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LONG-PERIOD DYNAMIC SPECTROGRAMS OF LOW-FREQUENCY INTERPLANETARY RADIO EMISSIONS

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Abstract. In this report we present dynamic spectrograms of the low-frequency interplanetary radio emissions as observed by Voyagers 1 and 2 from 1983 through mid-1986. The radio emissions were observed to be most intense in the latter portion of 1983 at 3 kHz but have also been detected at 2 kHz. The emission has been present almost continuously at either 2 or 3 kHz since late 1983. The spectrograms presented herein show that the phenomenon appears almost identically as observed by the two spacecraft separated by more that 10 AU, at least at the higher frequency. One feature revealed by the dynamic spectrograms which had not been noticed previously is a gradual rise in frequency of the 3-kHz component following the onset of the late 1983 event. These new observations reinforce the conclusion that the low-frequency emissions are freely propagating radio waves, but the two-component spectral structure implies that the previous model of emission at twice the plasma frequency at the inner heliosphere shock is inadequate to fully account for the observations. Either an additional source region or source mechanism is suggested.

Introduction

Evidence of a low frequency interplanetary radio emission was given by Kurth et al. [1984a,b] based on measurements by the Voyager 1 and 2 plasma wave receivers in the heliocentric radial distance range of about 13 to 20 AU. In these papers, Kurth et al. suggested that the inner heliospheric shock might be a reasonable source location for the radio emissions. Should this hypothesis prove correct, the Voyager observations would represent the first remote observations of the interaction region between the supersonic solar wind and the surrounding interstellar medium. The speculative nature of the interpretation, however, dictates that additional observations be made.

Over the intervening years, the Voyager spacecraft have continued monitoring the spectrum of the interplanetary radio emissions and this paper is a progress report on those observations. The primary result is that to the sensitivity of the Voyager plasma wave receivers the emissions appear continuously in either one or both bands centered near 2 and 3 kHz. The data are presented in the form of frequency-time spectrograms utilizing the waveform receiver portion of the plasma wave receivers on both spacecraft to allow comparison of the gross features of the emission from both spatial vantage points. Although the observations in this form lack temporal resolution better than a few weeks, the spectrograms allow a direct comparison between the two spacecraft. The radio signals can be detected with the Voyager 1 16-channel spectrum analyzer with much better temporal resolution. However, a failure within the Voyager 2 Flight Data System prohibits the detection of these very weak emissions at frequencies of 1 kHz or greater with the 16-channel analyzer, thus, we are not able to compare the observations from the two Voyagers at the higher time resolution. The Voyager plasma wave instruments are described in detail by Scarf and Gurnett [1977].

Observations

The observations which are the focus of this report are presented in Plates 1 and 2. Each plate represents Fourier transformed waveform receiver measurements displayed in a frequency-time format. The 213-component spectra making up the spectrograms are obtained once every four or so weeks by each of the spacecraft and are the result of averaging approximately 30 seconds of waveform observations, selected so as to avoid intermittent sources of spacecraft interference as much as possible. The intensity of the emission as a function of frequency is plotted by the use of a false-color scheme in which blue represents the weakest wave intensities and red the most intense. The color bar has been stretched so that the peak in the radio emission is just saturated (white), hence utilizing the full range of colors. As a result, some of the unavoidable spacecraft interference (such as the lines at 2.4 and 4.8 kHz), which is much more intense than the radio emission, appears as white in the spectrograms. Ticks across the top of the displays denote times when data are actually present. The spectrum between two observations is interpolated in order to show continuity between observations. The result is a spectrogram that represents intensity as a function of frequency (ordinate) and time (abscissa). Kurth [1986] demonstrated that the time scale for amplitude variations is on the order of weeks, hence, we believe the interpolation yields a credible spectrogram.

The most prominent feature in the two spectrograms (Plates 1 and 2) commences in late 1983, rises to a brief maximum intensity, and slowly decays over the following six months. The onset and peak of the event occur very close to 3 kHz but the emission frequency drifts toward 3.5 kHz throughout its decay phase. This drifting structure, which had not been noticed previously, could suggest source motion or increasing plasma frequencies in the source region on time scales of months. A similar rising frequency structure

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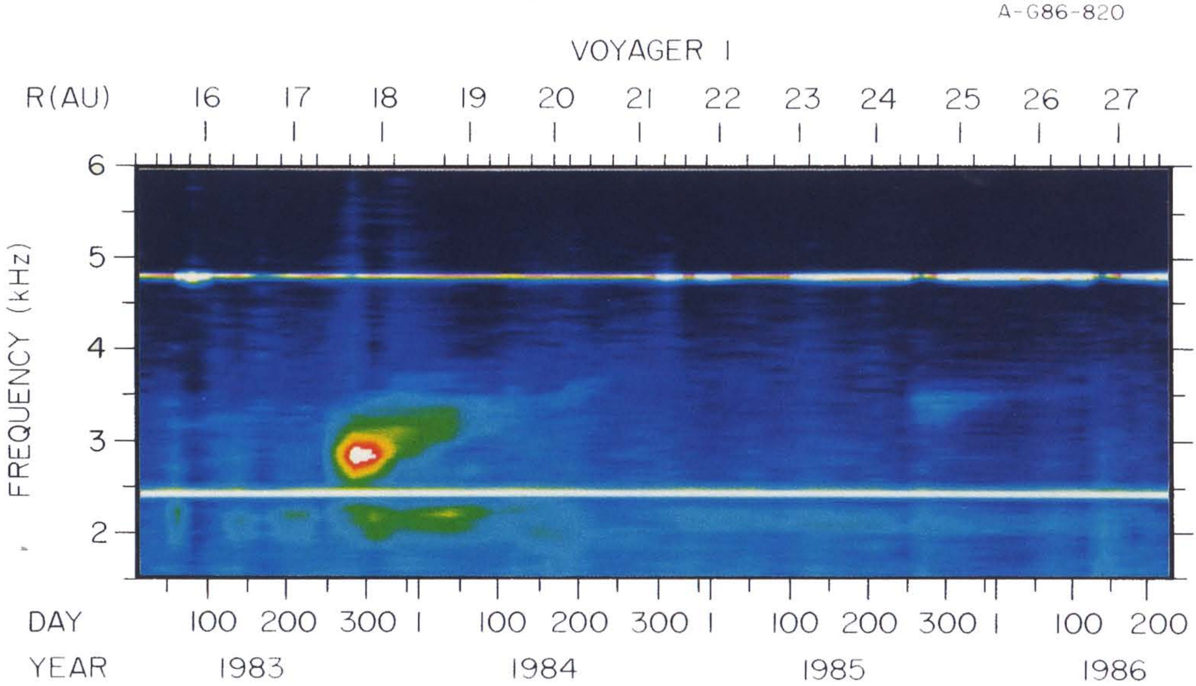

Plate 1. A frequency-time spectrogram made up of 30-second average Fourier transforms of waveform measurements obtained approximately once per month by Voyager 1. The tick marks at the top of the spectrogram indicate actual times when waveform data are available. The intensity scale is a false-color scheme in which blue represents the weakest wave activity and red the most intense. The white areas are saturated in this color scheme designed to address the dynamic range of the interplanetary radio emission and generally indicate interference from the spacecraft. The low-frequency interplanetary radio emission is prominently seen beginning in late 1983 and late 1985 at about 3 kHz as well as more continuously near 2 kHz.

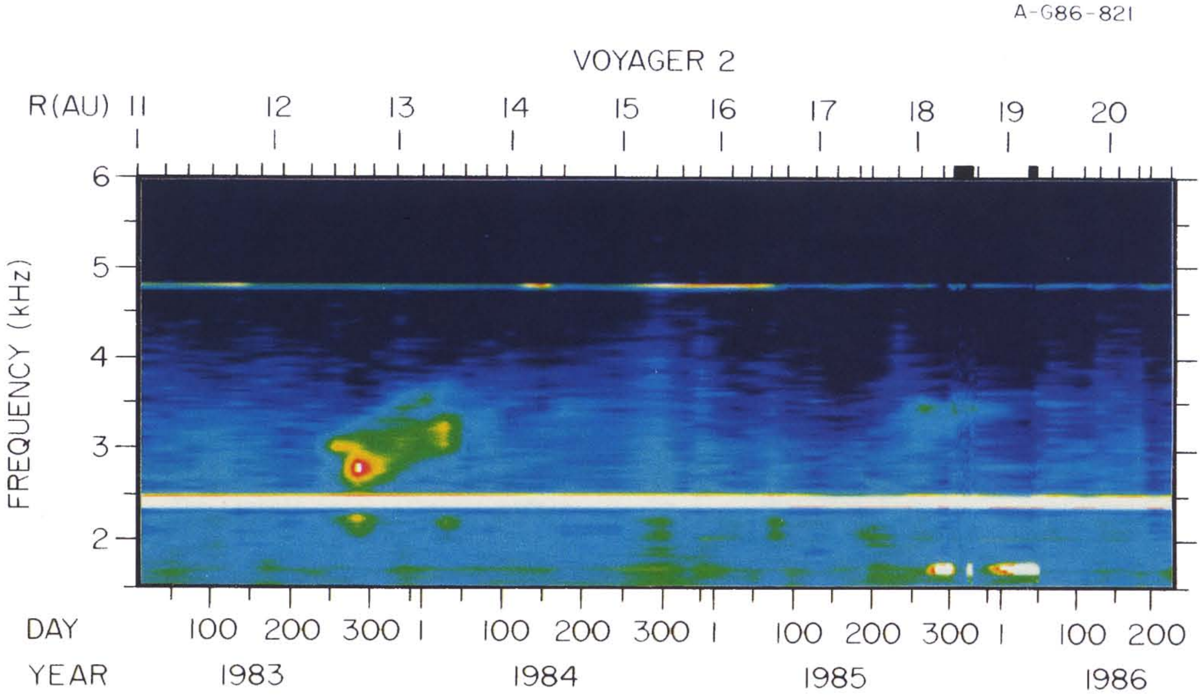

Plate 2. A spectrogram similar to that in Plate 1, but for Voyager 2. The Voyager 2 receiver is slightly less sensitive than the Voyager 1 receiver, hence, the radio emission is more difficult to observe, even though the color bar has been stretched to be similar to the Voyager 1 spectrogram. Even so, it is easy to see the good correspondence in the observations made by the two spacecraft, especially at 3 kHz. The intense, narrowband bursts at about 1.7 kHz in late 1985 and early 1986 are spacecraft interference.

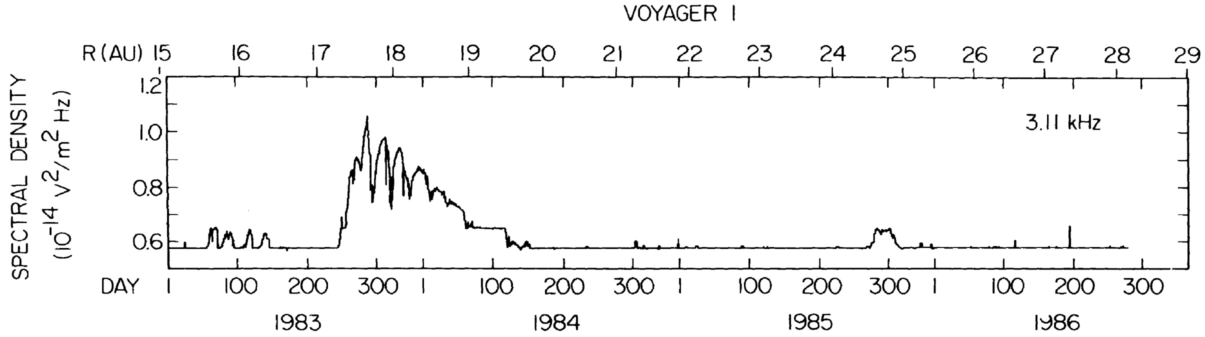

Fig. 1. Sliding 8.67-hour averages of the 3.11-kHz electric field spectral densities observed by Voyager 1 from the beginning of 1983 through mid-1986. The temporal variations match those shown in Plate 1 in a gross sense, however, these more continuous measurements reveal ~26-day amplitude variations during the 1983 event that are not apparent in the frequency-time spectrogram.

may also occur in the brief, weak event in late 1985 at 3 kHz, especially apparent in the Voyager 2 data set. The 3-kHz emissions in the Voyager 1 and 2 spectrograms are quite similar. While more structure appears in the 1983 Voyager 2 event, the apparent differences are due, in large part, to the slightly lower sensitivity of the Voyager 2 waveform receiver.

A second spectral component of the interplanetary radio emission can be seen in Plate 1 near 2 kHz. This more stable component is visible almost continuously from the onset of the 1983 event at 3 kHz through the end of the plotted interval. The 2-kHz emission is also present in the Voyager 2 spectrogram; but, it is more difficult to see owing to the slightly poorer sensitivity of the Voyager 2 instrument. Kurth [1986] showed further evidence for the 2-kHz band in the Voyager 2 data set utilizing time-averaged intensity versus frequency plots. Detection of the 2-kHz band by Voyager 2 is possibly impeded by generally greater local plasma frequencies near the spacecraft because of its smaller heliocentric radial distance.

The reader is cautioned in the use of Plates 1 and 2 because it is easy to forget that the spectrograms have a temporal resolution of the order of one month. Figure 1 is a plot of the Voyager 1 3.11-kHz spectrum analyzer channel for approximately the same time interval as the spectrogram in Plate 1. Figure 1 utilizes 8.67-hour sliding averages and, hence, shows temporal variations with much better time resolution than the spectrograms in Plates 1 and 2. Modulation with periods ≈ 26 days (discussed in detail by Kurth et al. [1984a]) show up clearly in the 1983 event in Figure 1, but are not evident at all in Plate 1. Near-daily waveform measurements obtained during the Voyager 2 Uranus Observatory Phase in late 1985 and early 1986 show intensity variations that are slow compared to a day and suggest that the 26 day modulations are the most rapid variations associated with the low-frequency radio emission [Kurth, 1986].

Discussion and Summary

The two long-period frequency-time spectrograms shown in Plates 1 and 2 provide substantial improvement in our knowledge of the spectrum of the low-frequency interplanetary radio emission. For the first time, it is clear that there is a high degree of correlation between the observations made from the two Voyager spacecraft, especially with respect to the gross spectral and temporal features of the emission. Heretofore, only snapshots of the emission spectrum could be directly compared between the two spacecraft. The strong correlation between the two sets of observations reinforces the conclusion that the observations are of freely propagating radio emissions because local sources would not be expected to correlate.

For the first time, it is possible to discern spectral drifts of importance to our understanding of temporal scales and velocities or variations in plasma parameters at or near the source of the emissions. The rate of drift in the 1983 3-kHz event is of the order of 1 kHz/yr. Because the usual solar-wind variations in density have a period of about one month, corresponding to a solar rotation, the observed long time scale leads to the conclusion that the local variations in solar-wind density are not responsible for the frequency shift.

It is important to consider the relationship between the two spectral components of the radio emission. If there is a good correlation between the two, one might be led to the conclusion that the sources of the two bands are related and, perhaps, colocated. On the other hand, different behavior by the two emission bands might suggest separate sources and perhaps different generation mechanisms.

Using the Voyager 1 spectrogram in Plate 1, there seem to be several aspects that imply the two components are unrelated. First, the 2-kHz component is present more regularly than the higher frequency component, even though the intensity of the 2-kHz tone has never exceeded the peak of the 1983 3-kHz event. Second, the drifting structure seen in the 3-kHz emission is not observed in the lower band. Finally, the bandwidth of the 2-kHz emission appears to be somewhat smaller than that for the 3-kHz emission, but this may be dependent on the relative strengths of the two bands. One aspect that points to some interdependency between the two emissions is the fact that both bands were most prominent during the 1983 event and the peaks for the two events occurred at nearly the same time, to within the poor temporal resolution afforded by the spectrograms. In fact, the drifting nature of the higher frequency component almost gives the impression that the two bands might have grown from a single, common emission. These same general conclusions may be drawn from the Voyager 2 spectrogram although the 2-kHz emission is more difficult to see with the Voyager 2 receiver.

As discussed by Kurth [1986], the two-component nature of the interplanetary radio emission cannot be explained by simple radiation from a single source at twice the local plasma frequency, f_p, at the source (the model proposed by Kurth et al. [1984a]). Further, the fact that the ratio of the frequencies of the two components is about 1.6:1 and not 2:1 implies that the emission is not being generated at both f_p and $2f_p$ at the same source. Fahr et al. [1985] have suggested that the heliopause, rather than the inner heliospheric shock, is a likely source location for the 3-kHz emission. This comment is motivated in part by the close proximity (30-46 AU) of the inner heliospheric shock implied if the source is associated with the shock [Kurth et al., 1984a,b; Suess and Dessler, 1985], which Fahr et al. argue is difficult to understand in view of the low external pressure they say is confining the solar wind. If the source of the radio waves is at the heliopause, the constraint on the distance to the inner shock is relaxed because the frequency of the emission cannot be used directly with a $1/R^2$ solar-wind model to predict a shock distance.

If one locates the 3-kHz emission region at the heliopause, then it is necessary to determine the location of the source of the 2-kHz component. One obvious possibility is again the inner heliospheric shock. Using the frequency of the emission, a $1/R^2$ solar wind density model and a density of 5 cm^{-3} at 1 AU one can calculate a distance to the shock [Kurth et al., 1984a,b] of about 40 AU, assuming a strong shock. Obviously, this result would be of little comfort to Fahr et al., but would fit the interstellar pressure inferred by Suess and Dessler [1985] as well as that obtained by Baronov [1986].

An alternate possibility is to assume that the heliosphere is not symmetric when comparing low solar latitudes with the regions over the poles, especially near solar minimum. The corotating flows of the low solar latitude interplanetary medium and the transient flow indicative of the high-latitude solar wind associated with coronal holes almost certainly imply that mean speed and mass-flux density vary systematically with solar latitude [Pizzo, 1986]. These variations could lead to a latitudinal dependence for solar-wind ram pressure that varies as a function of solar-cycle phase. The result might be a highly asymmetric shape for the terminal shock. Any model that relies on sources in vastly different locations, however, must be able to account for the nearly simultaneous peaks at 3 and 2 kHz for the 1983 event. This seems very difficult in view of the long times required for plasmas to flow over the large distances involved, however.

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References

Baronov, V. B., The interface between the heliosphere and the local interstellar medium (LISM), Adv. Space Res., in press, 1986.

Fahr, H. J., W. Neutsch, S. Grzedzielski, W. Macek, and R. Ratkiewicz-Landowska, Plasma transport across the heliopause, Space Sci. Rev., 43, 329, 1986.

Kurth, W. S., Recent observations of the very low frequency interplanetary radio emission, Adv. Space Res., in press, 1986.

Kurth, W. S., D. A. Gurnett, F. L. Scarf, and R. L. Poynter, Detection of a radio emission at 3 kHz in the outer heliosphere, Nature, 312, 27, 1984a.

Kurth, W. S., D. A. Gurnett, F. L. Scarf, and R. L. Poynter, A new radio emission at 3 kHz in the outer heliosphere, in: Proceedings of a Course and Workshop on Plasma Astrophysics (ESA SP-207), Varenna, Italy, August 28-September 7, 285, 1984b.

Pizzo, V. J., The nature of the distant solar wind, Adv. Space Res., in press, 1986.

Scarf, F. L., and D. A. Gurnett, A plasma wave investigation for the Voyager mission, Space Sci. Rev., 21, 289, 1977.

Suess, S. T., and A. J. Dessler, Probing the local interstellar medium, Nature, 317, 702, 1985.

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