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The Role of Satellite Io in Jupiter's Decametric Radio Emission

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ABSTRACT
The Jovian decametric emissions, first discovered by Burke and Franklin in the decametric wavelength range (DAM) at the frequency 22.2 MHz, originate in cyclotron instability of weakly relativistic electrons trapped in the Jovian magnetic field. Io is the most volcanically active moon of our largest planet Jupiter and Io-Jupiter constitutes a moon-planet system which is unique in our solar system. The asymmetry of the Io phase with respect to sources east and west of the Earth-Jupiter line (CML) does not imply an asymmetric beaming of DAM; it is caused by the delay the waves experience in traversing the magnetosphere. The rotation of the Jovian magnetosphere also plays an important role, as the propagation velocity of the waves is the sum of their group velocity and the velocity of the medium itself. In this paper an overview on these aspects of the Io-Jupiter system is presented. The paper critically focuses the role of Jovian magnetosphere and its satellite Io in relation to their radiation behaviour.
Keywords-Jupiter, Jovian magnetosphere, Satellite IO, Decametric emission

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I. INTRODUCTION

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. 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. Io-Jupiter constitutes a moon-planet system which is unique in our solar system. Io is the most volcanically active moon, while Jupiter is the largest and massive among the planets in size, mass, volume of the magnetosphere and magnetic field strength. Io influences Jupiter by supplying large number of ions to its magnetosphere, which dominates its energetic behaviour and dynamical properties. Jupiter heats Io's interior tidally, which again pushes the volcanic activity on Io. The role of satellite Io in Jupiter's decametric radio emission and the nature of their interaction were first elaborated by the Voyagers in 1979 [1, 2]. Subsequent exploration of this system by ground-based observatories and by the Galileo orbiter mission had improved the understanding of this complex electrical interaction between Io and Jupiter. Io is flexed by the gravitational pulls of Jupiter continually which causes Io to be molten and volcanos on its surface are almost continually erupting. The purpose of the paper is to focus the (i) Magnetic Field and Associated Magnetosphere of Jupiter, (ii) Satellite IO and its Interaction with Jupiter's magnetosphere.

II. Magnetic Field And Associated Magnetosphere Of Jupiter

The radio emissions seemed to follow a unique rotation period and it stayed very constant, neither slowing down nor speeding up. Most of the radio waves from Jupiter are polarized in nature. The

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magnetosphere of Jupiter is the cavity created in the solar wind by the planet's magnetic field. It extends up to seven million kilometers in the Sun's direction and almost to the orbit of Saturn in the opposite direction, Jupiter's magnetosphere is the largest and most powerful of any planetary magnetosphere in the Solar System. Jupiter is stronger by an order of magnitude, while its magnetic moment is roughly 18,000 times larger. The existence of Jupiter's magnetic field was first identified from observations of radio emissions at the end of the 1950s and was directly observed by the Pioneer 10 spacecraft in 1973. Jupiter's internal magnetic field is generated by electrical currents flowing in the planet's outer core, which is composed of metallic hydrogen [3].

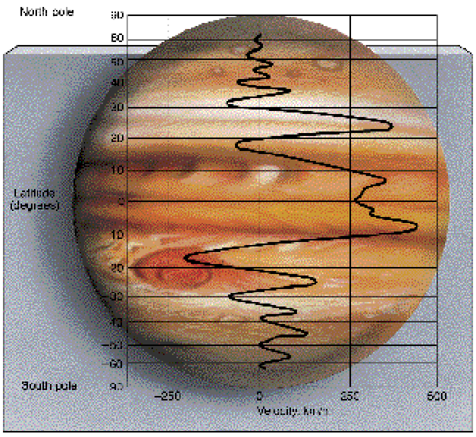

Fig. 1 Velocities of the zonal wind bands are superposed on Jupiter [3]

The velocities of the zonal wind bands, which circle the planet in alternating directions, are plotted in Figure 1. These bands spawn secondary and tertiary bands further to the north and south. By this mechanism, heat is propagated throughout the atmosphere, producing the apparent temperature excess, while the solid planet remains frozen. The Figure 1 shows the strongest westerly wind corresponds to the northern extreme of the GRS, which is rotating counter-clockwise.

III. SATELLITE IO AND ITS INTERACTION WITH JUPITER'S MAGNETOSPHERE

Jupiter has many moons out of which Io has a very important role as it is the most active satellite of the solar system. It turns out that Io has a very vital effect on radio emission.

The orbital position of Io is defined by something known as the Io phase. The Io phase is 0 degrees when Io is directly behind Jupiter as seen from Earth. The Io phase increases as Io orbits until it becomes 180 degrees when Io crosses in front of Jupiter as seen from Earth. The Io orbital position with respect to the Jupiter, Io phase and Jupiter's Central Meridian Longitude (CML) position and direction to the Earth is shown in figure 3.

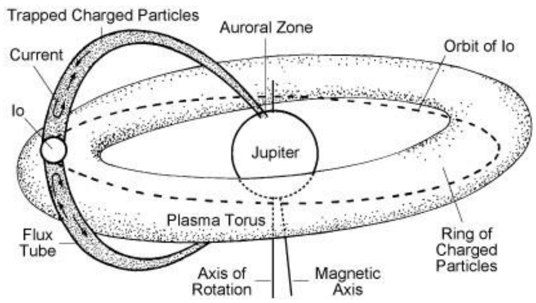

Fig. 2. A schematic diagram showing the Jupiter, Io and its orbit, Io plasma torus (not drawn to scale) [4].

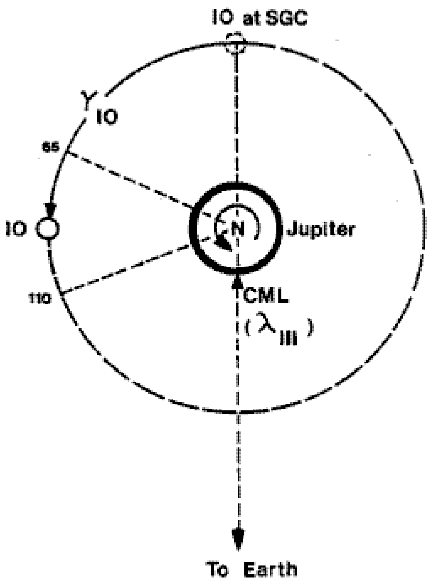

Fig. 3: Io phase w.r.t. the Jupiter CML and Earth direction

The "landmarks" or sources referred to at the beginning have both Io-related and non-Io-related components. The non-Io-related sources have a chance of being observed regardless of where Io is in its orbit. The Io-related sources all have higher probabilities of being heard than their corresponding non-Io-related sources. These sources have been labelled A, B and C roughly in order of the likelihood of observing them; the Io-related sources are Io-A, Io-B and Io-C. These sources are shown on Central Meridian Longitude (CML) versus Io-phase plots. The orientation of the Jupiter and Io's orbital position can play a large role in detecting decametric radio emissions (Figure 4 and 5) [4].

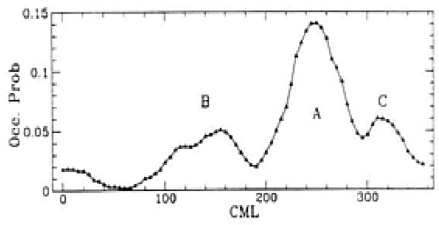

Fig. 4 The probability of detecting radio "landmarks" or sources A, B, and C are plotted against Jupiter's Central Meridian Longitude (CML). The A source has the highest probability of being detected. [4]

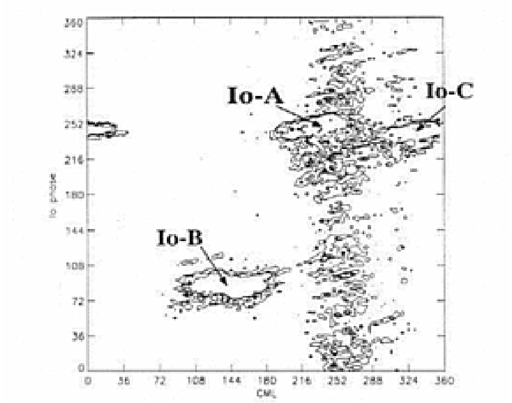

Fig. 5: Probability plotted against Io phase and CML shows Io-related and non-Io-related sources. The vertical stripes show non-Io-A and non-Io-C. [4]

IV. DISCUSSION

Jupiter's broad magnetic field is 14 times as strong as the Earth's, ranging from 4.2 gauss (0.42 mT) at the equator to 10–14 gauss (1.0–1.4 mT) at the poles, making it the strongest in the Solar System (except for sunspots) [5]. This field is believed to be generated by eddy currents — swirling movements of conducting materials—within the metallic hydrogen core. The field traps a sheet of ionized particles from the solar wind, generating a highly energetic magnetic field outside the planet — the magnetosphere. Electrons from this plasma sheet ionize the torus-shaped cloud of Sulphur-di-oxide (SO2) generated by the tectonic activity on the moon Io. Hydrogen particles from Jupiter's atmosphere are also trapped in the magnetosphere. Electrons within the magnetosphere generate a strong radio signature that produces bursts in the range of 0.6–30 MHz [5]. At about 75 Jupiter radii from the planet, the interaction of the magnetosphere with the solar wind generates a bow shock. Surrounding Jupiter's magnetosphere is a magnetopause, located at the inner edge of a magneto-sheath, where the planet's magnetic field becomes weak and disorganized. The solar wind interacts with these regions, elongating the magnetosphere on Jupiter's lee side and extending it outward until it nearly reaches the orbit of Saturn. The four largest moons of Jupiter all orbit within the magnetosphere, which protects them from the solar wind [6]. The magnetosphere of Jupiter is responsible for intense episodes of radio emission from the planet's Polar Regions. Volcanic activity on the Jovian moon Io injects gas into Jupiter's magnetosphere, producing a torus of particles about the planet. As Io moves through this torus, the interaction generates Alfvén waves that carry ionized matter into the polar regions of Jupiter. As a result, radio waves are generated through a cyclotron maser mechanism, and the energy is transmitted out along a cone-shaped surface. When the Earth intersects this cone, the radio emissions from Jupiter can exceed the solar radio output. Noise is due primarily to emissions from relativistic electrons spiralling in the galactic magnetic field. However, signals from earth-based sources such as arcing power lines, computers, electric motors and aquarium heaters may be added to the galactic background noise. These noise sources are generally broadband in nature and you cannot tune the radio to avoid them. If the total noise background (galactic plus terrestrial sources) is too high, then signals from Jupiter and the Sun will be masked by the local noise.

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