Chapter 3.3

THE GALACTIC EMISSION MAPPING (GEM) PROJECT: SUMMARY AND RESULTS

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Abstract The results of the activities under the GEM Project are described in the context of the more recent results of the modern missions to study the Cosmic Background Radiation. A summary of the papers and thesis based on the GEM Project is also given.

Introduction

With the results coming from recent Cosmic Background Radiation (CBR) experiments, large-scale surveys and deep sky observations the age of precision cosmology has been heralded. The physics of the early universe links the mechanism that originates the large structure of the universe that we see today with observable features of the CBR angular power spectrum. Density fluctuations at the time when the CBR photons decouple (t_d = 300,000 years) leave a characteristic imprint on the CBR angular power spectrum. CBR anisotropies at large angular scale (> 1°) are sensitive to interactions of the radiation field with the gravitational potential on the surface of last scattering, thus providing access to the primordial spectrum of fluctuations. Smaller angular scales (< 1°) on the other hand result from inhomogeneities influenced by gravitational instability growth, which in turn are very sensitive to the major cosmological parameters: baryonic matter density, dark matter density, curvature, Hubble constant and optical depth. Clearly, accurate measurements of CBR at all angular scales are a well established mechanism to pin down the details of the standard cosmological model.

W. Wamsteker et al. (eds.), Developing Basic Space Science World-Wide, 123-129.

The lofty goal of unmasking the exact value of the cosmological parameters with CBR observations cannot be achieved without paying close attention to potential contamination of these observations by foreground emission, such as those originating locally in the Milky Way. Depending on the angular scale and the band of the electromagnetic spectrum chosen for observations, the galactic emission could be the dominant contribution to the signal. For the range of frequencies relevant to CBR studies the galactic emission is always present and has to be dealt with either by creating a template to mask out regions of the sky dominated by galactic signal or by modeling the galactic emission and subtracting it out of the CBR maps. In this age of precision cosmology the ability to account for and separate galactic foregrounds from CBR maps has become a crucial task. When current and future CBR experiments (i.e. WMAP, Plank, etc) attempt to measure the polarization of the CBR, galactic contamination may be the source of the largest systematic error limiting the accuracy of the results.

The Galactic Emission Mapping (GEM) project originated from the recognition that accurate multi-frequency galactic emission models were a necessity for the analysis of CBR data and at the same time the existing galactic emission measurements at the time were not adequate to accomplish this task [15, 19]. A clear understanding of the galactic emission mechanisms in the radio, infrared and microwave regions of the electromagnetic spectrum is not only a necessary condition in the analysis of CBR data but in itself is an important source of data for studies of our galaxy. Galactic dynamics and morphology, the temperature density of the interstellar medium, the energy spectrum of cosmic ray electrons and the intensity of the magnetic field of the galaxy are some of the areas that can be studied with the GEM surveys.

The main sources of galactic emission are: a) synchrotron radiation from relativistic electrons spiraling under the influence of the magnetic field of the galaxy; b) thermal bremstrahlung emission inside hydrogen clouds and c) thermal radiation from dust along the plane of the galaxy. Each one of these sources has a characteristic and different spectral shape (parameterized with an spectral index) allowing for a separation into components at a given frequency. GEM measurements focus on the low frequency part of the spectrum (408 MHz, 1465 MHz, 2.3 GHz, 5 GHz and 10 GHz). These observations can be complemented with the CBR maps themselves (i.e. from COBE, WMAP, Plank, etc), which show the galaxy at higher frequencies. The goal of the GEM project is to obtain a full sky survey (spatial template) of galactic emission at the low frequencies mentioned above and an accurate determination of the spectral indices including spatial variations.

More accurate measurements of the spectral indices of the galactic emission components, allow for the reduction of the systematic errors affecting the determination of cosmological parameters from CBR observations. It will also be possible to perform a more precise determination of the baseline in point source surveys whose contribution affects the measurements of anisotropies at small angular scales. With respect to the large angle scale anisotropies an accurate estimation of the quadrupole component due to galactic contamination can help solve the unexpectedly low value of the CBR quadrupole measured by COBE (10^{+7}_{-4} μK) and WMAP (8 ± 2 μK). Galactic contamination is the leading uncertainty in the measured CBR quadrupole, thus improvements in the estimation of the galactic contribution to this component may point to hidden interesting physical effects, such as curvature effects, non-standard metrics, global rotation, etc.

1. The Project

The GEM radio-telescope consists of a 5.5 m diameter parabolic reflector with receivers at 408 MHz, 1465 MHz, 2.3 GHz, 5 GHz and 10 GHz mounted on a moving platform (~1 rpm) that allows to map bands of 60° from a network of observing sites spread in latitude for full sky coverage. The experimental approach and the goals of the project are described in papers [1, 6, 7, 8, 9, 10, 19 and 21].

The GEM collaboration began forming in 1990 when the first proposals were prepared. The collaboration is composed by the Lawrence Berkeley National Laboratory of the University of California, USA, the Centro Internacional de Física (CIF) and the Observatorio Nacional of the Universidad Nacional de Colombia, Bogotá, Colombia, the Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, Brazil, the University of Milan, Milan, Italy, University of Rome, Rome, Italy, and the Instituto Astronómico de las Canarias, Tenerife, Spain. These groups have been active during different phases of the experiment.

A prototype system was assembled and field-tested during December 1991 at the South Pole near the Amundsen-Scott Research Station. From these observations it was possible to obtain calibrated measurements of the sky temperature along directions of fixed pointing angle or 'drift' scans and 'nodding' scans. The results of these measurements are presented in [20].

During the period November 1993 through November 1994 the completed GEM system was assembled in the White Mountain Research Station, Owens Valley, California (+37° 22′ latitude and 1,250 m). Most of the observation time was devoted to diagnostics and calibration tests of the equipment. Data acquisition at 408 MHz and 1465 MHz was achieved and a partial 1465 MHz map covering the region $0^h < \alpha < 24^h$ and $+7° 10' < \delta < +67° 30'$ was completed. The results of the White Mountain acquisition period constitute the main topic of the PhD thesis work in [22]. Observations at 408 MHz from the White Mountain site had to be suspended due to radio frequency interference emanating from a meteorological station in the local airport.

GEM observations from equatorial latitudes were conducted from January through June 1995. For this campaign a site in a desert (+5° 38′ latitude and 2,173 m) near the town of Villa de Leyva, Colombia was selected [11]. A total of 1,618 hours of observation were completed as follows: 1,116 hours at 408 MHz, 131 hours at 1465 MHz, 231 hours at 2.3 GHz, and 140 hours at 5 GHz. A calibrated partial sky map at 408 MHz including a selection of 745 hours of observation covering the celestial band $0^h < \alpha < 24^h$, and $-24° 22' < \delta < +35° 37'$ was produced and is discussed in papers [2, 4, 5, 7, 8, 14, 16, 17, and 18]. The results of the analysis of the 2.3 GHz data including a partial map were presented in [13]. Observation with the 1465 MHz receiver was aborted due to strong radio frequency interference from a geo-stationary satellite. Two graduate thesis [23, 24] and two undergraduate thesis [25, 26] were produced from the GEM observations in Colombia.

Observations of the southern sky are being conducted since 1998 from the site in Cachoeira Paulista, SP, Brazil (-22° 41′ latitude and 500 m). The data acquisition campaign from this site has completed 1,356 hours of observation at 1465 MHz and 818 hours at 2.3 GHz taken during the time period July 1998 – November 1999. Partial maps have been obtained at these frequencies. These results have been presented in [3,12]. There are plans to take measurements from the Antarctic Brazilian Station.

The GEM results obtained thus far satisfy the goal of achieving sky brightness temperature measurements with absolute calibration of the zero level of the map to better than 0.1 K and an accuracy of the gain level to better than 3%. The requirement of internally consistent maps and full sky coverage have been achieved by using the same equipment from sites at different latitudes from the South Pole, to Brazil, to Colombia, to White Mountain in California. The major technical problem encountered is the presence of man-made radio interference. The project has provided a great opportunity for scientists and students in Latin America to participate in an important international scientific collaboration.

2. GEM Publications

2.1 Publications in Journals

1. C. Tello, T. Villela, G.F. Smoot, M. Bersanelli, N. Figueiredo, G. De Amici, M. Bensadoun., C.A. Wuensche, and S. Torres, "Spillover and diffraction sidelobe contamination in a double-shielded expriment for mapping Galactic synchrotron emission", *Astronomy & Astrophysics Supplement Series,* **145**, 495-508 (2000).

2. S. Torres, "The UN/ESA Workshop on Basic Space Science in Colombia, 1992: What has been achieved since then?", *COSPAR Bulletin*, **No. 144**, pp. 13-15, April 1999.

3. C. Tello, T. Villela, A. M. Alves, L. G. Arantes, G. Smoot, G. Deamici, S. Torres, M. Bersanelli, M. Bensadoun, A. Wuensche, N. Figueiredo, "A radio continuum survey of the Sky at 1465 MHz from 53 degrees South to 78 degrees north", *Revista Mexicana de Astronomía y Astrofísica Serie de Conferencias* (in press 1998)

4. V. Cañón, S. Torres, "Medición de la Radiación Sincrotrón en la Galaxia", *Revista Momento, Universidad Nacional* , (1998).

5. R. Casas, S. Torres, "Corrección de mapas de Radiación Cósmica de Fondo por contaminación galáctica y estimación del cuadripolo cosmológico", *Revista Momento, Universidad Nacional* , (1998).

6. C. Tello, T. Villela, C.A. Wuensche, N. Figueiredo, S. Torres, M. Bersanelli, M. Bensadoun, M. Limon, G. De Amici, G. Smoot, "Diffraction analysis of a double-shielded antenna in the Fraunhofer and Fresnel regimes", *Radio Science*, **34**, No. 3, May/June 1999.

7. S. Torres, "Cosmología y Modelos Galácticos con el Proyecto GEM", Boletín del Observatorio Astronómico, (1997)

8. S. Torres, V. Cañón, R. Casas, A. Umaña, C. Tello, T. Villela, M. Bersanelli, M. Bensadoun, G. De Amici, M. Limon, G. Smoot, C. Witebsky, "The GEM project: An international collaboration to survey galactic radiation emission", astro-ph/9605060, *Astrophysics and Space Science*, **240**, 225-234 (1996).

9. De Amici, G., Bensadoun, M., Limon, M., Smoot, G., Bersanelli, M., "A new instrument to map the absolute brightness of the sky at low radio frequencies", *Astroph. Lett Comm*., **32**, 153 (1995).

10. G. De Amici, S. Torres, M. Bensadoun, G. Dall'Oglio, M. Limon, G. Smoot, G. Sironi, T. Villela, C. Witebsky, "A research program to map the galactic emission at low frequencies", *Astrophysics and Space Science*, **214**, pp. 151-160 (1994).

11. S. Torres, G. Smoot, G. De Amici, M. Becerra, M. Chaux, J. Gómez, A. Umaña, "Site Evaluation and RFI Measurements in Colombia for a Galactic Radio Survey", *Revista Colombiana de Física*, **25**, pp. 23-30 (1993).

2.2 Publications in Conference Proceedings

12. C. Tello, T. Villela, G.F. Smoot, S. Torres, M. Bersanelli, "A new radio continuum survey of the sky at 1465 MHz between declinations –52˚ and +68˚", in *New Cosmological Data and the Values of the Fundamental Parameters*, International Astronomical Union, Symposium no. **201**, Manchester, England, Aug. 2000.

13. S. Torres, V. Cañón, R. Casas, A. Umaña, C. Tello, T. Villela, M. Bersanelli, G. De Amici, G. Smoot, "Long wavelength sky surveys with the GEM radio telescope", *Astrophysics and Space Science*, in *Seventh UN/ESA Workshop on Basic Space Sciences*, Eds. H. Haubold, M. C. Pineda, Tegucigalpa, Honduras, June 16-20 (1997)

14. S. Torres, T. Villela, G.De Amici, G. Smoot, M. Bersanelli, C. Tello, A. Umaña, "A Survey of the Galactic Emission at 408 from an Equatorial site", XXI Reunião Anual da Sociedade AstronômicaBrasileira, Sao Loureno, MG, Brasil, Jul 31-Agosto, 1996, Boletin da SAB, **16**, No 1, 99 (1996)

15. S. Cortiglioni, M.R. Attolini, N. Mandolesi, E. Palazzi, S. Montebugnoli, A. Orfei, M. Bersanelli and G. De Amici, "The importance of accurate galactic observations at radio-frequency for CMB experiments", *Mem. Soc. Astr. It.*, **66**, 84 (1995).

16. A. Umaña y S. Torres, "El Proyecto GEM de Observación de la Galaxia", en *De la Astronomía a la Cosmología: estudios y resultados recientes, Primera Escuela Nacional de Astrofísica*, Ed. S. Torres, Bogotá, Nov 28 -1 Dic. 1994, pp. 169-176

17. L. Chacón y S. Torres, "Interferencia en observaciones radioastronómicas" en *De la Astronomía a la Cosmología: estudios y resultados recientes, Primera Escuela Nacional de Astrofísica*, Ed. S. Torres, Bogotá, Nov 28 -1 Dic. 1994, pp. 177-184

18. T. Villela, A. M. Alves, C. Tello, G. Smoot, G. De Amici, S. Torres, A. Umaña, M. Bersanelli, "Resultados Preliminares do Projeto GEM em 408 MHz" en XX Reuniao Anual da Sociedade Astronômica Brasileira, Campos do Jordao, Sao Paulo, Brasil, Agosto 1 al 4, 1994, **Vol. 14**, No. 1, p. 100 (1994)

19. G. De Amici, G. Smoot, M. Bensadoun, M. Limon, W. Vinje, C. Witebsky, S. Torres, A. Umaña, M. Becerra, "Mapping the Absolute Brightness of the Sky at Low Frequencies" in *Back to the Galaxy*, Maryland, USA, Octubre 1992, edts. S.S. Holt and F. Verter, AIP Conference Proceedings Series, .**Vol. 278**, pp. 206-209 (1993)

20. De Amici, G., Smoot, G., Bensadoun, M, Bersanelli, M., Levin, S., Limon, M., and Vinje, W., "A new program to map the absolute temperature of the sky at low frequencies", in G. Chincarini et al. (edts): *Observational Cosmology*, ASP Conference Series (ASP, San Francisco) **51**, 527 (1993)

21. G.F. Smoot, G. De Amici, M. Limon, S. Torres and T. Villela, "A research program to map the absolute sky brightness at low frequencies," in *5th Symposium on Pan-American Collaboration in Experimental Physics*, August 17-21, 1992, Cartagena, Colombia.

2.3 Doctoral and Undergraduate Thesis

22. "Um experimento para medir o brilho total do céu em comprimentos de onda centimétricos", Camilo Tello, doctoral thesis, Instituto Nacional de Pesquisas Espaciais, São José dos Campos, Brazil, 1997, INPE-7036-TDI/664.

23. "Medición de la Radiación Sincrotrón en la Galaxia", Victor Cañón, master thesis, Universidad Nacional, Bogotá, Colombia, October 1997.

24. "Corrección de mapas de Radiación Cósmica de Fondo por contaminación galáctica y estimación del cuadripolo cosmológico", Rigoberto Casas, master thesis, Universidad Nacional, Bogotá, Colombia, Octuber 1997.

25. "Medición desde Colombia de la Radiación Difusa de la Galaxia a 408 MHz", Andrés Umaña , undergraduate thesis, Universidad de los Andes, Bogotá, Colombia, August 1995.

26. "Estudio de la Interferencia en Señales Medidas por un Radio Telescopio", Liliana P. Chacón, undergraduate thesis, Universidad de los Andes, Bogotá, Colombia, August 1994.