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Site evaluation and RFI spectrum measurements in Portugal at the frequency range 0.408–10 GHz for a GEM polarized galactic radio emission experiment

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Abstract

We probed for radio frequency interference (RFI) at three potential galactic emission mapping experiment (GEM) sites in Portugal using custom made omnidirectional disconic antennas and directional pyramidal horn antennas. For the installation of a 10-m dish dedicated to the mapping of polarized galactic emission foreground planned for 2005–2007 in the 5–10 GHz band, the three sites chosen as suitable to host the antenna were surveyed for local radio pollution in the frequency range 0.01–10 GHz. Tests were done to look for radio broadcasting and mobile phone emission lines in the radio spectrum. The results show one of the sites to be almost entirely RFI clean and showing good conditions to host the experiment.

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1. Introduction

Cosmic microwave background (CMB) cosmology made a huge leap forward from COBE maps (Smoot et al., 1992) towards high-resolution map-making. The data returned from recent and planed experiments (MAXIMA, Boomerang, DASI, CBI, VSA, NASA's WMAP and ESA's Planck Surveyor satellite, among others (Bennet et al. (2003), Dickinson et al. (2004), Mason et al. (2003)) offer a direct glimpse into the physics at the surface of last scattering, providing constraints on cosmological parameters and tests of theories of large scale structure formation and favoring the inflationary paradigm. Obscuring our view of the CMB are extragalactic and galactic foregrounds and the maximum cosmological information can only be obtained if the foregrounds are optimally extracted. Different physical components along the line of sight can be separated from the underlying cosmic signal by using a priori knowledge of their spectral a spatial characteristics, given a sufficiently dense sampling in frequency and spatial position. Typically, diffuse galactic emission is dominated by

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synchrotron radiation below 60 GHz and by thermal dust emission above 60 GHz (da Costa et al., 2003). Recently, CMB polarization is currently being detected (DASI – 2002, WMAP – 2003) see (Leitch et al., 2002; Kovac et al., 2002; Bennet et al., 2003; Kogut et al., 2003) and will constitute for the next decade the best probe of early Universe's physics.

Yet, while theoretically, foreground amplitudes would be generically distinguished by observing the different emission components where they are dominant, there are no reasonably known templates accounting for their amplitudes and effects. While for CMB total power (temperature) the foreground amplitudes can be reasonably estimated, the amplitude of polarized foregrounds like synchrotron or spinning dust is not known accurately.

1.1. Current GEM project

To address the problem of foreground estimation, the Galactic Emission Mapping project started as an international collaboration (`http://aether.lbl.gov` for detailed information) operating a portable 5.5-m dish with extensions to a 10-m surface capable of measuring the galactic emission at several latitudes in a wide range of frequencies (Torres et al., 1993, 1996). To integrate for large sky areas and since sensitivity is more important than resolution, GEM scanning strategy consists on an slow azimuthal dish rotation until the required sensitivity is attained (see Fig. 1). The resultant maps obtained at several locations would then be merged to produce templates covering large areas of the sky with constant angular resolution from 408 MHz up to 10 GHz and good absolute calibration of the zero-level of the maps.

With foreground cartography as one of the main tasks currently being pursued by CMB teams, the GEM project is evolving towards the measurements of galactic synchrotron polarization at higher frequencies 5–10 GHz (Tello et al., in preparation). Originally, the Berkeley team has developed a compact and portable 5.5-m diameter radio telescope antenna, which has been used for the total intensity observations. Observations were made from different locations, like near Bishop, California (fall 1993 through fall 1994), Villa de Leyva, Colombia (close to the equator 1995) and is currently operating at Cachoeira Paulista, Brazil (Tello, 1999; Tello et al., 1992) having now covered most of the southern hemisphere in 1.4 and 2.3 GHz. To also cover the northern hemisphere, and thus produce a template of most of the sky, one needs a good site in the northern hemisphere with suitable conditions for clima, RFI and infrastructure capabilities. Thus, Portugal was surveyed to find a suitable location to host a second antenna to complement the original GEM southern hemisphere maps. The GEM working frequencies were chosen because below 20 GHz, atmosphere contribution is negligible (Brandt, 1994). Also, for polarization measurements, besides water lines around 22 GHz, oxygen only contaminates polarization measurements for frequencies higher than 60 GHz, where oxygen molecular rotational modes may be an important concern for ground experiments (Hanany and Rosenkranz, 2003; Pardo).

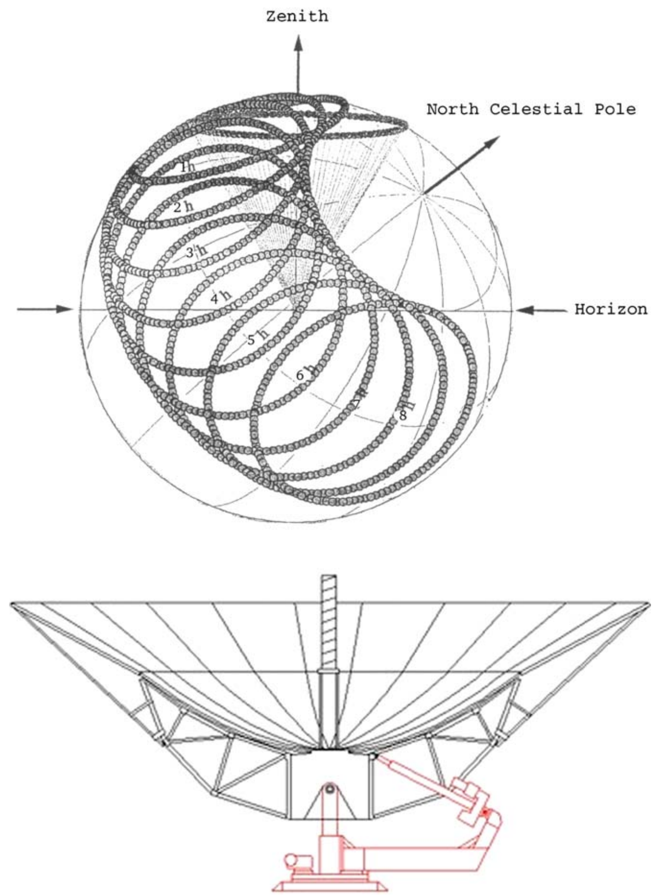

Fig. 1. Top figure represents a schematic view of the scanning strategy: azimuthal dish rotation for a given elevation. Bottom figure is a scheme of scanning instrument and mounting.

1.2. RFI sources

Radio observations need above all sites with no radio frequency interference (RFI). Perhaps, the biggest threat lies on Global System for Mobile Communications (GSM) networks, meaning frequency dispute with radio astronomers. GSM mobile phone networks use several bands around 900 MHz, 1.8 GHz and the near future Universal Mobile Telecommunications System (UMTS) to be shortly implemented will use several 2.1 GHz bands. Other telecommunications concerns are radio broadcast emissions, analog and digital television broadcast emissions, aeronautical communications – mainly along air corridors and airports, satellite communications (communications, meteorological and GPS) and amateur radio services, these using theoretically a wide range of bands from 3.5 to 250 GHz. Besides telecommunications, recent wireless computer networks use heavily the 2.37 GHz band with prospects for a near future 5 GHz upgrade. Also, microwave ovens will present leaks at 2.4 GHz despite the fact that they are in accordance with industrial standards. These leaks are insignificant to human health, but readily detected as bursts of microwave signal in nearby radiometers working at these frequencies. Besides these main concerns, secondary concerns as sources of RFI can be high-voltage power lines and old motorcycle engines. To conclude, one must avoid contact with human settlements. Of course, not all attributed frequencies by the telecommunications regulation authorities are susceptible of being contaminated. Either because they are used sporadically – easily eliminated in data processing – or because they are used heavily only in urban areas and do not appear in rural, isolated areas (See Tables 1, 2).

2. Sites evaluation

To find the best locations to host the experiment, several sites were selected after analyzing long term data of important weather variables – temperature, relative humidity (RH), insolation rate (giving an idea of good weather days) from their geographic areas. After correlating with GSM coverage maps, two sites in southern Portugal and one in central Portugal were, therefore, chosen for RFI measurements.

The sites main characteristics show a similar pattern for annual RH variation of 20–30% during most of the year. Temperatures tend to be high in summer (~30–35°), with high thermal amplitudes between night and day specially for site 1. These values indicate good conditions for night observations throughout the dry season, implying low water absorption at the GEM considered frequencies (Butler, 1998) Precise full characterization of the chosen site weather conditions, after installation of an on-site weather station. We plan to proceed with campaigns to check explicitly for the sites for annual, monthly and daily direct variations of water vapor content and temperature.

Table 1
Typical sources of RFI contaminations

RF source	Frequency bands (MHz)
GSM networks	890–960; 1710–1880
UMTS networks	1900–1980; 2110–2170
Radio broadcast	<230
TV broadcast	475–870
Satellite communication	20,000
Microwave ovens	2450
Computer wireless network	2370; 5800
Radio amateur	0.177–1300

Actually, while radio amateur service bands can go up to 250 GHz, they rarely exceed 1300 MHz.

Table 2
Best sites coordinates

Location	Longitude	Latitude	Elevation (m)
Califórnia	08° 01′ W	37° 18′ N	408
Castanheira da Serra	07° 52′ W	40° 11′ N	839

2.1. RFI measurements

Since GEM scanning strategy involves azimuthal rotation of 360° circles, the presence of even a single localized source of RFI signals can produce a substantial cut in the sky area surveyed. After correlating weather and GSM service coverage, several sites where chosen for survey. A primary search on GSM residual coverage reduced our target sample to three sites. For a first survey, we chose disconic antennas for its omnidirectionality and large band receiver capabilities. A second and more sensitive survey, using both discone and directional horn antennas was finally done for the most promising site. While disconic antennas may theoretically work for bands with higher frequency 10 times larger than the initial frequency (10:1), in practice we opted to optimally cover a frequency band range like 3:1. For the wide frequency range 100 MHz–10 GHz we built three disconic antennas covering optimally the bands 350–1050 MHz, 1.2–3.6 GHz, 3.6–10.8 GHz. The first antenna is, by above, still capable of detecting strong signals below 100 MHz (see Fig. 2).

In the first survey, the antennas were put on a 3-m high rod and connected to a spectrum analyzer (an HP8563A). Measurements were taken at different times to check for source variability. The results are shown in Fig. 3. It is quite clear that RFI appears to be concentrated, as expected, in three wide bands (radio ~ 88–100 MHz, tv ~ 500 MHz and GSM 0.9–1.1 GHz.). Simultaneously, the relative humidity measured was 23%.

The site of Castanheira da Serra, herafter site 1, shows promising conditions with only one RFI source appearing intermittently (tv). It also shows a very convenient orography with the presence of several higher mountains rings (~1000 m) screening signals that could pass from nearby villages. While not showing any other expected source, it showed some very low frequency signals (shortwave signals), most likely due to ionospheric reflections. A second more sensitive survey was accomplished for site 1 (July 2005). For this survey, several amplifiers (typical gain >30 dB) were used accordingly with the frequency band being scanned, the two lower frequency discone antennas, two pyramidal horn antennas (5 and 10 GHz), and a spectrum analyzer (HP8563A). For the 5 GHz band surveyed, a Miteq LNA (2–8 GHz band with 38 dB gain) was used. The discones where used to survey the spectrum below the 3 GHz, which was clean except for broadcast tv and radio at the frequencies of 460, 511 MHz. A 360° azimuth scan was done with the horn antennas, with steps of 20°, starting from the north, and with the antennas pointing 15° in declination (Fig. 4).

The setup calibration is determined using the standard Y-factor method, thus permitting the calculation of the true setup noise floor without prior knowledge of gain/loss

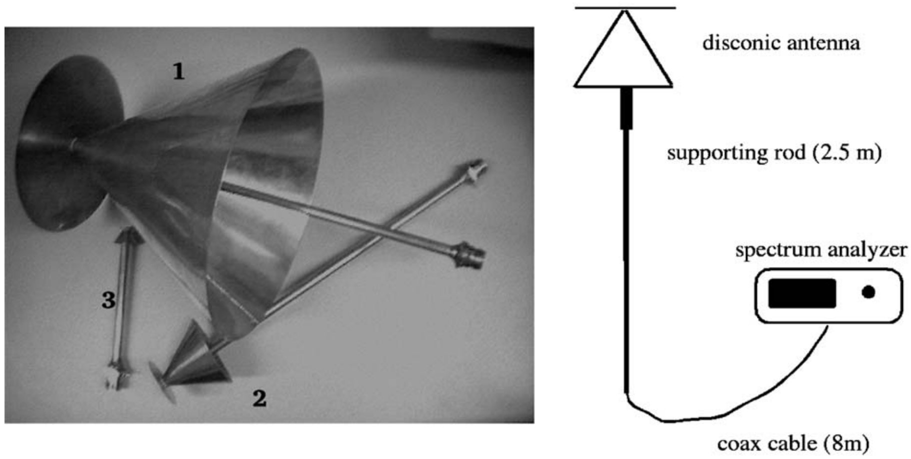

Fig. 2. The three disconic antennas used in our setup (right). They correspond to the bands: 1, 350–1050 GHz; 2, 1.2–3.6 GHz; 3, 3.6–10.8 GHz.

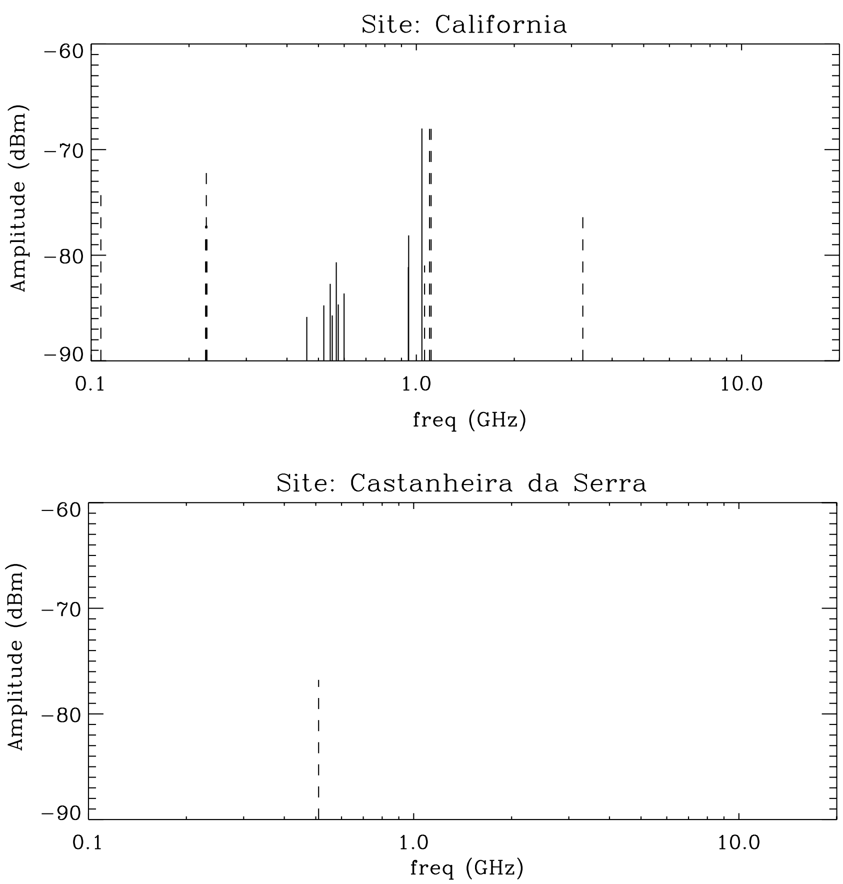

Fig. 3. RFI spectrum for two sites: Califórnia (as a comparison) and the chosen site of Castanheira da Serra. Signal amplitude are given in dBm. Solid lines are permanent signals and dashed lines represent intermittent signals detected during measurements. RFI lines appear, as expected, by bunches: radio services mainly at 100–200 MHz; tv broadcast bunch around the 500 MHz band and GSM services clearly peak around the 900 MHz and the 1.1 GHz bands.

of the various components of the system. The setup noise floor is then calculated as follows,

$$Y = \frac{\langle P_{\mathrm{gnd}} \rangle}{\langle P_{\mathrm{sky}} \rangle} = \frac{T_{\mathrm{gnd}} + T_{\mathrm{sys}}}{T_{\mathrm{sky}} + T_{\mathrm{sys}}} \tag{1}$$

Assuming $T_{\mathrm{gnd}} = 290$ K and assuming $T_{\mathrm{sky}} = 10$ K we calculate a T_{sys} of 1694 K. The equivalent noise floor at the input is given by $P_{\mathrm{sys}} = k_{\mathrm{B}}BT$, and that is −116.31 dBm/100 KHz. The amplitude of the peaks (the difference of the SA measured value and the SA measured peak value)

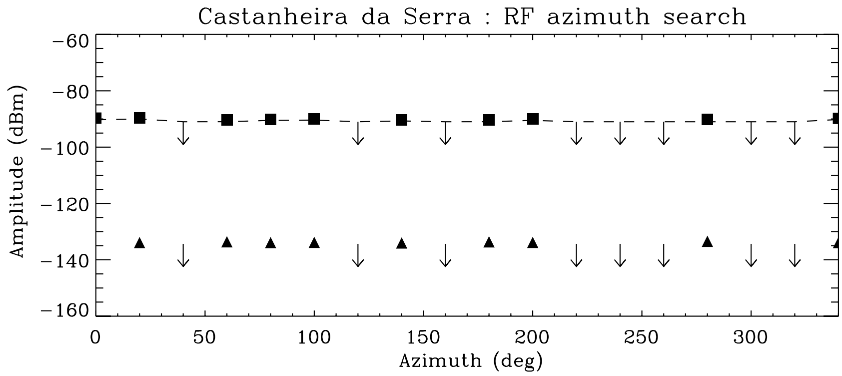

Fig. 4. Azimuth scan measurements with the 5 GHz horn antenna – with a 20° aperture – in a 500 MHz band centered on 5 GHz. Dashed line is the average fitted noise floor of the spectrum analyser (SA); squares represent the SA measured fluctuation peaks around the noise floor – the biggest noise floor fluctuations during the measurement duration; triangles represent the same values after calibration and gain corrections. The arrows are upper limits on noise fluctuations – no noise fluctuations were distinguished.

Table 3
Setup noise floor measurements for 5 GHz horn antenna

Target	Measurement (dBm)
Ground 1	−75.6
Ground 2	−75.8
Ground 3	−75.8
Sky 1	−76.4
Sky 2	−76.7
Zenith	−76.1

is added to the correct calibrated noise floor. For our purposes, we want the measurements referenced to the situation of zero antenna gain, or equivalently, absolute 0 dBi referenced offending signal. The absolute 0 dBi referenced offending signal presented on last column of the measurement table is calculated (in dB units) as,

$$P_{\mathrm{ref0dBi}} = P_{\mathrm{peak}} - P_{\mathrm{setup}} + P_{\mathrm{sys}} - G_{\mathrm{ant}} \quad (2)$$

The spectrum analyzer noise floor values appear in Table 3. The scan measurements and respective calibrated measurements are in Fig. 4.

For 5–10 GHz, we expect the galactic emission to be on the order of 0.5–100 mK. The typical total power emitted at these frequencies ($P = K_{\mathrm{B}}T_{\mathrm{signal}}B$) for a bandwidth $B = 200$ MHz (Tello, 1999) is about 1.38×10^{-18} to 2.76×10^{-16} W or −134 to −150 dBm (the later for weaker, high galactic latitude signals)[1]. For simplicity, we adopt hereafter the dBm units. One can see from Fig. 4, that our sensitivity noise floor is high: about −135 dBm, barely above our expected galactic signals.

2.2. Discussion

Despite our high noise probing sensitivity, one may ask however, that weaker signals could be present and masked under our setup noise that could become important when a sensible receiver is setup on an antenna. This shows that we should be aware of weak, distant signals that may be lurking below this survey noise sensitivity and still carefully shield the instrument. A problem could be the very weak signals coming from an almost isotropic distribution of distant sources, leaking in our bands. However, human density (and village density) and as a consequence transmission antennas density in the areas we surveyed is very sparse. For site1, the nearest important settlement is at a distance of 15 Km, and there are several mountain rings in between. We note, since we are going to operate near a protected radioastronomy band, where no interference other than harmonics are expected, the main concern would be the intermodulation generated products intrinsic to our receiver front-end. Harmonics and spurious of the GSM base stations are obliged by law to be at least 60 dB below carrier, therefore any unwanted signals that may fall inside our band would be at least 60 dB below the actuall received GSM signals. Also, RFI due to telecommunications may show strong variability with time and there could be the case where measurements were taken in a quiet period. We did, however, check GSM and radio coverage from portuguese operators with the official portuguese frequency and radio communications board (ANACOM – http:www.anacom.pt) and found the area of site1 to be a blank area (free of coverage). This was also checked directly at the nearest village, where GSM coverage is non existent. We note that the expected dish will survey at elevations higher than 45° to avoid horizon and ground problems, so sidelobes pick up would be much smaller. Typically, a cassegrain antenna, optimized for low sidelobes (as the one to be operated – a 9-m C-band Vertex antenna) at an elevation of 45–60° has an horizontal pick up lower than −40 dB. Other typical important problem is the ground pick-up noise. To minimize this problem, this experiment will work with ground shields consisting on a high tight mesh screens (fence), high enough to level out the horizon profile, thus reducing by at least 10 dB the ground noise (Tello et al., 1999) for a dish working at these

[1] 1 dBm is the unit for expression of power level in decibels with reference to a power of 1 mW; $\mathrm{dBm} = 10\log(P_{\mathrm{mW}})$ where P_{mW} is the power in mW.

elevations (>45°). Also, the antenna will be underilluminated (to about 6-m) to help reduce ground side-lobe pick-up and thus will have part of the parabola naturally working as rim-halo shield (paper in preparation).

Finally, to test our setup, we checked the antennas response, with the settings we used, at the laboratory (Instituto de Telecomunicações), to several generated signals and tested for GSM and weak wireless computer network signals.

3. Conclusions

Within the context of the Galactic Emission project, we surveyed several sites for climatic and RFI measurements. One of the sites – Castanheira da Serra – shows good climatic conditions (low humidity, high number of good weather days, stable geography) and a very low RFI on the survey bands to host a GEM antenna. In this particular, it clearly shows a clean radio spectrum, free of RFI spikes in the 5 GHz band down to −143 dBm sensitivity, close to the typical values of the expected polarized galactic emission signal amplitudes range.

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