The Metrewavelength Sky
ASI Conference Series, 2014, Vol. 13, pp 19 – 24
Edited by J. N. Chengalur & Y. Gupta

Solar observations at low frequencies with the Gauribidanur radioheliograph

R. Ramesh, C. Kathiravan, M. S. Sundara Rajan, Indrajit V. Barve and M. Rajalingam
Indian Institute of Astrophysics, Bangalore 560034, India

Abstract. Since 1997 the Indian Institute of Astrophysics is operating a low frequency ($\approx$ 30-120 MHz) radioheliograph at the Gauribidanur radio observatory, about 100 km north of Bangalore, for dedicated observations of the solar corona. The heliograph is currently being upgraded. Some of the related details are presented.

1. Introduction

Solar radio emission at different frequencies originate at different heights in the atmosphere due to the gradient in the electron density and the characteristics of radio wave propagation in an ionized medium like the solar atmosphere. With increasing height above the photosphere the emission shifts to correspondingly lower frequencies. Radio emission in the frequency range 30-120 MHz originates typically in the height range $\approx 0.8 - 0.2$ $R_{\odot}$ ($R_{\odot}$ = radius of the Sun) above the solar photosphere. Presently it is difficult to observe the above range at other frequency bands of the electromagnetic spectrum due to various limitations. One of the important reasons to observe the above height range in the solar corona on a daily basis is because the chain of solar activities leading to disturbances in the interplanetary medium and the terrestrial environment (commonly referred to as Space Weather and which is of social relevance) originate there. The other reasons are that the observations provide useful data to understand the coronal magnetic field, heating, turbulence, particle acceleration, etc. Also the observations are a good diagnostic tool for routine estimates of the electron density, temperature, and magnetic field in the solar corona. The emission mechanisms relevant to low-frequency radio emission from the Sun are the free-free emission (thermal bremsstrahlung), the plasma emission (at the fundamental and the 2nd harmonic) and the gyro-synchrotron emission Bastian (2004).

2. The instrument

The Gauribidanur RAdioheliograPH (GRAPH) is a T-shaped interferometer array of log-periodic dipoles Ramesh et al. (1998, 2006) (Ramesh R., 2011a). The effective collecting area (A_e) of each dipole is $\approx 0.5\lambda^2$. In the pre-upgrade configuration the GRAPH had an east-west arm of length $\approx$ 1280 m and a south arm of length $\approx$ 441 m. The angular resolution and sensitivity of the array were $\approx 7' \times 10'$ (R.A. $\times$ Dec.) and $\approx$ 100 Jy (5σ level, 1s integration time, $\Delta f = 1$ MHz, $T_{sys} \approx 5000$ K[1], total power mode[2]) at 120 MHz, respectively. It had provided several useful results related to[3]: 1) initiation and propagation of coronal mass ejections (CMEs), the drivers of the Space Weather, in the height range $< 1\ R_\odot$ above the solar photosphere; 2) 'true' kinematics of the CMEs in the three-dimensional space; 3) CME source region; 4) coronal plasma parameters in the above height range; 5) characteristics of the solar corona / CMEs at large distances from the Sun; 6) diagnostics of the pre-event structures of the CMEs; 7) seismology of the solar corona using radio burst emission as tracers; 8) plasma characteristics of radio emission associated with emerging magnetic flux from sub-surface layers of the solar photosphere; 9) electron acceleration associated with small scale non-thermal energy releases in the solar atmosphere; 10) magnetohydrodynamic shocks in the solar corona; 11) coronal magnetic field, one of the holy grails in observational solar physics; 12) weak non-thermal energy releases in the solar corona (nano/pico flares), important to address coronal heating and electron acceleration.

3. The upgrade

In the eighties data obtained with the coronagraph onboard the Solar Maximum Mission satellite and the Culgoora, Clark Lake radioheliographs showed, for the first time, how simultaneous observations in white light and low radio frequencies can be effectively combined to understand the solar corona and the transients like the coronal mass ejections (CMEs). Unfortunately, both instruments were closed down in the mid-eighties before such synergies could be fully realized. With the proposed Visible Emission Line coronagraph (VELC) to be launched onboard ADITYA I (the first Indian space mission for dedicated observations of the Sun) in a few years time Singh et al. (2011), it is important that a complimentary and dedicated solar observing facility like the GRAPH is upgraded since the angular resolution and the sensitivity of the GRAPH mentioned in Section 2 are coarse and limited by the present day standard. Note that there has been significant advances in the fields of signal transmission and processing since the commissioning of the GRAPH in 1997.

[1] https://www.cv.nrao.edu/~demerson/radiosky/rsky_p3.htm

[2] The actual sensitivity is expected to be still lower since the measurements on each baseline in an interferometer array are independant Anantharamaiah et al. (1989).

[3] http://www.iiap.res.in/solarradio/publication

Though new low frequency telescopes like the Low Frequency Array (LOFAR, ≈ 10-240 MHz) in Europe and Murchison Widefield Array (MWA, ≈ 80-300 MHz) in Australia are upcoming, these are primarily general purpose instruments. Only a small fraction of their time is likely to be devoted for solar observations. Also because of the geographical location of Gauribiudanur (≈ 77°E 13°N), the declination of the Sun will be high almost throughout the year. This is important since ionospheric perturbations can be significantly stronger at low frequencies particularly for radio sources at low elevations Mercier et al. (2009). Sun is a highly variable and unpredictable radio source, and should be continuously monitored with dedicated facilities. This is one of the primary reasons why the Nobeyama radioheliograph in Japan at 17 & 34 GHz (frequency overlap with the VLA in USA), the Owens Valley Solar Array in USA over 1-18 GHz (frequency overlap with the VLA), and the Nancay radioheliograph in France over 150-450 MHz (frequency overlap with the GMRT in India and also VLA) continue to be operated. Note that Nancay radioheliograph will have frequency overlap with the LOFAR and MWA also. These telescopes observe the Sun at higher frequencies compared to the GRAPH and hence the corresponding radio emission orginates normally at comparatively lower heights in the solar atmosphere.

High cadence observations of the corona off the solar limb in the height range $\approx 0.05 - 3\ R_\odot$ above the photosphere, one of the main strengths of the proposed VELC-ADITYA I will be nicely complimented by the low frequency radio observations from Gauribidanur. Importantly, 1) GRAPH will provide data on the above height range with comparatively higher time resolution which is easier to achieve at radio frequencies; 2) GRAPH will provide unique, simultaneous observations of the corona overlying the solar disk as well as off the solar limb; 3) radio observations are sensitive to a wide range of temperature, from $\approx 10^5 - 10^9$ K. This allows to observe the CMEs either directly because they are primarily 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; 4) the appearance of the corona changes with frequency due to optical depth and refraction effects. Thermal emission from the discrete sources in the solar atmosphere can be observed with better contrast at low frequencies due to a combination of refraction effects and lesser optical depth Lantos et al. (1987); Alissandrakis (1994); Ramesh et al. (2005). On the non-thermal side, plasma radiation is the mechanism relevant to most of the classical radio bursts. The solar flux, particularly at low frequencies, can vary dramatically due to these bursts. Observations at high frequencies meet the difficulties of an increasing contribution of the 'undisturbed' background corona and decreasing burst brightness Benz (2002). Note that the plasma radiation processes play a critical role primarily where the plasma frequency (f_p) is greater than the gyro-frequency (f_B); 5) since we also have the Gauribidanur Radio Interference Polarimeter (GRIP Ramesh et al. (2008)) and the Gauribidanur RAdio SPectrometer (GRASP Kishore et al. (2014)) operational, information on the solar coronal magnetic field through observations of circularly polarized radio emission, can be obtained Ramesh et al. (2010a, 2011b); Sasikumar et al. (2013); 6) radio observations are useful complementary tool to observe signatures of weak, transient energy releases in the solar atmosphere since the related non-thermal emission can easily be detected Benz (1995); Ramesh et al. (2010b, 2013). Availability of data obtained with the Gauribidanur LOw-frequency Solar Spectrograph (GLOSS Ebenezer et al. (2007)) is an added advantage in this regard.

The upgrade of the GRAPH is being carried out in a phased manner. The wish is to improve the angular resolution and sensitivity to a minimum of $\approx 1'$ and ≈ 1 Jy, respectively, at 120 MHz to probe the solar corona in finer detail. Note that we have mentioned the above values because: 1) high angular resolution radio observations during the solar eclipses indicate that structures of the above mentioned angular scale are present in the solar corona from where low frequency radio emission originates Ramesh et al. (1999, 2012); 2) improved sensitivity provides an opportunity to detect weak radio emitting features. In the Phase-I of the upgrade which was completed re-

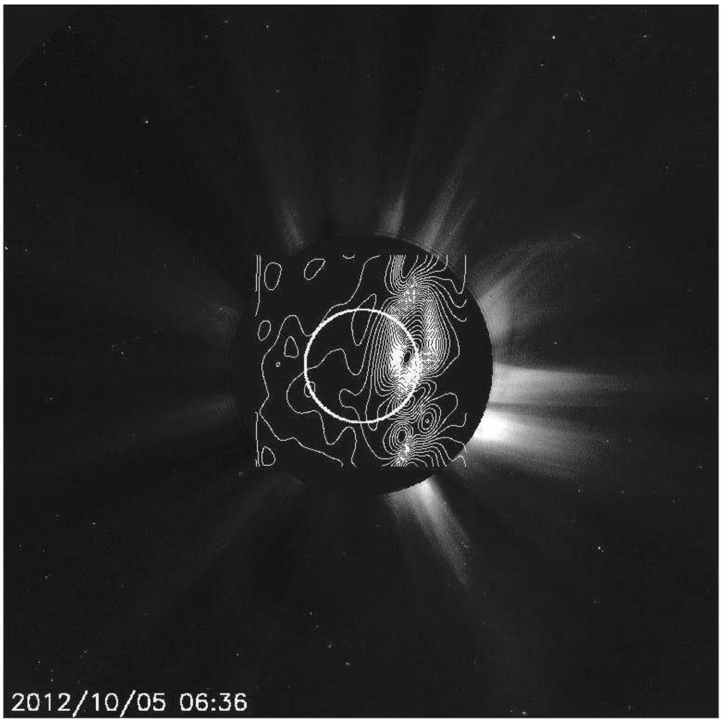

Figure 1. Composite of the radioheliogram (in contours) obtained with the GRAPH (after its Phase-I upgrade), and the white light image of the solar corona obtained with the C2 Large Angle and Spectrometric Corongraph (LASCO, Brueckner et al. (1995)) onboard the orbiting Solar and Heliospheric Observatory (SoHO). The 'open' circle near the center of the image represents the limb of the solar photosphere and the outer 'filled' black circle represents the occulting disk of the coronagraph. Its radius is $\approx 2.5\ R_\odot$. The field of view is $\approx 6\ R_\odot$. Solar north is straight up and east is to the left.

cently, the array has been expanded to ≈ 2560 m and ≈ 882 m the east-west and south directions, respectively. New log-periodic dipoles were installed in the 'expanded' arms of the GRAPH with a spacing of 10 m in the east-west direction and 7 m in the north-south direction, same as that in the pre-upgrade configuration. The signals from the different antenna groups (64 in total) are correlated in a 4096-channel correlator constructed using discrete digital circuit elements. The present angular resolution and sensitivity are $\approx 3' \times 5'$ and ≈ 25 Jy (5σ level, 1s integration time, $\Delta f = 4$ MHz, $T_{sys} \approx 5000$ K, total power mode) at 120 MHz. The plan is to replace the above correlator (in Phase-II of the upgrade) with a FPGA based re-configurable setup consisting of high speed analog-to-digital convertors (ADCs) that can handle larger bandwidths. The maximum baseline length will be increased to 10 km (in the multi-element grating interferometer mode, Kraus (1982)) in Phase-III. We expect to achieve our above mentioned wish regarding the angular resolution and sensitivity with the completion of the Phase-III.

Figure 1 shows the composite of the radioheliogram obtained on 2012 October 5 during the trial run of the GRAPH Phase-I upgrade and the corresponding white light coronagram obtained that day. There is a good correspondence between the position angle (measured in the counter clockwise direction from the solar north) of the enhanced white light features and the discrete radio sources. A suite of low frequency radio facilities for dedicated two dimensional imaging, spectral, and polarization observations of the Sun are presently in operation at the Gauribidanur observatory. Continued observations with these and similar dedicated radio instruments elsewhere will be very useful because of their uniqueness.

Acknowledgements

We thank the staff of the Gauribidanur observatory for their help in the fabrication, installation, operation and maintenance of the observing facilities there.

References

Alissandrakis C. E., 1994, Adv. Space Res., 14(4), 81

Anantharamaiah K. R., et al., 1989, in Perley R. A., Schwab F. R., Bridle A. H. eds, Synthesis Imaging in Radio Astronomy, ASP Conf. Ser. 6, 431

Bastian T. S., 2004, Planet. Sp. Sci., 52, 1381

Benz A. O., 1995, in Benz A. O., and Krüger A. eds, Coronal Magnetic Energy Releases, Lecture Notes in Physics 444, Springer, 1

Benz A. O., 2002, Plasma Astrophysics: Kinetic Processes in the Solar and Stellar Coronae, ASSL 279, Kluwer Academic Publishers, 89

Brueckner G. E., et al., 1995, Solar Phys., 162, 357

Ebenezer E., et al., 2007, Bull. Astr. Soc. India, 35, 111

Singh J., et al., 2011, Curr. Sci., 100(2), 167

Kishore P., Ramesh R., Kathiravan C., Rajalingam M., 2014, (this issue)

Kraus J. D., 1982, Radio Astronomy, Cygnus-Quasar, 6-33

Lantos P., Alissandrakis C. E., Gergely T., Kundu M. R., 1987, Solar Phys., 112, 325
Mercier C., Chambe G., 2009, ApJ. Lett., 700, L137
Ramesh R., Subramanian K. R., Sundara Rajan M. S., Sastry Ch. V., 1998, Solar Phys., 181, 439
Ramesh R., Subramanian K. R., Sastry Ch. V., 1999, Solar Phys., 185, 77
Ramesh R., 2005, in Dere K., Wang J., Yan Y. eds, Proc. IAU Symp. 226 on Coronal and Stellar Mass Ejections, Cambridge University Press, 83
Ramesh R., Sundara Rajan M. S., Sastry Ch. V., 2006, Exp.Astron., 21, 31
Ramesh R., et al., 2008, Solar Phys., 253, 319
Ramesh R., Kathiravan C., Sastry Ch. V., 2010a, Astrophys. J., 711, 1029
Ramesh R., et al., 2010b, ApJ. Lett., 719, L41
Ramesh R., 2011a, in Choudhuri A. R., Banerjee D. eds, Proc. 1st Asia-Pacific Solar Physics Meeting, Astr. Soc. India Conf. Ser., 2, 55
Ramesh R., Kathiravan C., Satya Narayanan A., 2011b, Astrophys. J., 734, doi:10.1088/0004-637X/734/1/39
Ramesh R., Kathiravan C., Indrajit V. Barve, Rajalingam M., 2012, ApJ., 744, doi:10.1088/0004-637X/744/2/165
Ramesh R., Sasikumar Raja K., Kathiravan C., Satya Narayanan A., 2013, Astrophys. J., 762, doi:10.1088/0004-637X/762/2/89
Sasikumar Raja, K., Ramesh R., 2013, Astrophys. J., 775, doi:10.1088/0004-637X/775/1/38