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GMRT observations of the WMAP cold spot

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Abstract. We describe observations of 20 square degree region towards the WMAP cold spot (l=207.80, b=-56.30; RA = 03h15m, Dec. = -19d35) made with the Giant Metrewave Radio Telescope at 625 MHz, and 325 MHz. We find deficiency in the number counts of radio sources towards the cold spot in a 3 sq. deg region at position (l= 206.600, b= -54.740), similar to that reported by Rudnick et al. (2007). We find that the average value of the spectral index of radio sources in the 3 sq. deg region ('Radio Cold Spot') is significantly flatter than that elsewhere in the field observed by us of about 20 square degrees. Further, most of the radio sources in the $\approx$ 3 sq. deg region are relatively compact compared to radio sources elsewhere. It may be noted that the cold spot indicates significant deviation of the CMB from Gaussianity and has been confirmed by the recently released Planck data. We discuss significance of our results.

1. Introduction

An extreme Cold Spot was discovered in the WMAP data of the CMB by Vielva et al. (2004) and was confirmed by Cruz et al. (2005, 2007). It has also been supported by the recent Planck observations (Planck XXIII, 2013). Its presence indicates significant deviation of the CMB from Gaussianity that is not expected in the Standard Inflationary Model. Recently, Fernandez-Cobos et al. (2013) have investigated the radial and tangential polarization patterns around the Cold Spot.

In 2007, Rudnick et al. reported that there is a deficiency of counts of radio sources and their flux distribution in the NVSS catalogue in the region of the Cold Spot. However, Smith & Huterer (MNRAS, 2010) concluded that the reported deficiency by Rudnick et al. is a posteriori choice. In this paper are summarized radio ob-

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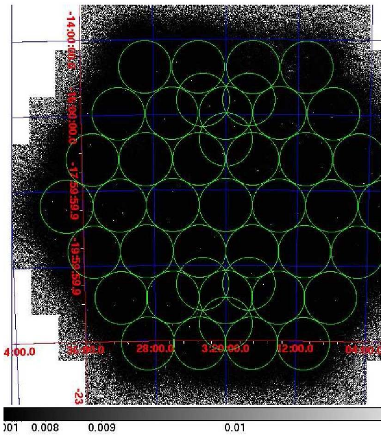

Figure 1. The 43 pointings made for the GMRT observations at the frequencies of 325 MHz, 625 MHz and 1280 MHz.

servations of the Cold Spot made with the GMRT. We have investigated radio source counts, spectral index and angular size distributions in a region around the Cold Spot at 325 MHz and 610 MHz. GMRT observations at 1280 MHz are being analyzed. Using AAÎľ optical telescope in Australia, optical and spectrographic observations have also been made by Greg Aldering and collaborators (including us) for 9 fields, covering 27 sq. deg. near the Cold Spot region. Data is being analyzed.

It has been suggested that the Cold Spot in the CMB could be created by: (a) by the Integrated Sachs Wolfe effect (Rees-Sciama, 1968) , as the CMB photons travel through a large void but Bremmer et al (2010) do not find a large void at z > 0.3 based on spectroscopic observations using the VLT; (b) Sunyev-Zeldovich (S-Z) effect caused by scattering in a large cluster of galaxies or (b) other causes such as cosmic texture and defects in the early universe (Cruz .et al. 2007)

2. GMRT observations

The region centered at l = 2090, b = - 570, (R.A. = 03hr 13m; Dec. = -20o 26$'$) with a size 10 0 on the sky was observed as described below (Fig. 1): (a1). At 325 MHz: 21st Dec. 2007, 7 pointing (HPW 1.40) over 7 hours (20 sq. deg.) (a2). At 325 MHz: 2nd Sept. 2008, 43 pointing (HPW 1.40) for 12 minute each (50 sq. deg.) (b). At 610 MHz: 12th Sept. 2008, 43 pointing at 610 MHz (HPW 0.750) for 12 minute each (16 sq. deg.). (c). At 1280 MHz: 8th & 9th August, 2008 and 13th and 15th Sept. 1280 MHz (HPW 0. 350) for 12 minute each (8 sq. deg.); the data at 1280 MHz is being analyzed.

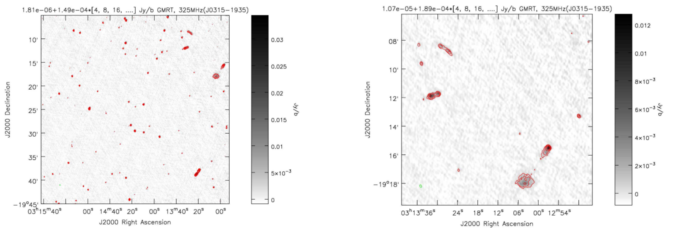

Figure 2. Left panel illustrates radio sources detected in a 40 arcmin x 40 arcmin part of the 30 sq. degrees mapped at 325 MHz. Right panel shows zoom of a 14’ x 14’ region.

3. Results

We have combined 325 MHz data for the 21st Dec. 2007 and 2nd Sept 2008 observations made with the GMRT over 30 sq. deg. region. Left panel in Fig. 2 illustrates radio sources detected in a 40 arcmin x 40 arcmin part of the 30 Sq degrees mapped at 325 MHz, showing rms 2 mJy. However, completeness limit was 8 mJy. Right panel shows zoom of a 14’ x 14’.

3.1 Counts of radio sources

In 2007, Rudnick et al. reported that there is a deficiency in the counts of radio sources and their flux distribution in the NVSS catalogue in the region of the Cold Spot. Similar deficiency was noted by Sirothia et al. (2009), as can be seen from Figure 1 of that paper in which are given number of sources within 10 radius circle centered at the coordinates of several observed fields on x-axis. From observations described in Section 2, we have determined number density in a 25 sq degree area in the NVSS-1420 MHz and GMRT-325 MHz data. Based on the median value of the spectral index $\alpha^{1400-325} \approx 0.87$ between the GMRT and NVSS data, we find that 5 mJy for NVSS at 1420 MHz corresponds to 17. 8 mJy at 325 MHz. We then calculate number density in a 25 sq degree area at 1420 MHz and at 325 MHz. We find 38 sources in a 10 radius circle in the region of the Cold Spot and 100 sources in the outside region.

3.2 Spectral distribution map

In Fig. 4 is shown spectral distribution map, for each of the 10 radius circle., of radio sources with flux density at 1400 MHz > 5mJy , based on the derived mean value of -0.82 of the spectral indices, $\alpha^{1400-325}$. Mean spectral index varies across the field. A flatter spectral index is noted near the NVSS Cold Spot.

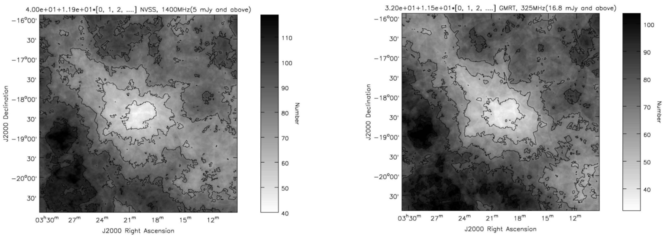

Figure 3. Left panel shows source number density (per 10 radius circle) of NVSS sources > 5 mJy at 1400 MHz; Right panel shows source number density (per 10 radius circle) for the GMRT 325 MHz sources > 17.8 mJy.

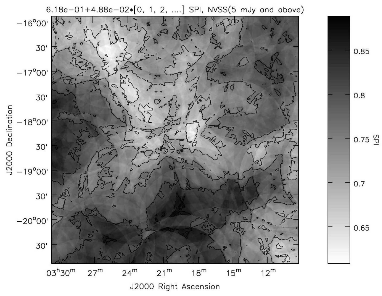

Figure 4. The spectral distribution map for each of the 10 radius circle of radio sources with flux density at 1400 MHz > 5mJy

3.3 GMRT and NVSS source counts around the WMAP Cold Spot

In Column 1 & 2 of the Table 1 are given counts of radio sources in different flux density range for the GMRT and NVSS sources. Rather than simply calculating rms of counts as N1/2 where mean value is N, we have calculated standard deviation of the distribution of counts given in the 2 slides presented earlier. We find that deficiency of counts (mean âĂŞ minimum) of radio sources is about 3 s.d. for S $\geq$ 17.8 for the GMRT observaions at 325 MHz and nearly the same for S $\geq$ 5 mJy for the NVSS data at 1420 MHz, implying significant deficiency. In Column 3 are given values of $\alpha^{1400-325}$ with its mean value of 0.82 and rms 0.06.

Table 1. In column 1 & 2 are given counts of radio sources in flux density ranges and in column 3 are given

4. Origin of the cold spot: a Summary

Of several anomalies seen in the WMAP/PLANCK, Cold Spot is the most prominent. Several suggestions have been made for its origin: (a). Its occurrence has been at-

Table 1. Counts and spectral indices of sources in different flux ranges.

	Flux Range (mJy)	Min.	Max.	Mean	s.d.
	≥ 17.8	38	103	69	11.7
GMRT	17.8 - 71.3	25	64	47	6.9
	≥ 71.3	9	41	22	6.3
	≥ 5	40	104	75	10
NVSS	5 - 20	28	69	55	5.7
	≥ 20	8	39	20	6
	≥ 5	0.66	0.93	0.82	0.047
$\alpha^{1400-325}$	5 - 20	0.61	0.96	0.82	0.06
S(1400)	≥ 20	0.63	1.04	0.82	0.054

tributed to the Integrated Sachs-Wolfe (ISW) effect: a flat and accelerating universe with Dark Energy has an evolving gravitational potential that introduces a net energy shift in the CMB photons traversing through a large void (Rees and Sciama 1968). However, spectroscopic observations by Bremer et al. (2010) using VLT have not detected a large void at $0.3<z<1$; (b).Sunyev-Zeldovich (S-Z) effect caused by scattering of the CMB photons in a large cluster of galaxies, but such a cluster is not seen towards the Cold Spot region; (c). Cruz et al. (2007) have proposed that the Cold Spot arises at the surface of last scattering itself due to inherent defects in the very early universe compatible with a cosmic texture.

5. Conclusion

GMRT observations at 325 MHz and 610 MHz show that: (a) radio source counts show deficiency towards the Cold Spot of about 50%; (b) the spectral index is significantly flatter towards the Cold Spot region and (c) it is also significant that angular sizes are smaller in the region of the Cold Spot. In the direction of the NVSS Cold Spot (2.5deg radii), about 85% sources are unresolved at 325 MHz and 78% sources are unresolved at 610 MHz. However, in region excluding NVSS Cold Spot, 70% sources are unresolved at 325 MHz and 64% sources are unresolved at 610 MHz. We plan further investigation of these results including reduction of observations made with the GMRT at 1280 MHz and also the optical as well spectrographic observations made with the AAΩ.

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