Highlights of Spanish Astrophysics VII, Proceedings of the X Scientific Meeting of the Spanish Astronomical Society held on July 9 - 13, 2012, in Valencia, Spain. J. C. Guirado, L. M. Lara, V. Quilis, and J. Gorgas (eds.)

Polarization of the Anomalous Microwave Emission

C. H. López-Caraballo[1,2] and R. Génova-Santos[1,2]

[1]Instituto de Astrofísica de Canarias, E-38200 La Laguna, Tenerife, Spain
[2]Departamento de Astrofísica, Universidad de La Laguna, E-38205 La Laguna, Tenerife, Spain

Abstract

The standard physical mechanisms of the continuum emission in the microwave range are the synchrotron, free-free, and/or thermal dust emissions. Nevertheless, and based on observations over the last two decades, we can find a new process of emission, called Anomalous Microwave Emission (AME), which consists of an excess of dust-correlated microwave emission (10–60 GHz). Observational studies of the AME, both in intensity and polarization, allowed us to extend our knowledge of the different physical processes in the Interstellar Medium (ISM), as well as its implications in the study of the inflationary epoch of the Universe, via the possible effects in the detectability of the polarization of the Cosmic Microwave Background (CMB), in particular the detection of B-modes. In this talk, we present a summary of the observational measurements of the polarization of the AME for: 1) the diffuse Galactic emission (only two works based on the WMAP data); and 2) individual Galactic regions, two HII regions LPH96 and Helix; and four dust clouds Perseus, ρ Ophiuchi, LDN1622 and Pleiades). Around the peak of the emission (20–30 GHz), the constraints on the fractional polarization of AME are of the order of $\sim$1% (95% C.L.) for both individual compact and large-scale Galactic regions. Then, we use these constraints in order to test the theoretical AME models available to date. Finally, we discuss the effects of a polarized diffuse AME contribution on the current and future polarized CMB experiments.

1 Introduction

In intensity, the AME has been detected by several experiments on both large scales and individual regions, including the discovery of AME in nearby galaxies: NGC6946 and the well-known Small Magellanic Cloud (SMC). The observations of large-scale Galactic emission (diffuse emission) show that the AME is the dominant physical process in the frequency range 20–30 GHz. In constrast, there is a little information about the polarization properties of the anomalous microwave emission. In literature, there are six individual Galactic regions (LPH96, Helix, Perseus, ρ Ophiuchi, LDN1622 and Pleiades) and two works on the diffuse

Galactic emission, with measurements or upper limits on the polarization in the relevant range of 10–40 GHz.

Various physical processes have been proposed to explain the observational AME properties; nevertheless, the observations favour (up to now) the electric dipole emission [7] (the so-colled *spinning dust*) from very small (less then 10^3 atoms) rapidly rotating ($\sim 1.5 \times 10^{10} s^{-1}$) dust grains in the interstellar medium. However, alternative explications (as the one based on magnetic dipole emission [8]) cannot be excluded. Measurements of the polarization properties of the AME may potentially distinguish between these two models.

Therefore, and from an observational point of view, it is important to characterize the frequency behaviour and the level of polarization of the AME. In this talk, we present the current observational status of the polarization of AME, and its implications on the study of the physical process(es) responsible for this emission, as well as its possible impact on the foreground correction of the CMB maps at low frequency.

2 Polarization of AME in galactic regions

As far as we are aware, there are only two works in the literature where the large-scale Galacitc AME polarization is discussed. First, [10] used the three-year WMAP data to estimate the fractional polarization of a diffuse AME contribution, assuming that the AME is traced by dust templates. Their results provide levels (in the polarized signal variance) of 1% in each WMAP band (23–94 GHz). More recently, [13] carried out a cross-correlation analysis between several template maps (for the synchrotron, dust and free-free) and the five-years WMAP polarized maps, obtaining that the polarized dust-correlated emission (AME) at 23 GHz is $\Pi_{\rm AME} = 3.2 \pm 0.9(stat) \pm 1.5(sys)$ per cent, translated to an upper limit of $\Pi_{\rm AME} < 5\%$ with a 95% of confidence level (C.L.).

For the polarization of AME in individual Galactic regions, the first measurement $\Pi = 3.4^{+1.5}_{-1.9}\%$ was reported by [1] for the G159.6-18.5 region, using the COSMOSOMAS experiment at 11 GHz. Then, [12, 5] calculated contraints on the fractional polarization (around $\sim$1% at 23 GHz) in WMAP bands (23–94 GHz). A detailed summary was presented by [15], for the regions: G159.6-18.5 , LPH96, Helix, ρ Ophiuchi, LDN1622 and Pleiades. The experiments used were COSMOSOMAS at 11 GHz, *Green Bank Telescope* (GBT) at 9.65 GHz, *Cosmic Background Imager* (CBI) at 31 GHz and the WMAP data (at 23, 33, 41, 61 and 94 GHz).

Our contribution includes constraints for G159.6-18.5 [12], Pleiades [9, 15], LPH96 and LDN1622 [15] cases, using the seven-year WMAP data at 23, 33 and 41 GHz. All the measurements and constraints are incluided in the Table 1, where the name of the region, the experiment and the resolution used in the estimation of the constraints are shown in columns 1 to 3. Columns 4 to 7 indicate the upper limits on the fractional polarization on the anomalous microwave emission $\Pi_{\rm AME}$, separated according to the frequency range for an easier comparation. The constraints are estimated with a 95% of confidence level. Finally, the last column provides the respective references.

For illustration, in the left panel of Fig. 1, we plot the values as listed in Table 1, for

Table 1: Current constraints on the fractional polarization (Π) of the anomalous microwave emission. The summary includes measurements for individual Galactic regions and for studies of the diffuse Galactic emission. Columns 1 to 3 show the name of the region, the experiment and the resolution used in the estimation of the constraints. The following four columns present the values of the fractional polarization, at each frequency range. Note that the upper limits are calculated with a 95% of confidencial level. The last column provides the respective references. This table is reproduced from [15].

Name	Experiment	Resol.	Π[%] (9–11 GHz)	Π[%] (22 GHz)	Π[%] (30–33 GHz)	Π[%] (40 GHz)	Ref.
			Galactic Regions				
G159.6-18.5	COSMOSOMAS	1°	$3.4^{+1.5}_{-1.9}$				[1]
"	WMAP7	1°		< 1.01	< 1.79	< 2.69	[12]
"	WMAP7	1°		< 1.4	< 1.9	< 4.7	[5]
LPH96	CBI	$\sim 9'$			< 10		[4]
"	WMAP7	1°		< 1.3	< 2.5	< 7.4	[15]
Helix	CBI	$\sim 9'$			< 12		[2]
ρ-Ophiucus	CBI	$\sim 9'$			< 3.2		[3]
"	WMAP7	1°		< 1.7	< 1.6	< 2.6	[5]
LDN1622	GBT	$\sim 1.3'$	< 2.7				[14]
"	WMAP7	1°		< 2.6	< 4.8	< 8.3	[9, 15]
Pleiades	WMAP7	1°		< 12.2	< 32.0	< 95.8	[15]
			Diffuse Galactic Emission				
Full-Sky	WMAP3	1°		< 1	< 1	< 1	[10]
Full-Sky	WMAP5	1°		< 5			[13]

each region (identified by different colors). In the peak of the intensity emission (20–30 GHz), the upper limits on the fractional polarization of AME are of the order of ∼1% (95% C.L.) for both individual and large-scale Galactic regions.

Up to now, the observations only provide upper limits on the polarized emission in regions with AME. However, they allow us to constrain the physical mechanism(s) responsible for this emission, in particular models that predict high fracctional polarization degrees.

In the right panel of Fig. 1, we compare all the constraints at 33 GHz, and the predictions of the polarization models: 1) for the electric dipole emission (ED or *spinning dust*) with grains in a *Cold Neutral Medium* (black solid line), with expected levels of $\sim 0.5\%$ at 33 GH [11]; and 2) for several models for the magnetic dipole (MD) emission, according to the contribution of two families: a) MD emission from grains in a single magnetic domain, where the orientation of the angular momentum is perfectly aligned in a direction either parallel or perpendicular to the magnetic field, with levels 10–20% at 33 GHz (dashed and dotted lines, depending on the grain shapes) proposed by [8]; b) MD emission from grains with randomly-oriented magnetic inclusions of two different materials, magnetite (Fe3O4, dash-dotted line) and maghemite (gamma Fe2O3, dash-triple-dotted line), where the predicted polarization fractions are at the level of 5-10%, see details in [6].

Note that the low degree of the observational polarized AME emission (in particular in

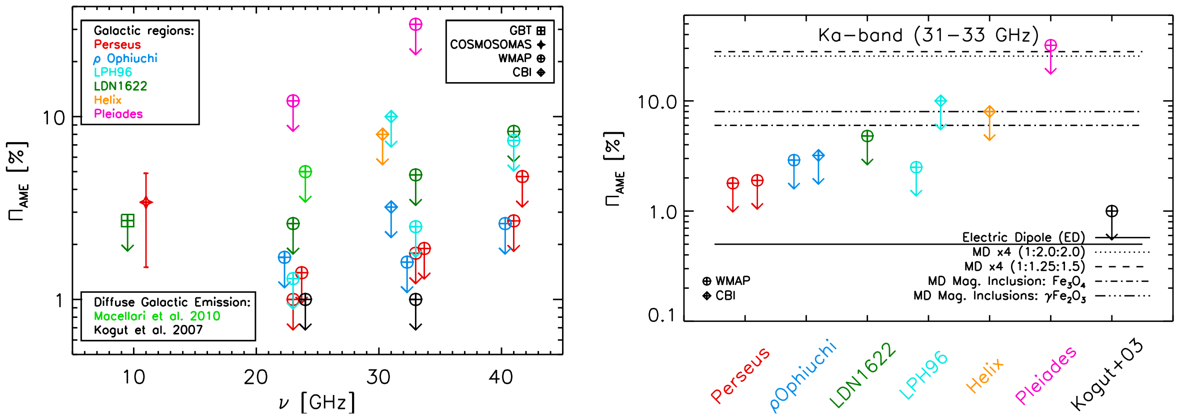

Figure 1: *Left panel:* Current observational upper limits on the polarization of the AME for both individual regions and diffuse Galactic emission (Table 1). *Right panel:* Predictions, at 33 GHz, for the electric dipole emission (ED) with grains in a *Cold Neutral Medium*, with grain alignment for the resonance relaxation (solid line), with expected levels of $\sim 0.5\%$ [11]; and for several models for the magnetic dipole (MD) emission, from grains perfectly aligned in a single magnetic domain (20–30% lines) and from grains with magnetic inclusions (7–10% lines).

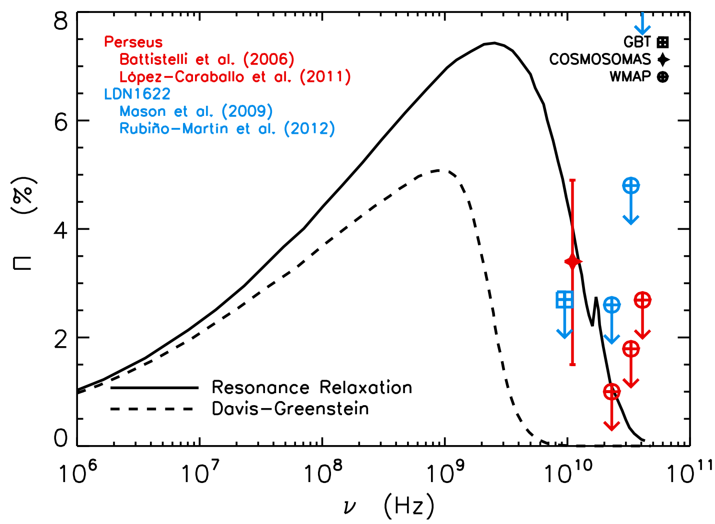

Figure 2: Constraints for Perseus [1, 12] and LDN1622 [14, 15] regions, in the range 10–40 GHz. The lines correspond to the polarized CNM models with grain alignment for both resonance (solid) and Davis-Greenstein (dashed) relaxation. Note that, the constraints are consistent with the polarized electric dipole emission model, see discussion in [15].

the range 20–40 GHz) allows us to exclude some models based on the MD emission, such as those described in this work. However, this does not rule out the magentic dipole emission

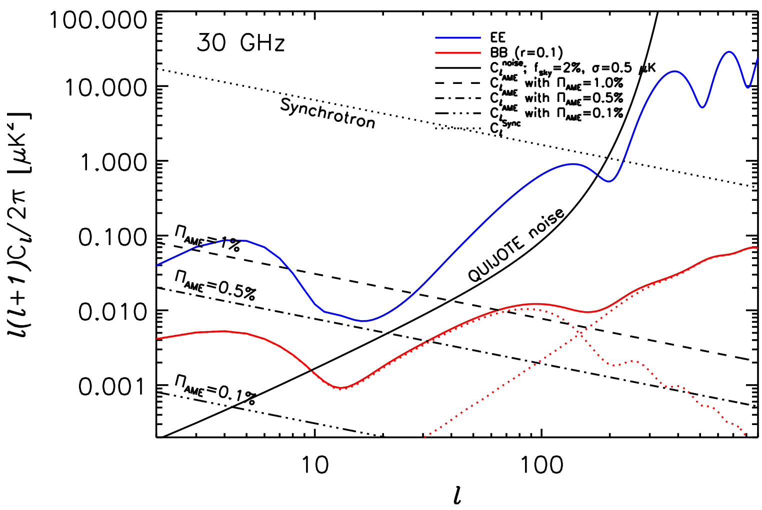

Figure 3: Sketch of the polarized angular power spectrum for the AME at 30 GHz ($C_l^{\rm AME}$). The black broken lines show the polarized AME $C_l^{\rm AME}$ for a fractional polarization of $\Pi_{\rm AME} =$ 1.0% (dashed), $\Pi_{\rm AME} = 0.5\%$ (dotted-dashed) and $\Pi_{\rm AME} = 0.1\%$ (dotted-dotted-dashed). The black dotted line corresponds to the syncrotron contribution in this frequency range. We also show the CMB polarization spectrum of the E-modes (blue line) and the B-modes with a tensor-to-scalar ratio r=0.1 (red line). For comparison, the QUIJOTE noise is drawn by the black solid line, for observations covering a sky fracction $f_{sky} = 2\%$, with a senstitivity of $\sigma = 0.5\mu$K per 1° (FWHM) beam.

as the physical responsible for the observed polarization (see discussion in [15]).

Moreover, the observations are consistent with the electric dipole emission. To illustrate this issue, Fig. 2 compare the two regions with multifrequency measurements: G159.6-18.5 and LDN1622; and the prediction from the polarized CNM model as presented by [11].

3 Implications on the detectability of the B-modes

As mentioned above, the detection of the B-mode polarization of the CMB opens a new window to carry out a detailed study of the physics of the very early Universe, confirming the existence of primordial gravitational waves (encoded in the B-mode signal). Therefore, the spectral and spatial AME characterization is very important, because a polarized AME diffuse contribution could act as a foreground contaminant for experiments designed to detect this B-mode signal, like the QUIJOTE-CMB experiment [16].

In the Fig. 3, we present our estimation of the contribution of the polarized AME diffuse component ($C_l^{\rm E,B,AME}$) to the angular power espectrum at 30 GHz, for $\Pi_{\rm AME}$ equal to 1% (dashed), 0.5% (dotted-dashed) and 0.1% (dotted-dotted-dashed), where:

$$\ell(\ell+1)C_\ell^{\rm E,AME}/2\pi \;=\; \ell(\ell+1)C_\ell^{\rm B,AME}/2\pi \;=\; A_{\rm AME}\;\ell^{-\alpha}\;\Pi^2_{\rm AME} \tag{1}$$

being $\alpha = 0.6$; and the normalization amplitude $A_{\rm AME}$ is obtained assuming that the r.m.s intensity contribution of the dust at 30 GHz is $\Delta T^{30\ \rm GHz} = 35.9\ \mu$K (extrapolated from the results of [13]). The black solid line corresponds to the QUIJOTE noise.

We also include the polarized power espectrum of the CMB, for the E-mode (blue) and the B-mode with tensor-to-scalar ratio r=0.1 (red). In particular, if $\Pi_{\rm AME}$ would be $\sim$0.5–1% and at large scales ($\ell \lesssim$100), the detection of the B-mode signal could be hindered for experiments, like QUIJOTE-CMB, which are aiming to reach sensitivities in the tensor-to-scalar ratio of r$\sim$0.05–0.1. A value of $\Pi_{\rm AME} = 0.1\%$ will probably only affect experiments aiming at r$\sim$0.01. Therefore, the tetermination of the level of the AME polarization, in the frequency range 20–40 GHz, is crucial to assess to what level it will affect the detection of the primordial B-mode signal.

References

[1] Battistelli, E.S., Rebolo, R., Rubiño-Martín, J.A., et. al 2006, ApJ, 645, L141

[2] Casassus S., Nyman L.-Å., Dickinson C., & Pearson T. J. 2007, 382, 1607

[3] Casassus, S., et al 2008. MNRAS, 391, 1075-1090

[4] Dickinson, C., et. al 2006, ApJL, 643, L111

[5] Dickinson, C., Peel, M., & Vidal, M. 2011, MNRAS, 418, L35

[6] Draine, B. T. & Hensley, B. 2012, ArXiv: 1205.7021

[7] Draine, B. T. & Lazarian, A. 1998, ApJ, 508, 157

[8] Draine, B. T. & Lazarian, A. 1999, ApJ, 512, 740

[9] Génova-Santos R., Rebolo R., Rubiño-Martín J. A., López-Caraballo C. H., & Hildebrandt S. R. 2011, 743, 67

[10] Kogut, A., et. al 2007, ApJ, 665, 355

[11] Lazarian, A., & Draine, B. T. 2000, 536, L15

[12] López-Caraballo C. H., Rubiño-Martín J. A., Rebolo R., & Génova-Santos R. 2011, ApJ, 729, 25

[13] Macellari N., Pierpaoli E., Dickinson C., & Vaillancourt, J. E. 2011, MNRAS, 418, 888

[14] Mason, B. S., et. al 2009, ApJ, 697, 1187.

[15] Rubiño-Martín J. A., López-Caraballo C. H., Génova-Santos R., & Rebolo R. 2012, Adv. in Astronomy, 2012, 351836

[16] Rubiño-Martín, J. A. et al. 2012, Proc. SPIE 8444, in press.