A Study of the Dust Bands in the Zodiacal Cloud using *AKARI* Mid-Infrared All-sky Survey Data

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ABSTRACT

The zodiacal cloud in our solar system emits thermal radiation from the interplanetary dust (IPD), which is the dominant foreground emission for mid-IR observations in space. The zodiacal cloud has small-scale spatial structures called "dust bands", which are formed by dust grains originating in the asteroidal main belt. It also has the smooth cloud, a dominant component of a several au scale. In the previous study, based on the *AKARI* 9 and 18 μm mid-IR all-sky survey data, the zodiacal cloud standard model (Kelsall et al. 1998) has been re-examined and improved especially for the smooth cloud (Kondo et al. 2016a). However, the improved model still does not well reproduce the observational data on small spatial structures. In this study, we further improve the Kelsall model for the dust bands, using the *AKARI* mid-IR all-sky survey data.

Keywords: Surveys – infrared: diffuse background – Zodiacal dust – Interplanetary medium

1. INTRODUCTION

In our solar system, there are not only planets and asteroids but also 1–10 μm sized grains called the interplanetary dust (IPD). IPD originates mainly from comets and asteroids. It is heated by the sun and emits thermal radiation at infrared wavelengths. IPD spreads over the entire solar system smoothly. The most dominant several au scale component is called the smooth cloud. Additionally, as revealed by IRAS, the finer-scale distributions originating from the asteroidal main belt are called the dust bands. Based on the observations of *COBE*/DIRBE, Kelsall et al. (1998) constructed the IPD distribution model. Kondo et al. (2016a) optimized the Kelsall model especially for the smooth cloud using the *AKARI* 9 and 18 μm mid-IR all-sky survey data. The result of subtracting the zodiacal emission using the Kondo model is shown in Figure 1. The residual along the ecliptic plane is mainly due to the small scale structure of the dust bands. Therefore, we further improve the Kelsall model for the dust bands.

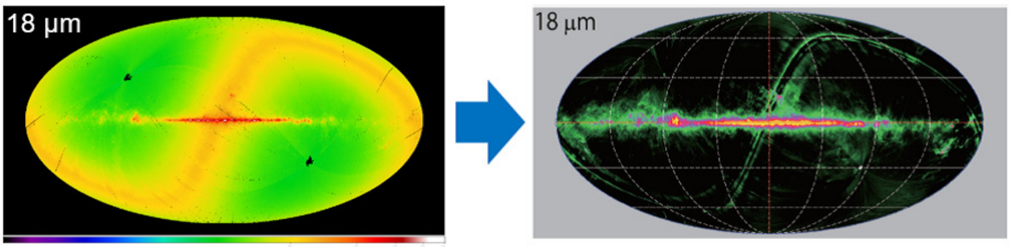

Figure 1. *AKARI* 18 μm diffuse map before (left) and after (right) subtracting the zodiacal emission using the Kondo model (Kondo et al. 2016b), projected in the galactic coordinates.

2. METHOD

We created the brightness map of the dust bands. We calculated the brightness of the zodiacal cloud except the dust bands using the Kondo model and subtracted it from the *AKARI* data. We smoothed the map with the boxcar of 7° in

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width along the ecliptic longitude to enhance the structure of the dust bands. The width of 7° is determined to minimize the standard deviations consisting of the random errors and intrinsic variations of the zodiacal emission. The smoothed map after subtracting the zodiacal light except the dust bands is shown in Figure 2. Based on this brightness map, we tried to improve the Kelsall model, using the following equation:

$$n(X,Y,Z) = \frac{n}{R}\exp\left[-\left(\frac{\zeta}{h}\right)^6\right]\left[1+\frac{1}{v}\left(\frac{\zeta}{h}\right)^p\right]\left\{1-\exp\left(-\left(\frac{R}{R_{\rm in}}\right)^{20}\right)\right\}, \quad (1)$$

$$\zeta \equiv |Z/R|,$$

$$R = R(X,Y,Z,i,\Omega), \qquad \zeta = \zeta(X,Y,Z,i,\Omega),$$

where (X, Y, Z) indicates the three-dimensional position in our Solar System and R is the distance from the sun $((X, Y, Z) = (0, 0, 0))$. These four parameters are normalized by 1 au. The model parameters for the dust bands are listed in Table. 1.

Table 1. Model parameters for the dust bands, using in Equation (1).

Parameter	Comments
n	Density at 3 au in units of au^{-1}
h	Scale height [deg]
v, p	Shape parameter
$R_{\rm in}$	Inner radius [au]
i	Inclination [deg]
Ω	Ascending node [deg]

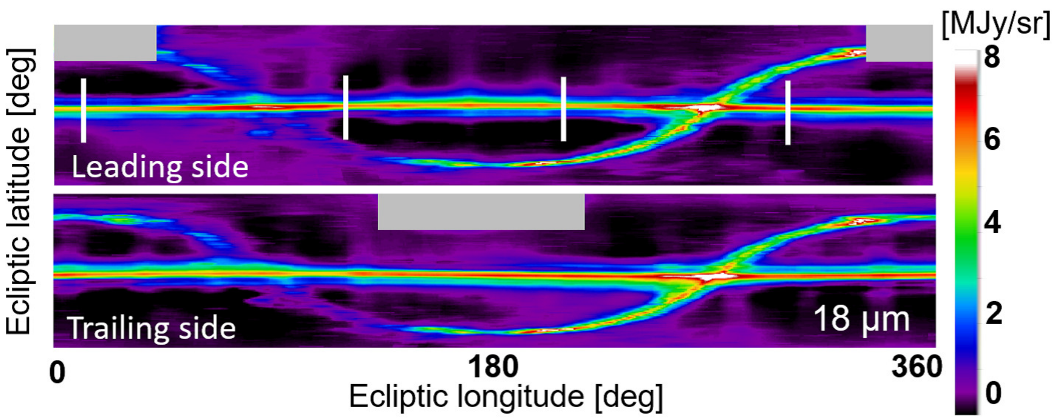

Figure 2. Brightness maps after subtracting the zodiacal emission except for the dust band component on the leading and trailing sides, projected in the ecliptic coordinates. The regions affected by the earthshine are masked. The horizontal component near the ecliptic plane corresponds to the dust bands and the curve passing the dust bands is the galactic plane. The white lines indicate the positions of the latitudinal profiles shown in Figure. 3.

3. RESULT

We show the latitudinal profiles of the brightness of the dust bands at 4 positions (at $\lambda = 5°, 120°, 190°, 300°$) in Figure 3. From the visual inspection of these profiles, we confirm the following features:

- Brightness peaks are present at $\beta \approx -10°, 0°$, and $10°$. The peaks at $\beta \approx \pm 10°$ originate from the same asteroid family and this pair of the peaks is called "dust band 1". The single broad peak at $\beta \approx 0°$ seems to be composed of two peaks at $\beta \approx \pm 1.4°$, which also originate from another asteroid family. This pair of the peaks is called "dust band 2".
- The brightness is different between the south and north peaks. In particular, in dust band 2, the peak which is nearer to the ecliptic plane is fainter than the other one (see the profiles at $\lambda = 5°$ and $190°$), calling for an asymmetrical distribution with respect to their midplanes.

- The shape of the profile is reversed toward a 180° opposite direction (see the profiles at λ = 120° and 300°)
- There is likely peaks at $\beta \approx \pm 17°$ (see the profiles at λ = 5° and 190°).

First, we reliably estimate the inclination angles, i, the ascending nodes of the midplanes for the dust bands, Ω, their inner radii, R_{in}, the scale heights, h, as a function of the longitude, using Equation (1). The result is shown in Table 2. Then, using $i, \Omega, R_{\mathrm{in}}$, and h thus determined, we optimize the latitudinal profiles by adjusting the other parameters in Equation (1) and also introducing a modulation factor in the shape parameter v to reproduce the asymmetric distributions. As a result, we successfully improve the model for the dust bands. We will report detailed procedures and results in a separate paper.

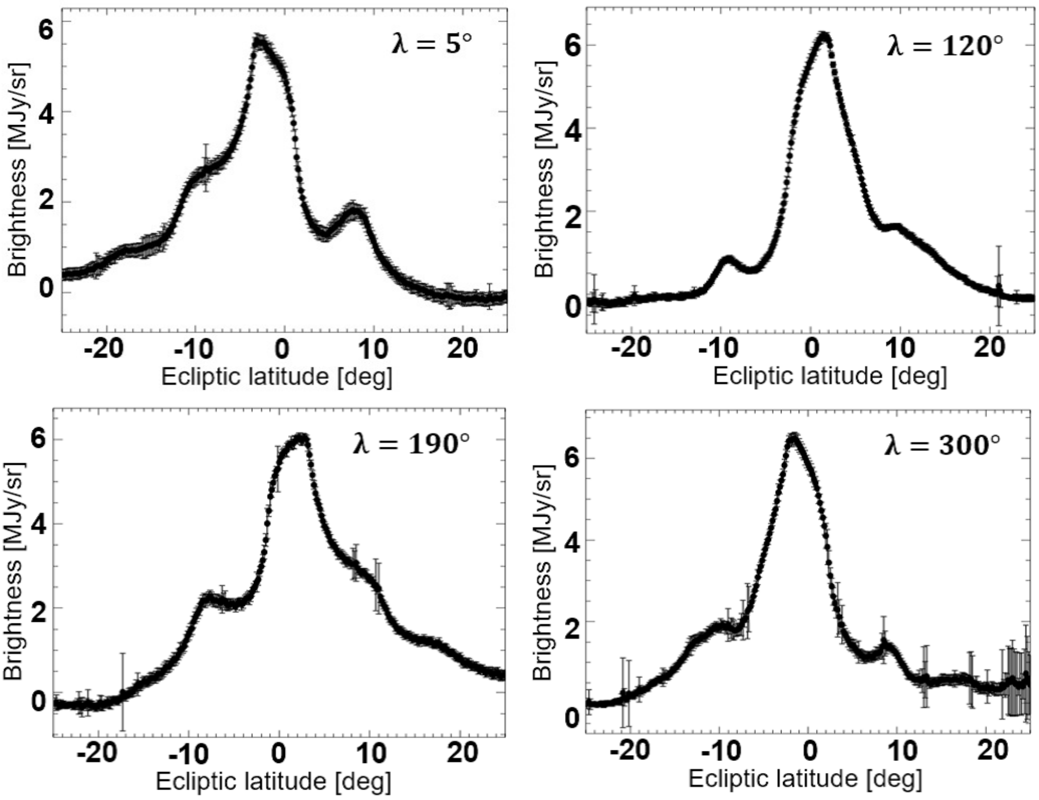

Figure 3. Latitudinal profiles of the brightness of the dust bands at λ = 5°, 120°, 190° and 300°, as denoted in the upper panel of Figure 2.

Table 2. Parameters in Kelsall et al. (1998) and in this study.

Parameters	Kelsall et al. (1998)	This study
	Dust band 1	
i	0.56°	1.15°
Ω	80°	93°
R_{in}	1.5 au	1.47 au
h	8.78°	8.78°
	Dust band 2	
i	1.2°	1.15°
Ω	30.3°	71°
R_{in}	0.94 au	1.0 au
h	1.99°	1.55°

4. SUMMARY

In this study, we aim to improve the standard zodiacal dust bands model, using the *AKARI* mid-IR all-sky survey data. We fine-tuned parameters of the dust bands and took into account asymmetrical distributions of the dust bands with respect to their midplanes. As a result, we confirm that our new model better reproduces the peak positions of the dust bands along the ecliptic longitude than the previous model.

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REFERENCES

Kelsall, T., Weiland, J. L., Franz, B. A., et al. 1998, ApJ, 508, 44
Kondo, T., Ishihara, D., Kaneda, H., et al. 2016a, AJ, 151, 71
Kondo, T., Ishihara, D., Kaneda, H., et al. 2016b, PhD thesis, Nagoya University