*Proceedings of the Brazilian Decimetric Array Workshop*
*São José dos Campos, Brazil - July 28 – August 1, 2008*

# SCIENCE WITH BRAZILIAN DECIMETRIC ARRAY (BDA) - SOLAR PHYSICS

**Hanumant S. Sawant[1], José R. Cecatto[1], Francisco C. R. Fernandes[2], and BDA Team***

*[1]Divisão de Astrofísica - Instituto de Pesquisas Espaciais - INPE*
*Av. dos Astronautas,1758 – 12201-970, São José dos Campos - SP, Brasil*
*(sawant@das.inpe.br, jrc@das.inpe.br))*
*[2]Instituto de Pesquisa e Desenvolvimento – IP&D /UNIVAP, São José dos Campos, Brasil*
*(guga@univap.br)*
**Participants from National and International Institutions:*
*Instituto Nacional de Pesquisas Espaciais - INPE, São José dos Campos, Brasil*
*Departamento de Computação – DC/PUCMinas, Poços de Caldas, Brasil*
*Centro de Radio Astronomia e Astrofísica Mackenzie, CRAAM, Univ. Mackenzie, São Paulo, Brasil*
*Departamento de Engenharia e Ciência da Computação – DC/UFSCar, São Carlos, Brasil*
*Departamento de Física, UFSM, Santa Maria, Brasil*
*Indian Institute of Astrophysics – IIA, Bangalore, India*
*National Center of Radio Astronomy – NCRA/GMRT/TIFR, Pune, India*
*New Jersey Institute of Technology – NJIT, New Jersey, U.S.A.*
*University of California, Berkeley – UCB, Berkeley, U.S.A.*

## ABSTRACT

Last ten years' simultaneous X-ray and radio investigations have suggested that the acceleration of the particles or heating is occurring near photosphere where densities are around $10^9$ – $10^{10}$ $cm^3$ this region. These densities correspond to emission in the decimetric band, and hence generated interest in the decimeter band observations. There is lack of the dedicated solar radio heliograph operating in the decimetre range. Hence development of the Brazilian Decimetric Array (BDA) operating in the frequency range has been initiated .Some of the fundamental investigations that can be carried out by BDA are: energetic transient phenomenon, coronal magnetic filed and its time evolution solar atmosphere.

## INTRODUCTION

In last fifty years resolutions – frequency/energy, time and spatial - in all wavelengths have been gradually improving. Observations in radio wavelengths have significantly contributed to better understanding of the following fundamental problems in solar flares a) energy storage and its release b) site of acceleration c) acceleration/ejection and transportation of the particles. Pick et al. (1990) and Bastian et al. (1999) have reviewed these observations. What sciences can be done with radio observations was discussed well in workshop at Kyoto and is summarised in Nobeyama proceedings by (Bastian et al., 1998 a). Moreover, Bastian et al. (1999) have clearly shown the need of high spatial/time resolution solar observations in the decimeter band.

Solar flares represents explosive phenomena of the solar activity releasing energy as large as $10^{26}$ – $10^{32}$ ergs, either by heating of the plasma or accelerating of particles, in majority of case in chromosphere. In the impulsive phase of the flares lasting for couple of minutes particles are accelerated up to 200 kev.

Some of these particles get trapped in the loop and travel to and from spiralling in helical orbits around the magnetic field lines generating microwave, millimetre and centimetre broad band emission by gyrosynchrotron mechanisms (Kundu, 1965). On the other hand some of these particles travel along the open magnetic field lines in the direction of the corona or in the closed magnetic field lines in the direction of the photosphere. By beam – plasma interaction these beams generate metric - decimetric type III bursts and their variants in the in meter and decimeter bands respectively. As these beams precipitates in the loop foot points of the loop they encounter high densities ~$10^{11}$ $cm^3$ and generate hard x-rays by bremsstrahlung mechanism. However it should be noted that the bursts in the decimeter band are generated mainly by the beam plasma interaction or gyrosynchrotron emission mechanisms.

Decimetric bursts have been observed since 1960 and continued in the same way up to 1970 and these observations remained to be stagnant for long time. However around 1980 for the first time Skylab observations indicated that the soft X-rays are generated in the solar atmosphere at height ~$2 \times 10^4$ km above the photosphere where densities are around $10^9$ – $10^{10}$ $cm^3$ (Moore et al., 1980). Recently investigations of X-ray by Ohyama and Shibata (1998) suggested that flare processes are occurring around the above mentioned densities. Thus, suggesting that the acceleration of the particles or heating is occurring near this region. These densities correspond to emission in the decimetric band, and hence regenerated interest in the decimeter band observations.

Existing theories in 1960 – 1970 suggested that decimetric emission generated due to beam plasma interaction by the beams traveling towards the photosphere would be strongly absorbed by the strong free – free emission, which is proportional to electron density.

However, following theoretical development in the estimations of the free – free emission suggested possibility of decimetric observations above 1000 MHz:

a) Solar atmosphere is not homogeneous and contains small-scale (length) high electron density irregularities due to fibrous nature of the magnetic field. Thus estimations of the free – free emission taking into consideration irregularities in densities will substantially reduce optical depth and hence allowing escape of decimetric emission along the density gradients.
b) In addition to that if emissions were to be due to plasma emission mechanisms which are preferentially at second harmonic optical depth is further reduced by factor of 16 in comparison to that of the fundamental (Dulk, 1985).

Stähli & Benz (1987) showed that second harmonic emissions can be observed up to or more than 6000 MHz considering presence of small scale – 100km – irregularities. However fundamental emission at 1000 MHz will be strongly absorbed.

Several high resolutions decimetric spectroscopes were put into regular operation in the last decade in the frequency range of (1000- 8000) MHz. They have been summarised by *(*Krüger and Voight, 1999) and recently by Sawant et al 2001.There exists a very few observations of sources sizes of the decimetre type III like bursts observed by Very Large Array (VLA) (Gopalswamy et al., 1995). Observations of the active regions at few spot frequencies in the decimeter range and that of the long duration bursts are obtained by using Ovens Valley Radio heliograph and VLA. However, there is lack of radio heliograph above 1000 MHz with high time and spatial resolutions mostly dedicated for solar observations. Brazilian Decimetric Array (BDA) will fill this gap for solar observations. However BDA can be also used for non-solar observations during solar minima and at night times.

In addition to that BDA will complement observations made by Nobeyama Radio heliograph at 17 and 35 GHz (Nishio et al., 1995) Radioheliograph of Nancy (Nancy,1993), operating at 169, 327 and 408 MHz and Gauribidnur Radioheligraph operating at 40 – 150 MHz (Subramanian et al., 1994, Ramesh et al., 1999). Combined observations of the active regions will lead to continuous investigations of the time evolution of the active regions at various altitudes. This is essential for predications of the solar activities and understanding of the fundamental problems in solar physics. Presently monitoring of the active region can be done by using is Radiolheliographs of Japan, (Nobeyama), Siberia (Siberian Solar radio Telescope- SSRT-), India (Gauribidnur), France (Nancy) and that of the USA (OVRO). However there is lack of the continuity of the observations between Europe and USA. BDA will have common time between Europe and USA thus will fill this gap, in addition to that BDA will be unique solar radioheliograph in Southern Hemisphere as shown in Figure 1.


Fig. 1 – Distributions of solar radio telescope in the world showing the importance of the position of the location of the BDA for continuos solar activity monitoring

Thus continuos monitoring of the solar activities and time evolution of active regions will lead to better prediction capabilities of the occurrences of the solar disturbances such as solar flares and coronal mass ejection - CMEs. These are the major causes of the disturbances in terrestrial magnetic fields and phenomena associated with that.

Some of the fundamental investigations that can be carried out by BDA are given below:

- ENERGETIC TRANSIENTS PHENOMENAS

<u>Objectives</u>

(i) Release of energy,
(ii) Acceleration of electrons and or heating of plasma.
(iii) Transportation of particles

(iv) Creation and destabilization of large scale structures

- MAGENTIC FIELDS IN THE CORONA

Objectives

(i) Estimation of coronal magnetic fields and
(ii) Time evolution of magnetic fields.

- SOLAR ATMOSPHERE

Objectives

(i) Coronal heating
(ii) Quite solar atmospheric structures.

**LOCATION OF ACCELERATION REGION**

In the last decade high resolutions observations in the almost all wavelengths and interpretations have lead to suggestion that the flare energy is released in space-time fragmented way (Valhos, 1994, Brown and Gary, 1994, Anastasiadis and Valhos, 1994). Also various fine structures including that of the type IIIdm bursts are observed during and prior to the impulsive phase of the flares. High resolution spectroscopic observations and their statistical investigations of the decimetric IIIdm bursts above 1000 MHz shows that their total duration is ~300 ms ,frequency range is of about 300 MHz and in majority cases, 80%, with the positive drift rates (Melendez et al., 1999). However there are a few fixed frequency observations of their positions. (Gopalswamy et al., 1995; Aschwanden et al., 1999). Bi-directional decimeric type IIIdm bursts are well related with the position of acceleration region (Aschwanden et al., 1995; Melendez et al., 1999). Thus simultaneous decimetric spectroscopic and imaging observations of BSS and BDA respectively will be able to map trajectories of the up - down going beams as shown in the Figure 2. This will enable more precise determination of the location of the acceleration region independent of density models and processes and nature of the liberation of energy to flares.

**CRHOMOSPHERIC EVAPORATION**

Chromospheric evaporation has been revised by Anttonucci et al. (1984 and references therein). Before the beginning flare – in pre flare phase – the turbulence in plasma of the active region begins and either it accelerate the particles and/or heat them. Hot plasma starts rising; this proccess is known as chromospheric evaporation (Sturrock et al., 1973) – though this is not a proper nomenclature. This can be inferred by broadening and blue shifts of the lines of Ca XIX and Fe XXV as observed in soft X-ray.

Until now the process of the chromospheric evaporation is investigated by observations of the soft X-ray and in H-alpha assuming the process of chromospheric evaporation is the process for transport of hot plasma. Aschwanden and Benz (1995) for the first time suggested that chromospheric evaporation could be investigated by radio observations in decimetric wavelengths generated by the beam of the electrons going down in loop and crossing up-going evaporation front. However this is just a speculation and need to be confirmed by simultaneous spectral and positional observations in radio, soft X-ray lines and H–alpha observations.

In reality, what is happening is that as hot and dense plasma rises up it creates a discontinuity in temperature and density, in the loop. Beam of the electrons moving towards the foot point of the loop interacts with this slowly upward moving "shock front" where a optical thickness is reduced due to its temperature dependence (~n $\times$ $T^{-3/2}$) allowing to escape high frequency radio emission. As the beam travels further it encounters high densities and lower temperature which increases opacity and radio emission is absorbed. Thus as the shock front moves up cut off in high frequency will be slowly decreased allowing to infer the velocity of shock front. Eventually the shock front will come in equilibrium with loop plasma and enabling escape of radio emission as shown in Figure 2. Investigations of the relative start timings of soft/hard x ray, beginning of the high frequency cut off and its drift rate will enable to determine exact parameters of the chromospheric evaporation. Simultaneous x-ray, BSS and BDA spectral/positional observations for the first time will allow to estimate the parameters of the chromospheric evaporation more accurately.

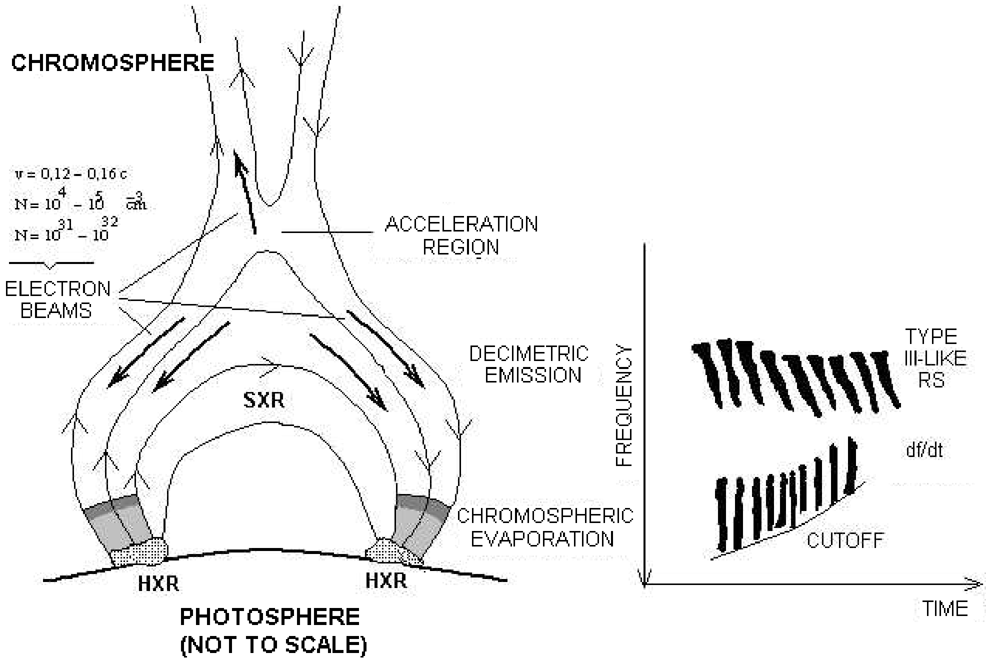


Fig. 2 - Left: A schematic representing flare scenario including the region of the acceleration, up/down going electron beams, chromospheric evaporation front and locations of soft/hard x ray sources, right: decimetric type III bursts - RS - with negative drift rates, high drift rate decimetric emission associated with chromospheric evaporation process, showing high frequency cut off and its slow drift rate associated with motion of chromospheric evaporation shock front.

## MAGNETIC FIELDS OF THE ACTIVE REGIONS, ERUPTIVE COMPONENT AND CMEs

### Active regions

Active regions are composed of various magnetic loops containing hot plasma. The new magnetic flux also emerges in the vicinity of these regions. They are observed routinely in optical wavelengths. However details of the magnetic field of the active regions are inferred by observations in EUV and soft X-rays.

Magnetic field at photospheric level is determined by the line observations in optical and infrared wavelengths and by extrapolation magnetic fields in the chromosphere and corona are determined. These extrapolations are sensitive to exact determination of magnetic fields at photospheric levels which are difficult to estimate. Moreover they have been extrapolated under the assumptions that magnetic fields are force free. This assumption is a questionable. Thus determination of the magnetic fields by this technique is ambiguous.

Low frequency radio emissions of the active regions say up to 5.0 GHz is due to optically thick gyro-resonance up to $4^{th}$ harmonic of electron cyclotron frequency given by following equation: $f_{MHz} = 2.8 \times x\ H_{gauss.}$ This emission is originated in a thin layer of constant magnetic field. Thus high spatial resolutions observations obtained by BDA of the active regions in the frequency range of 1–5 GHz will enable to determine the magnetic fields in the corona and their height dependence.

**Burst Component**

In the majority of cases for the weak microwave bursts, peak frequency is around 5.0 GHz and spectra below this frequency is optically thick (Guidice and Castelli, 1975). Peak frequency is dependent upon the intensity of magnetic field and the angle of source with line of sight. Thus BDA observations of the well observed weak microwave bursts having peak around 5.0 GHz will determine the magnetic field and its time variation in the sources region.

It is well known that radio method is the unique method to determine correct magnetic fields in the corona.

**Coronal Mass ejection**

One of the main objectives of the on going space weather programs is to use the spectral data for the prediction of the space weather forecast by using spectral tomographic techniques (Rosa et al., 2000 and references cited therein). Coronal mass ejection has been turned out to be central point for investigations of space weather prediction and solar-terrestrial relationship programs.

Followings are the main advantages of the detection of the CMEs in radio: normally in observations of optical coronograph solar disk is occulted and hence only CMEs propagating perpendicular to line of sight are observed. However in radio observations there is no occultation of solar disk and hence CMEs on the disk can also be observed by radioheliographs. In radio CMEs can be detected in its initial stage and they can be properly identified with optical structures on the disk. Whereas in optics, they can be identified with filaments and emerging loops only after their occurrences. Sensitivity of radio observations enables to detect free – free and non-thermal emissions emitted by CMEs. Thus, increasing the chances of detentions of CMEs**.** Bastin and Gary (1997) have concluded that thermal emission of CMEs due bremssstrahlung can be detected by instruments like BDA type. Hence improving the capability of space weather prediction program by detection of CMEs in its initial phase. Program to investigate association of CMEs with active regions, current sheets and coronal holes is in progress (Srivastava et al., 1998).

Majority of solar flares occurs in an active region associated with the sunspot. However CMEs can occur outside the active regions some of them at high latitudes extending up to the poles. Thus, occupying very large volumes in comparisons to flares. It makes it difficult to distinctly separate these two eruptive events. Flares are associated with activation of eruption of filaments associated with active regions. However this is also one of the signatures of the association with CMEs. CMEs have been found to be associated with bright chromospheric patches, which can be easily detected by BDA.

CME consists of dense nucleus, surrounded by halo and front loop. Piston – shock structure normally assumed does not explain above mentioned three components of the CMEs. In many cases it has been noted that velocity of the front loop is not a super Alfvenic. Then how a CME is expanding? Kinetic energy transported by CME is normally more than a thermal energy and hence a force responsible of expansion should be of magnetic origin. However, it is not known what type of magnetic instability is responsible for activation of CME.

During the solar maxima period (2000 - 2004) it will be difficult to understand the mechanisms of launch of CME due to super positions of the multiple events and interaction among the various active regions. Thus observations in decaying phase of the solar activity will lead to a better understanding of these mechanisms, when there will be a few active regions on the disk. During the solar maxima one can observe energetic CMEs and their radio images can be investigated with simultaneous observations of X-ray obtained by SOHO and LASCO on board of SOHO satellite.

During the decay phase when BDA will be in full operation, as mentioned above, the mechanisms of launch will be better understood. Spectral data of the active regions collected during earlier years and their investigations related to the activities associated with CMEs will able to improve the capabilities of prediction of flares and CMEs. This would consequently enhance the capabilities of space the weather program, one of the main objectives of the development of BDA.

## SOLAR ATMOSPHERE

### Coronal heating

There exist many models for interpretations of the heating of the solar corona. BDA observations will improve the work done on the following models: resonance wave heating (Ofman et al., 1998) and an old model of Parker (1988) of "nano-flares".

BDA observations of the some of the well observed active regions collected over a couple of years will enable determination of the magnetic fields, temperatures and their height variations in the loop which will provide the estimates of the rate of the energy deposit as a function of time and position. These are the inputs necessary for the resonant wave heating model.

In case of nano-flare model two inputs are required. One, number of small events occurring simultaneously over a wide band say from dm- mm – submm –etc. wave length. Such observations presently are not available.

The other input is energy contents of the smallest energy release events (Gary et al., 1997; Goplaswamy et al., 1995; Benz and Krucker, 1999). From our knowledge so far only one observation of tiny flares with high sensitivity has been reported by Gopalswamy et al (1994), which showed that energy content of this tiny flare was well above the canonical nano-flare value of $10^{23}$ ergs. The BDA can contribute. BDA can observe spatially resolved nano-flares to the limit of its sensitive in the decimer range, which will enable to determine the energy contents of the nano-flare more precisely.

### Background solar radiation

Background radiation is known to be originated in a weak magnetic field by free- free emission in solar atmosphere. Microwave radiation is generated under LTE condition and in that case Plank function is valid and for microwave Rayleigh-Jeans's approximation is valid In that case observed intensity is directly proportional to the kinetic temperature of the of the emitting sources for optically thick sources. Optical depth is proportional to n $T^{-3/2}$. Thus by varying frequency one can obtain the status, temperature – height, of the middle chromosphere, chromospheric and coronal transition region.

### Coronal holes

Coronal holes are of interest. The efforts will be made by using long duration integrated observations to find the difference between the emissions from surroundings and from coronal holes. It is known that high velocity streams are coming from coronal holes if we can infer the position of coronal holes it will help us in identifying the possible path of propagation of these energetic streams in the solar wind. This can be used as warning to satellites, since it is known that energetic particles may damage satellite payloads.

## EMISSION MECHANISMS OF FINE STRUCTURES

Since 1970 various catalogues of the fine structures in the decimeter wavebands are published (Tarstrom and Philip, 1971; Allaart et al., 1990; Isliker and Benz, 1994). Recently, with improved instrument capabilities more and more fine structures are discovered. Many plasma instabilities leading to various mechanisms are suggested for the interpretations of these fine structures. For the first time BDA can provide positions and dimensions of these fine structures this will improve capabilities of the interpretation of these fine structures by the theoretical plasma physics community.

## CORONAL ROTATION

Solar rotation has been estimated by various techniques (for recent reviews see Howard (1996). However, a clear understanding of the rotation of solar interior and exterior is still lacking. Coronal rotation is even less understood and investigated. Recently, Vats et al. (1998a) demonstrated a radio method for the determination of solar coronal rotation. Vats et al. (2001) have pursued this further by investigating the flux values at eleven radio frequencies, almost simultaneously observed, ten of which are closely spaced between 275-1755 MHz and the last one is 2.8 GHz. Using solar electron density models these emissions appear to originate in the solar corona in the heights ranging from 6 to 15 X $10^4$ km above the solar photosphere.

The later study indicates that the sidereal rotation period at the highest frequency (2800 MHz), which originates from the lower corona around $6 \times 10^4$ km, is ~ 24.1 days. The sidereal rotation period decreases with height to ~ 23.7 days at lower frequency (405 MHz), which originates from ~$13 \times 10^4$ km. This indicates that the solar corona rotates slightly faster at higher height. Kane et al. (2001) using the same time series however using different techniques for spectral analysis found many periodicities in the radio flux measurements.

All these investigations use the disc integrated solar flux and hence can not provide any information about the differential coronal rotation in latitude. Thus the radio maps of solar emission in the decimetric band will be useful for determining the differential rotation in latitude and will remove the ambiguities present in the above investigations which could due to the changes at various latitudes in the solar atmosphere. Moreover, Vats et al. (1998b) found that fractal dimension of solar radio emissions are minimum around 3 GHz and increases on either side of the frequencies. Hence high spatial resolution observations of the active regions of obtained by BDA in the frequency range of (1-5) GHz are more appropriate for investigations of coronal rotation and its latitude dependence.

## SIMULTANEOUS X RAYS – RADIO OBSERVATIONS

X-ray observations give emission measure and the temperature diagnostics, and in the case of hard X-ray it suggests the presence of nonthermal particles. Radio observations give us similar information. However they complement each other and hence simultaneous X-ray-radio observations give more complete parameters of the sources rather than either can do alone. Efforts are made since 1970 to compare positional data in radio and in X-ray band (Kane et al., Kundu et al., 1986; Sawant et al., 1984).

YOHOKOH satellite operated until 2000 and provided for the first time the images of solar hard X-ray flares. HESSI satellite was launched in 2002 (Ramaty and Mandzhavidze, 2000) for the first time it provides high resolution X-ray images over a wide energy band ranging from 10 KeV – 10 MeV with spatial resolutions in the range of 1 to 20 arc sec. and time resolutions are of the order of 10 ms for intense flares.

HESSI will be followed by SOLAR – B (Shimizu et al., 1999) Japanese satellite to be launched in 2004. Thus there will be always some X-ray satellite providing good opportunities to compare BDA images, in all its phases of development (2007 – 2010), with hard X-ray images. Good positional accuracy, high spatial and temporal resolutions multi-wavelength (X-ray-radio) observations of BDA in the decimetre wave band, where possibly energy to flares is released, for flares will lead to better understanding of the above mentioned various fundamental problems in solar physics.

## SPACE WEATHER FORECASTING

It was earlier thought that the solar fleas are responsible for the solar terrestrial relationships and perturbations caused on the earth such as failure of radio communication, of power grids and in oil/gas pipelines. In the space, various communication satellites have been damaged by excess of X-ray and energetic particle doses. Risk is further increasing with astronauts in space shuttles. Such missions will be increasing in near future to carry out various experiments on International Space Station. However recently it has become clear that CMEs also play important roles in the above mentioned problems.

Schmahl and Kundu (1997) have shown that multi-frequency observation will lead to better prediction capabilities of sunspot and irradiance .Since long it is known that 10.7-cm flux is correleted to sunspot number and area, the emission in Ly–alpha, Mg II and EUV and the total solar irradiance, which are the indicators of the solar activity. Here BDA observations at 10.7 cm can contribute significantly. Thus, forecasting community, ionospheric physicists, aeronomists. and space weather prediction community can download processed data at 2.7 GHz for their ready use. Such observations are presently lacking.

BDA has been designed to investigate fundamental problems in solar physics. Consequently it will improve the forecasting capability of solar terrestrial relationships and space weather programs. Just sitting below the galactic center it will significantly contribute to galactic extragalaxctic studies mentioned in next sections.

- BDA will provide radio images of the full Sun. It will provide the details of the active regions such as, its spectra magnetic field and its time evolution, simultaneously over selected frequencies, including 2.8 GHz, which are presently not available.
- Detection of CMEs its size, location and associated phenomena in it initial phases.

Thus observations over the period of the full solar cycle will be extremely valuable, providing groundwork necessary to make space weather forecasting a quantitative science and not just a statistical exercise.

## REFERENCES

Allaart, M. A. F., van Nieuwkoop, J., Slottje, C., Sondaar, L. H., *Solar Phys.*, 130, 183, 1990.
Anastasiadias, A., Vlahos, L. *ApJ*,. 428: 819-826, 1994.
Antonucci, E., Gabriel, A. H., Dennis, B. R., *Ap.J.*, 287, 917, 1984.
Aschwanden, M. J., Benz, A. O., *ApJ.*, 438, 997, 1995.
Aschwanden, M. J., Benz, A. O., Dennis, B. R., Schwartz, R. A., *Ap.J.*, 455, 347, 1995.
Barrs, J. W. M., Van Der Bruggs, J. F., Cassae, J. L., *Proc. IEEE*, 61, 1258, 1973.
Bastian, T. S, Gary, D. E., *J. Geophys. Res.*, 102, 14031, 1997.

Bastian T., Gopalswamy N., Shibasaki K. Solar Physics with Radio Observations, Proc. of the Nobeyama Symposium, Kyyoto, Japan, Oct.27 – 30, 1998a.
Bastian, T. S., Benz, A. O., Gary, D. E., *Ann. Rer. Astron. Astrophys.*, 36,131, 1998b.
Benz, A. O., Krucker, S., *Astron. Astrop.*, 341, 286, 1999.
Brown, J. C., Gray, N. *Space Science Reviews*, 68:93-96, 1994.
Bruggmann, G., Benz, A. O., Magun, A., Stehling, W., *Astron. Astrophys.*, 240, 506, 1990.
Christiansen W. N., Högbom J. A., Radiotelescopes, Cambridge Univ. Press, UK, 1987.
Clark, B. G., *Astron. Ap.*, 89, 377, 1980.
Cornwell, T. J., Wilkinson, P. N., *Mon. Not. Roy. Astron. Soc.*, 196, 1067, 1981.
Cornwell, T. J. in Synthesis Imaging, Proc. NRAO Summer School, Ed. Perley, R. A., Schwab, F. R., and Briddle, A. H., p109, 1986.
Cornwell T., “Very Long Baseline Interferometry and the VLBA”, *ASP Conference Series* Vol. 82, Ed. J. A. Zensus, P. J. Diamond, P.J. Napier, 1995.
Dulk, G. A., *Ann. Rev. Astron. Astrophys.*, 23, 169, 1985.
Erickson, W. C., Mahoney, M. J., Erb, K., *ApJ. Supp. Series*, 50, 403, 1982.
Gabriel, E., *Solar Phys.*, 175, 207, 1997.
Gary D. E, *JGR*, 102(A7), 14.031–14.040, 1997.
Gary, D. E., Hartl, M., Shimizu, T., *ApJ.*, 477, 958, 1997.
Gonzalez, W. D., Tsuratni, B. T., McIntosh, P. J., Gonzalez, A. L. C., *JGR Lett*, 23, 2577, 1996.
Gopalswamy, N., Payne, T. E. W., Schmahl, E. J., Kundu, M. R. et al., *ApJ.*, 437, 522, 1994.
Gopalswamy, N., Raulin, J. P., Kundu, M. R., Nitta, N., Len, J. R., Herrman, R., Zarro, D., Kosugi, T., *ApJ.*, 455, 715, 1995.
Guidice, D. A., Castelli, J. P, *Sol. Phys.*, 44, 155, 1975.
Hanaoka, Y. K. et al., Nobeyama Radio Observatory Report N# 360, 35-44, 1994.
Howard, R. F., *Annual. Review Astron.Astrphysics*, 34, 75, 1996.
Isliker, H., Benz, A. O., *Astron. Astrophys. Suppl. Series*, 104, 145, 1994.
Kane R. P., Vats, H. O., Sawant H. S., *Solar Phys.*, 2001.
Kosugi, T., Makishma, K., Murakami, T., Sako, T., *Solar Phys.*, 136, 17, 1991.
Krüger, A., Voigt, W., *Solar Phys.*, 161, 393, 1995.
Kundu, M. R., Solar radio astronomy, John Wiley & Sons, Inc. 1965.
Kundu, M. R., Gergely, T. E., Kane, S. R., Sawant, H. S., *Sol. Phys.*, 103, 153, 1986.
Lüdke, E., Sawant, H. S., Subramanian, K. R., Fernandes, F. C. R., Cecatto, J. R., Rosa, R. R., Sobral, J. H. A., Swarup, G., Gonzalez, W. D., Moron, C. E., Mucheroni, M. L., *Geofisica Internacional*, 39 (1), 147-152, 2000.
Nobeyama Radio Observatory Report n. 360. Hanaoka, Y. et al., *Proc. Kofu Symposium*, 1994.
Melendez, J. L., Sawant H. S., Fernandes, F. C. R., Benz, A. O., *Solar Phys.*, 187, 77, 1999.
Moore, R. et al., in Sturrock, P. A., Ed. Solar flares: a monograph from Skylab Solar Workshop II. Report of NASA Skylab Workshop on Solar flares. Boulder, Colorado University Press, p341, 1980.
Moron, C. E., Ribeiro, J. R. P., Saito, J. H., Sawant, H. S., Rosa, R. R., *Proc. SBAC-PAD'2000* 12$^{th}$ Sysmposium on Computer Architecture and High Performance Computing, pg. 313, 2000.
Mucheroni, M. L., Saito, J.H., Machado, G., Rosa, R. R., Sawant, H. S., Moron, C. E., *Proc. SBAC-PAD'2000* 12$^{th}$ Sysmposium on Computer Architecture and High Performance Computing, pg 175, 2000.
Nancy Radio Heliograph group, *Adv. Spac. Res.*, 13(9), 411, 1993.
Nakajima, H. et al., Nobeyama Radio Observatory Report, 339, 1993.
Nakajima, H. et al., *Proc. IEEE*, 82(5), 1994.

Narayan, R., Nityananda R., *Ann. Rev. Astron. Ap.*, 24, 127, 1986.
Nishio, M. Nakajima, H., Enome, S., Kofu Symposium, 19, 1995.
Nityananda, R.; Narayan, T., *Astron. Astrophy.*, 3, 319, 1982.
Ofman, L., Klimchuk, J. A., Davila, J. M., *ApJ.*, 493, 474, 1998.
Ohyama M., Shibata K., *ApJ.*, 499, 934
Parker, E. N., *ApJ.*, 330, 474, 1988.
Pearson T. J., Readhead A. C. S., *Ann. Rev. Astron. Astrophys.*, 22, 97, 1984.
Pick, M., Klein, K. L., Trottet, G., *Ap.J. Suppl. Series*, 73, 165, 1990.
Ramaty R., Mandzhavida, N., Astronomical Society of the Pacific Conference Series Vol. 206, 2000.
Ramesh, R., Subramanian, K.R., Sundrajan, M.S. and Sastry, Ch.V., *Solar Phys.*, 181, 444, 1998.
Rhode, U., Digital Phase Lockeded Loops, Theory and Applications, John Wiley & sons, 1982.
Rosa, R. R., Sawant, H. S., Valdivia, J. A., Sharma, A. S., *Adv. Space Res.*, 20, 233, 1997.
Rosa, R. R., Sawant. H. S., Ramos, F. M., Sharma, S., Valdivia, J. A., *Geofisica International*, 1999.
Rosa, R. R., Sawant, H. S., Costa Junior, R. A., Ramos, F. M., Cecatto, J. R., Fernandes, F. C. R., Mascarenhas, N., Saito, J. H., Moron, C. E., Mucheroni, M. L., *ASP Conference Series*, 206, 293-296, 2000.
Sawant, H. S., Gergely, T. E., Kundu, M. R., *Sol. Phys.*, 77, 249, 1982.
Sawant, H. S., Kane, S. R., Kundu, M. R. and Gergely, T. E., In Proc. of STIP Symp., Maynooth, Ireland, 113-118, 1984.
Sawant, H. S., Lattari, C. J. B., Benz, A. O., Dennis, B. R. *Sol. Phys.*, 130, 57, 1990.
Sawant, H. S., Sobral, J. H. A, Fernandes, F. C. R., Cecatto, J. R., Day, W. R. G., Neri, J. A. C. F., Alonso, E. M. B., Moraes, A., Adv. Space Res., 17(4/5), 385, 1996.
Sawant, H. S., Subramanian, K. R., Faria, C. Fernandes, F. C. R., Sobral, J. H. A., Cecatto, J. R., Rosa, R. R., Vats, H. O., J. A. C. F. Neri, E. M. B. Alonso, F. P. V. Mesquita, V. A. Portezani, A. R. F. Martinon, Solar Phys., 167, 2001.
Sawant, H. S., Subramanian, K. R., Lüdke, E., Sobral, J. H. A., Swarup, G., Fernandes, F. C. R., Rosa, R. R., Gonzalez, W. D., Cecatto, J. R., *Adv. Space Res.*, 25(9), 1809, 2000b.
Schmahl, E., Kundu, M. R., in Synoptic Solar Physics, ASP Conf. Ser., 1997.
Schwab F., *Proc. S.P.I.E.*, 231, 18, 1980.
Schwartz, U. J., *Astronomy and Astrophysics*, 65, 345, 1978.
Smith, D. F., Benz, A. O., *Solar Phys.*, 131, 351, 1991.
Srivastava, N., Gonzalez, W. D., Sawant, H. S., *Adv. Space Res.*, 20(12), 2355, 1998.
Stähli, M., Benz, A. O., *Astron. Astrophys.*, 175, 271, 1987.
Sturrock, P.A., Symp. on high energy phenomena in the Sun (NASA/GSFC Rept), 1973.
Subramanian, K.R., Sundarajan, M.S., Ramesh, R. and Sastry, Ch.V., STEP GBSC news, 4, 13, 1994.
Shumizu, T. et al., NRO Report No. 479, 459, 1999.
Swarup, G., *Indian Journal of Radio and Space Physics*, 43, 31, 1990.
Tarnstrom G. L., Philip, K. W. Scientifi Report, Univ. Alaska, UAG R-217, 1971.
Thompson, A. R., Clark, B. C., Wade, C. M., Napier, P. J., *ApJ. Supp. Series*, 44, 151, 1980.
Vats et al., *Solar Phys.*, 181, 351, 1998a.
Vats et al., *Earth, Moon and Planets*, 76, 141, 1998b.
Vats, H. O., Cecatto, J. R., Mehta, M., Sawant, H. S., Neri, J. A. C. F., *ApJ. Lett.*, 2001.
VanVleck, J. K., Middleton, D., *Proc. IEEE*, 54(1), 2, 1966.
Vlahos, L. *Space Science Reviews*, 68, 39-50, 1994.
Weinreb, S., MIT Technical Report, 412, 1963.
Zirin, H., Baumert, B. M., Hurford, G. J., *ApJ.*, 370, 779, 1991.