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The State-of-Play of Anomalous Microwave Emission (AME) research

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ABSTRACT

Anomalous Microwave Emission (AME) is a component of diffuse Galactic radiation observed at frequencies in the range $\approx$ 10–60 GHz. AME was first detected in 1996 and recognised as an additional component of emission in 1997. Since then, AME has been observed by a range of experiments and in a variety of environments. AME is spatially correlated with far-IR thermal dust emission but cannot be explained by synchrotron or free–free emission mechanisms, and is far in excess of the emission contributed by thermal dust emission with the power-law opacity consistent with the observed emission at sub-mm wavelengths. Polarization observations have shown that AME is very weakly polarized ($\lesssim 1$ %). The most natural explanation for AME is rotational emission from ultra-small dust grains ("spinning dust"), first postulated in 1957. Magnetic dipole radiation from thermal fluctuations in the magnetization of magnetic grain materials may also be contributing to the AME, particularly at higher frequencies ($\gtrsim 50$ GHz). AME is also an important foreground for Cosmic Microwave Background analyses. This paper presents a review and the current state-of-play in AME research, which was discussed in an AME workshop held at ESTEC, The Netherlands, June 2016.

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1. Introduction

Anomalous Microwave Emission (AME) is a dust-correlated component of Galactic emission that has been detected by cosmic microwave background (CMB) experiments and other radio/microwave instruments at frequencies $\approx$ 10–60 GHz since the mid-1990s (Kogut et al., 1996; Leitch et al., 1997). It is thought to be due to electric dipole radiation from small spinning dust grains in the interstellar medium (ISM), although the picture is still not clear. The emission forms part of the diffuse Galactic foregrounds that contaminate CMB data in the frequency range $\approx$ 20–350 GHz, and hence knowledge of their spatial structure and spectral shape can be exploited during CMB component separation (Dunkley et al., 2009a; Bennett et al., 2003; Planck Collaboration et al., 2016b). Since spinning dust emission depends critically on the dust grain size distribution, the type of dust, and the environmental conditions (e.g., density, temperature, interstellar radiation field), precise measurements of AME can also provide a new window into the ISM, complementing other multi-wavelength tracers.

The first mention of spinning dust grains in the literature was by Erickson (1957), who proposed this non-thermal emission as a contributor at high radio frequencies (GHz and above). The same basic mechanism of radio emission from rapidly spinning dust grains was also discussed by Hoyle and Wickramasinghe (1970) in the context of converting optical photons from stars into radio/microwave emission. Ferrara and Dettmar (1994) further developed the theory, estimating the contribution from radio-emitting dust in spiral galaxies. These earlier works outlined the basic mechanisms of how small dust grains with finite electric dipole moments can be spun up to high rotational frequencies, thus producing radio emission. They also understood that such emission would predominantly arise at relatively high frequencies. However, it was not until the late 1990s, after when observations detected excess emission at frequencies $\approx$ 10–60 GHz (Section 3), that detailed predictions of spinning dust emission were made by Draine and Lazarian (1998a,b). The field of AME research then became important, particularly since AME was known to be a significant CMB foreground (Section 4). Magnetic dust emission (MDE) on the other hand had not been discussed in the literature until the seminal work of Draine and Lazarian (1999) who proposed it as an alternative to spinning dust.

In this article, we provide a comprehensive review the state-of-play of AME research. For a previous review, see Dickinson et al. (2013) and articles within. Section 2 provides an overview of the theory of spinning dust, magnetic dust, and other emission mechanisms that may be contributing to AME. Observations of AME are summarised in Section 3. Section 4 discusses AME as a CMB foreground while in Section 5 we discuss various methodologies and goals for future research. Concluding remarks are made in Section 6. This article is partially an outcome of the discussions at the AME workshop[1] held 22–23 June 2016 at ESTEC (Noordwijk, The Netherlands). Previous AME workshops were held at Manchester[2] in 2012 and at Caltech[3] in 2013.

2. Models of candidate AME mechanisms

2.1. Spinning dust

2.1.1. Basic theory

A dust grain with electric or magnetic dipole moment μ rotating with angular frequency ω will produce emission according to the Larmor formula

$$P = \frac{2}{3}\frac{\omega^4\mu^2\sin^2\theta}{c^3}\,, \tag{1}$$

where P is the total power emitted at frequency $\nu = \omega/2\pi$ and θ is the angle between ω and μ. A schematic diagram of a single dust grain is shown in Fig. 1. It is immediately evident that the spinning dust emission spectrum will depend sensitively on the distribution of rotational frequencies attained by the grains as well as their distribution of dipole moments. Indeed, much of the theoretical modelling efforts have been toward accurate calculation of the distribution of rotation rates as a function of grain size and composition in various interstellar environments.

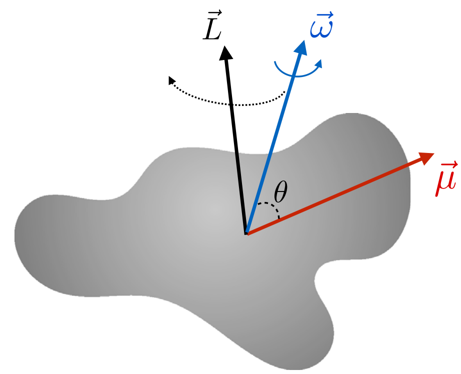

Fig. 1. Schematic spinning dust grain, with its permanent electric dipole moment $\vec{\mu}$, its instantaneous angular velocity $\vec{\omega}$, and its angular momentum $\vec{L}$, about which $\vec{\omega}$ precesses.

A spherical grain of radius a and mass density ρ rotating thermally in gas of temperature T will have a rotational frequency of

$$\frac{\omega}{2\pi} = 21\,\mathrm{GHz}\left(\frac{T}{100\,\mathrm{K}}\right)^{1/2}\left(\frac{\rho}{3\,\mathrm{g\,cm^{-3}}}\right)^{-1/2}\left(\frac{a}{5\,\mathrm{\mathring{A}}}\right)^{-5/2}. \tag{2}$$

To emit appreciably in the 20–30 GHz range as required to reproduce the observed AME, the grains must be very small, $a \lesssim 1$ nm.

2.1.2. Rotational dynamics

An interstellar dust grain is subject to a number of torques arising from its interactions with the ambient interstellar matter, which can both excite and damp rotation. Collisions with ions and neutral atoms, photon emission, H_2 formation, photoelectric emission, and interaction with the electric fields of passing ions ("plasma drag") have all been identified as contributing to grain rotation. The distribution of grain rotational velocities will generally be non-thermal resulting from the interplay of a number of different excitation and damping processes, including collisions with atoms and ions, and absorption and emission of radiation. Systematic torques (i.e., torques that do not have a time average of zero in grain coordinates), and impulsive torques (i.e., impacts that produce large fractional changes in the grain angular momentum) can be important.

Draine and Lazarian (1998b) presented the first comprehensive model of spinning dust emission taking most of these processes into account. For simplicity, they assumed $\langle\omega^4\rangle = 5/3\langle\omega^2\rangle^2$, consistent with a Maxwellian distribution. Recognizing that ultrasmall grains could simultaneously furnish an explanation for AME and the infrared emission bands, they focused their analysis on electric dipole emission from PAHs.

Ali-Haïmoud et al. (2009) improved on the treatment of the rotational dynamics by employing the Fokker–Planck equation to compute the angular velocity distribution. Notably, they found significantly less power in the tails of the distribution, particularly toward high values of

[1] http://www.cosmos.esa.int/web/ame-workshop-2016/schedule.
[2] http://www.jb.man.ac.uk/~cdickins/Man_AMEworkshop_July2012.html.
[3] https://wikis.astro.caltech.edu/wiki/projects/ameworkshop2013/AME_Workshop_2013.html.