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論　文　内　容　要　旨

(NO.　1)

氏　　名	木村　智樹	提出年	平成　２１年
学位論文の題　　名	Generation and Propagation of Jovian Quasi-Periodic Low Frequency Radio Bursts （木星準周期的低周波電波バースト現象の励起と伝搬）		

Jovian quasi-periodic (QP) bursts were discovered by Voyager (Kurth et al., 1989) and named "Jovian Type III bursts" due to their dispersive spectral nature. Their occurrence characteristics were investigated in detail based on Ulysses' observations. During Ulysses' first Jovian flyby in 1992, two kinds of QP bursts were identified (MacDowall et al., 1993): one with a periodicity of around 15 min during the inbound phase and the other with a periodicity of ~40 min during the outbound phase. They were named "QP15" and "QP40" bursts, respectively. The Ulysses/COSPIN observations during the outbound pass indicated that energetic (> 9 MeV) electron outbursts with a 40-min period were correlated with the QP40 radio bursts (McKibben et al., 1993). The Chandra X-ray Observatory observed an X-ray "hot spot" pulsating with an approximately 45-min period (Gladstone et al., 2002), and it has been suggested that the emissions are excited by precipitations of relativistic heavy magnetospheric ions (e.g., Cravens et al., 2003; Elsner et al., 2005). These observations imply the relativistic particle acceleration processes in the Jovian polar region, accompanied by quasi-periodic radio and auroral emissions. This thesis addressed the propagation and generation process of quasi-periodic radio bursts. We discussed the magnetospheric dynamics responsible for the particle acceleration process based on the radio emission studies. The following conclusions were obtained in the present study.

Occurrence Characteristics

Occurrence characteristics of QP bursts were investigated based on the wave data observed by Ulysses at the northern high latitudes and Galileo at the low latitudes. Statistics based on the Ulysses' wave data indicated that QP bursts observed at high latitudes are excited in a particular rotational phase (SSL=90°–300°) in the high latitudinal region (+30°–+90°). QP bursts observed at the low latitudes were also found to be excited in a particular rotational phase (SSL=300°–480°). Thus, it was concluded that QP bursts observed at low and high latitudes have "clock modulations" which are internally driven in a particular rotational phase with a similar manner to the phenomena found in Saturn's magnetosphere. It was also revealed that the meridional distribution of QP bursts forms a shadow zone in the equatorial region (|MLAT|<10°) of less than 30 Jovian radii from Jupiter where QP bursts are quenched. Statistics based on the Lomb-Scargle analysis indicated that the period of "~40 min" is the most dominant in amplitudes at all latitudes.

Polarization Properties

Polarization properties and source directions of QP bursts were investigated based on the wave data observed by Ulysses at the northern high latitudes and Cassini at the low latitudes. It was indicated that QP bursts observed at the northern high latitudes are left-handed (LH) circular polarized waves (the Stokes parameters, V =+0.7–+0.8, Q =0– +0.4, and U=0–+0.2). In addition, statistics of the Stokes parameters confirmed that QP bursts observed at the low latitudes are also LH circular polarized (V =0–0.6, Q,U~0). The direction findings at the low latitudes were performed based on the data observed by Cassini during the closest approach to Jupiter. It was found that some QP bursts have arrival directions at a distance of ~50 Rj from Jupiter with ~20 Rj ambiguity.

Interpretation of the Observation Results Based on the Ray Tracing

We discussed the source location, directivity, and propagation process of QP bursts based on the ray tracing analysis, comparing with the observation results. The parametric survey suggested that QP bursts observed at high latitudes have the source region located at $f \sim f_p$ (plasma frequency) surface (1.3–1.4 Rj) along high-latitudinal field lines. It was suggested that these QP bursts are left-handed ordinary (L-O) mode waves with significantly broadened beaming patterns like a "filled cone". On the other hand, the ray tracing suggested that QP bursts observed in the equatorial region are right-handed extraordinary (R-X) mode wave emitted from $f \sim f_{RX}$ (cutoff frequency of R-X mode) surface (~10–20Rj) along high-latitudinal field lines (L >~20). They are emitted from restricted L-value range with "filled cone" like beaming patterns. These results imply that QP bursts have two kinds of sources: one has higher altitudes (f_{RX} surface) emitting R-X mode waves and the other has lower altitudes (f_p surface) emitting L-O mode waves. Based on the ray tracing with the magnetosheath plasma model, we interpreted the direction finding results by Cassini as meaning that QP bursts from the polar region were scattered and reached to the apparent altitudes (~50 Rj) by the local density fluctuations in the magnetosheath and interplanetary space, and/or they have the real source region in the magnetosheath.

Microscopic Generation of Quasi-Periodic Bursts

Two possible scenarios were proposed for the microscopic generation mechanism of QP bursts: the "direct generation scenario" and "indirect generation scenario" They were examined based on the theoretical approaches. The growth rate calculations were performed to examine the direct generation scenario at low (~2 Rj) and high (~10 Rj) source altitudes. The results suggested that free-space O mode (i.e., L-O mode) waves are directly excited by relativistic electron beams via the Cyclotron Maser Instability (CMI). On the other hand, it was indicated that free-space X mode waves (i.e., R-X mode) waves are not excited effectively. This means that the observed shadow zone is not formed by the R-X mode waves. Ray tracing and theoretical study suggested that the O mode waves could propagate in the magnetosphere forming the observed shadow zone. The indirect generation scenario was examined referring to the previous theoretical study. It was concluded that the following mode conversion scenario is also possible at low and high source altitudes: (1) Z mode waves propagating toward Jupiter are excited at low and high altitudes via the cyclotron resonance, and (2) they are converted to free-space O mode waves at the density boundary where $f \sim f_p$. The growth rate calculation under conditions of the magnetosheath revealed that both of the direct and indirect processes are unreasonable in the magnetosheath. Thus, we interpreted the direction finding results by Cassini as the scattering process in the magnetosheath and interplanetary space.

Macroscopic Generation of QP Phenomena

Two possible scenarios were proposed for the relativistic particle acceleration process of the quasi-periodic phenomena: the “flux transfer event (FTE) scenario” and “field line resonance (FLR) scenario”. The two scenarios were examined based on in-situ and remote observations of plasma, magnetic field, and wave data performed by Galileo and Ulysses. The FTE scenario was examined based on observations of magnetic fields, solar wind, and QP bursts. It was confirmed that FTE signals at Jupiter’s magnetopause were not accompanied with periodic features similar to the QP phenomena. In addition, it was indicated that QP bursts do not respond significantly to any solar wind parameters. Thus, we concluded that the FTE scenario is not feasible for the relativistic particle acceleration process of QP phenomena. The FLR scenario was investigated based on the in-situ magnetic field data in the middle and outer magnetosphere. The results indicated that linear Alfven waves with a period of tens of minutes were propagating quasi-parallel with the background field lines in the middle magnetosphere. In addition, the Alfven waves were suggested to be propagating to the polar region accompanied with the relativistic electron bursts and QP radio bursts. Thus, we concluded that the Alfven waves propagating between the equatorial and polar region could be a generator of QP accelerations in the Jovian polar region.

There still remain some unsolved problems on the Jovian QP phenomena: e.g., the internal initiator of the Alfven waves, “40-min period”, and energy budget. This thesis proposed observational requirements to solve these problems as concluding remarks. The observations should be performed based on multi-spacecraft exploration with a full set of equipments in two kinds of orbital regimes: the “polar regime” and “equatorial regime”. In the polar regime, the exploration is performed by a spacecraft in the cusp or polar magnetopause and another spacecraft at the magnetic footprint in the polar region. In the equatorial regime, the exploration is performed by a spacecraft in the distant tail region and another spacecraft at the magnetic footprint in the polar region. These observations are expected to reveal the relativistic quasi-periodic acceleration process and relevant internal magnetospheric dynamics.

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