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Polarization from meteoroid grains in the Earth thermosphere

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Abstract

Tons of cosmic material from leftovers of comets and asteroids enter the Earth atmosphere every day. The majority of the studies of this influx usually rely on meteor observations and ground-based meteorite searches. Although global space-based monitoring is still missing, there is an increase in interest in Earth observation projects for meteor and meteoroid detections from space. This extraterrestrial influx attracted by the Earth makes the surroundings of low Earth orbit a rich source of information about chemistry and physical properties of near-Earth bodies. However, there is scant information about cosmic dust and small meteoroids (below a grain size of 1 cm) in the Earth thermosphere since they are difficult to be detected with the current facilities. In this work, we propose to use the dust grain polarization as a tool to detect and characterise these small meteoroid grains. For that, we build a density model of the infalling dust in the Earth thermosphere attending to different features and parameters obtained from measurements of meteorites, meteor showers and cometary dust observations. Then, we compute the expected signal of radiation and polarization of these infalling dust particles as viewed from a satellite in low Earth orbit with the Monte Carlo code RADMC-3D. We analyse their detectability from space depending on the different inputs of the model and we discuss the properties than we could retrieve regarding the simulated polarization.

1 Introduction

Tons of extraterrestrial material plunge into the Earth's atmosphere daily, providing additional information about leftovers of comets and asteroids. There are many studies to attempt to characterize this infalling material, where they estimate the particle influx, their size or their origin [1, 2]. Most of these estimates rely upon the measurements carried out by the networks monitoring fireball events and meteor showers, and by some ground-based meteorite searches [3, 4, 5]. These measurements are either focused on the interaction between the rocky body with the atmosphere or they need a body with certain size.

However, when we focus on the cosmic dust or the small meteoroids that are falling into the Earth, we realize that they are underestimated due to their difficulty to be detected with the current facilities [1]. And, consequently, there is scant information about their properties.

It is known that when interstellar dust particles are under a radiative field, they might align with it by the action of the radiative torques (RATs) [6, 7]. Furthermore, in the presence of a magnetic field, torques can lead grains to be aligned with it under certain conditions. In the near Earth environment, the particles in the upper atmosphere are expected to be aligned principally due to the solar radiation field (k-alignment) and the Earth magnetic field (B-alignment). So, the thermal emission from space dust is expected to be polarized due to this alignment of the grains.

We propose the observation of this infalling material with a satellite in the Low Earth Orbit. We focus on the cosmic dust and the small meteoroids that are at higher altitudes of the Earth atmosphere, from around the Karman line to the satellite position in about 500 km. And, we propose the polarization as a tool of characterization.

In this work, we study the grain alignment mechanisms in the Earth's upper atmosphere, and we compute the expected microwave signal of these aligned infalling particles and its polarization. This study is developed under the MARTINLARA (Millimeter wave Array at Room Temperature for INstruments in LEO Altitude Radio Astronomy) consortium[1]. In Sec. 2, we present a thorough review of the observational data on the properties of the grains that will serve as input for the numerical simulations, and the grain alignment in Earth environment. In Sec. 3, we analyse the properties of the predicted intensity and polarization maps. We conclude in Sec. 4 with a brief summary of the main results.

2 Infalling dust model

2.1 Dust grain properties

Modelling the properties of space dust in the thermosphere involves many uncertainties that arise from the limited data. We have built the infalling dust model with data from different sources such as dust of comets, meteorites and meteor showers. In this section, we review the current knowledge on their size distribution, composition, and spatial distribution.

Regarding the composition of the found meteorites [8], the interplanetary dust cloud of

[1]MARTINLARA's web project: `https://martinlara3.webnode.es/`

the model is mainly made of silicate, graphite, or iron.

The bodies of interest are cometary and asteroid dust and small meteoroids, so we focus on a range of the grain size from 0.01 μm to 1 cm. These particles are distributed following a power law distribution

$$\mathrm{dn(a) = n_0 a^{\alpha} da} \tag{1}$$

being n_0 a scale factor, a the radius of the grain, assumed to be spherical, and α the index of the power law. To determine the index of the power law, there are many space missions targeting comets [9, 10, 11]. The value of the index of the power law highly depends on the used technique. Due to the uncertainties, we decide to set four different models with $\alpha = [-3.5, -3.0, -2.5, -2.0]$.

There is scant information about the mass distribution above $\sim$130 km height in Earth atmosphere. We use the data from a meteor shower in 2009 January 4 [12] to extrapolate the spatial density of particles. We take the fitting curve of the data from 12 km to around 112 km in altitude, we estimate the particle density at an altitude of 130 km, and we assume that this value remains constant at higher altitudes, up to 500 km. Thus, the spatial density of the considered particles is 0.22 part $\mathrm{cm^{-3}}$.

2.2 Dust grain alignment

The interaction of the irregular grains in the Earth vicinity with the anisotropic solar radiation field results in a net radiative torque and grain alignment, with a time-scale for RAT precession t_{k} around the direction of the radiation [13]. However, this alignment is likely to be disrupted by the damping mechanism by collisions with atmospheric particles. Any initial alignment will be lost if the collision time-scale t_{damping} is smaller than the time the particles take to cross the atmosphere, t_{flight}. As we can see in Fig.1a, any initial radiative alignment is lost below $\sim$130 km by collisions with the dense atmospheric gas.

Moreover, depending on the properties of the particles, Earth magnetic field could be the direction of the grain alignment with a Larmor precession rate t_{B}. Figure 1b shows the direction of alignment according to the properties of the grains: if $t_{\mathrm{B}}/t_{\mathrm{flight}} > 1$, particles do not have time to interact with the magnetic field and remain aligned with the radiation field (silicates with $a \geq 0.03$ μm, carbonates with $a \geq 0.01$ μm, and irons with $a \geq 4.0$ μm), while for $t_{\mathrm{B}}/t_{\mathrm{flight}} < 1$ they become B-aligned if $t_{\mathrm{B}} < t_{\mathrm{k}}$ (silicates with $a < 0.03$ μm and irons with $a < 4.0$ μm).

3 Results

To carry out the simulations, we used the radiative transfer code RADMC-3D that computes the radiation produced by dust grains for a given composition and spatial distribution (given in Sec. 2). We have defined an evenly spaced 3D Cartesian grid with a resolution of 1 km in each direction with 50×50×370 cells. In the vertical direction, the grid starts at an altitude of 130 km and goes to a height of 500 km. The origin of our coordinate system is placed at

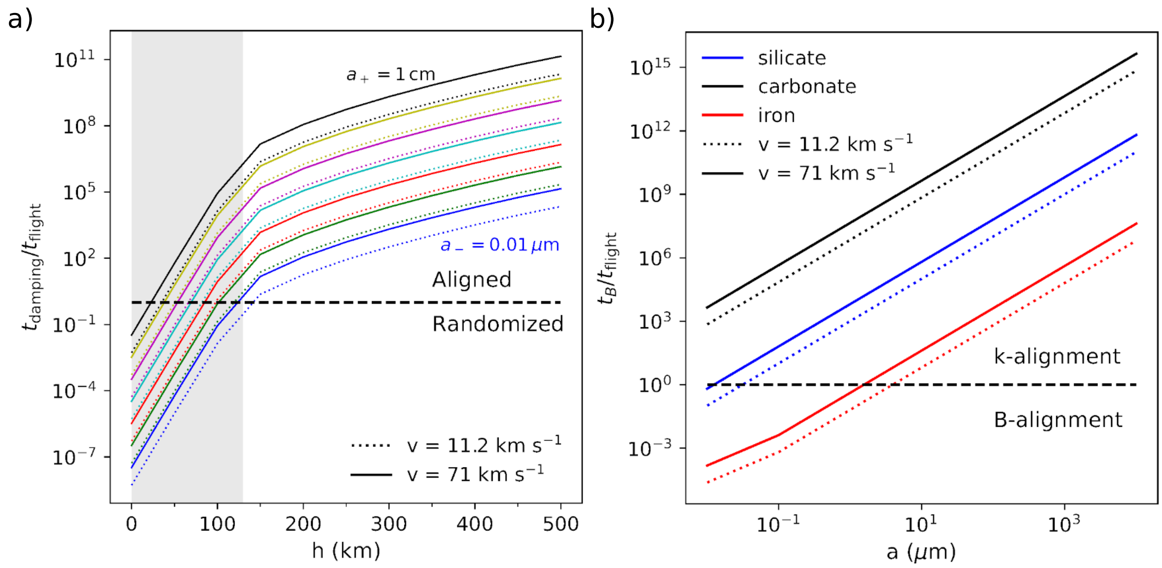

Figure 1: *a)* Disruption of alignment for silicates by grain collisions with the neutral gas as a function of height. *b)*Ratio of B-alignment time-scale over flight time for the species considered in this work.

the centre of the grid with the Z axis pointing to nadir from the satellite, the X axis pointing to the sun and Y defined following a positively right-handed system.

In Fig.2 we show the I and Q maps obtained for two different size distributions of the grains at 2220 GHz as observed from Equator, for the population of silicates aligned with the radiative field, and for irons aligned with the Earth magnetic field. We see the strong dependency of the magnitude of the Stokes vector on the dust size distribution, and how the direction of polarization changes with the direction of alignment.

We compute the degree of polarization as

$$P_{\rm al}(\%) = \frac{Q_{\rm al}}{(I_k + I_B)} \times 100 \tag{2}$$

where the subscript *al* refers to the considered alignment (k or B). Figure 3 shows the percent of polarization along an orbit: should we measure a polarization signal that increases as approaches through Equator, it might be the tracer of an iron population. Notice also that the polarization produced for the smallest iron grains is completely different than the polarization produced when grains are aligned with the solar radiation field, where the polarization slightly changes along the orbit.

Further details and results can be seen in [14].

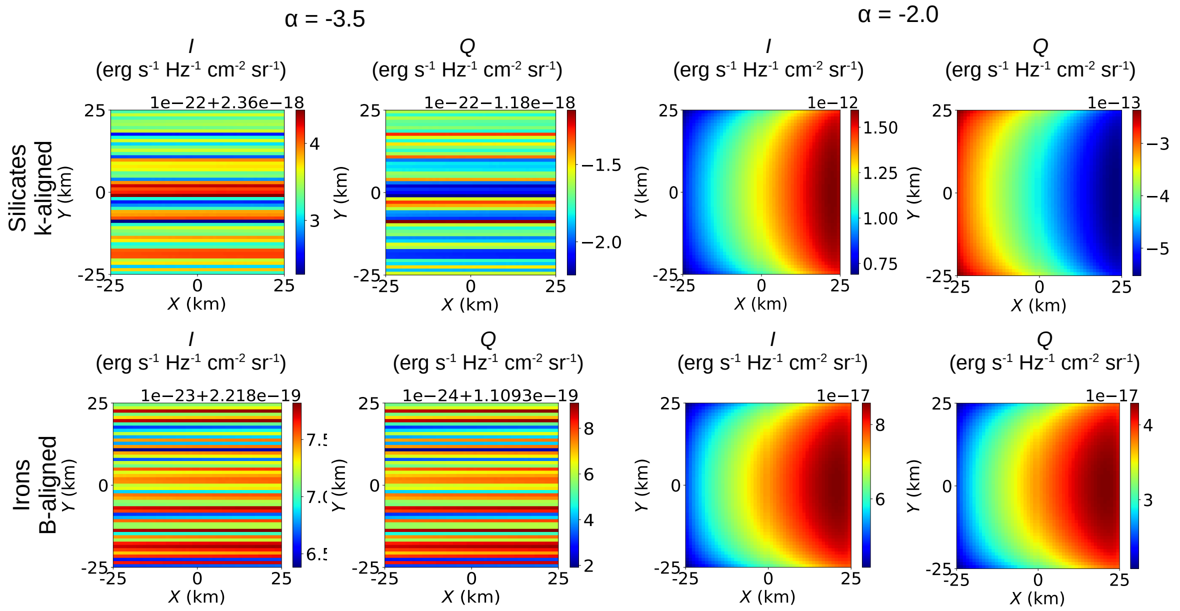

Figure 2: Intensity and Q-Stokes parameter maps for two different size distribution ($\alpha = -3.5$ and $\alpha = -2.0$). *Top:* Silicates that are aligned with the solar radiation field. *Bottom:* Iron grains that are aligned with the Earth magnetic field.

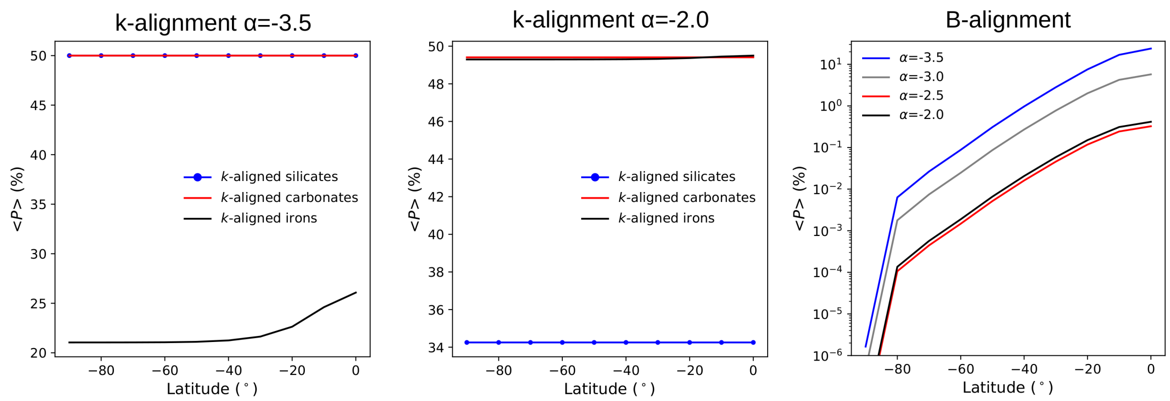

Figure 3: Percent polarization along the orbit for the three dust species with k-alignment (*left and middle*) and for iron with B-alignment (*right*) at 220 GHz.

4 Conclusions

In this work, we have built a model of the infalling space particles in the Earth upper atmosphere. Firstly, we study the grain alignment in the Earth surroundings having into account the radiative alignment torque method. First estimates of the expected signal and its polarization in microwave range have been calculated using the RADMC-3D code. The range of magnitudes for the different casuistic could be used as a baseline for future space missions. The polarization curves reveal dust properties such as grain size distribution and composition.

Acknowledgments

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