Modelling of Zodiacal Light Emission for Space Missions

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Abstract

Accurate planning of forthcoming missions requires an accurate knowledge of diffuse sources in order to optimize mission parameters and the scanning strategy to meet the expected performances. Zodiacal Light (ZL or Zody) is a well known contaminant for ground based and space-borne observations in the optical and infrared bands, and recent results from the Planck collaboration highlights its importance for high sensitivity observations in the millimetre domain [1]. In visible and near IR it determines the limit magnitude which can be reached by a survey so that proper modelling of ZL is needed for survey planning. Despite the physics of ZL emission is well known, dominated by scattering of Sun light from Interplanetary Dust Particles (IDPs) for wavelengths shorter than 3.5-μm, and their thermal emission for larger wavelengths, predicting and modelling of Zody is complicated by a number of subtleties [2]. The cloud of IDPs has a quite complex 3D structure, whose main geometrical parameters have been assessed in the last two decades, but their photometrical properties are affected by a significant level of uncertainty. In optical, current measures of the exact level of ZL contamination are affected by light from background stars. In sub-mm the worst uncertainty is the model of dust grains emissivity. The observer orbiting the Sun is moving within the cloud of IDPs, leading to an important time dependence in the perturbing signal and asking for a precise knowledge of the expected trajectory and scanning strategy of the mission. This poster illustrates this problem taking the ESA Euclid mission as a case study.

The Euclid Mission

Euclid is an **European Space Agency** (ESA) mission aimed to understand the nature of the dark Universe. Observations conducted on the **Cosmic Microwave Background** (CMB) Radiation proved the existence in our Universe of two dominant components whose nature is entirely unknown [3]: **Dark Matter** (26.8 %) and **Dark Energy** (68.3 %). To enlight the nature of Dark Matter and Dark Energy, Euclid will investigate the distance-redshift relationship and the evolution of cosmic structures by means of two instruments: **VIS**: high quality images to carry out the weak lensing galaxy shear measurements; **NISP**: redshift measurements for a wide sample of galaxies.

Zodiacal Light Contamination

ZL is the combination of scattered solar light and thermal emission due to IDPs forming a system of clouds approximately aligned with the ecliptic plane. The optical depth of the IDPs cloud is $\approx 10^{-7}$, so that the amount of light received is the line integral of the radiation scattered or emitted along the whole line of sight toward which the telescope is pointed $\widehat{\mathbf{P}}$ [2]

$$I_{\rm ZL}(\widehat{\mathbf{P}},t) = \int_0^{+\infty} dL \sum_c N_{{\rm ZL},c}(\mathbf{R}_{\rm E}(t)+L\widehat{\mathbf{P}}) F_{{\rm ZL},c}(\mathbf{R}_{\rm E}(t)+L\widehat{\mathbf{P}}) \qquad (1)$$

with L is the distance from the observer, $\mathbf{R}_{\rm E}$ the position of the observer, $F_{{\rm ZL},c}$ the production of ZL in a given solar system location, $N_{{\rm ZL},c}$ the density of IDPs in that location, c denotes the IDPs subcloud contributing to ZL. See left frame of Fig. 1 for a snap shot of the geometry. Since the observer is orbiting the Sun, $\mathbf{R}_{\rm E}$ will be a function of the observing time t, and $I_{\rm ZL}$ will be a function of time too. For a periodic orbit ZL will present an important seasonal variability as shown in Fig. 1 at right.

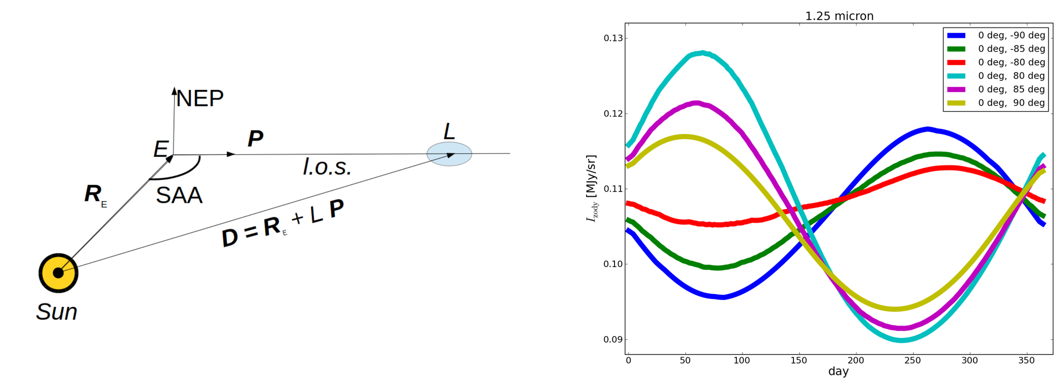

Figure 1: Left geometry of line integral Eq. 1. Right time dependence of ZL near the ecliptic for a telescope orbiting the Sun and kept at fixed Solar Aspect Angle (SAA) from it. Typical SAA for Euclid are in the range $85^\circ - 110^\circ$

Survey Optimization and ZEUS

In Euclid, as well as in many other surveys, operations are planned and optimized using one or more Survey Optimization Codes (SOCs). SOCs, which are based on static maps and catalogues, can hardly handle the inherent ZL time variability. Usually ZL contamination is accounted for in SOCs by including some routine based on some static approximation. The problem is: how to include a time dependent foreground in a code designed assuming static ones?

The most obvious solution would be to distribute a whole 3D model of the IDPs cloud to the teams in charge of developing the SOCs. But there is not a unique 3D model for ZL and until the end of the mission, there will be not a unique orbit file, in addition the same sequence of observations can be iterated many times during the optimization process, and the integration of Eq. 1 would lead to an slowing of the SOCs.

The ZEUS project (Zody EUclid Simulator) has the scope to decouple the ZL model from the optimization code. ZEUS is written in `Python` and needs the `pyfits` and `healpy` libraries. The Optimization Code produces a possible survey, i.e. a list of couples $(t, \widehat{\mathbf{P}})$. ZEUS computes the ZL contamination starting from a set of precomputed tables, which are representative of a particular combination of ZL model, $\mathcal{M}_{\rm ZL}$, and expected Euclid orbit $\mathcal{O}_{\rm EU}$.

ZEUS ZL compression

To compress the information produced by complex 3D models ZEUS exploits the periodicity of ZL signal. Using a 3D model of choice, as an example [2], a set of full sky map representing ZL contamination can be produced at discrete time intervals over a discrete set of pointing directions, $\mathbf{P}_i$, corresponding to the map pixels i. Three of those maps are presented in Fig. 2. ZL is computed using the widely used 3D model from COBE [2]. To represent the sky, ZEUS uses the HEALpix pixelization scheme [4], which has the advantage of allowing equiareal pixelization, a simple spatial interpolation and has a stable support library for `Python` and `C/C++`.

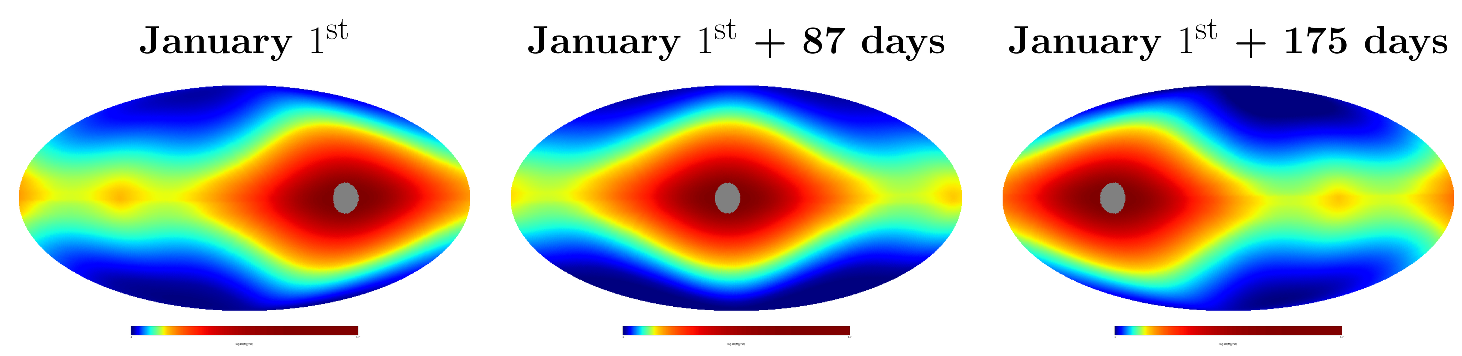

Figure 2: Full sky daily maps of ZL in ecliptic coordinates for Euclid mission at day 0, 87 and 175 of year. The gray spot is a region of the map too near the Sun. The 3D model is [2], and Euclid is assumed to be in the Earth-Sun L2 point, units are $\log_{10}$(MJy/sr), wavelength is 1.25 μm, ecliptic longitude 0 is at the map center.

At first ZEUS assumes an Ecliptic Corotating Reference Frame, whose longitudes originate from the Sun at the epoch of observation, $\lambda_\odot$, instead of γ. In this reference frame any pointing direction has a fixed height above the ecliptic and a fixed SAA. Further data compression is provided by expanding in Fourier series the time dependence of $I_{\rm ZL}$ for each corotating pixel i in the corotating map:

$$I_{{\rm zody},i}(t) = \bar{I}_{\rm zody,i} + \sum_{k=1}^{N_{\rm ft}} C_{{\rm z},i,k} \cos\frac{2\pi k t}{T_{\rm o}} + \sum_{k=1}^{N_{\rm ft}} S_{{\rm z},i,k} \sin\frac{2\pi k t}{T_{\rm o}} \qquad (2)$$

where $T_{\rm o}$ is the length of the mission, $\bar{I}_{\rm zody,i}$ is the yearly averaged zody emission, $C_{z,i,k}$ and $S_{z,i,k}$ are the Fourier cosine and sine coefficients of order k. Therefore, a data set for ZEUS provided for a given combination $(\mathcal{O}_{\rm EU}, \mathcal{M}_{\rm ZL})$ is a set of $2N_{\rm ft}+1$ HEALpix maps. Typically $N_{\rm ft} = 8$ and maps with resolution parameter $N_{\rm side} = 128$, so that each data set needs few tens of megabytes. Fig. 3 shows a map of the $\bar{I}_{\rm zody}$ and the power of the first two coefficients for a typical ZEUS data set.

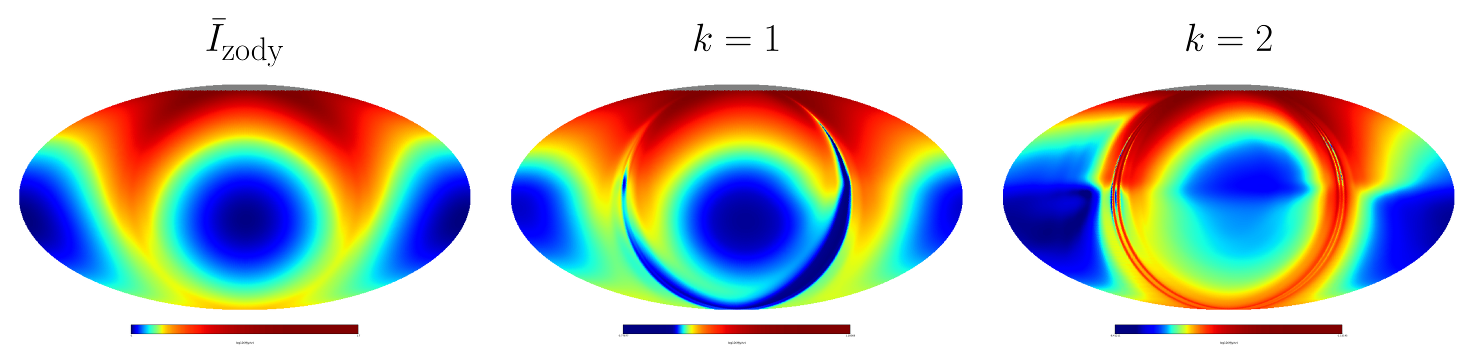

Figure 3: Power $(C^2_{z,i,k} + S^2_{z,i,k})$ of ZL Fourier transform. Euclid is assumed in L2 and ZL model is [2].

ZEUS Usage

At startup the SOCs using Zeus must load the appropriated ZEUS data set for the given ZL model and orbit. After that they have to provide to ZEUS the list of $(t, \widehat{\mathbf{P}})$ for which to compute $I_{\rm ZL}$, ZEUS uses t to derive the instantaneous $\lambda_\odot$ and rotates $\widehat{\mathbf{P}}$ in the corotating reference frame. From t ZEUS derives a set of HEALpix corotating maps using Eq. 2 from which the corresponding $I_{\rm ZL}$ are interpolation over the map. In Euclid a large number of observations are framed in time intervals so short that ZL can be considered a time constant. A single ZL corotating map can be used for many simulated observations compensating the computational cost for its derivation.

Results

The ZEUS package allows the integration of time dependent contamination from Zodiacal Light inside Euclid survey optimization codes which are designed for a static sky model. It decouples the complexity of Zodiacal Light 3D models from the that of the survey optimization. Compared to the use of a static ZL model the increase in coding complexity is quite modest. At the opposite of 3D models, ZEUS allows scalability easy parallelization.

The relative accuracy of ZEUS compared to a full 3D model is of the order of some 10^{-4}, two or three orders of magnitude below the intrinsic uncertainties in the models. The gain in speed with respect to a full 3D model is about two order of magnitudes.

Acknowledgments

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