

## **SOLAR DECIMETRIC EMISSION**

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### **ABSTRACT**

The importance of solar observations at decimetric wavelengths is explained. Characteristics of various types of decimetric radio bursts during flares are described. Radio observations of solar active regions are also described.

### **INTRODUCTION**

Radio observations of the Sun contribute to the understanding of many physical processes which occur on the Sun. From the thermal bremsstrahlung emission in the quiet Sun to thermal gyro - resonance in strongly magnetized solar active regions to the non thermal emission from MeV electrons accelerated in solar flares, observations of radio emission in the entire radio band provides additional means of understanding the myriad phenomena on the Sun from the base of the chromosphere to the outer Corona. The range of frequency in the band 300 – 3000 MHz roughly corresponds in height to the lower corona generally less than 1.2 solar radii. High frequency part of this spectrum is the operating frequency range of Brazilian decimetric array (BDA). In the solar corona, the characteristic frequency of the background plasma is: the plasma frequency and the electron gyro frequency that determine the observing radio frequency by  $f_p = 9000 \sqrt{n}$  Hz and  $f_c = 2.8 B$  MHz where  $n$  is the electron density/cm<sup>3</sup> and  $B$  is the magnetic field in Gauss. Radio emission is produced at these frequencies (fundamental) and or second harmonic (and higher for some gyro magnetic emissions. The decimeter range of 300 – 3000 MHz corresponds to source densities of  $1.2 \times 10^9$  to  $1.3 \times 10^{11}$  cm<sup>-3</sup> assuming fundamental emission. This is the range of densities where the primary energy release of flares is expected to take place. The way in which different radio frequencies can be used to probe different levels of the atmosphere is shown in the Figure 1.

The solar radio emission in the decimeter band has been studied extensively using spectrographs and imaging instruments. From the diagnostic point of view that the radiation in the band 1 – 5 GHz allow direct measurement of temperature and magnetic field without the complications arising in the analysis at other wavelengths like the knowledge of the chemical abundance etc. The large resurgence of solar radio astronomy in the past decade is due to the use of large interferometers like VLA and WSRT for imaging and radio spectrographs in different parts of the world in particular the Phoenix (Benz, 1998) in Zurich and the BSS (Sawant, 2003) at INPE in Brazil.

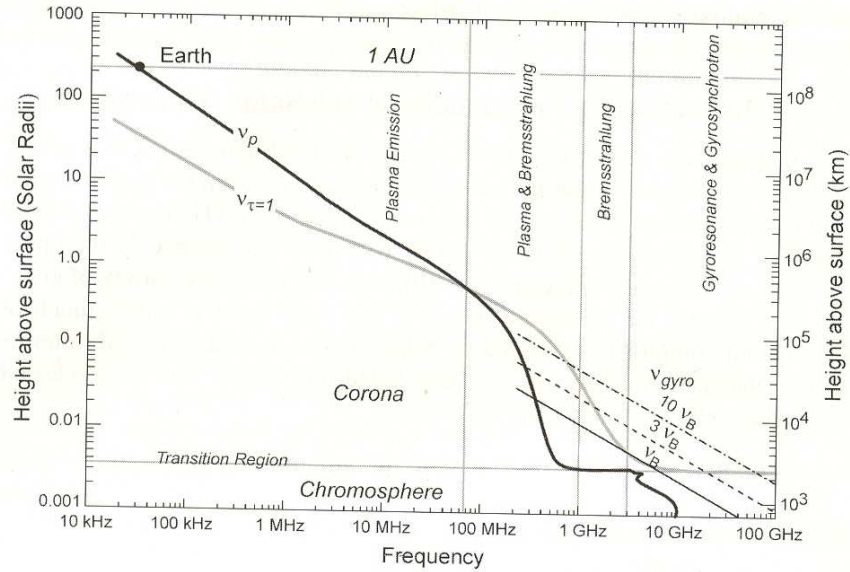


Fig. 1 - Characteristics radio frequencies in the solar atmosphere (Gary and Hurford, 1989).

For the past two decades imaging observations of solar active regions and flares with high spatial resolution ( $< 20$  sec of arc) were made by VLA and WSRT. Also RATAN and SSRT have been used to study the SUN. In recent years GMRT has been used to observe the Sun few times in a year. The spatial resolution of VLA ranges from 3 arc min at 330 MHz to about 5 arc sec at 15 GHz. Radio spectrographs in the decimetric band used in recent years for solar observations is shown in the Table 1.

Table 1 - Broadband spectrographs in the decimeter range

	Range (MHz)	Time resolution (s)	Spectral resolution $\Delta f / f$ (%)
Artemis (Greece)	470- 110	0.01	0.8
Beijing (China)	3700 – 3100	0.001	-
Hirasiso	2500 – 25	3 - 4	0.2
Ondrejov (Czech Rep.)	4800 – 800	0.1	0.6
Porto (Portugal)	600 – 200	0.1 or 0.01	$> 0.16$
Tremsdorf (Germany)	800 – 40	0.1 or 0.001	0.46
Zurich (Switzerland)	4000 – 100	$< 0.1$	0.2

## DECIMETRIC EMISSION FROM FLARES

The radio emission of flares at wavelengths from millimeter to decameter waves includes a large variety of radiation processes. They can be considered as different diagnostic tools particularly suited for the analysis of non thermal electron distribution, enhanced level of various kinds of plasma waves and dynamical plasma processes. From the study of solar flares using solar radio spectrographs it is

known that there is a variety of (flare related) bursts with distinctive morphologies in the frequency time domain. Situated in the spectrum between metric range ( $< 300$  MHz well known for five types of bursts) and the centimetric synchrotron emission at frequencies  $> 3$  GHz the decimetric emissions manifest a large variety of structures many of which are still unexplored. Figure 2 shows a typical example of broadband spectrum recorded by Phoenix 2 spectrograph. In addition to type III bursts many type III like burst were observed.

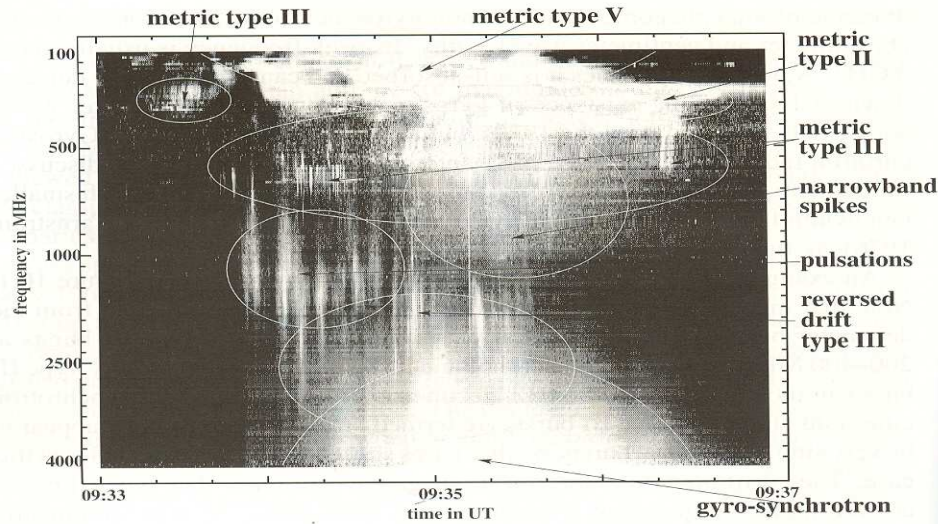


Fig. 2 - Broadband spectrum showing a rich variety of bursts in the meter – decimeter wavelengths (Benz, 1991).

The decimetric range has been systematically explored since 1980s with digital radio spectrographs with high spectral and temporal resolution (Benz, 1991). Most decimetric type III emissions are shaped similar to metric type III radio bursts. Their characteristics are:

- impulsive onset;
- occur in groups of some tens to hundreds;
- similar to metric and IP type IIIs;
- have short duration (0.5 – 1 sec);
- high drift rates  $< 100$  MHz;
- occur in groups (tens to 100s);
- reverse drift common as normal drift (above 1 GHz).

These bursts are interpreted on the basis of electron beams interacting with the ambient coronal plasma to excite a bump on tail instability of Langmuir waves. This emission can occur at fundamental and harmonics. The electromagnetic emission is assumed to be produced at the local plasma frequency and /or its harmonics. Type III bursts are a diagnostics of the electron density of the plasma traversed by the beam. The recent interest in type III bursts is motivated by their use as diagnostics for location of the electron acceleration process, as traces of the magnetic field lines along which electron propagates and the density of the ambient corona they traverse. Imaging observations have shown that type III sources are often not single, but emerge simultaneously into different directions. Down

propagating branches of type III bursts are sometime double sources. Their simultaneous existence suggests a common origin. Figure 3 shows radio bursts in the frame work of flare scenario.

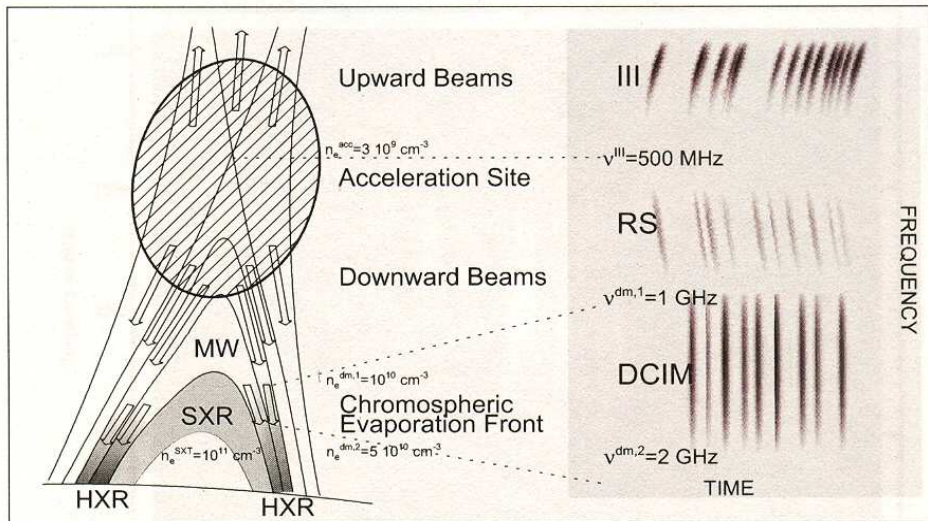


Fig. 3 - Acceleration region above the X-ray bright flare loop accelerating beams in the upward and downward direction is shown.

Spike bursts are seen very often in the decimetric band. Their characteristics are:

- short duration ( $< 0.1$  s);
- narrow band ( $\Delta f/f \sim 0.03$ );
- highly polarized;
- short rise and decay times;
- frequency of occurrence 300 MHz – 8 GHz;
- occur in clusters;
- correlated with flares.

The spike bursts are suggested due to Electron Cyclotron Maser Emission (ECME) generated by beams of electrons. They represent basic fragmentation of the energy release in flares.

Diffuse continua occur in the 1 – 3 GHz range than in other range of frequencies. Their characteristic duration ranges between one and some tens of seconds too long for type III burst and too short for a type IV burst. The circular polarization is found to be weak.

Stationary type IV events are continua of  $> 10$  minutes duration occurring in the 0.1 – 3 GHz range. This emission is usually modulated in time scales of 10s or less and is strongly polarized. The emissions are due to electrons trapped in loop shaped magnetic field lines. These broad band emissions occur usually above 1 GHz.

The emission is suggested due to Gyro synchrotron emission of mildly relativistic electrons.

## SOLAR ACTIVE REGIONS

Solar active regions are localized areas on the Sun where magnetic flux has erupted through the photosphere into the chromosphere and corona. They are characterized by the presence of sunspots in

white light, enhanced line emission (e.g., H $\alpha$ , CaII), and greatly enhanced soft X-ray (SXR) and radio emission. As their name implies, solar active regions are the sites of solar flares, a variety of radio bursts, enhanced coronal heating, and play a role in various mass ejections. A key goal of solar physics is to understand their birth, evolution, and decay, and their production of transient, energetic activity.

Manifestation of solar activity is shown as solar active regions which are three dimensional plasma structures of high density, temperature and magnetic field located above sun spots. Radio observations of the solar active regions show multi structure components of the plasma structures generated by different mechanism thermal and non-thermal in origin. The classification of these components and their mechanism depend on the imaging observations at many frequencies. When observed at centimeter wavelengths, a typical solar active region consists of a bright compact source embedded in a diffuse component of low brightness. The Active regions in this Figure 4 show 2 bands symmetric about the equator. The compact source corresponds to the positions of strong magnetic fields.

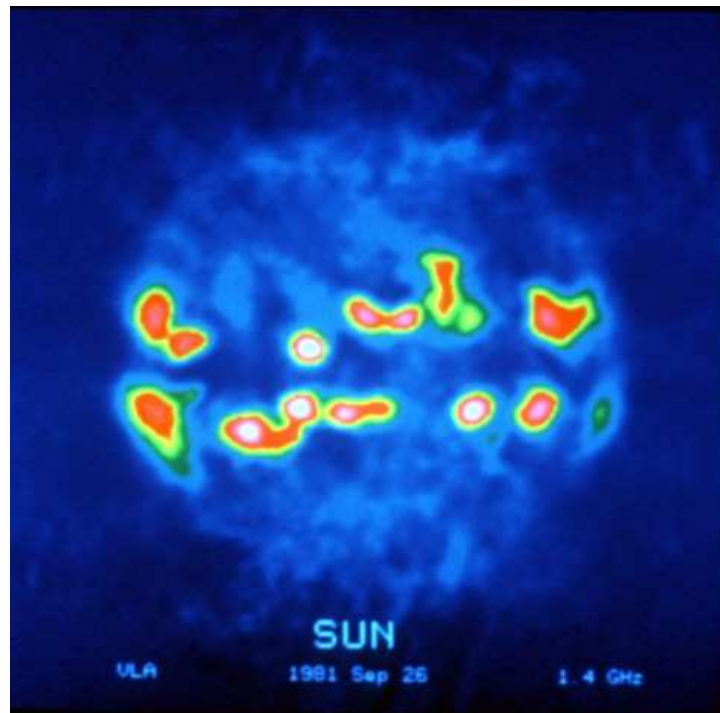


Fig. 4 - Brightness distribution of the Sun shows that the bright features, the solar active regions, form two bands symmetric about the solar equator (Dulk and Gary).

With brightness temperature of  $T_b \sim 10^6$  K, the compact sources are due to gyro resonance emission at low harmonics of the local gyro frequency. The diffuse component which is very well correlated with the H-alpha plage is associated with weaker magnetic fields. The low brightness ( $T_b \sim 10^6$  K) of the diffuse component is due to the optically thin thermal bremsstrahlung. The relative importance of the compact and diffuse sources is wavelength dependent. Diffuse components have spatial scale of the whole active regions of  $\sim 10^5$  km. This component is especially typical for wavelength range of 8- 12 cm and longer. The size of active region at 1.5 GHz  $\sim 100$  arc sec and their

sizes depend on the wavelength of observation (Lara et al., 1998). Study of Active Region Magnetic Field Structures Using VLA Radio, YOHKOH X-ray and MEES Optical Observations were made by Gopalswamy et al. (1994). Full disk VLA images at 20 cm wavelength revealed a number of compact ( $10'' - 20''$ ) low brightness sources which were the radio counter parts of EUV bright points detected by EIT (Lang and Wilson, 1997). Statistical analysis of Active regions at 21 cm shows an electron temperature  $\sim 4.5$  MK, Emission measure of  $5 \times 10^{28} \text{ cm}^{-3}$  and density  $1.2 \times 10^9 \text{ cm}^{-3}$ . Observations at 91cm using VLA have showed large scale (5- 10 arc min) that appear to connect widely spaced active regions on the solar surface. VLA observations at 20 cm shows also shorter (1- 2 arc min) loops above individual active regions that evolve in time scales of minutes to hours. Radio observations with the VLA have given information on the size, locations and time evolution of active regions. It has been found that observation of the variation of the size of the gyro resonance source with frequency shows an exponential relationship between the area and wavelength.

## CONCLUSIONS

The radio emissions at decimetric wavelengths originate in the upper chromosphere and base of the Corona. Their study is important since the acceleration of electrons takes place in these regions. Using spectrographs and imaging instruments, detailed investigations had been made to understand the physics of active regions.

## ACKNOWLEDGEMENTS

I would like to thank the funding authorities, FAPSEP, for their financial support to attend the BDA workshop.

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