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Low frequency solar radio astronomy at the Indian Institute of Astrophysics (IIA)

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Abstract. IIA is presently involved in the expansion of its existing radioheliograph operating in the frequency 120-40 MHz at the Gauribidanur radio observatory located about 80 km north of Bangalore. Once completed, the expanded array will have an angular resolution of $\approx 1'$ at a typical frequency of 100 MHz. This paper describes the development of solar radio astronomy activities at IIA since 1952 when the first observations were carried out.

Keywords : Sun: corona – Sun: radio radiation – telescopes

1. Introduction

Radio emission from the solar corona in the frequency interval 120-40 MHz originates typically in the radial distance (r) range $\approx 1.2 - 1.8\ R_{\odot}$ in the solar atmosphere which is difficult to observe in white light other than during total solar eclipses. Radio observations in the above frequency/distance range are considered to be useful to understand the chain of transient and energetic solar activities leading to disturbances in the terrestrial atmosphere ('Space Weather' events) because: (i) data can be obtained with high time resolution ≈ 100 ms; (ii) corona overlying the solar disk, as well off the limb can be simultaneously observed; (iii) the near-Sun characteristics of the coronal mass ejections (CMEs), the primary candidate for the Space Weather events, can be estimated. The primary acceleration / deceleration of a majority of the CMEs occur at $r < 2\ R_{\odot}$; (iv) wide range of temperature $\sim 10^5 - 10^9$ K can be studied. This allows observations of CMEs either directly (because they are basically density enhancements and therefore give rise to enhanced thermal emission), or indirectly (through transient non-thermal radio bursts related to activities in the solar atmosphere during the CME onset / propagation). Observations at frequencies < 100 MHz are useful for direct

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observations of CMEs since the observed radio brightness temperature (T_b) of the background corona is usually less than the coronal electron temperature (T_e) due to refraction effects and relatively smaller optical depth in the above frequency range. So a localized increase in the T_b due to an increase in the density can be observed with better contrast. As far as the indirect observations of CMEs are concerned, the non-thermal emission is in general intense at lower frequencies, and hence observations at frequencies < 100 MHz are useful. Events like non-thermal type II radio bursts which are considered to be signatures of magnetohydrodynamic (MHD) shocks in the solar corona are observed primarily at low frequencies.

2. Kodaikanal observatory

Radio astronomy at IIA began earlier to the formation of the institute in its present form. Continuous recording of solar radio flux was started in 1952 with two Yagi antennas at the observatory. The antennas were separated in distance and operated in the interferometer mode. The observing frequency was 100 MHz. The facility as well as the observations, perhaps the first of its kind in the country, was due to the efforts of B. N. Bhargava. Relation between solar radio events and geophysical activities (the latter through magnetometer records at the observatory) were studied. These were one of the earliest coordinated observations of solar-terrestrial events (see Fig. 1). Interferometer observations of radio star scintillations at 60 MHz was also carried out during this period. Under the Kodaikanal-Yale Project, recording of radio radiation from Jupiter at 22.2 MHz was carried out with a phase switching interferometer. The custom-built 3 GHz radio receiver from the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia was set up and put to use in 1965 by U. V. Gopala Rao. It was mounted on a 2 m paraboloid, and was used for regular solar patrol. During the late sixties and the early seventies, work on the fine structures in time, frequency, and polarization of transient emission from the solar corona at low frequencies ($\approx$ 25 MHz) were carried out at the observatory by Ch. V. Sastry. Due to space and terrain constraints, small-sized antenna arrays were used. The observations were carried out with high temporal ($\approx$ 15 ms) and frequency resolution ($\approx$ 100 KHz). Since then low frequency solar radio astronomy has become one of the branches of observational solar physics in the institute.

3. Gauribidanur observatory

3.1 The Gauribidanur Telescope (GEETEE)

Based on the experience gained from observations at the Kodaikanal observatory, the institute decided to construct a large low frequency radio telescope that can be used to obtain two-dimensional radio images of the solar corona, carry out all-sky radio source survey, observe pulsars, recombindation lines, in addition to observations of radio emission from other galactic and extra-galactic sources. Thanks to support from the Raman Research Institute (RRI), the project soon became a reality. A low frequency (34.5 MHz) radio telescope was set-up jointly with the RRI at the Gauribidanur radio observatory in the late seventies. The telescope, GEETEE, consists of 1000 dipoles arranged in a 'T' configuration. The two arms of the 'T' are oriented in the East-West (1.4 km) and South (0.5 km) directions. There was also a broadband array (BBA) operational in the range 30-70 MHz at the observatory during the mid-eighties. GEETEE provided the first evidence for: (i) slowly varying discrete sources in the outer solar corona; (ii) pulsating emission from the outer solar corona. Observations with the BBA established the plasma characteristics of microbursts in the solar corona.

3.2 The Gauribidanur radioheliograph (GRH)

Several interesting results on the solar corona were obtained with the GEETEE. However it was felt that a radio telescope with which one can carry out simultaneous multi-frequency observations would be useful since radio emission at different frequencies originate at different radial distances in the solar atmosphere. Several interesting activities in the solar corona were observed / reported for the first time during the late seventies and early eighties. It was the period during which the solar coronal mass ejections (CMEs) were discovered with the white light coronagraph on board OSO-7, and their connection with disturbances in the terrestrial atmosphere was gaining importance. Unfortunately there were no low frequency solar radio telescopes in operation, particularly at frequencies < 150 MHz, after the mid-eighties. The Culgoora radio heliograph in Australia, and Clark Lake radio heliograph in USA whose observing frequencies were in the above range operated in the seventies and early eighties. In some respects, both the above instruments were ahead of their time, observing the 'undisturbed' solar corona, coronal energy releases, and coronal shocks long before supporting EUV, SXR, and whitelight coronograph observations were routinely available. Both the instruments were closed down before such synergies could be fully realized. Because of the above reasons, and also since radio frequency interference (RFI) is comparatively is less in Gauribidanur it was decided to construct a low frequency radio heliograph for dedicated observations of the solar corona in the range 120-40 MHz.

The basic receiving element used in the GRH is a log-periodic dipole (LPD), and the array consists 192 of them (see Fig. 2). The dipoles are arranged in a 'T' configuration similar to the GEETEE: 128 LPDs are set-up as 16 groups in the East-West arm of length ≈ 1280 m, and 64 LPDs are set-up as 16 groups in the South arm of length ≈ 441 m. The present spatial and temporal resolutions of the instrument are ≈ 8′ (at 100 MHz), and ≈ 128 ms, respectively. The array is in regular operation since 1998. The frequency coverage of GRH is unique that it provides useful information on the solar corona in the radial distance range which is difficult to probe using the existing ground based and space borne white light coronagraphs (see Fig. 3). Also radio telescopes

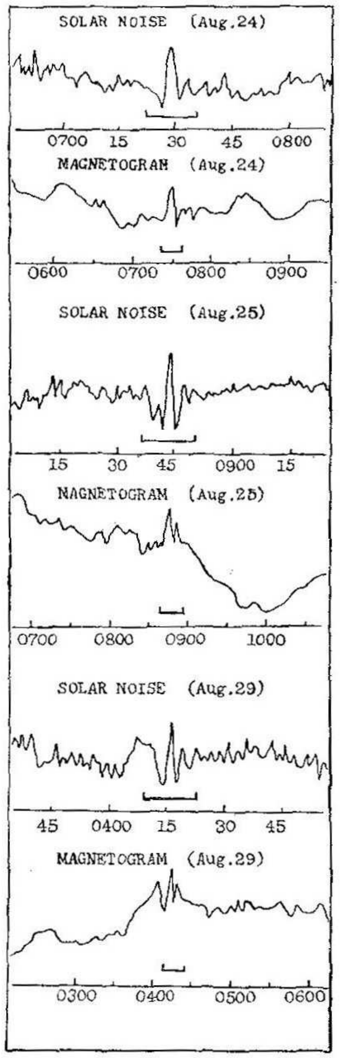

Figure 1. Coordinated observations of space weather events in 1952 at the Kodaikanal observatory (A.K.Das and B.N.Bhargava: 1953, Nature, Vol. 172, p. 855).

for dedicated observations of the Sun are presently not operational in the above frequency range elsewhere in the world. Some of the interesting results obtained with the GRH till date are: (i) density/temperature diagnostics of pre-event structure of CMEs; (ii) kinematics of CMEs close to the Sun; (iii) 'true' speed of CMEs in the three-dimensional space; (iv) estimation of the parameters of the CMEs at large distances from the Sun through angular broadening observations of distant cosmic radio source;

Figure 2. A section of the GRH.

(v) seismology of the solar corona using transient radio burst emission as tracers; (vi) plasma characteristics of radio emission associated with emerging magnetic flux from sub-surface layers of the solar photosphere; (vii) rotation rate of discrete sources in the solar corona; and (viii) MHD shocks in the solar corona and its relationship to flares and CMEs.

3.3 GRH expansion

Radio astronomers are trying hard to set up large antenna arrays for observations at low frequencies eversince the unfortunate closing down of Clark Lake array (USA) in particular. Some of the examples are the Long Wavelength Array (LWA) in USA, the Low Frequency Array (LOFAR) in Europe, and the Murchison Widefield Array (MWA) in Australia. Though observations of the Sun at low frequencies has also been included as a potential scientific goal, the primary science objectives of these arrays are related to the observations of different non-solar objects. But due to various reasons the construction of these facilities is either postponed or getting delayed. So it has become very important that existing solar dedicated low frequency instrument like the GRH which is operational in the range 120-40 MHz be augmented with more facilities. Improved angular resolution is often the critical driver for the evolution of astronomical telescopes of all types. Work is in progress since 2008 to increase the size of the GRH to $\approx$ 3 km in the East-West, and North-South directions, by populating the array with more number of antennas (384 as compared to the existing 192). This is Phase-I of the expansion programme. The angular resolution with the expanded array will be $\approx 3'$ at 100 MHz. In Phase II, it is proposed to extend the array to about 5 km in the East, West, North and South directions. The resolution will be $\approx 1'$ at 100 MHz. Presently the Phase-I of the expansion programme is in progress.

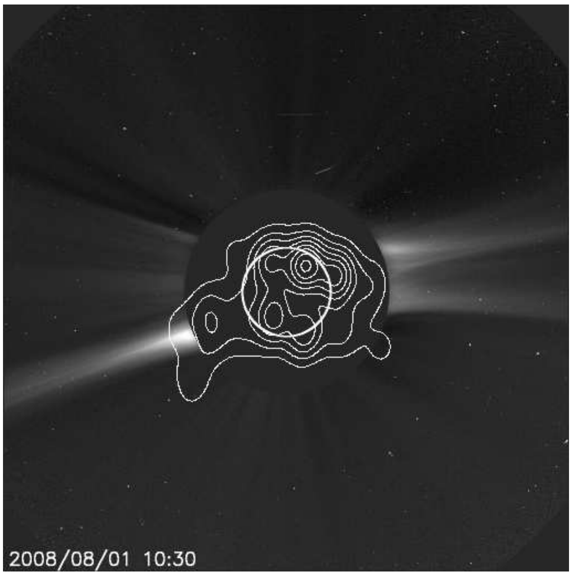

Figure 3. Radioheliogram obtained with the GRH at 77 MHz and white light image taken with the LASCO C2 coronagraph onboard SOHO on 1 August 2008. The inner white circle represents the limb of the solar photosphere ($r = 1\ R_\odot$). The outer dark circle indicates the occulting disk (radius $\approx 2.2\ R_\odot$) of the coronagraph (C. Kathiravan et al. 2010, Astrophys. J., Vol. 730, p91).

3.4 Gauribidanur radio spectrograph

This instrument is used for obtaining dynamic spectrum of transient radio burst emission from the solar corona in the frequency range 120-40 MHz (same as the GRH). The antenna system consists of 8 LPDs. A commercial spectrum analyzer is used as the back end receiver to obtain spectral information with an instantaneous bandwidth of $\approx$ 250 KHz. The temporal resolution is $\approx$ 43 ms. The radio spectrograph (CALLISTO) provided by ETH, Zurich is also in operation in the frequency range 450-40 MHz at the observatory. The spectral observations so far have provided clues to: (i) electron acceleration associated with small scale non-thermal energy releases in the solar atmosphere; (ii) occurrence of radio bursts associated with successive MHD shocks in the solar corona; and (iii) CME source region through observations of transient 'absorption' bursts.

3.5 Gauribidanur radio polarimeter

The existing direct estimates of the magnetic field in the solar corona using optical/ infrared, and radio emissions are limited to the 'inner' corona (< 1.2 $R_\odot$). In the 'outer' corona beyond 3 $R_\odot$, Faraday rotation observations of linearly polarized radio emission at higher frequencies (~ GHz) from background cosmic radio sources are used to derive the magnetic field. But measurements in the range 1.2-3 $R_\odot$ ('middle' corona) are not available until now. An East-West one-dimensional array of 32 LPDs in 0° and 90° orientations have been set-up at the observatory to measure the solar coronal magnetic field in the same radial distance range ($1.2 - 1.8\ R_\odot$) as the GRH. Some of the notable results obtained till date are: (i) magnetic field associated with streamers in the solar corona; (ii) magnetic field associated with very weak energy releases in the solar corona; (iii) model independent estimate of the magnetic field in the 'undisturbed' corona.

4. Conclusions

The Gauribidanur observatory is presently the only place in the world where a suite of low frequency radio facilities for dedicated two dimensional imaging, spectral, and polarization observations of the Sun are in operation. The related instruments offer the appropriate frequency coverage for space weather studies. With the proposed first Indian space coronagraph ADITYA expected to be launched in a few years time, continued observations with a dedicated, upgraded facility like the GRH is very crucial. Observations with the two instruments are expected to nicely compliment each other.

5. Acknowledgements

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http://www.iiap.res.in/centers/radio