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A Review: Sunspots, Solar Wind, Solar Flares and Solar Radio Burst

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Abstract: Solar observation is the scientific endeavour of studying the Sun and its behaviour and relation to the Earth and the remainder of the Solar System. The life on earth is driven by the sunlight incident form the atmosphere. Therefore climate is critically sensitive to the solar activity. To receive solar radiation data acquisition extended-Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory (e-CALLISTO) system was installed. This paper represents the brief review of sunspots, solar flares, solar wind and solar radio burst. Solar radio observations are relevant to such phenomena because they generally originate as events in the solar atmosphere, including flares, coronal mass ejections and shocks, that produce electromagnetic and particle radiations that impact the Earth. Low frequency solar radio emission arises in the solar atmosphere at the levels where these events occurs. We can use frequency as a direct measure of density and an indirect measure of height in the atmosphere. The main radio burst types are described. Solar burst can damage satellites. Very large flares can even create currents within electricity grids and knock out energy supplies.

Keywords: Solar activity, Active region, Sunspots, Solar flare, Solar wind, Solar burst.

I. INTRODUCTION

The sun is a hot sphere of gas whose internal temperatures reach over 20 million degrees kelvin due to nuclear fusion reactions at the sun's core which convert hydrogen to helium. The radiation from the inner core is not visible since it is strongly absorbed by a layer of hydrogen atoms closer to the sun's surface. Heat is transferred through this layer by convection. The surface of the sun, called the photosphere, is at a temperature of about 6000K and closely approximates a blackbody. The total power emitted by the sun is calculated by multiplying the emitted power density by the surface area of the sun which gives 9.5×10^{25}W [1]. The total power emitted from the sun is composed not of a single wavelength, but is composed of many wavelengths and therefore appears white or yellow to the human eye. The life on earth is driven by the sunlight incident form the atmosphere. Therefore climate is critically sensitive to the solar activity. The variation in the sun climate has important role in changing the life on the earth. So it is necessary to study and understand the solar activity. These variations in solar irradiance have been studied from space for more than two decades.The ground observatories increase rapidly. The increase in solar activity is shown by increase in number of sunspot, increase in various related measures of solar magnetic fields, the changing flow, thermal and mass profiles near the surface of the sun [2].

Deep in the core of the sun is a massive thermo-nuclear reactor generating very short wavelength energy (gamma and x-rays) to the surface of the sun; the wavelength gets elongated, or stretched, into the radio wavelengths, becoming the background radiation from the sun called the solar flux (SF).

It is measured at several observatories and reported daily by the National Oceanographic and Atmospheric Administration (NOAA). The solar flux is low during the quiet sun (SF <100) and elevated during the active sun (SF >100). It indicates of the electron density of an ionosphere. Higher the electron density, it becomes more reflective to HF signals, and the higher the maximum usable frequency (MUF) [3].

Magnetic compass was discovered by the Chinese about 2000 years ago. The magnetic compass arrived in Europe during the twelfth century, and proved a valuable aid to ocean navigation. By the sixteenth century the declination was being measured at various places so compass directions could be corrected for more accurate navigation. Then in 1600 William Gilbert published De Magnete, in which he concluded that the earth behaved as a giant magnet. The changes in the superficial, random magnetic field were first tried to calculate by Goldreich et al in 1991 [4,5]. Gauss and William Weber studied Earth's magnetic field which showed systematic variations and random fluctuations, suggested that the Earth was not an isolated body, but was influenced by external forces, which we called magnetic storms [6]. The first powerful geomagnetic solar storm was observed by Richard Carrington on 1st September 1859 [7].

There are several impacts of the solar radiation received at the Earth's surface. These changes include variations in the overall power received, the spectral content of the light and the angle from which light is incident on a surface. The variability is due to both local effects such as clouds and seasonal variations, as well as other effects such as the

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length of the day at particular latitude. Desert regions tend to have lower variations due to local atmospheric phenomena such as clouds. Equatorial regions have low variability between seasons. Cloud cover, air pollution, latitude of a location and the time of the year can all cause variations in solar radiance at the Earth's surface.

There is high impact of solar flare and coronal mass ejections (CMEs) on Earth and that can affect the life on the Earth. These phenomena can be observed using ground radio telescope. Radio observation are done since 1944 when J. S. Hey discovered that the sun emits radio waves [8,9]. The phenomena of CMEs in which more energy released on a time-scale of a few minutes to tens of minutes [10]. The solar flares are the intense explosions on the sun that expel large amount of electromagnetic energy into space. A sudden brightening in the solar atmosphere that spread across all atmospheric layers dissipating energy. This energy is stored magnetically in the corona prior to the event which builds up gradually taking place as the result of deep-seated convective motions that deliver high magnetic stress in the form of non-potential magnetic fields [11].

Now a day, a worldwide network **e**xtended-**C**ompound **A**stronomical **L**ow-cost **L**ow-frequency **I**nstrument for **S**pectroscopy and **T**ransportable **O**bservatory (e-CALLISTO) is keeping watch on different solar activities. CALLISTO network collects data located in many countries and data is made available worldwide. For full coverage of the solar radio emission, the number of stations is being connected to Callisto network using a public web interface [12]. The CALLISTO is a programmable heterodyne receiver built at ETH Zurich, Switzerland. Mainly used in applications such as observation of solar radio bursts and monitoring of RFI for astronomical science and education [13]. e-CALLISTO was installed at KTHM college, Nashik, Maharashtra (India). The locations details are as follows: Latitude 20.00, Longitude 73.78 and Altitude 576 meter. The photograph of the working system is shown in Figure 1. It includes the PC, controller circuit and CALLISTO. PC monitor screen shows the real time data acquisition of solar radiations using CALLISTO [14].

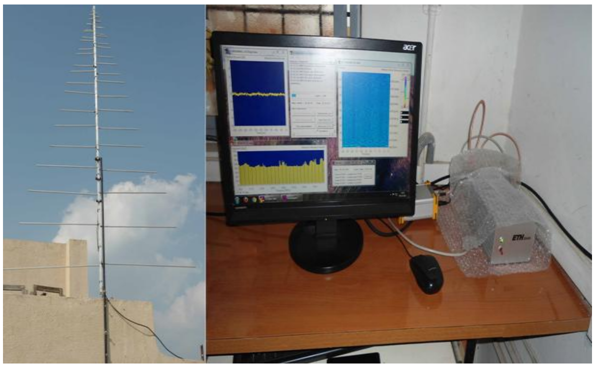

Fig. 1. LPDA installed on terrace of the building.

II. SUNSPOTS, SOLAR WIND AND SOLAR FLARE

Magnetic fields are created by things that are magnetic or by moving charged particles. A magnetic field is the description of the force a magnetic object exerts in the space surrounding the magnetic object. A force is a push or pull. When charged particles move around really fast they create magnetic fields. The Sun is made of positively charged ions and negatively charged electrons in a state of matter called plasma. Since the Sun is made of charged particles, magnetic fields are created by the movement of the particles. The Sun's charged particles move in three ways due to the Sun's high temperatures and the movement of its axis, which influence each other to make the Sun's magnetic field complex:

a. The Sun's high temperatures cause the positively charged ions and negatively charged electrons that make up its plasma to move around a lot. The moving plasma creates many complicated magnetic fields that twist and turn.
b. The extremely hot plasma that blows off the Sun as the solar wind also causes a magnetic field.
c. The plasma in the Sun also rotates around the Sun's axis. The plasma near the poles rotates slower than the plasma at the equator causing twisting and stretching of magnetic fields, too [15].

Sunspots

Sunspots are temporary phenomena on the photosphere of the Sun that appear as dark spots compared to surrounding regions. They are areas of reduced surface temperature caused by concentrations of magnetic field flux that inhibit convection. Sunspots usually appear in pairs of opposite magnetic polarity. The number of sunspots increase and decrease over time in a regular, approximately 11-year cycle, called the solar or sunspot cycle. More sunspots mean solar activity. The highest number of sun spots in any given cycle is designated “solar maximum,” while the lowest number is designated “solar minimum” [16].

Individual sunspots may endure anywhere from a few days to a few months, but eventually decay. Sunspots expand and contract as they move across the surface of the Sun with sizes ranging from 16 kilometres to 160,000 kilometres in diameter. The larger variety is visible from Earth without the aid of a telescope. They may travel at relative speeds, or proper motions of a few hundred meters per second when they first emerge [17].

Sunspots have two parts: the central umbra, which is the darkest part, where the magnetic field is approximately vertical and the surrounding penumbra, which is lighter, where the magnetic field is more inclined. Sunspot occurrence can be used to help predict space weather, the state of the ionosphere, and hence the conditions of short-wave radio propagation or satellite communications. Solar activity has been occupied in global warming.

Solar wind

The solar wind is a stream of charged particles (plasma) that streams off the Sun at about one million miles per hour. These particles come from the outermost layer of the Sun, called the corona. The corona is a very hot place, about 1.8 million °F or 1 million °C. High temperatures cause particles to move faster, so the particles in the corona move very fast. Some of the particles move so fast that the Sun's gravity is not strong enough to hold them down, and so they fly off, becoming part of the solar wind. The solar wind starts at the corona, and flies out into the Solar System away from the Sun. By the time that the solar wind reaches the Earth, the particles are moving at about 500,000 miles per hour [18].

The conditions in the solar wind in the Earth's vicinity are now referred to generically as "Space Weather". These conditions include the solar wind speed and density, magnetic field strength and orientation and energetic particle levels. They are largely controlled by the Sun, which is the source of the solar wind as well as of CME that impact the Earth with high densities and magnetic field strengths travelling at up to thousands of km s^{-1}. The Earth's magnetosphere and atmosphere have historically protected us from most of the potentially damaging effects of SpaceWeather. The magnetosphere's closed magnetic field lines cushion us from the shocks provided by changing conditions in the solar wind, and deflect much of the damaging ionized radiation flux from the Sun. The atmosphere absorbs most of the large flux of ionizing ultraviolet, extreme ultraviolet and soft X–ray photons produced by solar flares that would otherwise damage biological cells, and life has adapted to survive the resulting conditions at the surface of the Earth [19].

The solar wind strength depends on the solar cycle. When the solar wind is particularly strong, it disrupts satellites and electrical grids on Earth. A very strong solar wind can also cause auroras, also known as the Northern or Southern Lights.

Solar flares

Solar flares were first observed on the Sun by Richard Christopher Carrington and independently by Richard Hodgson in 1859 as localized visible brightening of small areas within a sunspot group. A solar flare is a sudden flash of brightness observed near the Sun's surface. It involves a very broad spectrum of emissions, requiring an energy release of typically 1×10^{20} joules of energy, but they can emit up to 1×10^{25} joules. Flares are often, but not always, accompanied by a CME. The flare ejects clouds of electrons, ions and atoms through the corona of the sun into space. These clouds typically reach Earth a day or two after the event. The frequency of occurrence of solar flares varies, from several per day when the Sun is particularly active to less than one every week when the Sun is quiet, following the 11-year cycle. Large flares are less frequent than smaller ones [19].

There are typically three stages to a solar flare. First is the precursor stage, where the release of magnetic energy is triggered. Soft x-ray emission is detected in this stage. In the second or impulsive stage, protons and electrons are accelerated to energies exceeding 1 MeV. During the impulsive stage, radio waves, hard x-rays, and gamma rays are emitted. The gradual build up and decay of soft x-rays can be detected in the third, decay stage. The duration of these stages can be as short as a few seconds or as long as an hour [20].

Solar flares affect all layers of the solar atmosphere (photosphere, chromo-sphere, and corona), when the plasma medium is heated to tens of millions of Kelvin, while the cosmic-ray-like electrons, protons, and heavier ions are accelerated to near the speed of light. They produce radiation across the electromagnetic spectrum at all wavelengths, from radio waves to gamma rays, although most of the energy is spread over frequencies outside the visual range and for this reason the majority of the flares are not visible to the naked eye and must be observed with special instruments. Flares occur in active regions around sunspots, where intense magnetic fields penetrate the photosphere to link the corona to the solar interior. Flares are powered by the sudden release of magnetic energy stored in the corona. X-rays and UV radiation emitted by solar flares can affect Earth's ionosphere and disrupt long-range radio communications. Direct radio emission at decimetre wavelengths may disturb the operation of radars and other devices that use those frequencies. The soft X-ray flux of X class flares increases the ionization of the upper atmosphere, which can interfere with short-wave radio communication and can heat the outer atmosphere and thus increase the drag on low orbiting satellites, leading to orbital decay. Energy in the form of hard x-rays can be damaging to spacecraft electronics and are generally the result of large plasma ejection in the upper chromospheres.

Solar flares strongly influence the local space weather in the vicinity of the Earth. They can produce streams of highly energetic particles in the solar wind, known as a solar proton event. These particles can impact the Earth's magnetosphere and present radiation hazards to spacecraft and astronauts. Additionally, massive solar flares are sometimes accompanied by coronal mass ejections (CMEs) which can trigger geomagnetic storms that have been known to disable satellites and knock out terrestrial electric power grids for extended periods of time.

A CME is material ejection from the corona. It occurs when a large amount of plasma escape from the gravitational field of sun. It reaches to the earth in several hours at high speed. Its arrival time is 2 to 4 hours [20]. The ejected plasma consists of electrons and protons and the entraining coronal magnetic field. CMEs can cause shock waves in the thin plasma of the helio-sphere, launching electromagnetic waves and accelerating

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particles to form showers of ionizing radiation. When CMEs impacts the earth's magnetosphere, it temporarily deforms the earth's magnetic field, changing the direction of compass needles and inducing large electrical ground currents in earth itself, a process called geomagnetic storm [21].

Solar burst

A burst is a sudden, rapid and intense variation in brightness. Solar burst were first observed on the Sun by Richard Christopher Carrington and independently by Richard Hodgson in 1859 as localized visible brightening of small areas within a sunspot group. The Solar Storm of 1859 known as the Carrington event was a powerful geomagnetic solar storm during solar cycle 10 (1855–1867). A solar coronal mass ejection hit Earth's magnetosphere and induced one of the largest geomagnetic storms on record, September 1–2, 1859. The associated white light flare in the solar photosphere was observed and recorded by English astronomers Richard C. Carrington (1826–1875) and Richard Hodgson (1804–1872) [22]. There are also important differences among the radio bursts, especially in the origin of the energetic electrons responsible for the bursts and the topology of the magnetic structures into which the electrons propagate. Solar radio bursts were amongst the first phenomena identified as targets for radio astronomy. Solar radio bursts at frequencies below a few hundred MHz were classified into 5 types in the 1960s [23]. For Space weather studies, three of the burst types are most relevant: Types II, III, and IV. Type I bursts are a non–flare related phenomenon, consisting of a continuum component and a burst component. Three types of low-frequency non-thermal radio bursts are associated with coronal mass ejections (CMEs): Type III bursts due to accelerated electrons propagating along open magnetic field lines, type II bursts due to electrons accelerated in shocks, and type IV bursts due to electrons trapped in post-eruption arcades behind CMEs. There are three low-frequency variants of type III bursts that originate in the interplanetary (IP) medium (i) isolated type III bursts from flares and small-scale energy releases, (ii) complex type III bursts during CMEs, and (iii) type III storms [24].

Solar burst affect photosphere, chromospheres and corona layers of the solar atmosphere, when the plasma medium is heated to tens of millions of Kelvin, while cosmic ray like electrons, protons, and heavier ions are accelerated to near the speed of light.

III.TYPE I , TYPE II AND TYPE III SOLAR RADIO BURST

Type I solar radio burst

Solar Radio Burst Type I is one of the main type of solar burst which is believed to provide a diagnostic of electron acceleration in the corona. It appears in chains of five or more individual bursts. Type I bursts are brief and very narrow band and tend to occur in drifting chains of 10–20 MHz bandwidth. Because they are not clearly associated with energy releases visible in other wavelength ranges, noise storms are an intriguing sign that energy release can continue in the corona on long timescales.

It is form of a storm radiation, which last for periods of hours or days and is the most common kind of solar radio emission at meter wavelengths. This burst consists of numerous narrow-band peaks, short duration, circularly polarized burst superimposed on a background of continuum radiation known as storms. Normally, a continuum and bursts come together, but have varying flux ratios. During solar maximum, the percentage of noise storm can exceed up to 13%. The burst often appears singly in time-frequency space. Irregularly, they tend to cluster together in tens or hundreds to form narrow-band "chains" of type I burst; the chain generally drifts slowly in frequency [24].

Type I radio noise storm head the list of solar events discovered at metric wavelength. The powerful noise storms at a long time and it appear as intense, narrow band bursts, superposed on a low intensity broadband continuum, in the range of 30-400 MHz. The radiation of the noise storm's components has a very high degree of ordinary-mode circular polarization (~100%) and to be generated by the plasma emission mechanism. Plasma emission is any indirect emission process in which the exciting agency generates plasma turbulence which cannot escape directly from the plasma and this turbulence leads to escaping radiation through some secondary process. Example of Type I burst is shown in Figure 2 [25].

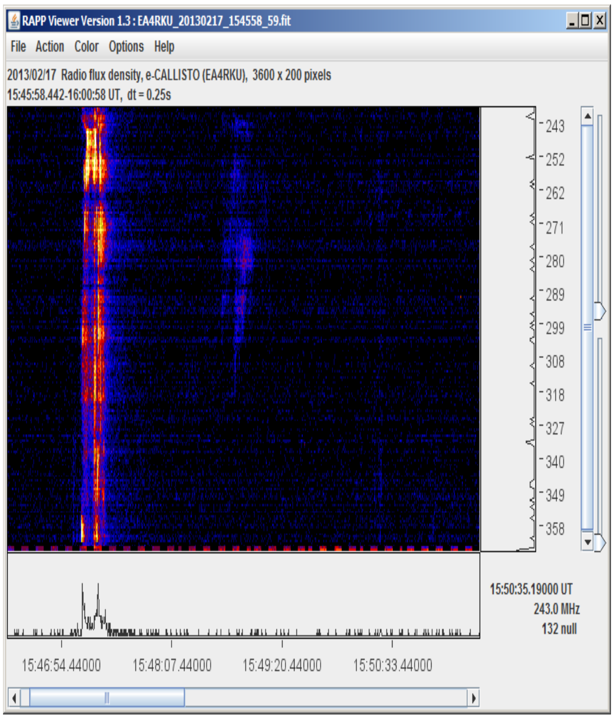

Fig.2. Photograph of solar radio burst type I

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Type II solar burst

Type II radio bursts were first discovered by Wild & McReady (1950) from the dynamic spectra of solar radio bursts. In the frequency time plane, a type II radio burst shows a drift from high to low frequency with a drift rate of 0.5 MHz/s. The slow drift rate of a type II burst is interpreted as the radio signature of a collision less Magneto hydrodynamic (MHD) shock wave generated in the tenuous solar corona. The radio emission process of a type II burst is due to the plasma oscillations from the electron accelerated at the moving shocks [26]. These plasma oscillations occur at the local plasma frequency and the scattering of the plasma waves on the background ions results in electromagnetic waves at the fundamental and the coalescence of two plasma waves results in the second harmonic. In some cases the fundamental harmonic bands of type II bursts are split into two, called as band-splitting. Band-splitting occurs form both the upstream and downstream of the coronal shock front. Type II bursts typically occur at around the time of the soft X–ray peak in a solar flare and are identified by a slow drift to lower frequencies with time in dynamic spectra. The frequent presence of both fundamental and second harmonic bands and splitting of each of these bands into two traces. The frequency drift rate is typically two orders of magnitude slower than that of the Type III bursts, so the two burst types are readily distinguished [27].

The emission mechanism of Type II bursts is assumed to be plasma emission at the plasma frequency and its harmonic. The observed frequency drift rate can be converted into a velocity if the dependence of electron density ne on height is known and it is found that a typical speed is of order 1000 km/s. For this reason Type II bursts are agreed to be evidence for shocks in the corona, rendered visible by the radiation of electrons that they accelerate.

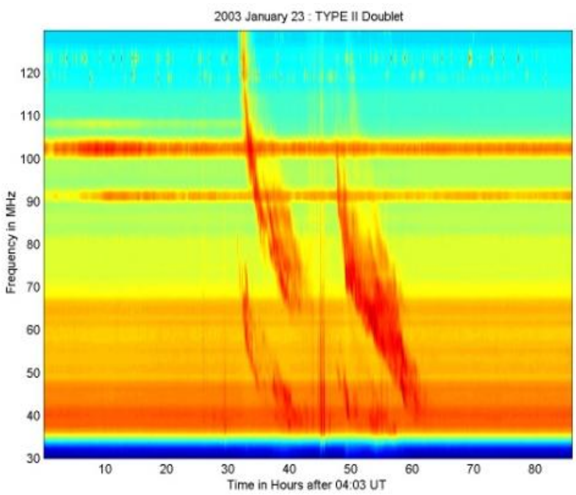

Fig. 3. Typical example of type II radio doublets observed with the Gauribidanoor digital solar radio spectrograph on 23/1/2003. Two type II bursts are seen in sequence with the first one starting at 04:32 UT and the second one at 04:49UTstructures [29].

There is almost always a delay between the flare onset and the start of Type II emission, which is attributed to the variation of the Alfven speed with height in the corona. As height increases, vA decreases and the Mach number of a disturbance moving at a constant speed increases, producing a stronger shock. The shocks that produce Type II emission have never been unambiguously identified at other wavelengths, although possible associations have been suggested and include coronal mass ejections, Morton waves, and soft X–ray ejecta. Both these bursts show the fundamental and harmonic [28]. Example of Type II solar radio burst is shown in Figure 3.

Type II bursts are always seen in conjunction with flares, even though some of those flares are very small events, and there is a very healthy controversy as to whether the shocks are driven by CMEs or by some other flare phenomenon with the improved coverage and sensitivity of coronagraphs in recent years, the correlation between Type II bursts and the presence of a coronal mass ejection (CME) has become increasingly tight, lending support to the idea that the shocks that produce Type II bursts are being driven by CMEs, without resolving the issue The particle acceleration exhibited by Type–II driving shocks, and their associations with flares and/or CMEs, make them important for space weather studies [30].

Type III solar burst

The common occurrence of Type III bursts early in the rise of impulsive solar flares may indicate that open field lines are an essential part of models for energy release by magnetic fields in such flares. Type III bursts are brief radio bursts that drift very rapidly in frequency versus time. Because the emission is at the plasma frequency or its harmonic, the drift in frequency with time can be directly converted into a drift from high to low ambient coronal density with time. Type III bursts have consistently the fastest drift rates of bursts at metric wavelengths, the exciter speeds tend to be of order one tenth the speed of light, and accordingly the only drivers for Type III bursts are beams of electrons of energies up to tens of keV. Such beams of electrons have long been known to be very efficient producers of electrostatic Langmuir waves via the bump in tail instability. They can be seen to start at densities corresponding to the very low corona frequencies up to several GHz [31].

IV. CONCLUSION

The Sunspots are magnetic storms on the surface of the Sun. Solar flares are strong flashes of x-rays and light energy that shoot off of the Sun’s surface into space at the speed of light. Coronal mass ejections (CMEs) are massive clouds of gas and magnetic matter that are eruptions spreading into space. Other solar events include solar wind streams that come from the coronal holes on the Sun and solar energetic particles that are primarily released by CMEs. The nature of low frequency solar radio bursts for the study of space weather has been discussed. Type III bursts are indicators of acceleration of electrons, and of the access of those electrons to open field lines, i.e., magnetic field lines in the corona that do not close within the solar atmosphere but instead become part of the solar wind. To observe solar burst extended-Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory (e-CALLISTO) was developed and implemented. It is working successfully.

Solar activity affects the Earth in many ways,

a) Damage to 21st century satellites and other high-tech systems in space can be caused by active Sun. Large solar flares have the potential to cause billions of dollars in damage to the world's high-tech infrastructure from GPS navigation to power grids to air travel to financial services.
b) Radiations hazards for astronauts and satellites can be caused by quiet Sun. Weak solar winds allow more galactic cosmic rays into the inner solar system.
c) Weather on Earth can also be affected. NOAA scientists have now concluded that carbon dioxide, volcanic eruptions, Sun's activity etc. are the factors determine global temperatures.
d) Global climate change including long-term periods of global cold, rainfall, drought, and other weather shifts may also be influenced by solar cycle activity.

Solar burst can damage satellites and have an enormous financial cost. Astronauts are not in immediate danger because of the relatively low orbit of this manned mission. The charged particles can also threaten airlines by disturbing the Earth's magnetic field. Very large flares can even create currents within electricity grids and knock out energy supplies.

Solar radio observations will continue to play an important role in space weather studies because they are sensitive to the regions of the solar atmosphere in which many space weather phenomena originate. For Space weather studies, three of the burst types are most relevant: Types II, III, and IV. Type I bursts are a non–flare related phenomenon, consisting of a continuum component and a burst component. Three types of low-frequency non-thermal radio bursts are associated with coronal mass ejections (CMEs): Type III bursts due to accelerated electrons propagating along open magnetic field lines, type II bursts due to electrons accelerated in shocks, and type IV bursts due to electrons trapped in post-eruption arcades behind CMEs.

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BIOGRAPHY

Vijay Kale (M.Sc, M.Phil, Ph.D, PGDIM, ADCSSA) is working as Associate Professor (Department of Electronic science, KTHM College, Nashik, Maharashtra, India). He has been in the teaching profession (UG and PG) since last 28 years. He has been presented research paper in international conferences (USA, Bangkok). He published research papers in national and international journals. He received R. Chandrasekhar award from Indian Physics Association (IPA), Savitribai Phule Pune University. He has written six books. He has worked on several academic committees of Savitribai Phule Pune University. He has worked as a resource person in refresher course, workshop etc. He is presently working on ARM microcontroller based sensor application, Wireless sensor application (water quality), e-CALLISTO, etc.