Debojyoti Halder, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 13, Issue 3, March 2023, pp. 129-135

RESEARCH ARTICLE OPEN ACCESS

A Short Review on Solar and Jovian Radio Emission

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ABSTRACT

The Sun and the Jupiter both astronomical objects emit radiation in radio frequencies and have much importance in the Earth's atmosphere. We have recorded data of both Solar and Jovian signal on NASA's Radio Jove instrument at 20.1 MHz. The simultaneous visibility of the two objects the Sun and the Jupiter is of much importance in this study. In this paper, we have done the comparison using the Jove receiving system on those dates especially when the Jupiter rises at nighttime. It shows that the intensity of solar radio emission is well above Jovian emission intensity. It has been observed that solar radio bursts are stronger than Jovian bursts. They occur usually when there are sunspots on the visible corona while Jupiter noise storms are more likely to occur at nighttime and so they are much prominently recorded.

***Keywords* -** Jovian decametric emission, Radio Frequency, Solar Radio emission

Date of Submission: 12-03-2023 Date of acceptance: 29-03-2023

I. INTRODUCTION

The Sun is the brightest radiation source in most frequencies, down to the radio spectrum, as it is the nearest star. When the sun is quiet, the galactic background noise dominates at longer wavelengths. During geomagnetic storms, the sun will dominate even at these low frequencies called active sun and can be detected every frequency. Radio observations of the Sun had an important part in determining our understanding of solar radio physics for many decades. Observed from decametre range (~ 20 MHz) to microwave (near 10 GHz), the solar bursts with characteristic time less than 1s include very short period regular or irregular pulsations, dips in radio emission, bursts, zebra-pattern structures etc. and this can be related with some kind of processes of energy release fragmentation[1,2]. In particular, the solar burst occurs when the magnetic field lines of solar flares reconnected after cutting the portion of the magnetic loops and release energy over the entire electromagnetic spectrum. It happened regularly in the sun following the eleven-year solar cycle activity[3]. Solar flares are one of the typical active phenomena of the sun where the stored magnetic energy is transformed into kinetic energy of highly accelerated particles via magnetic reconnection. Out of various solar activity events, solar flare is the most powerful one with sudden release of enormous electromagnetic energy[4,5]. One of the characteristic s of solar flares is its time duration. Solar flares observed at radio frequencies (called bursts) with duration less than 1s are the main features of the basic energy release process in flares.

Jupiter, on the other hand, being the largest planet in the Solar System, has the largest magnetosphere which is large enough to cover the sun and its visible corona. Its giant magnetosphere acting both as trap and an accelerator of energetic charged particles produces intense belts of radiation. The interaction of energetic particles with the surfaces of Jupiter's largest moons markedly affects their chemical and physical properties. Jupiter's volcanically active moon Io is a strong source of plasma, and loads magnetosphere of Jupiter with as much as 1,000 kg of new material every second. Strong volcanic eruptions on Io emit huge amounts of Sulphur dioxide, a major part of which is dissociated into atoms and ionized by the solar ultraviolet radiation, producing ions of Sulphur and oxygen: S^+, O^+, S^{++} and O^{++}[6]. These ions escape from the satellite's atmosphere and form the Io plasma torus - a thick and relatively cool ring of plasma encircling Jupiter, located near the moon's orbit[7]. The Io torus fundamentally alters the dynamics of the Jovian magnetosphere[8]. If charged particles, e.g., electrons and protons propagate through a magnetic field their paths are changed. The particles are accelerated and move in spirals around magnetic field lines towards either the south or the North Pole. The accelerated charged particles emit radiation that depends on the energy of the particles. For charged particles, travelling in Jupiter's magnetic field the energy is such that radio waves are generated there whose frequency increase the stronger the magnetic field is. This radio emission is named as cyclotron emission after a type of particle accelerator. The decametric radio waves have frequencies in the range between 10 and 40 MHz. From the knowledge of the cause of the radio waves and knowing that the frequency depends on the strength of the magnetic field one can estimate the maximum strength of Jupiter's magnetic field. Jupiter's rapid rotation and strong magnetic field carry the magnetospheric plasma past Io faster than lo orbits Jupiter, creating a wake in front of Io as it moves. In Jupiter’s radio emission, both Io and non-Io related components contribute. The non-Io related sources have a chance of being observed regardless of Io[9].

II. RECORDING INSTRUMENT FOR THE SOLAR AND JOVIAN EMISSION

The function of the antenna is to intercept the radio waves emitted by the Sun and the Jupiter to translate the signals into electrical current. The antenna is designed to receive signal corresponding to a frequency of 20.1 MHz as the Jupiter is mostly favorable around that frequency.

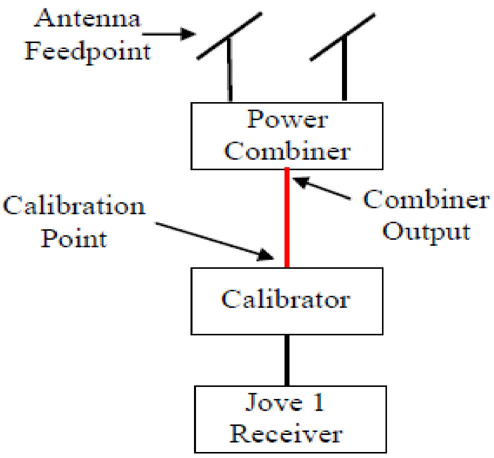

Figure1. Outline of the Set up

The radio Jove system consists of three parts:[10]

(a) **The Radio Jove antenna**:

It consists of two identical half-wave dipole antennas which can be phased together with a feed line. When converted to a full wave antenna the gain is increased by 2 dB but the angle of maximum sensitivity reduces from 90° to 60°. Radio Jupiter pro generates a real time display showing the location of both the sun and the Jupiter in the sky. It is particularly important that Jupiter be in the beam in order to realize the maximum antenna gain.

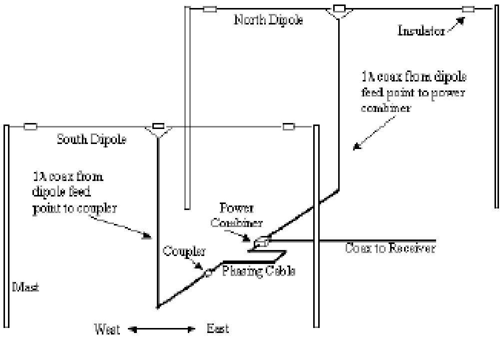

Figure 2. The Jove dipole system setup

(b) **The receiver:**

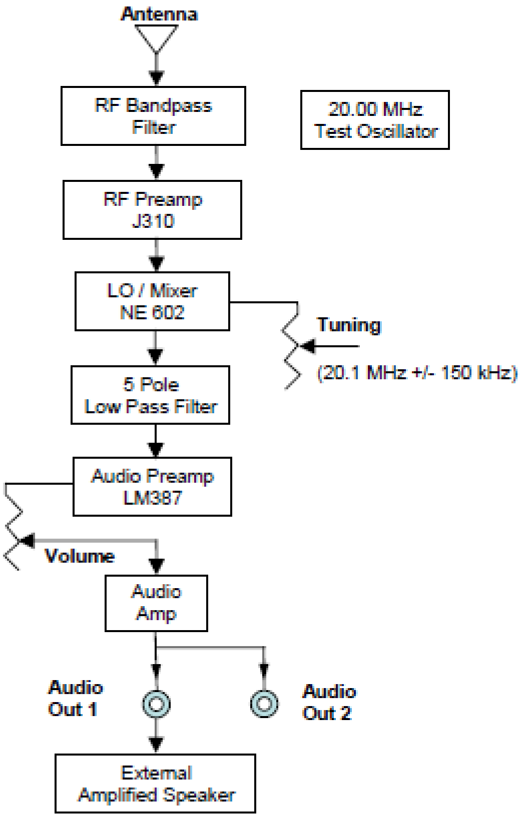

Figure 3. The Jove receiver block diagram

The receiver is a simple direct conversion design which operates over a narrow band of frequencies centered at a 20.1 MHz. The receiver works by taking weak signal from the antenna and filtering out frequency. It converts the radio frequency to 3.5 kHz audio spectrum and amplifies the signal. The filtering of frequency is accomplished by pairing the capacitors which resist direct current but passes oscillating current. The direct conversion of radio frequency to the audio frequency is done by subtracting the received signal from a reference signal generated by an oscillator in an IC.

(c) **The calibrator**:

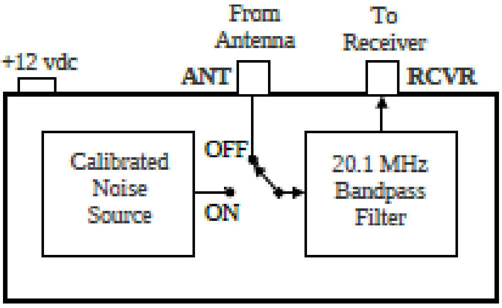

Figure 4. Block diagram of the calibrator

The RF 2080 C/F calibrator contains both a calibrated 25000° noise source and a 20.1 MHz band pass filter which has a loss of approx. 1.5 dB. The band pass filter reduces the interference to the Jove receiver caused by strong international broadcasting stations and nearby power lines.

III. LINEAR AND NON-LINEAR OPERATION OF THE RECEIVER

The Jove receiver exhibits linear operation over a wide range of signal strengths. However, at some point the output can no longer follow the input. In this non-linear region the receiver is said to be saturated which is shown in Figure 5. In the linear region we can calibrate the system at a single point. Calibration means measuring the Sky Pipe Unit (SPU) for a known noise temperature at the receiver antenna terminals. If the signals go into compression, then the calibration is no longer valid.

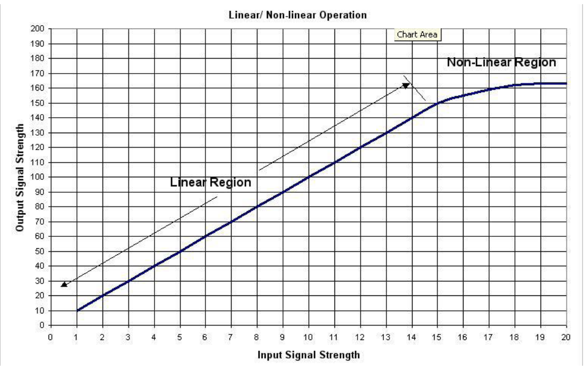

Figure 5. Linear and Non-linear region

IV. POSSIBLE RADIO SOURCES AT DECAMETRIC WAVELENGTH RANGE

The possible radio sources emitting on decametric wavelength range are mainly the Jupiter and the Sun. But in addition to these discrete sources and line emission of our Galaxy, there is a galactic background radiation which emits in this wavelength range.

V. DIFFUSED GALACTIC BACKGROUND NOISE

While observing any loud radio object in the sky, a steady background noise signal can be recorded which increases the base level of the received source signal. This background signal is called Cosmic Microwave Background Radiation (CMBR). This is due to the radio noise from the electrons gyrating in the magnetic field of our Galaxy[11,12]. This continuous distribution of diffuse radiation is extended in all around the Galactic plane. At large distance from the Galactic plane the radiation decreases more rapidly. The Galactic background is composed of two main components, one is concentrated to the Galactic plane with thermal spectra and the other has maximum along the Galactic plane with non-thermal spectra. While the thermal component arises from ionized hydrogen, the non-thermal is due to the synchrotron radiation from relativistic electrons moving in the Galactic magnetic field. The equivalent temperature of the synchrotron radiation depends both on the density of the relativistic electrons and the magnetic field strength. If the electron density is constant, the temperature distribution may give the magnetic field distribution across the Galactic background.

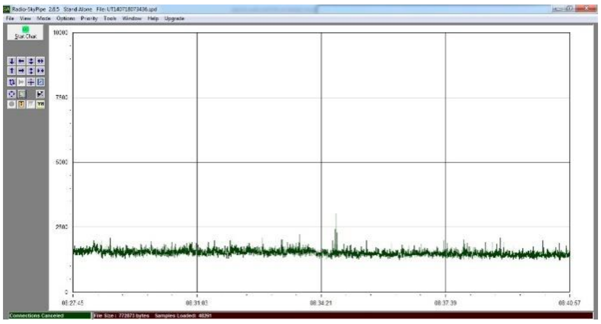

Figure 6. A typical sample of diffused galactic background noise received at Kalyani on July 18, 2014

VI. SOLAR DECAMETRIC EMISSION

The Sun is an extremely complex radio source whose radio emission has structure on angular scales < 1″to more than 0.5°. The intrinsic brightness distribution of the Sun varies on timescales ranging from less than one second, to minutes, hours, days, and years. The solar radio wavelength emissions are easily detectable. Some methods of detection of solar emission are briefly discussed here;

i) Ionospheric Effects: Strong solar blasts of X-rays come with large solar flares. When the X-rays hit the Earth's ionosphere, the ionospheric reflection of the radio waves is disturbed. At low frequencies, a dip in signal strength of distant stations can often be observed. At VLF frequencies the opposite effect is observed and the signal strength of distant station has a sudden rise and slow decline. Using a VLF receiver tuned to some distant station is a moderately reliable way to detect x-ray solar flares.

ii) Magnetic Storms: The Solar flares also emit high-velocity charged particles which take one or two days to reach Earth's atmosphere. When the particles arrive, they crash into the Earth's magnetic field and make it distorted. The distortion of the magnetic field causes the geomagnetic storms. iii) Thermal Emissions: The Sun is heated up to 6000K at the photosphere. When the Sun is in a period of low sunspot activity i.e., "*the quite Sun*" is easily detected at radio wave frequencies where its thermal emission is strongest.

The radio emission from the Sun has three distinct components: originating from quiet Sun, from bright regions and from transient disturbances such as flares or CMEs. The quiet Sun component is thermal radio emission from the solar atmosphere. Radio emission from bright regions corresponds to slowly varying components of radiation which are also due to thermal emissions. The third component consists of radio bursts. These are associated with the solar flares and originate from all layers of the solar atmosphere. These radio bursts can occur between 4 mm to 40 m wavelengths. The centimeter wave bursts occur most often and are characterized by a rapid rise in intensity, usually followed by a slow decay. They can be subdivided into impulsive bursts which last for a few minutes, post-bursts lasting for some few tens of minutes and gradual rise and fall of intensity which also lasts for few tens of minutes. The decimeter and meter wave bursts are more complex than the centimeter wave bursts, showing a great variety of radiation[13]. The solar radio bursts can be well classified into five different types. Out of which Type III bursts are most frequent bursts received from the solar corona. They are characterized by their short duration and fast drift from high to low frequencies in decimeter and meter wavelength range. It is assumed that the radio emissions are generated by beams of fast-moving electrons at levels of the local plasma frequency or its second harmonics.

A solar flare is a sudden brightening observed over the Sun's coronal surface or the solar limb which is interpreted as a large energy release of up to $6 \times 10^{25} J$ of energy. They are mainly followed by a enormous mass ejection from Solar Corona also known as a CME[14]. The flares occur in active regions around sunspots when accelerated charged particles, mainly electrons, interact with the plasma medium where intense magnetic fields penetrate the photosphere to link the corona to the solar interior. They are powered by the sudden release of magnetic energy stored in the corona. Scientific research has shown that the phenomenon of magnetic reconnection is responsible for the acceleration of the charged particles. On the Sun the magnetic reconnection may happen on solar arcades which are a series of closely occurring loops of magnetic lines of force. These lines of force quickly reconnect into a low arcade of loops leaving a helix of magnetic field unconnected to the rest of the arcade. The sudden release of energy in this reconnection is in the origin of the particle acceleration. The unconnected magnetic helical field and the material that it contains may violently expand outwards forming a coronal mass ejection[15]. This also explains why solar flares typically erupt from the active regions on the Sun where magnetic fields are much stronger on average. Solar flares are usually tremendous explosion from the sun with release of magnetic energy owing to accelerated particles, viz., electron and proton to extremely high energies. At a time when these accelerated particle crash into the solar atmosphere their kinetic energy is converted to X-rays and Gamma-rays. The occurrence of a flare can be thought of as a direct mechanism for accelerating particle to high energies in the Sun. Their output at higher energies affects the outer atmosphere of the earth. The Solar Flare bursts are nothing but non-thermal plasma radiations excited by energetic electron sensitivity and indicating the energy release in the corona of the Sun.

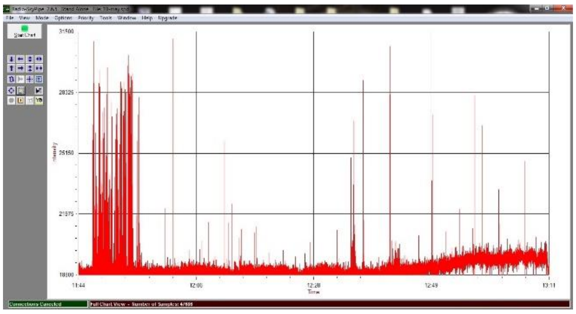

Figure 7. Typical solar radio emission at 20.1 MHz on May 10, 2014

VII. JOVIAN DECAMETRIC EMISSION

The Jovian decametric emission was first discovered in 1955 by B. F. Burke and K. L. Franklin at 22.2 MHz. The emission has an upper cut-off frequency of ~39.5 MHz. It can be detected from ground-based stations from the upper cut-off frequency of the emission down to the cut-off frequency of the terrestrial ionosphere which is usually around 5 to 10 MHz. The peak of the intensity of the emission occurs at around 18 MHz to 22 MHz[16]. If charged particles like electrons move in a magnetic field B and the velocity v perpendicular to B, the electrons start to move in a circle called gyration. If the v is not entirely perpendicular to the magnetic field, they start to move in a spiral motion. Billions of electrons spiraling along Jupiter's magnetic field lines radiate electro-magnetic waves from a few kHz to about 40MHz. The spiraling electrons radiate right circularly polarized (RCP) electro-magnetic waves at or near the local gyro-frequency,

$$\boldsymbol{\omega_g = 2.8\times B_g}\ \text{[MHz]},$$

where, B_g is the local magnetic field. Since the emitted frequency depends on the local magnetic field strength, the radio emissions from other Jovian planets having low magnetic fields, are lower in frequency (< 2 MHz) could not be detectable on the surface of Earth due to ionospheric cut-off.

Electrons are accelerated up to a few keV at Io by *Alfv´en* waves generated by Io's movement through the Jovian magnetic field. Those electrons travel in spirals to Jupiter on magnetic field lines. As Jupiter's magnetic field increases, the frequency of the emitted electro-magnetic waves also increases. The mechanism responsible for the emission is believed to the cyclotron maser instability. The emission is beamed into a thin hollow cone with axis parallel to the direction of the magnetic field lines in the region where the emission originates near the Jovian magnetic poles. The opening angle of the hollow cone seems to be around 70° to 80°. The radio waves are emitted in thin hollow cones with axis parallel to the magnetic field line. The emission can only be detected at Earth if the thin walls of the cone intersect the direction of Earth. The Io-related emission is emitted from a Previously Energized Flux Tube (PEFT), which is 20° to 0° behind the current Io Flux Tube (IFT). These *Alfv´en* waves produce an electric field parallel to the magnetic field, which accelerates the electrons towards Jupiter[17]. The emissions are produced by electrons ascending the Io magnetic flux tube after having mirrored near the top of the Jovian ionosphere. So the emission occurs at a frequency slightly above the local gyro-frequency.

Most of the radio waves from Jupiter are polarized. In fact, the polarization of the radio emission from Jupiter indicated the existence of a magnetic field in that planet. The decametric emission occurs in episodes called "storms", lasting from a few minutes to several hours. Two distinctive types of bursts can be received during a storm. The Long Bursts (*'L' bursts*) vary slowly in intensity with time and last from a few seconds to several tens of seconds, having an instantaneous bandwidth of a few MHz. The Short Bursts (*'S' bursts*) are very short in duration, have instantaneous bandwidth of a few kHz to a few tens of kHz, and drift downward in frequency at a rate of typically 20 MHz/s. They arrive at a rate of a few to several hundred bursts per second. In a 5 kHz bandwidth receiver they last only a few milliseconds. Sometimes both types of bursts can be detected simultaneously.

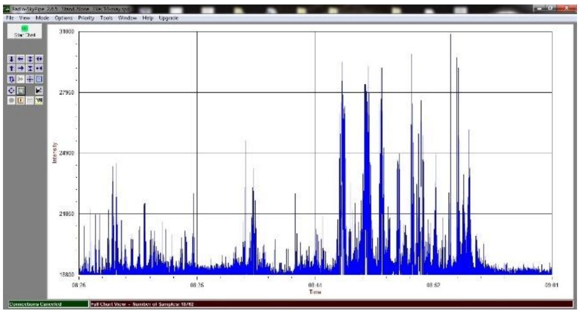

Figure 8. Jovian L-bursts on May 14, 2014

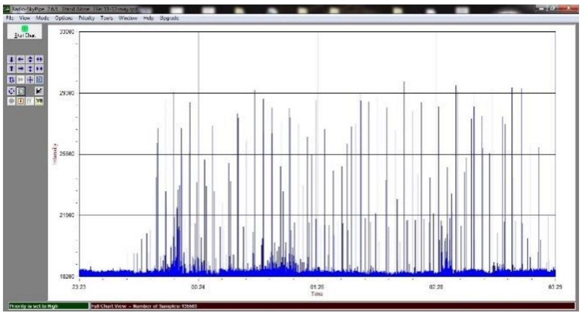

Figure 9. Typical graph of S-bursts may 11-12, 2014

VIII. COMPARISON OF YEARLY VISIBILITY AND DECLINATION OF SUN AND JUPITER

Figure 10 demonstrates the yearly visibility of the Sun and the Jupiter from 2010 to 2014. Visibility of the Jupiter is denoted by blue and that of the Sun is by yellow. The overlapping period is marked by green. According to this figure the period of overlapping for these two objects changes for each year. Figure 11 shows the jovecentric declination of Jupiter with respect to the earth from 2010 to 2019 running from -3o to +3o. This figure shows that the jovecentric declination angle takes peak from middle of 2011 to 2013 and then a decline phase comes lasting throughout 2014-2018.

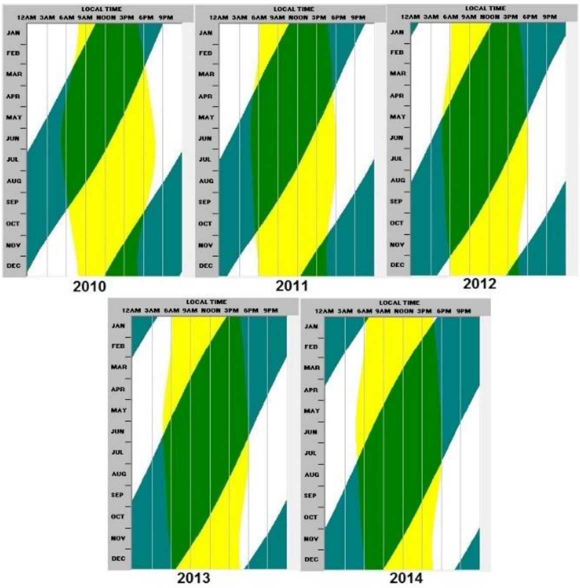

Figure 10. Yearly visibility of Jupiter over Kalyani

Figure 11. Jovecentric declination of Jupiter w.r.t the earth

IX. COMPARISON OF THE SOLAR AND JOVIAN RADIO EMISSIONS

Figure 12 shows the comparison of solar and Jovian radio emission. Red line indicates the solar radio emission whereas blue line shows the Jovian one. It is very much clear from the data recorded that when the Sun in present on the Kalyani sky, Jupiter does not have any effect on the atmosphere of earth. Whereas, at the night time, Jupiter radio bursts dominates. During time 11.34 a. m. (IST) to 16.47 p. m. (IST) solar radio emission dominates over Jovian radio emission but during 17.00 p. m. (IST) to 03.12 a. m. (IST) Jovian radio emission dominates.

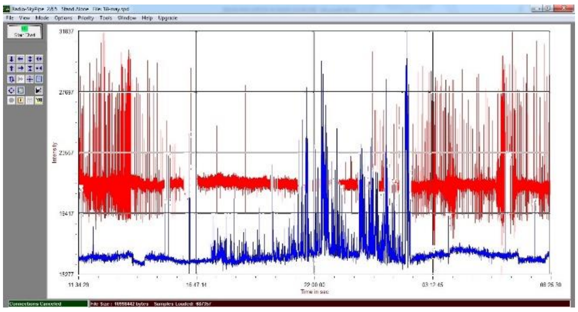

Figure 12. Comparison of the solar and Jovian radio emissions

X. CONCLUSION

As we continue to gather more information on Radio Jove and also gathering electromagnetic waves from the Sun, we came to the conclusion that there should be further work on this subject. Experiments include listening for more solar bursts near in the future and also identifying how this emission from the Sun can affect the communication on Earth. By doing all of this we could come and find a way in which our communication can be stronger and not be disturbed, nor interrupted by any solar or Jovian radio emission.

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