Absolute cold sky brightness temperature of the diffuse radio background from 50 to 1500 MHz

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Abstract

In this report, we present temperature of the cold sky as a function of observing frequencies of the upgraded Giant Metrewave Radio Telescope (uGMRT) in steps of 5 MHz interval. The key inputs in order to generate Table 1 and the corresponding Fig. 1 are Equation 1 and $T_{\rm sky}$ values listed in Section 3. We use simple command line `awk` script to generate the temperatures. We hope this document would be useful for our GMRT colleagues from the Engineering group and control room staff to perform routine system tests.

1 Introduction

The on-going upgrade of the GMRT have renewed interest in the measured system temperature at each observing frequency. Since efforts are being made to have lowest possible receiver temperature, hence an absolute value of cold sky temperature is a must.

This report is organized as follows. Section 2 gives a little background of radio astronomy, including what does the radio telescope detect (Section 2.4), etc. The methodology is presented in Section 3 and we summarise our findings in Section 4.

2 Basics

2.1 Intensity and Flux density

Electro-magnetic power in bandwidth $\Delta\nu$ from solid angle $\delta\Omega$ intercepted by surface δA is

$$\delta W \;=\; I\nu \,\delta\Omega \,\delta A \,\Delta\nu,$$

where, $I\nu$ is surface brightness (W m^{-2} Hz^{-1} sr^{-1}, a.k.a. specific intensity). $S\nu$ (W m^{-2} Hz^{-1}) is the flux density, integrated brightness over solid angle of source

$$S\nu \;=\; \int_{\Omega_s} I\nu \,\delta\Omega.$$

Note that
$S\nu = L\nu \,/\, 4\,\pi\, d^2$ is distance independent, and
$\Omega \propto 1/d^2 \Rightarrow I\nu \propto S\nu/\Omega$ is also distance independent.

2.2 Surface Brightness

In general the surface brightness is position dependent, i.e. $I\nu \;=\; I\nu(\theta,\phi)$,

$$I\nu(\theta,\phi) \;=\; \frac{2k\,\nu^2\,T(\theta,\phi)}{c^2},$$

(if $I\nu$ is described by a blackbody in the Rayleigh-Jeans limit, $h\nu/kT << 1$)
then

$$S\nu \;=\; \int_{\Omega_s} I\nu(\theta,\phi)\,\delta\Omega \;=\; \frac{2k\,\nu^2}{c^2}\int T(\theta,\phi)\,\delta\Omega;$$

i.e., the radio telescope maps the temperature distribution of the sky.

2.3 Brightness Temperature

Many astronomical sources DO NOT emit as blackbodies! However, brightness temperature (T_B) of a sources is defiled as the temperature of a blackbody with the same surface brightness at a given frequency:

$$I\nu \;=\; \frac{2k\,\nu^2\,T_B}{c^2}.$$

This implies that the flux density

$$S\nu \;=\; \int_{\Omega_s} I\nu d\Omega \;=\; \frac{2k\,\nu^2}{c^2}\int T_B\,d\Omega.$$

2.4 What does the Radio Telescope Detect?

Recall

$$\delta W \;=\; I\nu\,\delta\Omega\,\delta A\,\Delta\nu,$$

Telescope of effective area A_e receives power P_{rec} per unit frequency from an unpolarised sources but is only sensitive to one mode of polarization

$$P_{rec} \;=\; \frac{1}{2}\,I_\nu\,A_e\,d\Omega.$$

Telescope is sensitive to radiation from more than one direction with relative sensitivity given by the normalised antenna pattern $P_N(\theta,\phi)$:

$$P_{rec} \;=\; \frac{1}{2}\,A_e\int_{4\pi} I_\nu(\theta,\phi)\;P_N(\theta,\phi)\;d\Omega.$$

2.5 Antenna Temperature

Johnson-Nyquist theorem (1928):

$$P \;=\; kT.$$

The power received by the antennas:

$$P_{rec} \;=\; kT_A$$

$$P_{rec} \;=\; \frac{A_e}{2}\int_{4\pi} I_\nu(\theta,\phi)\;P_N(\theta,\phi)\;d\Omega.$$

Therefore,

$$T_A \;=\; \frac{A_e}{2k}\int_{4\pi} I_\nu(\theta,\phi)\;P_N(\theta,\phi)\;d\Omega.$$

Antenna temperature is what is observed by the radio telescope, or a "convolution" of sky brightness with the beam pattern, and it is an inverse problem to determine the source temperature distribution.

3 Method

In this report, we provide the cold sky temperature distribution in order to calibrate the system temperature. To achieve this, we use the following values of sky temperatures at a few specific frequencies from the Table 18.1, Chapter 18 of Low Frequency Radio Astronomy (the "Blue book").

- ⋆ 153 MHz, T_{sky} = 308 K,
- ⋆ 233 MHz, T_{sky} = 99 K,
- ⋆ 327 MHz, T_{sky} = 40 K,
- ⋆ 610 MHz, T_{sky} = 10 K, and
- ⋆ 1420 MHz, T_{sky} = 4 K.

Next

$$T_{sky} \;\propto\; (1/\nu)^{-\gamma} \tag{1}$$

where γ is typically 2.55 (Sirothia 2009) at low frequencies. Using above measurements, we obtain

- ⋆ γ (153,233) = 2.70,
- ⋆ γ (233,327) = 2.67,
- ⋆ γ (327,610) = 2.22, and
- ⋆ γ (610,1420) = 1.08.

We use these slopes to determine the sky temperatures at other frequencies.

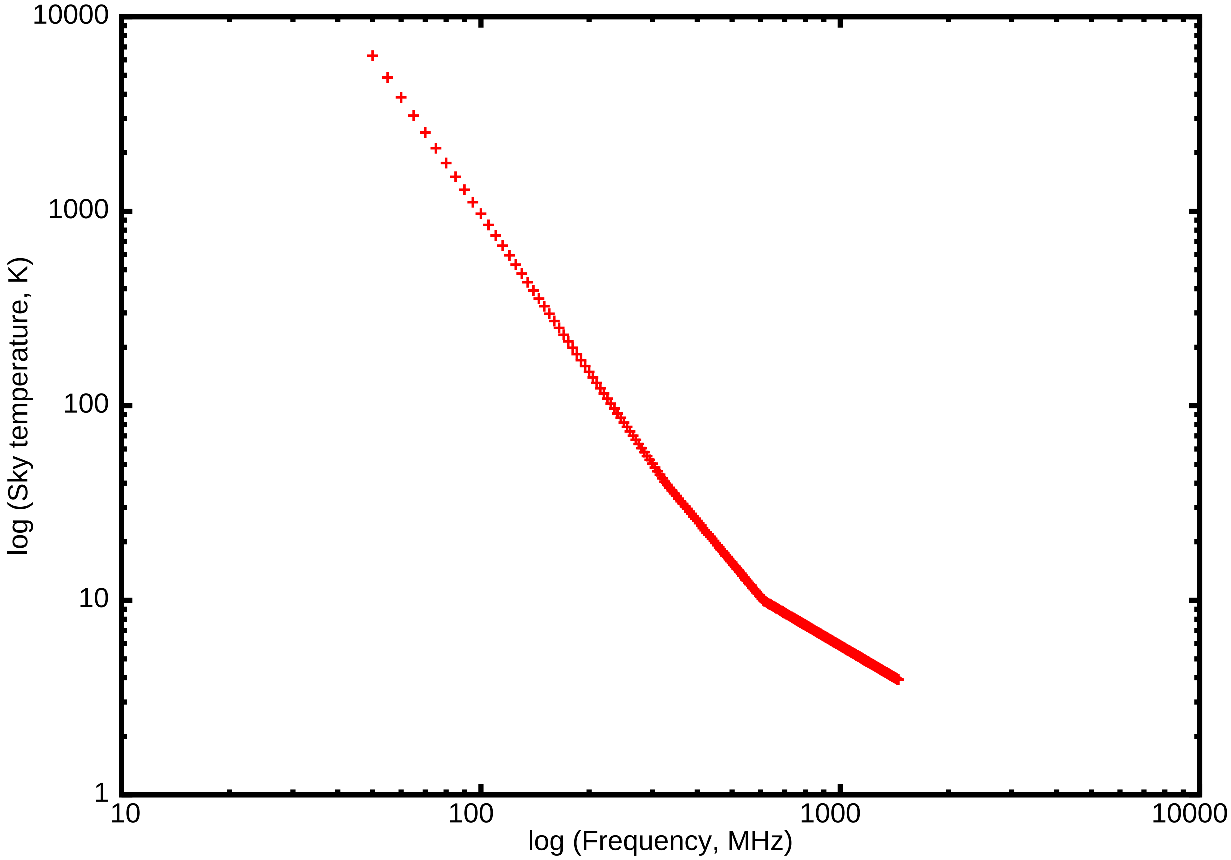

Figure 1: Plot showing temperature of the cold sky (in K) as a function of frequency (in MHz). Values plotted are from Table 1 giving temperature of the cold sky in steps of 5 MHz frequency interval. The measurements at a few specific frequencies listed in Section 3 are from the "Blue book".

4 Summary of Results

The temperature of the cold sky as a function of observing frequencies of the uGMRT are tabulated in Table 1 and plotted in Fig. 1. These values are presented in steps of 5 MHz frequency interval. Each chunk corresponds to each of the frequeny feeds of the uGMRT, which would be an instrument having (nearly) seamless frequency coverage, once the upgrade is complete.

We hope that this document would be useful for the Engineering team at the GMRT in order to perform appropriate system tests, thereby improve the performance of the GMRT.

5 References

– "Blue book": Low frequnecy Radio Astronomy, Eds. J.N. Chengalur, Y. Gupta & K.S. Dwarakanath (May 2003)

– Rogers, A.E. & Bowman, J.D., 2008 AJ, 136, 641

– Sirothia, S.K., 2009 MNRAS, 398, 853

(50-125 MHz)	(125-250 MHz)	(250-500 MHz)	(500-750 MHz)	(750-1000 MHz)	(1000-1250 MHz)	(1250-1500 MHz)
50 MHz 6298.8 K	125 MHz 531.5 K	250 MHz 82.0 K	500 MHz 15.6 K	750 MHz 7.99 K	1000 MHz 5.85 K	1250 MHz 4.59 K
55 MHz 4870.4 K	130 MHz 478.0 K	255 MHz 77.8 K	505 MHz 15.2 K	755 MHz 7.93 K	1005 MHz 5.81 K	1255 MHz 4.57 K
60 MHz 3851.1 K	135 MHz 431.8 K	260 MHz 73.8 K	510 MHz 14.9 K	760 MHz 7.87 K	1010 MHz 5.78 K	1260 MHz 4.55 K
65 MHz 3103.0 K	140 MHz 391.4 K	265 MHz 70.1 K	515 MHz 14.6 K	765 MHz 7.82 K	1015 MHz 5.75 K	1265 MHz 4.53 K
70 MHz 2540.6 K	145 MHz 356.0 K	270 MHz 66.8 K	520 MHz 14.3 K	770 MHz 7.76 K	1020 MHz 5.72 K	1270 MHz 4.51 K
75 MHz 2109.0 K	150 MHz 324.9 K	275 MHz 63.6 K	525 MHz 14.0 K	775 MHz 7.71 K	1025 MHz 5.69 K	1275 MHz 4.49 K
80 MHz 1771.9 K	155 MHz 297.4 K	280 MHz 60.6 K	530 MHz 13.7 K	780 MHz 7.65 K	1030 MHz 5.66 K	1280 MHz 4.47 K
85 MHz 1504.5 K	160 MHz 273.0 K	285 MHz 57.8 K	535 MHz 13.4 K	785 MHz 7.60 K	1035 MHz 5.63 K	1285 MHz 4.45 K
90 MHz 1289.5 K	165 MHz 251.2 K	290 MHz 55.1 K	540 MHz 13.1 K	790 MHz 7.55 K	1040 MHz 5.60 K	1290 MHz 4.43 K
95 MHz 1114.4 K	170 MHz 231.8 K	295 MHz 52.7 K	545 MHz 12.8 K	795 MHz 7.50 K	1045 MHz 5.57 K	1295 MHz 4.42 K
100 MHz 970.4 K	175 MHz 214.3 K	300 MHz 50.4 K	550 MHz 12.6 K	800 MHz 7.45 K	1050 MHz 5.54 K	1300 MHz 4.40 K
105 MHz 850.7 K	180 MHz 198.7 K	305 MHz 48.1 K	555 MHz 12.3 K	805 MHz 7.40 K	1055 MHz 5.52 K	1305 MHz 4.38 K
110 MHz 750.3 K	185 MHz 184.5 K	310 MHz 46.1 K	560 MHz 12.1 K	810 MHz 7.35 K	1060 MHz 5.49 K	1310 MHz 4.36 K
115 MHz 665.5 K	190 MHz 171.7 K	315 MHz 44.2 K	565 MHz 11.9 K	815 MHz 7.30 K	1065 MHz 5.46 K	1315 MHz 4.34 K
120 MHz 593.3 K	195 MHz 160.1 K	320 MHz 42.4 K	570 MHz 11.6 K	820 MHz 7.25 K	1070 MHz 5.43 K	1320 MHz 4.32 K
125 MHz 531.5 K	200 MHz 149.5 K	325 MHz 40.7 K	575 MHz 11.4 K	825 MHz 7.20 K	1075 MHz 5.40 K	1325 MHz 4.31 K
	205 MHz 139.9 K	330 MHz 39.2 K	580 MHz 11.2 K	830 MHz 7.16 K	1080 MHz 5.38 K	1330 MHz 4.29 K
	210 MHz 131.0 K	335 MHz 37.9 K	585 MHz 11.0 K	835 MHz 7.11 K	1085 MHz 5.35 K	1335 MHz 4.27 K
	215 MHz 123.0 K	340 MHz 36.7 K	590 MHz 10.8 K	840 MHz 7.06 K	1090 MHz 5.32 K	1340 MHz 4.25 K
	220 MHz 115.6 K	345 MHz 35.5 K	595 MHz 10.6 K	845 MHz 7.02 K	1095 MHz 5.30 K	1345 MHz 4.24 K
	225 MHz 108.8 K	350 MHz 34.4 K	600 MHz 10.4 K	850 MHz 6.97 K	1100 MHz 5.27 K	1350 MHz 4.22 K
	230 MHz 102.5 K	355 MHz 33.3 K	605 MHz 10.2 K	855 MHz 6.93 K	1105 MHz 5.25 K	1355 MHz 4.20 K
	235 MHz 97.0 K	360 MHz 32.3 K	610 MHz 10.0 K	860 MHz 6.89 K	1110 MHz 5.22 K	1360 MHz 4.19 K
	240 MHz 91.4 K	365 MHz 31.3 K	615 MHz 9.91 K	865 MHz 6.84 K	1115 MHz 5.19 K	1365 MHz 4.17 K
	245 MHz 86.7 K	370 MHz 30.4 K	620 MHz 9.82 K	870 MHz 6.80 K	1120 MHz 5.17 K	1370 MHz 4.15 K
	250 MHz 82.0 K	375 MHz 29.5 K	625 MHz 9.74 K	875 MHz 6.76 K	1125 MHz 5.14 K	1375 MHz 4.14 K
		380 MHz 28.6 K	630 MHz 9.65 K	880 MHz 6.72 K	1130 MHz 5.12 K	1380 MHz 4.12 K
		385 MHz 27.8 K	635 MHz 9.57 K	885 MHz 6.67 K	1135 MHz 5.09 K	1385 MHz 4.10 K
		390 MHz 27.0 K	640 MHz 9.49 K	890 MHz 6.63 K	1140 MHz 5.07 K	1390 MHz 4.09 K
		395 MHz 26.3 K	645 MHz 9.41 K	895 MHz 6.59 K	1145 MHz 5.05 K	1395 MHz 4.07 K
		400 MHz 25.6 K	650 MHz 9.33 K	900 MHz 6.55 K	1150 MHz 5.02 K	1400 MHz 4.06 K
		405 MHz 24.9 K	655 MHz 9.25 K	905 MHz 6.51 K	1155 MHz 5.00 K	1405 MHz 4.04 K
		410 MHz 24.2 K	660 MHz 9.18 K	910 MHz 6.48 K	1160 MHz 4.98 K	1410 MHz 4.03 K
		415 MHz 23.5 K	665 MHz 9.10 K	915 MHz 6.44 K	1165 MHz 4.95 K	1415 MHz 4.01 K
		420 MHz 22.9 K	670 MHz 9.03 K	920 MHz 6.40 K	1170 MHz 4.93 K	1420 MHz 4.00 K
		425 MHz 22.3 K	675 MHz 8.96 K	925 MHz 6.36 K	1175 MHz 4.91 K	1425 MHz 3.98 K
		430 MHz 21.8 K	680 MHz 8.88 K	930 MHz 6.32 K	1180 MHz 4.88 K	1430 MHz 3.96 K
		435 MHz 21.2 K	685 MHz 8.81 K	935 MHz 6.29 K	1185 MHz 4.86 K	1435 MHz 3.95 K
		440 MHz 20.7 K	690 MHz 8.74 K	940 MHz 6.25 K	1190 MHz 4.84 K	1440 MHz 3.93 K
		445 MHz 20.2 K	695 MHz 8.68 K	945 MHz 6.22 K	1195 MHz 4.82 K	1445 MHz 3.92 K
		450 MHz 19.7 K	700 MHz 8.61 K	950 MHz 6.18 K	1200 MHz 4.80 K	1450 MHz 3.91 K
		455 MHz 19.2 K	705 MHz 8.54 K	955 MHz 6.15 K	1205 MHz 4.77 K	1455 MHz 3.90 K
		460 MHz 18.7 K	710 MHz 8.48 K	960 MHz 6.11 K	1210 MHz 4.75 K	1460 MHz 3.88 K
		465 MHz 18.3 K	715 MHz 8.41 K	965 MHz 6.08 K	1215 MHz 4.73 K	1465 MHz 3.87 K
		470 MHz 17.9 K	720 MHz 8.35 K	970 MHz 6.04 K	1220 MHz 4.71 K	1470 MHz 3.85 K
		475 MHz 17.4 K	725 MHz 8.29 K	975 MHz 6.01 K	1225 MHz 4.69 K	1475 MHz 3.84 K
		480 MHz 17.0 K	730 MHz 8.23 K	980 MHz 5.98 K	1230 MHz 4.67 K	1480 MHz 3.82 K
		485 MHz 16.7 K	735 MHz 8.16 K	985 MHz 5.94 K	1235 MHz 4.65 K	1485 MHz 3.81 K
		490 MHz 16.3 K	740 MHz 8.10 K	990 MHz 5.91 K	1240 MHz 4.63 K	1490 MHz 3.80 K
		495 MHz 15.9 K	745 MHz 8.05 K	995 MHz 5.88 K	1245 MHz 4.61 K	1495 MHz 3.78 K
		500 MHz 15.6 K	750 MHz 7.99 K	1000 MHz 5.85 K	1250 MHz 4.59 K	1500 MHz 3.77 K

Table 1: Table showing temperature of the cold sky in steps of 5 MHz interval using methodology explained in Sec. 3. Columns, 50–125 MHz (Column 1), 125–250 MHz (Column 2), 250–500 MHz (Column 3), 500–1000 MHz (Columns 4 & 5), and 1000–1500 MHz (Columns 6 & 7), correspond to various frequency feeds of the uGMRT showing (nearly) seamless frequency coverage.