*Large-scale Structures and their Role in Solar Activity*
*ASP Conference Series, Vol. 346, 2005*
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# Radio and EUV Measurements of the Equatorial Coronal Hole of February 25, 1999

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**Abstract.** We present here the observations of the equatorial coronal hole made at 109 MHz on February 25, 1999 with the Gauribidanur Radioheliograph. The brightness temperature of this coronal hole is about $1.7 \times 10^5$ K. We compare our observations with EUV measurements of EIT onboard SOHO. Ray-tracing calculations show that the observed brightness temperature of this coronal hole can be due a decrement in density by factor of 4 compared to the Newkirk's density model.

## 1. Introduction

Coronal holes are large scale structures of the Sun where the plasma density is extremely low. They appear often in polar regions and are associted with open magnetic field configuration and the solar wind originates here. Coronal holes were first identified in X-ray plates by Underwood & Muney (1977), in X-ray images by Vaina, Krieger, & Timothy (1973), on EUV spectroheliograms by Reeves & Parkinson (1970), and in white light by Altshuler & Perry (1972). Metric wavelength observations of coronal holes were first made by Dulk & Sheridan (1974), Drago, Avignon, Thomas (1977), Lantos & Avignon (1975), and has been identified as regions of depressions in the radio images. Coronal holes has been studied from 30.9 MHz to 408 MHz by several groups (Table I, Lantos 1999). Radio observations at metric wavelengths are more suitable for the study of coronal holes since the radiation is sensivitve to both the temperature and the emission measure. Dulk & Sheridan (1974) have reported that coronal holes can show a decrease or increase in intensity of emission relative to the background emission at 160 MHz. Wang, Schmahl, & Kundu (1987) using the Clark Lake observations have shown that in the frequency range of 30 to 73.8 MHz coronal holes show a decreased emission compared to the background emission. The brightness temperature of coronal holes vary from about $2.0 \times 10^5$ K to $8.0 \times 10^5$ K in the frequency range of 30 to 408 MHz (Lantos 1999). It will be interesting to study nature of many coronal holes at a frequency around 100 MHz in order to find whether there is a decreased or increased emission compared to the background emission and also for comparison with EUV measurements. In this paper we present radio observations of the coronal hole observed on February 25, 1999 and compare with mesurements at EUV. We also present ray-tracing calculations to determine the density models which can give rise to the observed brightness temperature.

## 2. Observations

### 2.1. Radio

The observations presented here were made with the Gauribidanur Radioheliograph (Ramesh et al. 1998) which can operate in the frequency range of 40 - 150 MHz. The field of view and spatial resolution depends on the frequency and are respectively $3 \times 4$ deg and $5\times 8$ (RA $\times$ Dec) arc min at 150 MHz. The sensitvity of the system is about 200 Jy and the dynamic range of the heliograms is about 25 dB. Solar images were made mostly during meridian transit in the year 1999 at 109 MHz with a spatial resolution of $8 \times 11$ arc min. In this paper we present the coronal hole radio data of 25th February 1999. No flare activity was reported during our observing period (06:00 UT to 07:00 UT). Also no noise storm by Nancay Radioheliograph was reported in Solar Geophysical Data on that day (SGD 656, Part I). Figure 1 shows the radioheliogram obtained on the February 25, 1999. The circle shows the photospheric disk. The beam size is shown by the ellipse on the top right, and North is to the top. From the YOHKOH image of the Sun on February 25, 1999, we found a large coronal hole in the Eastern region of the Sun . The radio coronal hole is identifed as depressions in the equatorial region in the radioheliogram. The observed depth of depression seen in our radio heliogram is about 10 - 30%. The radio brigthness temperature has been averaged over the whole portion of the coronal hole and is about $1.7 \times 10^5$ K. The error in estimation of the brightness temperature is about 5%.

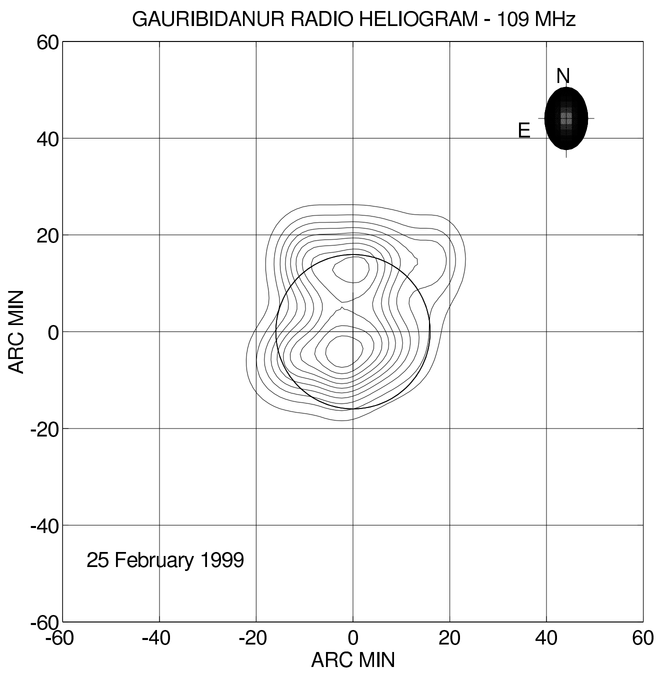


Figure 1. Radio heliogram obtained at 109 MHz on 25th February 1999.

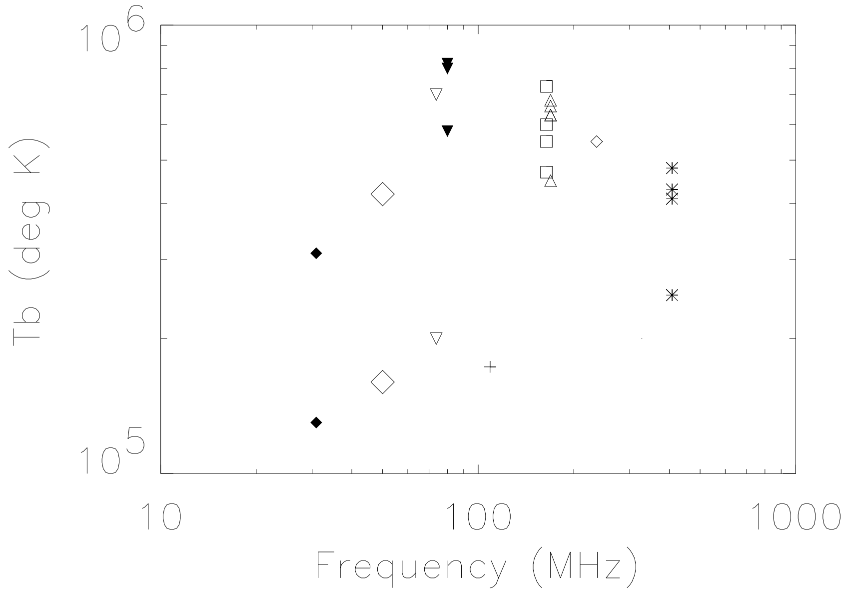


Figure 2. Brightness temperature of several coronal holes meaured in the frequency range of 30 to 410 MHz including GRH observations at 109 MHz indicated by the + symbol.

Figure 2 shows the brightness temperatures of several coronal holes in the frequency range of 30 to 410 MHz measured by several groups (Table I, Lantos 1999) in different periods including our observations at 109 MHz.

### 2.2. EUV

Investigations of the equatorial coronal hole of Febraury 25, 1999 were carried out with the aid of imaging data from the Extreme ultraviolet Imaging Telescope (EIT) on board the SoHO spacecraft. Full disk imaging of the Sun is done at four selected bandpasses in the extreme UV, and their image characteristics are shown on Table 1. The field of view is $45' \times 45'$ (or about 1.3 $R_\odot$ at L1).

Table 1. EIT Bandpass Filter & Image characteristics

| Filter Name | Wavelength Å | Peak Temperature Response - K | Image dimension pixel$^2$ |
|---|---|---|---|
| Fe IX | 171.075 | $\leq 8 \times 10^4$ | 1024 x 1024 |
| Fe XII | 195.127 | $1.36 \times 10^6$ | 512 x 512 |
| Fe XV | 284.150 | $1.6 \times 10^6$ | 1024 x 1024 |
| He II | 304 | $2 \times 10^6$ | 1024 x 1024 |

The EIT data on February 25, 1999, were anlysed in the 191.127 band, to estimate the temperature and the emission measure, in the coronal hole region identified from the 109 MHz radioheliogram. The raw compressed telemetry data

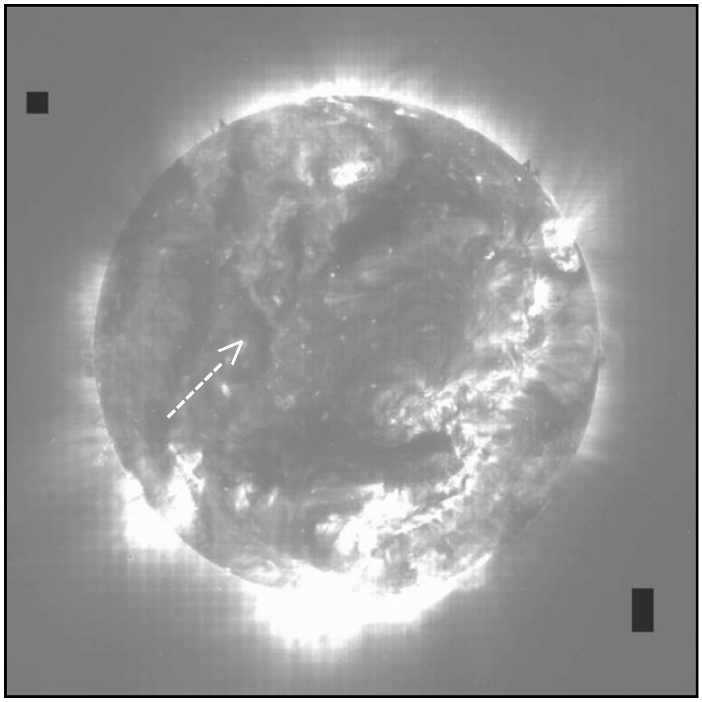

Figure 3. EIT image of the Sun showing the presence of equatorial coronal hole (indicated by the arrow).

(Level I), was corrected for missing-pixel blocks, degridded to remove the influence of the filter grid pattern, dark-current subtracted, flat-fielding, vignetting and degradation corrected for, before the normalised filter response for each of the four EIT bands was computed. The image calibration was performed using valid calibration lamps obtained from standard look-up table (see Sundaram & Subramanian 2004).

A solar emission measure of $10^{44}$ $cm^{-5}$ was assumed at L1 (a SoHO orbital parameter). The CHIANTI database on emission line spectrum was used to compute the synthetic spectra (in units of $photons\ s^{-1} sr^{-1}\ cm^3$ or ergs) (Mewe, Lemen, & van den Oord 1986), and hence the column emission measure, electron density, temperature and element abundances, as an isothermal emission measure approximation. The brightness temperature and EM were estimated for a given ratio of either FeXII/FeIX, X or FeXV/FeXII. Figure 3 shows the composite EIT image at 195 Å depicting the equatorial coronal hole which is the subject of our study. The EIT image was obtained with the 195.127Å (Fe XII) filter, The exposure time was 2.5 s. The image is of dimensions $512 \times 512$ pixel$^2$, with a plate scale of 5.24 arc sec.

The emission measure (EM) per unit area of the region occupied by the coronal hole is given by the expression:

$$EM \ = \ \int_{source} N_e(h)^2 \ dh \qquad cm^{-5} \tag{1}$$

where, $N_e(h)$ is the electron density along the ray-path h. Table 2 gives the values of the electron temperature ($T_e$) and EM determined from the EIT data.

Table 2. $T_e$ & EM of the equatorial coronal hole of February 25, 1999

| Day | Time ( UT ) HHMM | Wavelength $A^o$ | $T_e$ K | EM $cm^{-5}$ |
|---|---|---|---|---|
| 25feb99 | 2236 | 171 | 172802 | 1.33408e+25 |
| | 2336 | 171 | 172802 | 1.39945e+25 |

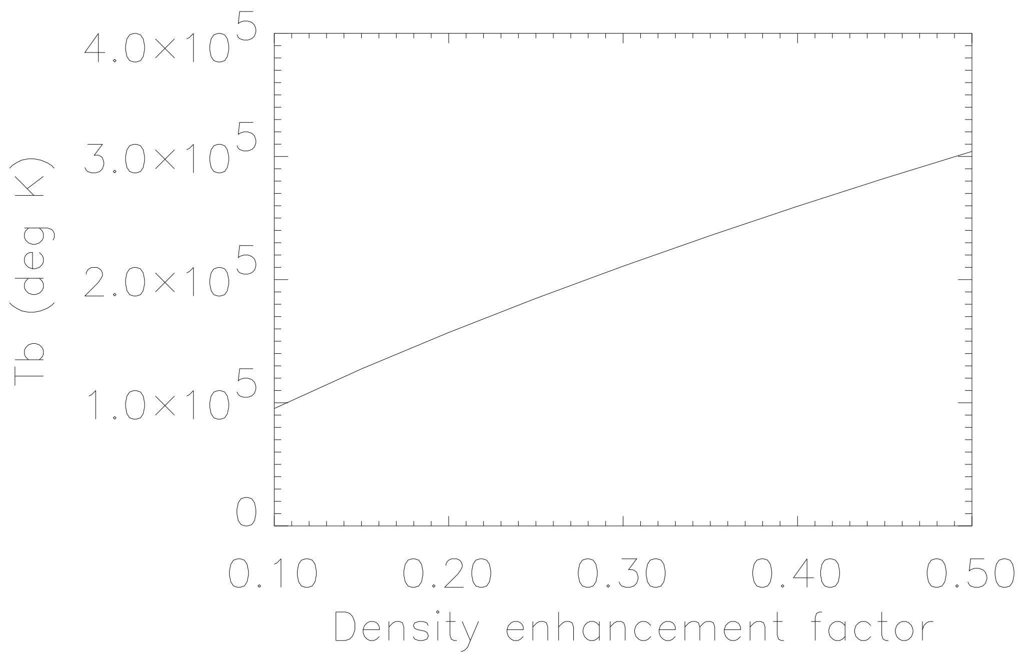


Figure 4. Variation of Brightness temperature at 109 MHz with density enhancement factors.

## 3. Discussion

The radio emission of the coronal hole is entirely due to thermal bremmstrahlung. The observed brightness temperature $T_b$ can be calculated using ray-tracing techniques (Smerd 1950; Bracewell & Preston 1956). $T_b$ depends on the kinetic temperature $T_e$ and on the emission measure ${N_e}^2dh$ where $N_e$ is the electron density and dh is the path length along the ray path. $T_b$ is related to the kinetic temperature $T_e$ by the relation $T_b = T_e(1-e^{-\tau})$ where $\tau$ is the optical depth. We assume a constant temperature for the material in the coronal hole. For the electron density we assume Newkirk's density multiplied by a density enhancement factor $D_{ef}$. In this case the density is given by $N_e = D_{ef} \times 4.2\times10^4$ $\times10^{4.32}/\rho$, where $\rho$ is measured in solar radii. We have computed the integrated optical depths and the brightness temperature at 109 MHz for the central ray for different values of density enhancement factors $D_{ef}$. We have used $D_{ef}$ values ranging from (0.1 to 0.5) suggested by Munro & Withbroe (1972) and Perry & Altschuler (1973) for a coronal hole, and temperature of a million degrees. Magnetic field effects are negected in these calculations. Also scattering of the radio emission due to density inhomogenities if any at 109 MHz is neglible for the central ray according to Riddle (1974). Figure 4 shows the variation of brightness temperature for different density enhancement factors ranging from 0.1 to 0.5. For the density enhancement factor of 0.25, the calculated brightness temperature agrees with the observed value( $1.7\times10^5$ K). The density in this case is about $4.2\times10^{8.2}$ $cm^{-3}$ and is in general agreement with density measurements of coronal holes made at EUV (Doyle et al. 1999).

## 4. Conclusion

We have measured the brightness temperature of the coronal hole of February 25, 1999 observed at 109 MHz as $1.7\times10^5$ K. Using the ray-tracing calculations we found that Newkirk's density reduced by a factor of 0.25, which explains the observed brightness temperature. The derived density is in close agreement with density determined from the EUV measurements.

**Acknowledgments.** We would like to thank Dr. R. Ramesh for many useful discussions. We also like to thank N. NanjeGowda, G. N. Rajasekara, and Anwar Saheb for the maintainance of the antenna, receiver system and collection of data. We thank the Raman Research Institute for the logistics provided at the Gauribidanur Radio observatory. Our thanks are also to the SOHO team for the EUV data made available to the solar community.

### References

Alstshuler, M. D., & Perry, M. R. 1972, Solar Phys., 23, 410
Bracewell, R. N., & Preston, G. W. 1956, ApJ, 123, 14
Doyle, J. G., Teriaca, L., & Bannerjee, D. 1999, A&A, 349,956
Drago, F. C., Avignon, Y., & Thomas, R. J. 1977, Solar Phys.,51,143
Dulk, G. A., & Sheridan, K. V. 1974, Solar Phys., 36, 191
Lantos, P. 1999, in NRO Report No. 479, Solar Physics with Radio Observations, ed. T. S. Bastian, N. Gopalswamy, & K. Shibasaki, 11
Lantos, P., & Avignon, Y. 1975, A&A, 41, 137
Mewe, R., Lemen, J. R., van den Oord, G. H. J. A&AS, 65, 511
Munro, R. H., & Withbroe, G. L. 1972, ApJS, 21, 1
Perry, R. M., Altschuler, M. D. 1973, Solar Phys., 28,435
Ramesh, R., Subramanian, K. R., Sundarajan, M. S., & Sastry, Ch. V. 1998, Solar Phys., 188, 92
Reeves, E. M., & Parkinson, W. H. 1970, ApJS, 21, 1
Riddle, A. C. 1974, Solar Phys., 36, 375
Smerd, S. F. 1950, Aust. J. Sci. Res, A3, 34
Sundaram, G. A. S, & Subramanian, K. R. 2004, ApJ, 605, 948
Underwood, J. H., & Muney, W. S. 1967, Solar Phys., 1, 129
Vaina, G. S., Krieger, A. S., & Timothy, A. F. 1973, Solar Phys., 32, 81
Wang, Z., Schmahl, E. J.,& Kundu, M. R. 1987, Solar Phys., 111, 419