ELECTROMAGNETIC TERRESTRIAL ENVIRONMENT AND THE CONTRIBUTION OF THE MAIN EMISSION SOURCES

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Abstract

EM waves radiated by impulsive lightning discharges cannot escape the ionosphere border. Since LF to HF frequencies are used in radio communication and broadcasting, in this frequency range natural radio noise has been the object of scientific investigations in the radio engineers' community. An interrelationship among the lightning flashes, the lightning-driven electromagnetic fields and occasional association of sprites, ELVES and other transient luminous events is reported in this paper. Natural contribution in the terrestrial environment and the different modes of propagation are considered emphasizing terrestrial natural and man-made radio noise sources within the magnetosphere-ionosphere system. We have considered electric field strength vs. frequency for atmospheric and cosmic noise as well as sprites arising from the quasi-electrostatic (QE) field for removal of a significant amount of charge in a large lightning stroke. The variation of electron density against altitude is considered corresponding to different temperature for the four transient luminous events. The positive CG strokes are assumed to be the electromagnetic source for the sprites and electromagnetic source for the Q-burst. A connection among sprites, positive cloud-to-ground strokes and Q-burst is critically focused. Worldwide lightning flash density observations are also analyzed showing some interesting findings. Further, lightning in outer planets of the solar system are taken into account with a special emphasis on Venusian's lightning on the basis of certain model as well as the variation of electron density with altitude in the Martian atmosphere. The power flux density values due to Jovian burst, Cassiopeia and Crab Nebula are outlined along with the synchrotron radiation pattern.

Keywords: *Impulsive lightning discharges, Radio communication, Radio noise, Electromagnetic fields, Sprites, ELVES, Transient luminous events, Venusian's lightning, Martian atmosphere.*

1 Introduction

VLF remote sensing experiments clearly suggested the direct disturbance of the lower ionosphere by lightning [1, 2]. Lightning discharges affect the lower ionosphere through energetic (>50 keV) bursts particles by whistler waves [3-5]. Different coupling mechanisms include large quasi-electrostatic (QE) thundercloud fields [6-9], runaway electron processes [10-14] as well as the heating of the ambient electrons caused by lightning electromagnetic pulses (EMP) [15-17]. Sprites are considered as an electric discharge or breakdown at mesospheric altitudes occurring above large positive cloud- to-ground lightning. In this paper an attempt has been made to find an interrelationship among the lightning flashes, the lightning-driven electromagnetic fields and an association of sprites, ELVES and other transient luminous events with some of their dominant features. The results have been extended to other planetary systems with a view to investigate the radiation characteristics therein [18-23].

2 Propagation modes

Propagation mode names and acronyms for natural contributions in the terrestrial environment are shown in Figure 1. We have shown in the figure a schematic representation of terrestrial natural and man-made radio noise sources within the magnetosphere-ionosphere system [24-26].

When a Radio wave propagates by ionospheric reflections their main culprit that largely disturbs in the Earth - atmospheric system is the atmospheric noise generated in lightning discharges. The lightning frequency domain of electromagnetic spectrum is shown in Figure 2. Several million lightning strokes occur daily from an estimated 2000 storms worldwide and the Earth is hit about 100 times a second by lightning. The discharge is very violent and can reach even up to 10000 ampere. The annual total released energy is of the order of 10^{19} J [24, 27-31].

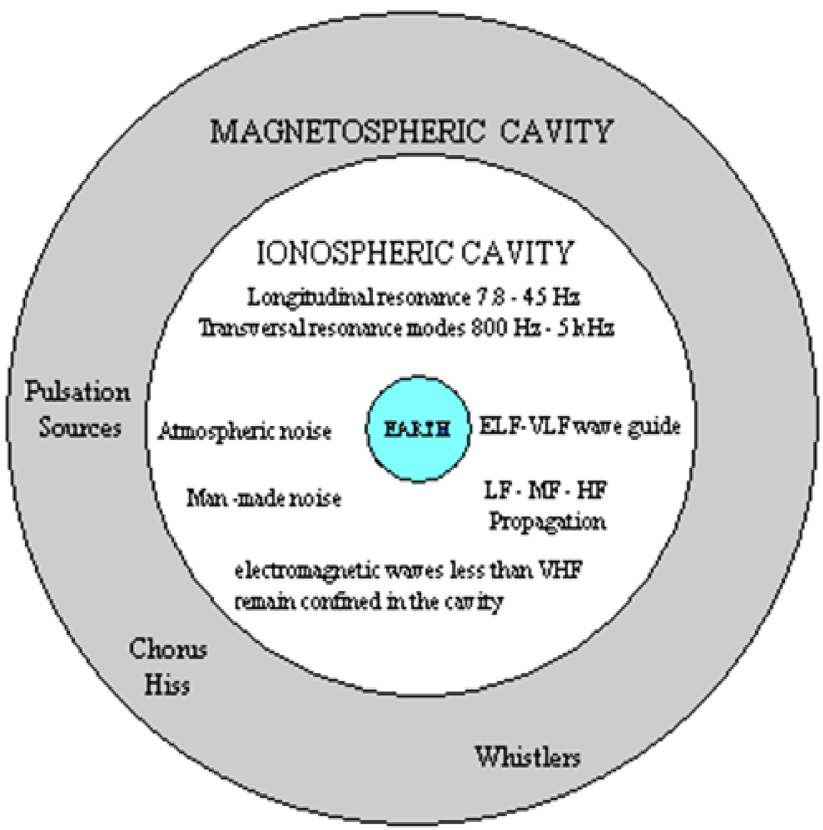


Figure 1 Natural contribution in the terrestrial environment and the different modes of propagation [24]

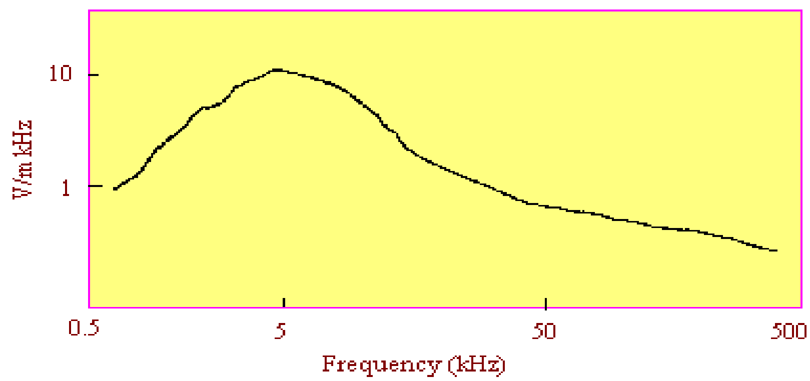


Figure 2 EM Spectrum in the lightning frequency domain [29]

In Table 1 a schematic representation of terrestrial natural and man-made radio noise sources within the magnetosphere-ionosphere system is presented. It appears from the table that in the very low frequency range the atmospheric discharge radiated energy originating from lightning is predominant. In the low frequency and medium frequency bands atmospheric noise originating from different sources has dominant role while in the high and very high frequency bands besides the atmospheric noise the cosmic noise is the main contributor [32-34]. The primary modes of propagation in different frequencies and the corresponding environments have also shown in the table.

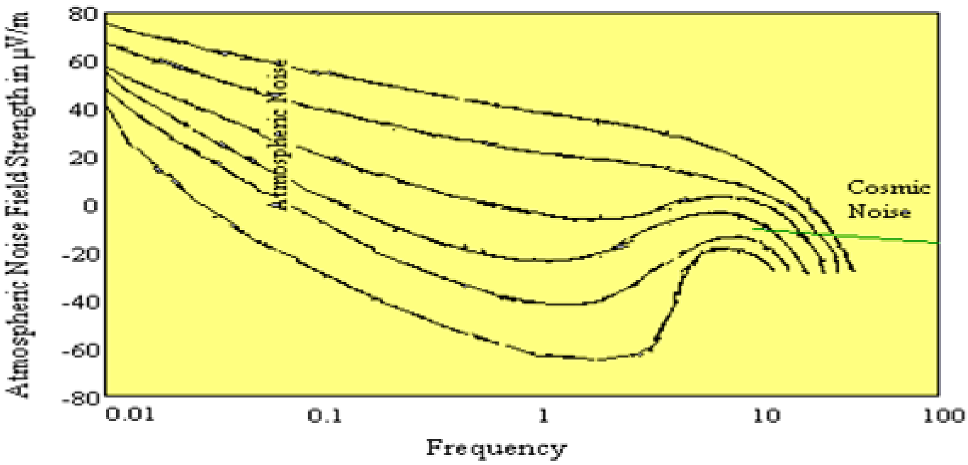
2.1 Natural LF to HF Noise

Natural electromagnetic noise amplitude is generally decreased in intensity with frequency and is affected by ionospheric condition. Since LF/MF/HF frequencies are used in radio communication and broadcasting, in this frequency range natural radio noise has been the object of scientific studies in the radio engineers' community. The electromagnetic waves radiated by impulsive lightning discharges cannot escape the ionosphere border. Radio waves are reflected by the upper layer of the atmosphere up to a critical frequency depending on local ionospheric condition [35-38].

Name	Frequency Range	Wavelength in meter	Main Natural Radio Noise Sources	Primary Mode of Propagation	Environment
Very Low Frequency (VLF)	3-30 kHz	105-104	Propagation in the ionospheric cavity of the atmospheric discharge radiate energy	Between ground and lower ionosphere. It is a ground wave and uses waveguide also.	Ionospheric cavity
Low Frequency (LF)	30-300 kHz	104-103	Atmospheric noise	Waveguide and ground wave.	Ionospheric cavity
Medium Frequency (MF)	300-3000 kHz	103-102	Atmospheric noise	E region of the ionosphere reflection (might) ground wave.	Ionospheric cavity
High Frequency (HF)	3-30 MHz	102-10	Atmospheric and cosmic noise	Reflection from E and F region of the ionosphere.	Ionospheric cavity
Very High Frequency (VHF)	30-300 MHz	10- 1	Atmospheric and cosmic noise	Line of sight, scatter from ionosphere. Reflection by active satellites.	Earth surface (mainly due to the cosmic noise that penetrates the ionospheric layers)

Table 1 Non Ionizing Radiation (NIR) electromagnetic waves from VLF to VHF bands

Electric field strength *vs.* frequency for atmospheric and cosmic noise may be taken into consideration with special emphasis. The angle of incidence between the wave and the ionospheric layers plays an important role depending on the path geometry of several propagating modes [39, 40]. Electric field strength vs. frequency for Atmospheric and Cosmic Noise (the ordinate is in dB/1 kHz) is shown in Figure 3. In the same figure we have shown cosmic noise at frequencies greater than the ionosphere plasma frequency. The cosmic noise lowest frequency depends on the ionospheric condition i.e. on electron plasma frequency about 15 to 30 MHz.



.**Figure 3** A plot of electric field strength vs. frequency for atmospheric and cosmic Noise (the ordinate is in dB/1 kHz) [24]

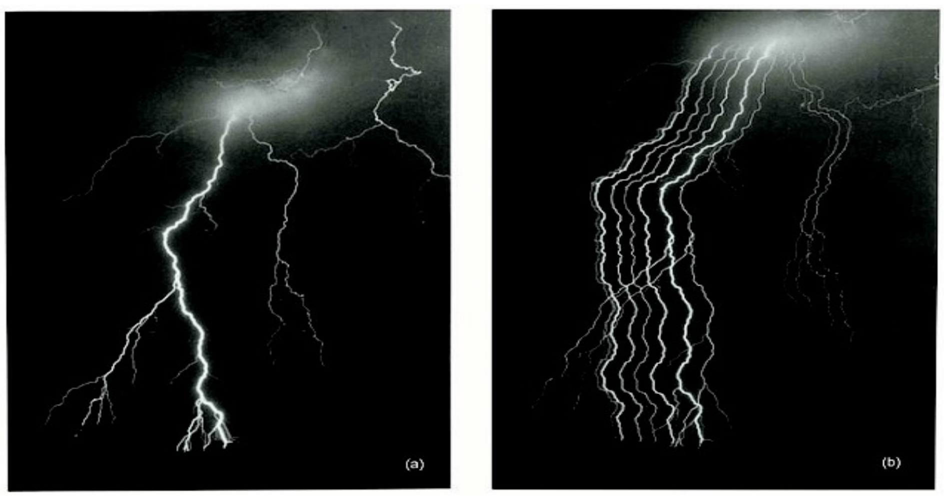


Figure 4 Dendritic structure of lightning flash [5, 41-43]

3 Lightning Plasmas

All images in these photos shown in Figure 4 are of the same lightning flash. The left photo (a) was taken with a stationary camera; photo (b) was taken with a camera that was moving horizontally during the flash (time advances from right to left). This is a downward flash as indicated by the downward direction of the branches. Photo (b) appears to show at least seven separate individual strokes following the same path from cloud to ground, with the first stroke being on the far right [41-43].

It is common for lightning to form ground surface arcs (plasma channels) that develop horizontally outward from its ground termination point. The photograph (Figure 5) shows surface arcing during a rocket-triggered flash. The lightning channel is outside the field of view. One of the surface arcs approaches the right edge of the photograph, a distance of 10 meters from the rocket launcher.

Figure 5 Surface arcing during a rocket-triggered flash; lightning channel outside the field of view [adapted from Fisher et. al. 1994 (http://www.rakov.ece.ufl.edu/teaching/5490/Effects&LPS_Section%209.pdf)]

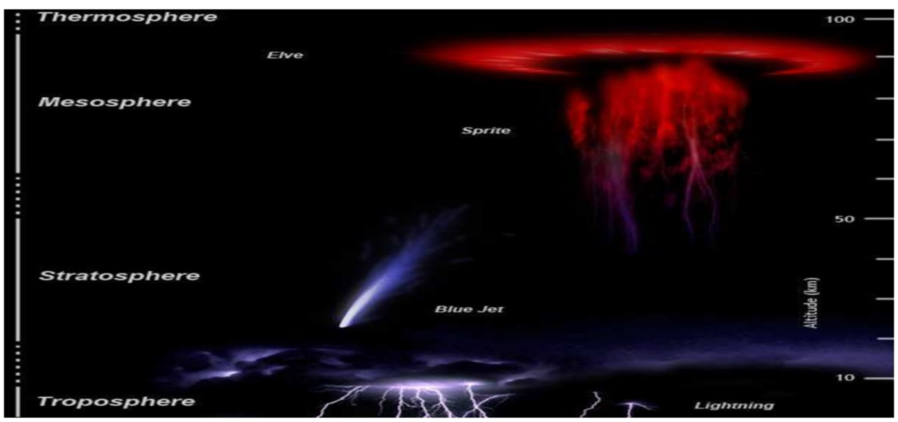


Figure 6 Transient luminous events [21, 25]

Transient luminous events are illustrated in Figure 6. Sprites are short-lived (a few ms), large luminous discharges that appear in the altitude range ~40 to 90 km above large thunderstorms. Sprites arise from the quasi-electrostatic (QE) field resulting from removal of a significant amount of charge in a large lightning stroke.

In addition to sprite and blue jet as shown in Figure 7, there is another transient luminous event called ELVES which is the abbreviation of Emission of Light at very low frequency perturbations from Electromagnetic pulse Sources. It was invented by Walter Lyons in 1993 at the location of Rocky Mountain. It was tested by low-light-level video camera by recording images of stars and a distant lightning storm. He set up the camera, recorder and video monitor without light. A few moments after he replaced a defective cable connector when the monitor displayed a twin flash of light [21, 27]. It w also viewed from above the thunderstorm by aircraft.

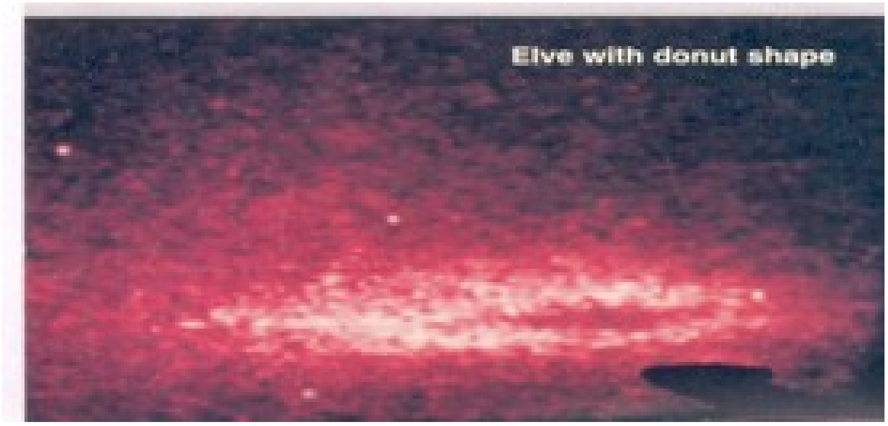


Figure 7 Emission of Light at very low frequency perturbations from Electromagnetic pulse Sources (ELVES) [7, 11]

Dominant Features	Red Spice	Blue Jets	Blue Starters	Elves
Altitude extent	40-90 km	20-40 km	18-21 km	70-105 km
Horizontal extent	20-50 km dia	3 km dia base 10 km top	<1 km	100-400 km dia
Shape	Three bright patches separated by dark bands	Upward flaring 15 degree full width	Vertical, spark-like	Defuse blobs
Time of Onset	3-30 ms after Lightning Onset	Quiet periods	Quiet periods	<500 ms after Lightning Onset
Duration	3 ms	200-300 ms	NA	<1 ms
Relationship to Lightning	Follow positive CG lightning	During periods of intense negative CG lightning	During periods of intense negative CG lightning	Follow positive CG lightning

Table 2 Characteristics of transient luminous events

A comparative study of the characteristics of transient luminous events, viz. red sprites, blue jets, blue starters and ELVES is made in Table 2.

If the variation of electron density (per m^3) against altitude (km) is considered corresponding to different temperature (K) for different luminous events, the characteristic changes will be as shown in Figure 8.

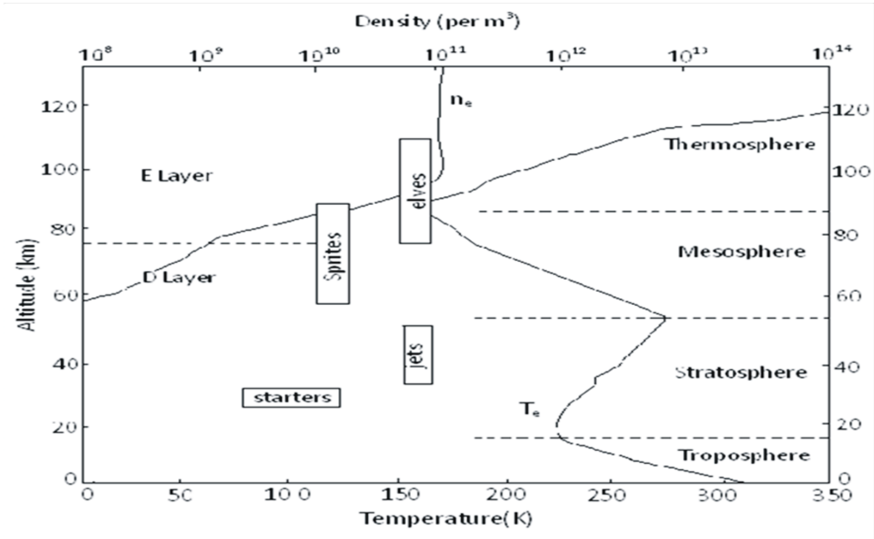


Figure 8 Variation of electron density for four luminous events [9, 10]

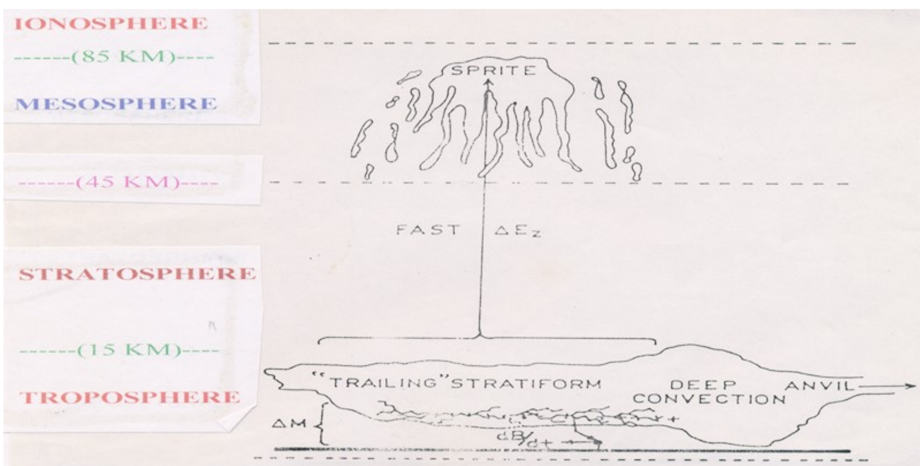


Figure 9 A schematic diagram, showing the connection among sprites positive cloud-to-ground (CG) strokes and Q-burst [11]

Figure 9 gives a schematic diagram, showing the connection among sprites positive cloud-to-ground (CG) strokes and Q-burst [7, 11]. The positive CG strokes are assumed to be the electromagnetic source for the sprites and electromagnetic source for the Q- burst. The EM radiation upon ground is represented by dB/dt while the change in the total dipole moment by δM at ELF in earth- ionsphere cavity.

The tropospheric-ionospheric coupling due to discharges of lightning and the subsequent propagation of the electromagnetic wave is illustrated in Figure 10.

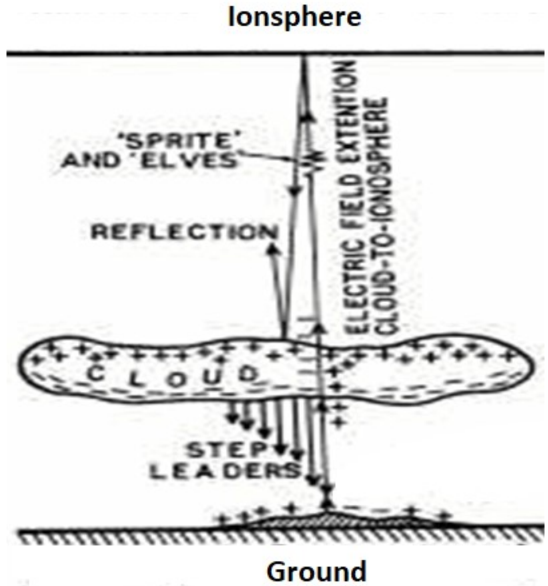


Figure 10 Schematic diagram of cloud-to-ground lightning discharge

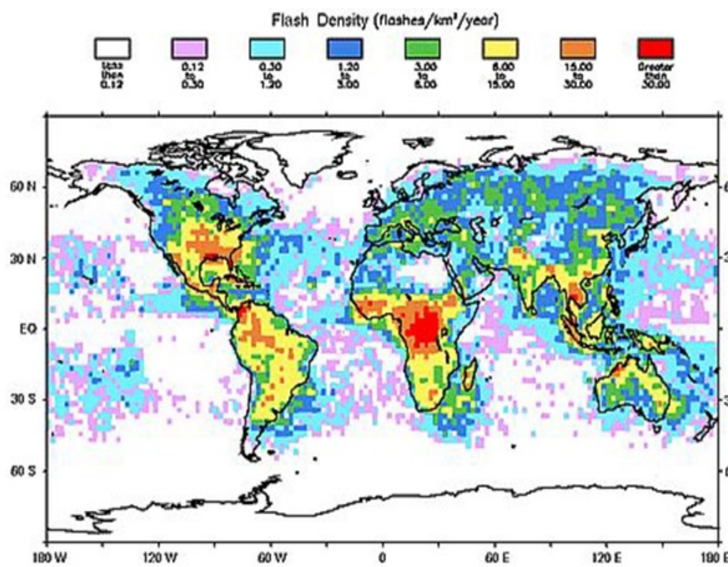


Figure 11 Worldwide lightning flash density observations [44]

Global Lightning when taken into account the Worldwide flash density observations for a one-year period, measured by the Optical Transient Detector orbiting at 750 km altitude and 70◦ inclination is represented in Figure 11.

The total charge lowered from a thundercloud at a given altitude to the ground in a lightning discharge is believed to be the most important parameter in determining its potential for producing a Sprite. The charge lowered to ground can be computed by integrating the current waveform over time. Figure 12 is a spectrogram from 100 Hz to 16 kHz of broadband data recorded at Palmer Station, Antarctica, during typical summer nighttime conditions. The vertical lines are sferics, which are broad in frequency and short in duration. They exceed the minimum amplitude in the spectrogram above ~5-7 kHz, and the ELF component of some sferics is clearly visible below ~500 Hz.

4 Lightning in outer planets of the solar system

Jupiter, Saturn, Uranus and Neptune all have lightning and active weather systems [46-48]. Flow chart in Figure 13 indicates that the processes linking the global atmospheric electrical circuit with global climate. Thick lines indicate established links and thin lines indicate suggested links.

The characteristic pattern of Venusian's Lightning [46] on the basis of certain model is revealed in Figure 14. Ion-aerosol model for Venus' atmosphere is shown in the figure. The solid curve gives predicted ionization rate when the effects of muons are included while the dashed line shows the result when the muon flux is ignored.

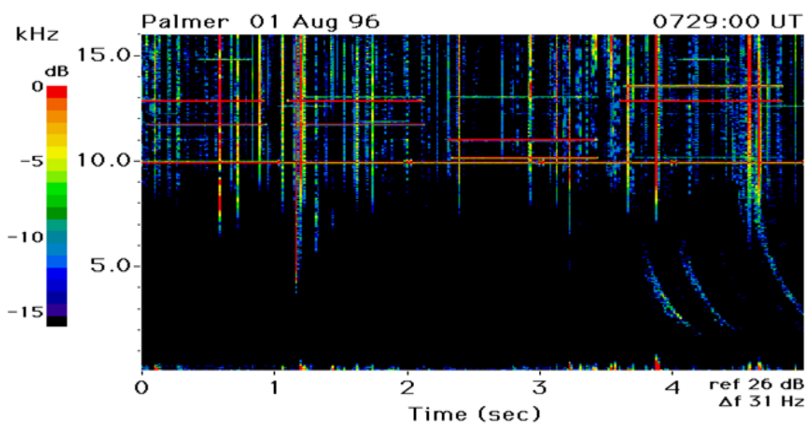


Figure 12 Spectrogram of broadband data recorded at Palmer Station, Antarctica, during nighttime summer [45]

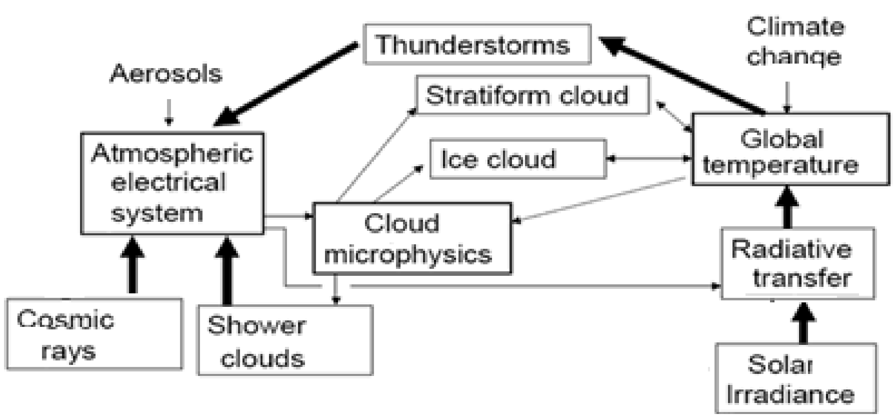


Figure 13 The processes linking the global atmospheric electrical circuit

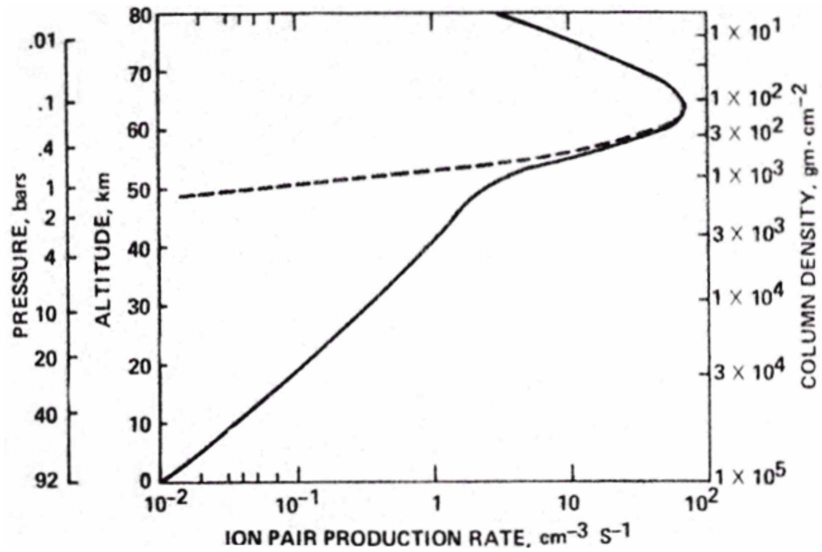


Figure 14 Venusian's lightning property on the basis of certain model [46]

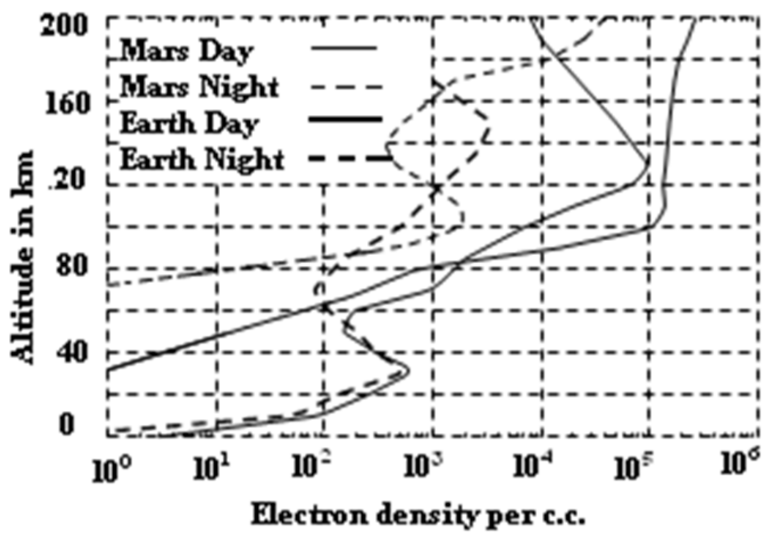


Figure 15 The variation of electron density with altitude in the Martian atmosphere [46]

In Figure 15 we have shown the variation of electron density with altitude in the Martian atmosphere.

The winds in the Martian dust devils are very complicated, with circular vortices, peaking in some cases at speeds 5 times greater than ambient levels in the center of the vortex. This central region is substantially hotter than the ambient surrounding surface temperature [47-49]. The winds in the Martian dust devils are very complicated, with circular vortices, peaking in some cases at speeds 5 times greater than ambient levels in the center of the vortex. Some sources of radio emissions and cosmic background are presented in Figure 16.

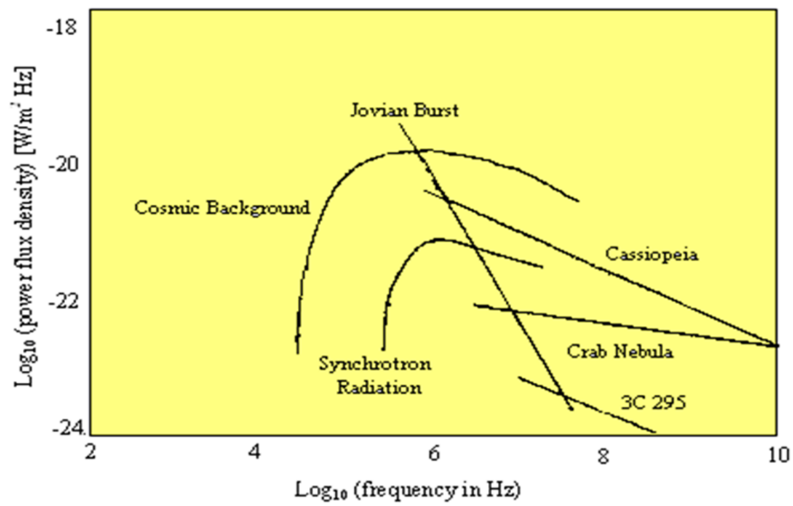


Figure 16 Sources of radio emissions and cosmic background [1, 2]

In the figure we have plotted the power flux density corresponding to different frequencies in Hz. The power flux density values due to Jovian burst, Cassiopeia and Crab Nebula are exhibited along with the synchrotron radiation pattern [47-49].

5 Conclusions

The Sun is the most powerful electromagnetic emitters in our solar system, able to generate very broad band radio emissions. Our Earth is not the only planet that exhibits a large variety of radio signals. Almost all the planets have electromagnetic background, e.g., Venus is quite similar to Earth and the four gas giants Jupiter, Saturn, Uranus and Neptune are natural emitters of HF Radio signals [50, 51]. Due to huge atmospheric discharges Jupiter is one of the major radio emitters. The microphysical mechanism of sprites and other luminous events causing electromagnetic radiation are considered with highest priority but we need further information for the development of suitable model. It may involve quiescent heating of the *D* region by thundercloud fields with individual discharges, broad ionization regions produced by lightning-radiated electromagnetic pulses or ionization columns associated with the sprites.

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