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) for the three potential Galactic Emission Mapping Experiment (GEM) sites at Portugal using custom made omnidirectional disconic antennas. For the installation of a 10-meter 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.

Key words: Radio Frequency Interference; Site testing; cosmic microwave
1 Introduction

Cosmic Microwave Background (CMB) cosmology made a huge leap forward from COBE maps forwards towards high resolution map-making. The data returned from recent and planned experiments (MAXIMA, Boomerang, DASI, NASA’s WMAP and ESA’s Planck Surveyor satellite (launch 2007) 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 knowledge of their spectral and spatial characteristics, given a sufficiently dense sampling in frequency and spatial position as an use of prior knowledge. Typically diffuse galactic emission is dominated by synchrotron radiation below 60GHz and by thermal dust emission above 60GHz. Recently, CMB polarization is currently being detected (DASI - 2002, WMAP - 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 foreground 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 (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. 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.

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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.

(see figure 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, GEM project is evolving towards the measurements of galactic synchrotron polarization characterization 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 antenna, which has been used for the first-stage observations. Observations were made from different locations, like near Bishop, California (fall 1993 through fall 1994), Leyva, Colombia (close to the equator 1995) and is currently working at Cachoeira Paulista, Brazil \[12,13\] 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\(^3\). 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\(^7\).\(^8\).

\subsection{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, 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 GHz 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.

\section{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, insolation rate (giving an idea of good weather days) from their geographic areas. The data statistics is publicly available from the Portuguese Instituto de Metereologia e Geofisica \(\text{http://www.meteo.pt}\). Portugal shows a temperate Atlantic climate with large variations despite its size. Main differences rest on altitude (mountainous and medium-high north/center
Typical Sources of RFI contaminations. Actually, while Radio Amateur service bands can go up to 250 GHz, they rarely exceed 1300 MHz.

| 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 commu.    | 20000                 |
| Microwave Ovens     | 2450                  |
| Computer Wireless Net. | 2370; 5800         |
| Radio Amateur       | 0.177-1300            |

| Location               | longitude | latitude | elevation |
|------------------------|-----------|----------|-----------|
| Califórnia             | 08° 01' N | 37° 18' W | 408 m     |
| Castanheira da Serra   | 07° 52' N | 40° 11’ W | 839 m     |

and flat-low south) and humidity, depending on sea distance. Although Atlantic winds induce high levels of rain in the winter season and mean high levels of humidity nationwide except for some parts in the interior center and south, spring and summer mean relative humidities around 20-30% or less in the country’s interior. These regions are also those with lower human density with some villages living still outside the GSM world. 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°C), with high thermal amplitudes between night and day specially for site 1 (average night temperature of ∼ 15°C or below). These values indicate good conditions for night observations throughout the dry season, implying low water absorption at the GEM considered frequencies. Precise full characterization of sites weather conditions, specially of Castanheira da Serra, will be available locally after installing instrumentation for weather measurements in the exact places and should enable a robust check on variations of temperature and relative humidity. We plan to proceed with campaigns to check explicitly for the sites for annual, monthly, diurnal direct variations of water vapor content and temperature.
Fig. 2. The three disconic antennas used in our setup (right). They correspond to the bands: 1-[350-1050]GHz; 2-[1.1-3.6]GHz; 3-[3.6-10.8]GHz.

2.1 RFI measurements

After correlating both climatic and GSM service coverage, we selected several sites for survey. A primary search on GSM residual coverage reduced our target sample to three sites. Since GEM scanning strategy involves azimuthal rotation of 360 degrees circles, the presence of even a single localized source of RFI signals can produce a substantial cut in the sky area surveyed. For this reason, we chose disconic antennas for its omnidirectionality and large band receiver capabilities (see figure 2). While disconic antennas may theoretically work for bands with initial frequency 10 times larger than the central frequency (10:1), in practice we opted to optimally cover a frequency band range like 3:1. For the wide frequency range [100MHz-10 GHz] we built three disconic antennas covering optimally the bands [350-1050]MHz, [1.1-3.6]GHz, [3.6-10.8]GHz. The first antenna is, by above, still capable of detecting strong signals below 100 MHz.

The antennas were then put on a 2.5-m high rod and connected to a spectrum analyzer (an HP8563A). Measurements were taken at different time to check for source variability. The results are shown in figures 1, 2. It is quite clear that RFI appears to be concentrated, as expected, in three wide bands (radio $\sim 88 – 100$ MHz, tv $\sim 500$ MHz and GSM 0.9-1.1 GHz.). Simultaneously, the relative humidity measured was 23%. The site of Castanheira da Serra, hereafter site1, shows promising conditions with only one RFI source appearing intermittently (tv). While not showing any other expected source, it showed some very low frequency signals (shortwave signals), most likely due to ionospheric reflections. 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. Ideally, the best situation would be
to test for RFI with a very sensitive amplifier circuit as close as possible to our desired sensitivity. For 5-10 GHz, we expect the galactic emission to be on the order of 1-100 mK. The total power emitted at these frequencies, considering a 300 MHz bandwidth is about -134 dBm, quite below our noise floor around -90 dBm. This shows that we should be aware of weak, distant signals that may be lurking below this preliminary survey noise sensitivity and carefully shield the instrument. 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, at an elevation of 45° to 60° has an horizontal pick up lower than -40dB. 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 60dB below carrier, therefore any unwanted signals that may fall inside our band would be at least 60 dB below the actual 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 check for this and registered several intermittent signals, most likely due to the occasional use of GSM (figure2). In site1, the intermittent signal seems to be a distant TV broadcast leaking through. 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 totally absent. Site1 also shows a very convenient orography with the presence of several higher mountains rings (∼ 1000m) screening signals that could pass from nearby villages.

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 down to the noise floor of -90 dBm.

\[1 \text{ dBm is the unit for expression of power level in decibels with reference to a power of 1 milliwatt; } \text{dBm}=10\log(P_{\text{mW}}) \text{ where } P_{\text{mW}} \text{ is the power in milliWatt.}\]
Fig. 3. RFI spectrum for the two sites. 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 appears 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.

3 Conclusions

Within the context of the Galactic Emission project, we surveyed several sites for climatic and RFI measurements. Two of the sites show good conditions - low humidity, high number of good weather days, stable geography and low RFI on the survey bands to host a GEM antenna, with one - Castanheira da Serra clearly showing a clean radio spectrum, free of RFI in the important
frequency range of 2-10 GHz.

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