

A NEW RADIO EMISSION AT 3 KHZ IN THE OUTER HELIOSPHERE

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ABSTRACT

Evidence of a radio source in the outer heliosphere is given based on observations made by the plasma wave receivers on Voyagers 1 and 2 at heliocentric radial distances ranging from 13 to 20 AU. The radio emission is observed in the frequency range of 2 to 3 kHz, and is above the local electron plasma frequency whenever supporting plasma density data are available. The maximum spectral density of the emission recorded to date is about $10^{-14} \text{ V}^2 \text{ m}^{-2} \text{ Hz}^{-1}$. The bandwidth of the radio noise is about 1 kHz. One of several possible sources considered for the emission is radiation at the second harmonic of the plasma frequency at the heliopause. Should this interpretation be correct, the data reported represent the first remote observations of the heliopause.

Keywords: Radio emission, outer heliosphere, Voyager

1. INTRODUCTION

The Voyager 1 and 2 spacecraft are currently sampling the interplanetary environment at heliocentric radial distances of 20 and 14 AU, respectively. Since the Saturn encounters in 1980 and 1981, the plasma wave data have shown very little activity in the outer heliosphere. The bottom panel of Fig. 1 shows the trajectories of Jupiter, Saturn, Uranus, and Voyagers 1 and 2 for the interval August 30, 1983 to February 21, 1984; during this time a radio emission near 3 kHz was being detected by the plasma wave instruments on both Voyagers (Ref. 1). The top panel of Fig. 1 shows a meridional view of the outer planets and the trajectories of the two Voyagers. In this view, the abscissa is in the ecliptic plane and the positions of the various objects have all been rotated into the same plane.

The observations discussed in this paper were obtained on both Voyager spacecraft using plasma wave receivers which measure the electric field component of plasma and radio waves in the frequency range of 10 Hz to 56 kHz by the use of 16-channel spectrum analyzers and wideband receivers with passbands of 40 Hz to 12 kHz (Ref. 2).

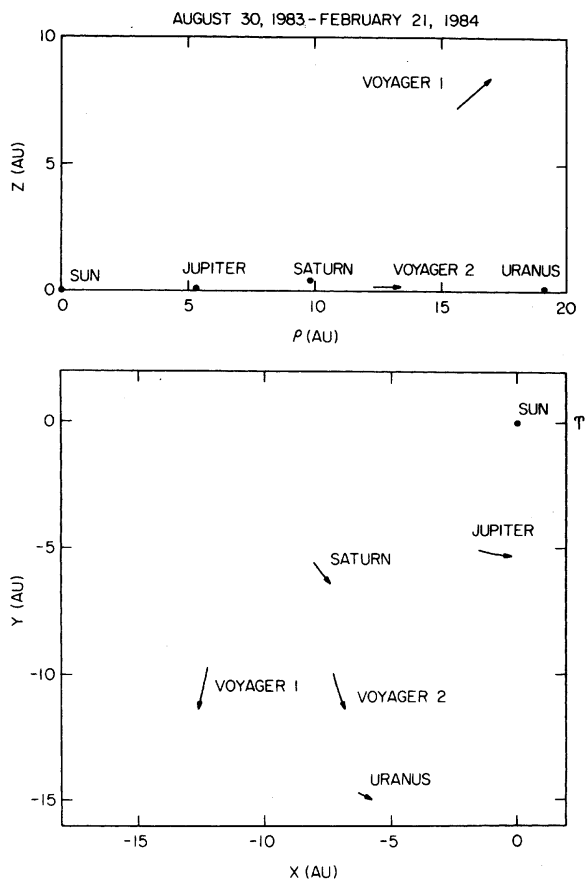


Fig. 1. The trajectories of Jupiter, Saturn, Uranus, and Voyagers 1 and 2 during the interval August 30, 1983 to February 21, 1984 (Ref. 1).

2. OBSERVATIONS

During a period from August 30, 1983 to about mid-1984, a very weak signal was apparent in the 3.11-kHz channel of the Voyager 1 plasma wave instrument. The 3.11-kHz data for about two and one-half years, 1982 through mid-1984, are plotted as a function of

VOYAGER 1 3.11 kHz
 JANUARY 1, 1982 - JULY 18, 1984

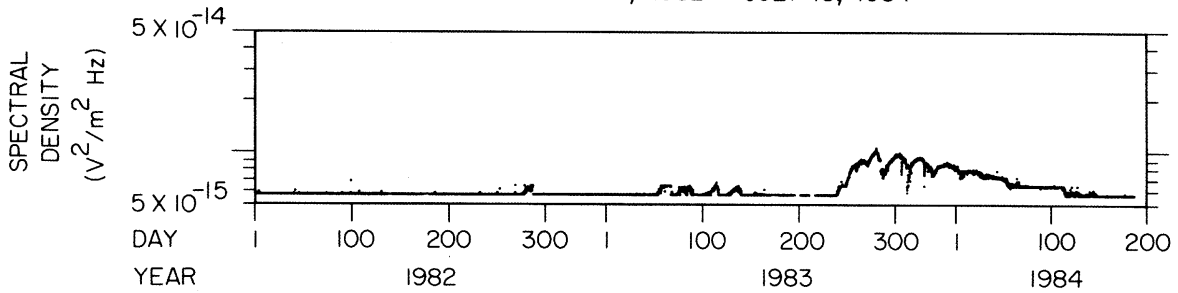


Fig. 2. Electric field spectral densities from the Voyager 1 3.11-kHz plasma wave receiver channel plotted as a function of time.

time in Fig. 2. Each point in Fig. 2 represents a 51.2-minute average of the electric field spectral density. It is apparent that from about day 243 (August 31), 1983 a smoothly varying signal was continuously present almost to the end of the plotted interval. A few much weaker and shorter events were also recorded in 1982 and early 1983.

In the main event, amplitude variations beginning about day 292, 1983 appear to be quasi-periodic with a period of about 26 days. This is close to the sidereal period of the sun, hence, we suspect the solar wind may be responsible, in part, for the amplitude variations. Amplitude variations within the averaging intervals were small compared to the long-term variations. While the onset of the event beginning in late 1983 is rather abrupt, rising over the period of a couple of weeks, the event decays with a time constant of months. The apparent step functions in amplitude are an artifact of the cutting levels of the analog-to-digital converter used in the data system onboard the spacecraft.

Detailed information on the spectrum of the emission can be obtained from wideband waveform measurements which are taken at several-week intervals throughout the cruise portion of the Voyager missions. An example of the wideband data are shown in Fig. 3

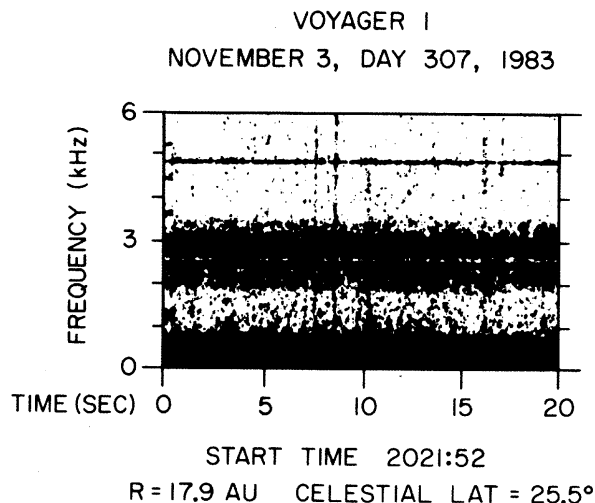


Fig. 3. A spectrogram showing the intensity of waves as a function of frequency and time for a 20-second interval. The diffuse emission seen between 2 and 3.5 kHz is the new radio emission reported herein (Ref. 1).

which is in the format of a frequency-time spectrogram with the amplitudes of waves plotted as a function of frequency (ordinate) and time (abscissa). The most intense waves are represented by black. The intense tones at frequencies below 1 kHz are interference from the operation of the onboard tape recorder used to record the wideband data. The very narrow tones at 2.4 and 4.8 kHz are the first and second harmonics of the spacecraft power supply. The diffuse noise between 2 and 3 kHz accounts for the response seen in the 3.11 kHz channel plotted in Fig. 2.

It is instructive to summarize the wideband observations for both spacecraft. Such a summary is attempted in Fig. 4. In this illustration we have plotted a 4-second average spectrum from several wideband intervals obtained after day 242, 1983. On the left-hand side of the figure, the spectra obtained from Voyager 1 are displayed, with the Voyager 2 spectra on the right. Note that the data shown in Fig. 3 are represented by the second left-hand panel from the top, labelled 307. In the cases shown in Fig. 4, the Voyager 1 wideband frames are obtained within a day or so of the Voyager 2 data, hence, the wideband samples can be compared almost directly.

The first comparison to make is an important one. The output of the Voyager 2 spectrum analyzer for frequencies of 1 kHz and greater is degraded by a partial failure in the Voyager 2 Flight Data System. Hence, a plot of the 3.11 kHz channel from Voyager 2 similar to Fig. 2 would not reveal the radio emission. The wideband data, however, is not affected by the failure, hence, Fig. 4 is evidence that the emission was detectable by both spacecraft over very similar intervals of time. Based on the appearance of the emission in the Voyager 2 wideband data, the emission apparently commenced between days 228 and 257, 1983 at Voyager 2 and conceivably could have been coincident with the Voyager 1 onset time. This close correspondence in onset times at two locations separated by nearly 10 AU (see Fig. 1) suggests the event is a temporal occurrence and not a spatial variation.

It is clear that the amplitude of the emission seen at Voyager 1 is nearly identical to that at Voyager 2. There is some difference in the receiver thresholds; Voyager 2 seems to be slightly less sensitive, hence, the lower frequency cutoff of the emission could be masked somewhat. What is more striking, however, is the constancy of the frequency of the peak of the emission between the 2 spacecraft separated by ~ 10 AU and spanning several months in

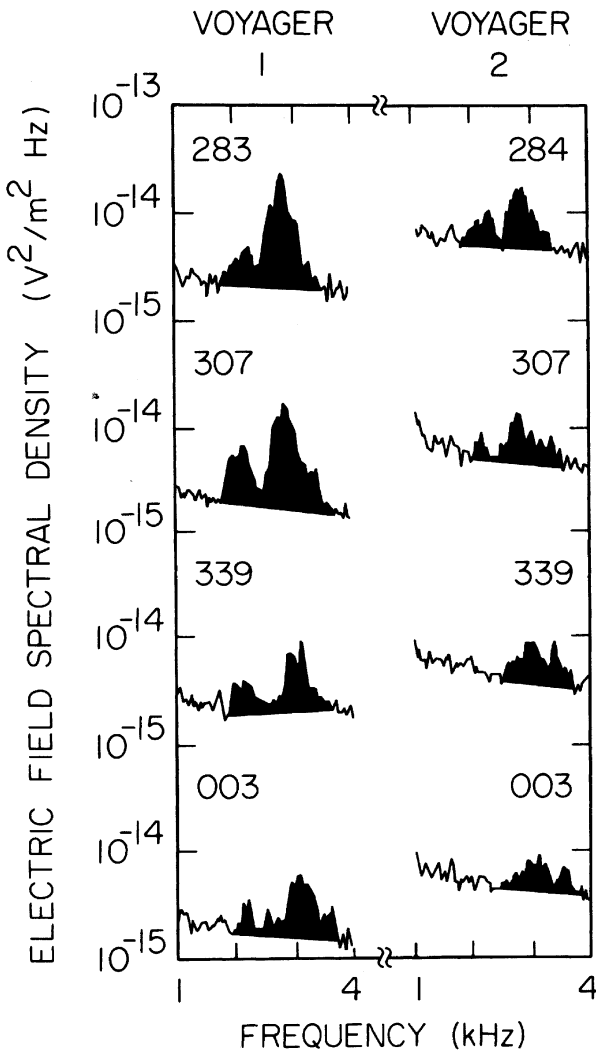


Fig. 4. A series of 4-sec average spectra obtained from both Voyagers. The numbers indicate day of 1983 except 003 is in 1984.

time. The solar wind plasma conditions could not be expected to remain so constant over time and distance, hence, this comparison suggests a source external to the solar wind.

3. DISCUSSION

Kurth et al. (Ref. 1) examined the observations summarized above in order to eliminate any possibility that the data could be explained by a local plasma phenomena. Although the question cannot be answered definitively, there is a reasonable case against local plasma effects and for freely propagating radio waves. The arguments put forth in Ref. 1 are as follows:

1. The emission is not likely to be electron plasma oscillations because the bandwidth is too large and the amplitude variations are too smooth to be consistent with plasma oscillations.

2. The other possible local effect, thermal electrostatic plasma noise (Ref. 3), was fairly easily eliminated based on near-earth observations of the phenomenon with a short (compared to the Debye length) electric antenna. The local emission

shows a very smooth $f^{-1.5}$ spectrum with no cutoff near the local plasma frequency and no peaks. The spectra shown in Figs. 3-4 clearly show both a cutoff and peaks.

3. Since all observations for which supporting plasma data were available showed that the lower frequency cutoff of the emission was at or above the local electron plasma frequency and that the emission was well above the electron gyrofrequency, the only remaining possibility was that the emission was freely propagating.

4. The nearly simultaneous onset of the event near day 243, 1983 at the two Voyager spacecraft separated by nearly 10 AU and the similarities in the spectra taken at both locations over an interval of several months is not consistent with a local source and implies a common, distant source.

Given that the emission at 3 kHz is a freely propagating radio wave, it is natural to ask what the source might be. In Ref. 1 it was first questioned whether Jupiter might be the source since the continuum radiation trapped in the distant Jovian magnetotail (Ref. 4, 5) is at about the same frequency as the emission reported herein. The extended tail cavity would provide a 'light pipe' which would allow the low frequency emission to 'tunnel' through the high density solar wind to a point where the waves were above the local solar wind electron plasma frequency and could escape in the direction of the Voyager spacecraft. However, the spectral shape, the lack of a variation in amplitude between the two spacecraft, and the lack of a 10-hour periodicity cast serious doubts on Jupiter as a source.

Saturn and Uranus were considered as possible sources in Ref. 1, however, both were ruled out primarily on the basis of insufficient intensity at these two sources, as well as a lack of a $1/R^2$ dependence in intensity between the two spacecraft from either planet.

A source located in the solar wind at large heliocentric distances (similar to the Voyager spacecraft) seems to be precluded by the lack of plasma waves such as electron plasma oscillations which might be a source for electromagnetic radiation (via the type III solar burst mechanism, for example). Also, the nearly constant frequency of the peak of the emission would not be consistent with a source imbedded in the solar wind which displays large scale density changes on times scales short compared to the lifetime of the event under study here.

One of the many possible sources of radiation beyond the heliosphere would be pulsars, but the bandwidth of the observed emission is probably too large and the flux detected by Voyager exceeds the total power flux received from the Crab nebula integrated across its entire radio spectrum by a factor of ~ 100 (Ref. 1).

In Ref. 1 it was suggested that the interaction between the solar wind and the interstellar wind just might be a reasonable source. The interaction referred to is the interface between the solar wind, moving outwards at 400 km/s with the interstellar wind, thought to be moving at about 20 km/s in a direction antiparallel to the direction of the Voyager 1 trajectory. Many suggest the interface may consist of a supersonic shock, sometimes referred to as the terminal shock.

The bow shock at the Earth and some interplanetary shocks are known to be the source of weak electromagnetic radiation (Refs. 4, 6-8) which is generated

via a type III solar burst-like mechanism (Ref. 9) from plasma oscillations at the plasma frequency near the shock.

Fig. 5 is a sketch of the salient features of the so-called $2f_p$ emission mechanism at the heliopause. We have assumed that since the magnetic field strengths probably match reasonably well across the heliopause and the interstellar wind speed is much lower than the solar wind speed that the interstellar wind is more dense than the outer heliosphere, although the basic mechanism does not require this assumption. We also assume the jump in plasma frequency across the shock is the maximum allowable; a factor of two.

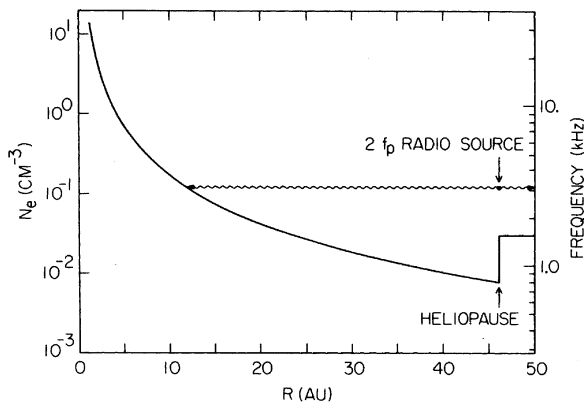


Fig. 5. A sketch showing the basic features of the $2f_p$ emission mechanism at the heliopause.

The source of the electromagnetic radiation for the heliopause source is a three wave process occurring close to the shock itself. Two of the waves are electron plasma oscillations which interact with each other and the third wave is an electromagnetic mode at twice the plasma frequency, hence the name $2f_p$. This mechanism would predict a weak, smoothly varying emission with a relatively narrow bandwidth, depending on the variations of density at the shock. The assumptions made above coupled with a $1/R$ variation in the solar wind plasma frequency yield an intriguing prediction for the distance to the heliopause (Ref. 1). The frequency of the emission gives $2f_p$ at the shock and the assumption of a jump of a factor of two in the plasma frequency at the shock gives the minimum plasma density in the outer heliosphere as seen in Fig. 5. Using 2 kHz as the plasma frequency at 18 AU and the $1/R$ law, the shock can be located at about 46 AU, with reasonably large error bars.

Actually, 46 AU is, in effect, a maximum distance due to the assumption that the interstellar wind has a higher density than the outer heliosphere and the shock is of maximum strength. If the density outside the shock is less than inside, the shock would have to be at about 24 AU. Pioneer 10 is well beyond that distance with no report of a heliopause shock, hence, we doubt the transition takes place so close.

4. CONCLUSIONS

We have presented observations of a radio emission detected in the outer heliosphere by the plasma wave receivers on both Voyagers at distances between about 13 and 20 AU and evidence that the observations are of a newly discovered radio emission, most probably emanating from somewhere in the outer heliosphere or beyond. Of the several possible sources, one which seems particularly exciting is the generation of $2f_p$ radiation at the heliopause. If this explanation holds true, these observations represent the first remote detection of the heliopause and predict a heliospheric radius of about 46 AU.

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