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Multi-colour photometry with GAIA of the diffuse sky background

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Abstract

The report discusses the possible multi-colour photometry of the diffuse sky surface with the Astro and Spectro telescopes of GAIA. The ordinary photometry of faint stars will give good results of the background for at least 500 million spots on the sky. Measurement from about 100 of these spots in a small area could be averaged to obtain a precision of about 0.5 S_{10} of GAIA medium-band photometry in each of the 5 million areas. It is concluded that GAIA medium-band photometry is suited to tackle a whole range of astrophysically interesting diffuse sky components. After modeling and subtracting the time-variable Zodiacal Light, GAIA could provide multi-wavelength all sky maps of the low galactic latitude Diffuse Galactic Light and the high latitude Galactic Cirrus Clouds. Possibly also the Extragalactic Background Light could be detected.

1 INTRODUCTION

The possible multi-colour photometry of the sky surface with the Astro and Spectro telescopes of GAIA has been discussed in some detail in the technical report [2] of which a summary is given here. This photometry makes use of the data in the patches for stars, thus no extra telemetry is required, only a proper data reduction on the ground, for instance as described in [4,5]. We only discuss the diffuse sky background, not however the locally increased brightness on nebulae or galaxies; GAIA measurement of galaxies has been studied in [7] and [8]. The reference paper on diffuse night sky brightness is [6].

The ordinary photometry of the faintest stars will give good results of the background for at least 500 million spots on the sky. The precision per spot for the mission average values is derived. At a typical sky brightness of $\mu_V = 23.0$ mag/arcsec^2 at high ecliptic and galactic latitudes (covering most of the sky) a precision of 0.003 mag is obtained in G and about 0.06 mag in all medium width photometric bands for spots of 7 arcsec diameter. We conclude that GAIA medium-band photometry is suited to tackle a whole range of astrophysically interesting diffuse sky components. The required accuracy and low level of straylight can probably be realised.

A main issue to be solved is the separation of the variable zodiacal light component from the two other known components of diffuse galactic light and galactic cirrus. A further yet unknown component, extragalactic background light, might then be detected. The multi-colour capability of the GAIA medium-band photometer is important here.

2 MEASUREMENTS AND PRECISION

Some characteristics of the various detection chains and the detailed results for the Astro and Spectro telescopes are given in [2]. The sky areas per patch obtained from the Spectro telescope are much larger than from Astro, and the total noise per sample is much smaller. This, together with longer integration times, leads to a much better precision for surface photometry with the Spectro telescope.

The Spectro sky mapper measures the sky in the G band and we assume that effectively 30 arcsec^2 contribute. The G band employs no filter, the whole CCD response corresponds to a central wavelength of 700 nm and a FWHM = 800 nm.

For the medium-band photometer in the Spectro telescope the patch covers an area of 7.0×2.0 arcsec^2, and the mission average is therefore obtained over a circle with diameter 7 arcsec, centred on a star. We assume that effectively 10 arcsec^2 are available for the surface photometry in each band.

The precision per spot on the sky given in Table 1 is calculated from the following formulae. Let b be the counts per sample from the sky during the integration time, and r be the total noise from the reading of a basic sample. The standard error of the sample is then

$$\sigma_{b1} = \sqrt{b + r^2} \tag{2.1}$$

with b calculated as

$$b = SAt/n_b \tag{2.2}$$

where S is the count rate per sample, A is the sky area of the patch, t is the integration time per sample, and n_b is the number of samples per patch containing background.

The standard error per sample of the mean value for the mission is

$$\sigma_b = \sigma_{b1}/\sqrt{n_b n_p} \tag{2.3}$$

where n_p is the number of patches collected during the mission. Usually one patch per scan of the star is collected, but sometimes (for P and u) 2 or 3 patches are collected in the medium-band photometer.

The signal-to-noise value is then

$$R = b/\sigma_b \tag{2.4}$$

and the standard error in magnitudes is

$$\sigma_m = 1.086/R. \tag{2.5}$$

The surface brightness μ_V may also be expressed in units of S_{10} as

$$\mu'_V = 10^{-0.4(\mu_V - 27.8)} \tag{2.6}$$

where the unit is defined as 1 S_{10} = 27.8 mag/arcsec^2 or 1 star of $m_V = 10$ mag per square degree. The corresponding standard error is

$$\sigma'_m = \mu'_V/R = \mu'_V \sigma_m/1.086 \tag{2.7}$$

These errors, multiplied with a margin factor 1.2, are given in Table 1, where the diffuse sky has been assumed to have a solar type spectrum. There are about 100 scans per star per band during the 5 year mission time which has been taken into account in the standard errors.

Table 1. The diffuse surface brightness measurements with the Spectro telescope. The wide G band measured in the Spectro sky mapper, and the medium width P band centred at 380 nm (FWHM = 26 nm). μ_V is the surface brightness, σ the standard error of the average of 100 scans with GAIA. The left and right half of the table give the same information in different units: in mag/arcsec^2 at left and in unit of S_{10} at right.

μ_V	σ_G [mag/arcsec^2]	σ_P	μ'_V [S_{10}]	σ'_G [S_{10}]	σ'_P [S_{10}]
21.0	0.001	0.013	515	0.5	6.2
22.0	0.002	0.027	205	0.4	5.1
23.0	0.003	0.062	82	0.2	4.7
24.0	0.006	0.149	32	0.2	4.5

Table 2. The components of diffuse sky background in the optical as seen from above the Earth's atmosphere.

Zodiacal Light (ZL)	30 - 100 S_{10}
Diffuse Galactic Light (DGL) *i.e.* scattered light from interstellar dust near the plane	30 - 50 S_{10}
Galactic Cirrus *i.e.* scattered light plus fluorescence emission (ERE) from interstellar dust at high latitudes	1 - 20 S_{10}
Line emission (H_α) from typical ionized high latitude galactic gas	0.2 - 2 rayleigh = 0.5 - 5 10^{-7} erg/s cm^2 sterad
Extragalactic Background Light (EBL) (not yet detected)	0.5 - 2 S_{10}

The standard error per scan is therefore about 10 times the values in the table. This must be taken into account when a variable sky background is encountered, especially in the zodiacal light.

The tables in [2] show that at a typical surface brightness of $\mu V = 23.0$ mag/arcsec^2 a precision of 0.003 mag is obtained in G and about 0.06 mag in all medium width photometric bands for spots of 7 arcsec diameter. Inside each spot a resolution about 0.5 arcsec will be obtained, with correspondingly lower photometric precision.

3 SCIENTIFIC INTEREST

The considerations in [2, 3] are followed here. With our current knowledge of the diffuse sky background in the optical as seen from above the Earth's atmosphere, there are four main components, listed in Table 2. For three of them an estimated range of values at 380 nm is given in units of S_{10}. A possible fifth component (EBL) has not yet been detected.

Zodiacal Light: There are probably no major open scientific issues about the ZL itself which would make an extensive multifilter optical photometry justified. But this may be a bit pessimistic in the sense that the multifilter aspect provided by GAIA would still be unique and would provide an accurate measure of the colour variation of the ZL over the sky. However, ZL is the main foreground component for the diffuse sky background as seen from above the

Earth's atmosphere. Therefore an accurate knowledge of ZL distribution over the sky and its variation with time are needed when studying the other components.

Diffuse Galactic Light, I: low galactic latitudes: About 1/3 of the (total) integrated galactic surface brightness at low latitudes is due to scattered light from interstellar dust. It is commonly called the Diffuse Galactic Light (DGL). The DGL has previously been measured over limited regions of the sky, but already in several filters 350 - 700 nm. GAIA with its complete sky coverage and many filter bands could contribute substantially to this field. The essential scientific result expected is the albedo and a rough shape of the dust scattering function, both for the full range of GAIA wavelength coverage. These results in turn will provide a good handle on restricting the interstellar grain models.

Diffuse Galactic Light, II: high latitude cirrus: The Infrared Cirrus as mapped by IRAS over the whole sky has a counterpart in the optical wave band. In the optical the radiation is due to starlight scattered by interstellar dust plus a possible contribution by fluorescence (Extended Red Emission, ERE). This Optical Cirrus has so far been measured only in limited areas. Scientifically one would expect very useful results on dust properties and their variations from cloud to cloud when the optical and IR cirrus measurements are compared with each other and with the accurate extinction measurements provided by GAIA for many million lines of sight.

Line emission (H_α) from ionised gas: This emission can be accurately measured also from ground. There are several extensive sky surveys both on the northern and the southern hemisphere going on. Therefore GAIA could probably not produce unique observational material here through its H_α filter photometry. (The intensity of this emission is taken from [9], and corrects the too large value given in [3].)

Extragalactic Background Light: This is a very weak isotropic component of the diffuse sky background. So far there is no measured value for the EBL in the optical domain, only upper limits. One can estimate that the EBL is about 0.5 to 2 S_{10}. This component is of great cosmological importance. Because of the (tentative?) detection of the far-IR EBL by COBE/DIRBE there is increased current interest also in the optical EBL. Being above the Earth's atmosphere the main problem for EBL measurement is how to separate it from the two dominating foreground sky components, *i.e.* the ZL and the Galactic Cirrus. Thanks to its multi-wavelength capacity the GAIA medium-band photometer would be in a good position to perform the separation based on the different SEDs of ZL, Galactic Cirrus, and EBL. However, the GAIA photometric sensitivity may be a problem here.

It appears that, in order to enable a separation of the ZL, DGL, Cirrus, and EBL components from each other, the most important medium band filters are 350, 380, and 405 nm. In order to measure the Red Extended Emission (ERE) a filter at about 700 nm would be needed.

4 CONCLUSIONS

The preliminary conclusion is that GAIA diffuse sky medium-band photometry can contribute interesting scientific results, if the following requirements can be met: (1) The average of some 100 spots may be formed to obtain an accuracy of 0.5 S_{10}, and (2) the instrumental stray radiation contribution from stars plus diffuse sky components is less than 0.5 to 1 S_{10}.

These requirements can be met: (1) A group of 100 spots from the instruments can be averaged to obtain an accuracy of 0.5 S_{10} with the medium-band photometer. This requires a careful calibration of GAIA photometry and this accuracy goal should be kept in mind when the photometric processing is designed and developed.

(2) The instrumental straylight from stars plus diffuse sky components should be less than 0.5 to 1 S_{10}. This is a requirement for the baffling of the telescopes. This is achieved with a

conical baffle extending from the focal plane of the Astro telescopes, discussed in Section 3.2.5 in [1] and shown in Figure 4.2/6 in the GAIA CTS Study Final Report. The Spectro telescope has no such baffle at present (see Figure 5.2/1) but it is possible to introduce it. This baffle seems to be required even for the sake of the medium-band photometer and the radial velocity spectrometer.

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