra of the integrated starlight have been calculated by Mattila (1980a,b). The most remarkable feature in the spectrum is the abrupt drop of intensity shortward of $\lambda = 4000$ Å. The shape of the integrated starlight spectrum and especially the size of the 4000 Å discontinuity have been found to depend only weakly on the galactic latitude and the imagined z-distance of the observer, z_0.

It is possible to draw some conclusions about the spectrum of the EBL by using plausible theoretical arguments. Radiation from galaxies and other luminous matter over a vast range of distances, from $z = 0$ up to $z \approx 3$ at least, contribute to the EBL. Therefore, any sharp spectral features of the source spectrum, lines, or discontinuities, are washed out. For the present study, it is important to recognize that the discontinuity at 4000 Å, although present in all galaxy spectra, does not occur in the integrated background light.

Figure 3 illustrates how the spectral energy distribution of the observable surface brightness difference, dark nebula minus surroundings, changes for different assumed values of the EBL intensity. It can be seen that the drop at 4000 Å increases when more EBL is present.

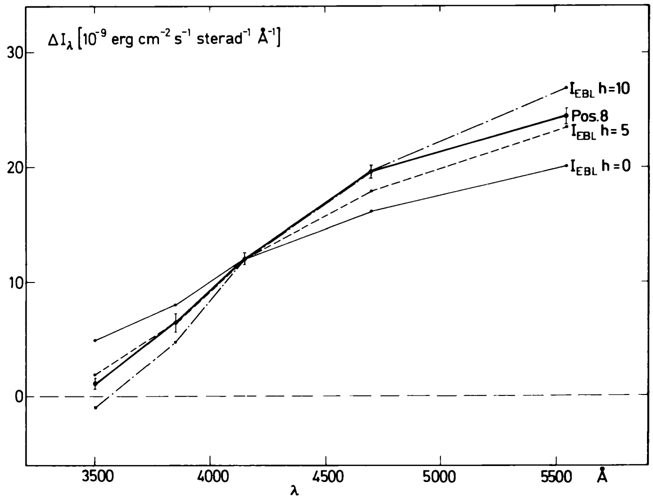

Figure 3. The observed spectrum for position 8 in L1642 (points with error bars) is compared with the pure scattered light spectrum (I_{EBL} $h = 0$) and two cases with corrections for an assumed EBL contribution, I_{EBL} $h = 5 \times 10^{-9}$ and 10×10^{-9} erg cm^{-2} s^{-1} sr^{-1} Å^{-1}. The scattered light spectrum has been derived empirically from the observed L1642 spectra in the range $A_B = 1$–2^m (see Figure 4c). The spectra have been normalized to the observed value of position 8 at 4150 Å.

More quantitatively, we can calculate the EBL from the following formula (see Mattila, 1976):

$$I_{EBL}(3850) \cdot h = I_{EBL}(4150) \cdot h = \frac{10^{-0.4\Delta m_{4000}} \Delta I_{obs}(4150) - \Delta I_{obs}(3850)}{1 - 10^{-0.4\Delta m_{4000}}}. \qquad (1)$$

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

In this formula, $\Delta I_{obs}(3850)$ and $\Delta I_{obs}(4150)$ are the observed surface brightnesses of the dark nebula at 3850 and 4150 Å, Δm_{4000} is the size in magnitudes of the 4000 Å jump in the scattered light spectrum, and h is the blocking factor of the cloud for an isotropic background radiation. A similar formula can be used for the wavebands at 3500 and 3850 Å, in which case a colour index Δm_{3600} is used.

6.2. Earlier Results in the L134 Area

The result of the first application of the above-described method to the dark nebula L134 area ($l = 4°$, $b = 36°$) gave an unexpectedly high EBL intensity of $(23 \pm 8) \times 10^{-9}$ erg $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}\ \mathrm{Å}^{-1}$ ($10 \pm 4\ S_{10}$) at 4000 Å (Mattila, 1976). Later, the same method was used by Spinrad and Stone (1978) at the same nebula; they obtained a 3σ upper limit of 10×10^{-9} erg $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}\ \mathrm{Å}^{-1}$ (or 5 S_{10}) to the EBL at 4000 Å. Surprisingly, their measurements did not show any surface brightness excess in L134, although this excess is readily seen both on red and blue photographic plates obtained of the L134 area with the ESO 1 m Schmidt telescope. Boughn and Kuhn (1986), again applying the dark cloud technique, observed a minimum excess surface brightness of 1.5×10^{-9} erg $\mathrm{s}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{sr}^{-1}\ \mathrm{Å}^{-1}$ at 6500 Å in the L134 cloud centre. Their "clear" comparison areas were, however, quite close to the cloud and were probably contaminated by a considerable amount of dust. Thus a conclusive upper limit to the EBL was not obtained from this experiment.

7. EVIDENCE FOR EBL IN THE L1642 AREA

7.1. Observations

We have continued the measurements of the EBL with the dark cloud technique in the area of the high-latitude dark nebula L1642 ($l = 210°$, $b = -36°.5$; Mattila and Schnur, in preparation). As compared with Mattila (1976), the observing and data analysis methods have been considerably improved. The observations were carried out in 20 nights in December 1980, 1987, and 1988 using the 1 m telescope of the European Southern Observatory (ESO). Five intermediate-band filters were used, centered at 3500 Å (u), 3850 Å, 4150 Å, 4700 Å (b), and 5550 Å (y). The field size was 88″. Both starcount data and far infrared (IRAS) surface brightness maps of the L1642 area (see Laureijs, Mattila, and Schnur, 1987) were used to select transparent areas around the cloud for fixing the background level. In addition, uvby β-photometry of several A-F type stars in these areas has been performed by Franco (1989), and his results prove that the extinction in our comparison areas is indeed very small, $A_V < 0^m.05$, for distances up to ~250 pc. The distance of L1642 has been found to be between 70 to 230 pc (Andreani et al., 1988; Franco, 1989).

The photoelectric surface photometry of weak extended objects is hampered by the time-variability of the airglow. In our observations, we have used a method in which the airglow fluctuations are eliminated by means of strictly simultaneous parallel observations with the ESO 50 cm telescope (see Schnur and Mattila, 1989, this volume). Because of the large angular size (~4°) of our total measurement area, a correction for the zodiacal light gradient is needed. This was done by fitting a plane through the background areas.

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

7.2. Qualitative Analysis

The spectral energy distributions for several measured positions in the cloud are presented in Figures 4a-d. The optical extinction, A_B, as determined from star counts for each position, is indicated. The following trends are noted: (1) The surface brightness increases with increasing optical depth until the extinction (at the respective wavelength) has reached a value of $1^{m}5$ to 2^{m}. Then it slowly decreases (see also Figure 7 in Laureijs, Mattila, and Schnur, 1987). (2) The spectra show a systematic tendency of reddening with increasing optical depth of the cloud position.

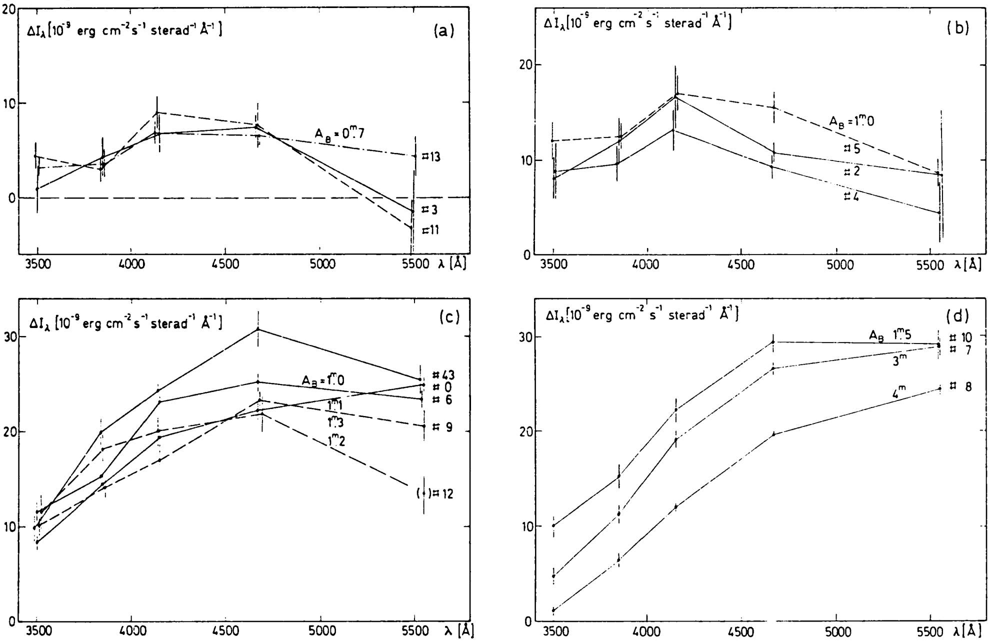

Figure 4. Observed spectral energy distributions, ΔI_λ, *dark nebula minus surrounding clear sky*. Labels indicate the blue extinction values as estimated from starcounts and $\tau 100 \mu m$. (a-b) Spectra for low opacity positions. (c) Spectra for intermediate opacity positions. (d) Spectra for high opacity positions.

The best chance of detecting the EBL is to look at the positions which have (a) the largest optical depth through the cloud and (b) the lowest surface brightness. In practice these two conditions are fulfilled for the same positions. In our observations of L1642, position 8 was identified to best fulfill both these conditions.

An EBL contribution for position 8 is strongly suggested. At this position the surface brightness of the cloud at 3500 Å is only marginally higher than the clear background, i.e., $\Delta I = (1.1 \pm 0.5) \times 10^{-9}$ erg cm^{-2} s^{-1} sr^{-1} Å^{-1}, whereas the surface brightness of the cloud at the longer wavelengths (λ = 3850, 4150, 4700, and 5550 Å) is clearly in excess above the background. This situation can arise only in one of the following two ways: (1) the albedo of the dust decreases strongly towards shorter wavelengths and drops to nearly zero at 3500 Å, or (2) there is a background light component, emanating from behind the cloud, of the same order of magnitude as the scattered light surface brightness of the cloud.

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

The first possibility is ruled out by the fact that at other, less opaque positions in the same cloud the surface brightness at 3500 Å is significantly different from zero and is about one-half of the values obtained at $\lambda \geq 4000$ Å. It is not to be expected that the albedo specifically at 3500 Å would drop strongly towards opaque areas.

The second possibility, i.e., an EBL, provides a natural explanation for the decrease of excess surface brightness at 3500 Å. This also explains the continuous sequence of the spectral energy distributions. For position 7, which is the second most opaque position in the cloud, the same tendency of an abnormally low 3500 Å brightness is observed. The same behaviour is seen for position 10. For a sufficiently low scattered light contribution, the dark nebula would be darker than the surrounding background (see Figure 3). Unfortunately, this case is, even at 3500 Å, just beyond the balance situation for the two components in the L1642 cloud.

For the determination of the scattered light contribution from the cloud we can use one of two methods:

1. The spectral shape of the energy distribution of the scattered light around $\lambda = 3500$–4000 Å is different from the expected EBL energy distribution (see section 6.1). The spectrum of the scattered light for the opaque positions of the cloud can be obtained by (a) calculating the synthetic starlight spectrum or (b) using the observed spectral energy distributions at other, less opaque positions in the cloud.
2. Models of the τ-dependence of the scattered light can be fitted to the observed surface brightness values at the *less opaque* parts of the cloud. The model fit predicts the scattered light contribution at the *more opaque* positions.

7.3. EBL Separation Using the Spectral Energy Distribution Method

Because of reddening (or blueing) in the cloud, the spectrum of the scattered light is not identical to the illuminating starlight spectrum. The reddening of the *diffuse* scattered radiation is different from the normal interstellar reddening, which is valid for point sources. Since the size of the jump at 4000 Å has to be measured in practice by using bandpasses that are some 100–300 Å apart, the quantity Δm_{4000} is influenced by the reddening.

The colour indices Δm_{3600} and Δm_{4000} for the scattered light can be determined from our observations in L1642. The observed spectra corresponding to intermediate extinctions in the range $A_B = 1$–2^m (Figure 4c) show a great similarity with the integrated starlight spectrum, both qualitatively and quantitatively. The reddening of the *diffuse* radiation is minimal for this extinction range (see Mattila, 1976). To make an empirical estimate of the reddening corrections to Δm_{3600} and Δm_{4000} needed for $\tau_B = 4$, we utilize the long-wavelength colour-index Δm_{5000}, which is not influenced by the EBL (because the unreddened scattered light spectrum is flat between 4700 and 5500 Å).

Using these empirical colour index values for the scattered light, we obtain from equation (1) and from an analogous formula for the 3500 and 3850 Å bands the result $I_{EBL}\,h = (6.0 \pm 1.3)\,10^{-9}$ erg cm^{-2} s^{-1} sr^{-1} Å^{-1}. The fraction h corresponding to the blockage of the EBL can be estimated to be $h = 0.9$ for $\tau \approx 4$. Thus $I_{EBL} = (6.7 \pm 1.4)\ 10^{-9}$ erg cm^{-2} s^{-1} sr^{-1} Å^{-1}.

7.4. EBL Separation Using the τ-dependence Method

The scattered light contribution at the opaque positions of the cloud can also be estimated by utilizing a model curve for $I_{sca}(\tau)$, obtained from multiple scattering calculations and fitted through the observed points at low and intermediate optical depths. The observed surface brightness difference at 3500 Å for position 8 then results in an EBL contribution of

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

$$I_{EBL}\, h \approx 5.2 \pm 2 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ Å}^{-1} \,.$$

Thus $I_{EBL} = 5.8 \pm 2 \times 10^{-9}$ erg cm^{-2} s^{-1} sr^{-1} Å^{-1}. This value agrees very well with the result which was obtained above with the spectral energy distribution method. The uncertainties in estimating the values of Δm_{3600} and Δm_{4000} for the scattered light are of the order of $\pm 0\overset{\mathrm{m}}{.}05$. This will introduce an error of about $\pm 2 \times 10^{-9}$ erg cm^{-2} s^{-1} sr^{-1} Å^{-1} to I_{EBL}. A similar uncertainty is inherent in the model calculations of τ-dependence method. Thus we adopt as an average value from these two methods

$$I_{EBL} = 6.5 \pm 2.5 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ Å}^{-1}$$

as the result of the present observations. This value corresponds to $3 \pm 1\ S_{10}(A\,0V)$ at 4000 Å. We would like to emphasize that this is still a preliminary value and refer to Mattila and Schnur (1989, in preparation) for the final results.

8. COMPARISON OF THE EBL MEASUREMENTS

A compilation of the different EBL determinations is presented in Table 2. The present result for the EBL intensity is significantly smaller than the previous value of Mattila (1976), i.e., $I_{EBL} = 23 \pm 8 \times 10^{-9}$ erg cm^{-2} s^{-1} sr^{-1} Å^{-1}. We think that most of the discrepancy is due to the much larger observational errors inherent in the 1976 values, which were based on a single-telescope observing technique. A part of the discrepancy may be due to a real difference of the background light intensities in these two directions: any galactic contribution would be stronger in the center direction (L134) than in the anticenter direction (L1642) because of the longer line of sight through the galactic halo. However, the galactic contamination of the present EBL results is expected to be minimal. In any case a repetition of the EBL measurement in the L134 area is of great interest, and observations have already been started at La Silla (Mattila and Schnur) and at Calar Alto (Mattila and Leinert). Comparing the upper limits of Dube, Wickes, and Wilkinson (1979) and Toller (1983) with our present EBL measurement, we conclude that there is no obvious discrepancy. Our measured value is close to these upper limits.

TABLE 2. Compilation of Results for the EBL Intensity.
(Unit is $1 \cdot 10^{-9}$ erg cm^{-2} s^{-1} sr^{-1} Å^{-1})

Authors	Year	I_{EBL}	λ(Å)	Site	Method
Roach and Smith	1968	<6	5300	ground	b-dependence
Lillie	1968	<5	4100	rocket	subtraction of foreground components
Mattila	1976	23±8	4000	ground	dark cloud L134
Spinrad and Stone	1978	<10	4000	ground	dark cloud L134
Dube et al.	1977,1979	<5.1	5115	ground	subtraction of foreground components
Toller	1983	<4.5	4400	R>3 AU	subtraction of starlight
Boughn and Kuhn	1986	(<1.5)*	6500	ground	dark cloud L134
Mattila and Schnur	1989	6.5±2.5	3500–4000	ground	dark cloud L1642
Tyson	1988	0.68+0.03 -0.01	4500	ground	galaxy counts

* Minimum surface brightness of the nebula (see text)

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

Recent galaxy counts by Tyson (1988), extending to $m_J \approx 27^m$, have provided an estimate of the EBL due to galaxies: $I_{EBL} = 0.7 \times 10^{-9}$ erg cm^{-2} s^{-1} sr^{-1} Å^{-1}. According to Tyson, 75% of this EBL value, i.e., $I_{EBL} = 0.5 \times 10^{-9}$ erg cm^{-2} s^{-1} sr^{-1} Å^{-1}, is due to galaxies fainter than $m_J = 20^m$ (which is comparable with the magnitude limit in our p.e. measurement areas). Thus, according to Tyson's result only a small fraction of our present observed EBL intensity can be explained in terms of integrated light of galaxies.

Acknowledgments—I gratefully acknowledge the collaboration with Dr. Gerhard Schnur on the EBL observations during the past ten years.

REFERENCES

Andreani, P., Ferlet, R., Lallement, R., Vidal-Madjar, A. 1988, *The ESO Messenger* **52**, 47.
Arp, H. 1965, *Astrophys. J.* **142**, 402.
Boughn, S.P., Kuhn, J.R., 1986, *Astrophys. J.* **309**, 33.
Dube, R.R., Wickes, W.C., Wilkinson, D.T. 1977, *Astrophys. J.* **215**, L51.
Dube, R.R., Wickes, W.C., Wilkinson, D.T. 1979, *Astrophys. J.* **232**, 333.
Franco, G. 1989, *Astron. Astrophys.* (in press).
Halley, E. 1721, *Philosophical Transactions* **31**, 22; **31**, 24.
Harrison, E. 1964, *Nature* **204**, 271.
Harrison, E. 1987, *Darkness at Night* (Cambridge and London: Harvard Univ. Press).
Harrison, E. 1989, in *Proc. IAU 139, Galactic and Extragalactic Background Radiation*, ed. S. Bowyer and Ch. Leinert (Dordrecht: Kluwer Academic Publisher).
Hogan, C.J., Rees, M.J. 1979, *Mon. Not. R. Astr. Soc.* **188**, 791.
Laureijs, R., Mattila, K., Schnur, G.F.O. 1987, *Astron. Astrophys.* **181**, 269.
Lillie, C.F. 1968, PhD thesis, University of Wisconsin (unpublished).
Loys de Chéseaux, J.-P. 1744, Traité de la comète qui apparut en décembre 1743, Lausanne, p. 223.
Martin, C., Bowyer, S. 1989, *Astrophys. J.* **338**, 677.
Mattila, K. 1970, *Astron. Astrophys.* **9**, 53.
Mattila, K. 1976, *Astron. Astrophys.* **47**, 77.
Mattila, K. 1980a, *Astron. Astrophys. Suppl.* **39**, 53.
Mattila, K. 1980b, *Astron. Astrophys.* **82**, 373.
Mattila, K., Schnur, G.F.O. 1983, *Mitt. d. Astron. Gesellsch.* **60**, 87.
Mattila, K., Schnur, G.F.O. 1988, *ESO Messenger* **51**, 34.
Mattila, K., Schnur, G.F.O. 1989, in preparation.
McVittie, G.C., Wyatt, S.P. 1959, *Astrophys. J.* **130**, 1.
Olbers, H.W.M. 1823, *Astronomisches Jahrbuch 1826* (hrsg. von J.E. Bode), p. 110.
Partridge, R.B., Peebles, P.J.E. 1967, *Astrophys. J.*, **148**, 377.
Penzias, A., Wilson, R. 1965, *Astrophys. J.* **142**, 419.
Roach, F.E., Megill, L.R. 1961, *Astrophys. J.* **133**, 228.
Roach, F.E., Smith, L.L. 1968, *Geophys. J.* **15**, 227.
Sandage, A., Tammann, G.A. 1965, *Ann. Rep. Mt. Wilson and Palomar Obs. 1964-1965*, p. 35.
Schnur, G.F.O. 1980, in *ESO Workshop on Two Dimensional Photometry*, eds. P. Crane and K. Kjär, p. 365.
Schnur, G.F.O., Mattila, K. 1989, in *Proc. IAU 139, Galactic and Extragalactic Background Radiation*, ed. S. Bowyer and Ch. Leinert (Dordrecht: Kluwer Academic Publisher).
Sharov, A.S., Lipaeva, N.A. 1973, *Soviet Astron.* **17**, 69.
Shectman, S.A. 1973, *Astrophys. J.* **179**, 681.
Shectman, S.A. 1974, *Astrophys. J.* **188**, 233.
Sherman, R.D., Silk, J. 1979, *Astrophys. J.* **231**, L61.
Spinrad, H., Stone, R.P.S. 1978, *Astrophys. J.* **226**, 609.
Stabell, R., Wesson, P.S. 1980, *Astrophys. J.* **242**, 443.
Tinsley, B.M. 1973, *Astron. Astrophys.* **24**, 89.
Toller, G.N. 1983, *Astrophys. J.* **266**, L79.
Tyson, J.A. 1988, *Astron. J.* **96**, 1.

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press

Wesson, P.S., Valle, K., Stabell, R. 1987, *Astrophys. J.* **317**, 601.
Weyman, R. 1967, *Astrophys. J.* **147**, 887.
Whitrow, G.J., Yallop, B.D. 1963, *Monthly Notices Roy. Astron. Soc.* **127**, 301.
Yoshii, Y., Takahara, F. 1988, *Astrophys. J.* **326**, 1.

G. Verschuur: *Are your observations affected by light pollution?*

K. Mattila: The light pollution level at La Silla is (still!) very low. In addition, since we are making a differential measurement, the light pollution adds only to the noise.

Cécile Gry and Alan Harris

https://doi.org/10.1017/S0074180900240825 Published online by Cambridge University Press