Polarization Characteristics of Io-Related Jovian Decametric Radiations

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Polarization measurements of Io-related Jovian decametric radiations (DAM’s) were made in a frequency range from 20.5 to 25.5 MHz at the Zao observatory of Tohoku University, Japan. In the analyses of axial ratios of polarization ellipses, the following two factors were particularly investigated which were expected to deform the original axial ratios of Io-related DAM’s; i.e., i) interferences caused by reflected wave components from ground, and ii) mutual cross-talks between one free-space mode wave to another free-space mode wave in anisotropic magnetized plasma along the ray paths. Totally 20 Io-related radio storms and 2 non-lo-A radio storms were selected for the analyses. Our major results are as follows: i) Most of Io-related DAM events indicate highly right-handed (RH) elliptical polarization and the mean value of the axial ratios for RH events is $-0.31 \pm 0.09$ (standard deviation). ii) Io-A and Io-B related DAM events indicate the significant difference in their axial ratios; i.e., $-0.35 \pm 0.08$ and $-0.26 \pm 0.06$ for RH Io-A and RH Io-B related DAM events, respectively. iii) Io-related DAM events indicate slightly more linear polarization than non-Io-A DAM events.

1. Introduction

Polarization of Io-related DAM’s is one of important characteristics to clarify the unknown generation mechanisms and little known plasma properties in and near the source regions. Since the discovery of Io-related DAM’s (Bigg, 1964), several observations have been tried to reveal the polarization characteristics (Green and Sherrill, 1969; Lecacheux et al., 1991; Barrow, 1992; Dulk et al., 1994). Their major findings are as follows. i) The polarization fraction $m$ is quite large ($m > 0.9$). ii) The polarization is always elliptical. The absolute values of the axial ratio $|\gamma|$ are generally less than 0.6. iii) Io-A related DAM events show more circular polarization than Io-B related DAM events. iv) Almost all events show nearly constant polarization as a function of frequency and time, even in the events that last for a few hours.

The purpose of this paper is to investigate polarization characteristics of Io-related DAM’s as quantitatively as possible with ground-based polarization measurements. For this purpose, we particularly took account of two factors which are expected to deform the original polarization and have never been investigated quantitatively. One factor is related to ground-based observation system; i.e., interferences by reflected wave components from ground. Another factor is originated in the propagating path from the source regions to observers; i.e., mutual cross-talks between one free-space mode wave and another free-space mode wave in anisotropic magnetized plasma. In Section 2 we describe the observation system. In Section 3 we show the influences of both the interferences by reflected wave components and the mutual cross-talks and show the calculation method of axial ratios under those influences; we give the observational results in Section 4. We discuss the origin of RH elliptical polarization briefly in Section 5, and present our summary in Section 6.

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2. Observation System

The observations were made by using the polarimeter with a band width of 2 MHz which was developed through this study in Tohoku University. The front-end of the system consists of orthogonally crossed log-periodic dipole antennas and a hybrid circuit for dividing received DAM’s into right-handed (RH) and left-handed (LH) polarization signals. The antennas are mounted on a tower of 15 meters high and the beam direction of the antenna is controlled for tracking Jupiter every 1 hour step. The half power beam width of one antenna is 65° in a horizontal plane and 130° in a vertical plane. The back-end consists of a 2-stage super-heterodyne receiver and an exclusive video tape recorder to record detected RH and LH signals being switched alternately every 1/60 sec with a band width of 2 MHz. The center frequency of observation frequency band is tunable at a selected frequency in a range from 20 to 40 MHz by changing the 1st local frequency of the receiver. The recorded signals are detected with a spectrum analyzer at a frequency resolution of 30 kHz. The detected signals are digitized with a 8 bits A/D converter and finally analyzed by computer system for calculating the axial ratio $\gamma$. The resolution for determination of $\gamma$ is 30 kHz in the frequency domain, and 100 msec in the time domain. The specifications of the instrumentation which cause calculation errors of $\gamma$ are summarized in Table 1. The expected error of $\gamma$ in the present system is approximately ±0.06 in case of $|\gamma| = 0.3$ for the worst.

| Specifications of the observation system. |
|------------------------------------------|
| Angle error from a right angle between crossed antennas | 2° max |
| Tracking error from the direction of Jupiter | 8° max |
| Gain difference between orthogonally crossed antennas | 1.2 dB max |
| Gain difference between RH and LH channels | 0.3 dB max |
| Mutual cross talk between RH and LH channels | -33 dB max |

3. Method of Analyses

3.1 Estimation of an observed axial ratio

The axial ratio is a conventional parameter which denotes a polarized state of radio waves. When the polarization fraction $m$ of a radio wave is equal to 1 (completely polarized state), the axial ratio is defined as the ratio of a length of minor axis to that of major axis of the polarization ellipse. Our polarization observations were made by measuring only the intensities of RH and LH components, we then calculated the observed axial ratio $\gamma_{obs}$ on the assumption that the $m$ values of the observed DAM’s are always equal to 1. In our analyses, the $\gamma_{obs}$ value was actually calculated to be,

$$\gamma_{obs} = \frac{(L_{DAM} - L_{background}) - (R_{DAM} - R_{background})}{(L_{DAM} - L_{background}) + (R_{DAM} - R_{background})}$$

where $L_i$ and $R_i$ ($i = \text{DAM, background}$) are the amplitude of a LH signal and that of a RH signal, respectively. In case of $m \neq 1$, $|\gamma_{obs}|$ is smaller than the actual $|\gamma|$. Most of Io-related DAM events are known to indicate $m > 0.9$ (Green and Sherrill, 1969; Dulk et al., 1994). In such the case of $m = 0.9$, the possible difference between $\gamma_{obs}$ and the actual $\gamma$ is 0.04 for $|\gamma_{obs}| = 0.3$.

Since our polarimeter recorded RH and LH signals alternately, there was no datum which had been sampled simultaneously at RH and LH channels. For calculation of $\gamma$ values, therefore, we have utilized the data of events which showed no significant change in their polarization characteristics for at least 100 msec.
3.2 Deformation of axial ratios caused by reflected wave components from ground

Since the antennas of the polarimeter have broad beam widths, a reflected wave component from ground can be detectable in addition to a direct-coming wave component. This leads to deformation of $\gamma_{\text{obs}}$ values. The reflection coefficients for vertical and horizontal components of radio waves differ in both the phase and the amplitude. The degree of the deformation then depends on how a direct-coming wave consists of horizontal and vertical components, that is, depends on the value of the $\gamma$ and the direction of the axes of the polarization ellipse. Since Io-related DAM's are generally subjected to the Faraday rotation in their propagating media because of their elliptically polarized nature, the degree of the deformation changes quasi-periodically corresponding to the Faraday rotation angle which changes with the frequency. In our polarization measurements with the wide-band polarimeter, this leads to quasi-periodical variation of $\gamma_{\text{obs}}$ values. An example of the deformation for several $\gamma$ values is indicated in Fig. 1(a), which is simulated after the actual observation conditions. The degree of the deformation depends also
on the elevation angle of Jupiter, because the incident angle of the reflected wave components to the antennas varies with the elevation angle. In Fig. 1(b), we show an example of the degree of the deformation as a function of the elevation angle for the case of the actual $\gamma = -0.4$. The variation of $\gamma_{\text{obs}}$ for one elevation angle is caused by the variation of the axis directions of the polarization ellipse.

Although the deformation leads to serious influence on the calculation of actual $\gamma$ values, we can recover the actual $\gamma$ value from $\gamma_{\text{obs}}$ by the synthesis method of direct-coming wave components with reflected wave components. We show examples of the recovered $\gamma$ values from $\gamma_{\text{obs}}$ for an Io-A related DAM event in Fig. 2 and an Io-B related DAM event in Fig. 3. In these cases, the derived $\gamma$ values are $-0.35$ and $-0.26$ for the Io-A related DAM event and the Io-B related DAM event, respectively.

3.3 Mutual cross-talks of DAM in anisotropic magnetized plasma

If there are large mutual cross-talks between one free-space mode wave and another free-space mode wave along the propagation paths of DAM, the observed $\gamma$ is different from the original one at Jupiter. In order to calculate the influence of the mutual cross-talks, we made the full
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Fig. 3. The same as in Fig. 2, but for the Io-B event on December 28, 1989.

Table 2. Parameters of the full wave analysis.

| Plasma space          | Plasma parameter (maximum value on ray paths) | Magnetic field strength | Electron density |
|-----------------------|-----------------------------------------------|-------------------------|------------------|
| Jovian plasma space   | 8 G                                           | 2 x 10^5 cm^{-3}        |
| Interplanetary plasma space | 5γ                                  | 5 cm^{-3}                |
| Terrestrial plasma space | 0.4 G                                         | 5 x 10^5 cm^{-3}        |

Segment length for every estimation step: 1/5 · λ
Estimation accuracy in an energy conversion rate: 10^{-9} (typical)

wave analysis for incidence of R-X and L-O mode waves to multi-layered static magnetized plasma which was modeled to represent plasma conditions along the propagation paths of DAM. We have divided a propagation path into that in three regions; i.e., Jovian plasma space, interplanetary space, and terrestrial plasma space; we calculated energy conversion rates from the energy of incident wave to those of transmit and reflect waves in each corresponding area. Parameters which were applied to the full wave analysis are summarized in Table 2. We show results of the full wave analysis in Fig. 4. In Jovian plasma space, an incident or generated R-X mode wave propagates through the space with little energy loss (Fig. 4(a)). This is the same with the case
Fig. 4. Energy conversion rates calculated by the full wave analysis. The frequency of an incident wave is set at 20 MHz. Open circles, solid circles, open triangles and solid triangles denote calculated energy conversion rates for transmit R-X mode waves, transmit L-O mode waves, reflect R-X mode waves and reflect L-O mode waves, respectively. (a) Result in Jovian plasma space for the incidence of a R-X mode wave. The local magnetic field vector is set to be parallel to the normal of multi-layers. (b) The same as in the panel (a), but for the incidence of a L-O mode wave. (c) Result in terrestrial plasma space for the incidence of a R-X mode wave. The angle between the local magnetic field vector and the normal of multi-layers is set at 45°. (d) The same as in the panel (c), but for the incidence of a L-O mode wave.
of a L-O mode wave (Fig. 4(b)). In terrestrial plasma space, although the energy conversion rate from a R-X mode wave to a L-O mode wave is slightly larger than that in Jovian plasma space, the amount is at most $10^{-5}$ (Fig. 4(c)). This is also nearly the same with the case of a L-O mode wave (Fig. 4(d)). The mutual cross talk in interplanetary space is negligible as compared with that in other plasma space. These full wave analyses show that the influence of the mutual cross talks are at most 0.01 in a $\gamma$ value even in terrestrial plasma space where the largest mutual cross-talk occurs. Observed $\gamma$ values are therefore nearly the same as the original ones at Jupiter.

4. Observation Results

We have made polarization measurements for 20 Io-related DAM storms and 2 non-Io-A DAM storms from November 1987 to February 1990 in a frequency range from 20.5 to 25.5 MHz. The summary plot of analyzed $\gamma$ values of 39 events in 22 DAM storms is indicated in Fig. 5. Each $\gamma$ value is calculated with the same procedure as mentioned in Subsection 3.2 on the assumption of $m = 1$. Among the 36 Io-related DAM events, 34 events were RH elliptical polarization. The mean value of $\gamma$ values for RH waves of all Io-related DAM events is $-0.31 \pm 0.09$ (standard deviation), while, the mean value of $\gamma$ values for RH waves of Io-A related DAM events and those of Io-B related DAM events are $-0.35 \pm 0.08$ and $-0.26 \pm 0.06$, respectively. The difference of $\gamma$ values between RH waves from Io-A and those from Io-B related DAM's is over the standard deviation of observation errors. In addition to this, it is known that there is no particular difference in the polarization fractions between Io-A and Io-B related DAM's. This difference of $\gamma$ values is, therefore, considered to be significant. The similar difference of $\gamma$ values between RH waves from Io-A related DAM source and those from Io-B related DAM source has been reported by Green and Sherrill (1969), Lecacheux et al. (1991) and Dulk et al. (1994).

All of the three non-Io-A DAM events have indicated RH polarizations, and the mean value of $\gamma$ is $-0.43 \pm 0.04$. The $m$ values of non-Io-A DAM events are not as well-known as those of Io-related DAM events, however, in case of $m \neq 1$ observed $|\gamma|$ values are always smaller than the actual $|\gamma|$ values as mentioned in Subsection 3.1. Consequently, the mean value of the actual

![AXIAL RATIO SUMMARY PLOT](image)

Fig. 5. Summary plot of analyzed $\gamma_{obs}$ values. Open circles and solid circles denote the $\gamma_{obs}$ values of RH polarization events and those of LH polarization events, respectively.
γ values for the non-Io-A DAM events does not exceed −0.43. This result suggests that the polarization of the non-Io-A DAM events is slightly more circular than that of Io-related DAM events.

5. Discussion: Origin of the RH Elliptical Polarization

Lecacheux et al. (1991) and Melrose and Dulk (1991) tried to explain the origin of the RH elliptical polarization as the following hypotheses; i.e., i) Io-related DAM’s are originated as R-X mode waves from the northern hemisphere of Jupiter (H-1), ii) each event is originally generated as elliptical polarized waves (H-2), and iii) the plasma density in and near source regions is fairly low, the original polarization is then maintained throughout the propagation paths to observers (H-3). According to these hypotheses, a γ value is equal to \( \cos \theta \), where \( \theta \) is the angle between the direction to the earth and the local magnetic field vector in the source region. Here, we examine their hypotheses based on our observation results. In Figs. 6(a) and 6(b), we show the plot for \( \cos \theta \) vs. \( \gamma_{\text{obs}} \) relation, where \( \theta \) is calculated by using the two magnetic field models; i.e., the GSFC-O4 model (Acuña and Ness, 1976) and the O6 model (Connerney, 1993), and on the assumption that the source locates at the position of \( f = f_g \) in the northern Io flux tube (IFT). Where \( f_g \) is a local gyro-frequency. In calculations of source locations, we have considered the transportation of the effects of the Io interaction with the Jovian magnetic field in the Io plasma torus with the Alfvénic speed forming the Alfvén wing (Drell et al., 1965; Neubauer, 1980). The flux tube of the transportation of the Io effects is here called “source IFT”. We call here the Jovian magnetic field line at the very moment occupied by Io, “apparent IFT”. Between source and apparent IFT’s there is an offset due to group refraction effects of the path of the generated Alfvén waves. The propagation paths of the Alfvén waves have been calculated by Bagenal (1983) precisely. The offset is given as a lead angle (Alfvén lead angle), and can be approximated for the propagation path from Io to the northern ionosphere as,

\[
\Delta \Phi = 2.5^\circ - 1.6^\circ \cos(\Lambda_{\text{Io}} - 202^\circ),
\]

where \( \Lambda_{\text{Io}} \) is system III longitude of Io. In either magnetic field model, the data of Io-A related DAM’s (symbol ‘o’ in Figs. 6(a) and 6(b)) indicate a correlation with \( \gamma = \cos \theta \) (dashed line). On the other hand, the data of Io-B related DAM’s (symbol ‘•’ in the same figures) indicate little correlation with \( \gamma = \cos \theta \), though the data of Io-B related DAM’s for the case using the O4 model show slightly more correlative feature than those for the case using the O6 model. This result shows that it is hard to accept their hypotheses just as they mentioned. As another possibility, we examine a following hypothesis that Io-related DAM’s are originated as L-O mode waves from the southern hemisphere of Jupiter (H-1'). In Figs. 6(c) and 6(d), we show the same plots as Figs. 6(a) and 6(b), but \( \theta \) values are calculated for the case of southern sources. Here the offset lead angle can be approximated for the path from Io to the southern ionosphere as,

\[
\Delta \Phi = 2.5^\circ + 1.6^\circ \cos(\Lambda_{\text{Io}} - 202^\circ).
\]

The result shows that, however, neither Io-A nor Io-B related DAM’s correlate with \( \gamma = \cos \theta \) for either magnetic field model.

These examinations suggest other possibilities as inferred by Melrose and Dulk (1991). One is related to ambiguity of Io-related DAM source locations which is caused by uncertainties in Jupiter’s magnetic field models; the other possible cause is in paths of energy injection from Io to source regions. These cause apparent discrepancies between \( \gamma_{\text{obs}} \) and \( \cos \theta \). Genova and Aubier (1985) and Genova and Calvert (1988) studied source locations of Io-related DAM’s using the observed high frequency limits and showed that there is an apparent longitudinal offset up to 70° between the apparent IFT and the source IFT based on the O4 model. We calculated \( \cos \theta \) values.
Fig. 6. Relation of $\cos \theta$ vs. $\gamma_{\text{obs}}$. Open circles and solid circles denote $\cos \theta$ values for Io-A related DAM events and those for Io-B related DAM events, respectively. (a) The $\theta$ values are calculated for northern sources based on the $O_4$ model. (b) The same as in the panel (a), but based on the $O_6$ model. (c) The same as in the panel (a), but for southern sources. (d) The same as in the panel (c), but based on the $O_6$ model.
Fig. 7. Plot of $\cos \theta$ as a function of the longitudinal lead angle. The symbols are the same as in Fig. 6. (a) The $\theta$ values are mean ones for observed data, and calculated for northern sources based on the $O_4$ model. (b) The same as in the panel (a), but based on the $O_6$ model. (c) The same as in the panel (a), but for southern sources. (d) The same as in the panel (c), but based on the $O_6$ model.
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as a function of the longitudinal offset for northern and southern sources by using H-1, 2, and 3 and H-1', 2, and 3. The results are shown in Fig. 7. For northern sources, \( \cos \theta \) values are equal to mean \( \gamma_{\text{obs}} \) values when lead angles are about 7° and 27° for Io-A and Io-B related DAM's, respectively, in case of the O4 model (Fig. 7(a)), while those are about 6° and 23°, respectively, in case of the O6 model (Fig. 7(b)). For southern sources, \( \cos \theta \) values are equal to mean \( \gamma_{\text{obs}} \) values at large lead angle; i.e., about -36° and 41° for Io-A and Io-B related DAM's, respectively, in case of the O4 model (Fig. 7(c)), while about -32° and 41°, respectively, in case of the O6 model (Fig. 7(d)). The mean Alfvén lead angles for northern and southern sources predicted by using Eqs. (2) or (3) are nearly same values for observed Io-A and Io-B related DAM events; i.e., those are about 1° and 4° for northern and southern sources, respectively. Therefore, the results of Fig. 7 indicate that the polarization characteristic is explained by H-1, 2, and 3, or, H-1', 2, and 3, if there is a longitudinal offset of about up to 20° for northern sources or about up to ±40° for southern sources. While it is necessary to explain the reason why the lead angles are different between Io-A and Io-B related DAM's, H-1, 2, and 3 and the requirement of longitudinal offset for northern sources are more plausible than those for southern sources as the origin of the RH elliptical polarization.

The present observation results suggest also the possibility of the propagation effect that results in the weak wave mode coupling in the Jovian plasma to solve the discrepancy. Hashimoto and Goldstein (1983) studied the occurrence probability of Io-related DAM's by using a ray-tracing method with electron distribution models of moderate density, and showed that Io-related DAM's are radiated quasi-perpendicularly to the local magnetic fields. In such a case Io-related DAM's are originated in a quasi-linear polarization state. If the R-X and L-O mode waves are weakly or not coupled in and near the source region, the ordinary magnetoionic theory is applied and Io-related DAM's should change the polarization state from quasi-linear to elliptical.

Cohen (1960) derived a “transitional” frequency, \( f_t \), as a critical value which divided the degree of mode coupling condition; i.e., when a wave frequency \( f \) is much greater than \( f_t \), the modes are strongly coupled and the wave propagates as if the magnetic field were absent, while, they are weakly coupled in case of \( f \ll f_t \). When Io-related DAM’s propagate quasi-perpendicularly as indicated by Hashimoto and Goldstein (1983), the \( f_t \) [Hz] is given as,

\[
f_t = (10^{17}NSB^3)^{\frac{1}{4}},
\]

where \( N, S, B \) are the number density of electrons [cm\(^{-3}\)], the scale of the field [cm], and the strength of magnetic field [Gauss], respectively. When we think the order of magnitude of \( f_t \) for the source region of 20 MHz DAM, the \( S \) and \( B \) might be taken as \( 1R_J = 7.1 \times 10^9 \) [cm], 7 [Gauss], respectively. Here we consider that the \( N \) is low, but not fairly low, say, \( N = 500 \) [cm\(^{-3}\)]. The plasma frequency to the gyro frequency ratio is 0.01:1 in this case, which might not be so bad for the wave generation condition by the cyclotron maser mechanism. These parameters give \( f_t \approx 100 \) [MHz], which is greater than DAM frequency; 20 MHz. While it is necessary to investigate the degree of mode coupling more precisely along ray paths, this simple estimation suggests that there is a possibility of weak mode coupling condition in and near source regions, and of the polarization state changing from quasi-linear to elliptical during the propagation.

6. Summary

Observations of axial ratio (\( \gamma \)) of Jovian decametric radiations (DAM’s) were made with consideration of deformation of \( \gamma \) caused by reflected wave components from ground. Actual \( \gamma \) value was then derived from directly observed \( \gamma \) value by eliminating the effect of the reflected wave components being separated from the direct-coming wave components. The full wave analyses were carried out to estimate the influence of the mutual cross-talks from one free-space mode wave
to another free-space mode wave along the propagation paths of DAM. The analyses indicated that the influence was at most 0.01 in $\gamma$; it is, therefore, confirmed that the derived $\gamma$ is almost the same as the original one at the source region of Jupiter.

The observational results indicated that in Io-related events the polarization of DAM showed mainly a right-handed (RH) elliptical state, and there was the significant difference of $\gamma$ values between RH waves of Io-A related DAM events and those of Io-B related DAM events. The mean $\gamma$ values for Io-A and Io-B related DAM events were $-0.35 \pm 0.08$ and $-0.26 \pm 0.06$, respectively.

For understanding the origin of the RH elliptical polarization, two assumptions are possible. One is the hypothesis of conservation of polarization in and near the DAM source regions. Being based on this assumption, the observation evidence of RH elliptical polarization can be interpreted by the shift of the source Io flux tube (IFT) about at most 20° in longitude from the apparent IFT. In this hypothesis the polarization at the source IFT is calculated on the assumptions of R-X mode DAM’s that were originated in an elliptically polarized state from the northern hemisphere of Jupiter and propagated preserving the original polarization. Another assumption is based on the concept of the propagation effect that results in the condition of mode coupling in and near source regions of DAM’s. A simple estimation of a “transitional” frequency (Cohen, 1960) for a DAM source region indicates that there is a possibility of the change of the polarization from a quasi-linear state to an elliptical state during the propagation through the Jovian plasma. Confirmation of the validity of these assumptions is deferred for future studies.

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REFERENCES

Acuña, M. H. and N. F. Ness, The main magnetic field of Jupiter, *J. Geophys. Res.*, 81, 2917–2922, 1976.
Bagenal, F., Alfvén wave propagation in the Io plasma torus, *J. Geophys. Res.*, 88, 3013–3025, 1983.
Barrow, C. H., Polarization of the Io-C radio emission from Jupiter, *J. Geophys. Res.*, 97, 8169–8172, 1992.
Bigg, E. K., Influence of the satellite Io on Jupiter's decametric emission, *Nature*, 203, 1008–1010, 1964.
Cohen, M. H., Magnetoionic mode coupling at high frequency, *Astrophys. J.*, 131, 664–680, 1960.
Connerney, J. E. P., Magnetic field of the outer planets, *J. Geophys. Res.*, 98, 18659–18679, 1993.
Drell, S. D., H. M. Foley, and M. A. Ruderman, Drag and propulsion of large satellites in the ionosphere: An Alfvén propulsion engine in space, *J. Geophys. Res.*, 70, 3131–3145, 1965.
Dulk, G. A., Y. Leblanc, and A. Lecacheux, The complete polarization state of Io-related radio storms from Jupiter: a statistical study, *Astron. Astrophys.*, 286, 683–700, 1994.
Genova, F. and M. G. Aubier, Io-dependent sources of the Jovian decametric emission, *Astron. Astrophys.*, 150, 139–150, 1985.
Genova, F. and W. Calvert, The source location of Jovian millisecond radio bursts with respect to Jupiter's magnetic field, *J. Geophys. Res.*, 93, 979–986, 1988.
Green, T. C. and W. M. Sherrill, Io-related polarization characteristics of the Jovian decametric emission, *Astrophys. J.*, 158, 351–363, 1969.
Hashimoto, K. and M. L. Goldstein, A theory of the Io phase asymmetry of the Jovian decametric radiation, *J. Geophys. Res.*, 88, 2010–2020, 1983.
Lecacheux, A., A. Boischot, M. Y. Boudjada, and G. A. Dulk, Spectra and complete polarization state of two, Io-related, radio storms from Jupiter, *Astron. Astrophys.*, 251, 339–348, 1991.
Melrose, D. B. and G. A. Dulk, On the elliptical polarization of Jupiter's decametric radio emission, *Astron. Astrophys.*, 249, 250–257, 1991.
Neubauer, F. M., Nonlinear standing Alfvén wave current system at Io: Theory, *J. Geophys. Res.*, 85, 1171–1178, 1980.