

NEPTUNE’S SMOOTHLY VARYING RADIO EMISSION BETWEEN 600 – 800 kHz

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Abstract

Besides a main bursty radio component observed between about 500 kHz and 1.3 MHz, and Neptune’s dominant smoothly varying radio emission patterns within the frequency range from about 20–600 kHz, the Planetary Radio Astronomy (PRA) instrument aboard Voyager 2 detected a second ‘smooth’ component. This emission occurred between about 600–800 kHz, and was only observed when the spacecraft was closer to the planet. We briefly describe the phenomenology of this emission component and determine its most probable source location by using an offset tilted dipole (OTD 2) model for Neptune’s magnetic field. Assuming that the emission originates near the electron gyrofrequency a geometrical beaming model is used in order to fit the observed emission episodes.

1 Introduction

At all the outer planets visited by Voyager 2, the Planetary Radio Astronomy (PRA) experiment [Warwick et al., 1977] aboard the spacecraft detected significant levels of radio activity. In August 1989, when the Voyager 2 spacecraft completed its survey of the giant planets with the flyby at Neptune, the discovery of intense non-thermal radio emission from Neptune raised the number of the radio planets to five (Earth, Jupiter, Saturn, Uranus, and Neptune).

The Voyager PRA receivers [Warwick et al., 1977] operate in two frequency ranges, a low-band (within the frequency range from 1.2 kHz up to 1.326 MHz, with 70 equally spaced frequency channels, each of 1 kHz bandwidth, where the channels are separated by 19.2 kHz) and a high-band (from 1.3 up to 40.5 MHz, scanned in 128 steps, each of 200 kHz, separated by 307.2 kHz). The PRA instrument detected Neptune’s left-handed (LH) as well as its right-handed (RH) polarized radio emission only in the low-band.

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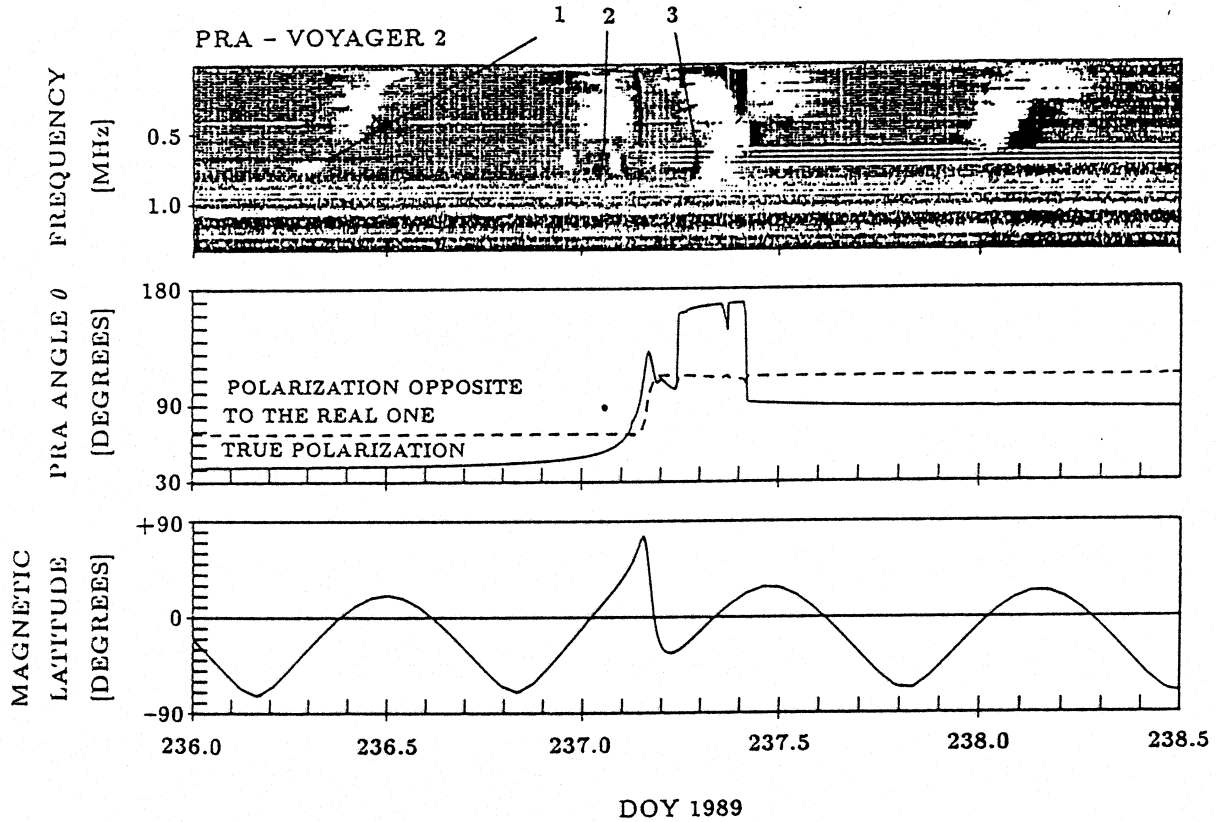


Figure 1: The top panel shows the dynamic spectrum of Neptune's radio emission detected from day of year (DOY) 236.0 thru DOY 238.5, 1989 (top panel). The narrow-banded events are denoted by numbers 1, 2, and 3. LH-polarized emission is indicated by black, RH-polarized episodes are coded by white. However (middle panel), the polarization sense shown in the top panel has to be reversed when the full lined curve (representing the measured polarization sense of the incoming wave) is above the dashed line (representing the antenna's electric plane). Consequently, within two time intervals polarization reversals have to be performed, around DOY 237.15 and from about DOY 237.2 thru DOY 237.4, 1989, respectively. The bottom panel exhibits the sub-spacecraft OTD 2 magnetic latitude versus time.

On day of year (DOY) 229, 1989, a few days before Voyager 2's closest approach (CA) to Neptune (on DOY 237, 1989), impulsive LH-polarized bursts were discovered in the PRA data at frequencies from about 650–800 kHz [Warwick et al., 1989]. These bursty episodes repeatedly occurred at distinct sub-spacecraft longitude ranges by an approximately 16 hours period. The average frequency coverage of these bursty events was from about 500 kHz up to 1326 kHz, the high-frequency limit of the low-band PRA receiver [Farrell et al., 1990]. Occasionally, besides this main bursty component other predominantly LH-polarized bursty episodes were identified in the PRA data, shifted by about 100° in sub-spacecraft longitude from the major component, and having a high-frequency limit of about 500 kHz [Desch et al., 1991]. Both bursty components originate from regions near the planet's south magnetic pole [Farrell et al., 1990; Desch et al., 1991].

Around the day of Voyager 2's CA on DOY 237, 1989, about 16 events of a broad-banded smoothly varying radio emission between a frequency range from 20 kHz to 600 kHz can

be observed. In each episode the same polarization pattern can roughly be identified: starting with LH-polarized emission at the emission's lower frequency limit, followed by a RH-polarized portion within the entire frequency range, and ending with a LH-polarized part at the high-frequency limit of the emission (Figure 1, top panel). The LH- and RH-polarized signals are associated with Neptune's southern and northern auroral zones, respectively [Ladreitner et al., 1991].

The repetition periods of both, the major bursty component as well as the broad-banded smoothly varying features were used to indirectly derive Neptune's rotation period assuming that the occurrence periods of the radio episodes are closely associated to the planet's intrinsic magnetic field. Power spectral analyses of the time series yielded an approximately 16.11 hours rotation period of the planet [Warwick et al., 1989].

The dynamic spectrum in Figure 1 (top panel) also exhibits another smooth radio component, however, observed at higher frequencies than Neptune's dominant smooth radio signals, and within the smaller frequency range from 600–800 kHz. This component was detected only close to the planet at about the time of CA. In this paper, we determine the source location of this narrow-banded smooth component by using the offset tilted dipole model [OTD 2, N.F. Ness, private communication] of Neptune's magnetic field, which is slightly different from the originally published OTD model [Ness et al., 1989]. The OTD 2 model is based on measurements from Voyager 2's magnetometer experiment [Behannon et al., 1977] within 3–15 Neptune radii (R_N). We also consider the visibility of appropriate source candidates capable of emitting the observed polarization and intensity patterns. Further, we assume that the emission is generated at the electron gyrofrequency, and emitted by a beaming pattern of a hollow cone. In this study, measurements and calculations at a frequency of 730.8 kHz are taken to be representative for the entire narrow-banded component. Armed with these constraints we compare the observed features with profiles calculated by a geometrical beaming model.

2 Observations

In Figure 1 (top panel), where Neptune's radio emission is shown around the time of Voyager 2's CA, two different radio emission phenomena are visible: (1) four episodes of the broad-banded, LH- and RH-polarized smooth emission, and (2), clearly separated from this dominant signals, three events of a second smooth component occurring at higher frequencies between about 600–800 kHz.

Note that within the time intervals around DOY 237.15, 1989, and from about DOY 237.2 thru DOY 237.4, 1989, the shown polarization sense for all frequencies is opposite to the polarization of the signal (Figure 1, top and middle panel; see also Leblanc et al. [1987], and respective references therein).

The events of the narrow-banded signal were also shorter in duration compared with the broad-banded radiation. All 3 episodes were detected at about times when the spacecraft crossed the magnetic equator (Figure 1, top and bottom panel). The emission was predominantly RH-polarized. A specific point is the polarization reversal within the frequency range of the narrow-banded radio component at about DOY 237.3, 1989 (Figure 1,

top panel). This reversal may be interpreted either due to a change of the polarization sense of the narrow-banded component itself, or, more obviously, as a consequence of detecting the narrow-banded smooth component preceding a high-frequency extension of the broad-banded smoothly varying component. In the latter case an eventual polarization reversal of the narrow-banded signal would be superimposed by the high-frequency extent of the broad-banded episode.

3 Source location determination

3.1 Intensity Model

The source location was determined by assuming the source region and modeling its respective intensity distribution in space. Then the calculated profile of the assumed source was compared with the observations. In order to fit the observed features we used the model given by Gulkis and Carr [1987], where the normalized subsource beam profile is given by

$$f(\Theta) = \frac{1}{2} + \frac{1}{2} \cos[n(\Theta - \Theta_0)]. \quad (3.1)$$

Here, Θ is the angle between the magnetic field line vector at a source element and the spacecraft, Θ_0 is the cone opening half angle of a hollow cone, and n is the quantity determining the beam thickness. The total intensity obtained for the spacecraft position is calculated by summing up the intensities of all subsource elements.

3.2 Visibility

As a first approach to determine the source region we performed a visibility study, i.e., whether or not certain regions are visible by the spacecraft when emission was observed. All radio horizons were calculated for an altitude corresponding to a gyrofrequency of 730.8 kHz. From plots of the inbound and outbound event it became quite clear that large parts of Neptune's hemisphere, specifically magnetic longitudes greater than 150° and northern auroral zones, can be excluded as possible source candidates. Furthermore, calculations of the radio horizon of the encounter event around DOY 237, 1989, reduced the possible source region towards equator-near latitudes and magnetic longitudes of $\lambda_{mag} \leq 130^\circ$ (Figure 2). From this calculations we conclude that at least large parts of the source have to be located within the white area of Figure 2.

4 Results

In Figure 3 we demonstrate a model fit for a source region located at the magnetic latitude of $\delta_{mag} = \pm 30^\circ$ and a longitude range extended from $\lambda_{mag} = 60^\circ - 90^\circ$. The failure of the fit is evident. Moreover, the plot is representative for all source models which are (1) outside the magnetic equator region, and/or (2) extended in magnetic longitude.

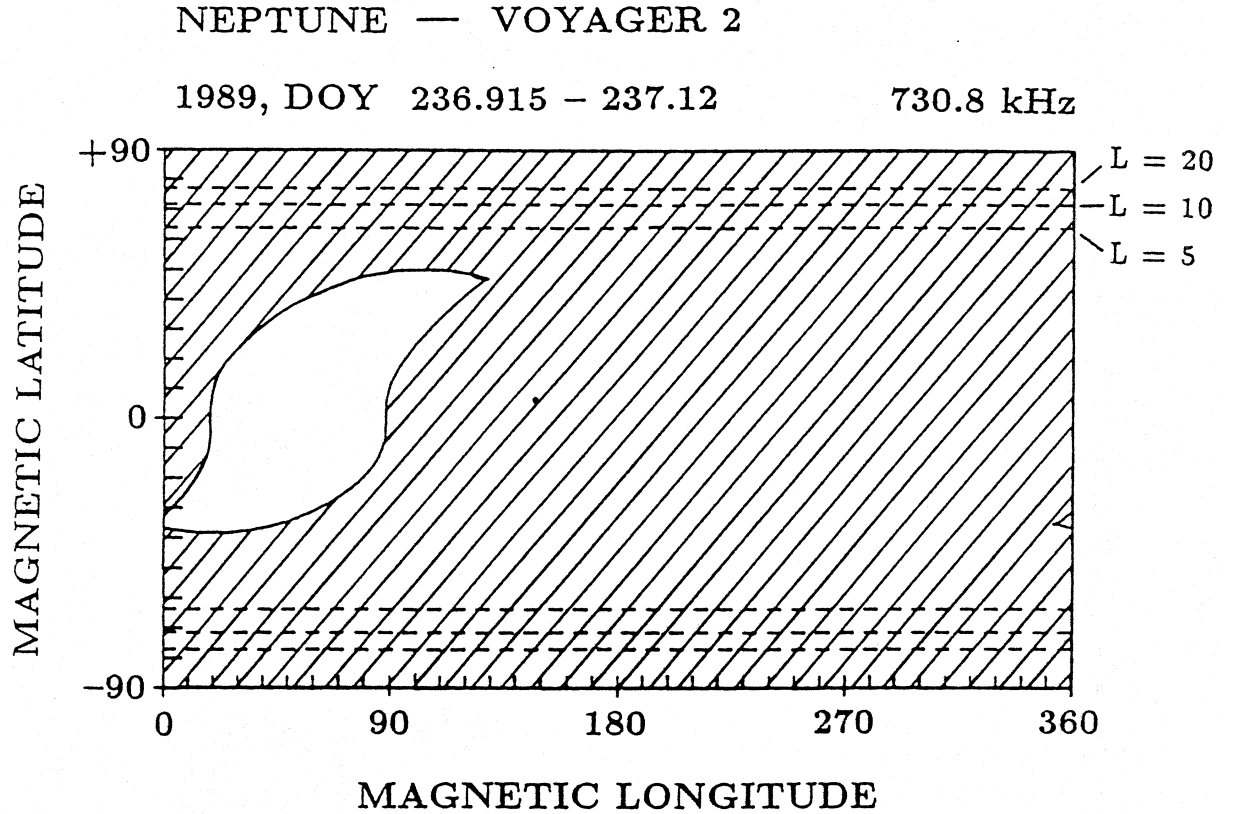


Figure 2: Radio horizon of the Neptune's sphere equal to $f=730.8$ kHz around Voyager 2's CA. The plot was performed by superimposing the horizons calculated from DOY 236.92 thru DOY 237.12, 1989, the start and stop times of the encounter episode. The hatched area cannot be seen by the spacecraft. The dashed lines represent the footprints of L -shells equal to 5, 10, and 20, respectively.

Neither changes of the model parameter Θ_0 nor varying the value of the beam thickness n could match the observations.

The scenario completely changed when we assumed both the source being located close to the magnetic equator as well as restricted to a very small area (point source). This is illustrated in Figure 4. Although systematic modeling has been done at 730.8 kHz for sources close to or at the equator for all magnetic longitudes suggested by visibility constraints displayed in Figure 2, the fit shown in Figure 4 represents the most reasonable outcome. While this fit is still far from being perfect, we believe that it nevertheless establishes the fact that the narrow-banded smooth component originates from Neptune's magnetic equator.

Specifically, the polarization sense of the emission and its reversal close to the time of CA is correctly predicted. A weak point of the fit is that the RH-polarized phase of the emission generally starts too early; but this will be discussed later. As mentioned in Section 2, the polarization reversal of the third event seen in Figure 1 at about DOY 237.3, 1989, is of specific interest. That is, the emission episode occurring at this time either consists of one component changing its polarization sense or is due to a merging of

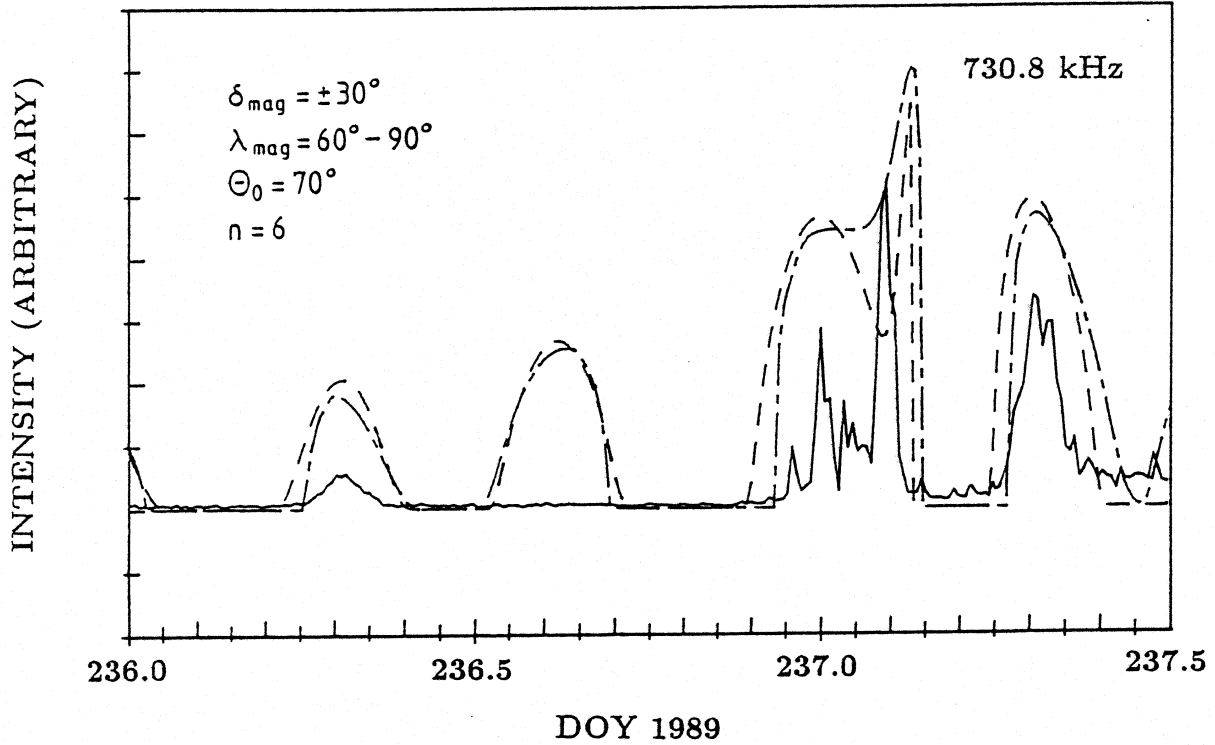


Figure 3: Comparison of the observed profile at 730.8 kHz (full line) with the computed intensity contours at $\delta_{\text{mag}} = +30^\circ$ (dot dashed line) and $\delta_{\text{mag}} = -30^\circ$ (dashed line), both extended from $\lambda_{\text{mag}} = 60^\circ - 90^\circ$. The model parameters used are a cone opening half angle of $\Theta_0 = 70^\circ$ and a beam thickness of $n = 6$ (according to $\Delta\Theta = 30^\circ$). Generally, sources located in northern regions as well as in southern zones cannot reproduce the observed intensity variations.

two components. From an overall view seen in Figure 1 the latter interpretation is more reliable. This is consistent with the calculated outcome of Figure 4. The fit predicts a short time RH-polarized emission at about DOY 237.3, 1989. Therefore, the following portion of the observed episode is due to a high-frequency extent of Neptune's dominant smooth emission.

5 Discussion

In this study we have used the OTD 2 magnetic field model which is valid inside about 3–15 R_N . Due to the frequency range concerned here, namely 600–800 kHz, the respective source is closer to the planet than 3 R_N , and therefore any outcome must be carefully handled. Recently, Connerney et al. [1991] presented a more accurate model of the Neptunian magnetic field obtained by the O_8 spherical harmonic model. As a consequence of this analysis, a multiple magnetic dip equator exists at the planet's surface (their Figures 8–11). Furthermore, at about a Neptunocentric latitude of $\delta = 0^\circ$ and $\lambda = 20^\circ$ (west longitude) the magnetic equator dips into the surface of Neptune.

We calculated the visibility constraints for Voyager 2's observations of the narrow-banded component in Neptunocentric coordinates, and found the point of the magnetic equator's

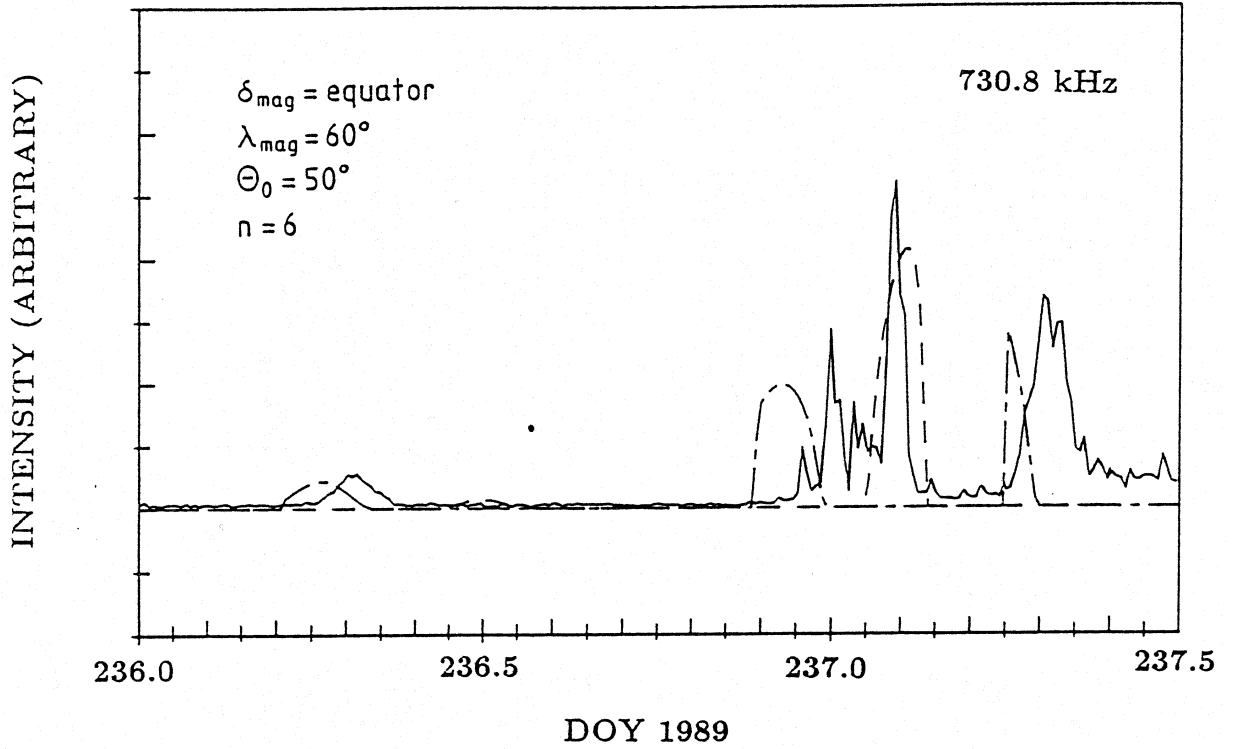


Figure 4: Calculated intensity modulation of a magnetic equator source at $\lambda_{mag} = 60^\circ$. The calculated RH-polarized part of the emission is indicated by the dot dashed line, while the dashed line denotes the computed LH-polarized portion of the component; the solid line shows the observed profile. For this fit we used a cone opening half angle of $\Theta_0 = 50^\circ$ and a beam thickness of $n = 6$ (according to $\Delta\Theta = 30^\circ$).

disappearance located within the region which was always seen by the spacecraft (this area is magnetically associated to the region shown in Figure 2). Moreover, this specific point on the magnetic equator is approximately at the point where we found the radio source. Therefore, we conclude that incorrect predictions of the magnetic equator radio source model (RH-polarized emission onsets start too early, the predicted dropout of the emission at the time of the polarization reversal at about DOY 237, 1989, is too long compared with the observed dropout) originate from the discrepancy between the OTD 2 and O₈ model, respectively.

We have demonstrated that the narrow-banded smooth emission originates from a small restricted area from Neptune's magnetic equator. All other possibilities assumed as northern or southern auroral zone models, respectively, or sources distributed along magnetic longitude ranges completely failed in matching the correct polarization and modulation of the start and stop times of the emission. Although the calculated fit does not perfectly reproduce the observed intensity variations, the computed outcome fits the characteristic features of the narrow-banded component and clearly favors an equatorial source. Besides Uranus [e.g. Kaiser et al., 1989; Rabl et al., 1991], Neptune seems to be the second radio

planet emitting radio signals from the magnetic equator.

Acknowledgements: The authors thank N. F. Ness for providing the OTD 2 model of Neptune's magnetic field.

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