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Zodiacal Light Emission in Cosmological Missions

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This contribution reviews the most difficult observational aspect of Zodiacal Light Emission (ZLE) in CMB missions below 1 THz: its separability from the background. We compare the background subtraction based on the use of priors and on differential methods exploiting signal time dependence. We illustrate the impact of systematics such as the straylight. Finally, we address the problem of differences in the ZLE geometrical properties possibly relevant at these frequencies.

Keywords: Zodiacal Light, cosmic background radiation.

1. Introduction

The physics of the Zodiacal Light Emission (ZLE) as a foreground for CMB studies has been already presented elsewhere in this issue[1] . We consider here some of the observational aspects crucial for ZLE detection at frequencies below 1 THz.

2. Separability of ZLE

How strong is the ZLE below 1 THz? The expected peak flux for the ZLE is about 0.6 MJy/sr at most, or about half of the Galactic emission in the corresponding sky regions[2] . So the limiting factor in detecting the ZLE in this frequency range is our ability to separate it from the background, mainly represented by the Galactic dust emission. Measures from COBE/FIRAS[3] shows how the ZLE spectrum, averaged over the sky, can be approximated in this frequency range by a modified blackbody at $T \sim 240$ K with an emissivity scaling as the square of the frequency, i.e. $\propto f^2$, not so different from the spectral shape of Galactic emission. Blind components separation techniques are not effective, and some prior have to be introduced. As an example the separation can be attempted by exploiting the planar symmetry of ZLE with respect to the Solar System fundamental plane which is tilted over the Galactic plane. In the ecliptic frame and in the case of perfect symmetry the multipole decomposition of the ZLE will be characterized by $a_{\ell,m} \neq 0$ just for ℓ even and $m = 0$. This can be used to define an optimal spatial filter to increase the ZLE S/N ratio. Alternatively, at scales of tens of degrees the properties of the background are known, so a low resolution template map of the Galactic emission, may be subtracted from an observed one with some level of confidence[2] . In general, the template can be produced extrapolating high frequency data, where detecting and removing the ZLE is relatively easier, or from low frequency data, where the ZLE is assumed to be not relevant. Of course, if ZLE is not properly removed at high frequency or if some residual ZLE is present at low frequency the pattern in the subtracted map will be distorted. A method which is nearly completely independent of any prior is based on the exploitation of the characteristic time dependence of the ZLE signal, either in TODs or in maps. Indeed, CMB missions does not scan the sky in a single shot. Rather the sky is scanned in small blocks, rings or some other closed figures, which are subsequently merged to obtain maps. In this time the observer moves within the cloud of Interplanetary Dust Particles (IDPs), making the ZLE time dependent. This can be relatively well modeled once the cloud geometry is know and the observer motion and scanning strategy are given. In particular it is very important to take in account the time distribution of the observations of the regions of sky which has to be sampled. As an exemplification, we may compare the scanning strategies of the COBE and *Planck* missions. The DIRBE instrument in the COBE satellite scanned the sky at 0.8 rpm in circles of 30 deg radius plus a slow precession which was made to keep the spin axis at 94 deg from the Sun. In this way the same region of sky was visited many times within some months allowing the detection of ZLE variability at the level of TODs. The *Planck* satellite scans the sky in narrow circles of about 85 deg radius, and the time needed to have enough circles to compose a full sky scan map is about 7 months. Rings are distributed nearly symmetrically with respect to the ecliptic. The period of repeated transits at low and intermediate ecliptic latitudes is of the order of half a year. For this reason the best strategy for *Planck* is to take the difference of maps produced in subsequent sky surveys[2] . Despite time dependence allows a full self-consistent detection of the ZLE, since in principle it does not require any prior knowledge of the background, its main limitation come from the fact that just the IDPs in the neighbor of the observed can be detected in this way. In fact, by taking as an example the widely used COBE model[4] , it is easy to see that only IDPs located within 2 AU from the observer, or 2.5 AU from the Sun, contributes significantly to the signal time variability, to be compared with the outer radius of the cloud which is limited by Jupiter's orbit at 5.2 AU from the Sun. In addition, the level of variability is small, less than ten percent of the integrated signal, and the risk of underestimating the total ZLE contamination even at wavelengths where the ZLE is strong, can not be neglected. In particular the contribution of cold dust components, as those discussed in [5] and [6] (see also references therein), can not be detected with this method. For this reason, exploiting time dependence and background subtraction can be regarded as complementary methods.

Having to do with weak signals, and taking again *Planck* as an exemplification, a number of technical problems affect the differential method: 1. calibration, 2. noise, 3. pointing errors, 3. bright sources, 4. asymmetric beams, 5. straylight associated to far sidelobes. Most of them have been reviewed extensively in [2] . The expected pointing errors for the *Planck* mission does not introduce relevant distortions in the differential profile, given the large angular scale implied by the ZLE. The worst effect occurs where the background signal introduces a strong contribution, i.e. near the Galactic plane and bright point sources, thus calling for suitable sky masking. The same holds for the relative calibration. However, the effect of spillovers have been not considered so that it is worth to spent some word on them taking again *Planck* as an exemplification. In this mission the main spillover is approximately located between the spin axis direction and the telescope LOS (separated by an angle of 85 deg). It is due to the light entering the top of the sun–shield, aligned with the spin axis, and scattered by the secondary mirror toward the focal plane[7] . The maximum perturbation occurs when the spin axis is near the Galactic center, and affects the regions of sky at about ±85 deg from it. Those regions are observed also when the spin axis is at about ±170 deg from the Galactic center. A localized fake seasonal variability will arise from the spillover effect. An upper limit of such effect can be estimated modeling the spillover as a beam with about 20 deg FWHM and a peak response of about -60 db with respect that in the main beam center[7] and pointing it toward a region near the Galactic center: for the *Planck* 857 GHz channel one finds $\sim 9 \times 10^{-5}$ MJy/sr, i.e. $\sim 0.2\%$ of the maximum of the expected seasonal variability. The geometry of the telescope and of the scanning strategy determines where the straylight effect is projected in the pixelized[8] observed sky map[9] . The ratio between this effect and the local amplitude of the signal induced by ZLE seasonal dependence amounts from ∼ few percent to ∼ ten percent. Depending on the level of confidence by which this systematic can be modeled, the corresponding region of sky shall be masked or a spillover map shall be introduced as a further component (with a possible free scaling parameter) in data analysis.

3. Modeling the ZLE signal

In phenomenological models like the widely used COBE model[4] the 3D distribution of the ZLE below 1 THz is splitted in a list of sub–clouds or components, indexed by c, made of IDPs with homogeneous properties and assumed to emit as blackbodies. Examples in the COBE model are: the dominating smooth cloud, the bands, the circumsolar ring and the trailing blobs[4] . A correction factor $E_f^{(c)}$ is then introduced to correct for the real emissivity within a given frequency band, and the 3D model is used to predict the integrated ZLE along a given line of sight, at a given epoch, for given positions of the observer, the Sun and the Earth. The expected time variation of the model is fitted by χ^2 minimization against the brightness variations of sky $\Delta I_{f,p,t}$, where f is the frequency band at which the observation is made, p is an index running over a list of selected positions in the sky, t runs over the list of epochs in which p is observed. Of course, the list of sample positions p shall be selected avoiding the regions where the ZLE is too weak, or the background is too badly modeled. On the other hand, smaller will be the region of sky considered eligible larger will be the statistical error. A trade off between the strength of the selection criteria and the effectively adopted survey area will have to be found, fixing in this way the ultimate accuracy of the method[2] . For the detection approach based on time variability, we can search for a χ^2 minimization, where

$$\chi^2 = \sum_f \sum_p \sum_{t\in p} \left(\sum_c C_f^{(c)} E_f^{(c)} \Delta Z_{f,p,t}^{(c)}(\bar{\Theta}^{(c)}) - \Delta I_{f,p,t} \right)^2 . \tag{1}$$

Here $C_f^{(c)}$ is a color correction derived from the instrumental bandpass and $\Delta Z_{f,p,t}^{(c)}$ is the model variation of ZLE for each component c. Systematics, such as the already discussed sidelobes, can be introduced as further components of the model. A similar treatment can be performed in the approach based on background subtraction. Free parameters of the model are the $E_f^{(c)}$ together with the shape parameters $\bar{\Theta}^{(c)}$.

4. The case of *Planck*

For *Planck*, the most conservative strategy will be to assume $E_f^{(c)}$ as free parameters[2] and $\bar{\Theta}^{(c)}$ to be frequency independent and provided by COBE/DIRBE[4]. From COBE/FIRAS[3] $E_f^{(\mathrm{smooth\ cloud})} \propto f^2$, but with quite large uncertainties, while no firm conclusions can be drawn for the secondary components, since they vary with f without a clear pattern. If they are constant then the relative importance of the secondary components will be larger below 1 THz than at higher frequencies. If *Planck* will succeed in imaging the ZLE below 1 THz with sufficient S/N ratio it will be able to measure the $\bar{\Theta}^{(c)}$ at least for the dominating smooth cloud. Do $\bar{\Theta}^{(c)}$ depend on f? This can not be excluded since below 1 THz ZLE comes from grains larger than $0.1 \div 1$ cm whose dynamics is mainly affected by collisions rather than by other effects such as radiation pressure, Pointing–Robertson effect or planetary perturbation. If a significant part of the IDPs of the ZLE complex comes from the Jupiter family of comets[10], it has to be expected that below 1 THz the ZLE will be more concentrated around the ecliptic than at higher frequencies. Direct imaging of ZLE below 1 THz will be likely able test this possibility.

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References

1. C. Burigana, R.D. Davies, P. de Bernardis, et al., *IJMPD* **22/6**, 1330011 (2013).
2. M. Maris, C. Burigana and S. Fogliani, *Astron. and Astrophys.* **452**, 685 (2006).
3. D.J. Fixsen and E. Dwek, *The Astrophys. J.* **578**, 1009 (2002).
4. T. Kelsall, J.T. Weiland, B.A. Franz, et al., *The Astrophys. J.* **508**, 44 (1998).
5. M. Maris, C. Burigana, A. Gruppuso, et al., *Mon. Not. R. Astron. Soc.* **415**, 2546 (2011).
6. M. Hansen, J. Kim, A.M. Frejsel, et al., *J. Cosm. and Astrop. Physics* **1210**, 059 (2012).
7. M. Sandri, F. Villa, R. Nesti, R., et al., *Astron. and Astrophys.* **428**, 299 (2004).
8. K.M. Górski, E. Hivon, A.J. Banday, et al., *Astrophys. J.* **622**, 759 (2005).
9. C. Burigana, D. Maino, K.M. Górski, et al., *Astron. and Astrophys.* **373**, 345 (2001).
10. D. Nesvorny and P. Jenniskens, *Meteoritics and Planet. Science Suppl.* **73**, 5372 (2010).